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PALYNOSTRATIGRAPHY OF THE SOUTH AFRICAN KAROO SUPERGROUP AND CORRELATIONS WITH COEVAL GONDWANAN SUCCESSIONS

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Thesis submitted to the Faculty of Science at the University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, February 2014

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DECLARATION

I hereby certify that this doctoral thesis is completely my own unaided work, and has not been submitted before for any degree or examination at any other University.

_____

Natasha Barbolini

_____ day of _____ 20____

ABSTRACT

The Main Karoo Basin of South Africa is renowned for its exceptional palaeontological record and while its vertebrate fossils have been extensively researched, Karoo floras have received considerably less attention. Poor yields of palynomorphs from the Beaufort and "Stormberg" groups have complicated the task of erecting a comprehensive palynozonation scheme for the Karoo Supergroup. For this study, 65 palynologically productive samples from the Dwyka, Ecca, Beaufort and "Stormberg" groups allowed for systematic descriptions of all palynomorphs, as well as the ranges of the different taxa through the entire Karoo stratigraphic succession. Taxa with restricted ranges are useful for biostratigraphic correlation and these palynomorphs were used to delineate microfloral zones for the Karoo basin. The Dwyka Group contains high numbers of acritarchs and is generally low in species diversity. Useful biostratigraphic taxa for the Ecca Group include *Cannanoropollis*, *Hamiapollenites*, *Platysaccus* and *Striatopodocarpites*. *Aratrisporites* is a marker for the Latest Permian / Early Triassic Beaufort Group, while *Cyathidites*, *Dictyophyllidites*, *Equisetosporites* and *Uvaesporites* are indicators of the Late Triassic / Early Jurassic "Stormberg" Group. Palynostratigraphic zones correlate largely with the Karoo vertebrate biozones and severe and sudden extinction events are recognised among Karoo palynomorphs in the upper *Tapinocephalus* and *Dicynodon* assemblage zones. The first comprehensive palynological biozonation scheme for the Main Karoo Basin is proposed and the study provides a broad overview of Gondwanan Carboniferous - Jurassic floras. This study demonstrates that palynology is useful in correlating age equivalent lithostratigraphic units in the proximal and distal sectors of the Karoo Basin. Microfloras from previous South African studies are integrated within the proposed palynostratigraphic scheme, and palynological signatures of the various Karoo formations are shown to be consistent. Despite the constraints of floral provincialism, South African microfloras can be correlated to selected Gondwanan biozonations from Australia, Africa, Antarctica, New Zealand and South America. Future studies should focus on sampling more intensively over

smaller stratigraphic intervals, which will assist in the correlation of time equivalent lithostratigraphic units in the different sectors of the basin, thus aiding in refinement of basin development models.

Key words: palynology, Karoo, vertebrate biozones, stratigraphy, Gondwana

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1. INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL INTRODUCTION

The Karoo Supergroup covers more than two-thirds of South Africa, and hosts a time extensive and largely unbroken palaeontological record of terrestrial plant and animal life from the Late Carboniferous until mid-Jurassic times. It is particularly noted for its wealth of fossil tetrapods, including synapsids, temnospondyls and sauropodomorph dinosaurs, which have allowed for a biostratigraphic subdivision of the Beaufort Group, and Elliot and Clarens Formations (Keyser & Smith, 1977-78; Kitching & Raath, 1984; Rubidge *et al*., 1995). These biozones are continually being refined as new taxonomic work is done (Yates, 2003; Hancox *et al*., 1995; Rubidge, 2005).

The Karoo Basin is also an excellent source of palaeobotanical fossils (e.g. Plumstead, 1956; Anderson & Anderson, 1983, 1985, 1989; Bamford, 1999, 2000; Adendorff *et al*., 2002, 2003; Prevec *et al*., 2008, 2009, 2010), but these have received less research attention than the vertebrates. The Gondwanan supercontinent appears to have formed a single plant kingdom (Anderson, 1977), however species level provincialism is evident throughout the Carboniferous to Cretaceous (McLoughlin, 2001). Cooler conditions were responsible for the replacement of lycophytes by seed-ferns during the Carboniferous, but floras were of low diversity due to glaciation of much of Gondwana (Anderson & Anderson, 1985; McLoughlin, 2001). In the Permian, a mixed and diversified *Gangamopteris* and *Glossopteris* macroflora was responsible for coal formation in the southern hemisphere, which included sub-arctic mosses, conifers, lycopods, ferns, seed ferns, cordaitales and early gymnosperms (Anderson & Anderson, 1985). Four distinctive floristic realms developed during the Permian: the Euramerican, Angaran, Cathaysian and Gondwana provinces (Chaloner & Lacey, 1973). Although pteridophytes and lycopods were dominant during the Early Permian, glossopterids soon replaced soon them as the prevailing flora until the transition to *Dicroidium* in the early Triassic as a result of the end-Permian mass

extinction (Anderson & Anderson, 1985). Ginkgos, conifers, cycads, bennettitaleans and new species of pteridosperms became prominent, which continued through to the Jurassic (Anderson & Anderson, 1985) however a major floristic turnover took place at the end of the Triassic with the diverse genus *Dicroidium* being replaced by conifers and bennettitaleans across the Southern Hemisphere (McLoughlin, 2001). In general, broad patterns of plant change across Gondwana during the Palaeozoic and Mesozoic periods are known, but finer taxonomic resolution is needed especially for biozonation purposes.

The spatial and temporal distribution of palynomorphs (organic-walled microfossils, particularly fossilized plant spores and pollen grains) can be influenced by variations in facies and sample spacing, but palynomorphs are generally far more ubiquitous than vertebrate fossils, meaning they are "an unrivalled biostratigraphic tool" (Eyles *et al*., 2002, p. 315). However, like all fossils, this applies only to rock units where good preservation allows for it. Palynological records for South Africa in particular are sketchy and isolated with a lack of inter-basinal correlation, but palynomorphs tend to evolve faster than other plant parts such as leaves or wood, and thus offer possibilities to refine biostratigraphic resolution (Falcon, 1975; Schopf & Askin, 1980).

The Main Karoo basin has been lithostratigraphically subdivided into three discrete regions on the basis of facies, provenance and transport directions, and stacking patterns (Catuneanu *et al*., 1998). Adjacent to the Cape Fold Belt lie two proximal facies, a western region (west of the 24° E meridian) and a southern region (east of the 24° E meridian). In the north-east of the basin lies the distal facies, away from the Cape Fold Belt. Diachronous deposition has occurred with regards to the distal and proximal facies. It is known that the uppermost stratigraphic units of the Dwyka and Ecca groups are younger in the distal sector than the proximal part of the basin (Catuneanu *et al*., 1998) and biostratigraphic correlation has indicated that the Ecca-Beaufort contact is also younger in the distal sector (Rubidge, 1995). Basin development models for the Karoo require

refinement, but this is dependent on reliable chronostratigraphic correlations. Palynology offers a solution to solve this problem.

1.2 OBJECTIVES

Objectives of this study are to:

1. Record the pollen and spore taxa throughout the Karoo stratigraphic succession and compare with previous studies in southern Africa and across Gondwana
2. Erect a comprehensive palynological biozonation scheme for the Late Carboniferous to Middle Jurassic of South Africa, incorporating northern and southern facies of the Main Karoo Basin
3. Compare the palynological biozonation to the existing vertebrate biozones of the Karoo, identifying similarities and discrepancies between plant and animal diversifications and extinctions
4. Utilise taphonomy of pollen and spores for palaeoenvironmental determination

1.3 LITERATURE REVIEW

1.3.1 KAROO LITHO- AND BIOSTRATIGRAPHY

The sedimentary succession of the Main Karoo Basin of South Africa records a period of more than 100 million years of almost continuous sedimentation, from the Late Carboniferous until mid-Jurassic times (Smith, 1990). Other Karoo aged basins are present in various parts of southern and central Africa and most basins have been sampled for palynomorphs but none of the basins have the time extensive record of South Africa. Sedimentation in the main Karoo Basin was primarily controlled by tectonics arising from the development of the Karoo foreland basin with the subduction of the palaeo-Pacific plate beneath the Gondwana plate (Catuneanu *et al*., 1998). Drift through various latitudes resulted

in glaciation during the Late Carboniferous / Early Permian, a fluvio-deltaic regime with progressive aridification from the Middle Permian through the Triassic, to aeolian conditions in the Early Jurassic (Smith, 1990; Catuneanu *et al*., 2005). Karoo sedimentation was terminated by the outpouring of the Drakensberg basaltic lavas in the Middle Jurassic (Smith *et al*., 1993).

The rocks of the Karoo Supergroup preserve a diverse range of fossil vertebrates, the most abundant of which are therapsids. These Permian and Triassic synapsids have allowed for a biostratigraphic subdivision of the rocks of the Beaufort Group (Keyser & Smith, 1977-78; Kitching, 1977; Rubidge *et al*., 1995) (Figure 1.2). The Elliot and Clarens formations have also been subdivided on the basis of their dinosaur fossils (Kitching & Raath, 1984) (Figure 1.2). The vertebrate biozones are intermittently refined as new fossils are collected and described, and some new subdivisions have been proposed (Figure 1.2). The vertebrate biozones of the Main Karoo Basin have international importance for the correlation of terrestrial Permian to Jurassic rocks, owing to their status as the most complete fossil tetrapod-bearing record of this age (Rubidge, 2005). Thus far, the lack of chronostratigraphic markers across Gondwana has hampered precise correlations of late Palaeozoic and Early Mesozoic sequences, and most of the Karoo rocks have been assigned ages on the basis of biostratigraphic correlation with better dated rocks elsewhere in Pangaea (Rubidge, 2005). Further correlations utilising microfossils as well as faunal remains offer new possibilities for refining the Karoo vertebrate biozones and may shed light on both faunal and floral continental biodiversity changes across Gondwana.

1.3.2 PALYNOLOGICAL RECORDS FOR THE LATE CARBONIFEROUS – MIDDLE JURASSIC OF GONDWANA

The Late Carboniferous to Middle Jurassic represents over 150 million years in the fossil record, and there is a profusion of palynological localities from all over Gondwana for this time period. Therefore the studies selected for review had to be

chosen according to both their significance as well as pertinence to the Main Karoo Basin. In order to facilitate the most meaningful correlations, localities selected were restricted to those originating from the Gondwanan floristic province and include south-central Africa, Australia, New Zealand, Brazil, Argentina, Chile, Bolivia, Uruguay, Antarctica, and India (Figure 1.1). Peri-gondwanan terranes such as North Africa, the Middle East and the northern margin of the Paraná Basin, Brazil (Scotese, 2004) were not included.

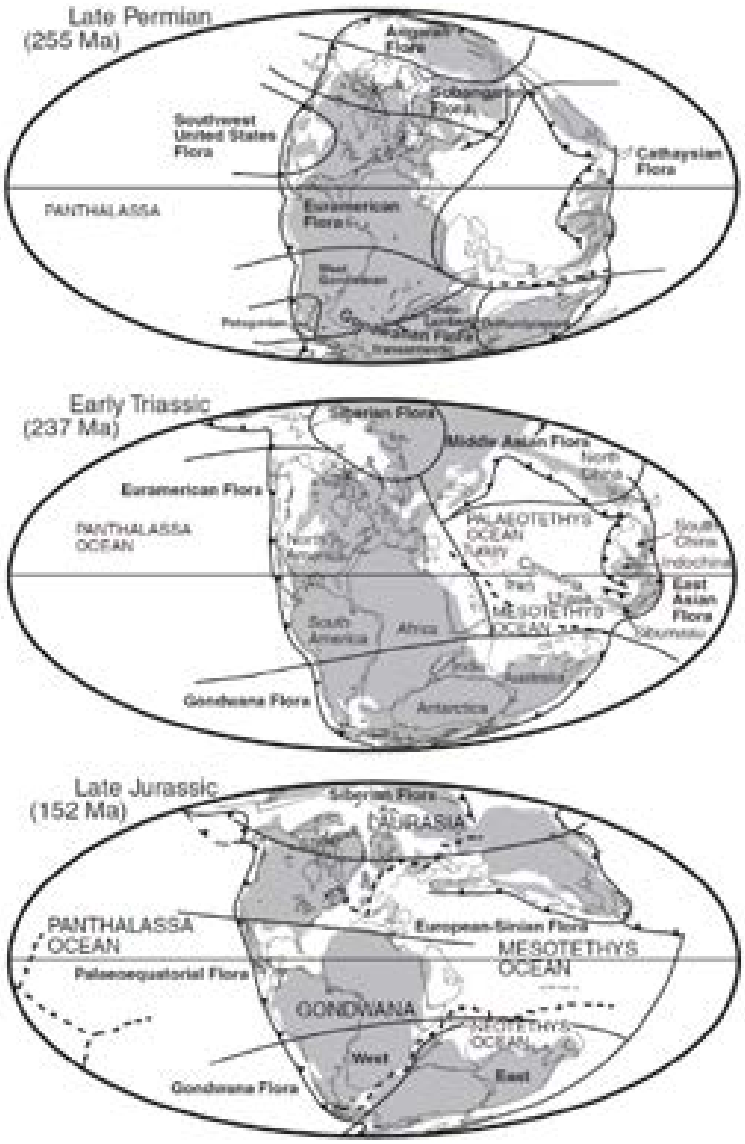


Figure 1.1: Global floristic provinces during the Permian, Triassic and Jurassic, with the Gondwanan flora to the south (modified from McLoughlin, 2001).

The studies reviewed below incorporate many different approaches to taxonomy, stratigraphy and palaeoecology. Most authors provide limited to no information on taxonomic groupings or parent plants of palynomorphs. Being that efforts to correlate dispersed Palaeozoic and Mesozoic spores and pollen to their parent plants are innately complex (Balme, 1995, p. 85), most palynologists have slightly different approaches to classification and taxonomy (Traverse, 2007), and that the main thrust of this project was biostratigraphical and not palaeoecological in nature, taxonomic or ecological groupings have not been provided along with the various taxa lists. These taxa lists are included mainly for the purposes of biozone correlations with the Karoo Basin in Chapter 3 (Results and Discussion).

1.3.2.1 Main Karoo Basin

The Main Karoo Basin (MKB) hosts a wealth of minerals and fossil fuels, and the palynology of Ecca coal-bearing strata has been extensively investigated due to its economic importance. Microfossils display excellent preservation in these carbonaceous rocks and are abundant in most samples. Less work has been done on the palynology of other Karoo formations, probably due to generally poor yields of palynomorphs. The glacial environment in which the rocks comprising the Carboniferous Dwyka Group were deposited was not conducive to a high plant biomass or diversity (Bamford, 2004), and Anderson (1977) noted a low abundance of pollen grains in Dwyka samples. Palynomorphs do not preserve well in oxidising or high-energy environments and are usually absent in coarse-grained sandstones, clays, red siltstones, volcanic rocks and metamorphosed rocks (Traverse, 2007). Such rocks comprise a significant part of the Beaufort and Stormberg groups which has complicated the task of erecting a comprehensive palynozonation scheme for the Karoo Basin. Two partial systems for the northern Karoo Basin spanning the Carboniferous and Permian periods have been designated by John Anderson and Grigor Aitken and are presented below, followed by other studies on the Main Karoo Basin in ascending stratigraphic order. Lithostratigraphy of the MKB is shown in Figure 1.2.

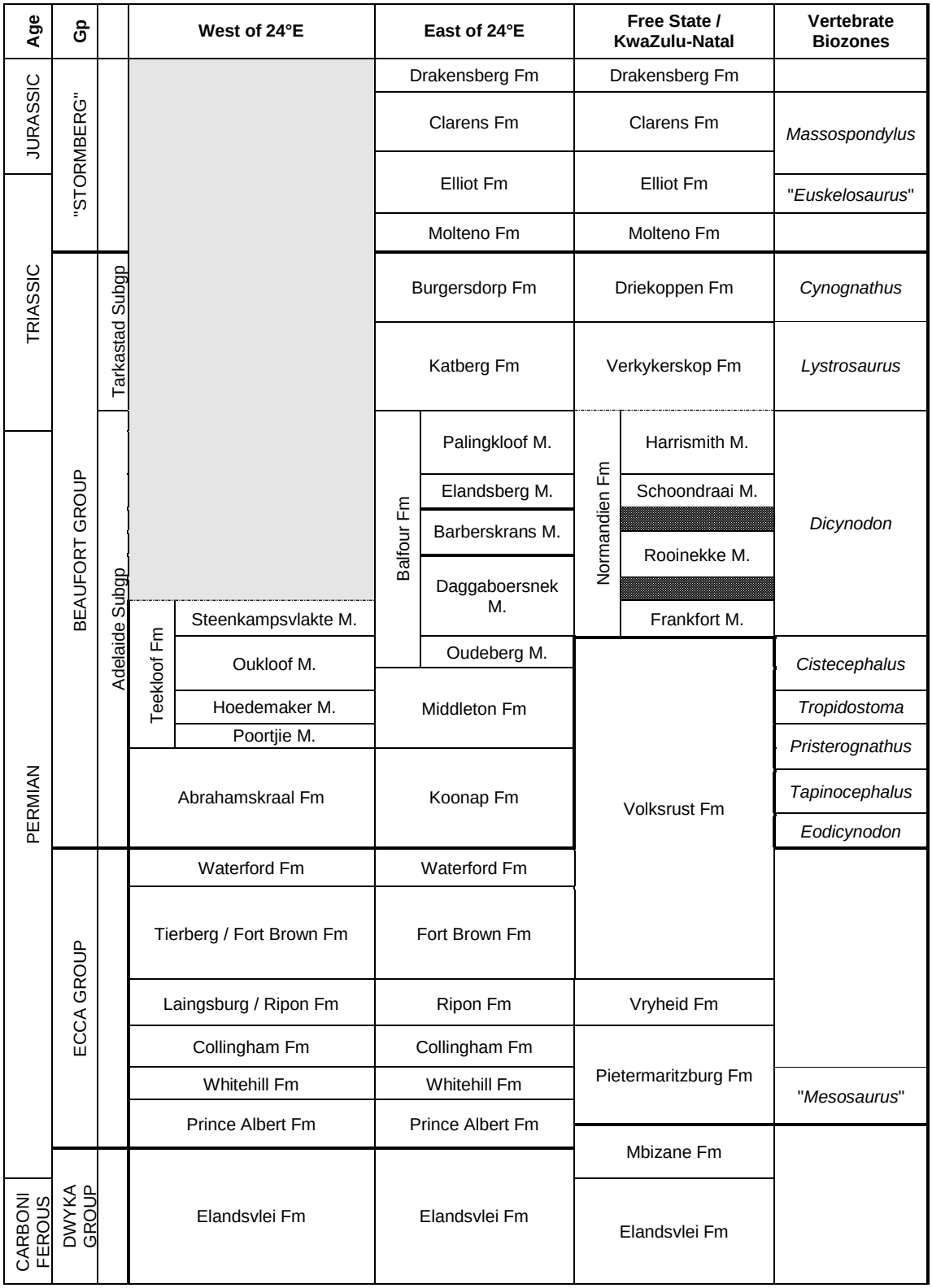


Figure 1.2: Litho- and vertebrate biostratigraphy of the Karoo Supergroup (Rubidge, 2005).

Previous Palynozonation Schemes for the Main Karoo Basin

Anderson (1977) subdivided the Dwyka, Ecca and Beaufort Groups of the Northern Karoo into seven zones according to their palynomorph content (Table 1.1). He assumed that the established vertebrate biozones of the Karoo would correlate with the microfloral zones, but this hypothesis had not been tested before the current study. Zone 1 (Dwyka Group and Pietermaritzburg Formation) is low in palynomorph abundance and diversity.

The Lower Ecca Zone 2 (Pietermaritzburg and Vryheid formations) was subdivided into 4 microfloral zones (Table 1.1). Zone 2a is dominated by *Gondisporites punctatus* and *G. parvus* (Lycopoda), subzone b by *Microbaculispora plumsteadi* (Sphenophyta), subzone c by *Gondisporites braziliensis* and *G. raniganjensis*, and subzone d by *Pityosporites* (Table 1.1).

The Middle Ecca Zone 3 (Vryheid Formation) has an extremely speciose microflora compared to the Dwyka, and spores are virtually absent (Anderson, 1977). This is consistent with the findings of Falcon (1978) who also found an increase in species diversity from Dwyka to Ecca samples in the Mid-Zambezi and Sabi-Limpopo Basins. Zone 3 was sub-divided into 4 microfloral zones, with *Granulatisporites austroamericanus* (*Microbaculispora tentula)* dominating subzones 3a and b, and subzone b being distinguished by the appearance of *Gnetaceaepollenites* as well as an increase in *Pityosporites* (Table 1.1). Subzone c is the most diverse assemblage and incorporates many species of *Mehlisphaeridium*, *Microbaculispora*, *Apiculatisporis*, and *Gnetaceaepollenites*. Also present are the pollen genera *Vestigisporites*, *Vittatina*, *Pityosporites*, and *Lueckisporites*. Characteristic species of Zone 3d include *Lueckisporites asulcus*, *Lueckisporites nyakapendensis* and *Pityosporites goraiensis* (Table 1.1).

Table 1.1: Characteristic palynomorphs of the Dwyka, Ecca and Beaufort groups, northern Karoo basin (compiled from Anderson, 1977).

Current stratigraphy (SACS, 1980)	Original stratigraphy by Anderson (1977)	Reference Area	Zones	Characteristic Species (More commonly used names)
Upper Balfour / Normandien Fm	*Daptocephalus* Zone (Beaufort Group)	Tetrapod- and macroflora -bearing floodplain deposits near Bergville / Harrismith	7	*Inaperturosporites inapertus* *Apiculatisporis bulliensis (Brevitriletes bulliensis)* *Apiculatisporis cornutus* *Vittatina lucifera (Weylandites lucifer)* *Pityosporites ovatus (Alisporites ovatus)* *Pityosporites goraiensis (Protohaploxypinus goraiensis)* *Pityosporites amplus (Protohaploxypinus amplus)* *Pityosporites micros (Protohaploxypinus limpidus)*
Middleton & Lower Balfour formations	*Cistecephalus* Zone (Beaufort Group)	Tetrapod-bearing floodplain deposits near Graaff-Reinet	6	
Normandien Fm	*Tapinocephalus* Zone equivalent (Beaufort Group)	Near shore fluvial and fluvio-deltaic deposits from Welkom / Virginia	5	*Cyclogranisporites bharadwaji* *Vittatina lucifera (Weylandites lucifer)* *Vittatina magma* *Vittatina densa (Vittatina africana)* *Pityosporites maximus (Alisporites potoniei)* *Lueckisporites asulcus* *Lueckisporites nyakapendensis* *Lueckisporites neohannonicus*
Volksrust Fm	Upper Ecca	Delta front and shelf deposits from Welkom / Virginia	4	*Gondisporites punctatus* *Gondisporites parvus*

				Gondisporites braziliensis *Gondisporites variabilis* *Gondisporites splendens (Indotriradites splendens)* *Microbaculispora labyrinthica* *Microbaculispora directa (Deltoidospora directa)* *Microbaculispora finegranulata* *Microbaculispora mediogranulata* *Microbaculispora micronodosa (Granulatisporites micronodosus)* *Microbaculispora trisina (Granulatisporites trisinus)* *Microbaculispora gondwanensis* *Microbaculispora villosa* *Microbaculispora ericiana (Didecitriletes ericianus)* ~~*Dulhuntyspora dulhuntyi*~~ - actually *Dulhuntyspora granulata* (Backhouse, 1991) *Polypodiisporites detritus* *Vittatina lucifera (Weylandites lucifer)* *Lueckisporites asulcus* *Lueckisporites nyakapendensis* *Lueckisporites hannonicus (Guttulapollenites hannonicus)* *Lueckisporites neohannonicus*
Vryheid Fm	Middle Ecca	Coals from Greylingstad / Bethal / Hendrina	3	*Mehlisphaeridium parvum* *Mehlisphaeridium fibratum* *Microbaculispora tentula (Granulatisporites austroamericanus)*

				Microbaculispora trisina (Granulatisporites trisinus) *Microbaculispora gondwanensis* *Microbaculispora irregularis (Converrucosisporites irregularis)* *Microbaculispora capilliformis (?Diatomozonotriletes townrowii)* *Apiculatisporis diversiformis* *Apiculatisporis levis* *Apiculatisporis bulliensis (Brevitriletes bulliensis)* *Apiculatisporis cornutus* *Vestigisporites rudis* *Vittatina nonsaccata* *Vittatina simplex* *Pityosporites levis* *Pityosporites fusus* *Pityosporites goraiensis (Protohaploxypinus goraiensis)* *Lueckisporites asulcus* *Lueckisporites nyakapendensis* *Lueckisporites welkomensis* *Lueckisporites hannonicus (Guttulapollenites hannonicus)* *Gnetaceaepollenites sinuosus* *Gnetaceaepollenites ovatus* *Gnetaceaepollenites bulbiger*
Vryheid Fm, Pietermaritzburg Fm	Lower Ecca	Ladybrand borehole, Welkom / Virginia, Sasolburg	2	*Mehlisphaeridium irregulare* *Maculatasporites indicus* *Pilasporites calculus*

				Pilasporites scissus *Zinjisporites spinosus* *Gondisporites punctatus* *Gondisporites parvus* *Gondisporites raniganjensis* *Gondisporites braziliensis* *Acanthotriletes* - laevigate form (= *Concavisporites mortonii)* *Acanthotriletes* - baculate form (= *Horriditriletes ramosus)* *Acanthotriletes* - granulate form (= *Granulatisporites microgranifer)* *Acanthotriletes* - spinate form (= *Acanthotriletes tereteangulatus)* *Microbaculispora eoericiana (Didecitriletes horridus)* *Microbaculispora plumsteadi (Cirrabaculisporites plumsteadiae)* *Microbaculispora lageniformis (Cirrabaculisporites lageniformis)* *Microbaculispora paramicronodosa* *Pachytriletes densus* *Apiculatisporis diversiformis* *Apiculatisporis minor (Divaricrassus minor)* *Apiculatisporis major (Apiculatisporis parmatus)* *Apiculatisporis levis* *Apiculatisporis bulliensis (Brevitriletes bulliensis)* *Apiculatisporis cornutus* *Polypodiisporites detritus*

				Vittatina multistriata (Striatoabieites multistriatus) *Vittatina lucifera (Weylandites lucifer)* *Vittatina triradiata (Marsupipollenites triradiatus)* *Pityosporites triassicus* *Pityosporites tenuicorpus (Alisporites tenuicorpus)* *Pityosporites ovatus (Alisporites ovatus)* *Pityosporites maximus (Alisporites potoniei)* *Pityosporites cancellatus (Striatopodocarpites fusus)* *Pityosporites amplus (Protohaploxypinus amplus)* *Pityosporites micros (Protohaploxypinus limpidus)* *Cycadopites cymbatus*
Pietermaritzburg Fm, Dwyka Group	Upper Dwyka Shales Dwyka Tillite	Glacial sequence of Welkom / Virginia	1	*Zinjisporites spinosus* *Microbaculispora tentula (Granulatisporites austroamericanus)* *Pachytriletes densus* *Punctatisporites gretensis* *Vestigisporites balmei* *Vestigisporites gondwanensis (Plicatipollenites gondwanensis)* *Cycadopites cymbatus*

Microfloral diversity declines again in the Upper Ecca Zone 4 (Volksrust Formation) but is abundant enough to distinguish five microfloral subzones (Anderson, 1977). Zone 4a is characterised by an abundance of *Gondisporites punctatus*, subzone b by the appearance of *Microbaculispora trisina* and *M. micronodosa*, *Polypodiisporites detritus*, and *Vittatina lucifera* (Table 1.1). *Lueckisporites asulcus* and *L. nyakapendensis* are abundant in Zone 4c. In Zone 4d, a number of new genera appear, including 5 species of *Microbaculispora*, and *Dulhuntyspora dulhuntyi* (actually *D. granulata* according to Backhouse, 1991). *Lueckisporites asulcus* and *L. nyakapendensis* once again dominate in Zone 4e (Table 1.1).

Microfloral diversity declines steadily as one moves through Zones 5 (? *Tapinocephalus* Assemblage Zone (AZ)), 6 (Middleton & Balfour formations = *Cistecephalus* & *Tropidostoma* assemblage zones) and 7 (? *Dicynodon* AZ) (Anderson, 1977). Zone 5 is subdivided into 5 subzones, with Zone 5a dominated by *Pityosporites maximus*, *Lueckisporites asulcus* and *L. nyakapendensis* (Table 1.1). Subzone b is also dominated by these genera as well as *Vittatina lucifera*, while subzone c is dominated specifically by *Vittatina lucifera* and *Pityosporites maximus*, subzone d by *Vittatina lucifera* only, and subzone e, by *Vittatina magma* (Table 1.1). Zone 6 is dominated by *Pityosporites micros*, and Zone 7, by *Pityosporites amplus* but these two zones have essentially the same pollen content (Table 1.1). Anderson (1977) could not obtain palynomorphs from the *Lystrosaurus* zone.

Two decades after the publication of Anderson's Karoo pollen biozonation, Aitken (1998) proposed a new microfloral biozonation scheme for the Northern Karoo, with ten zones for the Permian and Early Triassic (Table 1.2), incorporating earlier work by MacRae (1988). Aitken (1998) suggested an Ufimian - Kazanian (Late Permian) age for the No. 5 Seam (Vryheid Formation). Aitken (1998) observed no significant palynological changes over the Ecca-Beaufort boundary and also considered the Permo-Triassic boundary in the Karoo Basin to be gradational rather than punctuated. This was due to a tentative

palynological correlation of Biozone X of Aitken (1998) to the Early Triassic Jiuxaiyuan Formation of China that has yielded a *Lystrosaurus* fauna (Qu & Wang, 1986). This correlation was made on the FAD (first appearance datum) of the monolete spore *Aratrisporites* which is used by some researchers as a marker for the Early Triassic in continental deposits (e.g. Ouyang & Norris, 1999; Foster *et al*., 1998). This correlation is consistent with the finding that the FAD of *Lystrosaurus* is within the upper Normandien Formation (Smith & Ward, 2001).

The biozones of Aitken (1998) are each named after two palynomorph taxa with overlapping ranges, hence the terming of these biozones as "concurrent range zones" (Table 1.2). However some of these taxa range outside of their designated zones, meaning that these biozones are in fact abundance zones (Murphy & Salvador, 1999). For example, Biozone VII is named the *Protohaploxypinus limpidus – Lunatisporites pellucidus* zone and while the range of *Lunatisporites pellucidus* begins in this zone and extends to Biozone VIII, the range of *Protohaploxypinus limpidus* extends from Biozone III-IX, hence the two taxa are also found together in Biozone VIII. The biozonation given at the end of the thesis (Aitken, 1998) depicts Biozone I (*Potonieisporites novicus – Cannanoropollis densus*) as beginning in the Dwyka Group but all the correlation charts and text indicate that it begins in the lowermost Vryheid Formation, hence Table 1.2 has been modified to accommodate this. The FAD and LAD of *Chordasporites* of Aitken (1998) are also unclear with species lists indicating it to be present in Biozone VII, but the biozonation scheme depicting this taxon as being contained within Biozone VI.

Table 1.2: Palynozones for the Dwyka, Ecca and Beaufort groups of the northern Karoo Basin (redrawn from Aitken, 1998). Underlined taxa are considered distinctive species for the corresponding biozone.

Lithology		Biozone	Concurrent Range Zone	Characteristic Species
Beaufort Group	Estcourt Formation	**X**	*Aratrisporites – Calamospora plicata*	*Aratrisporites* sp. *Calamospora tener* *Falcisporites stabilis*
		IX	*Ephidripites – Cycadopites*	*Ephidripites* sp. *Cirratriradites* sp. *Cycadopites follicularis* *Cycadopites nevesi*
		VIII	*Osmundacidites senectus – Alisporites potoniei*	*Osmundacidites senectus* *Alisporites potoniei* *Vitreisporites pallidus* *Falcisporites stabilis* *Osmundacidites wellmanii* *Calamospora tener* *Thymospora pseudothiessenii*
Ecca Group	Volksrust Formation	**VII**	*Protohaploxypinus limpidus – Lunatisporites pellucidus*	*Protohaploxypinus limpidus* *Lunatisporites pellucidus* *Protohaploxypinus amplus* *Lunatisporites sp.* *Tetraporina tetragona* *Lueckisporites* sp. *Chordecystia sp.* *Peltacystia venosa*
		VI	*Guttulapollenites hannonicus – Protohaploxypinus rugatus*	*Guttulapollenites hannonicus* *Protohaploxypinus rugatus* *Kraeuselisporites enormis* *Haplocystia pellucida* *Sporocystia eraducia* *Weylandites magmus* *Chordasporites*

				australiensis
	Vryheid Formation	**V**	*Lueckisporites virkkiae – Corisaccites alutas*	*Lueckisporites virkkiae* *Corisaccites alutas* *Protohaploxypinus limpidus* *Protohaploxypinus amplus* *Alisporites potoniei* *Granulatisporites trisinus* *Lunatisporites* sp. *Bascanisporites undosus* *Protohaploxypinus rugatus* *Guttulapollenites hannonicus*
		IVB	*Striatopodocarpites fusus – Weylandites lucifer*	*Striatopodocarpites fusus* *Weylandites lucifer* *Gnetaceaepollenites sinuosus* *Striatopodocarpites cancellatus* *Striatopodocarpites fusus* *Striatopodocarpites gondwanensis* *Protohaploxypinus amplus* *Protohaploxypinus goraiensis* *Protohaploxypinus diagonalis* *Protohaploxypinus limpidus*
		IVA	*Granulatisporites trisinus* Interval Zone	No distinctive taxa *Granulatisporites trisinus*
		III	*Striatopodocarpites cancellatus – Marsupipollenites triradiatus*	*Striatopodocarpites cancellatus* *Marsupipollenites triradiatus* *Alisporites potoniei* *Kraeuselisporites enormis* *Gnetaceaepollenites sinuosus* *Concavisporites mortonii*

				Interradispora versus
		II	*Mehlisphaeridium colliensis – Alisporites splendens*	*Mehlisphaeridium colliensis* *Alisporites splendens* *Deltoidospora directa* *Laevigatosporites vulgaris* *Florinites eremus*
		I	*Potonieisporites novicus – Cannanoropollis densus*	*Potonieisporites novicus* *Cannanoropollis densus* *Limitisporites monstruosus* *Lophotriletes novicus* *Acanthotriletes tereteangulatus* *Cannanoropollis mehtae* *Cannanoropollis obscurus* *Deltoidospora directa* *Granulatisporites papillosus* *Punctatisporites gretensis*

In addition to the above biozonation schemes, many smaller ranging palynological studies have been carried out in the Main Karoo Basin, mostly from Permian rocks. Investigations into Carboniferous and Triassic rocks are less common.

Dwyka and Ecca groups

McLachlan & Anderson (1973) sampled for palynomorphs on two farms near Kimberley as part of a larger investigation into purported marine conditions during deposition of the Dwyka Group, Prince Albert and Whitehill formations. Unfortunately no details of the palynomorphs found are given, only stating that the "assemblages were compatible with the Lower Permian (Sakmarian) age suggested by the molluscs (J.M. Anderson, pers. comm.)" (McLachlan & Anderson, 1973, p. 45). Accordingly the palynomorphs recovered should be

similar to those of Assemblage Zone 1 of Anderson (1977) based on Anderson's proposed age as well as the rocks from which they are derived.

Falcon (1988, 1989) reported on the palynomorph content of the No. 2 seam, Witbank coalfield, Vryheid Formation as part of a larger study that examined macro- and micro-factors affecting the quality and distribution of the coal seam (Table 1.3). At the onset of deglaciation at the end of the Carboniferous, a distinctive and monosaccate-rich microflora existed, including *Virkkipollenites*, *Barakarites*, *Caheniasaccites*, *Plicatipollenites*, and *Potonieisporites* (Table 1.3). These taxa are typical of floras associated with deglaciation, and the microfloral assemblage is relatively low in diversity. In contrast pollen of the Vryheid Formation is much more diverse, with the introduction of the bisaccate striate pollens *Striatopodocarpites* and *Striatoabieites*, a new *Protohaploxypinus* species, and a new variety of spore taxa (Table 1.3). The No. 2 seam has been assigned an Early Permian age by Falcon (1988, 1989).

Table 1.3: List of palynomorph species in the Witbank and Highveld coal seams, Vryheid Formation (compiled from Falcon, 1988, 1999; Aitken, 1994).

No. 2 Seam (Falcon, 1988, 1989)	No. 5 Seam (Aitken, 1994)	
Alisporites gracilis	*Acanthotriletes tereteangulatus*	*Platysaccus radialis*
Alisporites plicatus	*Alisporites ovatus*	*Plicatipollenites gondwanensis*
Alisporites tenuicorpus	*Alisporites potoniei*	*Plicatipollenites trigonalis*
Apiculatisporis filiformis	*Alisporites sp. A*	*Polypodiisporites mutabilis*
Apiculatisporis levis	*Apiculatisporis cornutus*	*Potonieisporites novicus*
Caheniasaccites ovatus	*Apiculatisporis levis*	*Protohaploxypinus amplus*
Calamospora plicata	*Barakarites rotatus*	*Protohaploxypinus diagonalis*
Cycadopites cymbatus	*Calamospora plicata*	*Protohaploxypinus globus*
Cyclobaculisporites bharadwaji	*Cannanoropollis densus*	*Protohaploxypinus goraiensis*
Cyclogranisporites parvus	*Cannanoropollis janakii*	*Protohaploxypinus hartii*
Cyclogranisporites verrucosus	*Cannanoropollis obscurus*	*Protohaploxypinus jacobii*
Deltoidospora directa	*Circulisporites parvus*	*Protohaploxypinus latissimus*
Florinites eremus	*Cirratriradites fibulatus*	*Protohaploxypinus limpidus*

Gondisporites salisburyensis	*Cirratriradites africanensis*	*Protohaploxypinus microcorpus*
Granulatasporites obscurus	*Cirratriradites australensis*	*Protohaploxypinus suchonensis*
Illinites unicus	*Cirratriradites splendens*	*Protohaploxypinus sulcatus*
Limitisporites monstruosus	*Columinisporites sp.*	*Pteruchipollenites gracilis*
Lophotriletes dwykanensis	*Concavisporites mortonii*	*Pteruchipollenites sp. A*
Lophotriletes rarus	*Corisaccites alutas*	*Punctatisporites gretensis*
Marsupipollenites triradiatus	*Cycadopites cymbatus*	*Punctatosporites granifer*
Mehlisphaeridium colliensis	*Cycadopites follicularis*	*Punctatosporites rotundus*
Microbaculispora micronodosa	*Cycadopites nevesi*	*Quadrisporites horridus*
Microbaculispora tentula	*Cyclogranisporites gondwanensis*	*Secarisporites lobatus*
Neoraistrickia congoensis	*Cyclogranisporites verrucosus*	*Striatoabieites multistriatus*
Neoraistrickia ramosa	*Deltoidospora directa*	*Striatopodocarpites cancellatus*
Pakhapites sp.	*Florinites eremus*	*Striatopodocarpites fusus*
Parasaccites diffusis	*Gnetaceaepollenites sinuosus*	*Striatopodocarpites gondwanensis*
Peltacystia venosa	*Gondisporites sp.*	*Striatopodocarpites pantii*
Pilasporites calculus	*Granulatisporites microgranifer*	*Striatopodocarpites phaleratus*
Platysaccus leschiki	*Granulatisporites papillosus*	*Striatopodocarpites rarus*
Plicatipollenites indicus	*Granulatisporites trisinus*	*Striatopodocarpites solitus*
Potonieisporites novicus	*Horriditriletes gondwanensis*	*Striomonosaccites ovatus*
Potonieisporites thomasi	*Horriditriletes ramosus*	*Thymospora pseudothiessenii*
Protohaploxypinus amplus	*Indotriradites reidii*	*Verrucosisporites naumovae*
Punctatisporites gretensis	*Kraeuselisporites enormis*	*Verrucosisporites pseudoreticulatus*
Punctatisporites intrareticulatus	*Laevigatosporites vulgaris*	*Weylandites lucifer*
Retusotriletes diversiformis	*Limitisporites moersensis*	*Weylandites simplex*
Schizosporis scissus	*Limitisporites monstruosus*	*Zinjisporites eccensis*
Striatoabieites multistriatus	*Limitisporites sp.*	
Sulcatisporites ovatus	*Lophotriletes novicus*	
Sulcatisporites splendens	*Lophotriletes scotinus*	
Tetraporina tetragona	*Lueckisporites sp.*	
Tugasporites delasaucei	*Lueckisporites virkkiae*	
Verrucosisporites naumovai	*Lunatisporites sp.*	
Verrucosisporites parmatus	*Maculatasporites amplus*	
Verrucosisporites pseudoreticulatus	*Maculatasporites gondwanensis*	
Vestigisporites gondwanensis	*Marsupipollenites striatus*	
Virkkipollenites mehtae	*Marsupipollenites triradiatus*	
Virkkipollenites obscurus	*Mehlisphaeridium colliensis*	
Virkkipollenites radiatus	*Platysaccus papilionis*	

Falcon *et al*. (1984) investigated the palynoflora of the Witbank / Highveld coalfields in South Africa (Table 1.4) and correlated the seams to the zonation scheme for the Mid-Zambezi Basin in Zimbabwe (Falcon, 1975, 1978). The No. 1 and No. 2 seams contain similar monosaccate assemblages, deposited during the post-glacial regime in the early Ecca. The No. 3 to No. 5 seams are characterised by abundant bisaccates and striate bisaccates increase progressively from the basal seam upwards (Falcon *et al*., 1984). There is a significant increase in the number of pollen taxa from the No. 2 to the No. 4 seams, however Falcon *et al*. sampled only the coal seams and not the interbedded rocks, accordingly many taxa could possibly occur earlier than stated (Millsteed, 1994).

Aitken (1993, 1994, 1998) studied the palynology of the Vryheid Formation (Witbank / Highveld coal seams) in detail as part of his investigations into Permian Ecca and Beaufort Group rocks, which resulted in a Karoo biozonation scheme being erected (Aitken, 1998, presented earlier in the text). The No. 5 seam, Witbank coalfield, is dominated by striate bisaccate pollen genera, especially *Protohaploxypinus*, *Striatopodocarpites*, and *Weylandites* (Table 1.3). The No. 5 seam can be correlated with Zone V, Sub-zone H as erected by Falcon *et al*. (1984), and Biozone F of MacRae (1988) from the Waterberg, to which is it particularly similar. The No. 5 seam assemblage is also broadly comparable to the Striatiti florizone of Hart (1967) and Zone 5 of the northern Karoo Basin (Anderson, 1977). The No. 5 seam is tentatively suggested as being Guadalupian in age by Aitken (1998).

Millsteed (1994, 1999) investigated the palynology of the New Vaal Colliery south of Vereeniging in the northern Karoo Basin. The Vereeniging Sequence comprises the Bottom, Middle and Top coal seams, differing from the Witbank / Highveld coalfields which have five exploited seams numbered in ascending stratigraphic order (Jeffrey, 2005). Three stratigraphically significant palynomorph taxa were found in the Vereeniging coal-bearing strata: *Pseudoreticulatispora pseudoreticulata* (*Converrucosisporites pseudoreticulatus*), *Granulatisporites trisinus*, and *Praecolpatites sinuosus*. These species have also

Table 1.4: Indicator species of the Witbank and Highveld coal seams (compiled from Falcon *et al*., 1984).

Coal Seam	Indicator palynomorphs	
5	*Apiculatispora*	*Marsupipollenites triradiatus*
	Cirratriradites africanensis	*Microbaculispora*
	Densipollenites indicus	*Protohaploxypinus micros*
	Deltoidospora	*Striatopodocarpites cancellatus*
	Gnetaceaepollenites sinuosus	*Striatopodocarpites fusus*
	Gondisporites	*Sulcatisporites*
	Lueckisporites	*Vittatina*
	Marsupipollenites striatus	
4	*Marsupipollenites striatus*	*Protohaploxypinus micros*
	Platysaccus	*Striatoabieites multistriatus*
	Protohaploxypinus circumvens	*Striatopodocarpites cancellatus*
	Protohaploxypinus goraiensis	*Sulcatisporites potoniei*
	Protohaploxypinus globus	
3	*Densipollenites indicus*	*Striatopodocarpites rarus*
	Platysaccus leschiki	*Sulcatisporites potoniei*
	Protohaploxypinus	*Vesicaspora*
2	*Alisporites plicatus*	*Striatoabieites multistriatus*
	Florinites eremus	*Sulcatisporites potoniei*
	Lophotriletes rarus	*Sulcatisporites splendens*
	Neoraistrickia ramosa	*Vesicaspora luteus*
	Potonieisporites	*Vesicaspora milvinus*
	Protohaploxypinus diagonalis	*Virkkipollenites*
	Protohaploxypinus limpidus	
1	*Alisporites gracilis*	*Plicatipollenites*
	Alisporites tenuicorpus	*Potonieisporites*
	Apiculatisporis levis	*Protohaploxypinus amplus*
	Cycadopites cymbatus	*Punctatisporites gretensis*
	Deltoidospora directa	*Retusotriletes diversiformis*
	Gondisporites	*Sulcatisporites ovatus*
	Marsupipollenites triradiatus	*Verrucosisporites*
	Microbaculispora tentula	*Virkkipollenites*

been used to define three palynological stages in Australia (Kemp *et al*., 1977). In the Vryheid Formation, *P. pseudoreticulata* and *G. trisinus* were found in the Bottom Seam and their stratigraphic ranges extend upward through to the green band above the Top Seam, while the range of *P. sinuosus* begins directly above the Middle Seam (Millsteed, 1994). Therefore the Bottom and Middle Seams correlate to Stage 3b of Australia (Price, 1983) and the strata above the Middle Seam, to uppermost Stage 3b and basal stage L4 of Australia (Price, 1983). Millsteed (1994) recorded a sudden increase in the number of pollen taxa between the Middle and the Top Seams, similar to Falcon *et al*. (1984), who observed an increase from the No. 2 to the No. 4 seam in the Witbank coalfields. In the Vryheid Formation at Vereeniging, *P. sinuosus* occurs along with *Weylandites*, *Barakarites*, *M. striatus*, *Lueckisporites*, and *Platysaccus*. These taxa have also been found in the Vryheid Formation at Witbank, thus the Bottom and Middle Seams in Vereeniging correlate to the No. 2 Seam in Witbank, and the Vereeniging Top Seam is equivalent to the Witbank No. 4 Seam (Millsteed, 1994). On the basis of correlation with Australian strata, the Vryheid Formation was assigned an Artinskian (Sterlitamakian to early Baigendzhinian) age by Millsteed (1994).

Beaufort Group

Horowitz (1990) reported on palynomorphs from the *Tapinocephalus* - *Cistecephalus* Zone contact of the Lower Beaufort Group (Kitching, 1970) and recorded *Acanthotriletes* spp. (*Horriditriletes ramosus*), *Alisporites* sp. (*Pteruchipollenites indarraensis*), *Altitriletes densus*, *Apiculatasporites* spp., *Apiculatisporites* sp., *Gondisporites parvus*; *Gondisporites* spp., *Leiotriletes* spp. (*Deltoidospora directa*), *Maculatasporites indicus*, *Microbaculispora virkkiae*, *Perisaccus granulatus* (*Florinites eremus*), *Pityosporites* spp. (*Protohaploxypinus amplus*), *Taeniaesporites* sp. (*Protohaploxypinus goraiensis*), *Tetraporina superba*, *Vitreisporites pallidus* (*Platysaccus radialis*), *Vittatina nonsaccata*, *Vittatina* sp., and three unidentified monolete spores. Also present were acritarchs

/ algae of various species of *Veryhachium* as well as *Baltisphaeridium* spp., *Micrhystridium parvispinum*, and *Solisphaeridium rossignolii*.

Looy in Prevec *et al*. (2009) reported on the palynology of the Clouston Farm locality from the KwaZulu-Natal Normandien Formation (*Dicynodon* Assemblage Zone). The microflora is characterised by abundant *Protohaploxypinus* and *Striatopodocarpites* as well as common *Striatoabieites multistriatus, Lunatisporites* sp., *Weylandites lucifer*, *Granulatisporites papillosus*, *Lophotriletes novicus*, and *Calamospora plicata*. Rare elements include *Chordasporites waterbergensis* MacRae 1988, *Falcisporites*, cf. *Alisporites ovatus* Jansonius 1962, cf. *Cyclogranisporites gondwanensis* Bharadwaj & Salujha 1964, cf. *Apiculatisporis cornutus* Høeg & Bose 1960, and *Horriditriletes ramosus*. Correlation with western and eastern Australian basins supports a Wuchiapingian (early Lopingian) age assignment for the assemblage.

The Latest Permian glossopterid flora from Wapadsberg Pass in the Eastern Cape Province of the Karoo Basin yielded a palynological assemblage comprising bisaccate pollen (*Protohaploxypinus limpidus*, *P. goraiensis*, *Striatopodocarpites cancellatus*, *Lueckisporites virkkiae*, *Guttulapollenites hannonicus*, *Lunatisporites noviaulensis*, *L. cf. pellucidus*, *Alisporites tenuicorpus*, cf. *Chordasporites*, *Klausipollenites schaubergeri*, cf. *Hamiapollenites*, *Falcisporites stabilis*, *F. australis*), taeniate pollen (*Weylandites lucifer*) and acavate spores (*Columinisporites* sp. cf. *C. peppersii*, cf. *Calamospora* sp.) (Prevec *et al*., 2010). Microflora indicates the presence of a glossopterid-dominated woodland with a sphenophyte understory as well as a regional flora composed of gymnosperms, peltasperms, corystosperms and conifers dating to the Late Changhsingian.

Steiner *et al*. (2003) sampled strata from the Carlton Heights locality of the Balfour Formation, southern Karoo, and defined three palynological assemblage zones: a Late Permian *Klausipollenites schaubergeri* Zone (dominated by *Protohaploxypinus* and *Falcisporites*), a "fungal abundance spike" just above the Permo-Triassic boundary, dominated 100% by *Reduviasporonites chalastus* and

woody plant remains, and an Early Triassic *Kraeuselisporites-Lunatisporites* Zone, dominated by the lycopod *Kraeuselisporites* and the bisaccate pollen taxa *Lunatisporites* and *Platysaccus* (Figure 1.3). The fungal interval was construed to represent an excess of fungi on decaying plant matter created through the mass extinction event.

Steiner *et al*. correlated a laminated maroon mudstone to a stratigraphically equivalent unit recognized by Smith & Ward (2001) at the Bethulie - Lootsberg Pass in order to establish the base of the P-T event beds. However, Lindström & McLoughlin (2007) assert that the fungal spike lies 17 m above the P-T Boundary as defined by Retallack *et al*. (2003), and considerably above the top of the Permian based on carbon isotope data (Ward *et al*., 2005). Prevec *et al*. (2010) consider the samples defined by Steiner *et al*. (2003) as originating from the Early Triassic Katberg Sandstone to derive from the Late Permian Elandsberg Formation. Further intensive sampling at numerous intervals along the P-T boundary is the only way to resolve this debate. There is also much discussion surrounding the origin of *Reduviasporonites* itself. Geochemical analyses of specimens by Foster *et al*. (2002) suggest the spores are most probably of algal, not fungal origin and therefore unlikely to be related to the P-T mass extinction event, but there are many reported incidences of "fungal" spikes at the Permo-Triassic boundary from Italy (Visscher & Brugman, 1986), Israel (Eshet, 1990, 1992; Eshet *et al*., 1995), Kenya (Hankel, 1992) and Madagascar (Wright & Askin, 1987) as well as South Africa (Steiner *et al*., 2003). Chemical analyses argue that the affinity of *Reduviasporonites* is in fact inconclusive and could be of either fungal or algal origin, with isotopic signatures suggesting a fungal origin (Sephton *et al*., 2009). However Visscher *et al*. (2011) demonstrated close morphological similarity of *Reduviasporonites* to the modern filamentous fungi *Rhizoctonia*, supporting the hypothesis of fungal virulence at the end of the Permian period.

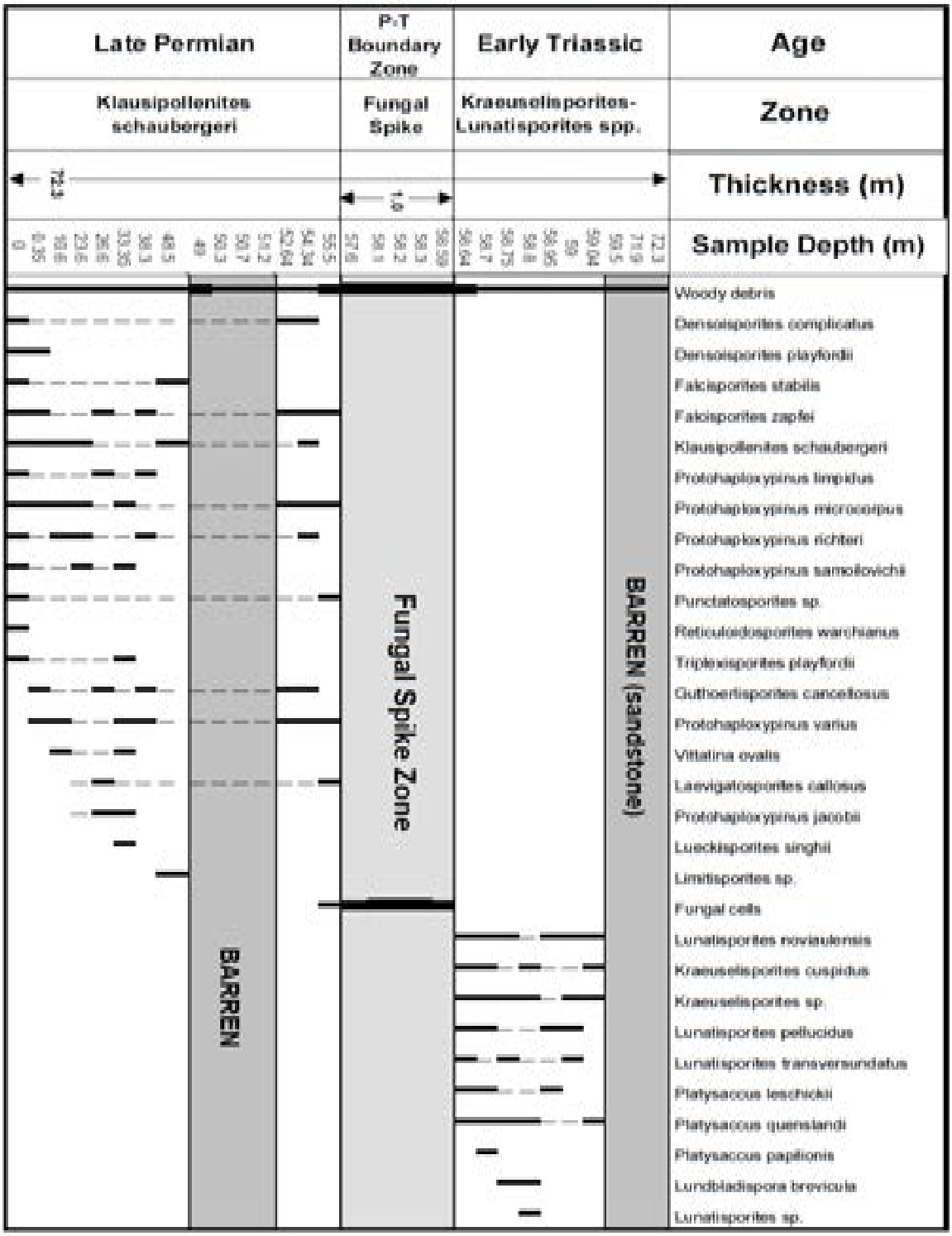


Figure 1.3: Palynomorph range chart of Carlton Heights, southern Karoo Basin (Steiner *et al*., 2003).

Beaufort Group / Molteno Formation

Stapleton (1974, 1977) produced internal reports for the Geological Survey of South Africa summarising palynological investigations into Beaufort and Molteno rocks of the Cape Province. These findings were later published (Stapleton, 1978). Both surface and borehole samples were processed and samples from only four localities proved to be productive: a lower Beaufort Group locality from near Beaufort West, two upper Beaufort Group localities near Hofmeyr and Burgersdorp, and a lower Molteno Formation locality near Steynsburg. Species recovered comprise *Densoisporites playfordii*, *Spinotriletes senecioides*, *Endosporites hexareticulatus*, *Cycadopites follicularis*, *Alisporites australis*, *Falcisporites zapfei* (*Limitisporites monstruosus*), *Klausipollenites staplinii*, *Platysaccus papilionis*, *Platysaccus praevius*, *Illinites kosankei*, *Protohaploxypinus microcorpus*, *Striatisaccus goswicensis* (*Klausipollenites schaubergeri*), *Striatites minor*, *Striatites richteri* (*Strotersporites richteri*), *Striatites samoilovichi* (*Protohaploxypinus samoilovichii*), and *Taeniaesporites pellucidus* (*Lunatisporites pellucidus*). From the palynology Stapleton (1977) proposed an early Early Triassic age for the Beaufort- Molteno contact, stated that Lower Beaufort rocks were deposited in a marine environment, and fossil vertebrates from the upper Beaufort Group are Permian in age. Incorrect stratigraphy is likely to be the cause of these erroneous conclusions.

The Triassic Molteno Formation has been extensively sampled for macroplants by Heidi and John Anderson and has also produced palynomorphs (Anderson & Anderson, 1983). The Little Switzerland plant fossil locality yielded 66 palynomorph species but many were not identified. Species identified to genus or species level are listed below (Table 1.5).

Table 1.5: Palynomorphs recovered from Little Switzerland, Molteno Formation, with postulated natural affinities (redrawn from Anderson & Anderson, 1983).

Palynomorph	Natural Affinity
Circulisporites parvus	Acritarcha
Circulisporites spA	
Reticulatasporites argentinus	
Microsporonites cacheutensis	
Aratrisporites parvispinosus	Lycophyta
Aratrisporites strigosus	
Discisporites (*Uvaesporites*) *verrucosus*	Sphenophyta & Filicophyta
Guthoerlisporites cancellosus (*Playfordiaspora crenulata*)	
Annulispora folliculosa	
Annulispora spA	
Duplexisporites gyratus	
Dictyophyllidites mortonii	
Lophotriletes bauhiniae	
Converrucosisporites cameroni	
Osmundacidites wellmanii	
Osmundacidites spA	
Osmundacidites spB	
Osmundacidites spC	
Osmundacidites spD	
Osmundacidites spE	
Osmundacidites spF	
Osmundacidites spG	
Retusosporites junior	
Retusosporites spA	
Polypodiisporites (*Thymospora*) *ipsviciensis*	
Punctatosporites walkomii	
Cycadopites grandis	Gymnospermophyta
Spherropollenites classopolloides	
Spherropollenites spA	
Enzonalasporites vigens	
Equisetosporites steevesi	
Megamonoporites argentinus	

Hamiapollenites insculptus	
Sulcosaccispora lata	*Dicroidium*
Alisporites australis	
Alisporites townrovii	
Alisporites spA	
Platysaccus queenslandi	
Cycadopites nitidus	*Lepidopteris*
Protohaploxypinus jacobii	*Rissikia*

Elliot and Clarens formations

The Triassic Elliot and Jurassic Clarens formations were deposited in fluvial and progressively aeolian environments respectively, and up till now no palynomorphs have been reported from either Formation.

1.3.2.2 Subsidiary Karoo Basins

Some of the Karoo basins in south-central Africa have palynomorph records for the Carboniferous, Permian, Triassic and Early Jurassic and summaries of these studies are presented below in ascending stratigraphic order by country. Locations of the relevant Karoo basins are shown in Figure 1.4, while their lithostratigraphy is illustrated in Figure 1.5 and in accompanying palynozonation diagrams within the text.

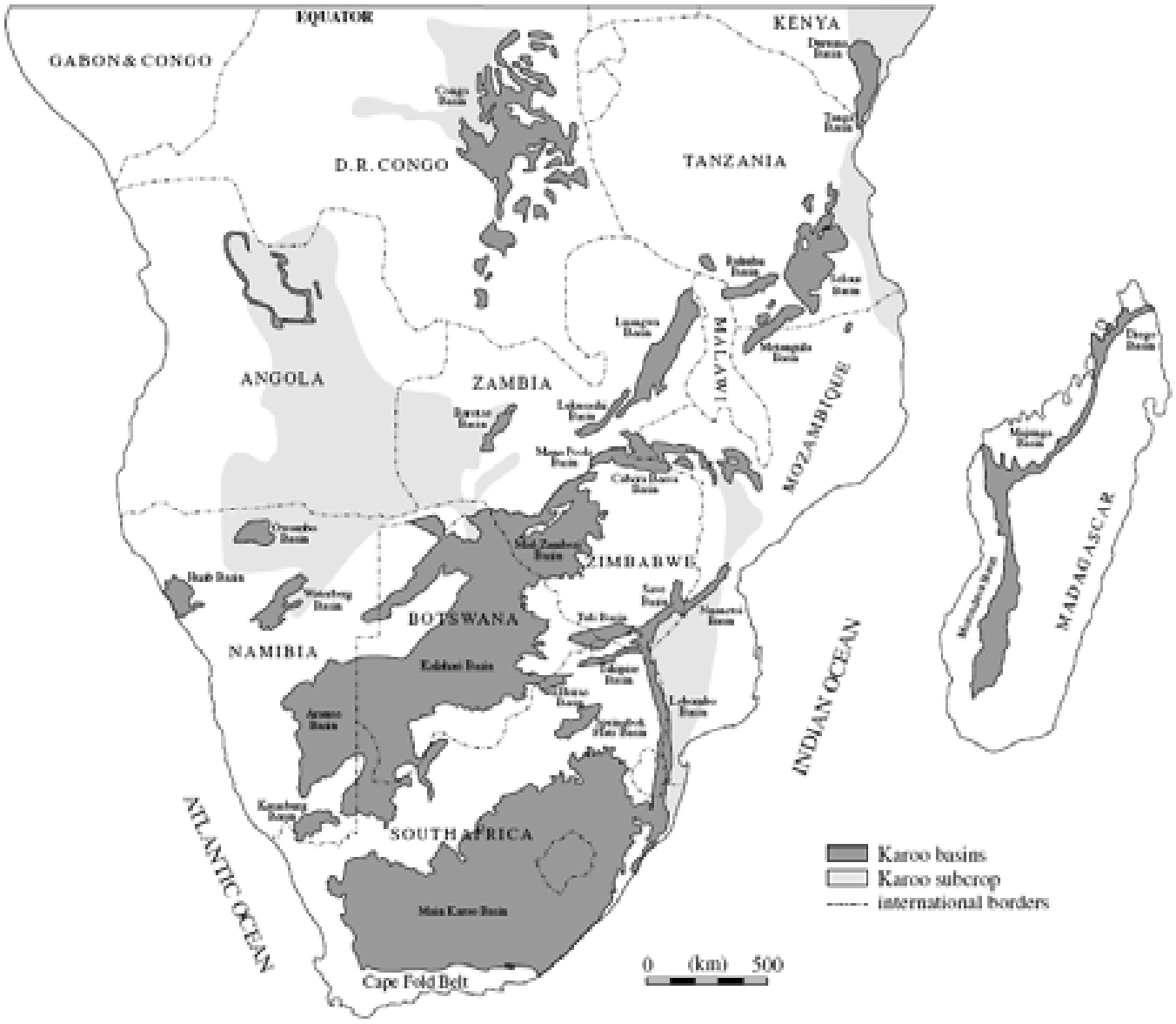


Figure 1.4: Karoo basins of southern and central Africa. Outcropping basins are shown in dark grey, while basin subcrops beneath unconsolidated sands are marked in light grey (Catuneanu *et al*., 2005).

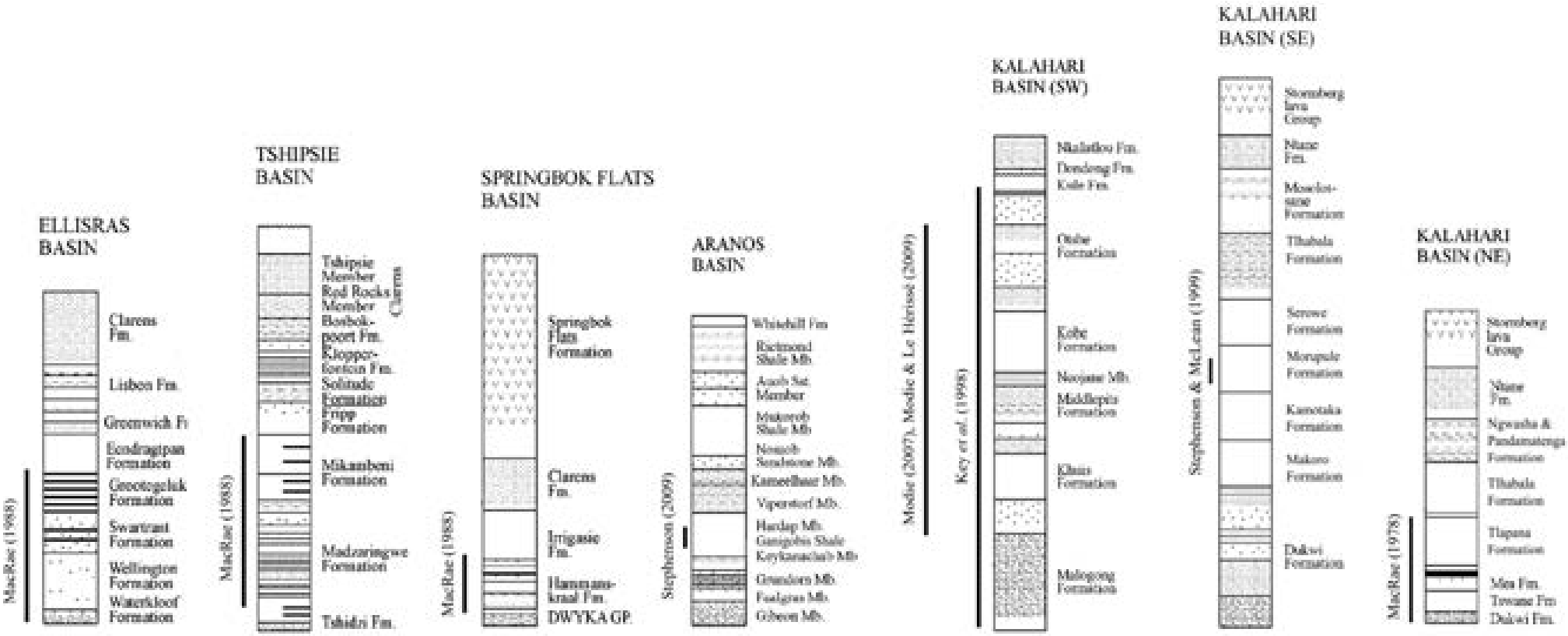


Figure 1.5: Lithostratigraphy of selected Karoo basins of south-central Africa and associated palynological studies. Intervals to which palynological investigations correspond are to the left of each stratigraphic column. Columns not to scale (modified from Catuneanu *et al*., 2005; Bangert *et al*., 1999; Hankel, 1987, 1992; Smith, 1984).

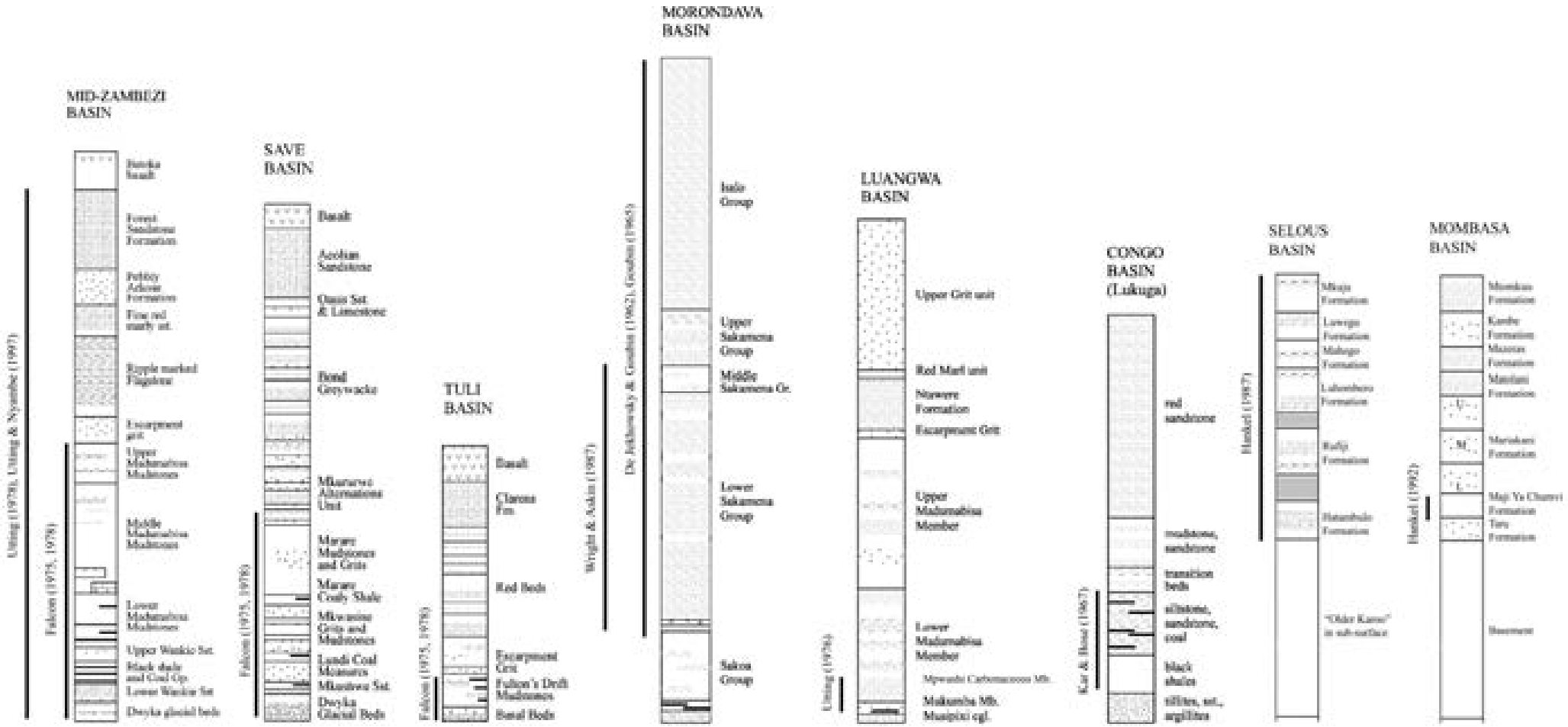


Figure 1.5 (continued)

South Africa

MacRae (1988) investigated the palynology of coal-bearing strata in the Ellisras (Waterberg) and Tshipise (Soutpansberg - Pafuri) basins, and the Hammanskraal plant fossil locality, Springbok Flats Basin (Figure 1.5). These Karoo aged basins are situated in the northern Limpopo province of South Africa.

Table 1.6: Carboniferous and Permian biozones of the Ellisras and Tshipise Basins and their lithostratigraphy (redrawn from MacRae, 1988).

<table>
<tr><th>Zone</th><th>Name</th><th>Key Palynomorphs</th><th>Ellisras Basin</th><th>Tshipise Basin</th></tr>
<tr><td>F</td><td>Striatopodocarpites fusus – Weylandites lucifer</td><td>Weylandites lucifer
Gnetaceaepollenites sinuosus
Striatopodocarpites fusus</td><td></td><td rowspan="2">Mikambeni Formation</td></tr>
<tr><td>E</td><td>Kraeuselisporites enormis - Striatopodocarpites cancellatus</td><td>Cirratriradites africanensis
Kraeuselisporites enormis
Alisporites potoniei
Protohaploxypinus limpidus
Striatopodocarpites cancellatus</td><td rowspan="2">Grootgeluk Formation</td><td rowspan="2">Madzaringwe Formation</td></tr>
<tr><td>D</td><td>Laevigatosporites vulgaris – Alisporites sp. 1</td><td>Deltoidospora directa
Laevigatosporites vulgaris
Alisporites sp. 1
Platysaccus radialis</td><td rowspan="3">Enkelbult Formation</td></tr>
<tr><td>C</td><td>Cyclogranisporites gondwanensis Interval Zone</td><td>No indicator taxa as Biozone C is an informal zone</td><td rowspan="4">Basement</td></tr>
<tr><td>B</td><td>Potonieisporites novicus – Cannanoropollis densus</td><td>Verrucosisporites sp.
Limitisporites monstruosus
Cannanoropollis densus
Potonieisporites novicus
Caheniasaccites ovatus</td><td rowspan="2">Wellington Formation</td></tr>
<tr><td>A</td><td>Plicatipollenites gondwanensis – Granulatisporites papillosus</td><td>Granulatisporites papillosus
Plicatipollenites goraiensis
Pteruchipollenites gracilis
Cannanoropollis mehtae
Cannanoropollis janakii</td><td>Dwyka Formation
Basement</td></tr>
</table>

MacRae (1988) identified six recognisable biozones (Table 1.6) and recorded significant floral changes from Biozone A to Biozone B, accordingly the Carboniferous / Permian boundary was proposed to lie between these two zones.

Namibia

Stephenson (2009) reported a well-preserved and diverse assemblage of palynomorphs from the Ganigobis Shale Member (Dwyka Group) of the Aranos Basin in southern Namibia (Figure 1.5) which is correlated with the *Converrucosisporites confluens* Oppel Zone in the Canning Basin of Australia. This Australian Zone is defined by the presence of *Converrucosisporites confluens* along with a minimum of four of the fourteen specified accessory taxa (Foster & Waterhouse, 1988). Present in the Ganigobis Shale Member are the accessory taxa *Caheniasaccites ovatus*, *Cannanoropollis* spp., *Cycadopites cymbatus*, *Horriditriletes ramosus*, *Plicatipollenites* spp., and *Striatoabieites multistriatus* (Stephenson, 2009). The most abundant taxa are *Alisporites indarraensis*, *Converrucosisporites grandegranulatus*, *Cristatisporites* spp., *Horriditriletes uruguaiensis*, *Lundbladispora braziliensis*, *Lundbladispora* spp., *Microbaculispora tentula*, and *Vittatina* spp. (Stephenson, 2009). Ash layer IIb of the Ganigobis Shale Member is radiometrically dated as 302.0 ±3.0 Ma (i.e. Pennsylvanian; Gzhelian or Kasimovian), suggesting the base of the *Converrucosisporites confluens* Oppel Zone may be older than previously suggested.

Botswana

MacRae (1978) analysed core samples from Dwyka and Ecca Group rocks near Francistown, north-eastern Botswana (Figure 1.5). Three concurrent range zones were erected on a palynological basis: Concurrent Range Zone I (rich in monosaccate pollen), Concurrent Range Zone II (bisaccates more abundant than

monosaccates), and Concurrent Range Zone III (no monosaccates, bisaccate striate miospores dominant) (Figure 1.6). These zones were correlated with Zones 1-3 of the Dwyka and Ecca Groups, Zimbabwe (Falcon, 1975), and Zones 1-3 of the Northern Karoo Basin, South Africa (Anderson, 1977) respectively. Substantial coal seams in the Francistown area of Botswana were thought to be equivalent in age to the Lower and Middle Ecca of the Main Karoo Basin (MacRae, 1978).

Key *et al*. (1998) sampled boreholes from the Tshabong area of south-western Botswana situated in the Kalahari Basin of the Karoo Supergroup (Figure 1.5). Palynomorphs were Carboniferous and Permian in age (Dwyka and Ecca Groups). A complete species list is not given but in rocks of the Dwyka Group, the monosaccates *Cannanoropollis* (*Vestigisporites*) and *Plicatipollenites*, and *Granulatisporites* (*Microbaculispora*) are particularly abundant. The presence of marine acritarchs in the Dwyka Group indicate a glacial marine environment. Palynomorphs formerly restricted to the Beaufort Group in South Africa were recovered from Tshabong rocks, confirming the existence of the Beaufort Group in southern Botswana. Another significant finding was that no significant coal seams were located in the south-western area of Botswana (Key *et al*., 1998).

Stephenson and McLean (1999) reported a palynological assemblage from Morupule in southeast Botswana, Kalahari Basin (Figure 1.5). Forty-five species of pollen, spores and acritarchs were recorded and stratigraphically important taxa include *Verrucosisporites pseudoreticulatus*, *Procoronaspora spinosa*, *Laevigatosporites colliensis*, *Striatopodocarpites cancellatus*, and *Microbaculispora micronodosa*. Small trilete miospores are most abundant in the coals, while carbonaceous mudstones are dominated by gymnospermous bisaccate pollen.

Concurrent Range Zone I	Concurrent Range Zone II	Concurrent Range Zone III
SPECIES RANGE INITIATION: Lower limit of species range not defined in core $N1/_3$.	*A. tereteangulatus* *P. rotundus* *Apiculatisporites sp.* *Punctatisporites sp.* *T. pseudothiessenii* *Lophotriletes sp. A* *G. parvivermecosus* *C. parvus* *S. cancellatus* *P. leschiki* *S. rarus* *P. limpidus* *S. fusus* *Fimbriaesporites sp.* *P. micros* *S. splendens* *F. fimbriatus* *A. plicatus* *S. communis*	No new species – Upper limit of concurrent range zone III not defined in core $N1/_3$.
SPECIES RANGE TERMINATION: *N. ramosus* *C. ornatus* *P. gretensis* *C. splendens* *Densosporites sp.* *Z. restricta* *Z. bullatus* *G. vrystaatensis* *P. indicus* *P. distinctus* *V. radiata* *V. obscura* *V. densus* *C. ovatus* *E. ellaensis* *V. mehtae* *C. flavatus* *V. minima*	*D. directa* *M. tentula* *Apiculatisporites sp.* *P. calculus* *C. plicata* *Lophotriletes sp. A* *N. congoensis* *Punctatisporites sp.* *S. cancellatus* *P. leschiki* *V. sp. cf. V. trisecatus* *Tetraporina sp.* *S. fusus* *Fimbriaesporites sp.* *Q. horridus* *Z. eccensis* *T. thiessenii* *S. communis*	*P. novicus* *P. micros*
RESTRICTED SPECIES: *N. ramosus* *C. ornatus* *P. gretensis* *C. splendens* *Densosporites sp.* *Z. restricta* *Z. bullatus* *G. vrystaatensis* *P. indicus* *P. distinctus* *V. radiata* *V. obscura* *V. densus* *C. ovatus* *E. ellaensis* *V. mehtae* *C. flavatus* *V. minima*	*Apiculatisporites sp.* *Lophotriletes sp. A* *S. cancellatus* *P. leschiki* *S. fusus* *Fimbriaesporites sp.* *S. communis*	No restricted species
QUANTITATIVE CONTENT: (Supra-generic) Aletes : 20–40% Triletes : 20–35% Monosaccates : 20–30% Disacciatrileti : 0–15% Striatiti : 0–10% Plicati : 0–10% Monoletes : 0– 5% Zonotriletes : 0– 5%	Triletes : 40–70% Aletes : 20–70% Monoletes : 5–30% Disacciatrileti : 5–35% Striatiti : 5–30% Monosaccates : 0–10% Plicati : 0– 5%	Triletes : 20–55% Striatiti : 20–50% Aletes : 20–30% Disacciatrileti : 15–20% Plicati : 0–20% Monoletes : 0– 5%

Figure 1.6: Concurrent Range Zones I, II and III of north-eastern Botswana and their quantitative content (MacRae, 1978).

The Morupule deposits have been correlated with the 3a Microfloral Biozone of the northern Karoo (Anderson, 1977), Sub-Biozone F of the northern Karoo and Mid-Zambezi Basins (Falcon *et al*., 1984), the upper section of Biozone B in the Waterberg (MacRae, 1988), and the upper section of the LM Biozone in Zambia (Utting, 1978) (Figure 1.7). An Aktastinian age (early Artinskian) for the Morupule rocks is proposed due to correlation with Australian Permian strata (Stephenson & McLean, 1999).

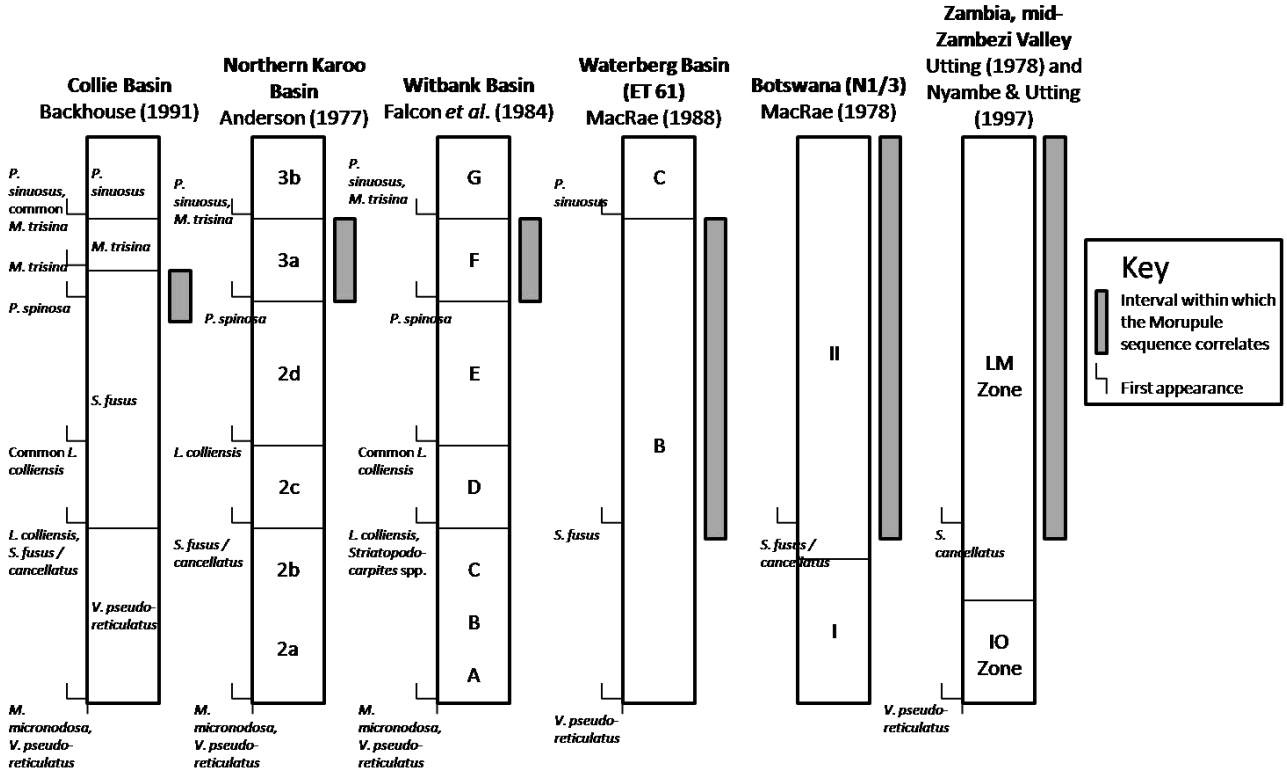


Figure 1.7: Stratigraphic correlation of Morupule rocks to biozonation schemes for southern Africa and the Collie Basin, Australia (redrawn from Stephenson & McLean, 1999).

Modie (2007) and Modie & Le Hérissé (2009) recognised three assemblage zones in the Kalahari Karoo Basin of Botswana (Figure 1.5): the *Hamiapollenites bullaeformis* Assemblage Zone (Biozone KK 1), the *Cyclogranisporites gondwanensis* Assemblage Zone (Biozone KK 2), and the *Platysaccus papilionis*–

Striatopodocarpites fusus Assemblage Zone (Biozone KK 3) (Figure 1.8). The *Hamiapollenites bullaeformis* Biozone can be correlated to the *Vittatina costabilis* Interval Zone, Paraná Basin, South America. The *Cyclogranisporites gondwanensis* and *Platysaccus papilionis–Striatopodocarpites fusus* zones are similar to the *Lueckisporites virkkiae* Interval Zone, Paraná Basin, South America (Modie & Le Hérissé, 2009). Age of the zones ranges from Late Carboniferous to latest Early or earliest Middle Permian (Modie & Le Hérissé, 2009).

Zimbabwe

Falcon (1975) investigated the palynology of the Mid-Zambezi and Save-Tuli (Sabi-Limpopo) Basins of Zimbabwe (Figure 1.5), working on the Dwyka, Ecca and Lower Beaufort Groups (Carboniferous and Permian rocks). A significant change is evident in the floral communities, from primarily monosaccate pollen and trilete spores during the Carboniferous, to striate bisaccate- dominated pollen in the Permian (Table 1.7). Four assemblage zones were erected: Assemblage Zone I (Dwyka Group + Lower Wankie Sandstone: *Virkkipollenites* - *Plicatipollenites* Assemblage), Assemblage Zone II (black shales and coals: Transition Zone), Assemblage Zone III (Upper Wankie Sandstone: *Densosporites* - *Gondispore* assemblage), and Assemblage Zone IV (Madumabisa Mudstone: *Vittatina* - *Lueckisporites* Assemblage) (Table 1.7).

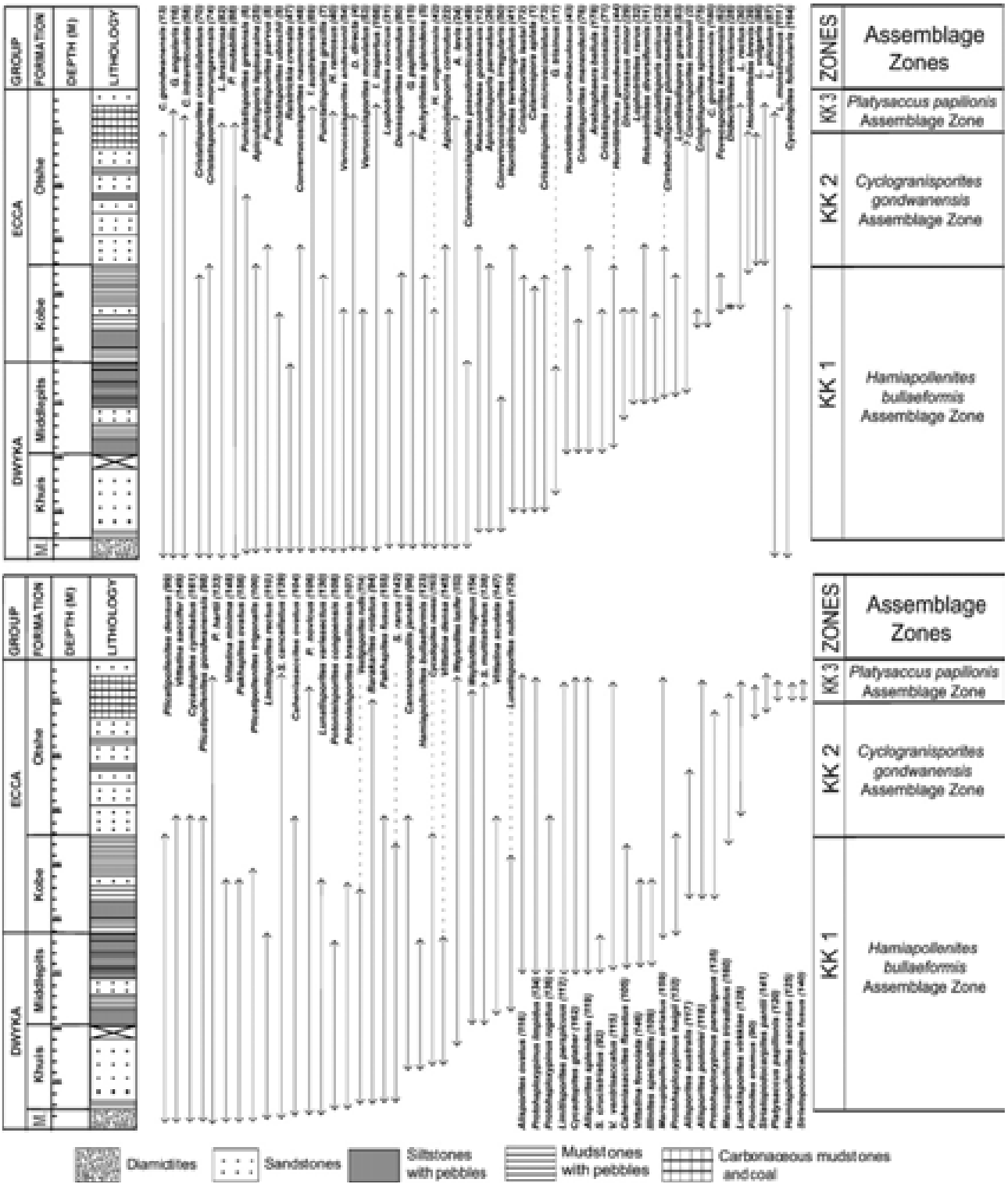


Figure 1.8: Late Carboniferous and Permian Assemblage Zones of the Dwyka and Ecca Groups, Kalahari Karoo Basin, Botswana (Modie & Le Hérissé, 2009).

Table 1.7: Palynomorph diagram of the four Assemblage Zones and eight Assemblage Sub-zones of the Permian Matabola Flats borehole in the Mid-Zambezi Basin (redrawn from Falcon, 1975).

<table>
<tr><td></td><td></td><td>ASSEMBLAGE ZONES</td><td>ASSEMBLAGE SUB-ZONES</td></tr>
<tr><td rowspan="3">Madumabisa Mudstone</td><td>H</td><td rowspan="3">Assemblage Zone IV
Vittatina-Lueckisporites Assemblage
Notable genera:
Protohaploxypinus Platysaccus
Striatopodocarpites Sulcatisporites
Vittatina Thymospora
Hamiapollenites Marsupipollenites
Lueckisporites Rheinschospora
Quantitative content:
Disaccites 40-75% Striatiti 25-60%
Monosacciti <5% Triletes 0-20%
Aletes 0-15%</td><td>Assemblage Sub-zone H
Taeniaesporites-Guttulapollenites Assemblage

Striatiti dominant > 50%</td></tr>
<tr><td>G</td><td>Assemblage Sub-zone G
Cirratriradites africanensis Assemblage

Introduction of:
Cirratriradites Vittatina
Hamiapollenites Lueckisporites</td></tr>
<tr><td>Upper Wankie Sandstone</td><td rowspan="3">F</td><td rowspan="2">Assemblage Zone III
Densosporites- Gondispore assemblage
Introduction of:
Thymospora
Rheinschospora
Verrucosphaera</td><td>Assemblage Sub-zone F
Quantitative content:
Disaccites 20-40% Striatiti 10-20%
Monosacciti <5% Triletes >40%
Aletes 10-30%</td></tr>
<tr><td rowspan="3">Black Shales & Coals</td><td rowspan="2">E</td><td rowspan="2">Assemblage Zone II

Transition Zone: miospores genera and species characteristic of both assemblages</td><td>Assemblage Sub-zone E
Introduction of:
Laevigatosporites
Lophotriletes</td></tr>
<tr><td>D</td><td>Assemblage Sub-zone D
Introduction of:
Striatopodocarpites
Densipollenites
Striatoabieites</td></tr>
<tr><td rowspan="4">Lower Wankie Sandstone

Dwyka III

Dwyka II

Dwyka I</td><td>C</td><td rowspan="3">Assemblage Zone I
Virkkipollenites-Plicatipollenites Assemblage
Notable genera:
Microbaculispora Calamospora
Granulatisporites Cycadopites
Punctatisporites Protohaploxypinus
Zinjispora Apiculatisporis
Acanthotriletes Lophotriletes
Retusotriletes Potonieisporites</td><td>Assemblage Sub-zone C
Acanthotriletes Assemblage
Monosaccites notably abundant</td></tr>
<tr><td>B</td><td>Assemblage Sub-zone B
Quadrisporites horridus Assemblage</td></tr>
<tr><td rowspan="2">A</td><td rowspan="2">Assemblage Sub-zone A
Granulatisporites-Microbaculispora tentula</td></tr>
</table>

Falcon (1978) compared the Permo-Triassic palynofloras from opposite sides of the Rhodesian watershed, namely the Mid-Zambezi and Save-Tuli (Sabi-Limpopo) basins (Figure 1.5). Six Concurrent Range Zones and twelve Concurrent Range Subzones were recognised, with Sub-zones A-H present in the Mid-Zambezi Valley and Sub-zones D-L in the Sabi-Limpopo Valley. Total species diversity increases from the Dwyka to Lower Beaufort floras and then declines again. The main coal-forming period appear to have been during deposition of Subzones D-G (Lower - Upper Ecca). Falcon established that Permian microfloras of Zimbabwe (Rhodesia) were closely related to those of South Africa, Botswana, Zambia, Tanzania, Peninsular India and Western Australia. They were only superficially similar to those of Gabon, Congo, Malagasy, Salt Range, Indian and Eastern Australia (Falcon, 1978).

Madagascar

De Jekhowsky & Goubin (1962) and Goubin (1965) erected four major units and twelve pollen subzones (Table 1.8) for the Late Permian – Late Jurassic Morondava Basin of southwest Madagascar, working on the Sakamena and Isalo groups and the Jurassic Series (Figure 1.5).

Wright & Askin (1987) described a microfloral assemblage from the Permo-Triassic southern Morondava Basin of Madagascar (Figure 1.5). The latest Permian samples (Lower Sakamena Group) are dominated by *Guttulapollenites hannonicus*, *Weylandites* spp. and *Lueckisporites virkkiae*, while *Protohaploxypinus*, *Striatopodocarpites*, *Platysaccus* spp., *Alisporites* spp., *Falcisporites* spp., *Scheuringipollenites* spp., and *Klausipollenites schaubergeri* are common. Rare elements in this latest Permian assemblage include *Protohaploxypinus microcorpus*, *Lunatisporites pellucidus* and pteridophyte spores.

Table 1.8: Late Permian – Late Jurassic pollen zones of the Morondava Basin, southwest Madagascar (redrawn from Goubin, 1965).

Unit IV	Early - Late Jurassic Upper Isalo Group	*Pilasporites* sp., *Exesipollenites tumulus, Classopollis classoides, Inaperturopollenites orbicularis, Araucariacites australis, Applanopsis trilobatus, Applanopsis dampieri, Podocarpidites marwickii*
Unit III	Middle Triassic - Early Jurassic Lower Isalo Group	*Graminoides cornes, Laricoïdites desquamatus, Samaropollenites speciosus, Sulcatisporites prolatus, Podocarpidites ellipticus, Pityosporites insularis, Falcisporites enodis, Cuneatisporites radialis, Rimaesporites aquilonis*
Unit II	Early - Middle Triassic Upper Sakamena Group Middle Sakamena Group	*Stroteršporites pantii, Lunatisporites pellucidus, Vitreisporites pallidus, Taeniaesporites noviaulensis, Taeniaesporites ovatus, Striomonosaccites morondavensis, Platysaccus leschickii, Cycadopites follicularis*
Unit I	Late Permian Lower Sakamena Group	*Platysaccus praevius*, *Platysaccus fuscus*, *Guttulapollenites hannonicus*, *Guttulapollenites gondwanensis*, *Alisporites papillo*, *Vittatina*, *Lueckisporites virkkiae*

The Lower Sakamena assemblage can be correlated to the *Playfordiaspora crenulata* Zone in Australia (Foster, 1982). Thirty-five percent of the taxa disappear at the P–T boundary, and *L. pellucidus*, *Striatopodocarpites pantii* and *P. microcorpus* become common in the Middle Sakamena Early Triassic assemblages, with some taxa that are characteristic of the Permian persisting e.g. *Densipollenites indicus*, *Protohaploxypinus limpidus*, *Striatopodocarpites rarus* and *G. hannonicus*. In the earliest Triassic assemblage, 42% of the taxa appear for the first time, including *Densoisporites playfordii*. The Middle Sakamena microflora is said to be the time equivalent of the upper *Protohaploxypinus microcorpus* Zone and the *Lunatisporites pellucidus* Zone of Australia (Foster, 1982).

Zambia

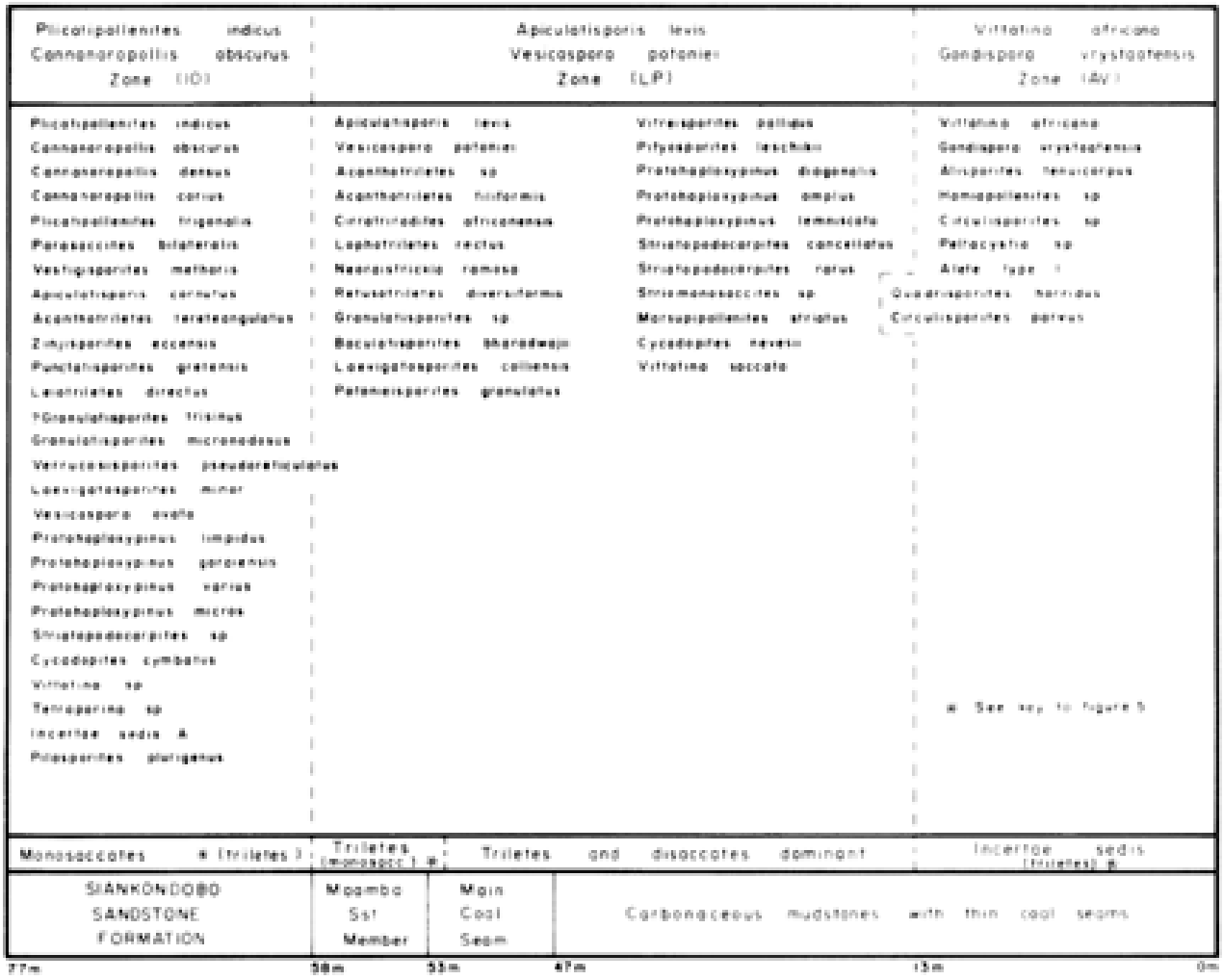
Utting (1976) examined pollen and spore assemblages from the Luwumbu Coal Formation (Lower Karoo) of the Luangwa Basin, Zambia (Figure 1.5) and established two distinct assemblages. The Mukumba Siltstone Member (lower unit) is quantitatively dominated by the monosaccates *Cannanoropollis* and *Plicatipollenites*, while the overlying Mpwashi Carbonaceous Member (containing thin coal seams) yielded a diverse microflora dominated by striate and non-striate bisaccate pollen and trilete spores, but also containing monosaccates, polyplicates, colpates, monolete and alete spores. The most common taxa are *Protohaploxypinus*, *Vesicaspora* and *Acanthotriletes*, while *Cannanoropollis* is abundant in the lower section of the younger assemblage. The microfloras show similarities to the upper part of the Lower Coal Measures of the Ketewaka / Mehuchuma coalfield of Tanzania. No age is proposed for the Luwumbu Coal Formation based on the palynology.

Utting (1978) recorded the palynology of the Siankondobo Sandstone and Gwembe Coal formations, Kazinze area in the Mid-Zambezi Basin of Zambia (Figure 1.5). A threefold zonation was erected (Table 1.9) and these zones were correlated to the Luwumbu Coal Formation of north Luangwa, Zambia. Utting noted that it was not possible to recognise the three subdivisions of Zone 1 of Falcon (1975) in either the Kazinze or north Luangwa areas.

The work of Utting (1978) was supplemented by further palynological investigations by Nyambe & Utting (1997) which also sampled the younger Madumabisa Mudstone and Interbedded Sandstone and Mudstone formations as well as the subordinate Karoo formations of Kazinze area, Mid-Zambezi Basin, Zambia (Figure 1.5). Monosaccate palynomorphs dominate the basal section of the Siankondobo Sandstone Formation (Table 1.10). Utting (1978) correlated the *Plicatipollenites indicus* - *Cannanoropollis obscurus* Zone to Zone 1 of Falcon (1975), however Césari (2007) suggested that due to the presence of *Vittatina* sp. and *Converrucosisporites confluens*, Zone IO is better correlated with Subzone C,

Zimbabwe (Falcon, 1975). Microfloras indicate ages of Late Carboniferous (Gzhelian) to Early Permian (Asselian to Early Sakmarian) for the Siankondobo Sandstone Formation, Early Permian (Artinskian to Kungurian) age for the Gwembe Coal Formation, Late Permian (Tatarian) age for the Madumabisa Mudstone, and Early or Middle Triassic (Late Scythian or Anisian) age for the Interbedded Sandstone and Mudstone (Nyambe & Utting, 1997).

Table 1.9: Threefold palynozonation of the Siankondobo Coalfield locality, Gwembe Coal Formation, Kazinze area, Zambia (Utting, 1978).



Congo

Kar & Bose (1967) described the palynoflora of Permian coal seams in the Greinerville Region of the Congo Basin (Figure 1.5). Trilete spores are dominant in all the seams, with *Punctatisporites*, *Lutorimites*, *Neocalamospora*, *Leiotriletes*, *Apiculatisporis*, *Cyclogranisporites*, *Microbaculispora*, *Indotriradites* and *Enigmaspora* being particularly common. Bisaccates are also abundant, and striate bisaccates are represented by *Strotersporites*, *Striatopiceites* and *Lunatisporites*. Non-striate bisaccates include *Cuneatisporites*, *Raniganjiasaccites*, *Monoletesaccites*, *Valiasaccites*, *Jugasporites*, *Høegiasaccites* and *Walikalesaccites* (Kar & Bose, 1967). The non-striate bisaccate *Sulcatisporites* comprises 84% of one sample. All other palynomorph groups are poorly represented. The monolete *Tiwariasporis* is more abundant than *Laevigatosporites* and *Luenaites*. The following aletes are present: *Berckmaniates*, *Aleteverrucosispora*, *Maculatasporites* and *Tetraporina* (Kar & Bose, 1967). Monosaccate genera present are *Cannanoropollis*, *Parasaccites*, *Caheniasaccites*, *Divarisaccus* and *Potonieisporites*. *Trochosporites* is the solitary polysaccate genus, and the polyplicates and monocolpates include *Boutakoffites*, *Ginkgocycadophytus*, *Zaireacolpites*, *Fusacolpites* and *Decussatisporites* (Kar & Bose, 1967).

Table 1.10: Palynozones of the Dwyka, Ecca, Beaufort and Stormberg groups of the mid-Zambezi Valley, southern Zambia (redrawn from Nyambe & Utting, 1997). Dotted lines represent uncertainty about how far zones extend.

System		Stage	Lith. Unit	Palynomorph Zone	Characteristic Taxa	Rock Unit
Triassic	Mid	Anisian		?		
			'Stormberg'	Unnamed	*Pityosporites* sp., *Falcisporites stabilis, Alisporites* sp., *Sulcatisporites* sp., *Platysaccus queenslandi, Rimaesporites aquilonis, Lunatisporites pellucidus, Apiculatisporis* sp., *Calamospora* sp., *Verrucosisporites* sp., *Uvaesporites* sp., *Aratrisporites fischeri, Playfordiaspora crenulata (Guthoerlisporites cancellosus)*	Interbedded Sandstone & Mudstone Fm
	Early	Scythian				
Permian	Late	Tatarian	Beaufort	Unnamed	*Guttulapollenites hannonicus, Corisaccites alutas, Protohaploxypinus limpidus, Protohaploxypinus goraiensis, Striatopodocarpites* sp., *Sulcatisporites prolatus, Vitreisporites pallidus, Reticuloidosporites warchianus, Polypodiisporites mutabilis, Weylandites lucifer, Botryococcus* sp.	Madumabisa Mudstone Fm
		Kazanian				
		Ufimian				

	Early	Kungurian				
		Artinskian	Mid-Ecca	*Brevitriletes levis - Scheuringipollenites maximus*	*Punctatisporites gretensis, Deltoidospora directa, Cirratriradites africanensis, Brevitriletes levis, Horriditriletes filiformis, Protohaploxypinus limpidus, Protohaploxypinus amplus, Striatopodocarpites cancellatus, Striatopodocarpites rarus, Plicatipollenites indicus, Scheuringipollenites maximus, S. ovatus, Vittatina saccata, Cycadopites cymbatus, Pilasporites plurigenus, Circulisporites* sp.	Gwembe Coal Fm
		Sakmarian				
		Asselian	Dwyka	*Plicatipollenites indicus - Cannanoropollis obscurus*	*Plicatipollenites indicus*, *Cannanoropollis obscurus, Brevitriletes cornutus, Acanthotriletes tereteangulatus, Zinjisporites eccensis, Microbaculispora micronodosa, Converrucosisporites pseudoreticulatus, Cycadopites cymbatus*	Siankondobo Sandstone Fm.
Carboniferous	Late	Gzhelian		?	?	?

Tanzania

Hankel (1987) analysed Late Permian, Triassic and Early Jurassic Karoo rocks from the Selous Basin, southern Tanzania (Figure 1.5) (originally given as the Luwegu Basin - Wopfner & Kaaya, 1991 assigned the Karoo megasequence into the Selous Basin instead). Biostratigraphically significant taxa in the Late Permian Sumbadzi Member, Hatambulo Formation are *Guttulapollenites hannonicus*, *Lueckisporites virkkiae*, and *Vittatina cincinnata*, and the assemblage has been correlated to Unit I, Lower Sakamena Formation, Madagascar (de Jekhowsky & Goubin, 1962; Goubin, 1965) and Subzone H, Middle Madumabisa Shale of the Mid-Zambezi Basin of Zimbabwe (Falcon, 1975). The Carnian (Late Triassic) Mahogo Formation assemblage is dominated by non-taeniate bisaccate pollen (for definitions of terminology see Punt *et al*., 2007), particularly *Falcisporites* and is distinguished by the presence of both *Staurosaccites quadrifidus* and *Camerosporites secatus* (Hankel, 1987). It has been correlated with Subunit B of the *Staurosaccites quadrifidus* assemblage zone, Onslow Microflora, Carnarvon Basin, western Australia (Dolby & Balme, 1976). Microflora of the lower Luwegu Formation (Late Carnian) is also dominated by non-taeniate bisaccate pollen (primarily *Falcisporites*) and is distinguished by the abundance of *Samaropollenites speciosus* (Hankel, 1987). *Camerosporites secatus* is absent from this assemblage, with *Camerosporites pseudoverrucatus* present instead, and has been correlated with the *Samaropollenites speciosus* assemblage zone, Onslow Microflora, Carnarvon Basin, western Australia (Dolby & Balme, 1976) and Zone III A, Isalo I Formation, Morondava Basin of Madagascar (Goubin, 1965).

Palynoflora of the uppermost Luwegu Formation (Norian), also dominated by non-taeniate bisaccate pollen, is distinguished by the abundance of *Minutosaccus crenulatus* (Hankel, 1987) and can be correlated with the *Minutosaccus crenulatus* assemblage zone, Onslow Microflora, Carnarvon Basin, western Australia (Dolby & Balme, 1976), and Zone III B, Isalo I Formation, Morondava Basin of Madagascar (Goubin, 1965). The Rhaetian Mkuju Formation palynoflora

is dominated by trilete spores, with less bisaccate pollen than underlying formations (Hankel, 1987). *Polypodiisporites ipsviciensis* and *Duplexisporites problematicus* are very abundant, and can be correlated to the lower part of the Leigh Creek Coal Measures, Northern Basin, South Australia, referable to the Ipswich Microflora (Dolby & Balme, 1976). The Liassic Madaba Formation produced a microfloral assemblage comprising only *Classopollis chateaunovi* (predominant), *Classopollis simplex*, *Classopollis anasillos* and *Exesipollenites tumulus* (Hankel, 1987). It can be correlated with the *Classopollis chateaunovi* assemblage subzone of the Liassic Eneabba Member, Perth Basin, western Australia (Filatoff, 1975), Zone IV A, Isalo II Formation, Madagascar (Goubin, 1965) and the upper part of the Leigh Creek Coal Measures, South Australia (Playford & Dettmann, 1965).

Kenya

Hankel (1992) recorded a Late Permian to Early Triassic microflora from the Maji Ya Chumvi Formation in the Mombasa (Duruma) Basin of Kenya. The lower part of the section can be correlated to the upper *Protohaploxypinus microcorpus* Zone (Late Permian) of Australia (Foster, 1982) and shares the following distinctive taxa: *Triplexisporites playfordii*, *Playfordiaspora crenulata*, *Falcisporites australis*, *Lunatisporites noviaulensis*, *Protohaploxypinus microcorpus*, *P. samoilovichii*, and the genera *Lueckisporites* and *Weylandites* (Hankel, 1992). The upper part can be correlated to the succeeding *Lunatisporites pellucidus* Zone (Early Triassic) (Foster, 1982) and the following taxa are characteristic of both assemblages: *Densoisporites playfordii*, *Limatulasporites limatulus*, *Kraeuselisporites cuspidus*, *Falcisporites australis*, *Lunatisporites noviaulensis*, *L. pellucidus* and *Protohaploxypinus samoilovichii*. *Chordecystia chalasta* Foster 1979 (*Reduviasporonites chalastus*) is found in both the lower and upper parts of the section and comprises 24% of the Late Permian assemblage, and 4-10% of the Early Triassic assemblage (Hankel, 1992). The presence of this much debated

taxon (e.g. Visscher *et al*., 1996; Foster *et al*., 2002; Steiner *et al*., 2003) is significant considering that the microflora spans the P-T boundary.

1.3.2.3 Australia

The palynology of Australia has been extensively researched (e.g. de Jersey, 1962, 1964, 1970; Evans, 1967, 1969; Foster, 1979, 1982; Price, 1983, 1997; Waterhouse, 1976, Kemp *et al*., 1977; Segroves 1972; Helby, 1974; Helby *et al*., 1987; Paten, 1969; Gilby & Foster, 1988; Price & Filatoff, 1990; Draper *et al*., 1990) and as a result Australia has a very well-established biozonation to which other Gondwana assemblages are constantly compared (Lindström & McLoughlin, 2007). Of particular importance is the association of a marine fauna with the *Converrucosisporites confluens* Oppel Zone in the Canning Basin of Australia (Foster and Waterhouse, 1988) that allows correlation with the standard Early Permian stages of the south Urals, Russia (Stephenson, 2009). However, due to provincialism some key index taxa in Australian basins are rare or absent elsewhere in Gondwana, for example the genus *Dulhuntyspora*, and this hinders global correlations (Backhouse, 1991). The palynozonations of eastern and western Australia are generally similar but certain differences exist with regards to relative abundances of species, and some endemics are present (Mory & Backhouse, 1997). The current Carboniferous - Early Jurassic zonation for western Australia is drawn from Backhouse (1991), Mory & Backhouse (1997), Backhouse *et al*. (2002), Filatoff (1975) and revised by Eyles *et al*. (2002), while the palynostratigraphy of eastern Australia was researched by Price (1983), Helby *et al*. (1987), Price & Filatoff (1990), Draper *et al*. (1990) and revised and consolidated by Price (1997).

Western Australia

Eyles *et al*. (2002) revised the palynostratigraphy of western Australia and correlated the Carboniferous and Permian strata of seven western Australian basins (Figure 1.9).

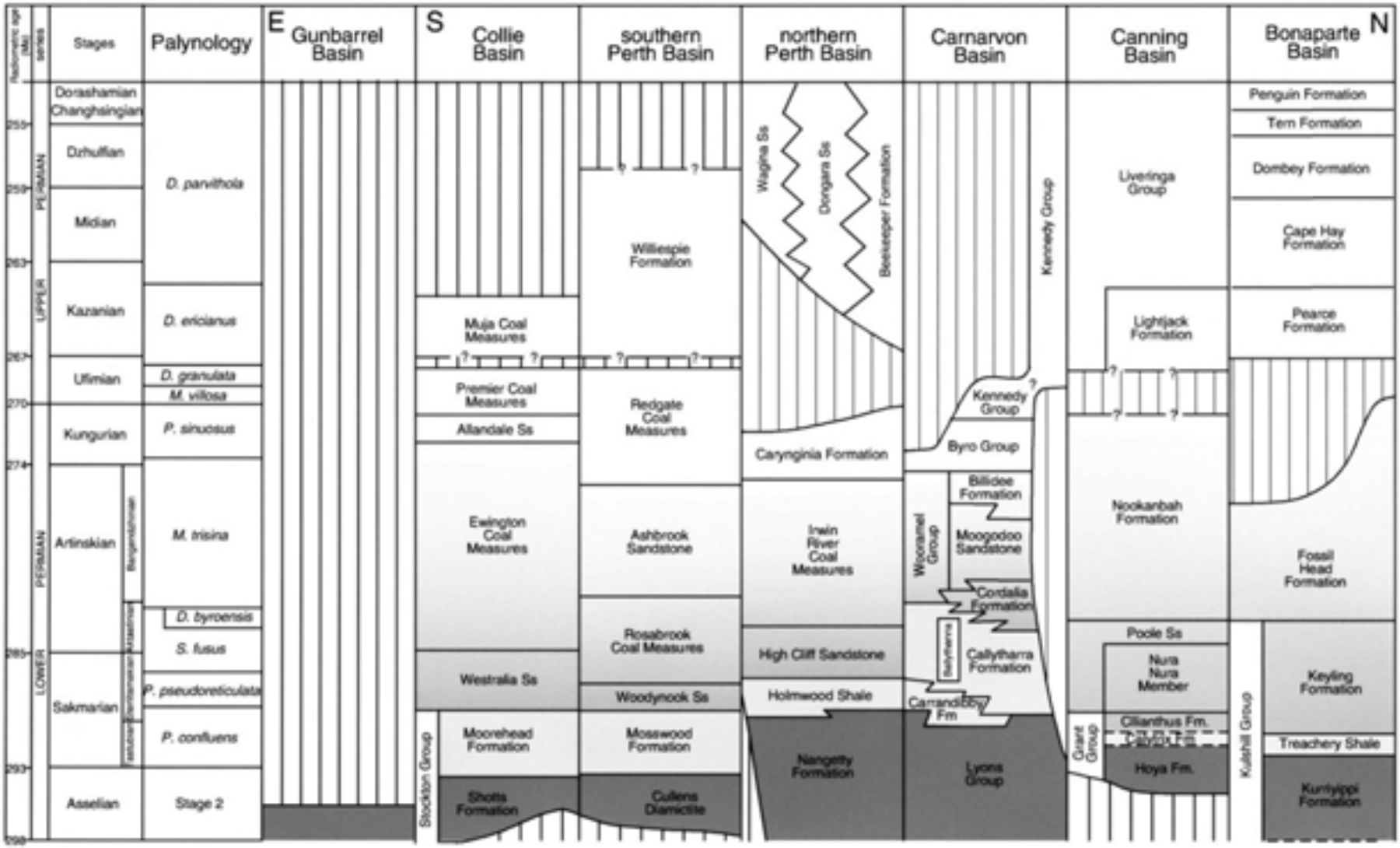


Figure 1.9: Correlation of the Carboniferous and Permian strata of seven western Australian basins, showing established spore-pollen zones and lithostratigraphy (Eyles *et al*., 2002).

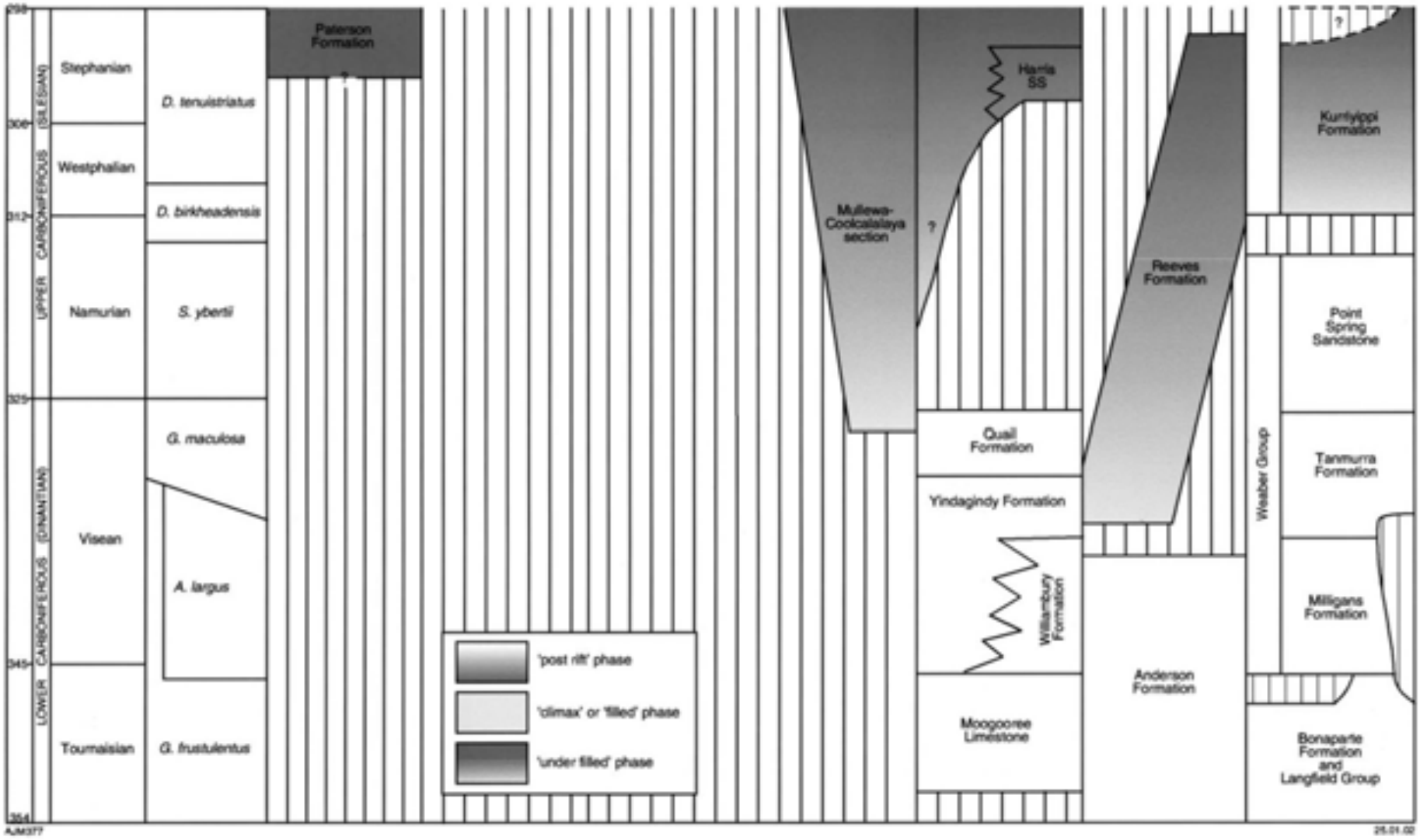


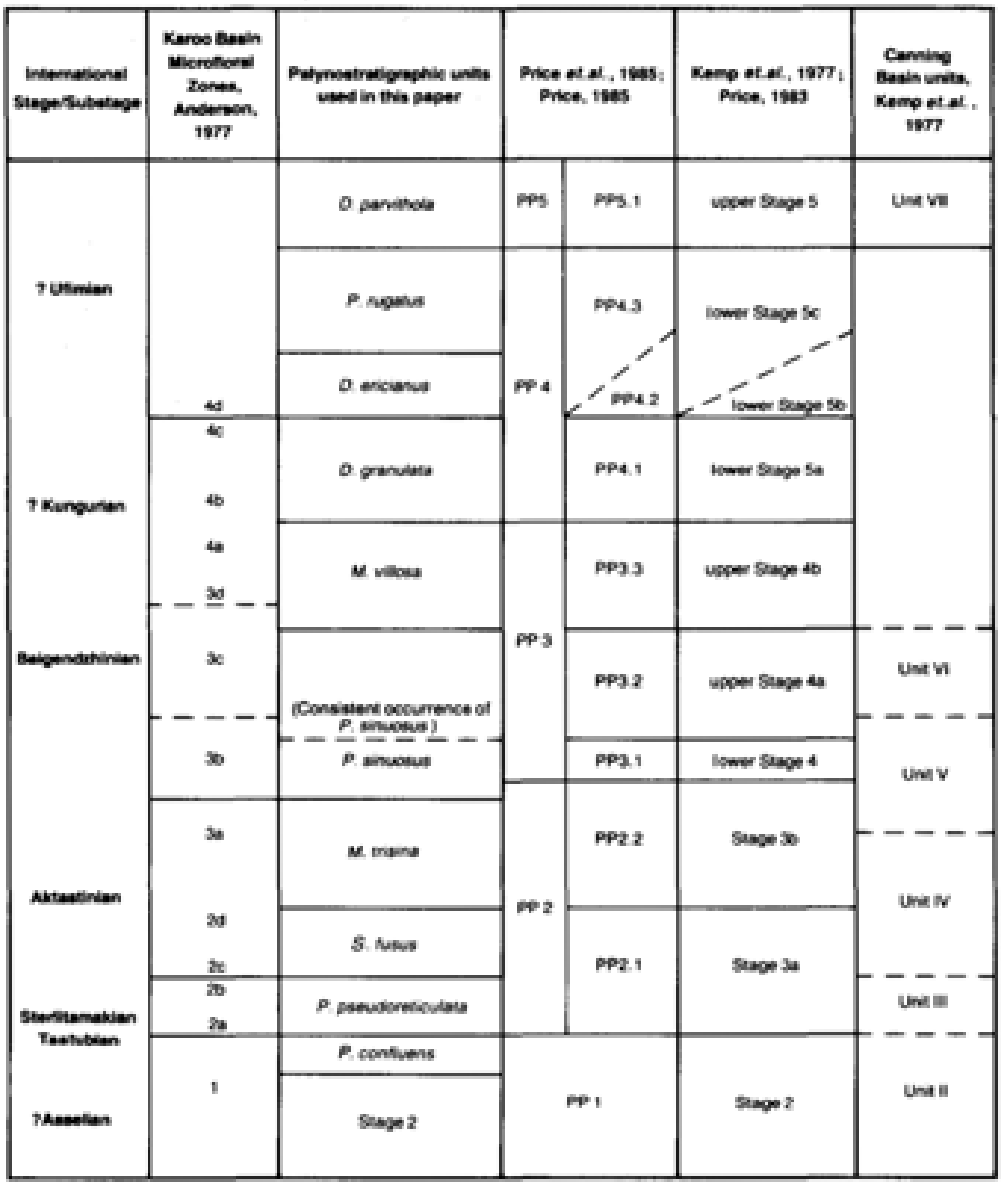
Figure 1.9 (continued)

Backhouse (1991) documented the palynostratigraphy of the Collie Basin, western Australia and correlated this to the northern Karoo Basin microfloral zones of Anderson (1977) and eastern Australia (Table 1.11). The palynostratigraphy of the Collie and Karoo Basins is found to be similar below the *P. sinuosus* Zone, and an age of Latest Carboniferous/Asselian to early Late Permian is suggested for the Permian Collie Basin. The scheme of Backhouse (1991) is based on the same index taxa as used by Price (1983) but instead of defining zones based on the first consistent appearance of a taxon as Price did, the zones of Backhouse (1991) are named after and defined by the FAD of that particular index taxon. These zones are described in detail below.

The *Pseudoreticulatispora* (*Converrucosisporites*) *confluens* Zone of Foster and Waterhouse (1988) is restricted to a small interval at the base of the Collie Coal Measures, and above Stage 2 of the Stockton Formation (Backhouse, 1991). The base of Stage 2 is defined by the introduction of taeniate bisaccate pollen and its microflora is very similar to that of the overlying *P. confluens* Zone, lacking only *P. confluens* itself. *Protohaploxypinus amplus*, *P. limpidus* and *Striatoabieites multistriatus* are present, *Microbaculispora tentula* and *Cycadopites cymbatus* are most abundant, and *Punctatisporites gretensis*, *Horriditriletes ramosus*, *Verrucosisporites andersonii*, *Jayantisporites pseudozonatus* and *Pteruchipollenites gracilis* fairly common (Backhouse, 1991).

The base of the *Pseudoreticulatispora pseudoreticulata* Zone is defined by the first occurrence of *Pseudoreticulatispora pseudoreticulata* and the top by the first occurrence of *Striatopodocarpites fusus*, and also contains *Jayantisporites variabilis*, *Marsupipollenites triradiatus*, *Diatomozonosporites townrowii* and species of *Scheuringipollenites* (Backhouse, 1991). Non-striate bisaccate pollen as well as *Microbaculispora tentula* (*Granulatisporites austroamericanus*) are abundant, while radial monosaccate pollen, *Punctatisporites gretensis* and *Cycadopites cymbatus* are considerably less abundant than in underlying zones (Backhouse, 1991).

Table 1.11: Correlation and ages of Permian palynozones of western and eastern Australia with the South African Karoo Basin microfloral zones (Backhouse, 1991).



The base of the *Striatopodocarpites fusus* Zone is characterised by the first appearances of *Striatopodocarpites fusus* and *S. cancellatus*, and the top, by the first appearance of *Microbaculispora trisina* (Backhouse, 1991). Other taxa appearing at the base of this zone are *Florinites eremus* and *Laevigatosporites colliensis*. *Horriditriletes tereteangulatus* becomes very abundant, and species of

Scheuringipollenites more common. *Microbaculispora tentula* and *Cycadopites cymbatus* are less common, with *C. cymbatus* being rare above this zone (Backhouse, 1991).

The base of the *Microbaculispora trisina* zone is defined by the first occurrence of *Microbaculispora trisina* and the top by the first occurrence of *Praecolpatites sinuosus* (Backhouse, 1991). *Horriditriletes tereteangulatus* is undoubtedly the most abundant species, with *Jayantisporites variabilis*, *Laevigatosporites colliensis*, *Marsupipollenites striatus*, *Striatopodocarpites fusus*, *Protohaploxypinus amplus*, *P. limpidus* and *Scheuringipollenites maximus* all common (Backhouse, 1991).

The base of the *Praecolpatites sinuosus* Zone is marked by the first appearance of *Praecolpatites sinuosus* and the top, by the first appearance of *Microbaculispora villosa* (Backhouse, 1991). *Altitriletes densus* is common in the lower and middle sections of the zone. *Dictyotriletes aules* is present in the upper part, but is more common in the overlying *Microbaculispora villosa* zone. *Horriditriletes tereteangulatus* remains the most abundant species in the lower half of the zone, but diminishes in relative abundance above this level. Also frequent in this zone are *Microbaculispora micronodosa*, *Jayantisporites variabilis*, *Gondisporites raniganjensis*, *G. wilsonii*, *Protohaploxypinus amplus*, *P. limpidus*, *Scheuringipollenites maximus* and *S. ovatus* (Backhouse, 1991).

The base of the *Microbaculispora villosa* Zone is characterised by the first occurrence of *Microbaculispora villosa*, and the top by the first occurrence of *Dulhuntyspora granulata* (Backhouse, 1991). *Propinquispora praetholus* also appears here and extends into the overlying *Dulhuntyspora granulata* Zone, which is consistent with the range indicated for this species by Price (1983). *Protohaploxypinus amplus*, *P. limpidus*, *Scheuringipollenites maximus*, *Leiotriletes directus* and *Marsupipollenites triradiatus* are common in all samples, and *Striatopodocarpites fusus*, *Scheuringipollenites ovatus* and *Gondisporites raniganjensis* are common in some samples (Backhouse, 1991).

The base of the *Dulhuntyspora granulata* Zone is defined by the first appearance of *Dulhuntyspora granulata*, and the top by the first appearance of *Didecitriletes ericianus* (Backhouse, 1991). Abundant taxa in the underlying *M. villosa* Zone are also the prevalent forms in this zone (Backhouse, 1991).

The base of the *Didecitriletes ericianus* zone is marked by the first occurrence of *Didecitriletes ericianus* and the top, by the first appearance of *Protohaploxypinus rugatus* (Backhouse, 1991). In most borehole sections, *D. ericianus* and *Dulhuntyspora dulhuntyi* first occur at roughly the same stratigraphic horizon. Bisaccate pollen is dominant, and the most abundant species are *Leiotriletes directus* and *Marsupipollenites triradiatus*. *Microbaculispora micronodosa*, *Horriditriletes filiformis*, *Retusotriletes diversiformis* and *Brazilea scissa* are common in some samples from this zone (Backhouse, 1991).

The base of the *Protohaploxypinus rugatus* Zone is marked by the first appearance of *Protohaploxypinus rugatus* and the top of the zone is provisionally marked by the first appearance of *Dulhuntyspora parvithola*, although this species is not found in the Collie Basin (Backhouse, 1991). In general this zone is similar in microfloral composition to the *D. ericianus* zone, and the acritarchs *Brazilea scissa*, *Peltacystia venosa* and *P. monile* are common in several samples (Backhouse, 1991).

Mory & Backhouse (1997) reported on the Permian palynostratigraphy of the Carnarvon Basin, western Australia. This basin contains an almost continuous sequence of Permian palynological zones from the Late Carboniferous to the Late Permian (Figure 1.10). A similar zonation scheme is used to that established by Backhouse (1991) for the Collie Basin with some minor modifications. A new early Artinskian *Didecitriletes byroensis* subzone is established at the top of the *Striatopodocarpites fusus* Zone, and the *P. rugatus* Zone is not seen in the Carnarvon Basin.

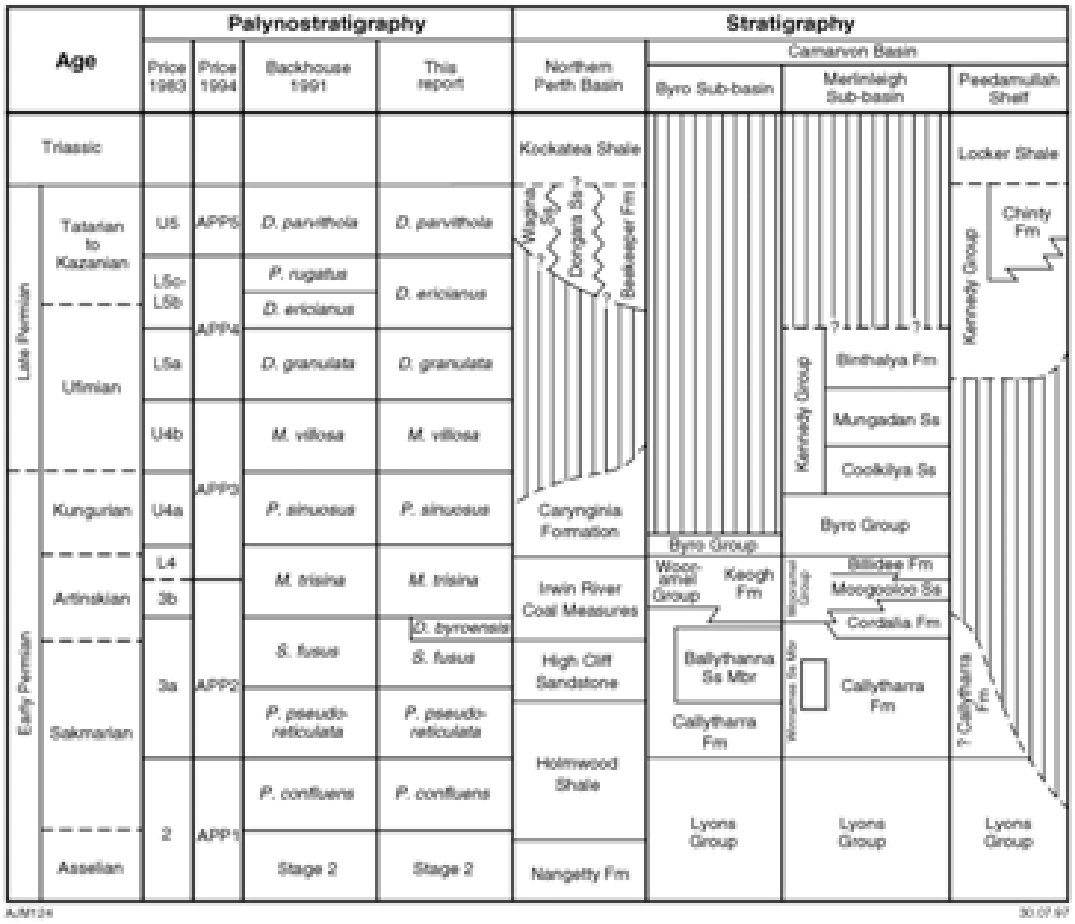


Fig 1.10: Permian stratigraphy and palynozones of the Carnarvon Basin and correlation to northern Perth Basin stratigraphy (Mory & Backhouse, 1997).

Backhouse *et al*. (2002) revised the Latest Triassic and Early Jurassic palynomorph and dinoflagellate zones of Helby *et al*. (1987) for the Carnarvon Basin, western Australia (Figure 1.11).

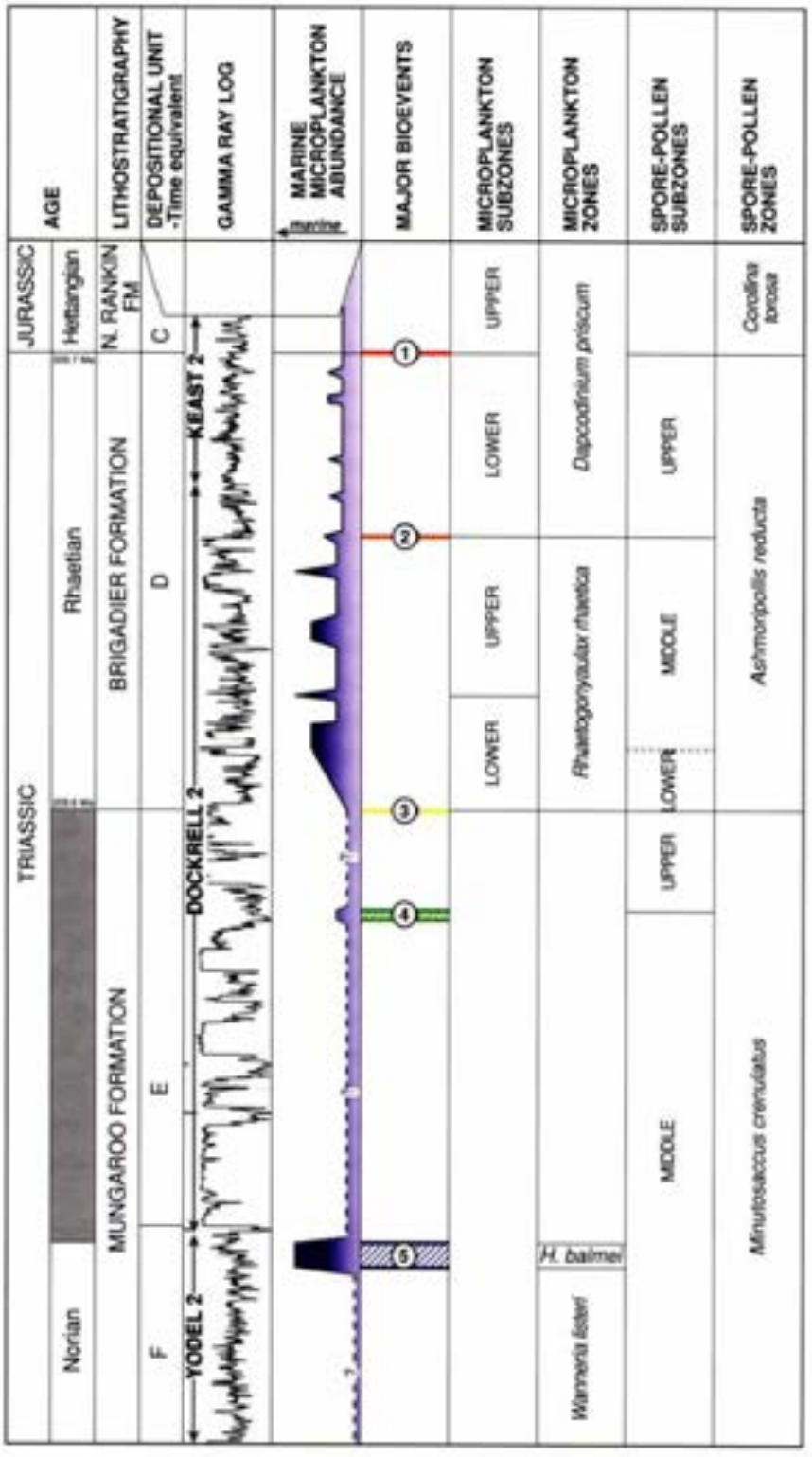


Figure 1.11: Lithostratigraphy and palynological / dinocyst zonation for the Latest Triassic and Early Jurassic of the Carnarvon Basin, western Australia (Backhouse *et al*., 2002).

Filatoff (1975) described the Jurassic palynology of the Perth Basin, western Australia and proposed nine palynostratigraphic units. Two major units, the *Exesipollenites tumulus* and *Callialasporites dampieri* assemblage zones, span the Early to early-Middle Jurassic, and late-Middle to Late Jurassic respectively. The *E. tumulus* Zone can be sub-divided into the *Classopollis chateaunovi* and the *Dictyophyllidites harrisii* assemblage subzones. The overlying *C. dampieri* Zone comprises the *Dictyotosporites complex*, *Klukisporites scaberis* and *Contignisporites cooksonii* Oppel zones, and the informal *Murospora florida* Unit (Filatoff, 1975).

Eastern Australia

Price (1997) consolidated previous palynostratigraphic zones erected in eastern Australia (Price, 1983; Price & Filatoff, 1990; Draper *et al*., 1990) and listed first appearances of characteristic taxa through the Carboniferous, Permian and Triassic (Figure 1.12).

Helby *et al*. (1987) proposed a palynological zonation for the Australian Mesozoic using dinoflagellates as well as spores and pollen. The Late Permian – Latest Triassic *Falcisporites* Superzone is dominated by nonstriate bisaccate pollen and comprises ten eastern Australian subzones and nine western Australian subzones designated by Helby *et al*. (Figure 1.13).

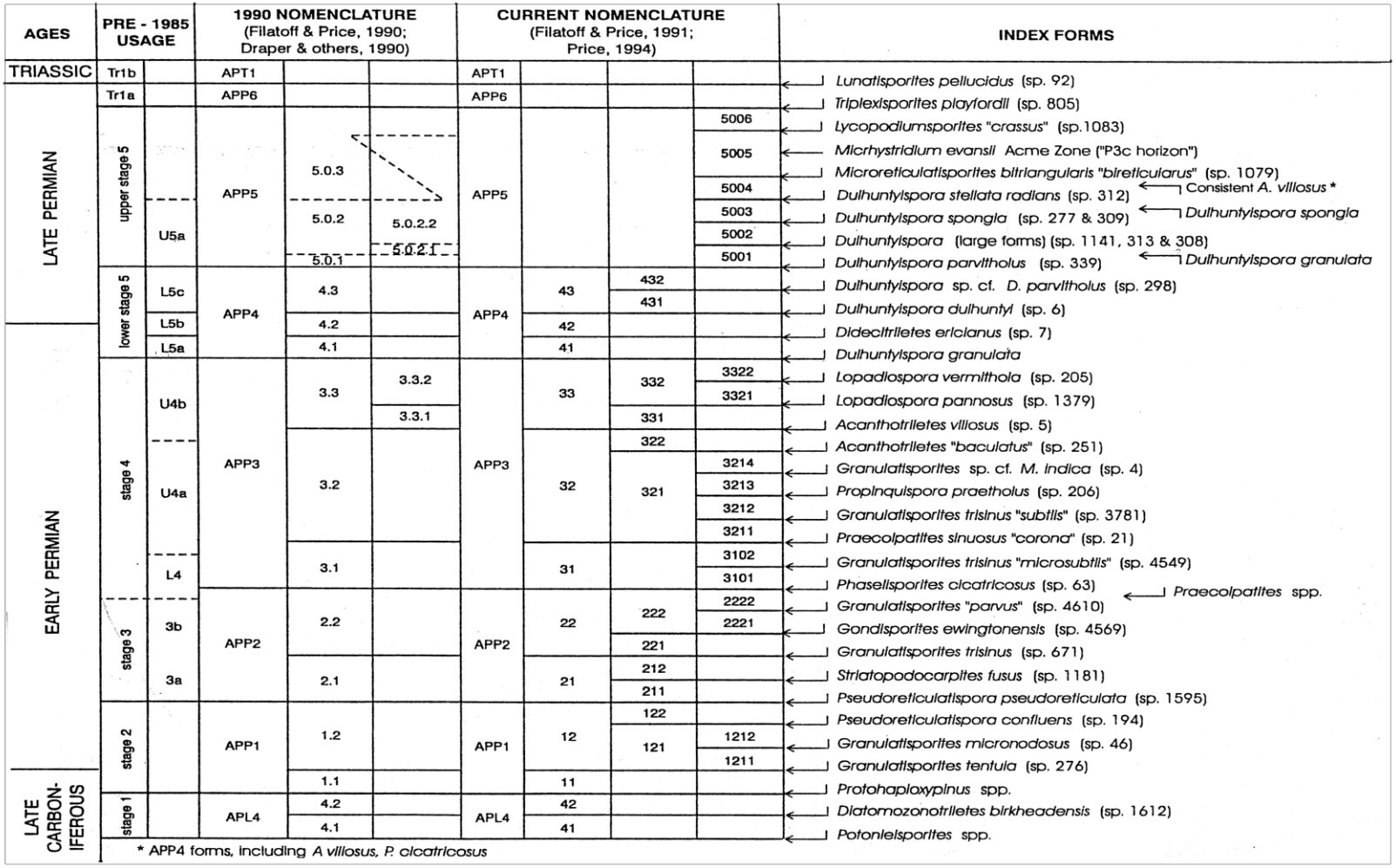


Figure 1.12: Previous and current palynostratigraphy for the Carboniferous, Permian and Triassic of eastern Australia (Price, 1997). Index forms to the right have allowed subdivision of the main zones into sub-sections e.g. APP1 is divisible into subzones 1.1 and 1.2 by the FAD of *Granulatisporites tentula*, and sub-zone 1.2 is further divisible into sections 1.2.1 and 1.2.2. by the FAD of *Pseudoreticulatispora confluens*.

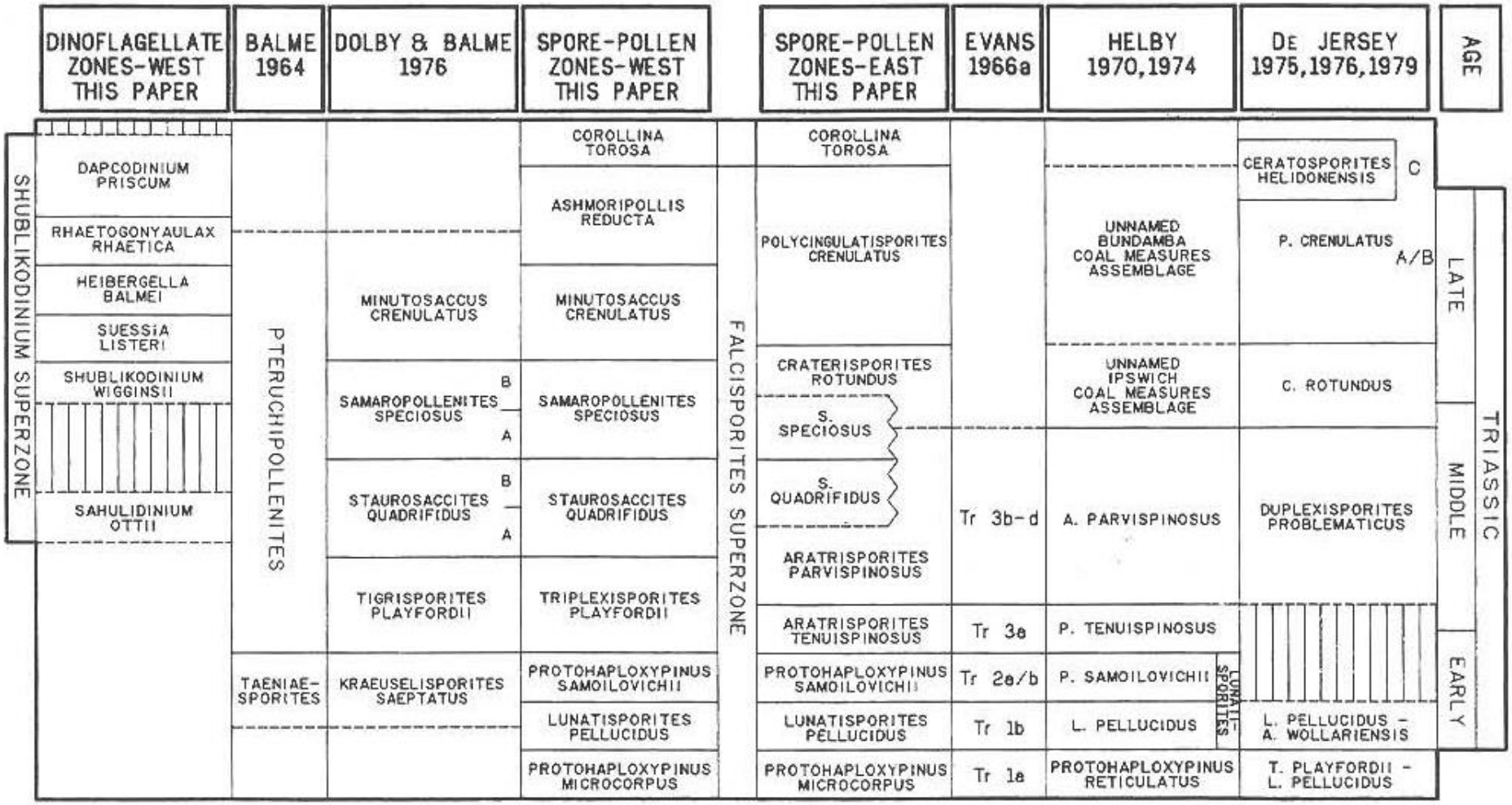


Figure 1.13: Triassic palynomorph and dinoflagellate zones of eastern and western Australia (Helby *et al.*, 1987).

Southern Australia

Gilby & Foster (1988) studied an Early Permian succession of the Arckaringa Basin, South Australia. The Permian series in this basin comprises three formations: at the base lies the Boorthanna Formation (a glacigene unit), overlain by the Stuart Range Formation (dark-coloured marine shales), and finally the Mount Toondina Formation (coal seams, grey micaceous shale and sandstone, mostly non-marine). The Stuart Range Formation palynoflora contains abundant *Cannanoropollis* spp., *Plicatipollenites* spp. and *Cycadopites cymbatus* while *Microbaculispora tentula*, *Apiculatisporis cornutus*, *Horriditriletes ramosus*, *Pseudoreticulatispora pseudoreticulata* and *Striatoabieites multistriatus* are common (Gilby & Foster, 1988). Acritarchs dominate the assemblage, particularly the non-spinose acritarch *Leiosphaeridia*. Spinose acritarchs include *Diexallophasis*? spp. and the genus *Micrhystridium*. The Mount Toondina Formation palynoflora contains abundant striate pollen, particularly *Protohaploxypinus limpidus* and *Striatopodocarpites*. Spores such as *Apiculatisporis cornutus*, *Horriditriletes ramosus* and *Microbaculispora tentula* are more abundant than pollen grains. *Scheuringipollenites ovatus*, *Botryococcus*, *Spongocystia*, and *Tetraporina* are common in some samples (Gilby & Foster, 1988).

1.3.2.4 New Zealand

Zhang & Grant-Mackie (2001) reported on Late Triassic – Early Jurassic palynofloral assemblages from the Murihiku strata of New Zealand (Figure 1.14). The Triassic-Jurassic boundary is placed between Assemblages II and III (within the upper part of the local Otapirian Stage). Assemblage I, the *Polycingulatisporites crenulatus – Annulispora microannulata - Aratrisporites flexibilis* Assemblage is Early-Middle Norian in age. Dominant spores are *Annulispora microannulata* and *Dictyophyllidites mortonii*, and *Deltoidospora directa*, *Uvaesporites verrucosus*, *Aratrisporites* spp., *Polycingulatisporites*

crenulatus, *Densoisporites psilatus*, *Rogalskaisporites ambientis*, *Foveogleicheniidites atavus*, *Anapiculatisporites pristidentatus*, *Kyrtomisporis minor*, *Craterisporites rotundus*, and *Thymospora ipsviciensis* are common (Figure 1.14). *Alisporites* spp., *Cycadopites* spp., *Equisetosporites steevesii*, and small numbers of *Protohaploxypinus* spp. and *Rugaletes intestiniformis* represent the main pollen taxa.

Assemblage II, the *Foveosporites moretonensis* - *Densoisporites psilatus* - *Steevesipollenites claviger* Assemblage is Rhaetian in age (Zhang & Grant-Mackie, 2001). The dominant spores are *Densoisporites psilatus* and *Uvaesporites* spp. (Figure 1.14). Taxa from Assemblage I persist, however *Aratrisporites* is markedly less abundant while *Thymospora ipsviciensis*, *Camarozonosporites rudis*, *Foveogleicheniidites atavus*, *Limatulasporites limatulus*, *Lycospora pallida*, and *Rugaletes intestiniformis* are absent. Younger elements such as *Foveosporites moretonensis*, *Lycopodiumsporites* cf. *austroclavatidites*, *L. rosewoodensis*, *Rugaletes awakinoensis*, and *Polycingulatisporites moomensis* appear. Dominant pollen grains are *Alisporites* spp., *Equisetosporites steevesii*, and small numbers of *Protohaploxypinus* spp. and *Playfordiaspora crenulata*. The first appearance of *Classopollis meyeriana*, *Perinopollenites elatoides*, *Vitreisporites signatus*, and *Steevesipollenites claviger* is seen in this assemblage (Figure 1.14).

Assemblage III, the *Toripustulatisporites hokonuiensis* - *Kyrtomisporis minor* - *Polycingulatisporites radiatus* Assemblage is late Otapirian - early Aratauran (Hettangian) in age (Zhang & Grant-Mackie, 2001). Most taxa in this assemblage range from underlying strata, with the new elements *Toripustulatisporites hokonuiensis*, *Kyrtomisporis elsendoornii*, *Antulsporites* spp., *Cibotiumspora juncta*, and *Lycopodiumsporites semimuris* (Figure 1.14). It contains *Polycingulatisporites* in high numbers.

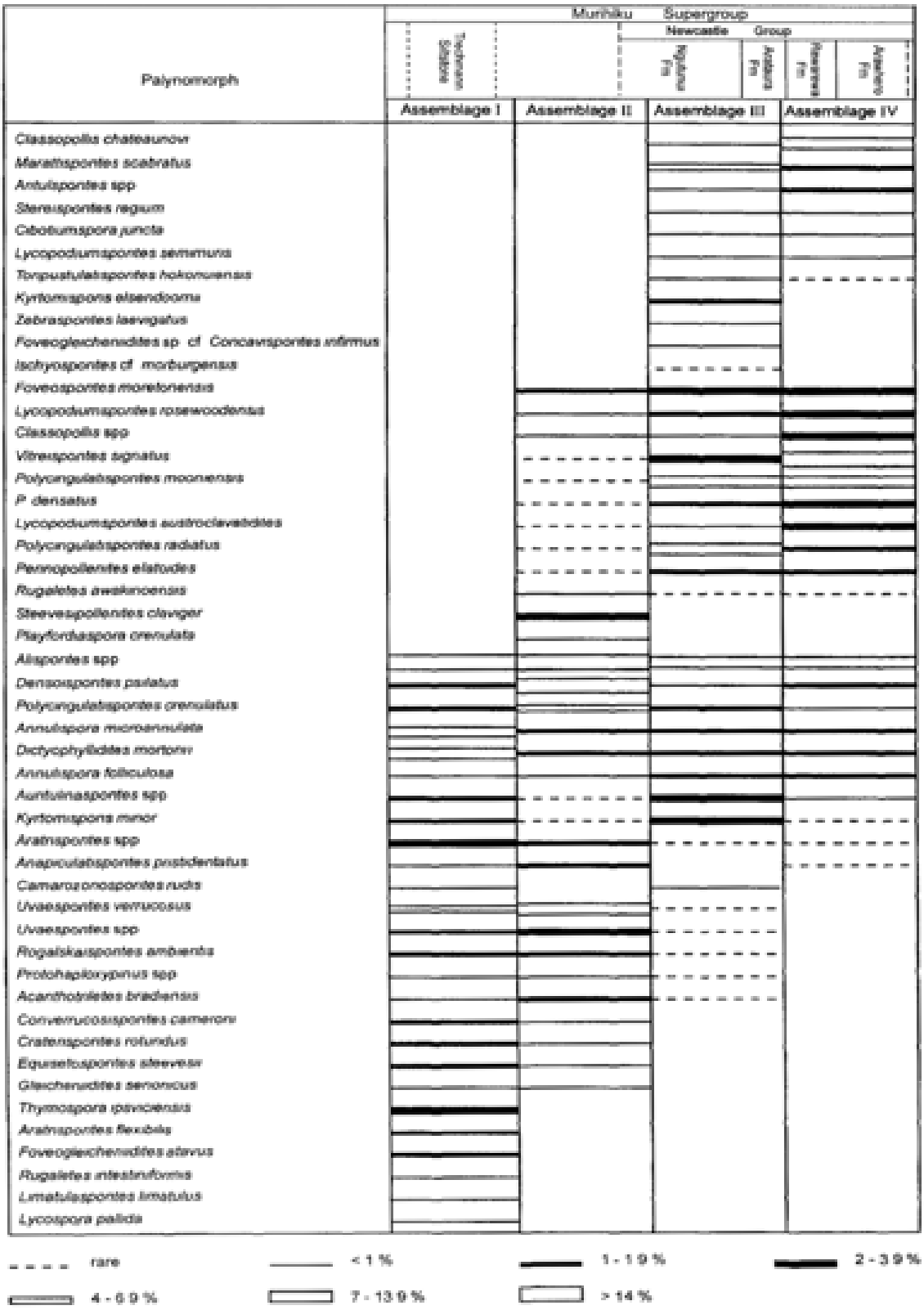


Figure 1.14: Ranges of biostratigraphically important palynomorphs of Assemblages I - IV of the Triassic and Jurassic Murihiku strata, New Zealand (Zhang & Grant-Mackie, 2001).

Assemblage IV, the *Classopollis chateaunovi* - *Lycopodiumsporites austroclavatidites* Assemblage is Aratauran (Hettangian-Sinemurian) in age (Zhang & Grant-Mackie, 2001). *Polycingulatisporites* remains common, and *Lycopodiumsporites austroclavatidites* and *L. semimuris* are present in greater numbers than earlier assemblages. Also common are *Annulispora folliculosa*, *Antulsporites varigranulatus*, *Deltoidospora directa*, *Dictyophyllidites atraktos*, *Foveosporites moretonensis*, *Osmundacidites wellmanii*, *Rogalskaisporites cicatricosus*, *Vitreisporites signatus*, *Inaperturopollenites* spp. and *Perinopollenites elatoidesi* (Figure 1.14). This assemblage is characterised by the increase of *Classopollis chateaunovi*, coupled with Jurassic taxa such as *Lycopodiumsporites austroclavatidites*, *L. semimuris*, *Antulsporites varigranulatus*, *A. clavus*, *Polycingulatisporites mooniensis*, *Perinopollenites elatoides*, and *Vitreisporites signatus* (Figure 1.14).

1.3.2.5 Brazil

Daemon and Quadros (1970) proposed 6 palynozones (G-L) for the Gondwana section of the Paraná Basin, based on 40 selected species of spores and pollen. The palynology indicates an Upper Pennsylvanian (Stephanian C) to Upper Permian (Kazanian) age for the Upper Palaeozoic sedimentary sequence in the Paraná Basin. The palynostratigraphy of the Paraná Basin was revised by Souza and Marques-Toigo (2003, 2005) and Souza (2006), who proposed a new palynozonation for the Late Carboniferous Itararé Subgroup (Figure 1.15), integrating the intervals proposed by Daemon and Quadros (1970). The *Ahrensisporites cristatus* Interval Zone (AcZ) is assigned a Pennsylvanian (late Bashkirian to Kasimovian) age and includes eleven exclusive spore species (Figure 1.15, Figure 1.16). The overlying *Crucisaccites monoletus* Interval Zone (CmZ) is defined only by the presence of its namesake taxon and is dated late Pennsylvanian (Kasimovian to Gzhelian). Both zones are dominated by trilete spores and monosaccate pollen grains, with rare taeniate pollen (Figure 1.16). The basal *Protohaploxypinus goraiensis* Subzone of the *Vittatina costabilis* Interval

Zone (VcZ) is dated to the Early Permian (Early Cisuralian) and dominated by monosaccate pollen grains with a significant increase in taeniate pollen (mainly *Protohaploxypinus*) and the appearance of polyplicate pollen (*Vittatina*) (Figure 1.15, Figure 1.16).

Playford & Dino (2000) documented the palynology of the Carboniferous - Permian Tapajós Group of the Amazonas Basin subsurface, northern Brazil and designated seven assemblage zones: *Spelaeotriletes triangulus* Zone (Westphalian A-B), *Striomonosaccites incrassatus* Zone (Westphalian C), *Illinites unicus* Zone (Westphalian C), *Striatosporites heyleri* Zone (Westphalian C-D), *Raistrickia cephalata* Zone (Westphalian D), *Vittatina costabilis* Zone (Early Permian); and *Tornopollenites toreutos* Zone (Late Permian) (Figure 1.17).

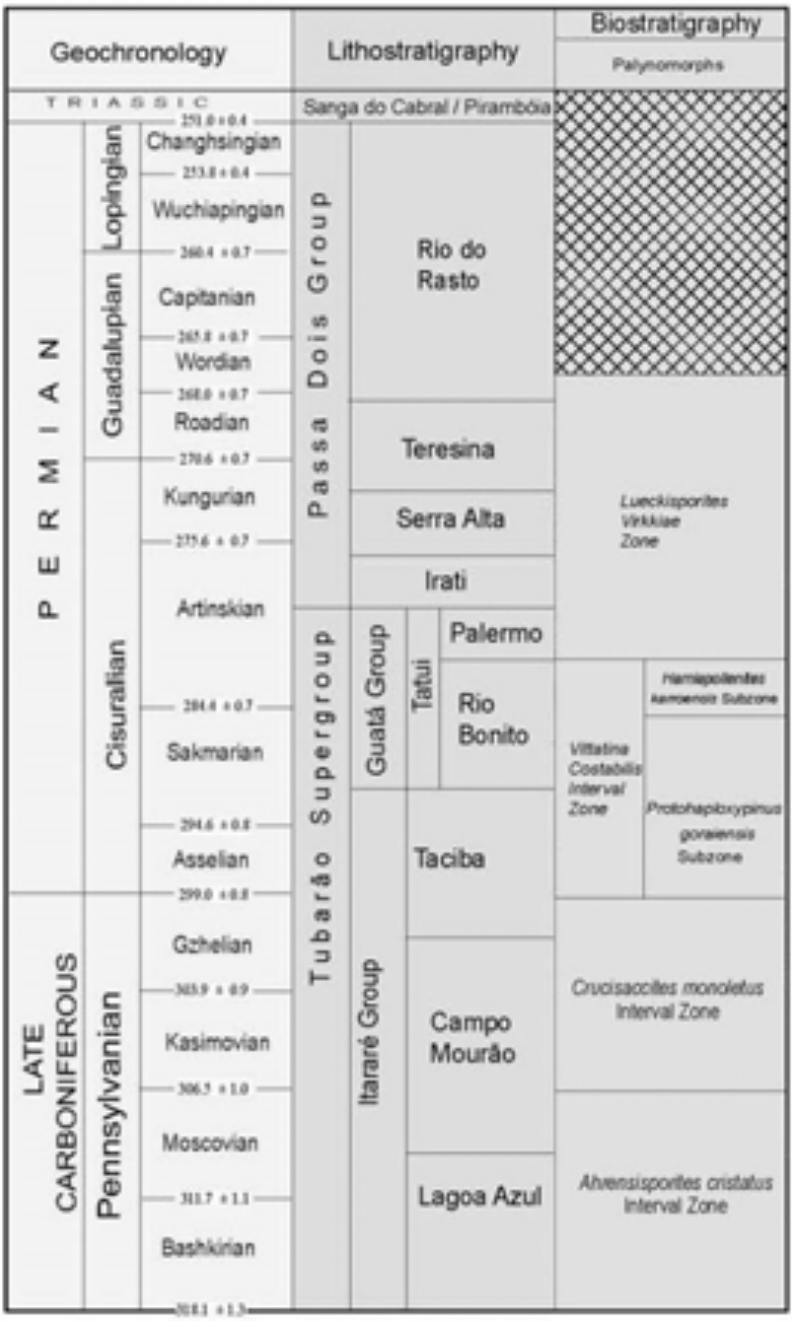


Figure 1.15: Carboniferous, Permian and Triassic litho- and biostratigraphy of the Paraná Basin, Brazil, combining information from Souza and Marques-Toigo (2003, 2005), Souza (2006) and Daemon and Quadros (1970) (Holz *et al.*, 2010).

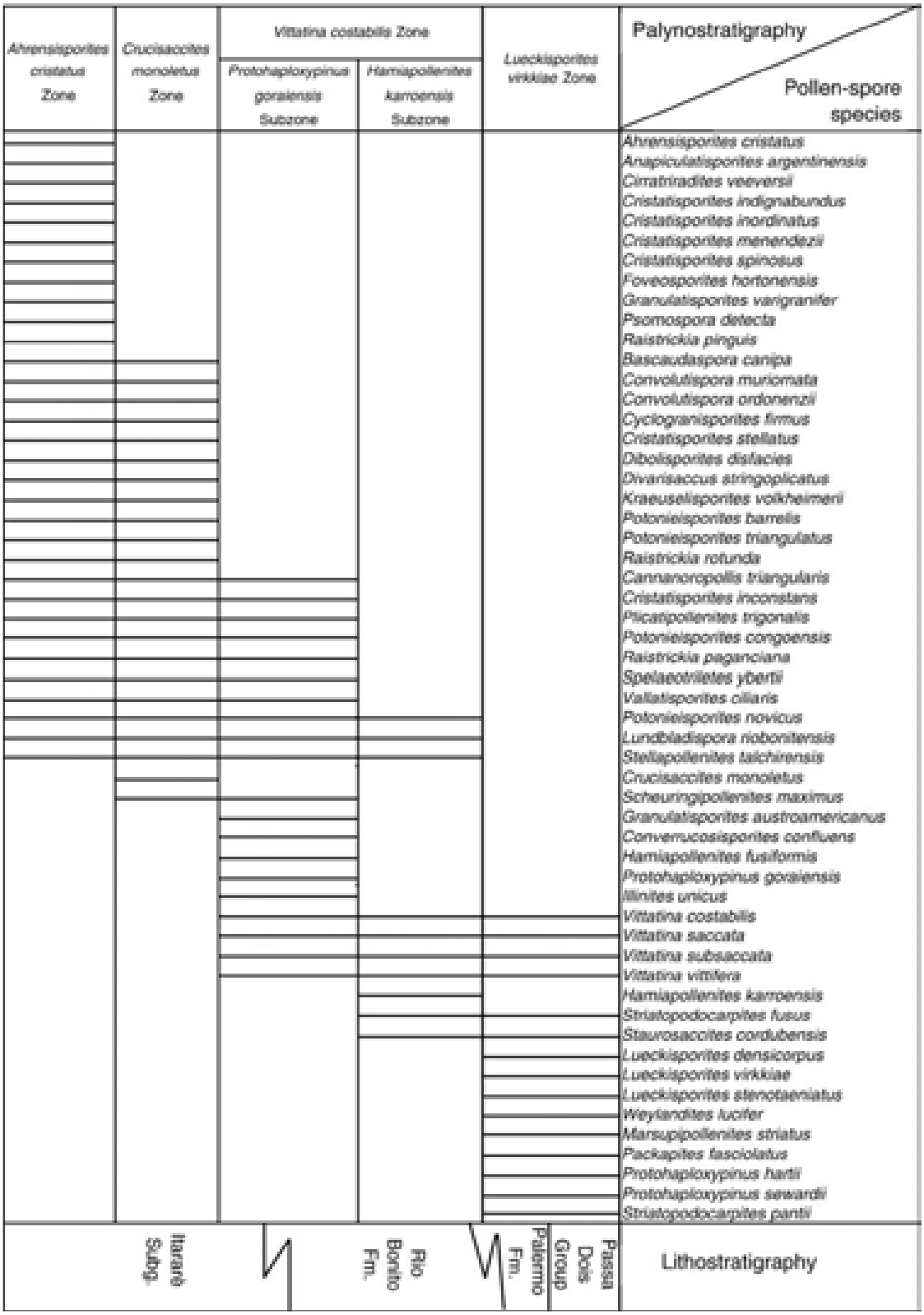


Figure 1.16: Palynozonation of Late Carboniferous strata of the northeastern Paraná Basin, Itararé Subgroup, Brazil (Souza, 2006).

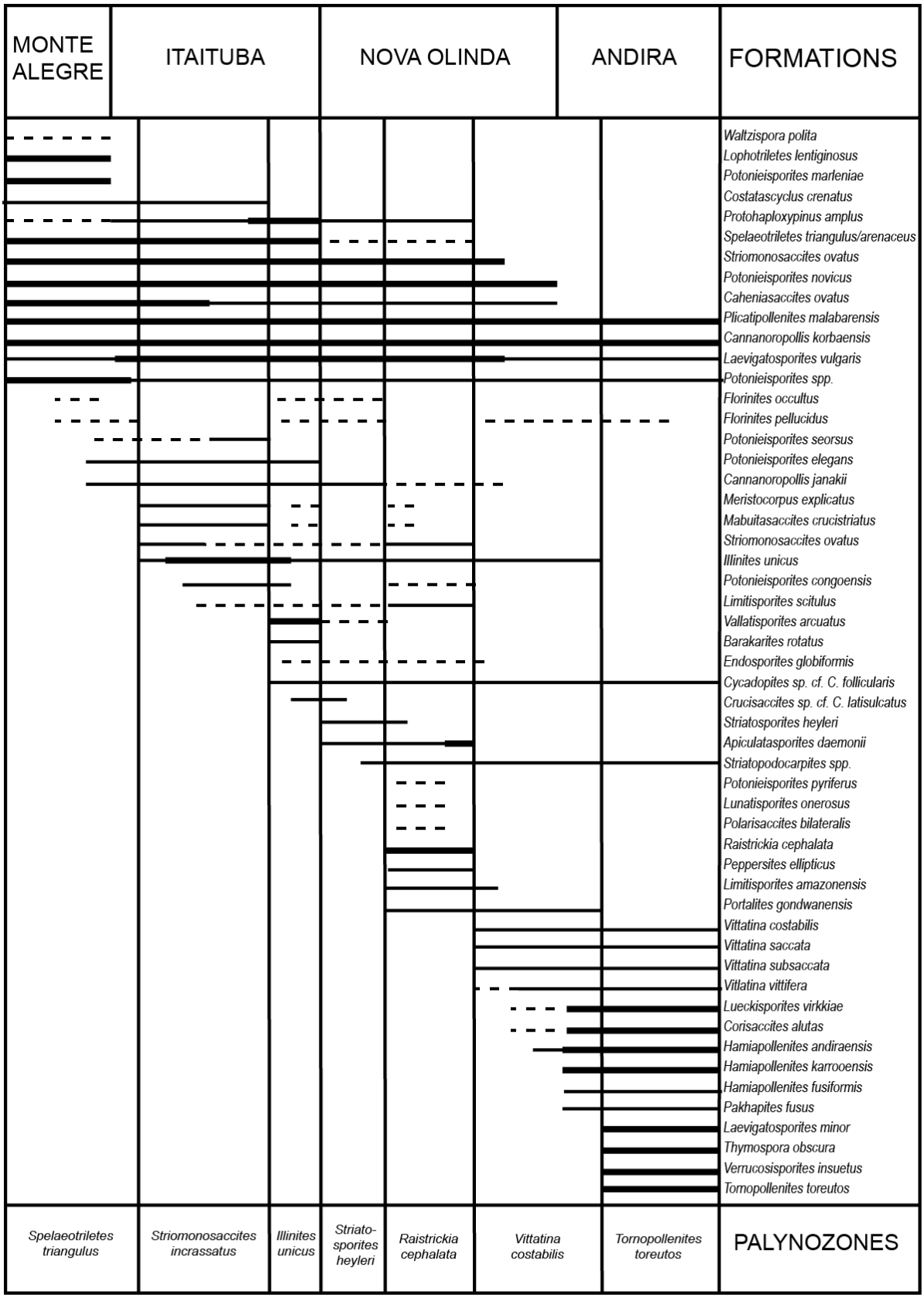


Figure 1.17: Palynozones of the Carboniferous - Permian Amazonas Basin, Brazil (redrawn from Playford & Dino, 2000).

1.3.2.6 Argentina

César and Gutiérrez (2000) and César *et al*. (2011) summarized the Carboniferous and Permian palynozones of central-western Argentina (Figure 1.18), replacing previous proposals for the region (e.g. Archangelsky *et al*., 1987, 1996; Azcuy, 1979; Azcuy & Jelin, 1980; Azcuy, 1986; César, 1986). Palynozonation schemes for Argentina, Brazil and South Africa can be correlated using radiometric dates as tiepoints between regions (César *et al*., 2011).

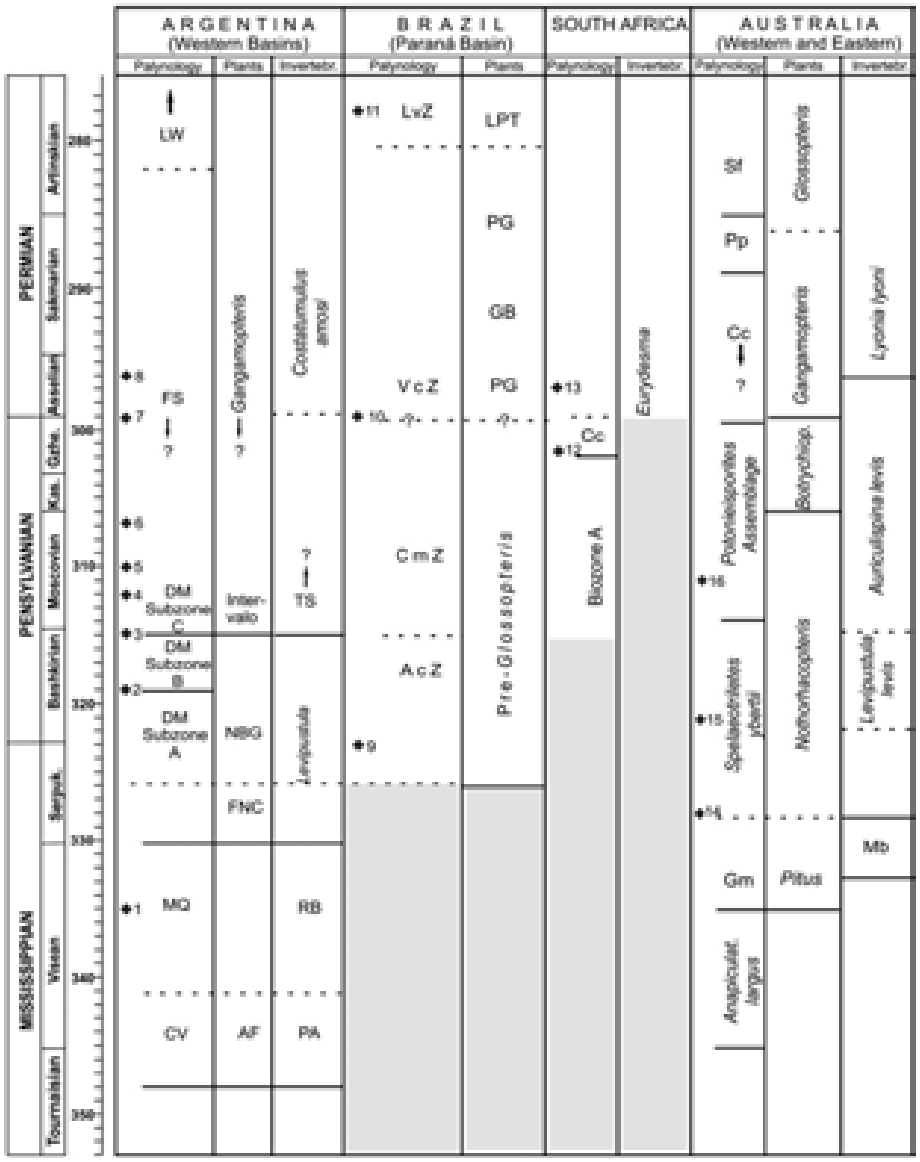


Figure 1.18: Correlation of Argentinean, Brazilian and South African palynozones by radiometric dates (César *et al*., 2011).

The Late Visean *Reticulatisporites magnidictyus – Verrucosisporites quasigobbetti* (MQ Biozone) contains the distinctive taxa *Verrucosisporites congestus*, *Verrucosisporites cortaderensis*, *Reticulatisporites magnidictyus*, *Dibolisporites malimanensis* and *Verrucosisporites quasigobbetti* (César *et al*., 2011).

The Namurian (Serpukhovian and Bashkirian) *Raistrickia densa – Convolutispora muriornata* (DM Biozone) is divided into three subzones (César *et al*., 2011). Distinctive species of DM-Subzone A are *Reticulatisporites asperidictyus*, *Foveosporites hortonensis*, *Raistrickia rotunda*, *Cristatisporites menendezii* and *Plicatipollenites densus*. DM-Subzone B contains *Ahrensisporites cristatus*, *Convolutispora muriornata*, *Granulatisporites austroamericanus* (= *Microbaculispora tentula*), *Spelaeotriletes ybertii* and *Protohaploxypinus* sp. . Characteristic taxa of DM-Subzone C include *Apiculatisporis variornatus*, *Lundbladispora braziliensis*, *Raistrickia cephalata*, *Horriditriletes uruguaiensis* and *Protohaploxypinus* sp. (César *et al*., 2011).

The Early Permian *Pakhapites fusus – Vittatina subsaccata* (FS Biozone) is characterised by *Colpisaccites granulosus*, *Hamiapollenites fusiformis*, *Kraeuselisporites sanluisensis*, *Verrucosisporites patelliformis* and *Vittatina subsaccata* (César *et al*., 2011). The Artinskian *Lueckisporites – Weylandites* (LW Biozone) contains the distinctive taxa *Lueckisporites stenotaeniatus*, *Vittatina fasciolata*, *Weylandites magmus*, *Staurosaccites cordubensis* and *Lueckisporites latisaccus* (César *et al*., 2011).

Di Pasquo (2002) described palynomorphs from the *Crassispora kosankei-Cystoptychus azcuyi* palynozone of the Upper Carboniferous Tupambi Formation, northern Argentina. 39 species of Upper Carboniferous age were identified with the most abundant taxa being *Crassispora kosankei* and *Cystoptychus azcuyi*. Also present are *Granasporites medius*, *Cristatisporites rollerii*, *C. stellatus*, *C. saltitensis*, *Kraeuselisporites volkheimerii*, *Apiculatasporites parviapiculatus*, *A. caperatus*, *Granulatisporites parvus*, *Apiculiretusispora alonsoi*, *Waltzispora*

polita, *Punctatisporites glaber*, *Calamospora hartungiana*, *Schopfipollenites ellipsoides*, *Meristocorpus* sp. and the green alga *Botryococcus*.

1.3.2.7 Chile

Zavattieri *et al*. (2003) describe the microflora of the Upper Triassic Panguipulli Formation, Chile. The assemblage comprises 17% spores (*Apiculatisporis*, *Aratrisporites*, *Baculatisporites*, *Cacheutasporites*, *Calamospora*, *Deltoidospora*, *Dictyophyllidites*, *Gleicheniidites*, *Neoraistrickia*, *Osmundacidites*, *Punctatisporites* and *Rogalskaisporites*) and 81.9% gymnosperm pollen (*Accinctisporites*, *Alisporites*, *Chordasporites*, *Cuneatisporites*, *Cycadopites*, *Equisetosporites*, *Falcisporites*, *Goubinispora*, *Inaperturopollenites*, *Klausipollenites*, *Lunatisporites*, *Minutosaccus*, *Platysaccus*, *Podocarpidites*, *Protodiploxypinus*, *Sulcatisporites*, *Sulcosaccispora* and *Vesicaspora*). The microfloral assemblage is associated with a megaflora principally comprising *Dicroidium*, *Cladophlebis*, *Gleichenites*, *Linguifolium*, *Pseudoctenis* and *Sphenobaiera*. Correlation with other palynological assemblages from Argentina and Gondwana indicate an early Late Triassic age for the Panguipulli Formation, which is of the Ipswich microfloral type (temperate to warm-temperate climate, highly seasonal, and moist).

1.3.2.8 Bolivia

Di Pasquo (2009) analysed samples from the Pando X-1 borehole in northern Bolivia and recorded 48 species, 22 of which represent the first incidences of such taxa from the Pennsylvanian of Bolivia, including *Florinites eremus*, *Protohaploxypinus varius*, *Striatopodocarpites antiquus*, *Striatopodocarpites gondwanensis*, *Striatopodocarpites solitus*, and *Vittatina* sp. . Scolecodonts, microforaminifera and algae were also present in the assemblage but rare. A Moscovian (early Pennsylvanian) age for the assemblage is suggested on the

presence of the striate pollen taxa *Lahirites segmentatus*, *Limitisporites scitulus*, *Lunatisporites onerosus* and *Vittatina* species.

1.3.2.9 Uruguay

Beri *et al*. (2011) reported on 184 palynomorph taxa from boreholes spanning the Permian San Gregorio to Yaguarí formations of Uruguay (Figure 1.19). Two assemblage zones were proposed: the *Cristatisporites inconstans*-*Vittatina saccata* Assemblage Zone (IS) and the *Striatoabieites anaverrucosus*-*Staurosaccites cordubensis* Assemblage Zone (AC). The IS Assemblage Zone is characterised by trilete spores and monosaccate pollen with a lesser component of non-taeniate bisaccate, taeniate bisaccate and plicate pollen, and the AC Assemblage Zone is dominated by taeniate and non-taeniate bisaccate pollen. An early Cisuralian age is proposed for the lower IS Zone, and a late Cisuralian–Guadalupian age for the AC zone.

Beri *et al*. (2013) analysed palynological assemblages from Permian boreholes of Uruguay dating from the early Cisuralian to approximately the early Guadalupian, in order to better understand the evolution of palynofloras during the Permian period. It proved difficult to define clear biohorizons for the Early Permian but a sporomorph turnover was observed during deposition of the Artinskian Mangrullo Formation (correlated with the Iratí Formation of southern Brazil) which coincides with an arid climatic phase for the region (Beri *et al*., 2013).

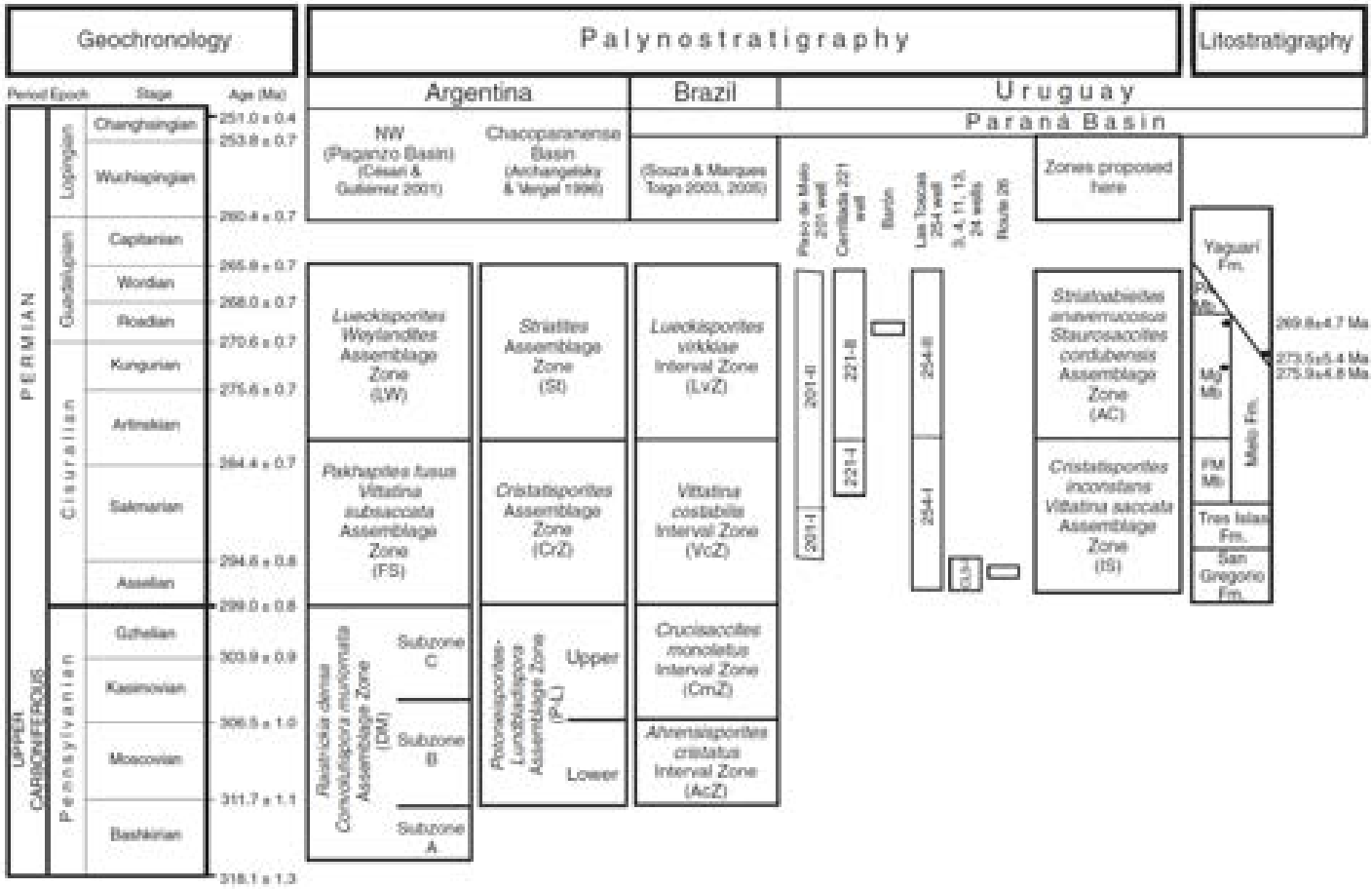


Figure 1.19: Permian lithostratigraphic units and palynozones of Uruguay compared to palynozones of Brazil and Argentina (Beri *et al*., 2011).

1.3.2.10 Antarctica

Palynological investigations in Antarctica have mainly focused on three areas: the Prince Charles Mountains of East Antarctica (Foster *et al*., 1994; McLoughlin *et al*., 1997; Lindström & McLoughlin, 2007), the Central Transantarctic Mountains (Farabee *et al*., 1990) and Dronning Maud Land, East Antarctica (Larrson *et al*., 1990; Guy-Ohlson & Lindström, 1994). Table 1.12 shows the lithostratigraphy of the three areas from the Early Permian to the Middle Triassic.

Larrson *et al*. (1990) analysed Asselian-Sakmarian palynomorphs from the Late Palaeozoic Beacon Supergroup at Milorgfjella, Dronning Maud Land, Antarctica. The Milorgfjella microflora is quantitatively dominated by trilete spores (50-70%), and *Punctatisporites gretensis*, *Punctatisporites parvus*, *Granulatisporites* spp., *Microbaculispora tentula*, *Horriditriletes* spp. and *Verrucosisporites andersonii* are the most abundant taxa. Gymnosperm pollen grains include *Plicatipollenites* spp. and *Cannanoropollis* spp. . The monosulcate *Cycadopites cymbatus* is also present.

Table 1.12: Correlation of the Prince Charles Mountains, Central Transantarctic Mountains and Dronning Maud Land litho-stratigraphy from the Early Permian to the Middle Triassic. No scale implied (redrawn from McLoughlin *et al*., 1997; Larrson *et al*., 1990; Lindström & McLoughlin, 2007; Cohen *et al*., 2013).

<table>
<tr><th>Period</th><th>Epoch</th><th>Stage</th><th colspan="2">Lambert Graben, Prince Charles Mountains</th><th>Central Transantarctic Mountains</th><th>Dronning Maud Land</th></tr>
<tr><td rowspan="12">TRIASSIC</td><td rowspan="3">Upper</td><td>Rhaetian</td><td></td><td></td><td rowspan="2"></td><td rowspan="12">?</td></tr>
<tr><td>Norian</td><td rowspan="3">Flagstone Bench Fm</td><td>McKelvey Mb.</td></tr>
<tr><td>Carnian</td><td rowspan="3">Jetty Mb.</td><td rowspan="2">Falla Fm</td></tr>
<tr><td rowspan="2">Middle</td><td>Ladinian</td><td rowspan="4">Fremouw Fm</td></tr>
<tr><td>Anisian</td></tr>
<tr><td rowspan="2">Lower</td><td>Olenekian</td><td rowspan="2">Ritchie Mb.</td></tr>
<tr><td>Induan</td></tr>
<tr><td rowspan="13">PERMIAN</td><td rowspan="2">Lopingian</td><td>Changhsingian</td><td rowspan="5">Bainmedart Coal Measures</td><td>McKinnon Mb.</td><td rowspan="11">Buckley Fm</td></tr>
<tr><td>Wuchiapingian</td><td>Grainger Mb.</td></tr>
<tr><td rowspan="3">Guadalupian</td><td>Capitanian</td><td>Glossopteris Gully Mb.</td></tr>
<tr><td>Wordian</td><td>Toploje Mb.</td></tr>
<tr><td>Roadian</td><td colspan="2" rowspan="2">Radok Conglomerate</td></tr>
<tr><td rowspan="5">Cisuralian</td><td>Kungurian</td></tr>
<tr><td>Artinskian</td><td rowspan="4"></td><td rowspan="4">Beacon Supergroup</td></tr>
<tr><td>Sakmarian</td></tr>
<tr><td rowspan="2">Asselian</td><td>MacKellar Fm</td></tr>
<tr><td>Pagoda Tillite</td></tr>
</table>

Foster *et al*. (1994) described a well-preserved Late Triassic microflora from the upper Flagstone Bench Formation, Prince Charles Mountains, East Antarctica. The most abundant taxa include *Enzonalasporites vigens*, *E. densus*, cf. *Ellipsovelatisporites* sp., *Minutosaccus crenulatus*, cf. *Rimaesporites aquilonalis*, *Ovalipollis ovalis*, *Samaropollenites speciosus*, and *Duplicisporites scurrilis*. The assemblage is correlated to the Australian *Minutosaccus crenulatus* Zone (of Norian age). Also present in the assemblage are rare spinose acritarchs and one specimen of a dinocyst of the *Shublikodinium-Rhaetogonyaulax* plexus, which represented the first record of a Triassic dinocyst from Antarctica (Foster *et al*., 1994).

McLoughlin *et al*. (1997) and Lindström & McLoughlin (2007) studied the palynology of the Permo-Triassic transition in the Prince Charles Mountains, East Antarctica (Figure 1.20). The Permian palynoflora is dominated by long-ranging striate bisaccates (mostly *Protohaploxypinus* and *Striatopodocarpites*) and the non-striate genus *Scheuringipollenites*. The disappearance of coal strata together with *Glossopteris* coincide with a loss of 32% of typical Permian palynomorphs, but the remainder survive to the earliest Triassic, whereupon a further 34% of the lingering Permian taxa are lost, and Triassic pioneer taxa appear (Lindström & McLoughlin, 2007). The result of these stepwise extinctions was an actual increase in palynomorph diversity during the earliest Triassic. After the end-Permian mass extinction only 27% of taxa from the Early Permian McKinnon Member survived to the late Induan Ritchie Member (Lindström & McLoughlin, 2007). Palynological and lithological data suggest that high latitude areas of Gondwana such as the Prince Charles Mountains were affected by global warming later in the Permian than areas to the north and west (Lindström & McLoughlin, 2007). While the end-Permian extinction appeared to have impacted various Gondwana regions differently, it gave way to a generally sub-humid to semi-arid, and less seasonal climate across southern Gondwana (Lindström & McLoughlin, 2007).

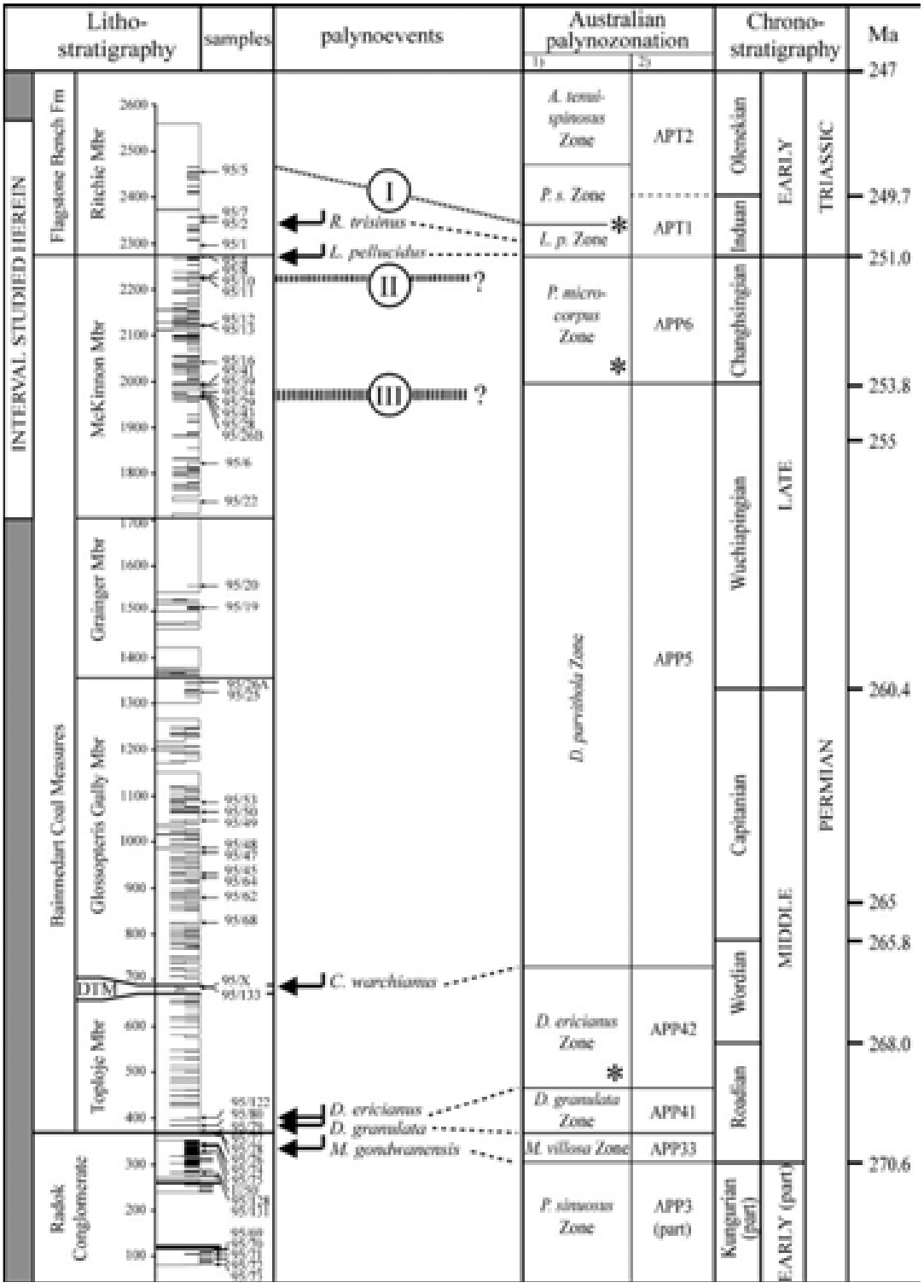


Figure 1.20: Important palynoevents in the Permian to Early Triassic sequence of the Prince Charles Mountains, Antarctica and correlation to Australian palynozonations (Lindström & McLoughlin, 2007).

Farabee *et al*. (1990) correlated Permian and Triassic assemblages from the Central Transantarctic Mountains to Australian stages (Figure 1.21). The Buckley Formation is interpreted as Late Permian in age and the overlying Fremouw and Falla formations are Early and Late Triassic respectively. Farabee *et al*. (1990) concluded that Antarctican microfloras are more similar to those of Australia than elsewhere in Gondwana.

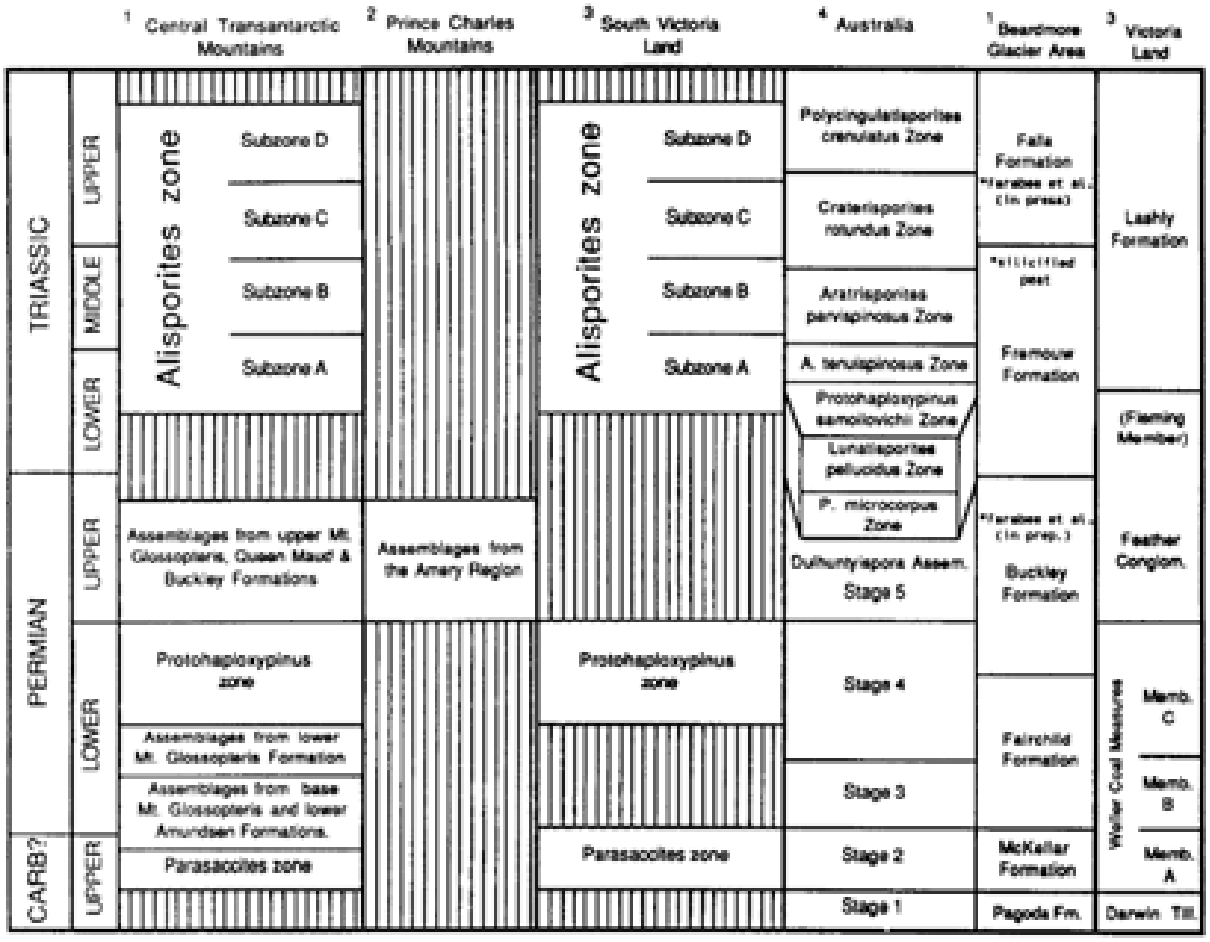


Figure 1.21: Permian and Triassic palynoassemblages from the central Transantarctic Mountains and correlation to Australian palynological stages (Farabee *et al*., 1990).

1.3.2.10 India

Much palynological work has been done on the various Gondwana basins of India e.g. Bharadwaj (1962), Bharadwaj & Salujha (1964), Bharadwaj & Srivastava (1969), Tiwari (1964), Kar (1968), Lele (1973), Tiwari & Singh (1981), Tiwari & Tripathi (1992), Singh *et al*. (1995), Tripathi (1996), Meena (1999), Jana *et al*. (2002), Jha (2006), but variations in taxonomic nomenclature contribute to difficulties in correlation with southern Africa and other Gondwanan localities (Modie, 2007). The master Gondwana basins of India are shown in Figure 1.22, and deposits range from Carboniferous to Cretaceous in age (Mukhopadhyay *et al*., 2010).

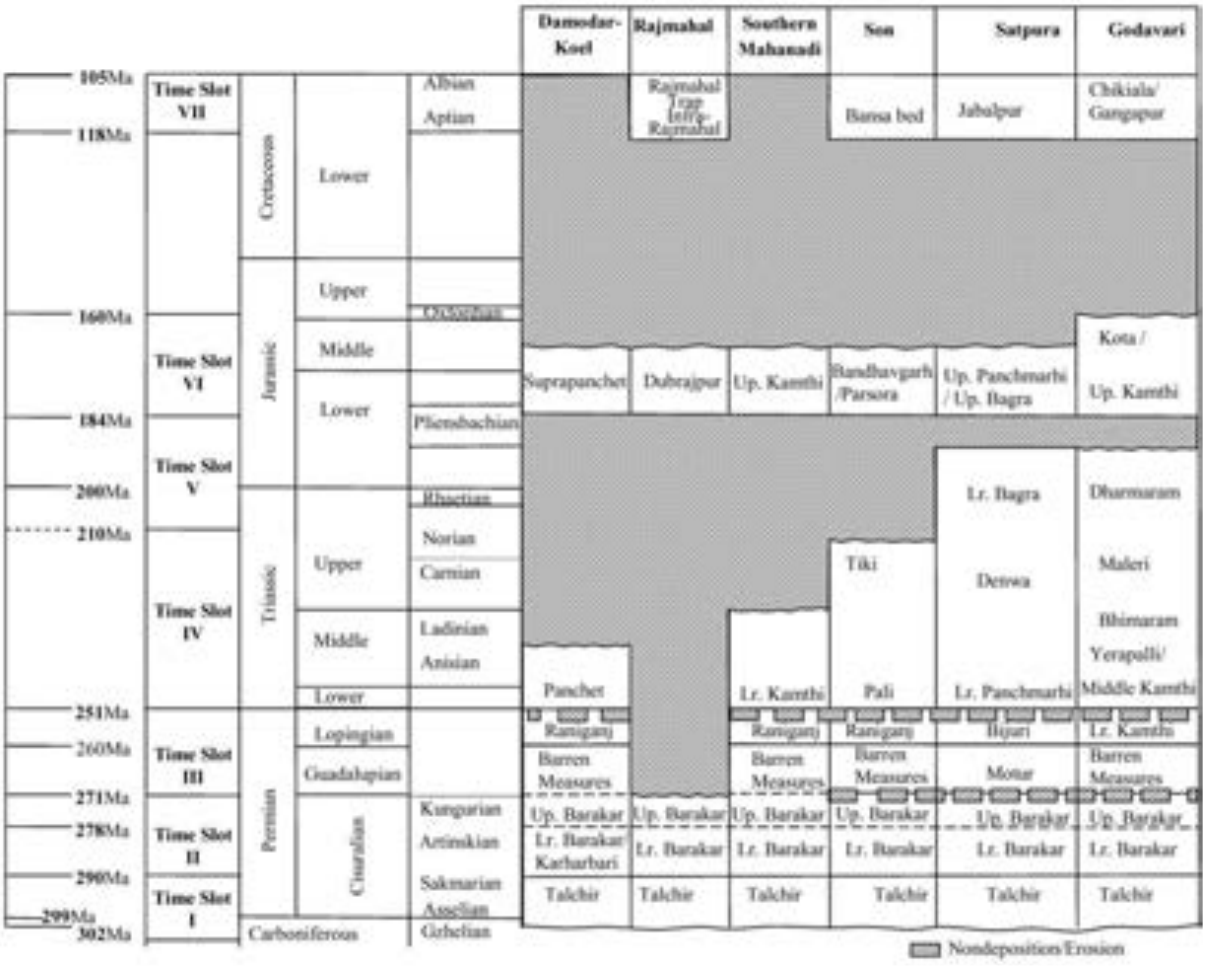


Figure 1.22: Correlation of Carboniferous - Cretaceous formations of the Gondwana basins of India (Mukhopadhyay *et al*., 2010).

Vijaya *et al*. (2012) describe the Permian and Triassic palynostratigraphy of the Singrauli Gondwana Basin, incorporating earlier work by Tripathi *et al*. (2005) and summarising existing Indian palynozonations. The Singrauli Gondwana Basin is located in the northernmost part of the Son-Mahanadi master Gondwana Basin (Figure 1.22), and Vijaya *et al*. (2012) recognised 10 assemblage zones in the basin that can be correlated to previously described Indian and Australian palynozones (Figure 1.23).



Figure 1.23: Palynozones of the Permian and Triassic Singrauli Gondwana Basin, India and correlation to existing Indian (Tiwari & Tripathi, 1992) and Australian (Helby *et al*., 1987; Backhouse, 1993) palynozonations (Vijaya *et al*., 2012).

Tripathi *et al*. (2005) studied the palynology of the Raniganj and Parsora formations in the Mahuli-Mahersop area, Singrauli Coalfield, South Rewa Gondwana Basin (part of the Son-Mahanadi master Gondwana Basin). Five palynoassemblages were identified, indicating latest Permian (Assemblage l), earliest Triassic (Assemblage II), and Late Triassic (Assemblage A / B / Ill) ages. Early and Middle Triassic deposits were found to be absent in the South Rewa Gondwana Basin. The assemblages can be correlated to existing palynological zones of India and Australia (Figure 1.24).

<table>
<tr><th>SERIES</th><th>STAGE</th><th>SOUTH REWA
(1)</th><th>KRISHNA-
GODAWARI
(2)</th><th>RAJMAHAL
(3)</th><th>DAMODAR
(4)</th><th>PRESENT
STUDY
(5)</th></tr>
<tr><td rowspan="4">LATE TRIASSIC</td><td>RHAETIC</td><td></td><td></td><td>Arcuatipollenites tethysensis
Assemblage Zone</td><td></td><td>Assemblage
B</td></tr>
<tr><td>NORIAN</td><td rowspan="2">Tiliaspories balmei
Zone</td><td>Enzonalaspories ignacii-Minutosaccus crenulatus
Assemblage Zone</td><td>Dubrajiporites triassicus Assemblage Zone

Brachysaccus ovalis
Assemblage zone</td><td></td><td>Assemblage
III b

Assemblage
III a</td></tr>
<tr><td>CARNIAN</td><td>Rimaesporites potonieii samaropollenites speciosus Assemblage Zone</td><td>Rajmahalispora regulata Assemblage Zone</td><td></td><td>Assemblage
A</td></tr>
<tr><td rowspan="2">MIDDLE TRIASSIC</td><td>LADINIAN</td><td rowspan="2">Rimaesporites potonieii
Zone</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">Goubinispora indica Assemblage Zone</td><td rowspan="2"></td></tr>
<tr><td>ANISIAN</td></tr>
<tr><td rowspan="2">EARLY TRIASSIC</td><td rowspan="2">SCYTHIAN</td><td></td><td rowspan="2"></td><td rowspan="2"></td><td>Playfordiaspora cancellosa
Assemblage Zone</td><td rowspan="2"></td></tr>
<tr><td>Krempipollenites indicus Zone</td><td>Krempipollenites indicus Assemblage Zone</td><td>Krempipollenites indicus
Assemblage Zone</td><td>Assemblage
II</td></tr>
<tr><td>LATE</td><td>PERMIAN</td><td></td><td></td><td>Densipollenites magnicorpus
Assemblage Zone</td><td>Densipollenites magnicorpus
Assemblage Zone</td><td>Assemblage
I</td></tr>
</table>

Figure 1.24: Spore-pollen assemblages of the Raniganj and Parsora formations, Singrauli Coalfield and correlations to existing Late Permian and Triassic palynological zones of India and Australia (Tripathi *et al*., 2005).

Tripathi *et al*. (2012) studied the palynology of the Talchir, Barakar and Barren Measures formations, Tatapani–Ramkola Coalfield, South Rewa Gondwana Basin and defined five palynological assemblages: (i) *Scheuringipollenites barakarensis*, (ii) *Faunipollenites varius*, (iii) *Gondisporites raniganjensis*, (iv) *Densipollenites magnicorpus*, and (v) *Krempipollenites indicus* zones (Figure 1.25). The Talchir Formation can be dated palynologically to the late Early Permian, the Barakar Formation can be dated to the Late Permian, and the Barren Measures assemblage can be correlated to the palynoflora of the Raniganj Formation which is of Early Triassic age (Tripathi *et al*., 2012).

Vijaya *et al*. (2009) reported on palynologically productive coprolites from the Upper Triassic Maleri Formation, Pranhita-Godavari Valley, India. Species present include *Antulsporites varigranulatus*, *Aratrisporites* spp., *Cadargasporites baculatus*, *Dubrajisporites isolatus*, *Enzonalasporites vigens*, *Foraminisporis coelatus*, *Grandispora spinosa*, *Kraeuselisporites saeptatus*, *Polycingulatisporites reduncus*, *Staurosaccites* spp., *Tethysispora unica* and *Tikisporites balmei*. The presence of *Classopollis classoides* and *Callialasporites turbatus/dampieri* suggest a Norian to Rhaetian age (Vijaya *et al*., 2009).

Palynological studies from various Carboniferous – Jurassic aged basins of south-central Africa, Australia, New Zealand, Brazil, Argentina, Chile, Bolivia, Uruguay, Antarctica, and India have been summarised above. Although these localities shared generally similar floras during the Late Palaeozoic and Mesozoic periods, intra-Gondwanan floristic provincialism is consistently apparent (McLoughlin, 2001) which will naturally be reflected in their palynological content. This will be assessed further in Chapter 3 (Results and Discussion) where assemblages from these localities are correlated to the Karoo palynomorphs of this study.

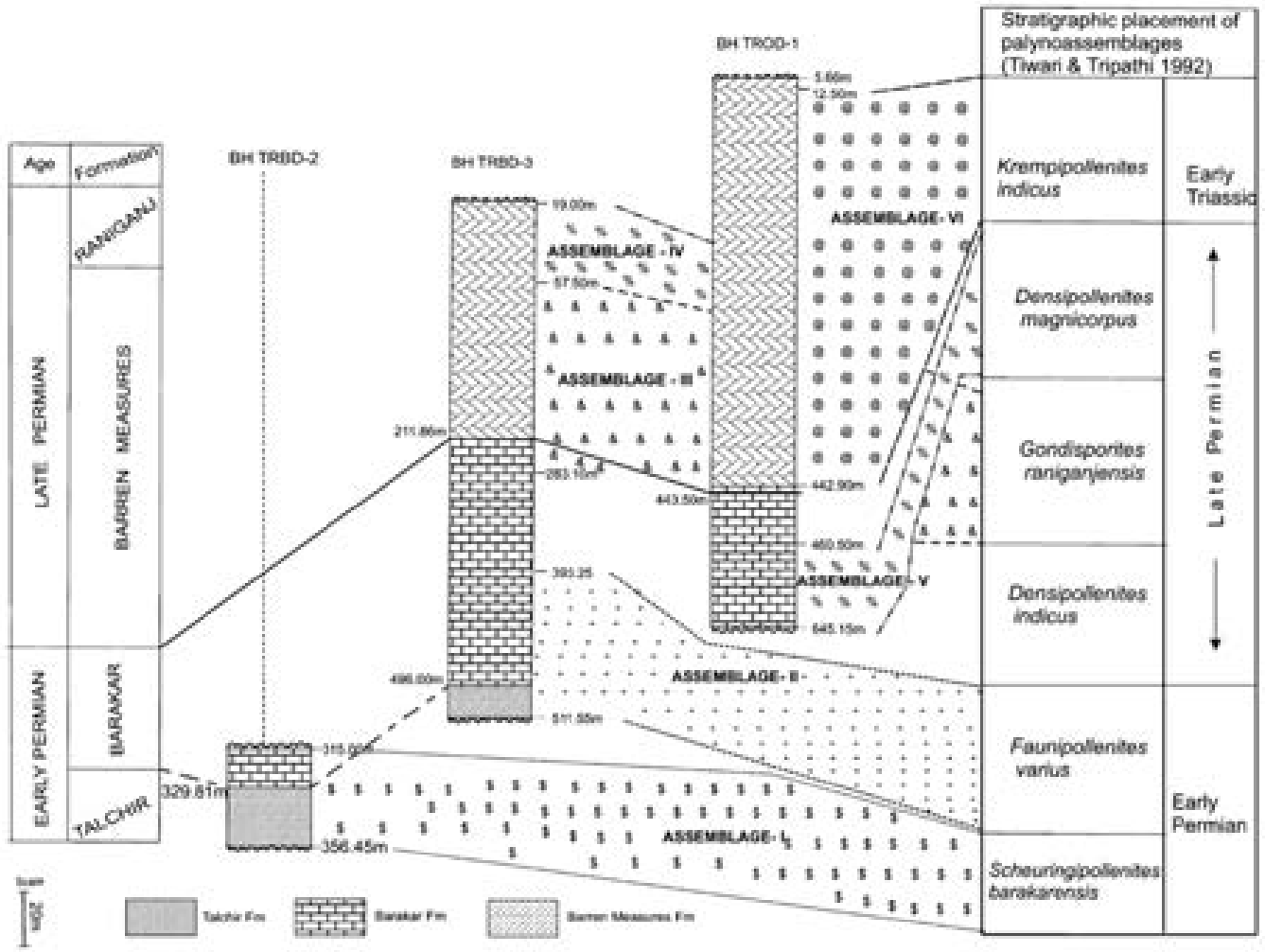


Figure 1.25: Permian and Triassic palynological assemblage zones of the Talchir, Barakar and Barren Measures formations, India (Tripathi *et al*., 2012).

2. MATERIALS AND METHODS

2.1 SAMPLING

The Main Karoo Basin of South Africa was sampled extensively for this study, with 275 samples collected from road cuttings and outcrops from the western region (west of the 24° E meridian), southern region (east of the 24° E meridian) and the north-east distal facies (Figure 2.1, Figure 2.2). Over the course of the project sampling protocols were developed that ensured the highest probability of success, which depended primarily on an understanding of palynomorph taphonomy.

Palynomorphs are organic microfossils the size of silt or fine sand particles and include terrestrial microspores, megaspores, cryptospores, isospores, pollen, colonial algae and fungal spores as well as marine dinoflagellates, "microforams," chitinozoans, scolecodonts, and acritarchs of uncertain origin (Traverse, 2007). They are preserved better in acidic, reducing and low-energy sedimentary conditions than alkaline, oxidising, high-energy sedimentary situations (Traverse, 2007). The Ecca Group has relatively abundant, well-preserved palynomorphs, however the rocks of the Beaufort and Stormberg Groups were deposited in progressively more arid fluvio-lacustrine environments (Smith *et al*., 1993) that were less conducive to good palynomorph preservation. Accordingly for this study a large amount of sample material (± 500 - 750 g) was taken from each site in order to compensate for low concentrations of miospores, and also to test different treatment methods on each sample. This allowed for preparation of multiple slides.

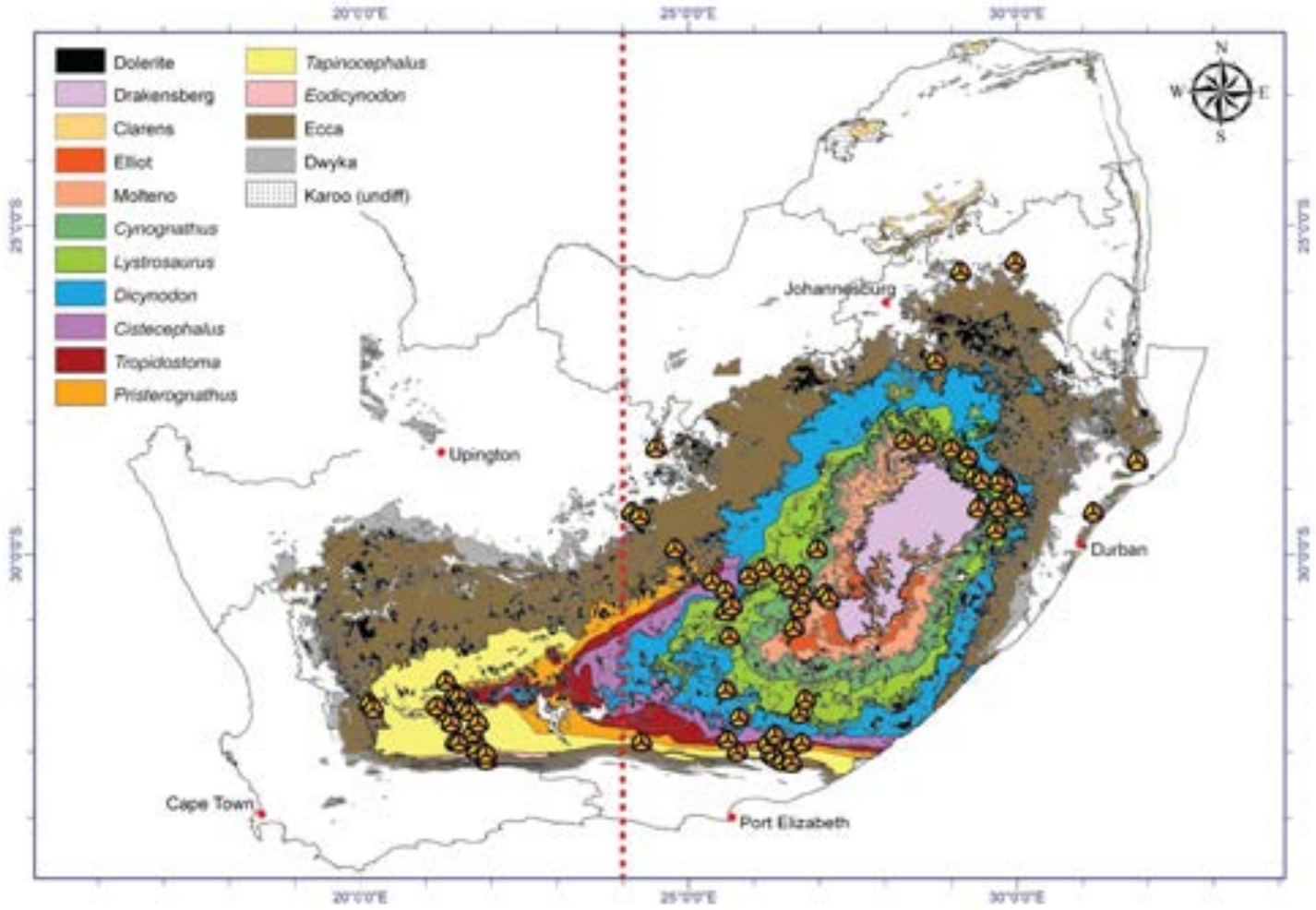


Figure 2.1: **Locations of 275 rock samples taken from the Main Karoo Basin. Samples derive from various formations and members of the Dwyka, Ecca, Beaufort and Stormberg groups west of 24° E, east of 24° E, and KwaZulu-Natal. The dashed line indicates 24° E.**

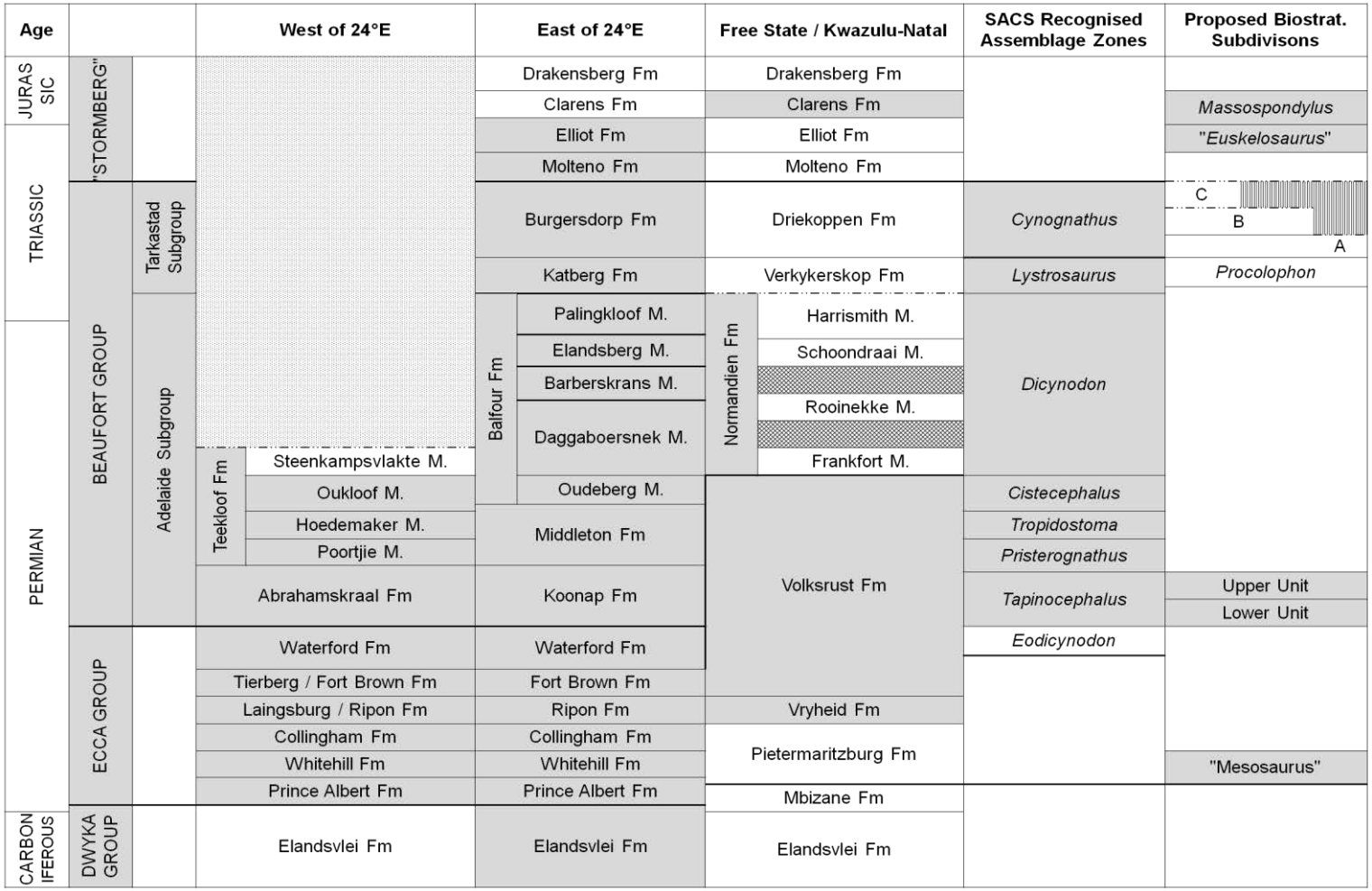


Figure 2.2: Current bio- and litho-stratigraphic subdivision of the Karoo Supergroup with members, formations and vertebrate biozones sampled for palynomorphs highlighted in grey (modified from Rubidge, 2005). SACS = South African Committee for Stratigraphy, 1980.

For this study it was attempted to sample every Member / Formation of the Karoo Supergroup in all three regions of the basin, but it was not always possible to locate suitable lithologies for sampling purposes. Reddish mudstones and coarse sandstones indicate oxidising or high-energy environments in which palynomorphs would have been destroyed, and such rocks are therefore not palynologically productive. Such rocks are common in various Beaufort Group formations and comprise the dominant lithologies of the Elliot and Clarens formations, complicating the task of obtaining palynomorphs from these formations.

Through extensive travelling and experimentation, suitable lithologies for sampling were located for most members and formations of the Karoo Supergroup. As well as the usual dark brown to black carbonaceous siltstones and mudstones, blue, green, purple, and grey silts and muds were also sampled as well as "dirty" sandstones containing some silt. If two different colour rocks were present at the same site, both colours were sampled. One colour often proved to be productive where the other was not. Samples of both outcrops and road cuttings were collected by digging partway into the rock in order to obtain less weathered material.

Previous attempts (e.g. Stapleton, 1974, 1977; Anderson, 1977) to obtain palynomorphs from the rocks of the southern Karoo have repeatedly been frustrated by the effects of the Cape Fold Belt, metamorphism and widespread dolerite intrusions from the Drakensberg Group volcanics in this part of the basin. This has destroyed some of the existing pollen sequences through heat and devolatization (Falcon, 1975; Anderson, 1977). In the western and southern regions of the Karoo Basin, areas with much dolerite or obvious folding were avoided.

Early in the study it became apparent that samples from road cuttings and quarries generally appeared to be more productive than samples from outcrops. This observation was borne out throughout the study with outcrops comprising only

one quarter of the total of productive samples. This is believed to be due to road cuttings having experienced less weathering than outcrops even if the road cuttings are many years old. The Clarens Formation samples from the Champagne Valley area were derived from a recent rockfall in the mountains meaning that material was unusually fresh and unweathered.

No borehole material was used in this study, for although cores generally yield the best palynofloras due to being unweathered, it is sometimes difficult to determine from what formation or biozone the samples originated.

Samples collected in the field were placed in new plastic zip-lock bags and labelled in permanent marker with their GPS co-ordinates and details of the lithology they were obtained from. This information was duplicated in a field notebook along with further notes on locality, biozones, altitude, other fossils present, etc. for later reference (see Table 3.1). Zip-lock bags were wrapped individually in layers of newspaper to prevent the plastic tearing and transported back to the Evolutionary Studies Institute (ESI) palynology laboratory for chemical processing.

2.2 SAMPLE PREPARATION

2.2.1 CHEMICAL PREPARATION

Fossil pollen deposits are typically low in concentration, diluted by much inert material and only the exines of grains are preserved (Faegri & Iversen, 1989). Palynomorphs are generally prepared by using hydrochloric acid to dissolve carbonates, hydrofluoric acid to dissolve silicates, brief oxidation if the sample is organic, and a float-sink procedure to separate out palynomorphs from heavier mineral matter (e.g. Staplin *et al*., 1960; Phipps & Playford, 1984). Karoo samples were subjected to various permutations of acid preparation, oxidation and acetolysis (methods from Moore *et al*., 1991; Traverse, 2007) in order to

determine the best treatment for individual samples. A flowchart of preparation methods is given below (Figure 2.3).

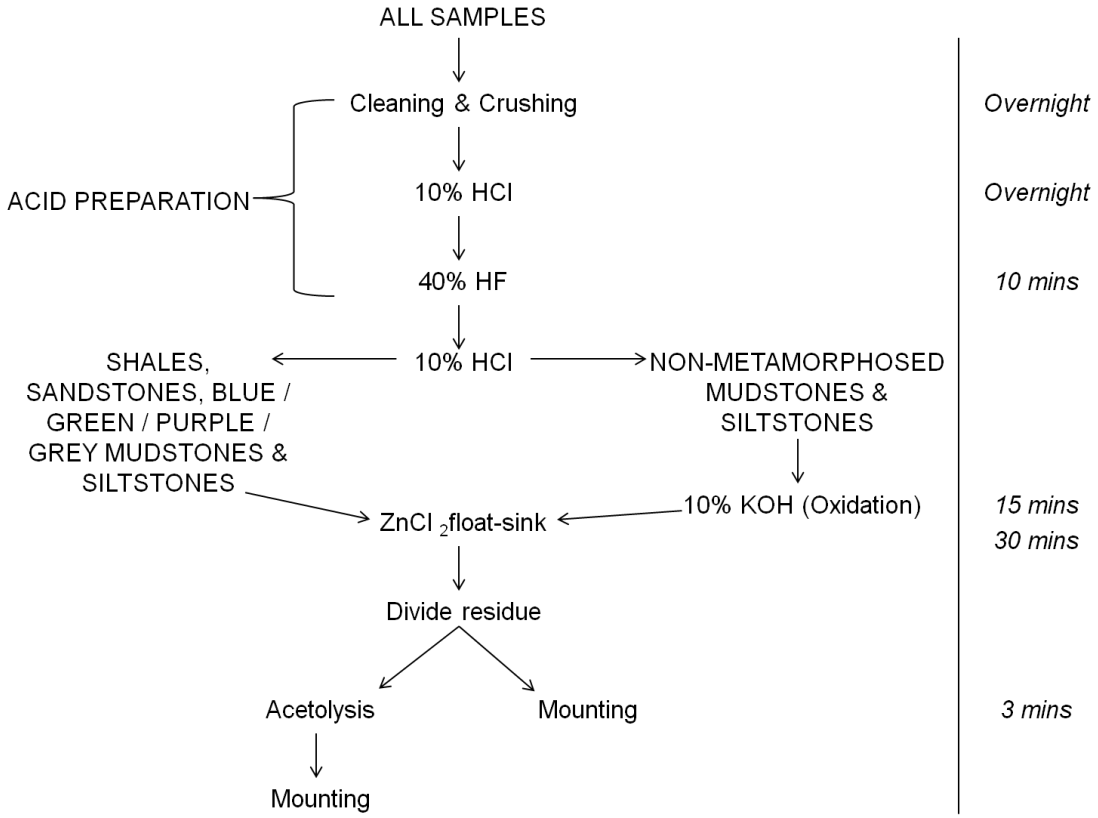


Figure 2.3: Flowchart of methods for preparing Karoo palynomorphs.

Through experimentation it was determined that productive slides were obtained only from samples derived from the western and southern regions of the basin if they were not subjected to oxidation treatment (Figure 2.3). Lithologies from these areas included shales, sandstones, and blue, green, purple or grey mudstones and siltstones. Palynomorphs are very sensitive to oxidation and high alkalinity (Traverse, 2007) and although these samples contained much organic matter, it was mostly degraded to various degrees and already delicate. Oxidation treatment either destroyed palynomorphs completely or damaged them to the point of being completely unidentifiable. Unfortunately this made examination of these slides

more difficult and time-consuming because of the large amounts of AOM (amorphous organic matter) present that partially obscured miospores. Samples from the Free State and KwaZulu-Natal areas were prepared using standard oxidation treatment (Figure 2.3).

After heavy mineral separation, each residue was divided and one part subjected to acetolysis. The other part was left as is. In some cases, acetolysis appeared to clear the slide of debris, concentrating the miospore fraction and dramatically enhancing slide quality, and in other cases miospores were completely removed from the preparation. No causal relationship to lithology was observed in this regard and thus each residue was divided into two parts as part of standard procedure so that both acetolysed and non- acetolysed slides could be compared. Further slides were then prepared from the most productive residue.

Standard laboratory procedures against contamination were followed with all equipment being thoroughly scrubbed with boiling water and liquid soap before and after each use, and left to stand in 40% nitric acid for approximately 1 hour. Equipment was rinsed with distilled water and stored in a dust-proof cupboard.

2.2.2 SLIDE PREPARATION

Residues were pipetted onto on 25 x 76 mm glass slides (thickness of 1 mm) with a dab of glycerin jelly, sealed with 22 x 50 mm glass coverslips and dried on a warming plate. Collected samples allowed a total of 500 slides to be made and examined for palynomorphs. Permanent mounts were made so that slides would last for future reference and sealed with nail polish to prevent drying out of the jelly.

2.2.3 MICROSCOPE ANALYSIS

Prepared slides were examined with an Olympus BX51 light microscope. Visual counts of each slide were made under 400x magnification. Counts of approximately 200 grains per sample are considered to be satisfactory for fossil preparations and prove statistically reliable (Traverse, 2007). Very rare taxa are the exception and would require counts of several thousand in order to achieve statistically acceptable standard deviations, which is not feasible under any circumstances (Traverse, 2007). Accordingly standard practice was followed in this study: where abundant miospores were present on a slide, 250 - 300 grains were counted. Some slides contained relatively few miospores and in such cases, further slides from the same residue were counted until a total of not less than 150 grains was reached. The number of slides made from each sample varied according to the amount of sample material collected and the necessity of requiring additional slides in order to reach a satisfactory total count. Samples containing fewer than 150 grains were not included in the final counts. Multiple studies have shown that if less than 150 grains are counted per spectrum, the variations of the pollen curves generally represent statistical uncertainties rather than true ecological variances (Faegri & Iversen, 1989). Slides were re-scanned for rare elements after counting was complete.

Photographs were taken under 1000x magnification (oil immersion) to show fine detail. A ColorView Soft Imaging System and Analysis™ software were used for digital photography and images were stacked using CombineZP™ software. Palynomorphs were identified and described on the basis of shape, ornamentation, laesura type, colpi or sacci, and by comparison with the literature. In general, even although palynomorphs were often abundant in a sample, they tended to be poorly preserved and therefore it was often difficult to locate a perfectly preserved specimen displaying all diagnostic characters of that species for photographic purposes. In such cases, taxonomic assignments could be made when many grains recognised as being of the same type were found on one slide, each displaying one or more (but not all) diagnostic characters of a species. Identifications were done

"blindly" without first checking information on the age and stratigraphic occurrences of the various types. Once a preliminary identification had been made, the known age range of that particular species was checked against the stratigraphic occurrences of the palynomorphs in order to confirm identifications. Taxonomic assignments were done using both the photographs and by eye through the microscope while examining various grains of the same type. All spores and pollen grains were measured and orientated following Traverse (2007) and are presented in plates in Appendix A.

2.2.4 CLASSIFICATION OF PALYNOMORPHS

It is a continuing problem in palynology that no single classification system has been accepted and is under the protection of the International Code of Botanical Nomenclature (Greuter *et al*., 2000) (or any other code). Accordingly, the various turmal categories are completely informal and used on sole discretion of the author (Traverse, 2007). The system most widely used by Western palynologists is that of Potonié (1956, 1958, 1960, 1966, 1970): the turmal classification of anteturmas Sporites and Pollenites, with further subdivisions under these two main units. Palynomorphs are classified solely on morphological characteristics with little knowledge of the parent plants that produced them and it is unlikely that most miospore morphotypes reflect real-world species (Traverse, 2007).

Other systems for classifying Palaeozoic and Mesozoic miospores are variations of Potonié's original classification. For example, Hart (1965) incorporated certain modifications for species that are typically Permian in occurrence. MacRae (1978, 1988) and Aitken (1993, 1994, 1998) adopted the original system of Potonié with modifications by Hart, and this is generally retained here. Tables for the anteturmas Sporites (Table 2.1) and Pollenites (Table 2.2) illustrate the specific turmal classifications applied to the Karoo palynomorphs of this study. As "the various turmal categories are completely informal and do not enjoy the protection of the International Code of Botanical Nomenclature (Greuter *et al*., 2000), or any

other code...The individual units in the system are not subject to rules of priority, and one should not use author citations and dates for the units...which imply that they are validly published names subject to priority" (Traverse, 2007, p. 233).

For the purposes of this work, the term “spore” refers to embryophyte microspores made of sporopollenin, while “pollen” is also made of sporopollenin but has the functional difference of containing the microgametophyte of a seed plant within the microspore wall. Fungal spores, algal spores and acritarchs are all presented together under the Turma Aletes-Inaperturates and possible natural affiliations mentioned in their descriptions in Appendix A. The reasons for the presentation of the Karoo palynomorphs in this manner are manyfold. This work is primarily focused on a stratigraphic analysis of the pollen taxa contained within the established vertebrate biozones of the Main Karoo Basin, and correlation of the palynomorphs to Karoo macroplant records was beyond the scope of this work. Much additional research would be necessary to satisfactorily address the taxonomy and palaeoenvironmental distribution of fungal spores, algae and acritarchs in the Karoo Basin.

The classification of fossil palynomorphs is obviously on morphological characteristics alone, and the resultant artificial morphotaxa do not necessarily represent natural groupings. In addition, as turmal units are not formally approved by the International Code of Botanical Nomenclature (Greuter *et al*., 2000) there is no standard palynological format for specific turmas to be used and hence the system employed herein was intended to present the various types of palynomorphs recovered without an in-depth investigation into their botanical and ecological nature. It was feared that a superficial review of these aspects could result in incorrect assumptions regarding the palaeoenvironment and stratigraphy of the Karoo Basin, as has occurred in the past (see page 28 for discussion on Stapleton, 1978).

There is still strong debate in the literature over the natural affinities of taxa such as *Reduviasporonites* (see page 26 for full review) and while it is likely that the

Karoo Basin has much information to contribute to this debate, a good deal of further research would be necessary before any definite conclusions could be made. For the above reasons it was decided that a thorough investigation of the botanical and palaeoecological aspects of the Karoo palynomorphs recovered in this study would be conducted at a later stage.

Due to the repetitive nature of type descriptions, systematic palynology as well as micrographs of all palynomorphs and their stratigraphic occurrence are given in full in Appendix A rather than forming part of Chapter 3 (Results and Discussion) which deals primarily with the use of Karoo palynomorphs for biostratigraphic purposes and their correlations to other Gondwanan localities.

Table 2.1: Turmal classification applied to the embryophyte spores, fungal spores and algal remains from Karoo rocks. Table format is derived from Traverse (2007).

Anteturma	**SPORITES**							***Diagnostic feature***
Turma	**TRILETES**			**MONOLETES**		**ALETES - INAPERTURATES**		*Aperture*
Supra-subturma	ACAVATI TRILETES		LAMINATI TRILETI	ACAVATO MONOLETES	PERINO MONOLETES	ACAVATALETES		*Stratification*
Subturma	AZONOTRILETES	AURICULATI	ZONOLAMINATITRILETES	AZONOMONOLETES		AZONALETES	ZONALETES	*Equatorial features*
Infraturma	**Laevigati Apiculati Murornati**	**Laevigati Murornati**	**Cingulicavati Murornati**	**Laevigatomonoleti Apiculatimonoleti**		**Laevigati Apiculati Murornati**	**Laevigati**	*Sculpture*

Table 2.2: Turmal classification applied to the pollen taxa from Karoo rocks. Table format is derived from Traverse (2007).

POLLENITES							**Anteturma**
PRAEPOLLENITES	**SACCITES**		**PLICATES**				**Turma**
CIRCUMPOLLES	MONO SACCITES	DISACCITES	COSTATES	PRAECOLPATES	MONOSULCATES	POLY PLICATES	**Subturma**
Singulipollenites	**Triletesacciti Aletesacciti**	**Disacciatrileti Striatiti**	**Costati**				**Infraturma**

3. RESULTS AND DISCUSSION

This chapter deals primarily with the biostratigraphic significance of the microflora recovered from Karoo rocks in the course of this study, and addresses their correlations to Gondwanan palynological assemblages. For clarity and to avoid repetition, the Results and Discussion chapters have been combined, while the systematic descriptions of all palynomorphs are given separately in Appendix A. In this chapter, palynological productivity of the Karoo Supergroup is discussed, microfloral trends of different turmal groups are explored, and palynomorphs with restricted ranges are identified. These restricted-range palynomorphs are key to defining associations of taxa which could subsequently be correlated with the vertebrate biozones of the Karoo Supergroup. The stratigraphic value of the palynomorphs recovered and the degree to which they can assist in understanding Karoo basin development is evaluated. Changes in palynofloras are related to known extinction events in the Palaeozoic and Mesozoic eras. The extent to which palaeoenvironments can be reconstructed by means of palynology, as well as the natural affinities of palynomorphs are examined, and finally Karoo palynofloras are correlated to established microfloral zones from different countries of Gondwana.

3.1 SAMPLE PRODUCTIVITY

Rock samples from the Dwyka, Ecca, Beaufort and Stormberg Groups of the western (W), southern (E) and north-eastern (KZN) regions of the basin all yielded sufficient numbers of identifiable palynomorphs to provide a good statistical sample, albeit in varying states of preservation (Figure 3.1). Although some probable new species were recognised during microscopy, there were not sufficient specimens of well-preserved material in order to formally designate any new species at this stage. Where appropriate, types that could not be precisely identified to species level have been compared to existing species from other parts of Pangaea. Further research may reveal these to in fact be new species. GPS

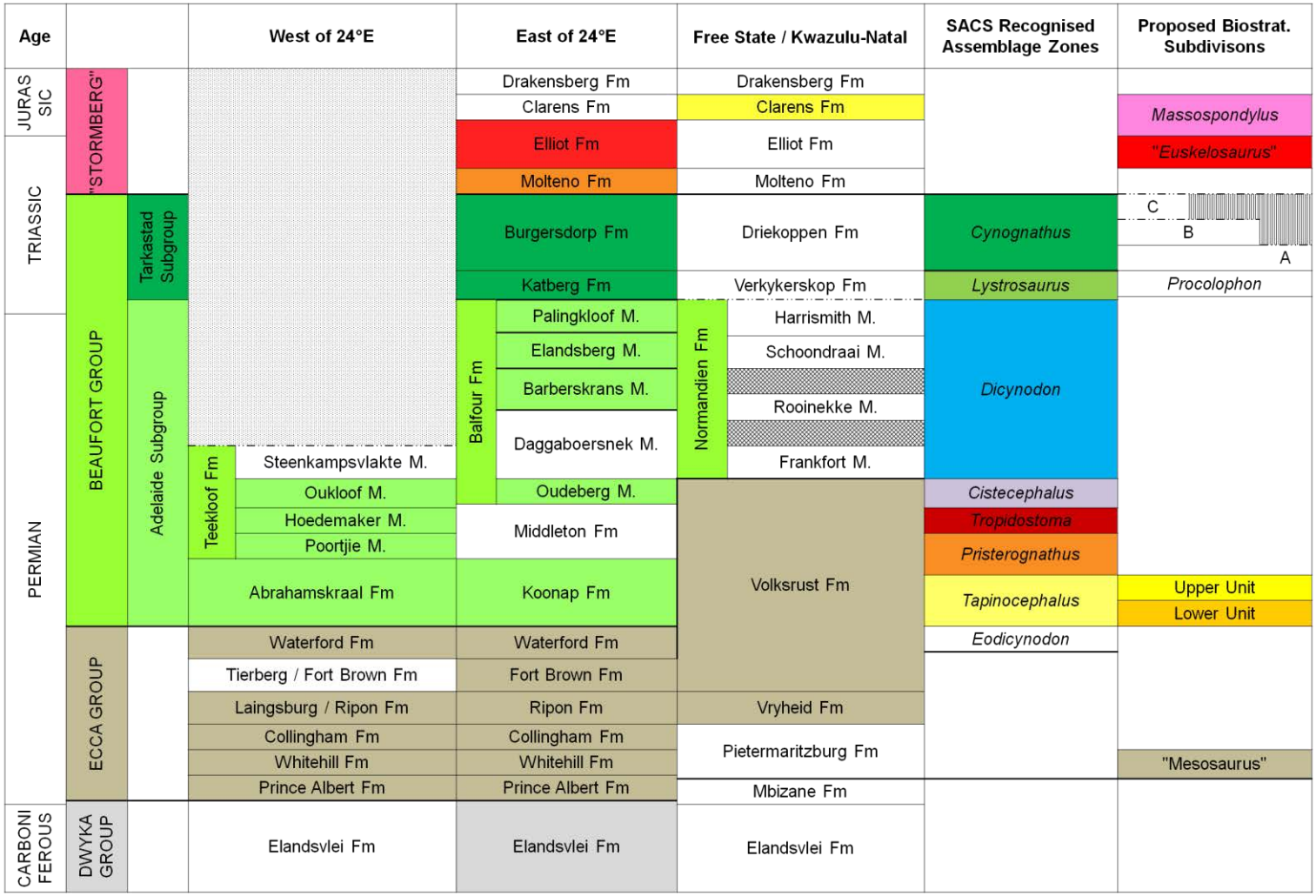


Figure 3.1: Current bio- and litho-stratigraphic subdivision of the Karoo Supergroup with palynologically productive members, formations and vertebrate biozones highlighted in colour (modified from Rubidge, 2005).

coordinates and locality as well as the stratigraphic provenance of each sample are detailed in Table 3.1.

Of significance is the fact that samples from every formally recognised vertebrate biozone of the Beaufort Group, except for the *Eodicynodon* Assemblage Zone, were palynologically productive (Figure 3.1). In total, 65 productive samples ranging from the Carboniferous to Jurassic of the Karoo Supergroup were obtained from a total of 275 samples collected (Figure 3.2). This reflects a productivity ratio of 24% which is significantly lower than in mainstream palynomorph studies of peats, coals and carbonaceous mudstones and siltstones. Many of the samples processed were "dirty" sandstones containing some silt or metamorphosed rocks in which organic matter was degraded, so this lower productivity ratio is to be expected.

With the exception of taxa from the northern Ecca Group, the preservation of palynomorphs in the Karoo Supergroup is generally poor. This is consistent with the metamorphism created by the development of the Karoo retroarc foreland basin in front of the Cape Fold Belt (Catuneanu *et al*., 1998). Most palynomorph micrographs in books and publications are of "super specimens", but in practice palynomorphs are not nearly as well preserved and may be torn, compressed, crumpled, folded, corroded or carbonised (Traverse, 2007). Although some of the Karoo types were represented by many specimens, all of the grains had undergone damage in one or more of these respects, and in such cases only tentative identifications could be made (indicated by Cf. preceding the genus name). In order not to weaken the palynostratigraphic conclusions of the project, these types were not included in the pollen zonations or used for correlations of different stratigraphic units. Further palynological work on Karoo rocks may shed light on how to regard such specimens, as it is felt they can still be stratigraphically informative. However for the present work, they are included for taxonomic records only.

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Table 3.1: Locality list of palynologically productive rock samples obtained from the Main Karoo Basin along with their GPS co-ordinates, biozone and sample type.

Basin Area / Stratigraphic Unit / Sample No.	GPS Co-ordinates	Biozone	Type of sample	Locality
KZN.Clarens Fm 1	S29°01.334' E029°23.740'	*Massospondylus* AZ	Rockfall	Champagne Valley Landslide, carbonaceous black shale
KZN.Clarens Fm 2	S29°01.334' E029°23.740'	*Massospondylus* AZ	Rockfall	Champagne Valley Landslide, carbonaceous black shale
KZN.Clarens Fm 3	S29°01.334' E029°23.740'	*Massospondylus* AZ	Rockfall	Champagne Valley Landslide, carbonaceous black shale
KZN.Clarens Fm 4	S29°01.334' E029°23.740'	*Massospondylus* AZ	Rockfall	Champagne Valley Landslide, carbonaceous black shale
KZN.Clarens Fm 5	S29°01.334' E029°23.740'	*Massospondylus* AZ	Rockfall	Champagne Valley Landslide, carbonaceous black shale
KZN.Clarens Fm 6	S28°26.356' E028°23.854'	*Massospondylus* AZ	Road cutting	R712 by road at Clarens
E.Upper Elliot Fm 7	S30°48.036' E027°14.443'	*Massospondylus* AZ	Road cutting	Road just after Lady Grey
E.Lower Elliot Fm 8	S30°44.725' E027°10.775'	*Euskelosaurus* AZ	Road cutting	Road just after Lady Grey
E.Molteno Fm 9	S28°26.359' E028°23.858'	n/a	Road cutting	Ash River Outfall, Clarens
E.Burgersdorp Fm 10	S30°29.351' E026°34.375'	*Cynognathus B* AZ	Outcrop	Farm Slootkraal -Bethel, red and blue mudstones
E.Burgersdorp Fm 11	S30°29.337' E026°34.311'	*Cynognathus B* AZ	Outcrop	Farm Slootkraal -Bethel, red and blue mudstones
E.Katberg Fm 12	S31°24.097' E025°45.236'	Upper *Lystrosaurus* AZ	Road cutting	Farm Middelwater, N10 to Steynsburg
E.Katberg Fm 13	S32°20.701' E026°54.315'	*Lystrosaurus* AZ	Road cutting	R67 Whittlesea, Fort Beaufort District
E.Palingkloof M. 14	S30°44.384' E025°39.494'	*Dicynodon* - *Lystrosaurus* AZ Contact	Road cutting	Road from Steynsburg to Venterstad, R390

E.Elandsberg / Palingkloof Contact 15	S30°24.416' E026°14.261'	*Dicynodon* AZ	Outcrop	Farm Fairydale, Permo-Triassic boundary
E.Elandsberg M. 16	S32°30.846' E026°48.139'	*Dicynodon* AZ	Road cutting	R67 past Fort Beaufort
E.Barberskrans M. 17	S32°12.795' E025°40.880'	*Dicynodon* AZ	Road cutting	PE / Cradock Rd N10
KZN.Normandien Fm 18	S29°09.835' E029°58.994'	*Dicynodon* AZ	Road cutting	Towards Pietermaritzburg
KZN.Normandien Fm 19	S29°07.594' E029°57.073'	*Dicynodon* AZ	Road cutting	Estcourt
KZN.Normandien Fm 20	S29°03.806' E029°54.712'	*Dicynodon* AZ	Road cutting	N3 to Harrismith
KZN.Normandien Fm 21	S29°48.383' E029°46.083'	*Dicynodon* AZ	Plant fossil locality	Bulwer (above Frankfort M.), black mudstone with *Glossopteris*
KZN.Normandien Fm 22	S29°48.383' E029°46.083'	*Dicynodon* AZ	Plant fossil locality	Bulwer (above Frankfort M.), black mudstone with *Glossopteris*
KZN.Normandien Fm 23	S29°26.450' E030°05.984'	*Dicynodon* AZ	Plant fossil locality	Lidgetton - *Glossopteris* locality
KZN.Normandien Fm 24	S29°26.450' E030°05.984'	*Dicynodon* AZ	Plant fossil locality	Sheba's Breasts (Estcourt)
E.Oudeberg M. 25	S32°35.125' E025°53.162'	*Cistecephalus* AZ	Road cutting	PE / Cradock Rd N10, associated plants in mudstone
W.Oukloof M. 26	S32°10.457' E021°37.836'	Middle *Cistecephalus* AZ	Road cutting	Farm Vogelfontein, Theekloof Pass R353
W.Oukloof M. 27	S32°11.001' E021°37.567'	*Cistecephalus* - *Tropidostoma* AZ Contact	Road cutting	Farm Vogelfontein, Theekloof Pass R353
W.Upper Hoedemaker M. 28	S32°11.701' E021°37.412'	*Tropidostoma* AZ	Road cutting	Farm Willowdene, Theekloof Pass R353
W.Middle Hoedemaker M. 29	S32°12.198' E021°36.984'	*Tropidostoma* AZ	Road cutting	Farm Willowdene, Theekloof Pass R353
W.Upper Poortjie M. 30	S32°13.453' E021°37.522'	*Pristerognathus* AZ	Road cutting	Farm Hoedemaker, Theekloof Pass R353
W.Poortjie M. 31	S32°58.141' E021°59.153'	*Pristerognathus* AZ	Outcrop	Farm Bloukrantz, *Diictodon* Level
W.Middle to Lower Poortjie M. 32	S32°22.960' E021°42.494'	*Pristerognathus* AZ	Road cutting	Farm Michau's Request, Theekloof Pass R353
W.Uppermost Abrahamskraal Fm 33	S32°27.187' E021°43.454'	*Pristerognathus* AZ	Road cutting	Road to Fraserburg-Merweville

E.Koonap Fm 34	S32°57.102' E024°23.909'	*Pristerognathus* AZ	Outcrop	Uintjiesvlakte (Rietfontein, Klipplaat), dark blue siltstone with equisetalean stems
E.Koonap Fm 35	S32°57.102' E024°23.909'	*Pristerognathus* AZ	Outcrop	Uintjiesvlakte (Rietfontein, Klipplaat), green siltstone with *Glossopteris* leaves
E.Koonap Fm 36	S30°35.424' E025°30.298'	*Pristerognathus* AZ	Outcrop	Grampian Hill, Gariep Dam, purple mudstone
E.Koonap Fm 37	S33°04.936' E026°23.521'	Upper *Tapinocephalus* AZ (on the presence of *Eunotosaurus* - Hancox & Rubidge 2002, Rubidge 2005, Rubidge *et al.* 1999)	Outcrop	Peninsular, mudrock 750 m above Ecca-Beaufort Contact (*Eunotosaurus* locality)
W.Abrahamskraal Fm 38	S32°57.784' E021°59.168'	*Tapinocephalus* AZ	Road cutting	Combrikskraal, Road to Leeu-Gamka, first purple mudstone
W.Abrahamskraal Fm 39	S32°24.580' E020°19.373'	*Tapinocephalus* AZ	Road cutting	Ouberg Pass
W.Abrahamskraal Fm - Mudstone D 40	S32°56.998' E021°39.681'	*Tapinocephalus* AZ	Road cutting	Merweville Road
W.Abrahamskraal Fm - Mudstone B 41	S32°55.120' E021°37.727'	*Tapinocephalus* AZ	Road cutting	Farm Melkbosfontein
KZN.Volksrust Fm 42	S27°13.964' E028°51.125'	n/a	Plant fossil locality	New Cornelia
KZN.Volksrust Fm 43	S28°44.173' E031°48.735'	n/a	Plant fossil locality	NW of Empangeni
E.Waterford Fm 44	S33°06.302' E026°36.729'	n/a	Road cutting	Grahamstown - Fort Beaufort Rd R67, Ecca Pass
E.Waterford Fm - Facies B 45	S33°06.131' E026°24.752'	n/a	Outcrop	Farm Conniston
E.Waterford Fm - Facies A 46	S33°06.164' E026°24.749'	n/a	Outcrop	Farm Conniston
W.Lower Waterford Fm 47	S33°01.639' E022°00.066'	n/a	Outcrop	Farm Combrikskraal
W.Base of the Waterford Fm 48	S32°24.361' E020°18.323'	n/a	Road cutting	Ouberg Pass
E.Uppermost Fort Brown Fm 49	S33°06.275' E026°24.879'	n/a	Road cutting	Conniston, R344 Grahamstown-Adelaide
E.Fort Brown Fm 50	S33°07.801' E026°25.331'	n/a	Road cutting	Farm Lindsey

E.Fort Brown Fm 51	S33°07.079' E026°23.508'	n/a	Road cutting	Grahamstown / Fort Beaufort Rd
E.Fort Brown Fm 52	S33°04.849' E025°50.948'	n/a	Road cutting	PE / Cradock Rd N10
KZN.Vryheid Fm 53	S25°51.880' E029°13.058'	n/a	Plant fossil locality	Greenside Colliery - No. 5 Seam
KZN.Vryheid Fm 54	S25°40.813' E030°02.120'	n/a	Plant fossil locality	Belfast / eMakhazeni
E.Upper Ripon Fm 55	S33°11.718' E026°37.031'	n/a	Road cutting	Grahamstown - Fort Beaufort Rd R67
E.Middle Ripon Fm 56	S33°12.288' E026°37.342'	n/a	Road cutting	Grahamstown - Fort Beaufort Rd R67, Ecca Pass
W.Ripon Fm 57	S33°07.125' E021°56.042'	n/a	Road cutting	Prince Albert Rd, Farm Virginia, fine-grained mudstone, proximal turbidite
E.Collingham Fm 58	S33°12.935' E026°37.574'	n/a	Road cutting	Grahamstown - Fort Beaufort Rd R67, Ecca Pass
W.Collingham Fm 59	S33°08.064' E021°56.764'	n/a	Outcrop	Farm Swartebult, Whitehill Fm outcropping nearby
E.Whitehill Fm 60	S29°36.729' E024°20.342'	*Mesosaurus* AZ	Outcrop	Farm Ramah (Roux)
E.Whitehill Fm 61	S29°32.875' E024°20.186'	*Mesosaurus* AZ	Road cutting	Road to Luckoff, Whitehill Fm quarry
W.Whitehill Fm 62	S33°07.446' E022°02.541'	*Mesosaurus* AZ	Outcrop	Farm De Kalk, above is Matjiesfontein Chert
E.Prince Albert Fm 63	S29°32.896' E024°19.270'	*Mesosaurus* AZ	Road cutting	Road to Orania just after road to Luckoff
W.Prince Albert Fm 64	S33°12.708' E022°01.954'	*Mesosaurus* AZ	Outcrop	Prince Albert
E.Elandsvlei Fm 65	S28°35.963' E024°36.736'	n/a	Outcrop	Farm Nooitgedacht, shaly units

3.2 MICROFLORAL COMPOSITION

Microfloral trends are illustrated in a Tilia™ pollen diagram (Figure 3.3). The microflora from these rocks includes trilete, alete and monolete spores, and monosulcate, polyplicate, monosaccate and bisaccate pollen. Palynomorph taxonomic diversity is high, with 116 genera and 190 species present (Figure 3.3). Systematic palynology, micrographs and stratigraphic occurrences of all palynomorphs are given in Appendix A.

On the left of Figure 3.3, all of the taxa are arranged in alphabetic order, and on the far right these taxa are all illustrated as part of their turmal group, where the abundance of alete, trilete, monolete and zonotrilete spores, and monosaccate, bisaccate, monosulcate and polyplicate pollen is shown. Alete spores (cross-hatch pattern) are superimposed above trilete spores (solid black) in order to better illustrate their inverse relationship. A shortened version of the total pollen diagram is presented as Figure 3.4 in order to make easier comparisons between stratigraphic units and turmal groups.

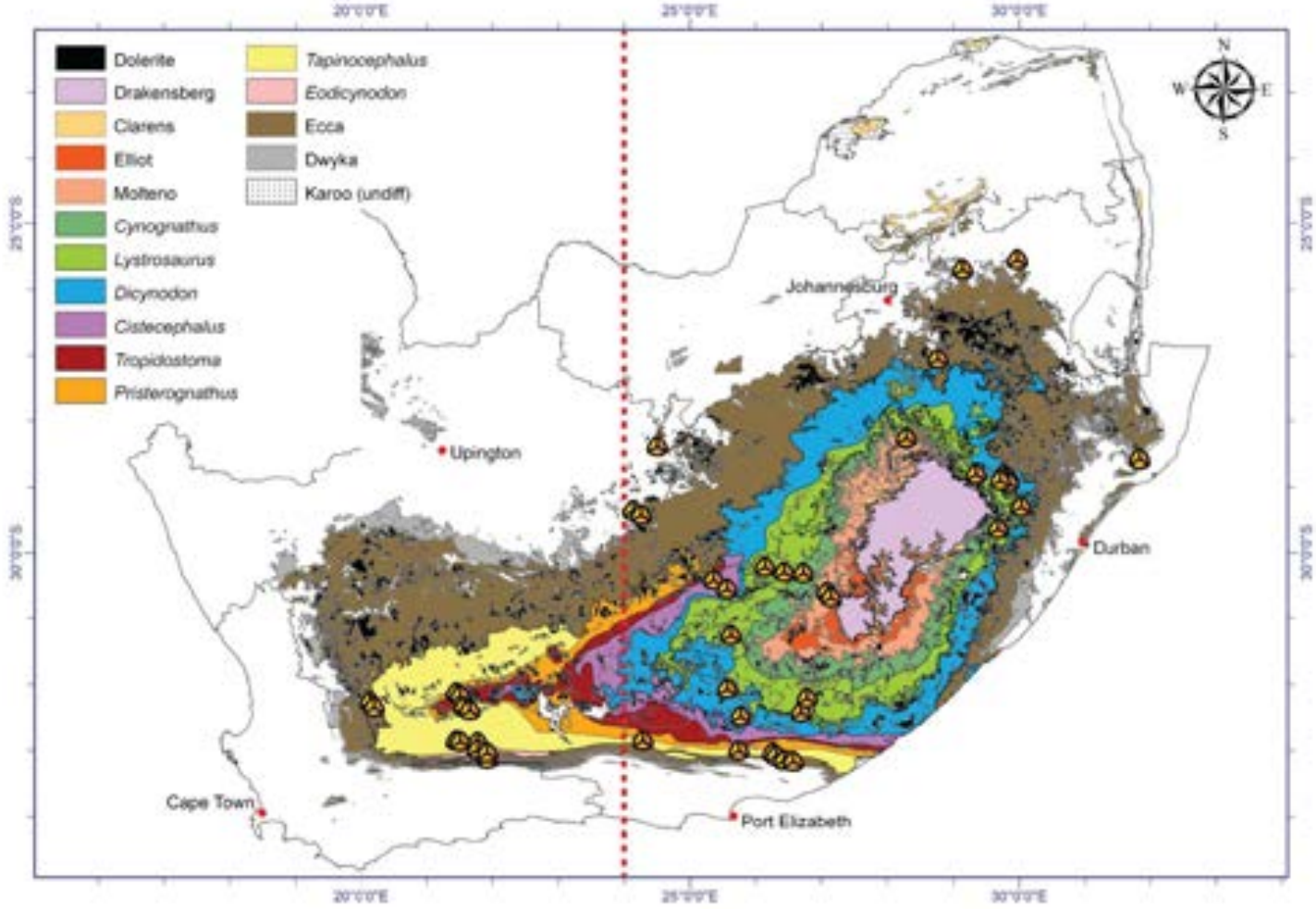


Figure 3.2: Locations of 65 palynologically productive rock samples obtained from the Main Karoo Basin. The dashed line indicates 24° E.

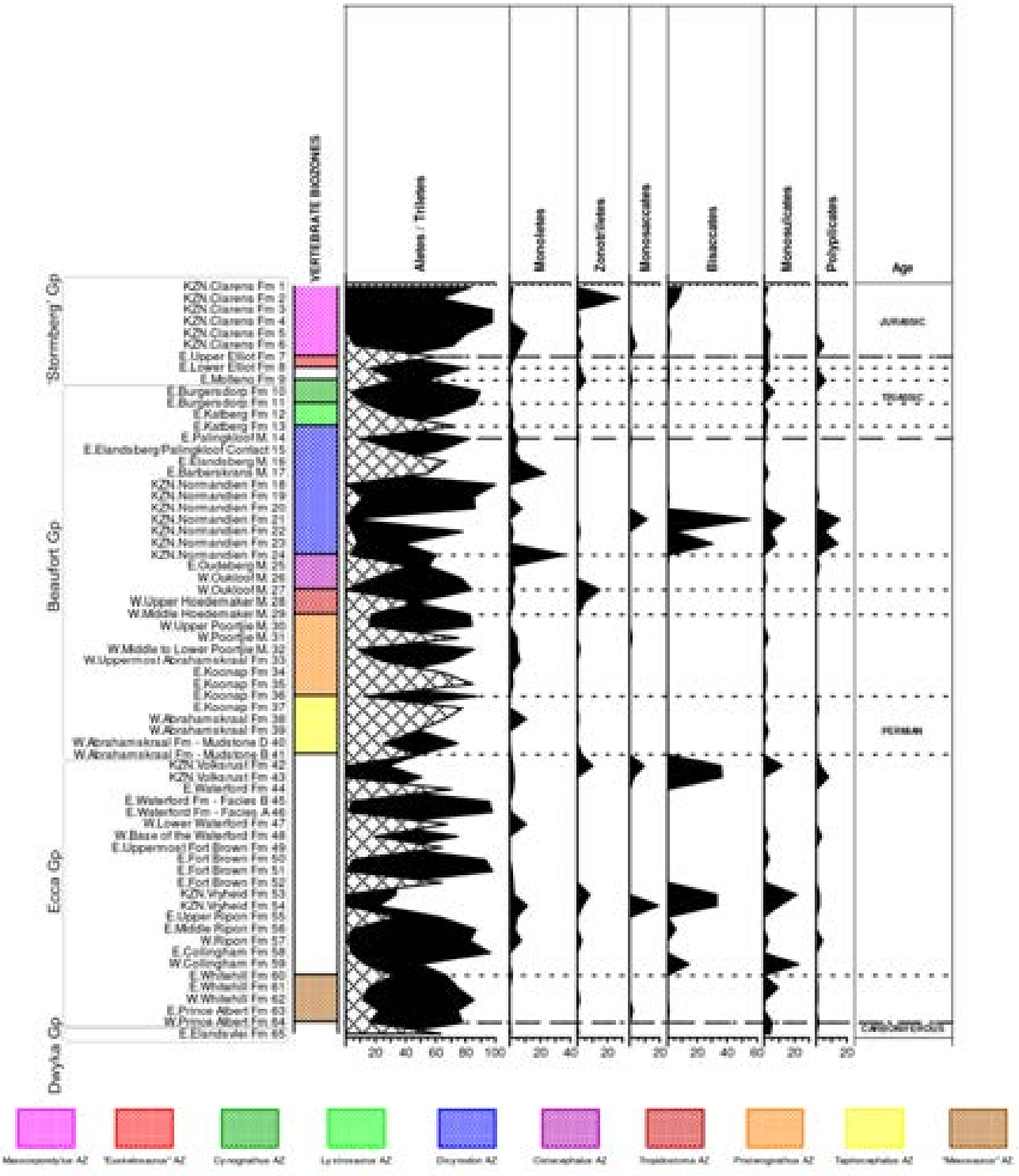


Figure 3.4: **Condensed Tilia™ pollen diagram of all taxa displayed as part of their turmal group, demonstrating relationships between turmal groups and litho- and biostratigraphic units of the Karoo Supergroup. Triletes are illustrated in solid black and overlain by aletes in a cross-hatch pattern.**

3.2.1 TRILETE AND ALETE SPORE TRENDS

Triletes are the most abundant group throughout the Karoo stratigraphic succession, quantitatively dominating most stratigraphic horizons (Figure 3.4). Aletes are the second most abundant group, and dominate the remainder of the samples (E.Elandsvlei Fm 65, E.Collingham Fm 58, E.Fort Brown Fm 52, E.Uppermost Fort Brown Fm 49, W.Lower Waterford Fm 47, E.Waterford Fm 44, W.Abrahamskraal Fm 38, E.Koonap Fm 37, E.Koonap Fm 35, E.Koonap Fm 34, E.Barberskrans M. 17, E.Elandsberg M. 16, E.Katberg Fm 13, E.Upper Elliot Fm 7). Triletes have an inverse relationship with aletes as far as abundance is concerned and in every horizon in which triletes decrease, aletes show a corresponding increase and vice versa (Figure 3.4), except for the following samples:

- **KZN.Clarens Fm 2**: no aletes present, triletes dominant, significant component of zonotriletes
- **KZN.Normandien Fm 21**: no aletes present, triletes only a minor component, significant component of monosaccate, bisaccate, polyplicate and monosulcate pollen
- **KZN.Normandien Fm 23**: small proportion of aletes, triletes present but do not dominate, significant component of non-taeniate bisaccate, monosulcate and polyplicate pollen
- **KZN.Volksrust Fm 42**: no aletes present, triletes drop dramatically, significant component of zonotrilete spores and bisaccate, monosulcate and monosaccate pollen
- **KZN.Volksrust Fm 43**: triletes and aletes both drop severely, significant component of bisaccate and polyplicate pollen
- **KZN.Vryheid Fm 53**: no aletes present, triletes drop dramatically, significant component of monosulcate and bisaccate pollen
- **KZN.Vryheid Fm 54**: no aletes present, triletes only a minor component, significant component of monolete spores and monosaccate, bisaccate and polyplicate pollen

An examination of microfloral trends over period boundaries reveals that triletes increase as aletes decrease over the Carboniferous - Permian and Permo - Triassic boundaries, while the reverse is true for the Triassic - Jurassic boundary (Figure 3.4). There are multiple possibilities to explain the alternating dominance of trilete and alete spores that can be observed throughout the Karoo Supergroup: it may be facies-controlled, a reflection of regional environmental changes through time, a reflection of only the very localised immediate environment in which the palynomorphs were deposited, or as a result of selective post-depositional destruction of palynomorphs. Analysis of sample lithologies indicates that this relationship was not influenced by lithology, with both aletes and triletes dominating various siltstone, mudstone and "dirty" sandstone samples (Table 3.2, Figure 3.3).

Stapleton (1977) found an abundance of alete spores in some samples from the Lower Beaufort Group, which at the time were interpreted to indicate marine incursions, however it is now known that from the Middle Permian onwards Karoo deposition was completely terrestrial (Hancox, 2000). Fungi, bryophytes, pteridophytes and marine, brackish and freshwater algae can all produce alete spores (Balme, 1995; Traverse, 2007), although algal remains are often not preserved in the fossil record (Looy, pers. comm.). Therefore an abundance of alete spores can indicate either damp terrestrial environments, marine incursions, or "fungal spikes" (e.g. Steiner *et al*., 2003). In this study, dominance of alete spores in particular samples is not likely to be a reflection of the regional environment through time because the climate became progressively more arid during deposition of the Karoo Supergroup (Smith *et al*., 1993), yet alete spores are as abundant in the Upper Elliot Formation as in the Waterford Formation (Table 3.2, Figure 3.3). Furthermore, the botanical affinities of trilete spores include lycopsids, sphenopsids and pteridophytes, which are also water-dependant plants (Traverse, 2007). If the abundance of trilete and alete spores was indeed a reflection of regional environmental changes, both groups should exhibit a progressive decrease in accordance with the drying climate, but this is not the case.

Table 3.2: Palynological samples dominated by alete spores in the Karoo Supergroup and their depositional environments.

Sample	Lithology	Depositional environment	Reference
E.Upper Elliot Fm 7	mudstone	fluvio-lacustrine deposits	Smith *et al*., 1993
E.Katberg Fm 13	sandstone	distal braided alluvial fan	Smith *et al*., 1993
E.Elandsberg M. 16	siltstone	fluvial deposition	SACS, 1980
E.Barberskrans M. 17	sandstone	fluvial deposition	Catuneanu *et al*., 2005
E.Koonap Fm 34	dark blue siltstone	shallow lacustrine facies at the base, delta distributary and meandering river channels, crevasse splays, mud-dominated floodplain	Catuneanu *et al*., 2005
E.Koonap Fm 35	green siltstone	shallow lacustrine facies at the base, delta distributary and meandering river channels, crevasse splays, mud-dominated floodplain	Catuneanu *et al*., 2005
E.Koonap Fm 37	mudstone	shallow lacustrine facies at the base, delta distributary and meandering river channels, crevasse splays, mud-dominated floodplain	Catuneanu *et al*., 2005
W.Abrahamskraal Fm 38	purple mudstone	fluvial meandering rivers, lower to upper delta plain sedimentation	Smith *et al*., 1993
E.Waterford Fm 44	mudstone	delta-front and delta-plain	Smith *et al*., 1993
W.Lower Waterford Fm 47	mudstone	delta-front and delta-plain	Smith *et al*., 1993
E.Uppermost Fort Brown Fm 49	mudstone	shallow water prodelta	Smith *et al*., 1993
E.Fort Brown Fm 52	mudstone	shallow water prodelta	Smith *et al*., 1993
E.Collingham Fm 58	mudstone	deep water distal turbidite environment	Kingsley, 1977
E.Elandsvlei Fm 65	shale	submerged platform, marine ice	Visser *et al*., 1990

It is possible that the alternating phases of trilete / alete dominance are reflecting seasonal changes in the localised immediate environment but there is currently no evidence to support or refute this hypothesis. A far more in-depth investigation combining palaeosol studies and taphonomic data with palynological information would be necessary to investigate this premise further.

The last possible explanation for the inverse relationship between trilete and alete spore abundance in the Karoo stratigraphic succession is that microfloras were subjected to selective destruction after deposition. This may have occurred through tectonic or biological means. Metamorphosed palynomorphs are no longer identifiable, and so in samples with carbonised trilete spores, the lighter-coloured and recognisable fungal alete spores / acritarchs would appear to dominate the sample. Almost all of the alete-dominated samples originate from the southeastern region of the Karoo Basin, and two from the western region (Table 3.2). No samples from the KZN / Free State areas are dominated by alete spores, and the Vryheid, Volksrust, Normandien and Clarens Formations are the exceptions to the inverse relationship between alete and trilete spore abundance. The northern distal facies of the Karoo Basin, being removed from the Cape Fold Belt, is known to have experienced minimal metamorphism (Catuneanu *et al*., 1998) and it was already expected that better palynomorph preservation would be encountered in samples from the northern Karoo facies. Greater investigation into post-depositional alteration dynamics is undoubtedly necessary before a conclusive judgment can be made.

Palaeozoic microfungal remains are often associated with plant tissues and may have had saprophytic, mutualistic or parasitic life strategies (Taylor *et al*., 2009). An intriguing possibility to explain the dominance of alete spores in certain samples is that fungi can digest sporopollenin and have been shown to attack spores and pollen after they have been deposited in sediments (Elsik, 1966; Srivastava, 1976; Stubblefield & Taylor, 1984). The fungi would then release their own reproductive bodies and it is these spores that would be preserved at the expense of the original spores and pollen grains. This is an avenue which can be

further explored by investigating evidence of fungal relationships to land plants during the Palaeozoic and Mesozoic.

3.2.1.1 Possible Reworking of Trilete and Alete Spores

Reworking is a taphonomic dilemma that should always be considered when studying palynomorphs simply because they are so robust, but there is unfortunately no universal test to establish whether this has occurred (Traverse, 2007). Palynomorphs darken in colour as they are subjected to thermal metamorphism and so different coloured palynomorphs in the same sample may be an indication that they are not the same age. There is some evidence of reworking in the Main Karoo Basin (e.g. Smith & Kitching, 1997) and it is unlikely that the Karoo palynomorphs are completely free from reworking. The question is really to what extent reworking may have occurred and whether it took place frequently enough to undermine biostratigraphic correlation.

Anderson (1977) considered it possible that the acritarchs he recovered from the *Tapinocephalus* AZ were in fact reworked from the Middle Ecca (Anderson, 1977, p. 55). Horowitz (1990) reported that most of the taxa he identified from the *Tapinocephalus* AZ range down into the Ecca (Anderson, 1977) which could be consistent with reworking, but this was not seen in this study with the *Tapinocephalus* AZ preserving a unique microflora. However it was important to consider whether the alete spores dominating many of the Karoo samples could be reworked because they tend to be lighter than the pollen grains.

It is known that palynomorphs with the same thermal history can sometimes vary in colour, due to variations in wall thickness and composition of individual grains (Pross *et al*., 2007), and small temperature increases within a single sample (Yule *et al*., 1998). Specifically, spores and pollen exines (constructed of sporopollenin) are said to be more susceptible to thermal maturation than chitinous walled fungal spores and acritarchs, and will darken to black fastest (W. C. Elsik *in* Traverse,

2007). Fungal spores will retain their original colour for longer than botanical spores or pollen, and acritarchs (diverse bodies of unknown origin) are most resistant to geothermal maturation along with dinoflagellate cysts (Traverse, 2007). These predispositions mean that in a thermally matured sample containing botanical spores, pollen, fungal spores and acritarchs, the fungal spores and acritarchs may be a much lighter colour than botanical spores and pollen.

Normally older specimens tend to be reworked into younger sediments, and reworked specimens are likely to be more corroded than the "native" microflora (Traverse, 2007). The alete spores present in the Karoo Basin are not corroded, generally displaying good preservation. Horowitz (1990) also found that acritarchs in the Lower Beaufort Group of South Africa were much better preserved than spores and pollen from the same samples. The alete spores were generally found in conjunction with trilete spores and pollen appropriate to the age of the rocks from which they were derived. Therefore, the available evidence does not seem to support reworking on a large scale for the Karoo microfloras.

3.2.2 POLLEN, MONOLETE AND ZONOTRILETE SPORE TRENDS

Monoletes are very rare to non-existent in the Carboniferous and Early Permian samples of the Dwyka Group and Whitehill Formation respectively, but are present in small numbers stratigraphically upwards from the Ripon Formation to the Clarens Formation. Abundance of monoletes fluctuates in the different stratigraphic horizons, showing neither a progressive increase nor decrease from the Permian to the Jurassic (Figure 3.4).

Significant numbers of mono- and bisaccate pollen are represented in the Vryheid, Volksrust, Normandien and Clarens formations, while saccates are extremely rare or non-existent through the Carboniferous, Earliest Permian and Triassic (Figure 3.4).

Zonotrilete spores are present in small numbers in many samples but show increases in abundance in the Vryheid and Volksrust formations, Hoedemaker and Oukloof members, and Molteno and Clarens formations (Figure 3.4).

Monosulcates are consistently present in the Karoo stratigraphic succession but show the greatest increases in abundance in the Vryheid, Volksrust and Normandien formations. Minor increases in quantities of monosulcates are seen in the Elandsvlei, Whitehill, Collingham, Burgersdorp and Clarens formations (Figure 3.4).

Polyplicate pollen is present in small numbers from the Carboniferous to the Jurassic but shows significant increases in the Ripon, Volksrust, Normandien, Molteno and Clarens formations (Figure 3.4).

The greatest diversity of spore assemblages appear to derive from the Vryheid, Volksrust, Normandien and Clarens formations, all from the Free State / KwaZulu-Natal regions of the basin. This can be attributed to ideal sample lithologies from these formations - carbonaceous mudstones, siltstones or shale that were not subjected to post-depositional metamorphism. In contrast, the paucity of saccate pollen in the Triassic may reflect either dilution by the local signal, poor preservation, or absence of the conifers that produced such pollen. The dominant glossopterid flora, a foremost producer of striate bisaccate pollen, went extinct at the Permo-Triassic boundary but striate saccate pollen is also generally abundant in Early Triassic floras the world over (e.g. Traverse, 2007) and so the lack of these pollen taxa in the Triassic Karoo palynoflora is not likely to be attributable to this extinction event.

3.3 RESTRICTED RANGE TAXA

Biostratigraphic units may be based on a single fossil taxon, a combination of taxa, on relative abundance of different taxa, or on variations of any of the features related to the content or distribution of fossils (Murphy & Salvador, 1999). In this work, units have been established partly through the presence or absence of certain taxa, and partly through their quantitative relationship to each other, following Faegri & Iversen (1989). In the rocks of the Karoo Supergroup, particular trilete and alete spore taxa (*Apiculatisporis cornutus*, *Granulatisporites minor*, *Granulatisporites* sp., *Maculatasporites eraduensis*, *Punctatisporites* sp. A, *Verrucosisporites* sp. A) are present from the Carboniferous to the Jurassic (Figure 3.3) and do not contribute to stratigraphic refinement of the Karoo succession. Many other taxa also have long ranges and are not as helpful in defining biostratigraphic units for the Karoo. Short range taxa are listed in Table 3.3 and these are most useful for biostratigraphic purposes. Some of these types have ghost ranges and are referred to as Lazarus taxa (Benton & Harper, 2009). The ghost ranges could be as a result of poor preservation in certain rock layers, alternatively this phenomenon could be caused by the life history of plants, which require very small minimum population sizes relative to vertebrates and may therefore rebound from near-extinction and reappear later in the stratigraphic section (Traverse, 2007).

An additional Tilia™ pollen diagram was constructed using only restricted range taxa as listed in Table 3.3 (Figure 3.5). There are 68 genera and 93 species that have restricted ranges and all the major turmal groups (aletes, triletes, monoletes, zonotriletes, monosaccates, bisaccates, monosulcates, polyplicates) are represented (Figure 3.5). A condensed version of the restricted range pollen diagram is presented as Figure 3.6 in order to make easier comparisons between stratigraphic units and turmal groups (Figure 3.5 was constructed in the same manner as Figure 3.3, and Figure 3.6 in the same manner as Figure 3.4).

Triletes remain quantitatively dominant in most samples from throughout the Karoo stratigraphic succession (Figure 3.6), however the percentage of restricted range trilete taxa is now strongly decreased relative to the other turmal groups. The inverse relationship with regard to relative abundance of alete to trilete spores holds true with one group consistently increasing as the other decreases, except for the horizon W.Upper Hoedemaker M. 28 where triletes and aletes are equal in number. No restricted range trilete or alete taxa are present in the samples E.Whitehill Fm 61, E.Collingham Fm 58, E.Fort Brown Fm 50, E.Waterford Fm 44, W.Middle to Lower Poortjie M. 32, W.Oukloof M. 27, W.Oukloof M. 26, KZN.Normandien Fm 18, and E.Burgersdorp Fm 10.

Table 3.3: List of taxa with a restricted stratigraphic range found in rocks of the Karoo Supergroup and their known global occurrences. Taxa in black are restricted to one sample. Taxa in blue have a relatively long range and are useful only as general indicators. Taxa in red reflect either unexpected correlations between two or more formations, or alternatively represent Lazarus taxa. Taxa in green have a short range or indicate a valuable correlation between two or more formations.

TAXON	SAMPLE RANGE	PRESENT IN	PREVIOUSLY REPORTED FROM	REFERENCES
Apiculiretusispora sp.	53	KZN.Vryheid Fm 53	Pennsylvanian / Late Carboniferous - Early Permian of South America	Gutiérrez & Limarino (2001), Mori *et al*. (2012)
Appendicisporites sp.	22	KZN.Normandien Fm 22	Cretaceous of Australia, Egypt, Argentina	Archangelsky *et al*. (2012), Burger (1993), Ibrahim (1996)
Aratrisporites tenuispinosus	13	E.Katberg Fm 13	Early Triassic of Western Poland, Early to Middle Triassic of Australia	Dolby & Balme (1976), Orlowska-Zwolinska (1984)
Barakarites rotatus	54-42	KZN.Vryheid Fm 54, KZN.Volksrust Fm 42	Early Permian of South Africa, Permian of Australia, India, Late Carboniferous - Early Permian of Argentina, Late Permian of Antarctica	Aitken (1994), Cisterna *et al*. (2011), Foster *et al*. (1985), Lindström & McLoughlin (2007), Millsteed (1999)
Bennettiteaepollenites sp.	5	KZN.Clarens Fm 5	Middle Jurassic of Germany	Potonié (1958)
Brazilea scissa	37-17	E.Koonap Fm 37, E.Barberskrans M. 17	Latest Carboniferous / Earliest Permian of Argentina, Permian of Australia, Late Permian of Antarctica, Early Permian of South Africa	Anderson (1977), Cisterna *et al*. (2011), Falcon (1988, 1989), Lindström & McLoughlin (2007)
Brevitriletes bulliensis	24	KZN.Normandien Fm 24	Late Triassic of Argentina, Permian to Triassic of New Zealand	Raine *et al*. (2011), Zavattieri & Mego (2008)
Brijrajisporites distinctus	38	W.Abrahamskraal Fm 38	Permian of India	Tiwari (1968)
Calamospora mesozoica	42	KZN.Volksrust Fm 42	Triassic & Jurassic of New Zealand & Australia	Raine *et al*. (2011)

Cannanoropollis mehtae	63-42	E.Prince Albert Fm 63, KZN.Vryheid Fm 54, KZN.Volksrust Fm 42	Carboniferous & Early Permian of Argentina	Aitken (1998), Falcon (1988, 1989), Gutiérrez & Césari (2000), MacRae (1988)
Cannanoropollis obscurus	54-42	KZN.Vryheid Fm 54, KZN.Volksrust Fm 42	Permian of Zambia, Australia, Early Permian of South Africa	Aitken (1994, 1998), Falcon (1988, 1989), Foster (1975), Utting (1976)
Chordasporites australiensis	42	KZN.Volksrust Fm 42	Middle Triassic to Jurassic of Australia, Permian & Triassic of Antarctica	de Jersey (1962), Lindström & McLoughlin (2007)
Chordasporites endroedii	42	KZN.Volksrust Fm 42	Pennsylvanian of Bolivia, Late Permian of South Africa	Aitken (1998), di Pasquo (2009)
Cingulaletes minor	52-51	E.Fort Brown Fm 52, E.Fort Brown Fm 51	Permian of Russia	Hart (1965)
Circulisporites parvus	63	E.Prince Albert Fm 63	Early Permian-Late Triassic of Australia, Permian-Jurassic of India, Early Permian of South Africa & Antarctica, Late Triassic Molteno Fm of South Africa	Anderson & Anderson (1983), Farabee *et al*. (1990), Raine *et al*. (2011), Vijaya *et al*. (2012)
Concavisporites bohemiensis	54-28	KZN.Vryheid Fm 54, W.Upper Hoedemaker M. 28	Late Triassic & Early Jurassic of China & New Zealand	Zhang & Grant-Mackie (2001)
Converrucosisporites micronodosus	63	E.Prince Albert Fm 63	Permian of New Zealand, South America, South Africa, Australia	Anderson (1977), Falcon (1988, 1989), Playford & Dino (2002), Playford & Rigby (2008), Raine *et al*. (2011)
Converrucosisporites naumoviae	55-19	E.Upper Ripon Fm 55, E.Fort Brown Fm 51, E.Waterford Fm - Facies A 46, E.Waterford Fm - Facies B 45, KZN.Volksrust Fm 42, W.Abrahamskraal Fm - Mudstone D 40, E.Koonap Fm 35, W.Uppermost Abrahamskraal Fm 33, W.Upper Poortjie M. 30, W.Middle Hoedemaker M. 29, KZN.Normandien Fm 19	Permian of Australia & Early Permian of South Africa	Anderson (1977), Backhouse (1991), MacRae (1988), Modie & Le Hérissé (2009)
Converrucosisporites sp.	7	E.Upper Elliot Fm 7	Permian of Gondwana	e.g. Anderson (1977), Backhouse (1991), MacRae (1988), Modie & Le Hérissé (2009), Stephenson (2009)
Convolutispora intrareticulatus	55-25	E.Upper Ripon Fm 55, E.Koonap Fm 35, E.Oudeberg M. 25	Early Permian of South Africa	Millsteed (1999)

Corisaccites alutas	59	W.Collingham Fm 59	Permian of West Pakistan, No. 5 Seam Witbank - Early Permian of South Africa	Aitken (1994), Venkatachala & Kar (1966)
Cyathidites minor	7-1	E.Upper Elliot Fm 7, KZN.Clarens Fm 6, KZN.Clarens Fm 5, KZN.Clarens Fm 3, KZN.Clarens Fm 2, KZN.Clarens Fm 1	Late Triassic & Jurassic of Svalbard, New Zealand	Bjærke & Manum (1977), Zhang & Grant-Mackie (2001)
Cycadopites cymbatus	54-22	KZN.Vryheid Fm 54, E.Uppermost Fort Brown Fm 49, KZN.Volksrust Fm 42, KZN.Normandien Fm 22	Permian of Australia, Antarctica, Congo, Zambia, India, South America & South Africa	Anderson (1977), Backhouse (1991), Balme & Backhouse (1993), Balme & Hennelly (1956), Foster & Waterhouse (1988), Gilby & Foster (1988), Lindström (1996), Potonié & Lele (1961), Segroves (1970), Stephenson & Osterloff (2002), Tiwari (1965)
Densoisporites psilatus	22	KZN.Normandien Fm 22	Late Triassic to Early Jurassic of New Zealand, Australia, Argentina & China	Lindström & McLoughlin (2007), Zavattieri & Mego (2008), Zhang & Grant-Mackie (2001
Dictyophyllidites mortonii	19-4	KZN.Normandien Fm 19, E.Barberskrans M. 17, E.Katberg Fm 12, E.Molteno Fm 9, E.Lower Elliot Fm 8, KZN.Clarens Fm 4	Late Triassic & Early Jurassic of Australia, New Zealand & China, Late Triassic Molteno Fm of South Africa	Anderson & Anderson (1983), Raine *et al*. (2011)
Disectispora lobata	59-39	W.Collingham Fm 59, W.Abrahamskraal Fm 39	Permian of Brazil	Tiwari & Navale (1967)
Duplexisporites gyratus	6	KZN.Clarens Fm 6	Late Triassic of India, Late Triassic to Early Jurassic of Australia & New Zealand, Late Triassic Molteno Fm of South Africa	Anderson & Anderson (1983), Raine *et al*. (2011), Vijaya *et al*. (2009)
Duplicisporites granulatus	34	E.Koonap Fm 34	Middle to Late Triassic of Spain, Italy & Switzerland	Leschik (1956), Roghi (2004), Zavialova & Roghi (2005)
Equisetosporites steevesi	9-6	E.Molteno Fm 9, KZN.Clarens Fm 6	Triassic & Jurassic of New Zealand, Late Triassic Molteno Fm of South Africa	Anderson & Anderson (1983), Zhang & Grant-Mackie (2001)
Florinites eremus	54-53	KZN.Vryheid Fm 54, KZN.Vryheid Fm 53	Pennsylvanian of Bolivia, Permian of Australia, Late Carboniferous to Early Permian of South Africa	Balme & Hennelly (1955), Foster (1979)
Foveosporites moretonensis	5	KZN.Clarens Fm 5	Latest Triassic & Early Jurassic of New Zealand	Zhang & Grant-Mackie (2001)
Foveosporites sp. A Modie 2007	63	E.Prince Albert Fm 63	Permian of Botswana	Modie (2007)

Gondisporites variabilis	42-41	KZN.Volksrust Fm 42, W.Abrahamskraal Fm - Mudstone B 41	Early & Late Permian of Australia & South Africa	Anderson (1977), Backhouse (1991)
Granulatisporites convexus	14	E.Palingkloof M. 14	Pennsylvanian of USA	Peppers (1970)
Granulatisporites papillosus	57-48	W.Ripon Fm 57, KZN.Vryheid Fm 54, W.Base of the Waterford Fm 48	Late Carboniferous to Late Permian of South Africa	Aitken (1998), MacRae (1988), Prevec *et al*. (2009)
Hamiapollenites dettmannae	54-53	KZN.Vryheid Fm 54, KZN.Vryheid Fm 53	Permian of Australia, Iraq, Oman & Saudi Arabia	Foster (1975), Jan *et al*. (2009), Stephenson (2008)
Hemisphaerium inominatum	19	KZN.Normandien Fm 19	Early Carboniferous of Saudi Arabia	Hemer & Nygreen (1967)
Hilidicellites strangulatus	30	W.Upper Poortjie M. 30	Tertiary of Equatorial Africa	Kalgutkar & Jansonius (2000), Salard-Cheboldaeff & Locquin (1980)
Horriditriletes filiformis	54-42	KZN.Vryheid Fm 54, KZN.Volksrust Fm 42	Permian of Gondwana	e.g. Foster (1979), Lindström & McLoughlin (2007), Playford & Rigby (2008)
Horriditriletes ramosus	42	KZN.Volksrust Fm 42	Permian of Gondwana, Carboniferous of Botswana & Zambia	e.g. Foster (1979), Modie & Le Hérissé (2009), Nyambe & Utting (1997)
Inapertisporites circularis	60	E.Whitehill Fm 60	Maastrichtian of Colombia, Late Cretaceous of Colorado	Kalgutkar & Jansonius (2000), van der Hammen (1954)
Inapertisporites communis	65	E.Elandsvlei Fm 65	Maastrichtian of Colombia, Late Cretaceous of Colorado	Kalgutkar & Jansonius (2000), van der Hammen (1954)
***Inapertisporites* sp. A**	16-13	E.Elandsberg M. 16, E.Katberg Fm 13	-	-
Inaperturopollenites dubius	35-20	E.Koonap Fm 35, E.Koonap Fm 34, KZN.Normandien Fm 20	Triassic & Jurassic of Antarctica, New Zealand	Thomson & Pflug (1953), Zhang & Grant-Mackie (2001)
Involutisporonites foraminus	39-13	W.Abrahamskraal Fm 39, W.Uppermost Abrahamskraal Fm 33, W.Middle Hoedemaker M. 29, E.Oudeberg M. 25, KZN.Normandien Fm 24, E.Katberg Fm 13	Late Cretaceous of Colorado	Clarke (1965)
Ischyosporites volkheimeri	24	KZN.Normandien Fm 24	Late Cretaceous of Argentina, Early Cretaceous of Antarctica, Late Jurassic of Falkland Plateau	Kotova (1983), Povilauskas (2011), Riding *et al*. (1998)

Lacrimasporonites levis	8-7	E.Lower Elliot Fm 8, E.Upper Elliot Fm 7	Late Cretaceous of Colorado	Clarke (1965), Jansonius & Kalgutkar (2000)
***Lacrimasporonites* sp. A**	25-11	E.Oudeberg M. 25, E.Burgersdorp Fm 11	Late Cretaceous of Colorado	Clarke (1965), Jansonius & Kalgutkar (2000)
Laevigatosporites vulgaris	34	E.Koonap Fm 34	Pennsylvanian - Permian worldwide	e.g. Playford & Rigby (2008)
Laevolancis divellomedium	36-29	E.Koonap Fm 36, W.Middle Hoedemaker M. 29	Emsian of Russia	Burgess & Richardson (1991)
Limbosporites denmeadii	14-2	E.Palingkloof M. 14, KZN.Clarens Fm 4, KZN.Clarens Fm 2	Middle to Late Triassic of New Zealand & Australia	Raine *et al*. (2011)
Lophotriletes scotinus	48-23	W.Base of the Waterford Fm 48, W.Abrahamskraal Fm - Mudstone D 40, W.Poortjie M. 31, KZN.Normandien Fm 23	Permo-Carboniferous of Tasmania, Permian of Australia, Late Carboniferous - Early Permian of South Africa	Aitken (1994), Anderson (1977), Segroves (1970), Truswell (1978)
Lundbladispora braziliensis	42	KZN.Volksrust Fm 42	Late Carboniferous to Early Permian of Oman & Saudi Arabia, Permian of South Africa, Late Carboniferous to Permian of South America	Anderson (1977), Archangelsky & Gamerro (1979), Marques-Toigo & Picarelli (1984), Pant & Srivastava (1965), Stephenson (2004)
Marsupipollenites striatus	54-21	KZN.Vryheid Fm 54, W.Poortjie M. 31, KZN.Normandien Fm 22, KZN.Normandien Fm 21	Permian of Gondwana	e.g. Millsteed (1999), Playford & Dino (2002)
Marsupipollenites triradiatus	42-20	KZN.Volksrust Fm 42, KZN.Normandien Fm 20	Permian of Gondwana	e.g. Anderson (1977), Backhouse (1991), Balme (1970), Foster (1979), Millsteed (1999)
Mehlisphaeridium fibratum	31-15	W.Poortjie M. 31, KZN.Normandien Fm 23, E.Elandsberg/Palingkloof Contact 15	Early Permian of Australia, Early & Late Permian of South Africa	Anderson (1977), Millsteed (1999), Segroves (1967)
Micrhystridium karrooense	19	KZN.Normandien Fm 19	Early Permian of South Africa	Millsteed (1999)
Micrhystridium stellatum	28	W.Upper Hoedemaker M. 28	Early Cretaceous of Canada, Middle Jurassic of Greenland, Devonian-Carboniferous of Portugal / Spain	Gonzalez *et al*. (2005), Koppelhus & Hansen (2003), Singh (1971)
Minutosaccus acutus	42	KZN.Volksrust Fm 42	Early Triassic of Germany, Australia, India	Dolby & Balme (1976), Mädler (1964), Tripathi *et al*. (2006)

Platysaccus papilionis	54-42	KZN.Vryheid Fm 54, KZN.Volksrust Fm 42	Permian & Triassic of Australia, Permian of India & South Africa	Anderson (1977), Balme & Hennelly (1955), Bharadwaj (1962), Foster (1975, 1979), MacRae (1988)
Platysaccus radialis	54-42	KZN.Vryheid Fm 54, KZN.Volksrust Fm 42	Pennsylvanian of Bolivia, Permian of South Africa	Aitken (1994), di Pasquo (2009), MacRae (1988)
Playfordiaspora crenulata	17-16	E.Barberskrans M. 17, E.Elandsberg M. 16	Permian to Triassic-Jurassic boundary of New Zealand, Late Triassic Molteno Fm of South Africa	Anderson & Anderson (1983), Raine *et al*. (2011)
Plicatipollenites gondwanensis	43-21	KZN.Volksrust Fm 43, KZN.Normandien Fm 21	Latest Carboniferous / Earliest Permian of Northern Ethiopia, Permian of Australia, South America, Early & Late Permian of South Africa, India, Congo, Early Permian of Antarctica	Anderson (1977), Azcuy & di Pasquo (2000), Backhouse (1991), Balme & Hennelly (1956), Foster (1975, 1979), MacRae (1988), Millsteed (1999), Marques-Toigo & Klepzig (1995)
Plicatipollenites sp.	6	KZN.Clarens Fm 6	Carboniferous & principally Permian of Gondwana	e.g. Azcuy & di Pasquo (2000), Foster (1979)
Potonieisporites magnus	21-6	KZN.Normandien Fm 21, E.Molteno Fm 9, KZN.Clarens Fm 6	Pennsylvanian of Bolivia, Carboniferous to Early Permian of South Africa, Early Permian of Australia, Late Carboniferous of Argentina, Permian of India	di Pasquo (2009), Gilby & Foster (1988), Gutiérrez (1993), MacRae (1988 - as *P. novicus*), Vijaya *et al*. (2012)
Praecolpatites sinuosus	64-37	W.Prince Albert Fm 64, W.Whitehill Fm 62, E.Koonap Fm 37	Permian of Australia, New Zealand, Antarctica, South Africa	Aitken (1998), Anderson (1977), MacRae (1988), Millsteed (1999), Raine *et al*. (2011), Lindström & McLoughlin (2007)
Protohaploxypinus latissimus	54	KZN.Vryheid Fm 54	Early Permian of South Africa, Russia	Aitken (1994), Luber & Waltz (1941), Samoilovich (1953)
Protohaploxypinus limpidus	59-21	W.Collingham Fm 59, KZN.Volksrust Fm 43, KZN.Volksrust Fm 42, KZN.Normandien Fm 23, KZN.Normandien Fm 21	Permian of South America, Antarctica, Australia, South Africa	Aitken (1998), Balme & Hennelly (1955), Balme & Playford (1967), Lindström *et al*. (1997), MacRae (1988), Millsteed (1999), Playford & Dino (2000), Prevec *et al*. (2010), Steiner *et al*. (2003)
Protohaploxypinus microcorpus	54	KZN.Vryheid Fm 54	Triassic of New Zealand, Late Permian of Antarctica, Australia, Permian of South Africa	Aitken (1994), Foster (1982), Lindström & McLoughlin (2007), Steiner *et al*. (2003), Zhang & Grant-Mackie (2001)
***Protohaploxypinus* sp.**	59-21	W.Collingham Fm 59, W.Middle Hoedemaker M. 29, KZN.Normandien Fm 21	Wide-ranging through Permian & Triassic of Gondwana	e.g. Aitken (1994), Lindström & McLoughlin (2007), MacRae (1988), Millsteed (1999)
Pteruchipollenites landianus	54-21	KZN.Vryheid Fm 54, KZN.Normandien Fm 23, KZN.Normandien Fm 21	Permian of South Africa, Paraguay	MacRae (1988), Muff *et al*. (1999)

Punctacolpites jamottei	34	E.Koonap Fm 34	Permian of Congo	Kar & Bose (1967)
Pustulatisporites distinctus	56-19	E.Middle Ripon Fm 56, E.Oudeberg M. 25, KZN.Normandien Fm 19	Early Permian of Turkey	Ağrali & Akyol (1967)
Retialetes radforthii	34	E.Koonap Fm 34	Late Mississippian of Western Canada	Staplin (1960)
Reticulatisporites bifrons	64-59	W.Prince Albert Fm 64, W.Collingham Fm 59	Carboniferous of Australia, Argentina	Balme (1995), Césari & Limarino (2002)
Scheuringipollenites ovatus	54-23	KZN.Vryheid Fm 54, KZN.Vryheid Fm 53, KZN.Volksrust Fm 43, KZN.Normandien Fm 23	Permian of Gondwana incl. South Africa	e.g. Aitken (1994, 1998), Anderson (1977), Backhouse (1991), Balme (1970), Falcon (1988, 1989), Foster (1979), Lindström (1996), MacRae (1988), Segroves (1969)
Scheuringipollenites sp.	24	KZN.Normandien Fm 24	Permian of Gondwana	e.g. Backhouse (1991), Balme (1970), Foster (1979), Lindström (1996), Segroves (1969)
Schopfites dimorphus	16	E.Elandsberg M. 16	Westphalian C-D of USA, Carboniferous of Great Britain	Kosanke (1950)
Sphaeroporalites solus	47	W.Lower Waterford Fm 47	Early Carboniferous of Saudi Arabia	Hemer & Nygreen (1967)
***Striatoabieites* sp.**	23-21	KZN.Normandien Fm 23, KZN.Normandien Fm 21	Late Carboniferous to Triassic of Australia & South Africa	e.g. Anderson (1977), Campbell *et al*. (2001), Millsteed (1999), Playford & Dino (2002), Stephenson *et al*. (2003)
Striatopodocarpites cancellatus	59-42	W.Collingham Fm 59, KZN.Vryheid Fm 54, KZN.Vryheid Fm 53, KZN.Volksrust Fm 42	Permian of Gondwana	e.g. Balme & Hennelly (1955), Foster (1979), MacRae (1988), Millsteed (1999)
Striatopodocarpites fusus	54-42	KZN.Vryheid Fm 54, KZN.Volksrust Fm 42	Permian of Gondwana	e.g. Balme & Hennelly (1955), Foster (1979), MacRae (1988), Millsteed (1999)
Striatopodocarpites cf. *rarus*	63	E.Prince Albert Fm 63	Permian of Australia, India, South America, Botswana, Early Permian of Pakistan, Late Carboniferous to Late Permian of South Africa	Aitken (1994), Balme (1970), Bharadwaj & Salujha (1964), Foster (1979), MacRae (1988), Marques-Toigo & Klepzig (1995), Modie & Le Hérissé (2009)
Striatopodocarpites solitus	42	KZN.Volksrust Fm 42	Pennsylvanian of Bolivia	di Pasquo (2009)
Tripunctisporis maastrichtiensis	13	E.Katberg Fm 13	Cretaceous of New Zealand	Herngreen *et al*. (1986), Raine *et al*. (2011)

Uvaesporites verrucosus	11-2	E.Burgersdorp Fm 11, E.Molteno Fm 9, E.Lower Elliot Fm 8, E.Upper Elliot Fm 7, KZN.Clarens Fm 2	Triassic to Jurassic of New Zealand, Late Triassic of Australia, Latest Triassic of India, Late Triassic Molteno Fm of South Africa	Anderson & Anderson (1983), Vijaya *et al*. (2012), Zhang & Grant-Mackie (2001)
Verrucosisporites andersonii	42	KZN.Volksrust Fm 42	Permian of Australia, Argentina, West Papua, Early Permian of South Africa, Antarctica	Anderson (1977), Backhouse (1988, 1991), Larsson *et al*. (1990), Lindström (1994, 1995), Millsteed (1999), Playford & Rigby (2008), Vergel (1998)
Verrucosisporites sp. MacRae 1988	54	KZN.Vryheid Fm 54	Permian of South Africa	MacRae (1988)
Vittatina fasciolata	57-21	W.Ripon Fm 57, W.Base of the Waterford Fm 48, KZN.Volksrust Fm 42, KZN.Normandien Fm 22, KZN.Normandien Fm 21	Early Permian of Russia, South America, Congo, Zambia, Madagascar, West Papua, Argentina, Botswana & South Africa, Late Permian of India, Permian of Australia & Antarctica	Anderson (1977), Backhouse (1991), Balme & Hennelly (1956), Bharadwaj (1962), Césari & Gutiérrez (2000), de Jersey (1979), Hart (1965), Kar & Bose (1967), Modie & Le Hérissé (2009), Playford & Rigby (2008), Samoilovich (1953)
Vittatina multistriata	42	KZN.Volksrust Fm 42	Early Permian of South Africa	Anderson (1977)
Vittatina sp.	42	KZN.Volksrust Fm 42	Permian to Triassic of Gondwana	e.g. Aitken (1998), Césari *et al*. (2011)
Zinjisporites congoensis	42	KZN.Volksrust Fm 42	Early Permian of South Africa & Congo, Permian of Australia	Anderson (1977), Backhouse (1991), Kar & Bose (1967), Millsteed (1999)
Zinjisporites spinosus	41	W.Abrahamskraal Fm - Mudstone B 41	Early Permian of Antarctica, South Africa, Madagascar, Congo, Arabian Peninsula	Anderson (1977), Besems & Schuurman (1987), Hart (1965), Kar & Bose (1967), Larsson *et al*. (1990)

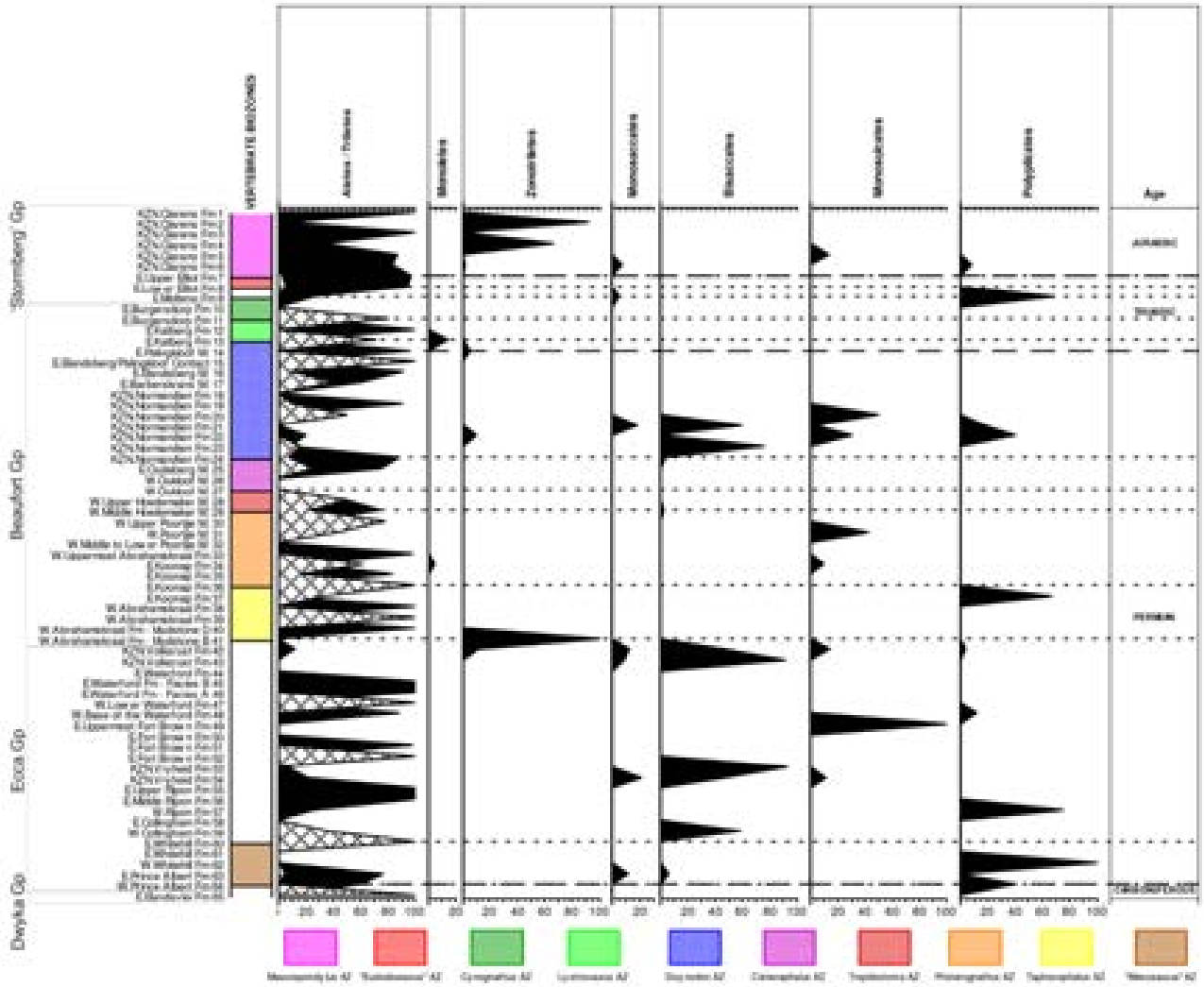


Figure 3.6: Condensed Tilia™ pollen diagram of restricted range taxa displayed as part of their turmal group, demonstrating relationships between turmal groups and stratigraphic provenance. Triletes are illustrated in solid black and overlain by aletes in a cross-hatch pattern.

Restricted range trilete taxa increase as restricted aletes decrease over the Carboniferous - Permian, Permo-Triassic and Triassic - Jurassic boundaries (Figure 3.6). Significantly, this is not the case when considering all taxa in the study, where triletes dominate over the Carboniferous - Permian and Permian - Triassic boundaries, and aletes dominate over the Triassic - Jurassic boundary

(Figure 3.4). This implies that interpretation of palaeoenvironments based purely on quantitative trends of different taxa should be treated with caution.
Other turmal groups become far more significant when long range taxa are removed from consideration as many of the trilete and alete taxa extend for much or all of the Karoo stratigraphic succession. Restricted range monolete taxa are first encountered in the lower *Pristerognathus* Assemblage Zone (AZ), reappear in the Normandien Formation, disappear until the Permo - Triassic boundary whereupon they increase significantly until the mid- *Lystrosaurus* AZ, and then vanish from the stratigraphic succession (Figure 3.6).

Restricted range zonotriletes first appear in the Volksrust Formation, increase dramatically at the base of the *Tapinocephalus* AZ and then disappear, are later present in small numbers in the Normandien Formation and Palingkloof Member, and then increase significantly in the Clarens Formation (Figure 3.6).

Restricted range monosaccates are present in the Prince Albert, Vryheid, Volksrust, Normandien, Molteno and Clarens formations, displaying marked increases just above the Carboniferous - Permian and Triassic - Jurassic boundaries (Figure 3.6).

Many restricted range bisaccate taxa occur in the Prince Albert, Collingham, Vryheid, and Volksrust formations. Restricted range bisaccates are also present in the *Tropidostoma* and upper *Cistecephalus* assemblage zones, increasing in the *Dicynodon* AZ and then vanishing until the Jurassic Clarens Formation (Figure 3.6).

Restricted range monosulcate taxa are present in the Vryheid, Uppermost Fort Brown, and Volksrust Formations, with increases in both the lower and upper *Pristerognathus* AZ, and then reappearing only in the lower *Dicynodon* AZ and the Clarens Formation (Figure 3.6). Restricted range polyplicate taxa are abundant in the Elandsvlei, Whitehill, Ripon, Vryheid, and Waterford Formations (Figure 3.6). Polyplicates spike in the upper *Tapinocephalus* and lower *Dicynodon*

assemblage zones, in the Molteno Formation and at the Triassic - Jurassic boundary (Figure 3.6).

3.4 ASSEMBLAGE ZONES

Figure 3.7 gives restricted range taxa assemblages for each stratigraphic entity of the Karoo Supergroup.

West of 24°E	East of 24°E	Free State / Kwazulu-Natal	Biozone	Index Taxa
		Clarens Fm	***Massospondylus***	
		Bennettiteaepollenites sp.		*Bennettiteaepollenites* sp.
		Dictyophyllidites mortonii		*Converrucosisporites* sp.
		Duplexisporites gyratus		***Cyathidites minor***
		Equisetosporites steevesi		***Dictyophyllidites mortonii***
		Foveosporites moretonensis		*Duplexisporites gyratus*
		Limbosporites denmeadii		***Equisetosporites steevesi***
		Plicatipollenites sp.		*Foveosporites moretonensis*
		Potonieisporites magnus		***Lacrimasporonites levis***
		Uvaesporites verrucosus		***Limbosporites denmeadii***
	Upper Elliot Fm			*Plicatipollenites* sp.
	Converrucosisporites sp.			***Potonieisporites magnus***
	Cyathidites minor			***Uvaesporites verrucosus***
	Lacrimasporonites levis			
	Uvaesporites verrucosus			
	Lower Elliot Fm		***"Euskelosaurus"***	.
	Dictyophyllidites mortonii			***Dictyophyllidites mortonii***
	Lacrimasporonites levis			***Lacrimasporonites levis***
	Uvaesporites verrucosus			***Uvaesporites verrucosus***
	Molteno Fm			
	Dictyophyllidites mortonii			
	Equisetosporites steevesi			
	Potonieisporites magnus			
	Uvaesporites verrucosus			
	Burgersdorp Fm		***Cynognathus***	
	***Lacrimasporonites* sp. A**			***Lacrimasporonites* sp. A**
	Uvaesporites verrucosus			***Uvaesporites verrucosus***
	Katberg Fm		***Lystrosaurus***	*Aratrisporites tenuispinosus*
	Aratrisporites tenuispinosus			***Dictyophyllidites mortonii***
	Dictyophyllidites mortonii			***Inapertisporites* sp. A**
	***Inapertisporites* sp. A**			***Involutisporonites foraminus***
	Involutisporonites foraminus			*Tripunctisporis maastrichtiensis*
	Tripunctisporis maastrichtiensis			

	Palingkloof M.	**Normandien Fm**	***Dicynodon***	*Appendicisporites* sp.
	Granulatisporites convexus	*Appendicisporites* sp.		***Brazilea scissa***
	Limbosporites denmeadii	*Brevitriletes bulliensis*		*Brevitriletes bulliensis*
	Elandsberg/Palingkloof Contact	***Converrucosisporites naumoviae***		***Converrucosisporites naumoviae***
	Mehlisphaeridium fibratum	***Cycadopites cymbatus***		***Cycadopites cymbatus***
	Elandsberg M.	*Densoisporites psilatus*		*Densoisporites psilatus*
	***Inapertisporites* sp. A**	***Dictyophyllidites mortonii***		***Dictyophyllidites mortonii***
	Playfordiaspora crenulata	*Hemisphaerium inominatum*		*Granulatisporites convexus*
	Schopfites dimorphus	***Inaperturopollenites dubius***		*Hemisphaerium inominatum*
	Barberskrans M.	***Involutisporonites foraminus***		***Inapertisporites* sp. A**
	Brazilea scissa	*Ischyosporites volkheimeri*		***Inaperturopollenites dubius***
	Dictyophyllidites mortonii	***Lophotriletes scotinus***		***Involutisporonites foraminus***
	Playfordiaspora crenulata	***Marsupipollenites striatus***		*Ischyosporites volkheimeri*
		Marsupipollenites triradiatus		***Limbosporites denmeadii***
		Mehlisphaeridium fibratum		***Lophotriletes scotinus***
		Micrhystridium karrooense		***Marsupipollenites striatus***
		Plicatipollenites gondwanensis		***Marsupipollenites triradiatus***
		Potonieisporites magnus		***Mehlisphaeridium fibratum***
		Protohaploxypinus limpidus		*Micrhystridium karrooense*
		***Protohaploxypinus* sp.**		***Playfordiaspora crenulata***
		Pteruchipollenites landianus		***Plicatipollenites gondwanensis***
		Pustulatisporites distinctus		***Potonieisporites magnus***
		Scheuringipollenites ovatus		***Protohaploxypinus limpidus***
		Scheuringipollenites sp.		***Protohaploxypinus* sp.**
		***Striatoabieites* sp.**		***Pteruchipollenites landianus***
		Vittatina fasciolata		***Pustulatisporites distinctus***
				Scheuringipollenites ovatus
				Scheuringipollenites sp.
				Schopfites dimorphus
				***Striatoabieites* sp.**
				Vittatina fasciolata
	Oudeberg M.		***Cistecephalus***	***Convolutispora intrareticulatus***
	Convolutispora intrareticulatus			***Involutisporonites foraminus***
	Involutisporonites foraminus			***Lacrimasporonites* sp. A**
	***Lacrimasporonites* sp. A**			***Pustulatisporites distinctus***
	Pustulatisporites distinctus			
Hoedemaker M.			***Tropidostoma***	***Concavisporites bohemiensis***
Concavisporites bohemiensis				***Converrucosisporites naumoviae***
Converrucosisporites naumoviae				***Involutisporonites foraminus***
Involutisporonites foraminus				***Laevolancis divellomedium***
Laevolancis divellomedium				*Micrhystridium stellatum*
Micrhystridium stellatum				***Protohaploxypinus* sp.**
***Protohaploxypinus* sp.**				

Poortjie M.			*Pristerognathus*	
Converrucosisporites naumoviae				***Converrucosisporites naumoviae***
Hilidicellites strangulatus				***Convolutispora intrareticulatus***
Lophotriletes scotinus				*Duplicisporites granulatus*
Marsupipollenites striatus				*Hilidicellites strangulatus*
Mehlisphaeridium fibratum				***Inaperturopollenites dubius***
Abrahamskraal Fm	**Koonap Fm**			***Involutisporonites foraminus***
Brijrajisporites distinctus	***Brazilea scissa***		*Tapinocephalus*	*Laevigatosporites vulgaris*
Converrucosisporites naumoviae	***Converrucosisporites naumoviae***			***Laevolancis divellomedium***
Disectispora lobata	***Convolutispora intrareticulatus***			***Lophotriletes scotinus***
Gondisporites variabilis	*Duplicisporites granulatus*			***Marsupipollenites striatus***
Involutisporonites foraminus	***Inaperturopollenites dubius***			***Mehlisphaeridium fibratum***
Lophotriletes scotinus	*Laevigatosporites vulgaris*			*Punctacolpites jamottei*
Zinjisporites spinosus	***Laevolancis divellomedium***			*Retialetes radforthii*
	Praecolpatites sinuosus			***Brazilea scissa***
	Punctacolpites jamottei			*Brijrajisporites distinctus*
	Retialetes radforthii			***Converrucosisporites naumoviae***
Waterford Fm	**Waterford Fm**	**Volksrust Fm**		***Disectispora lobata***
Granulatisporites papillosus	***Converrucosisporites naumoviae***	***Barakarites rotatus***		***Gondisporites variabilis***
Lophotriletes scotinus		*Calamospora mesozoica*		***Involutisporonites foraminus***
Sphaeroporalites solus		***Cannanoropollis mehtae***		***Lophotriletes scotinus***
Vittatina fasciolata		***Cannanoropollis obscurus***		***Praecolpatites sinuosus***
	Fort Brown Fm	*Chordasporites australiensis*		*Zinjisporites spinosus*
	Cingulaletes minor	*Chordasporites endroedii*		
	Converrucosisporites naumoviae	***Converrucosisporites naumoviae***		
	Cycadopites cymbatus	***Cycadopites cymbatus***		
		Gondisporites variabilis		
		Horriditriletes filiformis		
		Horriditriletes ramosus		
		Lundbladispora braziliensis		
		Marsupipollenites triradiatus		
		Minutosaccus acutus		
		Platysaccus papilionis		
		Platysaccus radialis		
		Plicatipollenites gondwanensis		
		Protohaploxypinus limpidus		
		Scheuringipollenites ovatus		
		Striatopodocarpites cancellatus		
		Striatopodocarpites fusus		
		Striatopodocarpites solitus		
		Verrucosisporites andersonii		
		Vittatina fasciolata		
		Vittatina multistriata		

		Vittatina sp. *Zinjisporites congoensis*	
Ripon Fm	**Ripon Fm**	**Vryheid Fm**	
Granulatisporites papillosus ***Vittatina fasciolata***	***Converrucosisporites naumoviae*** ***Convolutispora intrareticulatus*** ***Pustulatisporites distinctus***	*Apiculiretusispora* sp. ***Barakarites rotatus*** ***Cannanoropollis mehtae*** ***Cannanoropollis obscurus*** ***Concavisporites bohemiensis*** ***Cycadopites cymbatus*** ***Florinites eremus*** ***Granulatisporites papillosus*** ***Hamiapollenites dettmannae*** ***Horriditriletes filiformis*** ***Marsupipollenites striatus*** ***Platysaccus papilionis*** ***Platysaccus radialis*** *Protohaploxypinus latissimus* *Protohaploxypinus microcorpus* ***Pteruchipollenites landianus*** ***Scheuringipollenites ovatus*** ***Striatopodocarpites cancellatus*** ***Striatopodocarpites fusus*** *Verrucosisporites* sp. MacRae 1988	
Collingham Fm			
Corisaccites alutas ***Disectispora lobata*** ***Protohaploxypinus limpidus*** ***Protohaploxypinus* sp.** ***Reticulatisporites bifrons*** ***Striatopodocarpites cancellatus***			
Whitehill Fm	**Whitehill Fm**		***"Mesosaurus"*** ***Cannanoropollis mehtae*** *Circulisporites parvus* *Converrucosisporites micronodosus* *Foveosporites* sp. A Modie 2007 *Inapertisporites circularis* ***Praecolpatites sinuosus*** ***Reticulatisporites bifrons*** *Striatopodocarpites* cf. *rarus*
Praecolpatites sinuosus	*Inapertisporites circularis*		
Prince Albert Fm	**Prince Albert Fm**		
Praecolpatites sinuosus ***Reticulatisporites bifrons***	***Cannanoropollis mehtae*** *Circulisporites parvus* *Converrucosisporites micronodosus* *Foveosporites* sp. A Modie 2007 *Striatopodocarpites* cf. *rarus*		
	Elandsvlei Fm		
	Inapertisporites communis		

Figure 3.7: **(See caption on page 135)**

Figure 3.7: Indicator taxa present in each formation / member and vertebrate biozone of the Karoo Supergroup from the western, southern and north-eastern regions. Taxa in black are restricted to one sample. Taxa in blue have a relatively long range and are useful only as general indicators. Taxa in red reflect either unexpected correlations between two or more formations, or alternatively represent Lazarus taxa. Taxa in green have a short stratigraphic range or indicate a valuable correlation between two or more formations.

The feasibility of defining each Karoo stratigraphic entity based on its palynoflora can be determined by considering the range of each indicator species both in this study (Figure 3.7) and globally (Table 3.3) as well as the particular grouping of species for each stratigraphic unit. Green species (short range) are considered most useful for correlations between different stratigraphic units, and blue / red species less so because they have a longer stratigraphic range.

The Dwyka Group was deposited in a glacial environment that was not conducive to a high plant biomass or diversity (Bamford, 2004) and the productive sample from the Elandsvlei Formation east of 24° E reflects this with a low diversity of taxa, mostly long range acritarchs and one restricted range acritarch species, *Inapertisporites communis* (Figure 3.7). Anderson (1977) also reported a low diversity of species from the Dwyka Group consisting solely of spores and acritarchs.

The warmer, humid environment during the extended depositional range of the Ecca Group encouraged a proliferation of plant life and the highly carbonaceous, mostly low-energy environments (Smith *et al*., 1993) provided the perfect setting for excellent palynomorph preservation. Accordingly the samples from the Vryheid and Volksrust formations of the provinces of KZN and the Free State contain a large number of distinctive taxa and can be easily recognised on their palynoflora alone (Figure 3.7). Probably due to the sheer number of species found in both Vryheid and Volksrust samples, these formations have far more taxa in common (six green and

four blue species) than any of their western or southern equivalents (Figure 3.7). This can be attributed to excellent palynomorph preservation in the northern distal facies of the Karoo as discussed above.

The Vryheid Formation contains 4 species previously known from the Early Permian of South Africa and 4 species from the Early Permian of elsewhere in Gondwana (Table 3.3), thus it is chronologically well-constrained by its palynoflora.

The Prince Albert Formation microflora includes *Reticulatisporites bifrons* from the Carboniferous of Australia and Argentina, *Circulisporites parvus* from the Early Permian of South Africa and three species from the Early Permian of Gondwana (Table 3.3). The Collingham Formation microflora also contains the Carboniferous species *Reticulatisporites bifrons* and five other species, all from the Permian of Gondwana (Table 3.3). The Prince Albert and Collingham formation microfloras are diverse and both stratigraphic units can be well defined on the basis of their palynology.

Visser (1993) considered the Vryheid Formation to be chronologically equivalent to the upper Prince Albert and Whitehill Formations, while the Volksrust Formation grades laterally into the Tierberg / Fort Brown Formation (Catuneanu *et al*., 2005). Cole & McLachlan (1990) stated that the Whitehill Formation could be correlated to the upper Vryheid Formation but whether this correlation was made on a palynological or lithological basis is unclear. Restricted range palynomorph taxa within these formations indicate the following relationships: the Vryheid Formation has one green species (short range) in common with the Ripon Formation and one blue species (longer range) each in common with the Collingham and Prince Albert formations. The Volksrust Formation microflora has one blue species (longer range) in common with the Koonap Formation, two blue species in common with the Ripon, Fort Brown and Waterford formations, and one green and one blue species in common with the Abrahamskraal Formation (Figure 3.7). In other words, the palynomorph content of the Vryheid Formation is most similar to the Ripon Formation but also shows similarities to the Prince Albert and Collingham formations, and that of the Volksrust Formation is most similar to the Abrahamskraal

Formation but also shows similarities to the Ripon, Fort Brown and Waterford formations. Restricted range palynomorphs from the Pietermaritzburg Fm may aid in attaining better resolution of these correlations.

The Ecca-Beaufort boundary is known to be highly diachronous (Turner, 1999; Rubidge *et al*., 1999) and this is reflected by palynology. The Middle to Upper Volksrust and Abrahamskraal formations were being deposited simultaneously, accounting for the similarity in palynoassemblages between the two formations despite them belonging to the Ecca and Beaufort Groups respectively.

Palynoassemblages from lithostratigraphically equivalent units of the Ecca Group in the western region (west of the 24° E meridian), southern region (east of the 24° E meridian) and the north-east distal facies (KZN & Free State) have no restricted range taxa in common. The Prince Albert Formation microflora in the western region of the basin contains different restricted range taxa to that of the Prince Albert Formation microflora in the southern region, and this also holds true for the Whitehill, Ripon and Waterford Formations in the western and southern regions. Although the western and eastern -equivalent formations have many long ranging taxa in common, each region of the Karoo Basin in the Ecca Group appears to preserve unique indicator species (Figure 3.7). This microfloral provincialism becomes less pronounced in the Beaufort Group, with the Abrahamskraal and Koonap formation microfloras sharing one blue restricted range taxon and the Normandien and Balfour formation microfloras sharing two blue species (Figure 3.7). Although not as stratigraphically comprehensive, Anderson (1977) also found many species restricted to either the northern or southern Karoo facies and suggested that this was either due to different sedimentary facies in the north and south, or that plant colonization differed in these regions. Macroplants of the Ecca Group display a fair amount of floral provincialism during the Early Permian (Bamford, 2004) and this is supported by palynology (Anderson, 1977; Falcon *et al*., 1984; this work).

In the Beaufort Group the *Tapinocephalus* and *Pristerognathus* Assemblage Zones contain many taxa found in the Permian of Gondwana (Table 3.3) and although each species on its own is not a precise indicator of that biozone, together the specific

grouping of taxa in each assemblage zone may be used as a marker of that biostratigraphic horizon (Figure 3.7).

The *Tropidostoma* Assemblage Zone contains a microfloral assemblage of which most taxa, the majority being acritarchs, have not previously been reported from Late Permian sediments of Gondwana (Table 3.3). However, this finding may extend their ranges to span the Late Permian, and their association with each other may prove a palynological marker for this assemblage zone.

Due to the paucity of productive samples from the *Cistecephalus* Assemblage Zone, this biozone cannot be precisely defined by its palynomorph content as yet. The index species of this assemblage are not exclusive to the *Cistecephalus* AZ, both in South Africa (Figure 3.7) and globally (Table 3.3). However, the particular association of taxa *Convolutispora intrareticulatus*, *Involutisporonites foraminus*, *Lacrimasporonites sp. A* and *Pustulatisporites distinctus* can possibly be used as an indicator for this zone.

The northern Normandien Formation is chronologically equivalent to the southeast Balfour Formation based on the presence of the therapsid *Dicynodon lacerticeps* (Catuneanu *et al*., 2005) and the microfloral assemblages of these two formations share two restricted range species (Figure 3.7). Together the Normandien and Middle to Upper Balfour Formations correspond to the *Dicynodon* Assemblage Zone, which contains a combination of palynomorphs described from Permian and Triassic rocks: *Brazilea scissa*, *Converrucosisporites naumoviae*, *Lophotriletes scotinus*, *Marsupipollenites striatus*, *Marsupipollenites triradiatus*, *Mehlisphaeridium fibratum*, *Micrhystridium karrooense*, *Plicatipollenites gondwanensis*, *Protohaploxypinus limpidus*, *Pteruchipollenites landianus*, *Pustulatisporites distinctus*, *Scheuringipollenites ovatus* and *Vittatina fasciolata* are known from the Permian, and *Densoisporites psilatus*, *Dictyophyllidites mortonii*, *Inaperturopollenites dubius* and *Limbosporites denmeadii* are common in the Triassic (Table 3.3). The *Dicynodon* AZ can be well defined on the basis of its microflora.

A significant floral turnover is seen at the transition from the *Dicynodon* to the *Lystrosaurus* Assemblage Zone (Figure 3.7) which is consistent with the extinction of more than 90% of Late Permian gymnosperm species as a result of the end-Permian extinction event (Retallack, 1995; Visscher *et al*., 1996; Looy *et al*., 1999). Steiner *et al*. (2003) observed the disappearance of Late Permian gymnosperm pollen at the top of the *Dicynodon* Zone, which was replaced by a lycopod spore and bisaccate gymnosperm pollen -dominated microflora in the Early Triassic (Eshet *et al*., 1995; Visscher *et al*., 1996). Cirilli *et al*. (1998) also found a gradual decrease of exclusive Permian palynomorphs and a simultaneous increase of Triassic taxa in the Upper Permian Bellerophon Formation of the Badia Valley, northern Italy, just below the Permo-Triassic transition preserved within the Tesero Oolitic Horizon.

The *Cynognathus* Assemblage Zone has few index taxa but can possibly be defined on the first appearance of *Uvaesporites verrucosus* (Figure 3.7) which is present in Late Triassic rocks of Australia, South Africa and India (Table 3.3).

The Molteno Formation microflora sample comprises one Late Triassic species (*Uvaesporites verrucosus*) and two Late Triassic / Early Jurassic species (*Dictyophyllidites mortonii*, *Equisetosporites steevesi*). This is consistent with the accepted Late Triassic age for the Molteno Formation, however this combination of taxa cannot be considered distinctive for the Molteno alone as all three species are also present in the Clarens Formation palynoflora (Figure 3.7).

The Lower and Upper Elliot Formations can each be distinguished by their particular microfloral assemblages (Figure 3.7). Both formations contain the Triassic taxa *Dictyophyllidites mortonii* and *Uvaesporites verrucosus*, however the Upper Elliot can be distinguished by the first appearance of *Cyathidites minor*, a species known from the Late Triassic and Jurassic of New Zealand and Australia (Table 3.3).

The *Massospondylus* Range Zone microflora incorporates taxa from the Upper Elliot and Clarens formations and contains many index species on which this assemblage zone can be recognised (Figure 3.7). The palynoflora consists of species known from Triassic and Jurassic rocks (*Cyathidites minor*, *Equisetosporites steevesi*,

Foveosporites moretonensis), typical Triassic taxa (*Duplexisporites gyratus*, *Limbosporites denmeadii*, *Uvaesporites verrucosus*) and typical Jurassic taxa (*Bennettiteaepollenites* sp.) (Table 3.3). There is no obvious significant floral turnover in taxa with restricted ranges between the Lower and Upper Elliot, or between the Upper Elliot and the Clarens formations. However an obvious concord can be seen between all formations of the "Stormberg" Group, distinguishing them from Lower Beaufort Group rocks and reflecting the major stratigraphic gap that is known to be present between the Tarkastad Subgroup and Molteno Formation (SACS, 1980; Cole, 1992).

There are three possibilities to explain why combinations of palynomorphs typical of both the Permian and Triassic are present in the *Dicynodon* AZ, and species typical of both the Triassic and Jurassic are present in the *Massospondylus* Range Zone. The first possibility is that transitory microfloral phases are present in the Karoo Supergroup. This means that some older palynomorphs are persisting past a period boundary and other younger taxa are appearing slightly before a boundary, resulting in a combination of the two palynomorph groups. This may support the hypothesis of a protracted crisis at the end of the Permian period (Looy *et al*., 2001; Lindström & McLoughlin, 2007), alternatively it may be as a result of the frequently observed "fuzziness" of sporomorph boundaries (Traverse, 2007). This "fuzziness" may occur because plant species can quite easily rebound from near-extinction and reappear in the stratigraphic section (a possible reason for their ghost ranges as explained in Section 3.3), or because palynomorphs are classified on the basis of their morphology and almost never represent only a single species of plant (Traverse, 2007).

The third hypothesis is that some samples from the Normandien and Balfour Formations actually derive from the Triassic *Lystrosaurus* AZ and other samples are from the Permian *Dicynodon* AZ, resulting in an artificial combination of Permian and Triassic palynomorphs. This may be possible because *Lystrosaurus* first appears in the stratigraphic record below the Katberg Sandstone, in the Palingkloof Member (Smith & Ward, 2001). This is supported by the fact that no Permian taxa are present in the Katberg Formation microflora, which contains only typical Triassic

species genera such as *Dictyophyllidites* and *Aratrisporites*. If the hypothesis of transitory microfloral phases was correct, one should expect to find a few taxa typically found in Permian rocks present in the Katberg Formation microflora, but this is not seen.

Some researchers use the FAD of *Aratrisporites* to define the P–T boundary (Foster, 1982; Foster *et al*., 1998; Foster & Afonin, 2005) but the parent plants of this pleuromeiacean monolete cavate spore could have been strongly facies dependent (Retallack, 1975, 1977) and hence the first appearance of this spore may not be a reliable chronostratigraphic marker (Lindström & McLoughlin, 2007). In the Normandien Formation two specimens of Cf. *Aratrisporites strigosus* are present which may indicate that either this sample derives from the Harrismith Member and that this member is Triassic in age, that the range of *Aratrisporites* extends into the Upper Permian of South Africa, or else that on further examination, these specimens may prove to be a new genus.

In this study the Triassic - Jurassic boundary is taken to be on the contact between the Lower and Upper Elliot formations (Olson & Galton, 1984), however if the boundary is actually contained within the Upper Elliot Formation (see Knoll, 2004), the sample from the Upper Elliot may be in fact be Latest Triassic in age, explaining the combination of Triassic and Jurassic taxa in the *Massospondylus* Range Zone. In the future more intensive stratigraphic sampling must be undertaken throughout the *Dicynodon* and *Massospondylus* zones in order to investigate this.

Due to the fact that the Karoo microflora generally correlates very well with the existing and formally accepted vertebrate biozonation (Figure 3.7), it was considered unnecessary to designate informal pollen biozones (e.g. Biozone A, B, C etc.) for the Karoo Supergroup, especially considering that radiometric dates are now available for many Karoo formations (Bangert *et al*., 1999; Coney *et al*., 2007; Duncan *et al*., 1997; Fildani *et al*., 2007, 2009; Jourdan *et al*., 2005; Rubidge *et al*., 2013; Turner, 1999). Since the pollen content of most formations is known, this provides good stratigraphic resolution for imminent studies both in South Africa and Gondwana and should allow for easier and more accurate correlations in future.

3.5 EXTINCTION EVENTS

Organisms constantly undergo speciation and extinction, but certain periods in geological time preserve a greater than average amount of biodiversity loss. Mass extinctions are the most severe losses of biodiversity throughout Earth's history and involve global extinctions across a wide range of ecologies in a relatively brief amount of time (Benton & Harper, 2009). The Karoo Supergroup preserves a record of two of the "Big Five" mass extinctions, namely the end-Permian and end-Triassic events, and significant faunal changes are observed at the end of the *Tapinocephalus*, *Cistecephalus*, *Dicynodon* and *Euskelosaurus* zones (Kitching & Raath, 1984; Rubidge, 1995; Rubidge, 2005, Nicolas & Rubidge, 2009). There is significant debate over whether extinction events affected continental floras in the same ways, and to the same extent, as the marine and vertebrate realms (e.g. Knoll, 1984; Looy *et al*., 2001; Lindström & McLoughlin, 2007; Traverse, 2007). Unfortunately the macroplant record for the Main Karoo Basin is highly underrepresented in the Stormberg (except for the Molteno Formation) and the Triassic Beaufort Group - this is as a result of collecting bias and low preservation potential rather than reflecting impoverished floras (Anderson & Anderson, 1985; Bamford, 1999, 2000, 2004). Palynology gives a clearer indication of floral diversities through time (Figure 3.8).

The palynomorph record from the Carboniferous Dwyka Group reflects an artificial rate of speciation and unknown rate of extinction because the palynomorph content of the underlying Witteberg Group is not known. The number of species that "appear" in the Dwyka Group is very likely inflated, and the number of species that go extinct obviously cannot be determined (Figure 3.8). The remainder of the samples reflect natural rates of floral diversity. Early Permian samples show high rates of speciation consistent with an ameliorating climate and increasingly high plant biomass (Anderson & Anderson, 1985) (Figure 3.8). Minor losses of species are seen in the No. 5 Seam (Vryheid Formation) and Fort Brown Formation, and environmental conditions remain unchanged through deposition of the Waterford Formation. The highest rate of

speciation in the entire Karoo Supergroup occurs during deposition of the Volksrust and Abrahamskraal formations, concurrent with no losses of species at all (Figure 3.8). The upper *Tapinocephalus* AZ records a severe extinction event, with a loss of species 75% of that of the end-Permian mass extinction (Figure 3.8). Microflora recovers to some extent at the base of the *Pristerognathus* AZ but minor extinctions occur in the middle of this assemblage zone and the middle-upper *Tropidostoma* AZ (Figure 3.8). Many new species are introduced upon deposition of the Normandien and Balfour formations but species diversity declines dramatically at the end of the Permian, during which by far the highest loss of species in the entire Karoo Supergroup is seen (Figure 3.8). Further extinctions are recorded in the middle and upper *Lystrosaurus* AZ together with impoverished rates of speciation (Figure 3.8). Secondary floral turnovers are seen in the Molteno and Lower Elliot formations with heightened rates of extinction in the Upper Elliot Formation (Figure 3.8). A larger floral turnover is manifest in the Clarens Formation with both high rates of speciation and extinction - this is thought to indicate a hiatus between the Upper Elliot and Clarens formation samples rather than true changes in the floras (Figure 3.8).

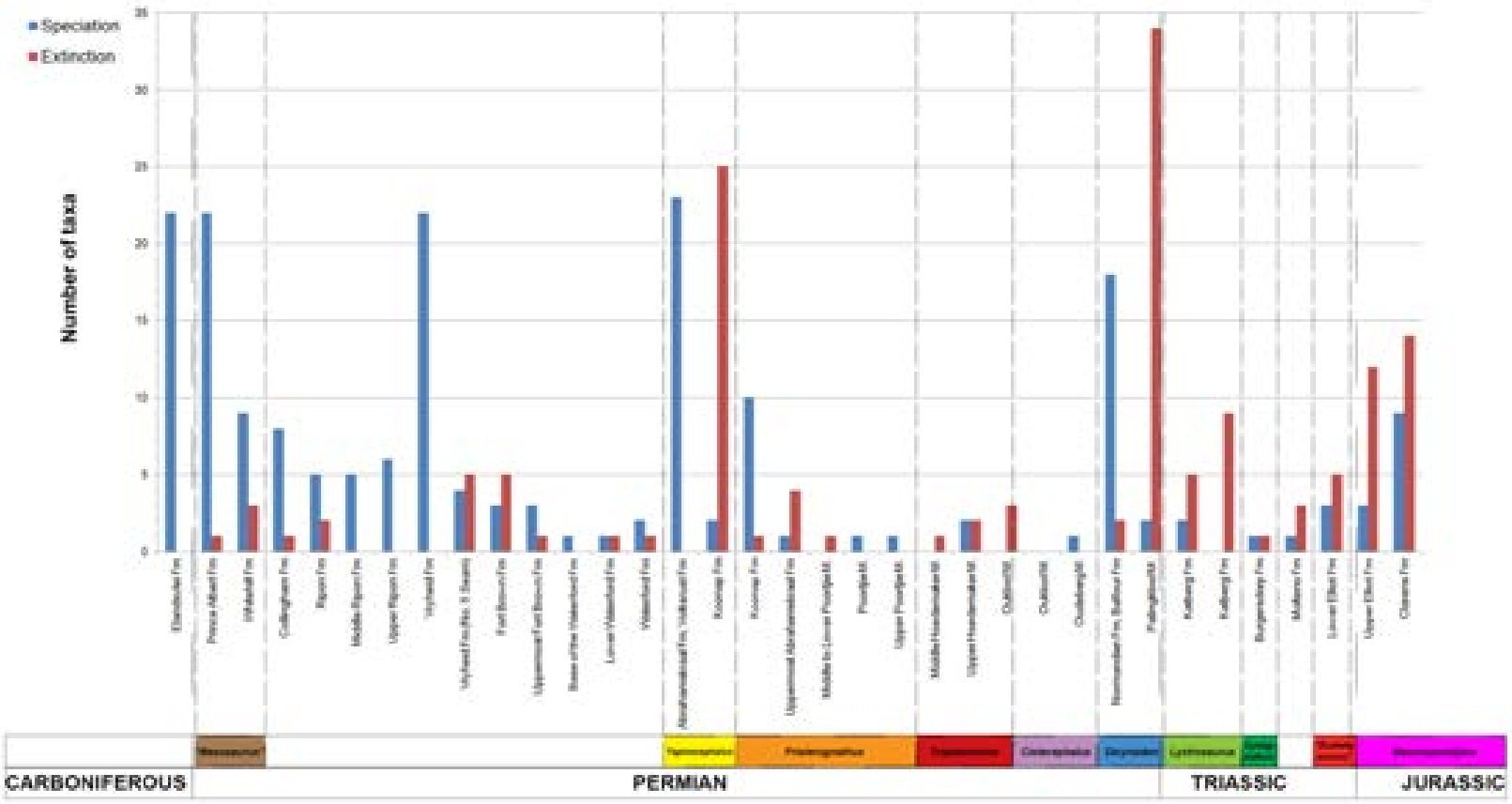


Figure 3.8: **Rates of palynomorph speciation and extinction in the Karoo Supergroup from the Carboniferous to the Jurassic. Rates of speciation and extinction refer to the number of taxa that have their FAD and LAD in that stratigraphic entity respectively. Where possible, samples thought to be chronologically equivalent have been grouped together in order to more accurately reflect microfloral changes through time, using information from Figure 3.7 and Appendix B (this work), and Rubidge *et al*. (1995).**

Three extinction events that occurred from the Carboniferous to Jurassic periods are globally recognised and they remain the subject of much research. Because of its excellent preservation the Karoo Supergroup is ideal for studying faunal diversity changes (Rubidge, 2005) and this can now be said for the palynology as well. These extinctions and the way in which they affected Karoo faunas and floras are discussed in more detail below.

3.5.1 END-GUADALUPIAN EVENT

This extinction event occurred during the Middle-Late Permian and primarily affected marine invertebrates (Jin *et al*., 1994), but precise timing as well as its effects in the terrestrial realm are controversial. Retallack *et al*. (2006) reported extinctions of both fossil plants and vertebrates together with a negative carbon isotopic anomaly at the end of the Guadalupian, using spore and pollen ranges from Falcon (1975), Anderson (1977), Stapleton (1978), MacRae (1988), Horowitz (1990), and Steiner *et al*. (2003) to determine plant extinction rates.

Wignall *et al*. (2009) argued for an earlier dating of this event because of correlation of the marine extinction to the onset of Emeishan volcanism in the mid-Capitanian (260 Ma). Rubidge *et al*. (2013) obtained radiometric dates for the *Pristerognathus*, *Tropidostoma* and *Cistecephalus* assemblage zones which also did not support an extinction at the end of the Guadalupian in the Karoo Basin. According to these dates, this event would have occurred in the lower-middle *Tropidostoma* AZ (International Chronostratigraphic Chart - Cohen *et al*., 2013) but no significant faunal turnover is observed at this stratigraphic horizon. A vertebrate extinction is however recorded at the end of the *Tapinocephalus* AZ (Rubidge, 2005) and this correlates very well to the great loss of palynomorph species in the Koonap Formation (Figure 3.8). Whether these extinctions are related to the "end- Guadalupian event" as described by Retallack *et al*. (2006) remains to be seen but at present there is little evidence for it (Rubidge *et al*., 2013, this work).

3.5.2 END-PERMIAN EVENT

The precise cause of the end-Permian mass extinction remains uncertain but it seems likely that a combination of factors was responsible for ecosystem breakdown, the results of which sent both the oceans and land into chaos (Erwin *et al*., 2002). The eruption of the Siberian Traps certainly played a major role causing runaway greenhouse warming and acid rain (Renne *et al*., 1995; Ward, 2007; Smith *et al*., 2012) but cannot completely account for the carbon isotopic swing (Wignall, 2001). A bolide impact, marine anoxia and gas hydrates have also been suggested (Bowring *et al*., 1998; Erwin, 2006). Faunal changes in the Karoo include the extinction of all pareiasaurs (Groenewald & Kitching, 1995), gorgonopsians, and dicynodonts (except for *Lystrosaurus*) (Smith & Ward, 2001). Only three forms of therocephalians survived this extinction event (*Moschorhinus*, *Tetracynodon* and *Ictidosuchops*) (Kitching, 1977; Groenewald & Kitching, 1995). Of significance is that the dominant and diverse *Glossopteris* flora from the southern hemisphere was wiped out (e.g. Retallack, 1995).

The *Dicynodon* Assemblage Zone encompasses the event bed that is correlative to the end-Permian extinction, considered here to be contained within the Palingkloof Member on the basis of much vertebrate fossil collecting in the Bethulie and Lootsberg Pass areas by Smith & Ward (2001). Although the end-Permian event bed in the Main Karoo Basin (Smith & Ward, 2001) has been correlated with the marine Permo–Triassic boundary by means of isotope stratigraphy (MacLeod *et al*., 1999), the P–T boundary global stratotype section and point (GSSP) at Meishan, China is situated at a slightly higher stratigraphic level than the ‘‘Permo–Triassic” mass extinction level (Metcalfe *et al*., 2009). Accordingly the mass extinction in fact occurs in the upper Changhsingian stage (Latest Permian) and is not concurrent with the Permian–Triassic boundary (Metcalfe *et al*., 2009).

Extinctions and recovery rates of therapsids over this boundary are reminiscent of a Signor-Lipps curve (Smith & Ward, 2001) and this complicates an

understanding of whether the end-Permian extinction was a catastrophic event, or more protracted. Palynology assists in solving this problem because a defining characteristic of mass extinctions is that they are not ecologically selective (Benton & Harper, 2009) and so palynomorphs should provide a similar reconstruction of such events to other kinds of organisms. Palynomorphs are more ubiquitous than large, comparatively rare vertebrate skeletons and macroplants, therefore the last appearances of palynomorph genera are less likely to be missed in the rock record. On the other hand, hiatuses across the boundary would affect both micro- and macrofossils equally, making a gradual extinction seem sudden.

This study did not set out to undertake detailed sampling of the Permo-Triassic boundary in the Karoo but samples were collected from the Late Permian Normandien Formation and Palingkloof Member, and Early Triassic Katberg Formation of the Beaufort Group which straddle the P-T boundary. No abnormal pollen was noted in these samples such as has been observed over the Permo-Triassic boundary (e.g. Looy *et al*., 2001; Foster & Afonin, 2005, Prevec *et al*., 2010). The dramatic loss of species within the Palingkloof Member (Figure 3.8) is concurrent with a sudden and catastrophic event among Permian floras. This is in contrast to the idea that while vertebrates and marine invertebrates seem to have died out suddenly, floristic changes were rather more protracted (e.g. Looy *et al*. 2001; Rees, 2002).

3.5.2.1 Palaeoenvironmental Reconstruction of the End-Permian Event

The Earth underwent severe environmental changes during (or as a result of) the end-Permian mass extinction (Erwin *et al*., 2002) but as yet there is little consensus on what exactly those changes were. In the Karoo Basin a transition from a warm temperate climate (Ward *et al*., 2005) to a dry and hot flood-plain environment is postulated, with a sedimentological and taphonomic signature indicative of severe drought conditions in the lower *Lystrosaurus* AZ (Smith, 1995; Smith *et al*., 2012). On palaeosol, sedimentological and palaeontological

evidence, Retallack *et al*. (2003) suggested a climatic shift from arid and highly seasonal in the Permian to semi-arid and less seasonal in the Triassic. McLoughlin *et al*. (1997) consider that sedimentological and palaeobotanical evidence from Antarctica points towards a change from consistently wet conditions in the Late Permian to a more seasonally dry climate in the Triassic.

Palynomorphs can be used as proxies for reconstructing palaeoenvironments but much remains unknown regarding the natural affinities of palynomorphs because discoveries of *in situ* spores and pollen are rare (Traverse, 2007), and different morphospecies and even morphogenera have been produced by the same cone (Bek & Opluštil, 1998). Botanical affinities of palynomorph indicator species from the Karoo Basin do not contribute a great deal to reconstructing palaeoenvironmental conditions over this extinction event (Figure 3.9). Most indicator taxa present in the *Dicynodon* and *Lystrosaurus* assemblage zones are water-dependant and occupied swamps, wetlands and other aquatic environments, with some less water-reliant elements including Glossopteridales, Cycadophyta, Ginkgophyta and Coniferopsida in the *Dicynodon* AZ (Figure 3.9). This may concur with the view that the Permo-Triassic boundary heralded a climatic shift from arid and highly seasonal in the Permian to semi-arid and less seasonal in the Triassic (Retallack *et al*., 2003).

Allochthonous palynoassemblages represent a broader ecological community than assemblages of autochthonous origin, but can suffer greater damage through extended transport in fluvial systems (Traverse, 2007), hence these assemblages tend to be less well-preserved than autochthonous microfloras. It may be possible that palynological samples obtained from allochthonous deposits in this study proved to be largely unproductive and the productive samples are thus mostly autochthonous in nature, not reflecting the greater regional environment of the time. Alternatively certain depositional environments of the Carboniferous, Upper Permian and Triassic were simply not ideal for the preservation of pollen, explaining the paucity of saccate pollen from these time periods.

	Indicator Palynomorph	Botanical Affinity	Known Habitats
Lystrosaurus	*Aratrisporites tenuispinosus*	Isoetalean lycopsids *Cylostrobus* & *Lycostrobus* (cones of Pleuromeiales) (Helby & Martin, 1965), and *Annalepis zeilleri* (Grauvogel-Stamm & Duringer, 1983)	Pleuromeiales occupied varying habitats from semi-arid (Wang & Wang, 1982), seasonally wet (Cantrill & Webb, 1998) to tidal (Retallack, 1975).
	Dictyophyllidites mortonii	Cheiropleuriaceae / Dipteridaceae / Matoniaceae *: Phlebopteris* (Ash *et al*., 1982; Litwin, 1985; Zavattieri & Volkheimer, 2003)	Wetlands (Volkheimer *et al*., 2007), tropical rainforest (Melendi *et al*., 2003)
	***Inapertisporites* sp. A**	Fungal spore (Elsik, 1968)	Water bodies / aquatic habitats
	Involutisporonites foraminus	Aquatic fungal genus (Kalgutkar & Braman, 2008)	Shallow, pond-like aquatic habitats (Kalgutkar & Braman, 2008)
	Tripunctisporis maastrichtiensis	Sphagnopsida moss spores (Macphail, 1999; Traverse, 2007)	Wet habitats - contributes to formation of peat bogs / mires (Taylor *et al*., 2009), fluvial environments (Götz *et al*., 2011)
Dicynodon	***Brazilea scissa***	Zygnematacean algae (Grenfell, 1995)	Fluvial and lacustrine facies - swamps, marshes and shallow, stagnant, oxygenated water bodies algae (Grenfell, 1995)
	Brevitriletes bulliensis	Equisetopsida, ?Zosterophyllopsida, Polypodiopsida (Balme, 1995)	Humid tropical / subtropical rainforest (Bell & Hemsley, 2000), lowland swamp forest (Taylor *et al*., 2009)
	Converrucosisporites naumoviae	Cheiropleuriaceae / Dipteridaceae / Matoniaceae and botryopterid ferns (Traverse, 2007)	Alongside streams (Nagalingum & Cantrill, 2006), wetlands (Volkheimer *et al*., 2007), tropical rainforest (Melendi *et al*., 2003)
	Cycadopites cymbatus	Bennettitales, Cycadales (Balme, 1995)	Humid, permanently moist environments (Pott *et al*., 2008; Pott & McLoughlin, 2009)
	Densoisporites psilatus	Pleuromeiales (Balme, 1995)	Pleuromeiales occupied varying habitats from semi-arid (Wang & Wang, 1982), seasonally wet (Cantrill & Webb, 1998) to tidal (Retallack, 1975).
	Dictyophyllidites mortonii	*Phlebopteris*: Matoniaceae (Ash *et al*., 1982; Litwin, 1985)	Wetlands (Volkheimer *et al*., 2007), tropical rainforest (Melendi *et al*., 2003)
	Granulatisporites convexus	*Gordonopteris lorigae* (van Konijnenburg-van Cittert *et al*., 2006), *Clathropteris:* Dipteridaceae (Litwin, 1985)	Warm and humid tropical climate (Wachtler, 2011), alongside streams (Nagalingum & Cantrill, 2006), marshes and riverbanks (van Konijnenburg-van Cittert, 2002)
	Hemisphaerium inominatum	Zygnematacean algae (Grenfell, 1995)	Fluvial and lacustrine facies - swamps, marshes and shallow, stagnant, oxygenated water bodies algae (Grenfell, 1995)
	***Inapertisporites* sp. A**	Fungal spore (Elsik, 1968; Jansonius & Kalgutkar, 2000)	Water bodies / aquatic habitats

Inaperturopollenites dubius	Cordaites (Looy *et al*., 2001)	Lowland peat mires, poorly to well drained mineral soils, a few giant forms in upland settings (Taylor *et al*., 2009)
Involutisporonites foraminus	Aquatic fungal genus (Kalgutkar & Braman, 2008)	Shallow, pond-like aquatic habitats (Kalgutkar & Braman, 2008)
Ischyosporites volkheimeri	Schizaeaceae : Polypodiopsida (Balme, 1995)	Humid tropical / subtropical rainforest (Bell & Hemsley, 2000)
Limbosporites denmeadii	Lycopsida (Raine *et al*., 2011)	Swamps, tropical rainforest (Taylor *et al*., 2009)
Lophotriletes scotinus	Botryopteridales : Polypodiopsida (Balme, 1995)	Humid tropical / subtropical rainforest (Bell & Hemsley, 2000)
Marsupipollenites striatus	?Ginkgoopsida: ?Glossopteridales (Balme, 1995)	Wide range of habitats (Taylor *et al*., 2009), cool and constantly moist mires (McLoughlin *et al*., 1997)
Marsupipollenites triradiatus	*Polytheca elongata:* ?Glossopteridales (Balme, 1995)	Swamps (Taylor *et al*., 2009), fluvial and lacustrine environments (Cúneo *et al*., 1993), cool and constantly moist mires (McLoughlin *et al*., 1997)
Mehlisphaeridium fibratum	Probable algae (Foster *et al*., 1985)	Water bodies / aquatic habitats
Micrhystridium karrooense	Acanthomorph acritarch (Bjærke & Manum, 1977)	? Proximal / nearshore assemblages (Mory & Backhouse, 1997)
Playfordiaspora crenulata	Cycadofilicalean pollen (Bharadwaj & Venkatachala, 1968)	Forest climbers (Burnham, 2009)
Plicatipollenites gondwanensis	Gymnospermopsida (Raine *et al*., 2011)	Wide range of habitats (Taylor *et al*., 2009)
Potonieisporites magnus	Coniferopsida: Emporiaceae, Rufloriaceae, Utrechtiaceae (Balme, 1995)	Wide range of habitats (Taylor *et al*., 2009)
Protohaploxypinus limpidus	Ginkgoopsida: Glossopteridales, Peltaspermales (Balme, 1995)	Wide range of habitats (Taylor *et al*., 2009), cool and constantly moist mires (McLoughlin *et al*., 1997)
Pteruchipollenites landianus	*Pteruchus*: Ginkgoopsida (Balme, 1995; Taylor *et al*., 2009), *Dinophyton spinosus*: Gnetales (Krassilov & Ash, 1988)	Wide range of habitats (Taylor *et al*., 2009), mesic environments (Doyle *et al*., 1982)
Pustulatisporites distinctus	Unknown (Pittau *et al*., 2008)	-
Scheuringipollenites ovatus	Ginkgoopsida (Peltaspermales): Coniferopsida (Podocarpaceae, Ulmanniaceae, Voltziales s.1.) (Balme, 1995)	Wide range of habitats (Taylor *et al*., 2009)
Schopfites dimorphus	Unknown (Ravn, 1983)	-
***Striatoabieites* sp.**	Coniferopsida (Balme, 1995)	Wide range of habitats (Taylor *et al*., 2009)
Vittatina fasciolata	Peltaspermales: Ginkgoopsida (Balme, 1995)	Wide range of habitats (Taylor *et al*., 2009)

Figure 3.9: Botanical affinities of the *Dicynodon* and *Lystrosaurus* Zones indicator palynomorphs and their known habitats.

Much remains to be understood about how floras responded to the end-Permian event (e.g. McLoughlin *et al*., 1997) but a greater understanding of whether or not floral losses differed relative to the vertebrate and marine invertebrate extinctions may shed light on the root causes of the mass extinction itself.

3.5.3 END-TRIASSIC EVENT

The end-Triassic event may not fit the profile of a mass extinction at all, lasting for 5 myr or more, and seems to be an event of depressed origination as much as increased extinction (Bambach, 2006). Likely causes include anoxia and global warming related to the eruption of flood basalts triggered by the breakup of Pangaea (Wignall, 2001). Globally the event involved the loss of many marine taxa (Benton & Harper, 2009) and in the Karoo a faunal change from large basal sauropod and prosauropod dinosaurs to smaller taxa such as *Massospondylus* took place (Kitching & Raath, 1984; Yates & Kitching, 2003). In South Africa this faunal turnover corresponds with the Triassic - Jurassic boundary and is contained within the Elliot Formation, possibly on the contact between the lower *Euskelosaurus* and upper *Massospondylus* Range Zones (Kitching & Raath, 1984; Olson & Galton, 1984). At present, macroplant records of this event are relatively scarce (Anderson & Anderson, 1985) and thus it is not possible to infer floral losses from fossil plants. Palynology supports the hypothesis for a protracted extinction (Bambach, 2006) beginning in the Late Triassic but in the Karoo Supergroup there is a major palynological turnover within the Upper Elliot formation (Figure 3.8). Depressed origination as suggested by Bambach (2006) is not observed among palynomorphs from the Karoo.

3.6 MICROFLORAL CORRELATIONS

3.6.1 SOUTH AFRICAN CORRELATIONS

Previous palynological work in the South African Karoo Basin has enabled correlation of this succession with other Gondwanan microflora-bearing sequences, but this has often been hampered by the lack of a solid stratigraphic foundation, especially for older work. In Figure 3.10, Carboniferous, Permian and Triassic microfloras from previous South African studies are integrated within the Karoo palynostratigraphic scheme using both stratigraphic and palynological data. Correlations are made on the basis of shared taxa rather than using quantitative trends in abundance of various species. These trends can be affected by localised environmental factors and are not useful for regional correlations.

Although the study of MacRae (1988) was not located within the Main Karoo Basin, it is a major South African palynozonation that has been used for correlation purposes in many other South African studies, hence it is included in the South African rather than the Gondwana correlation chart. Formations of the Waterberg and Pafuri Basins differ from those of the Main Karoo Basin but they preserve very similar microfloras and can be correlated to Dwyka and Ecca group microfloras of this and previous studies on Karoo rocks (Figure 3.10). Concurrent Range Zone A of MacRae (1988) can be correlated with Zone 1 of Anderson (1977) which not only encompasses the Dwyka Group but also includes the Pietermaritzburg Fm (former Upper Dwyka Shales) (Cole, 2005). These zones bear little resemblance to the Dwyka microflora recovered from this study as they include palynomorphs from the Lower Ecca as well as the Dwyka groups.

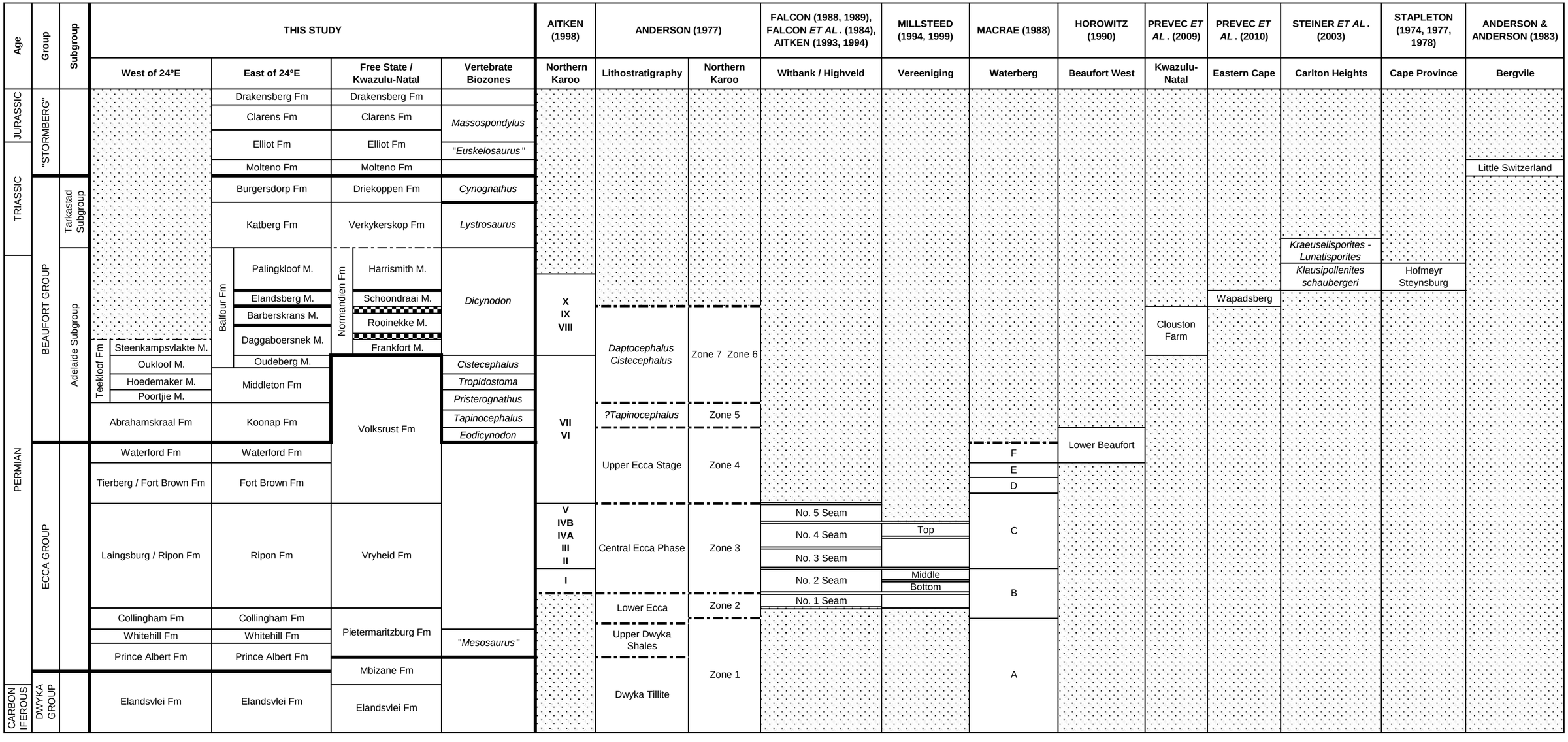


Figure 3.10: Correlation of South African palynological studies within the palynostratigraphic context of this work, using data from Aitken (1993, 1994, 1998), Anderson (1977), Anderson & Anderson (1983), Falcon (1988, 1989), Falcon *et al*. (1984), Horowitz (1990), MacRae (1988), Millsteed (1994, 1999), Prevec *et al*. (2009, 2010), Stapleton (1974, 1977, 1978) and Steiner *et al*. (2003). Dotted lines indicate uncertainty regarding the upper / lower limits of a section. Shared palynomorph taxa for each correlation are either listed in the text or in Appendix B. Thickness of formations not to scale.

Palynofloras of the No. 2 seam, Witbank coalfield (Falcon, 1988, 1989), No. 5 seam, Witbank coalfield (Aitken, 1993, 1994), No. 1, 3 and 4 Seams (Falcon *et al*., 1984) and the Bottom, Middle and Top Seams of the New Vaal Colliery, Vereeniging (Millsteed 1994, 1999) can be correlated with microflora recovered from the Vryheid Formation in this study (Figure 3.10), but these studies incorporate many additional species not recovered here. This can be explained by the fact that the above authors concentrated their study on the Vryheid Formation alone whereas this work did not focus on intensive re-sampling of already well known palynofloras. The Witbank and Vereeniging seams also share many taxa that are distinctive of the Early Permian with the Prince Albert and Ripon (12 species), Collingham (9 species) and Whitehill (7 species) formations (Appendix B).

Biozone IVB of Aitken (1998) and Concurrent Range Zones A and B of MacRae (1988) can be correlated with the Vryheid Formation microflora of this study (Figure 3.10). The presence of *Corisaccites alutas*, *Granulatisporites trisinus*, *Protohaploxypinus limpidus*, *Protohaploxypinus* sp. and *Striatopodocarpites cancellatus* in the Collingham Formation may suggest an association with Biozone V of Aitken (1998), corresponding to the No. 5 Seam, upper Vryheid Formation but this is tentative as these species have long ranges through the Vryheid and Volksrust formations (Figure 3.10). Zone I of Aitken (1998) also correlates very well to the No. 2 seam, Witbank coalfield (Falcon, 1988, 1989). Although the microflora of Zone 3 of Anderson (1977) is derived from the Vryheid Formation, it only shares the taxa *Granulatisporites trisinus*, *Striatopodocarpites fusus* and *Vestigisporites rudis* with the Vryheid Formation microflora of this study.

The Fort Brown and Waterford formation microfloras have 9 and 8 species respectively in common with the palynoflora of the Witbank and Vereeniging seams (Appendix B). Comparison to the Volksrust Formation microfloras of Aitken (1998), Anderson (1977) and this study reveals 11 species in common with the Ripon Formation microflora, 10 shared taxa with the Abrahamskraal and

Waterford formation microfloras, and 9 species in common with the Fort Brown Formation microflora (Appendix B). This is generally congruent to correlations using only palynomorph taxa with a restricted range (Section 3.4) and indicates that the Vryheid Formation microflora shows the strongest similarities to that of the Prince Albert and Ripon formations, but can also be linked to the Collingham, Fort Brown, Waterford and Whitehill formation microfloras. The Volksrust Formation palynoflora is most similar to that of the Ripon, Waterford and Abrahamskraal formations but also shows strong similarities to the Fort Brown Formation palynoflora. For the most part, these palynological correlations lend support to the lithological correlations for the Ecca Group proposed by Catuneanu *et al*. (2002).

The microfloras of Biozones VI and VII of Aitken (1998) are derived from the Volksrust Formation and correlate well to the Volksrust Formation microflora of this study as well as Zone 4 of Anderson (1977) and Concurrent Range Zones D, E and F of MacRae (1988) (Figure 3.10, Appendix B).

Palynological samples were obtained from outcrops and boreholes near Beaufort West by Horowitz (1990) and the area was identified as being approximately on the "*Tapinocephalus* - *Cistecephalus* contact, Lower Formation of the Beaufort Group" (Horowitz, 1990, p. 537). The microflora correlates to Zone 4 of Anderson (1977), Biozone VII of Aitken (1998) and the Volksrust - Abrahamskraal formation palynofloras of this study on the presence of *Altitriletes densus*, *Apiculatisporis* sp., *Gondisporites parvus*, *Horriditriletes ramosus*, *Protohaploxypinus amplus*, *Protohaploxypinus goraiensis*, *Pteruchipollenites* sp., *Vittatina* sp. and *Vitreisporites pallidus*, indicating that these samples were likely derived from the Upper *Tapinocephalus* Zone (Figure 3.10).

Palynofloras from Clouston Farm, Normandien Formation, KwaZulu-Natal (Prevec *et al*., 2009) and Wapadsberg Pass, Balfour Formation, Eastern Cape (Prevec *et al*., 2010) correlate well with the microflora from the *Dicynodon* AZ of this study (Figure 3.10, Appendix B). Zones VIII, IX and X of Aitken (1998) can

also be correlated to these assemblages with many distinctive taxa in common, particularly *Falcisporites stabilis*, *Columinisporites* sp., *Vitreisporites pallidus*, *Lunatisporites pellucidus* and *Aratrisporites* sp. . Zones 6 & 7 of Anderson (1977) correlate well with the Clouston Farm microflora of Prevec *et al*. (2009) and the two assemblages share abundant *Protohaploxypinus* as well as *Alisporites ovatus*, *Apiculatisporis cornutus* and *Weylandites lucifer* (Figure 3.10). Additional taxa that may be added to the Normandien Formation as indicators of that stratigraphic entity include the above taxa as well as *Chordasporites waterbergensis*, *Protohaploxypinus goraiensis*, *Lueckisporites virkkiae*, *Guttulapollenites hannonicus*, *Lunatisporites noviaulensis*, *Klausipollenites schaubergeri* and *Falcisporites australis* (Prevec *et al*., 2009, 2010).

The palynological study of Carlton Heights in the southern Karoo Basin by Steiner *et al*. (2003) is one of the most controversial in recent years, with many authors disputing the stratigraphic assignment of these samples as well as the fungal spike itself (see Literature Review for full discussion and references). Prevec *et al*. (2010) places the Wapadsberg Pass assemblage at the base of the *Klausipollenites schaubergeri* Zone of Steiner *et al*. and this correlation is retained here (Figure 3.10). The two assemblages share the taxa *Protohaploxypinus limpidus*, *Klausipollenites schaubergeri* and *Falcisporites stabilis* and the microflora from the *Klausipollenites schaubergeri* Zone of Steiner *et al*. (2003) likely derives from the Elandsberg Member, Balfour Formation and can be dated as Late Changhsingian in age (Prevec *et al*., 2010). No counterpart to the fungal spike of Steiner *et al*. (2003) was located in this study or any other as yet, but *Reduviasporonites chalastus* was found in many stratigraphic intervals throughout the Karoo Supergroup. Prevec *et al*. (2010) place the Permo-Triassic boundary in the *Kraeuselisporites-Lunatisporites* Zone of Steiner *et al*. (2003) on the basis of correlation with the Australian palynozones. The Katberg Formation microflora of this study bears little resemblance to the *Kraeuselisporites-Lunatisporites* Zone of Steiner *et al*. (2003) and is thought to be younger in age.

Palynological investigations by Stapleton (1974, 1977, 1978) produced a microflora that can be best correlated with the *Klausipollenites schaubergeri* Zone of Steiner *et al*. (2003) on the presence of *Densoisporites playfordii*, *Falcisporites zapfei* (*Limitisporites monstruosus*), *Klausipollenites schaubergeri*, *Platysaccus papilionis*, *Protohaploxypinus microcorpus* and *Protohaploxypinus samoilovichii* (Figure 3.10). Stapleton (1977) assigned these palynomorphs an early Early Triassic age on their known ranges from other localities in Gondwana but believed them to derive from Uppermost Beaufort and Molteno rocks. This cannot be correct because the Molteno Formation is of Late Triassic age (Hancox, 1998). An examination of the palynomorphs indicates their age assignment is approximately correct as all taxa are known from either the Late Permian or Early Triassic of other Gondwanan localities. Regarding their stratigraphic assignment, the Molteno Formation "is easily confused with analogous upper Beaufort Group (Permo-Triassic) fluvial deposits" (Catuneanu *et al*., 2005, pg. 241), and the palynology supports the hypothesis that these samples were in fact taken from Late Permian and Early Triassic Beaufort Group rocks and not the Beaufort - Molteno contact.

The palynology of the Little Switzerland locality is derived from the Molteno Formation (Anderson & Anderson, 1983) and can be correlated to the Molteno Formation palynoflora on the presence of *Dictyophyllidites mortonii*, *Thymospora ipsviciensis*, *Equisetosporites steevesi* and *Uvaesporites verrucosus* (Figure 3.10). The palynological diversity of the Molteno Formation is not significantly higher than that of other Karoo formations, suggesting that the huge diversity of macroplant fossils (Anderson & Anderson, 1985) is as a result of extensive sampling and preservation biases rather than higher ecological diversity among plants during the Late Triassic.

The Elliot and Clarens formations have not yielded microfloras before this study and hence these palynofloras cannot be correlated to any other South African studies as yet.

It is apparent from the above palynological correlations that the South African microfloras are well constrained by the lithological formations they are derived from (Figure 3.7). Falcon *et al*. (1984) noted that the palynozones correlated well with the boundaries of the lithostratigraphic units in the Witbank coalfield. This is true for other biozones as well, for example the Volksrust Formation microfloras comprising Zones 3 and 4 of Anderson (1977) correlate well to the Volksrust Formation microfloras of Aitken (1998) comprising Biozones VI and VII. This is not necessarily the case for other African Karoo Basins or Gondwana successions and until it is shown to be true for other coeval localities, it would be rash to correlate formations from different basins solely on their palynological content. However it is possible to correlate microfloras from indeterminate localities in the Main Karoo Basin to microfloras with known stratigraphic provenance, meaning that palynology can be used to infer stratigraphic information for Karoo rocks.

3.6.2 GONDWANAN CORRELATIONS

A significant problem in correlating Gondwanan microfloras is provincialism (e.g. Truswell, 1981) and this is particularly evident in the Permian with elevated levels of endemic taxa (Prevec *et al*., 2009). This is reflected palynologically with, for example, several stratigraphically useful Australian species absent from other continents in Gondwana. These include *Dulhuntyspora dulhuntyi* (Backhouse, 1991), *Dictyotriletes aules*, *Protohaploxypinus rugatus* and *Bascanisporites undosus* (Anderson, 1977). This is unfortunate because the Australian palynozones are calibrated against independently dated marine faunas (Foster & Archbold, 2001; Metcalfe *et al*., 2008), carbon isotopes, and radiometric dates (Metcalfe *et al*., 2008), making them the current standard biostratigraphic classification for the southern hemisphere (Prevec *et al.*, 2010). Figure 3.11 relates the microfloral representation resulting from this work to the standard Australian palynozones (see Literature Review for references) as well as selected Gondwanan biozonations from Africa, Antarctica, New Zealand and South America. Biozonation schemes that are dissimilar or show only broad similarities

to the Karoo Basin microfloras have not been included because such correlations would be tentative at best and are thus likely to be revised in future.

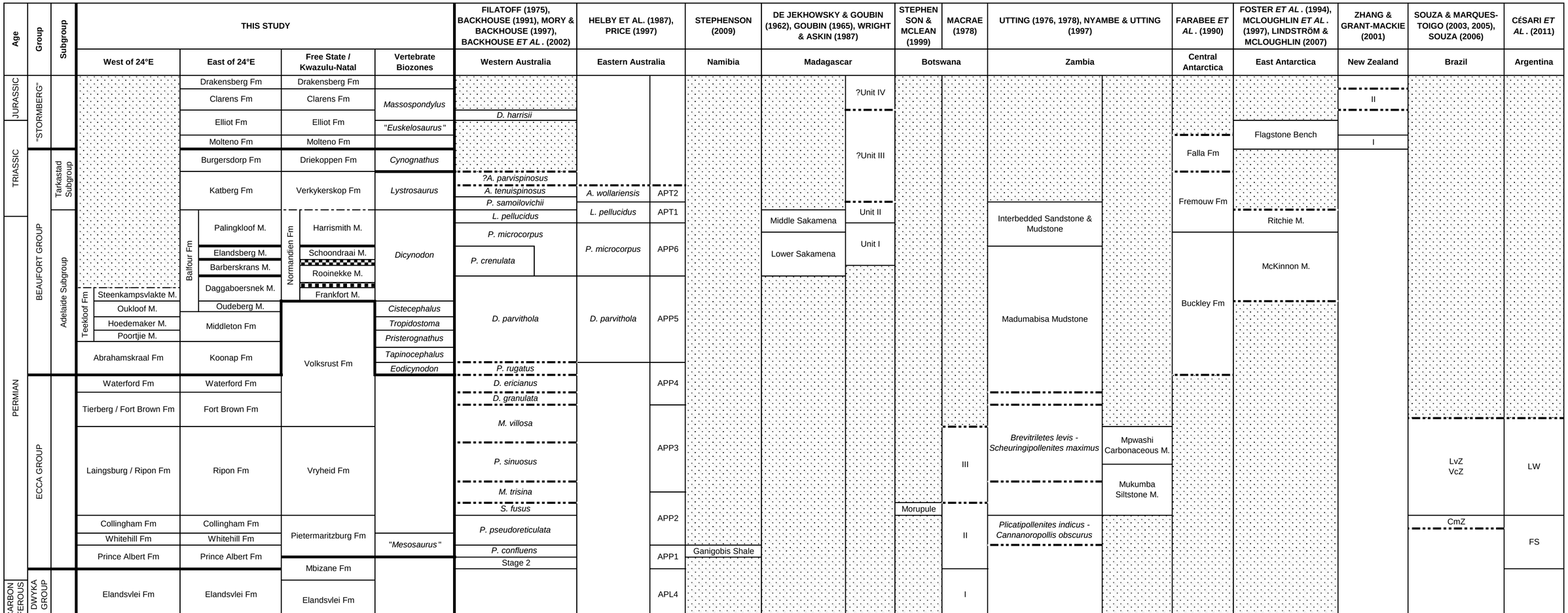


Figure 3.11: Correlation of microfloras from the Main Karoo Basin of this study to palynological biozones and successions of Australia, Africa, Antarctica, New Zealand and South America. Dotted lines indicate uncertainty regarding the upper / lower limits of a section. Where necessary, shared palynomorph taxa for each correlation are either listed in the text or in Appendix B. Thickness of formations not to scale.

3.6.2.1 Australian Correlations

In Australia the base of Stage 2 of Evans (1967, 1969) and Kemp *et al*. (1977) / APP1 of Price (1997) is defined by the introduction of taeniate bisaccate pollen which is first seen in the Prince Albert Formation in this study (Appendix B). Using the amended definition of Powis (1984), Stage 2 can also be correlated with the Prince Albert Formation on the collective first appearance of *Acanthotriletes tereteangulatus* and *Apiculatisporis cornutus* (Figure 3.11). The *Pseudoreticulatispora* (*Converrucosisporites*) *confluens* Oppel Zone of Foster and Waterhouse (1988) lies directly above Stage 2 in Australia with the two zones preserving a similar microflora except that Stage 2 does not contain *P. confluens* (Backhouse, 1991). This taxon does not appear to be present in South Africa however it has been recovered from the Ganigobis Shale Member of Namibia as well as other successions associated with Carboniferous-Permian deglaciation (Stephenson, 2009). The *P. confluens* Oppel Zone is thus tentatively placed between Stage 2 and the overlying *Pseudoreticulatispora pseudoreticulata* Zone of Backhouse (1991) / APP2 of Price (1997), corresponding with the upper Prince Albert Formation, and the Pietermaritzburg Formation (Figure 3.11). In this study productive samples were not obtained from the Pietermaritzburg Formation and *Converrucosisporites pseudoreticulatus* is first seen in the Vryheid Formation, but Anderson (1977) noted this species in the Pietermaritzburg Formation.

The base of the *Striatopodocarpites fusus* Zone is characterised by the first appearances of *Striatopodocarpites fusus* and *S. cancellatus* (Backhouse, 1991) and in this study, these are in the Vryheid and Collingham formations respectively (Appendix B). Aitken (1998) first recorded both these taxa in Biozone IVB which is correlated with the Vryheid Formation microflora of this study. *Florinites eremus* also appears in the *S. fusus* Zone in Australia and is first recorded from the Vryheid Formation in this study. Accordingly the *Striatopodocarpites fusus* Zone is placed at the base of the Vryheid Formation for the present, but this may have implications for the age of the Collingham Formation. Either this formation is of similar age to the Vryheid Formation, or alternatively the Collingham Formation

is slightly older and the *S. fusus* Zone in fact begins in this formation, or possibly *S. cancellatus* appears earlier than *S. fusus* in South Africa (Figure 3.11).

The base of the *Microbaculispora trisina* Zone is defined by the first occurrence of *Microbaculispora trisina* (*Granulatisporites trisinus*) and the top by the first occurrence of *Praecolpatites sinuosus* (Backhouse, 1991). This is problematic because in the Karoo microflora *Granulatisporites trisinus* first occurs in the Whitehill Formation and *Praecolpatites sinuosus* is already present in the Prince Albert Formation (Appendix B). Backhouse (1991) found the palynostratigraphy of the Collie and Karoo Basins to be similar only below the *P. sinuosus* Zone, and correlated the *M. trisina* zone with the lower part of Zone 3 of Anderson (1977), corresponding approximately to the No. 2 Seam, Vryheid Formation. The *Praecolpatites sinuosus* Zone correlates to the middle part of Zone 3 of Anderson (1977) (Backhouse, 1991). The overlying zones are not correlatable with this study because their indicator taxa were not recovered in this study, however Anderson (1977) did report these taxa thus allowing a correlation with the zones of Backhouse (1991). The *Microbaculispora villosa* Zone is characterised by the first occurrence of *Microbaculispora villosa* and the top by the first occurrence of *Dulhuntyspora granulata* (Backhouse, 1991) and can be correlated to the upper part of Zone 3 and lower part of Zone 4 of Anderson (1977) (Figure 3.11). The succeeding *Dulhuntyspora granulata*, *Didecitriletes ericianus*, and *Protohaploxypinus rugatus* zones of Backhouse (1991) / APP4 of Price (1997) are correlatable to the remainder of Zone 4 of Anderson (1977) (Figure 3.11). The *Dulhuntyspora parvithola* Zone of Backhouse (1991) / APP5 of Price (1997) can be considered to terminate at the base of the New Wapadsberg Pass assemblage of Prevec *et al*. (2010) and therefore extends into the *Dicynodon* AZ of this study.

The *Protohaploxypinus microcorpus* Oppel Zone of Helby (1974) is defined by the oldest common occurrence of *Falcisporites australis* and *P. microcorpus* together with *Playfordiaspora velata* and *Triplexisporites playfordii*. This zone can be correlated with the *Klausipollenites schaubergeri* Zone of Steiner *et al*. (2003) on the presence of the indicator taxon *P. microcorpus* as well as

Triplexisporites playfordii, *Playfordiaspora crenulata* and *Densoisporites* spp. (Figure 3.11). *Protohaploxypinus microcorpus* was only recovered from the Vryheid Formation during the current study but the *Playfordiaspora crenulata* Zone of Foster (1982) is considered a basal subzone of the *P. microcorpus* Zone, and *P. crenulata* is restricted to the Barberskrans and Elandsberg members in this study. This permits a definite correlation to this Late (but not latest) Changhsingian (Metcalfe *et al*., 2008) aged zone (Figure 3.11). The *P. crenulata* Zone / APP601 subzone of Price (1997) is associated with the last known *Glossopteris*-dominated macrofloras in the Bowen Basin of Australia (Foster, 1982) and less than 2 m below the last occurrence of *Vertebraria* fossils in the Buckley Formation of Antarctica (Collinson *et al*., 2006).

On the basis of recent studies by Thomas *et al*. (2004) and Metcalfe *et al*. (2008), the Permo-Triassic boundary can be placed in the lower part of the *Lunatisporites pellucidus* (Helby, 1974) and APT1 of Price (1997) zones. The *Kraeuselisporites-Lunatisporites* Zone of Steiner *et al*. (2003) can be correlated with the *L. pellucidus* and the overlying *Protohaploxypinus samoilovichii* zones of Helby (1974). *Aratrisporites tenuispinosus* is present in the Katberg Formation microflora of this study providing a well-constrained correlation with the Triassic *Aratrisporites tenuispinosus* Zone of Helby *et al*. (1987) (Figure 3.11). Younger Triassic palynozones of Helby *et al*. (1987) and Backhouse *et al*. (2002) do not correlate well with Karoo microfloras of this study because the characteristic index taxa of Australia are absent in South African rocks.

The presence of Cf. *Dictyophyllidites harrisii* in the Upper Elliot Formation may suggest a correlation with the *Dictyophyllidites harrisii* Sub-zone of Filatoff (1975), which is considered to be Early Jurassic in age (Figure 3.11), however more confirmed specimens of this type would need to be recovered from the Upper Elliot in order to be certain of this. The remainder of the Jurassic palynozones of Filatoff (1975) differ in species content to Karoo rocks.

The Australian practice of defining palynozones based on the first appearance of particular index taxa is an excellent one but unfortunately endemism and differing stratigraphic ranges can prevent some of these biozones from being successfully correlated to South African rocks. Future work should focus on examining the stratigraphic ranges of possible index taxa in South Africa in order to develop a similar system for Karoo microfloras, because such palynozones are a more reliable and accurate way of correlating basin-wide formations than the current practice of defining and correlating abundance biozones.

3.6.2.2 African Correlations

Namibia:

The Ganigobis Shale Member microflora (Dwyka Group, Namibia) can be correlated with the *Converrucosisporites* (*Pseudoreticulatispora*) *confluens* Oppel Zone on the presence of *Converrucosisporites confluens*, *Caheniasaccites ovatus*, *Cannanoropollis* spp., *Cycadopites cymbatus*, *Horriditriletes ramosus*, and *Plicatipollenites* spp. (Stephenson, 2009) (Figure 3.11).

Madagascar:

Unit I of the Morondava Basin, southwest Madagascar (Goubin, 1965) contains elements of both the Wapadsberg Pass assemblage of Prevec *et al*. (2010) and the *Klausipollenites schaubergeri* Zone of Steiner *et al*. (2003) and is hence accorded a position corresponding to the *P. microcorpus* Zone (Figure 3.11). This unit was said to be Late Permian by Goubin (1965) and this age is in accordance with the South African and Australian palynozones. The microfloral assemblage from the Lower Sakamena Group, Morondava Basin (Wright & Askin, 1987) can be correlated to the *Playfordiaspora crenulata* Zone in Australia (Foster, 1982), both containing *Guttulapollenites hannonicus*, *Weylandites* spp., *Lueckisporites*

virkkiae, *Protohaploxypinus*, *Striatopodocarpites*, *Platysaccus* spp., *Alisporites* spp., *Falcisporites* spp., *Scheuringipollenites* spp., *Klausipollenites schaubergeri*, *Protohaploxypinus microcorpus* and *Lunatisporites pellucidus* (Figure 3.11).

The Middle Sakamena microflora (Wright & Askin, 1987) is said to be Early Triassic in age and can be correlated with the upper *Protohaploxypinus microcorpus* and *Lunatisporites pellucidus* zones of Australia (Foster, 1982) (Figure 3.11). Unit II of the Morondava Basin, southwest Madagascar (Goubin, 1965) can be correlated with the *Kraeuselisporites-Lunatisporites* Zone of Steiner *et al*. (2003) on the presence of *Platysaccus leschickii*, *Lunatisporites pellucidus* and *Taeniaesporites* (*Lunatisporites*) *noviaulensis* (Figure 3.11).

The microfloras of Units III (Middle Triassic - Early Jurassic) and IV (Early - Late Jurassic) of the Morondava Basin, southwest Madagascar (Goubin, 1965) are not similar to the Karoo microfloras and at present it is unknown how they relate to the Main Karoo Basin.

Botswana:

The base of Concurrent Range Zone II of MacRae (1978), north-eastern Botswana can be correlated with the Prince Albert Formation palynoflora on the species range initiations of *Acanthotriletes tereteangulatus*, *Apiculatisporis* sp., *Circulisporites parvus*, *Lophotriletes* sp., and *Striatopodocarpites* cf. *rarus* (Figure 3.11). Concurrent Range Zones I and III of MacRae (1978) do not correlate well with the Karoo microfloras of this study but can be correlated with Zones 1 and 3 of Anderson (1977).

The Morupule microflora, southeast Botswana (Stephenson & McLean, 1999) can be correlated to the *Striatopodocarpites fusus* Zone of Backhouse (1991) and the base of the Vryheid Formation microflora in this study on the presence of *Striatopodocarpites fusus*, *Striatopodocarpites cancellatus*, *Procoronaspora*

spinosa, *Laevigatosporites colliensis*, *Converrucosisporites* (*Verrucosisporites*) *pseudoreticulatus*, and *Florinites eremus*, and the absence of *Microbaculispora trisina* (Figure 3.11).

Zimbabwe:

The palynozones of Falcon (1975, 1978) erected within the Mid-Zambezi and Sabi-Limpopo Basins of Zimbabwe differ markedly from the Karoo microfloras with regard to first appearance datums of species and this complicates correlations. The upper boundary of Assemblage Zone I (*Virkkipollenites - Plicatipollenites* Assemblage) can be placed within the Prince Albert Formation of this study on the FAD of *Striatopodocarpites rarus*. The upper boundary of Assemblage Zone II (Transition Zone) is marked by the FAD of *Striatopodocarpites cancellatus*, which this is first seen in the Collingham Formation of this study (Appendix B). The upper boundary of Assemblage Zone III (*Densosporites -Gondispore* assemblage) is marked by the FAD of *Striatopodocarpites fusus* and *Vittatina* sp. which are first seen in the Vryheid and Ripon formations of this study respectively, therefore these formations can be correlated to Assemblage Zone IV (*Vittatina-Lueckisporites* Assemblage). However, this does not agree with the age of the rocks from which these microfloras are derived. Assemblage Zone IV is associated with the Madumabisa Mudstone, which is Late Permian in age (Nyambe & Dixon, 2000). Zone V was thought by Falcon (1978) to be the equivalent of the Triassic *Lystrosaurus* or *Cynognathus* Zones in the MKB, and is marked by the FAD of *Alisporites* (*Pteruchipollenites*) *landianus*, but this taxon is first seen in the Vryheid Formation of this study (Appendix B). Further research into the palynology of Zimbabwe may shed light on differences between the Main Karoo and Mid-Zambezi / Sabi-Limpopo Basins but at this point their microfloral zones cannot be correlated.

The Mukumba Siltstone and Mpwashi Carbonaceous member palynoassemblages (Utting, 1976) can be correlated to the Vryheid and Ripon formation microfloras

of this study on the presence of *Acanthotriletes tereteangulatus*, *Apiculatisporis* sp., *Cyclogranisporites gondwanensis*, *Deltoidospora directa*, *Converrucosisporites pseudoreticulatus*, *Cannanoropollis densus*, *Cannanoropollis mehtae*, *Cannanoropollis obscurus*, *Cycadopites cymbatus*, *Granulatisporites trisinus*, *Hamiapollenites* sp., *Horriditriletes filiformis*, *Marsupipollenites striatus*, *Striatopodocarpites cancellatus* and *Vittatina* sp. (Figure 3.11).

Zambia:

The *Plicatipollenites indicus* - *Cannanoropollis obscurus* Zone, Kazinze area, Zambia (Nyambe & Utting, 1997) can be correlated with the Whitehill and Collingham formation microfloras of this study and the *P. pseudoreticulata* Zone of Australia on the presence of *Converrucosisporites pseudoreticulatus* and the absence of *Striatopodocarpites fusus* and *S. cancellatus* (Figure 3.11). The *Brevitriletes levis* - *Scheuringipollenites maximus* Zone (Nyambe & Utting, 1997) can be correlated with the Vryheid and Volksrust formation microfloras of this study on the presence of *Cycadopites cymbatus*, *Deltoidospora directa*, *Horriditriletes filiformis*, *Protohaploxypinus limpidus*, *Striatopodocarpites cancellatus* and *Scheuringipollenites ovatus* (Appendix B, Figure 3.11). A possible correlation with the Koonap Formation palynoflora is also suggested by the presence of *Deltoidospora directa*, *Pilasporites plurigenus* and *Punctatisporites gretensis* (Appendix B, Figure 3.11). The base of the Madumabisa Mudstone Fm microflora (Nyambe & Utting, 1997) can be related to the assemblage of Horowitz (1990) on the presence of *Protohaploxypinus goraiensis* and *Vitreisporites pallidus*.

This Madumabisa microfloral zone is thought to extend upwards to the Wapadsberg Pass assemblage of Prevec *et al*. (2010) on the presence of *Guttulapollenites hannonicus*, *Protohaploxypinus limpidus*, *Protohaploxypinus goraiensis*, *Striatopodocarpites* and *Weylandites lucifer* (Figure 3.11). The

Interbedded Sandstone & Mudstone Fm microflora (Nyambe & Utting, 1997) can be partly correlated with the Barberskrans and Elandsberg member palynofloras of this study, the *Playfordiaspora crenulata* Zone of Foster (1982), and the *Klausipollenites schaubergeri* Zone of Steiner *et al*. (2003) on the presence of *Alisporites*, *Falcisporites stabilis*, *Lunatisporites pellucidus* and *Playfordiaspora crenulata* (Figure 3.11). This microfloral unit also contains elements of the Triassic Katberg Formation palynoflora of this study (*Uvaesporites* and *Aratrisporites*) and the *Kraeuselisporites-Lunatisporites* Zone of Steiner *et al*. (2003) (*Lunatisporites pellucidus*, *Platysaccus queenslandi*) and can be considered to span the Permo-Triassic boundary (Figure 3.11). This is in accordance with the ages proposed for these microfloral units by Nyambe & Utting (1997): Late Carboniferous (Gzhelian) to Early Permian (Asselian to Early Sakmarian) for the Siankondobo Sandstone Formation, Early Permian (Artinskian to Kungurian) age for the Gwembe Coal Formation, Late Permian (Tatarian) age for the Madumabisa Mudstone, and Early or Middle Triassic (Late Scythian or Anisian) age for the Interbedded Sandstone and Mudstone.

3.6.2.3 Antarctic Correlations

Dronning Maud Land:

The Asselian-Sakmarian Milorgfjella assemblage of Larrson *et al*. (1990) can be broadly compared to the Ecca Group microflora of this study but many of the palynomorphs have differing stratigraphic ranges to the Antarctic assemblage, making correlation to a specific formation difficult at present.

Prince Charles Mountains:

The Late Triassic Flagstone Bench palynoflora of Foster *et al*. (1994) can be correlated to the Molteno and Lower Elliot formation microfloras of this study

based on the presence of *Baculatisporites comaumensis*, *Cycadopites* sp., *Dictyophyllidites mortonii*, *Thymospora ipsviciensis* and *Uvaesporites verrucosus* (Figure 3.11).

Palynoflora of the Late Permian McKinnon Member, Prince Charles Mountains, East Antarctica (McLoughlin *et al*., 1997; Lindström & McLoughlin, 2007) can be correlated with the Normandien Formation microflora of this study on the presence of *Florinites eremus*, *Inaperturopollenites* sp., *Marsupipollenites striatus*, *Marsupipollenites triradiatus*, *Protohaploxypinus limpidus*, *Scheuringipollenites ovatus* and *Weylandites lucifer* (Figure 3.11). Distinctive palynomorphs of the Early Triassic Ritchie Member, Prince Charles Mountains, East Antarctica (McLoughlin *et al*., 1997; Lindström & McLoughlin, 2007) include *Aratrisporites* sp., *Densoisporites psilatus* and *Dictyophyllidites mortonii*, and these are contained within the upper Normandien Formation microflora of this study (Figure 3.11).

Central Transantarctic Mountains:

Palynomorphs of the Late Permian Buckley Formation, Central Transantarctic Mountains (Farabee *et al*., 1990) can be correlated with the *P. rugatus* and *D. parvithola* zones of Australia and the Volksrust and Normandien formation palynofloras of this study on the presence of *Acanthotriletes* sp., *Calamospora* sp., *Cannanoropollis* sp., *Chordasporites* sp., *Cycadopites follicularis*, *Deltoidospora directa*, *Horriditriletes ramosus*, *Lophotriletes novicus*, *Marsupipollenites striatus*, *Marsupipollenites triradiatus*, *Protohaploxypinus limpidus*, *Striatopodocarpites cancellatus* and *Striatopodocarpites fusus* (Figure 3.11). Microflora of the Early Triassic Fremouw Formation, Central Transantarctic Mountains (Farabee *et al*., 1990) includes *Aratrisporites* sp., *Dictyophyllidites mortonii* and *Scheuringipollenites* sp. which are contained within the upper Normandien Formation microflora of this study (Figure 3.11). The Late Triassic Falla Formation microflora can be correlated with the Burgersdorp and Molteno

formation palynofloras of this study on the presence of *Dictyophyllidites mortonii* and *Uvaesporites verrucosus* (Figure 3.11).

3.6.2.4 New Zealand Correlations

Assemblage I of Murihiku, New Zealand, the *Polycingulatisporites crenulatus – Annulispora microannulata - Aratrisporites flexibilis* Assemblage (Zhang & Grant-Mackie, 2001) can be correlated with the Molteno Formation microflora of this study on the presence of *Dictyophyllidites mortonii*, *Thymospora ipsviciensis*, *Equisetosporites steevesi* and *Uvaesporites verrucosus* (Figure 3.11). Assemblage I of Murihiku is Early - Middle Norian in age (Zhang & Grant-Mackie, 2001).

Assemblage II of Murihiku, the *Foveosporites moretonensis - Densoisporites psilatus - Steevesipollenites claviger* Assemblage (Zhang & Grant-Mackie, 2001) can be tentatively correlated with the Clarens Formation microflora of this study at present due to the presence of *Foveosporites moretonensis* (Figure 3.11). However if *Foveosporites moretonensis* appears earlier than detected in than the present study, then Assemblage II of Zhang & Grant-Mackie (2001) could also be correlated with the Elliot Formation microflora on the presence of *Equisetosporites steevesi*, *Thymospora ipsviciensis* and *Uvaesporites verrucosus*. Assemblage II of Murihiku is Rhaetian in age (Zhang & Grant-Mackie, 2001). Assemblages III and IV of Zhang & Grant-Mackie (2001) appear to be younger than the Jurassic microflora recovered in this study.

3.6.2.5 South American Correlations

<u>Western Argentina and Paraná Basins:</u>

Pakhapites fusus is present in the Early Permian Prince Albert, Whitehill, Collingham, Fort Brown and Waterford formations and this allows a correlation

with the *Pakhapites fusus – Vittatina subsaccata* (FS Biozone) of Césari *et al*. (2011) in Argentina (Figure 3.11). *Vittatina fasciolata* first appears in the Ripon Formation of this study and ranges upwards into the Waterford, Volksrust and Normandien formations, permitting correlation with the Artinskian *Lueckisporites – Weylandites* (LW Biozone) of Césari *et al*. (2011) and the *Vittatina costabilis* Interval Zone (VcZ) in the Paraná Basin, Brazil (Souza & Marques-Toigo, 2003, 2005; Souza, 2006) (Figure 3.11). The *Crucisaccites monoletus* Interval Zone (CmZ) of Souza & Marques-Toigo (2003) underlies the VcZ Zone but is defined only by the presence of *C. monoletus* and *Scheuringipollenites maximus*, which were not recovered in this study. This zone also contains *Apiculatisporis*, *Cycadopites* and *Reticulatisporites* all of which it shares with the Prince Albert Formation, which can accordingly be correlated with the CmZ (Figure 3.11).

3.6.2.6 Indian Correlations

Most of the characteristic species that define Indian Permian and Triassic palynozones (see Literature Review) are not present in the Karoo Basin microfloras and accordingly correlations with these palynozones are not possible at present. This problem has also been encountered by other researchers (e.g. Modie, 2007; Modie & Le Hérissé, 2009) and may be as a result of phytogeographic differences between India and southern Africa during the Palaeozoic and Mesozoic periods, or incompatible present-day taxonomic approaches. An in-depth taxonomic review of Indian palynomorphs would be necessary to address this problem.

4. CONCLUSIONS

This work represents the first comprehensive palynological biozonation scheme for the Main Karoo Basin. It involved the collection of 275 samples from outcrops from the western region (west of the 24° E meridian), southern region (east of the 24° E meridian) and the north-east distal facies of the Main Karoo Basin, 65 of which were productive. Palynomorphs in all the stratigraphic horizons have been identified and those taxa useful for biostratigraphic correlation have been recognised. This pioneering study has demonstrated that it is indeed possible to obtain reliable palynological "signatures" for the different stratigraphic entities of the Karoo Supergroup. The magnitude of this undertaking necessarily meant that the biozonation presented herein is a broad overview of the highly complex floras that existed from the Carboniferous to the Jurassic and provides a skeleton for future studies that will sample more intensively over smaller stratigraphic intervals.

Every formally recognised vertebrate biozone of the Beaufort Group, except for the *Eodicynodon* Assemblage Zone was found to be palynologically productive in this study. The Prince Albert, Collingham, Vryheid, Volksrust and Elliot formations can be well defined on the basis of their palynoflora, as can the *Dicynodon*, *Lystrosaurus* and *Massospondylus* assemblage zones. The Dwyka Group and Molteno Formation can be tentatively defined on the basis of their palynoflora, as can the *Tapinocephalus*, *Pristerognathus* and *Cynognathus* assemblage zones.

Trilete spores are the most abundant group throughout the Karoo stratigraphic succession, closely followed by alete spores, while monoletes, zonotrilete spores, monosulcate and polyplicate pollen are consistently present in small numbers. Monosaccate and bisaccate pollen are well represented in the Vryheid, Volksrust, Normandien and Clarens formations but extremely rare in the Carboniferous, Earliest Permian and Triassic periods.

Because of lithological differences between rock formations of the proximal and distal sectors of the Main Karoo Basin, it has in the past been difficult to correlate time equivalent lithostratigraphic units in the different sectors. This study demonstrates that palynology is useful in correlating age equivalent lithostratigraphic units which differ from a lithological point of view in the proximal and distal sectors of the basin. Palynology indicates that for the Ecca Group, the microflora of the Vryheid Formation in the northern part of the basin is most similar to that of the Prince Albert and Ripon formations in the south, but also shows similarities with the underlying Whitehill and Collingham formations. The palynomorphs of the Volksrust Formation of the Ecca Group in the distal part of the basin are most similar to those of the Ripon Formation in the proximal sector, but also show strong similarities to those of the Abrahamskraal and Waterford formations. In addition to being useful for intrabasinal stratigraphic correlations, palynology also manifests the diachronous nature of the Ecca-Beaufort and Burgersdorp-Molteno boundaries, as well as corroborating previously proposed vertebrate extinction events in the Karoo Basin. Severe extinction events are recorded in the upper *Tapinocephalus* and upper *Dicynodon* assemblage zones.

This and previous studies of the Karoo Basin microfloras have shown that the palynological signatures of the various Karoo formations are consistent, with similar assemblages of taxa being recovered from a specific formation in multiple studies. It has also proved possible to correlate microfloras from indeterminate localities to microfloras with known stratigraphic provenance, meaning that palynology can be used to infer stratigraphic information for Karoo rocks. However the possibility exists that transitory microfloral phases may be present in the Karoo Supergroup and this would somewhat hamper the use of palynology in assigning unknown rocks to a specific formation. Future studies sampling over smaller stratigraphic intervals will confirm or refute the existence of transitory microfloral phases in South Africa.

Because the Main Karoo Basin presents such a time extensive record of sedimentation, this study has facilitated chronostratigraphic correlations between different Carboniferous - Jurassic Basins of Gondwana. These correlations have highlighted the need for a new South African palynozonation to be set up according to the Australian practice of designating pollen zones based on the first appearance of key index taxa. This would possibly result in more accurate correlations both within the Main Karoo Basin and to other Gondwanan successions. Despite the presence of endemic floras in different parts of Gondwana, this study demonstrates that microfloras present in the Karoo stratigraphic succession can be correlated to successions from Australia, Africa, Antarctica, New Zealand and South America. In the Main Karoo Basin, palynostratigraphic zones correlate largely with the Karoo vertebrate biozones. As good radiometric dates are now available for most of the Permian vertebrate biozones, it is now possible to extrapolate accurate ages for equivalent palynozones in other Gondwana basins. Due to the excellent floral and faunal fossil record of the Karoo Basin, future integrated studies of faunas, macroplants and microfloras combined with absolute dates can potentially make South Africa the standard type section to which other Gondwana successions are compared.

5. APPENDIX A - SYSTEMATIC PALYNOLOGY

ANTETURMA SPORITES

TURMA TRILETES

SUPRASUBTURMA ACAVATITRILETES

SUBTURMA AZONOTRILETES

Infraturma Laevigati

Altitriletes densus Venkatachala & Kar 1968 Plate 1 (2)	
DESCRIPTION	Amb circular to sub-triangular. Trilete laesurae distinct and raised, radii thin, curved and extend one half to two thirds of spore radius, bordered by labra. Exine thick and laevigate, sometimes bearing sparse grana.
SIZE	45 - 65 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Uppermost Fort Brown Fm 49, E.Waterford Fm 44, KZN.Volksrust Fm 42 'Stormberg' Group: E.Molteno Fm 9
TOTAL ABUNDANCE	52 specimens

Cf. *Biretisporites modestus* McKellar 1974 Plate 1 (7)	
DESCRIPTION	Amb sub-triangular with convex sides and rounded apices. Trilete laesurae extending to or almost to spore periphery bordered by elevated lips. Exine 1 – 1.5 µm thick and laevigate.

SIZE	27 - 32 µm
STRATIGRAPHIC RANGE	‘Stormberg’ Group: KZN.Clarens Fm 3, KZN.Clarens Fm 2
TOTAL ABUNDANCE	5 specimens

Calamospora mesozoica Couper 1958 Plate 1 (10)	
SYNONYMY	*Calamospora tener* (Leschik) de Jersey 1962
DESCRIPTION	Amb circular, some specimens may be compressed. Trilete laesurae distinct, radii thin and extend one half of spore radius. Exine approx. 0.5 - 1 µm thick and laevigate.
SIZE	42 - 51 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	6 specimens

Calamospora plicata (Luber & Waltz) Hart 1965 Plate 1 (11)	
SYNONYMY	*Calamospora aplata* Bharadwaj & Salujha 1964
DESCRIPTION	Amb subcircular, specimens often compressed and folded to display polygonal edges. Trilete laesurae placed off-centre of grain, distinct and extends one fourth to one half of spore radius, bordered by darkened labra. Exine 0.5-1 µm thick, laevigate to scabrate.
SIZE	35 - 60 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Ripon Fm 57, KZN.Vryheid Fm 54, E.Fort

	Brown Fm 52, E.Waterford Fm - Facies A 46, KZN.Volksrust Fm 42 Beaufort Group: KZN.Normandien Fm 20, KZN.Normandien Fm 19 'Stormberg' Group: E.Molteno Fm 9, KZN.Clarens Fm 6, KZN.Clarens Fm 5
TOTAL ABUNDANCE	41 specimens

Concavisporites bohemiensis Thiergart 1953 Plate 1 (13)	
DESCRIPTION	Amb triangular with straight to slightly convex sides and sharp angles. Trilete laesurae with radii distinct, surrounded by arcuate kyrtomes protruding from outline of spore body. Exine approx. 1 µm thick and laevigate to scabrate.
SIZE	22 - 24 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54 Beaufort Group: W.Upper Hoedemaker M. 28
TOTAL ABUNDANCE	13 specimens

Cyathidites minor Couper 1953 Plate 2 (6)	
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight to slightly convex. Trilete laesurae distinct, radii thin and extending almost to spore periphery. Exine thin and laevigate.

SIZE	20 - 35 µm
STRATIGRAPHIC RANGE	‘Stormberg’ Group: E.Upper Elliot Fm 7, KZN.Clarens Fm 6, KZN.Clarens Fm 5, KZN.Clarens Fm 3, KZN.Clarens Fm 2, KZN.Clarens Fm 1
TOTAL ABUNDANCE	171 specimens

Deltoidospora directa (Balme & Hennelly) Norris 1965 Plate 2 (5)	
SYNONYMY	*Leiotriletes directus* Balme & Hennelly 1956 *Microbaculispora directa* Anderson 1977
DESCRIPTION	Amb triangular, apices rounded, inter-apical region straight to slightly concave. Trilete laesurae with radii distinct, may sometimes be obscured by folding. Exine thin, laevigate, often folded.
SIZE	26 - 58 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: W.Prince Albert Fm 64, E.Prince Albert Fm 63, W.Whitehill Fm 62, E.Whitehill Fm 61, E.Whitehill Fm 60, W.Collingham Fm 59, E.Collingham Fm 58, W.Ripon Fm 57, E.Middle Ripon Fm 56, E.Upper Ripon Fm 55, KZN.Vryheid Fm 54, E.Fort Brown Fm 52, E.Fort Brown Fm 51, E.Fort Brown Fm 50, E.Uppermost Fort Brown Fm 49, W.Base of the Waterford Fm 48, W.Lower Waterford Fm 47, E.Waterford Fm - Facies A 46, E.Waterford Fm - Facies B 45, E.Waterford Fm 44, KZN.Volksrust Fm 42 Beaufort Group:

	W.Abrahamskraal Fm - Mudstone B 41, W.Abrahamskraal Fm 39, W.Abrahamskraal Fm 38, E.Koonap Fm 37, E.Koonap Fm 36, E.Koonap Fm 35, E.Koonap Fm 34, W.Uppermost Abrahamskraal Fm 33, W.Middle to Lower Poortjie M. 32, W.Poortjie M. 31, W.Upper Poortjie M. 30, W.Middle Hoedemaker M. 29, W.Upper Hoedemaker M. 28, W.Oukloof M. 27, W.Oukloof M. 26, E.Oudeberg M. 25, KZN.Normandien Fm 22, KZN.Normandien Fm 20, KZN.Normandien Fm 19, E.Barberskrans M. 17, E.Elandsberg M. 16, E.Elandsberg/Palingkloof Contact 15, E.Palingkloof M. 14, E.Katberg Fm 13, E.Katberg Fm 12, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 'Stormberg' Group: E.Molteno Fm 9, E.Lower Elliot Fm 8
TOTAL ABUNDANCE	836 specimens

Deltoidospora magna (de Jersey) Norris 1965 Plate 2 (2)	
SYNONYMY	*Leiotriletes magnus* de Jersey 1959
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight to slightly concave. Trilete laesurae distinct and thickened when seen, bordered by folded labra. Laesurae not apparent in some specimens as it is obscured by folds. Exine approx. 1-2 µm thick and laevigate.
SIZE	25 - 50 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group:

	E.Prince Albert Fm 63, W.Whitehill Fm 62, E.Whitehill Fm 61, E.Whitehill Fm 60, W.Collingham Fm 59, W.Ripon Fm 57, E.Uppermost Fort Brown Fm 49, E.Waterford Fm 44 <u>Beaufort Group:</u> W.Abrahamskraal Fm - Mudstone B 41, W.Abrahamskraal Fm - Mudstone D 40, W.Abrahamskraal Fm 39, W.Abrahamskraal Fm 38, E.Koonap Fm 36, E.Koonap Fm 34, W.Middle to Lower Poortjie M. 32, W.Poortjie M. 31, W.Upper Poortjie M. 30, W.Middle Hoedemaker M. 29, W.Upper Hoedemaker M. 28, W.Oukloof M. 27, W.Oukloof M. 26, E.Oudeberg M. 25, KZN.Normandien Fm 24, E.Elandsberg M. 16, E.Elandsberg/Palingkloof Contact 15, E.Palingkloof M. 14, E.Katberg Fm 12, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 <u>'Stormberg' Group:</u> E.Molteno Fm 9, E.Lower Elliot Fm 8
TOTAL ABUNDANCE	484 specimens

Cf. *Dictyophyllidites harrisii* Couper 1958 Plate 2 (7)	
DESCRIPTION	Amb triangular, apices sharp, inter-apical region straight to slightly concave. Trilete laesurae distinct with radii extending to spore periphery, clearly raised and bordered by distinct labra. Exine laevigate.
SIZE	36 - 56 µm
STRATIGRAPHIC RANGE	<u>'Stormberg' Group:</u>

	E.Upper Elliot Fm 7
TOTAL ABUNDANCE	7 specimens

Dictyophyllidites mortonii (de Jersey) Playford & Dettmann 1965 Plate 2 (8)	
DESCRIPTION	Amb sub-triangular, apices narrowly rounded, inter-apical region slightly concave to slightly convex. Trilete laesurae distinct with radii extending at least three fourths of spore radius, bordered by membranous elevated labra. Exine 1-2 µm thick and laevigate, proximal exine with a kyrtome, the limits of which run parallel to the laesurae.
SIZE	28 - 45 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 19, E.Barberskrans M. 17, E.Katberg Fm 12 'Stormberg' Group: E.Molteno Fm 9, E.Lower Elliot Fm 8, KZN.Clarens Fm 4
TOTAL ABUNDANCE	26 specimens

Cf. *Latipulvinites kosankii* Peppers 1964 Plate 3 (6)	
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight. Trilete laesurae distinct, radii extend to periphery of spore body, framed by elevated prominent triradiate ridges. Exine laevigate to infrapunctate. Also compare with *Triricta reticulatus* Wilson 1962.

SIZE	45 - 65 µm
STRATIGRAPHIC RANGE	‘Stormberg’ Group: KZN.Clarens Fm 5
TOTAL ABUNDANCE	11 specimens

Punctatisporites gretensis Balme & Hennelly 1956 Plate 3 (12)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region convex. Trilete laesurae distinct, radii thin, curved and extend two thirds of spore diameter. Characteristic splitting of the spore along one radius. Exine thick, approx. 6 µm and laevigate.
SIZE	30 - 40 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 37, W.Upper Poortjie M. 30, E.Elandsberg/Palingkloof Contact 15, E.Katberg Fm 13, E.Burgersdorp Fm 11 ‘Stormberg’ Group: E.Molteno Fm 9
TOTAL ABUNDANCE	56 specimens

Cf. *Punctatisporites minutus* Kosanke 1950 Plate 3 (11)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region strongly convex. Trilete laesurae distinct, radii thin with lips slightly developed, and extend almost to spore periphery. Exine 1-2 µm thick and laevigate.
SIZE	20 - 31 µm
STRATIGRAPHIC RANGE	Beaufort Group:

	KZN.Normandien Fm 22, KZN.Normandien Fm 19 ‘Stormberg’ Group: KZN.Clarens Fm 5
TOTAL ABUNDANCE	86 specimens

Cf. *Punctatisporites obliquus* Kosanke 1950 Plate 3 (13)	
DESCRIPTION	Amb circular to oval to spherical. Exine punctate, punctations are closely spaced giving the spore a minutely papillate ornamentation. Trilete mark indistinct.
SIZE	31 - 45 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: E.Whitehill Fm 60, E.Fort Brown Fm 52, E.Waterford Fm 44 Beaufort Group: E.Barberskrans M. 17, E.Katberg Fm 12, E.Burgersdorp Fm 10 ‘Stormberg’ Group: E.Upper Elliot Fm 7
TOTAL ABUNDANCE	32 specimens

Cf. *Punctatisporites parvus* Anderson 1977 Plate 3 (14)	
DESCRIPTION	Amb sub-circular to oval. Trilete laesurae distinct, radii extend full length of spore body. Exine 1 µm thick, laevigate to infragranulate.
SIZE	20 - 44 µm

STRATIGRAPHIC RANGE	Ecca Group: E.Waterford Fm 44 Beaufort Group: W.Poortjie M. 31, W.Middle Hoedemaker M. 29, W.Oukloof M. 26, E.Barberskrans M. 17, E.Katberg Fm 13
TOTAL ABUNDANCE	31 specimens

Punctatisporites sp. A Ibrahim *emend*. Potonié & Kremp 1954 Plate 3 (15)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region straight to convex. Trilete laesurae indistinct. Exine punctate.
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: W.Prince Albert Fm 64, W.Collingham Fm 59, E.Collingham Fm 58, W.Ripon Fm 57, E.Upper Ripon Fm 55, E.Fort Brown Fm 51, E.Fort Brown Fm 50, E.Waterford Fm 44, KZN.Volksrust Fm 43 Beaufort Group: W.Abrahamskraal Fm - Mudstone B 41, W.Abrahamskraal Fm - Mudstone D 40, W.Abrahamskraal Fm 39, E.Koonap Fm 35, E.Koonap Fm 34, W.Uppermost Abrahamskraal Fm 33, W.Middle to Lower Poortjie M. 32, W.Upper Poortjie M. 30, W.Upper Hoedemaker M. 28, W.Oukloof M. 27, W.Oukloof M. 26, E.Oudeberg M. 25, KZN.Normandien Fm 23, KZN.Normandien Fm 21, KZN.Normandien Fm 20, E.Elandsberg M. 16, E.Elandsberg/Palingkloof Contact 15,

	E.Palingkloof M. 14, E.Katberg Fm 12, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 'Stormberg' Group: E.Molteno Fm 9, KZN.Clarens Fm 5, KZN.Clarens Fm 4, KZN.Clarens Fm 3, KZN.Clarens Fm 2, KZN.Clarens Fm 1
SIZE	30 - 40 µm
TOTAL ABUNDANCE	608 specimens

Infraturma Apiculati

Subinfraturma Baculati

Acanthotriletes tereteangulatus Balme & Hennelly 1956 Plate 1 (1)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region concave. Trilete laesurae distinct and thin, no labra present. Radii taper towards tips and extend to spore periphery. Exine approx. 1 µm thick with baculate ornamentation. Baculi elongate and thin.
SIZE	22 - 42 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Prince Albert Fm 63 Ecca Group: E.Middle Ripon Fm 56, E.Fort Brown Fm 51, KZN.Volksrust Fm 43 Beaufort Group: W.Abrahamskraal Fm 39, KZN.Normandien Fm 22, KZN.Normandien Fm 21, E.Burgersdorp Fm 11 'Stormberg' Group: KZN.Clarens Fm 6, KZN.Clarens Fm 4,

	KZN.Clarens Fm 2, KZN.Clarens Fm 1
TOTAL ABUNDANCE	241 specimens

Baculatisporites comaumensis (Cookson) Potonié 1956 Plate 1 (6)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region strongly convex. Trilete laesurae indistinct and thin, radii extend almost to spore periphery. Exine densely ornamented with small short baculi.
SIZE	34 - 36 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 34 'Stormberg' Group: E.Lower Elliot Fm 8
TOTAL ABUNDANCE	2 specimens

Brijrajisporites distinctus Tiwari 1968 Plate 1 (9)	
DESCRIPTION	Amb circular. Trilete laesurae discernible to distinct, radii thin and extend two thirds of spore body, bordered by labra formed by fusing of ornaments. Exine on both faces ornamented with blunt baculi, spore body outline forms a wavy ridge, in top view separated by an incomplete negative reticulum.
SIZE	60 µm
STRATIGRAPHIC RANGE	Beaufort Group: W.Abrahamskraal Fm 38
TOTAL ABUNDANCE	1 specimen

Cf. *Conbaculatisporites* sp. Klaus 1960 Plate 1 (12)	
DESCRIPTION	Amb triangular, apices broadly rounded, sides slightly concave. Trilete laesurae extends three fourths of spore radius. Exine ornamentation of irregularly spaced baculi and echinae, ornaments slightly denser at apices.
SIZE	35 - 37 µm
STRATIGRAPHIC RANGE	<u>'Stormberg' Group:</u> E.Lower Elliot Fm 8
TOTAL ABUNDANCE	3 specimens

Horriditriletes filiformis (Balme & Hennelly) Backhouse 1991 Plate 3 (2)	
DESCRIPTION	Amb subtriangular to subcircular. Trilete laesurae discernible to distinct, radii thin, extending to or nearly to spore periphery, sometimes bordered by narrow labra. Exine 0.5-1 µm thick, ornamented distally and proximo-equatorially with discrete, narrowly elongate spinae and baculi having typically blunted apices. Proximal face has sparse, diminished ornamentation.
SIZE	22 - 27 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> KZN.Vryheid Fm 54, KZN.Volksrust Fm 42
TOTAL ABUNDANCE	5 specimens

Horriditriletes ramosus (Balme & Hennelly) Bharadwaj & Salujha 1964 Plate 3 (3)	
SYNONYMY	*Neoraistrickia ramosa* (Balme & Hennelly) Hart 1960 *Acanthotriletes* (baculate form) Anderson 1977
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight to slightly convex. Trilete laesurae indistinct due to ornamentation. Exine thin with baculate ornamentation. Baculi thick and blunt-tipped.
SIZE	35 - 39 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	3 specimens

Cf. *Lobatisporites* sp. Tiwari & Moiz 1971 Plate 3 (8)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region concave. Trilete laesurae distinct, radii thin and extend almost to spore periphery. Exine thin and heavily baculate, baculi of medium length and thick.
SIZE	20 - 25 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Prince Albert Fm 64 Beaufort Group: W.Middle Hoedemaker M. 29
TOTAL ABUNDANCE	84 specimens

Neoraistrickia truncata Singh 1964 Plate 3 (10)	
DESCRIPTION	Amb triangular, apices rounded, cheilocardioid. Trilete laesurae extends one half to three fourths of spore radius, sometimes indistinct. Exine approx. 1 µm thick, with blunt-edged baculate ornamentation.
SIZE	17 - 32 µm
STRATIGRAPHIC RANGE	Beaufort Group: W.Abrahamskraal Fm 38, E.Koonap Fm 37, E.Koonap Fm 34, W.Middle to Lower Poortjie M. 32, W.Middle Hoedemaker M. 29, KZN.Normandien Fm 20, E.Burgersdorp Fm 10 'Stormberg' Group: E.Lower Elliot Fm 8
TOTAL ABUNDANCE	41 specimens

Subinfraturma Nodati

Apiculatisporis cornutus (Balme & Hennelly) Høeg & Bose 1960 Plate 1 (3)	
DESCRIPTION	Amb circular, occasionally sub-circular to sub-triangular. Trilete laesurae distinct to discernible, radii with thin labra that extend to spore periphery. Exine approx. 1-2 thick with echinate ornamentation on distal face. Echinae are short with a wide base (coni).
SIZE	18 - 25 µm
STRATIGRAPHIC RANGE	Ecca Group:

	W.Prince Albert Fm 64, E.Middle Ripon Fm 56 Beaufort Group: W.Upper Poortjie M. 30, KZN.Normandien Fm 22, E.Katberg Fm 13 'Stormberg' Group: KZN.Clarens Fm 1
TOTAL ABUNDANCE	19 specimens

Apiculiretusispora sp. Streel 1964 Plate 1 (4)	
DESCRIPTION	Amb circular to sub-circular. Trilete laesurae distinct, radii thin with no labra, extend to spore periphery. Exine 1 - 2 µm thick with sparse echinate ornamentation on distal face only. Echinae low and wide (coni).
SIZE	20 – 24 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 53
TOTAL ABUNDANCE	4 specimens

Brevitriletes bulliensis (Helby ex de Jersey) de Jersey & Raine 1990 Plate 1 (8)	
SYNONYMY	*Apiculatisporis bulliensis*
DESCRIPTION	Amb roundly triangular. Trilete laesurae indistinct to discernible, radii thin. Exine sparsely ornamented with thin echinae, exine may develop small folds.
SIZE	18 - 25 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 24

TOTAL ABUNDANCE	2 specimens

Lophotriletes novicus Singh 1964 Plate 3 (7)	
DESCRIPTION	Amb sub-triangular, apices broadly rounded, inter-apical region straight to slightly concave. Trilete laesurae discernible to distinct, radii taper sharply towards apices, extend three fourths of spore body radius. Exine 0.5 - 1 μm thick with ornament of unevenly spaced low coni and lesser baculae and grana.
SIZE	29 - 48 μm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> E.Prince Albert Fm 63, KZN.Vryheid Fm 54, KZN.Vryheid Fm 53, KZN.Volksrust Fm 42 <u>Beaufort Group:</u> W.Abrahamskraal Fm - Mudstone D 40, W.Abrahamskraal Fm 38, KZN.Normandien Fm 23, KZN.Normandien Fm 22, KZN.Normandien Fm 20, KZN.Normandien Fm 18, E.Palingkloof M. 14 <u>'Stormberg' Group:</u> KZN.Clarens Fm 5, KZN.Clarens Fm 2, KZN.Clarens Fm 1
TOTAL ABUNDANCE	200 specimens

Lophotriletes scotinus Segroves 1970 Plate 3 (9)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region straight to slightly convex. Trilete laesurae distinct,

	radii extend to almost spore periphery, thin with no labra. Exine thin with sparse echinate ornamentation on distal face only. Echinae short and wide (coni).
SIZE	20 - 26 μm
STRATIGRAPHIC RANGE	Ecca Group: W.Base of the Waterford Fm 48 Beaufort Group: W.Abrahamskraal Fm - Mudstone D 40, W.Poortjie M. 31, KZN.Normandien Fm 23
TOTAL ABUNDANCE	17 specimens

Toripustulatisporites hokonuiensis de Jersey 1990 Plate 4 (7)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region strongly concave. Trilete laesurae distinct, radii thin and extend almost to spore periphery. Exine heavily ornamented with pustules, baculi and verrucae, ornamentation is reduced in equatorial region.
SIZE	33 - 41 μm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 36 'Stormberg' Group: E.Lower Elliot Fm 8, E.Upper Elliot Fm 7, KZN.Clarens Fm 1
TOTAL ABUNDANCE	8 specimens

Subinfraturma Verrucati

Cf. *Converrucosisporites irregularis* (Anderson) Modie 2007 Plate 1 (14)	
DESCRIPTION	Amb triangular-oval, inter-apices straight to slightly convex, apices narrowly rounded. Laesurae indistinct to discernible, radii thin and extend to spore periphery. Exine 0.5 µm thick, distal sculpturing of irregular rugulae and subordinate verrucae. A negative reticulate pattern is created by inter-connected narrow grooves between the muri.
SIZE	34 - 41 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: E.Whitehill Fm 60 Beaufort Group: W.Middle to Lower Poortjie M. 32, W.Upper Hoedemaker M. 28
TOTAL ABUNDANCE	29 specimens

Converrucosisporites micronodosus (Balme & Hennelly) Playford & Dino 2002 Plate 1 (15)	
SYNONYMY	*Granulatisporites micronodosus* Balme & Hennelly 1956 *Microbaculispora micronodosa* Anderson 1977
DESCRIPTION	Amb subtriangular with rounded apices, inter-apical region straight to convex. Trilete laesurae distinct and bordered by narrow elevated lips,

	extends three-fourths to full spore body. Exine 1-1.5 µm thick with verrucate ornamentation on distal face and equatorially. Proximal face either laevigate or ornamentation is highly reduced.
SIZE	40 - 65 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63
TOTAL ABUNDANCE	9 specimens

Converrucosisporites naumoviae (Hart) Backhouse 1991 Plate 1 (16)	
SYNONYMY	*Microbaculispora naumovae* (Hart) Anderson 1977
DESCRIPTION	Amb sub-triangular, apices narrow to slightly broadly rounded, inter-apical region straight to convex. Trilete laesurae distinct, radii thin and extend to spore periphery sometimes with weak labra. Exine approx. 0.5 - 1 µm thick with heavy verrucate and subordinate granulate ornamentation, verrucae are small and tightly packed, circular to sub-circular or polygonal to elongate in shape. Ornamentation is often reduced on the proximal face.
SIZE	26 - 57 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Upper Ripon Fm 55, E.Fort Brown Fm 51, E.Waterford Fm - Facies A 46, E.Waterford Fm - Facies B 45, KZN.Volksrust Fm 42 Beaufort Group: W.Abrahamskraal Fm - Mudstone D 40, E.Koonap Fm 35, W.Uppermost Abrahamskraal

	Fm 33, W.Upper Poortjie M. 30, W.Middle Hoedemaker M. 29, KZN.Normandien Fm 19
TOTAL ABUNDANCE	837 specimens

Converrucosisporites pseudoreticulatus (Balme & Hennelly) Modie 2007 Plate 1 (17)	
SYNONYMY	*Verrucosisporites pseudoreticulatus* Balme & Hennelly 1956 *Microbaculispora pseudoreticulata* Anderson 1977 *Pseudoreticulatispora pseudoreticulata* (Foster & Waterhouse) Millsteed 1999
DESCRIPTION	Amb sub-triangular, apices rounded to slightly sharp, inter-apical region straight to convex. Trilete laesurae discernible, radii thin and extend to spore periphery. Exine 1 µm thick with dense ornamentation of verrucae on the distal face. Ornamentation is much reduced on the proximal face.
SIZE	41 - 50 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> KZN.Vryheid Fm 53 <u>Beaufort Group:</u> E.Koonap Fm 35, E.Koonap Fm 34 <u>'Stormberg' Group:</u> E.Molteno Fm 9
TOTAL ABUNDANCE	37 specimens

Converrucosisporites sp. Potonié & Kremp 1954 Plate 1 (18)	
DESCRIPTION	Amb subtriangular with rounded apices, inter-apical region straight to convex. Trilete laesurae indistinct. Exine 1- 1.5 µm thick with verrucate and baculate ornamentation.
SIZE	27 - 29 µm
STRATIGRAPHIC RANGE	<u>'Stormberg' Group:</u> E.Upper Elliot Fm 7
TOTAL ABUNDANCE	10 specimens

Schopfites dimorphus Kosanke 1950 Plate 4 (4)	
DESCRIPTION	Amb circular. Trilete laesurae indistinct to discernible, radii extend one half to two thirds of spore body. Exine ornament of with low, irregularly shaped verrucae. Some of the smaller verrucae are connected by low, irregular ridges. Along the margins of the larger verrucae are sharp coni. Area surrounding trilete laesurae has no ornamentation.
SIZE	37 - 40 µm
STRATIGRAPHIC RANGE	<u>Beaufort Group:</u> E.Elandsberg M. 16
TOTAL ABUNDANCE	7 specimens

Cf. *Secarisporites lobatus* Neves 1961 Plate 4 (5)	
DESCRIPTION	Amb sub-circular to roundly triangular. Trilete laesurae indistinct, often obscured by ornamentation, radii thin, extending to periphery of spore body. Spore outline is strongly lobate, exine ornamented with verrucae of variable size which occasionally anastamose. Equatorial elements fuse to produce a pseudocingulum.
SIZE	35 - 41 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> W.Ripon Fm 57, E.Fort Brown Fm 52, E.Fort Brown Fm 50, E.Uppermost Fort Brown Fm 49, W.Lower Waterford Fm 47 <u>Beaufort Group:</u> W.Oukloof M. 26, E.Barberskrans M. 17, E.Katberg Fm 13
TOTAL ABUNDANCE	16 specimens

Verrucosisporites andersonii (Anderson) Backhouse 1988 Plate 4 (9)	
SYNONYMY	*Cyclogranisporites verrucosus* Anderson 1977
DESCRIPTION	Amb sub-circular, laesurae indistinct to discernible, extends two thirds of spore radius with *curvaturae imperfectae*. Exine ornamentation of dense verrucae.
SIZE	37 - 46 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> KZN.Volksrust Fm 42

TOTAL ABUNDANCE	4 specimens

Verrucosisporites polygonalis Lanninger 1968 Plate 4 (10)	
DESCRIPTION	Amb subtriangular. Trilete laesurae indistinct, extends three fourths of spore radius. Proximal surface laevigate, distal surface ornamentation of polygonal verrucae, rounded or flattened in profile.
SIZE	25 - 38 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> E.Prince Albert Fm 63, E.Whitehill Fm 60, E.Upper Ripon Fm 55, E.Fort Brown Fm 50, E.Waterford Fm 44 <u>Beaufort Group:</u> W.Abrahamskraal Fm - Mudstone B 41, E.Koonap Fm 36, W.Poortjie M. 31, E.Elandsberg M. 16
TOTAL ABUNDANCE	24 specimens

Verrucosisporites sp. A (Ibrahim) Smith & Butterworth 1967 Plate 4 (11)	
DESCRIPTION	Amb triangular, apices sharp to rounded. Trilete laesurae discernible. Exine thin with verrucate ornamentation.
SIZE	17 - 40 µm
STRATIGRAPHIC RANGE	<u>Dwyka Group:</u> E.Elandsvlei Fm 65 <u>Ecca Group:</u> W.Whitehill Fm 62, W.Collingham Fm 59, W.Ripon Fm 57, E.Upper Ripon Fm 55, E.Fort

	Brown Fm 50, W.Base of the Waterford Fm 48 Beaufort Group: W.Abrahamskraal Fm - Mudstone B 41, W.Abrahamskraal Fm 38, W.Uppermost Abrahamskraal Fm 33, W.Poortjie M. 31, W.Upper Poortjie M. 30, W.Middle Hoedemaker M. 29, W.Oukloof M. 27, KZN.Normandien Fm 22, KZN.Normandien Fm 20, KZN.Normandien Fm 19, KZN.Normandien Fm 18, E.Barberskrans M. 17, E.Elandsberg M. 16, E.Elandsberg/Palingkloof Contact 15, E.Palingkloof M. 14, E.Katberg Fm 12, E.Burgersdorp Fm 11 'Stormberg' Group: E.Molteno Fm 9, E.Lower Elliot Fm 8, KZN.Clarens Fm 1
TOTAL ABUNDANCE	566 specimens

Verrucosisporites sp. MacRae 1988 Plate 4 (12)	
DESCRIPTION	Amb circular to subcircular to subtriangular. Trilete laesurae extends to spore periphery, raised on exinal folds creating the effect of a narrow labrum. Distal face ornamented with large flattened irregularly shaped verrucae, sometimes anastomosing but typically discrete. Proximal surface laevigate to punctate.
SIZE	34 - 52 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54
TOTAL ABUNDANCE	6 specimens

Subinfraturma Granulati

Cf. *Cyclogranisporites firmus* Jones & Truswell 1992 Plate 2 (3)	
DESCRIPTION	Amb circular to sub-circular. Trilete laesurae discernible to distinct and thin, radii extend three fourths to full length of spore body, sometimes bordered by slight labra. Exine 3 - 4 µm ornamented with low grana and anastomosing verrucae, producing the appearance of a negative reticulum. Compressed spores tend to split along the laesurae.
SIZE	44 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	2 specimens

Cyclogranisporites gondwanensis Bharadwaj & Salujha 1964 Plate 2 (4)	
DESCRIPTION	Amb circular to roundly triangular. Trilete laesurae distinct and thin, radii extend one half to three fourths of spore body. Exine approx. 1 µm thick and granulate.
SIZE	27 - 39 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Prince Albert Fm 64, W.Ripon Fm 57, E.Upper Ripon Fm 55, E.Fort Brown Fm 51 Beaufort Group: E.Koonap Fm 37, W.Oukloof M. 26, KZN.Normandien Fm 22, KZN.Normandien Fm

	20, E.Palingkloof M. 14 ‘Stormberg’ Group: E.Lower Elliot Fm 8
TOTAL ABUNDANCE	114 specimens

Granulatisporites austroamericanus Archangelsky & Gamerro 1979 Plate 2 (11)	
SYNONYMY	*Microbaculispora tentula* Tiwari 1965 *Granulatisporites angularis* (Staplin) Ybert 1975
DESCRIPTION	Amb triangular, apices rounded, inter-apical region straight to slightly convex, one side noticeably more convex than the other two sides. Trilete laesurae distinct, radii simple and extend to spore periphery, bordered by marginal folds. Exine 0.5 - 1 μm thick, distal face comprehensively ornamented with discreet grana, ornamentation much reduced on the proximal face.
SIZE	31 - 40 μm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42 ‘Stormberg’ Group: E.Lower Elliot Fm 8, E.Upper Elliot Fm 7, KZN.Clarens Fm 1
TOTAL ABUNDANCE	23 specimens

Granulatisporites convexus Kosanke 1950 Plate 2 (12)	
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight to slightly convex. Trilete

	laesurae distinct, radii thin and extend two thirds of spore body. Exine approx. 3-5 µm thick and laevigate, however under SEM the exine is seen to be granulate (hence the genus).
SIZE	55 - 63 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Palingkloof M. 14
TOTAL ABUNDANCE	38 specimens

Cf. *Granulatisporites microgranifer* Ibrahim 1933 Plate 2 (14)	
DESCRIPTION	Amb triangular, apices rounded, inter-apical region concave. Trilete laesurae distinct, radii simple and extend to spore periphery, bordered by narrow labra in some specimens. Exine 0.5 - 1 µm thick, dense ornamentation of fine grana.
SIZE	22 - 36 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Whitehill Fm 62, E.Whitehill Fm 61, W.Collingham Fm 59, W.Lower Waterford Fm 47 Beaufort Group: W.Abrahamskraal Fm - Mudstone B 41, E.Koonap Fm 36, E.Koonap Fm 35, W.Middle to Lower Poortjie M. 32, W.Oukloof M. 27, W.Oukloof M. 26, KZN.Normandien Fm 24, KZN.Normandien Fm 19, E.Elandsberg/Palingkloof Contact 15, E.Katberg Fm 13, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 'Stormberg' Group: E.Lower Elliot Fm 8, E.Upper Elliot Fm 7
TOTAL ABUNDANCE	447 specimens

Granulatisporites minor de Jersey 1960 Plate 2 (15)	
DESCRIPTION	Amb triangular, apices narrowly rounded to sharp, inter-apical region straight to slightly convex. Trilete laesurae discernible to distinct, radii thin and extend to periphery of spore body. Exine approx. 1 µm thick, ornamentation of small closely packed grana.
SIZE	20 - 35 µm
STRATIGRAPHIC RANGE	<u>Dwyka Group:</u> E.Elandsvlei Fm 65 <u>Ecca Group:</u> W.Prince Albert Fm 64, E.Prince Albert Fm 63, W.Whitehill Fm 62, E.Whitehill Fm 61, E.Whitehill Fm 60, W.Collingham Fm 59, W.Ripon Fm 57, E.Middle Ripon Fm 56, E.Upper Ripon Fm 55, E.Fort Brown Fm 52, E.Fort Brown Fm 51, E.Fort Brown Fm 50, E.Uppermost Fort Brown Fm 49, W.Base of the Waterford Fm 48, W.Lower Waterford Fm 47, E.Waterford Fm 44 <u>Beaufort Group:</u> W.Abrahamskraal Fm - Mudstone D 40, W.Abrahamskraal Fm 39, W.Abrahamskraal Fm 38, E.Koonap Fm 36, E.Koonap Fm 35, E.Koonap Fm 34, W.Middle to Lower Poortjie M. 32, W.Poortjie M. 31, W.Upper Poortjie M. 30, W.Middle Hoedemaker M. 29, W.Upper Hoedemaker M. 28, W.Oukloof M. 27, W.Oukloof M. 26, E.Oudeberg M. 25, KZN.Normandien Fm 22, KZN.Normandien Fm 20, KZN.Normandien Fm 19, KZN.Normandien Fm 18, E.Barberskrans

	M. 17, E.Elandsberg M. 16, E.Elandsberg/Palingkloof Contact 15, E.Palingkloof M. 14, E.Katberg Fm 13, E.Katberg Fm 12, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 <u>'Stormberg' Group:</u> E.Molteno Fm 9, E.Lower Elliot Fm 8, E.Upper Elliot Fm 7, KZN.Clarens Fm 6, KZN.Clarens Fm 5, KZN.Clarens Fm 4, KZN.Clarens Fm 3, KZN.Clarens Fm 2, KZN.Clarens Fm 1
TOTAL ABUNDANCE	2337 specimens

Granulatisporites papillosus Hart 1965 Plate 2 (16)	
DESCRIPTION	Amb triangular, apices sharp, inter-apical region straight. Trilete laesurae distinct, radii thin, and extend to spore periphery. Radii bordered by light-coloured labra. Exine thin and granulate.
SIZE	28 - 49 μm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> W.Ripon Fm 57, KZN.Vryheid Fm 54, W.Base of the Waterford Fm 48
TOTAL ABUNDANCE	35 specimens

Granulatisporites trisinus Balme & Hennelly 1956 Plate 3 (1)	
SYNONYMY	*Microbaculispora trisina* Anderson 1977
DESCRIPTION	Amb triangular, apices rounded, inter-apical region straight to slightly convex. Trilete laesurae distinct and bordered by thin labra, radii extend to periphery

	of spore. Exine 1-2 µm thick with granulate sculpture.
SIZE	45 - 68 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Whitehill Fm 62, W.Collingham Fm 59, W.Ripon Fm 57, KZN.Vryheid Fm 54, E.Fort Brown Fm 51 Beaufort Group: E.Koonap Fm 36, W.Middle to Lower Poortjie M. 32, W.Upper Hoedemaker M. 28, W.Oukloof M. 26, KZN.Normandien Fm 23, KZN.Normandien Fm 18, E.Katberg Fm 12, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 'Stormberg' Group: E.Lower Elliot Fm 8, KZN.Clarens Fm 5
TOTAL ABUNDANCE	139 specimens

Granulatisporites sp. Ibrahim *emend*. Potonié & Kremp 1954 Plate 2 (17)	
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight to concave. Trilete laesurae indistinct. Exine ornament of fine densely packed grana.
SIZE	20 - 35 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: W.Prince Albert Fm 64, W.Whitehill Fm 62, E.Whitehill Fm 61, W.Collingham Fm 59, E.Collingham Fm 58, W.Ripon Fm 57, E.Middle Ripon Fm 56, E.Upper Ripon Fm 55, KZN.Vryheid

	Fm 53, E.Fort Brown Fm 50, W.Base of the Waterford Fm 48, W.Lower Waterford Fm 47, E.Waterford Fm - Facies A 46, E.Waterford Fm 44 Beaufort Group: W.Abrahamskraal Fm - Mudstone D 40, W.Abrahamskraal Fm 39, W.Abrahamskraal Fm 38, E.Koonap Fm 36, W.Uppermost Abrahamskraal Fm 33, W.Middle to Lower Poortjie M. 32, W.Poortjie M. 31, W.Upper Poortjie M. 30, W.Middle Hoedemaker M. 29, W.Oukloof M. 27, W.Oukloof M. 26, KZN.Normandien Fm 24, KZN.Normandien Fm 22, KZN.Normandien Fm 20, KZN.Normandien Fm 19, KZN.Normandien Fm 18, E.Barberskrans M. 17, E.Elandsberg/Palingkloof Contact 15, E.Palingkloof M. 14, E.Katberg Fm 13, E.Katberg Fm 12, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 'Stormberg' Group: E.Molteno Fm 9, E.Lower Elliot Fm 8, KZN.Clarens Fm 6, KZN.Clarens Fm 4, KZN.Clarens Fm 3, KZN.Clarens Fm 2, KZN.Clarens Fm 1
TOTAL ABUNDANCE	1354 specimens

Granulatisporites sp. MacRae 1988 Plate 2 (13)	
DESCRIPTION	Amb triangular, apices narrowly rounded to sharp, inter-apical region slightly concave to slightly convex. Trilete laesurae distinct, radii extend to periphery of spore body, bordered by thick elevated labra. Exine ornament of closely spaced medium-

	sized grana on both the proximal and distal faces.
SIZE	34 - 36 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Collingham Fm 58 Beaufort Group: KZN.Normandien Fm 22
TOTAL ABUNDANCE	2 specimens

Interradispora sp. Price *in* Foster 1979 Plate 3 (4)	
DESCRIPTION	Amb triangular, apices narrowly rounded to sharp, inter-apical region straight to strongly convex. Trilete laesurae distinct, radii extend one half to three fourths of spore body radius, bordered by narrow, sometimes sinuous labra. Exine ornamentation of grana and pila on both the proximal and distal face. Larger grana occur in the middle of the proximal surface.
SIZE	20 - 24 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63 'Stormberg' Group: E.Lower Elliot Fm 8, KZN.Clarens Fm 5, KZN.Clarens Fm 2
TOTAL ABUNDANCE	8 specimens

Cf. *Striasporis striatus* Kar 1969 Plate 4 (6)	
DESCRIPTION	Amb circular to sub-circular. Trilete laesurae

	distinct and thin, radii extend three fourths to full length of spore body. Exine striated proximally, contact area smooth, striations roughly parallel in each inter-radial area, sometimes joined at their ends forming a triangular pattern. Exine ornamented with small grana or verrucae in areas between striations.
SIZE	38 - 46 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54
TOTAL ABUNDANCE	8 specimens
PREVIOUSLY REPORTED FROM	Permian of India

Subinfraturma Gemmati

Pustulatisporites distinctus Ağrali & Akyol Plate 3 (16)	
DESCRIPTION	Amb lenticular. Trilete laesurae often indistinct due to ornamentation, radii thin and extend one half to three fourths of spore. Exine thin and distinctly gemmate, forming "pustules". Pustules are usually not visible with LO analysis.
SIZE	25 µm x 20 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Middle Ripon Fm 56 Beaufort Group: E.Oudeberg M. 25, KZN.Normandien Fm 19
TOTAL ABUNDANCE	26 specimens

Infraturma Murornati

Subinfraturma Reticulati

Convolutispora intrareticulatus (Anderson) Millsteed 1999 Plate 2 (1)	
SYNONYMY	*Cyclogranisporites intrareticulatus* Anderson 1977
DESCRIPTION	Amb circular to sub-circular. Trilete laesurae discernible to distinct, often obscured by overlapping ridges, radii extend two thirds to full radius of spore. Exine reticulate, caused by closely packed overlapping anastomosing vermiculate ridge-like processes. Spore border laevigate.
SIZE	28 - 42 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> E.Upper Ripon Fm 55 <u>Beaufort Group:</u> E.Koonap Fm 35, E.Oudeberg M. 25
TOTAL ABUNDANCE	3 specimens

Foveosporites moretonensis de Jersey 1964 Plate 2 (9)	
DESCRIPTION	Amb roundly triangular to circular. Trilete laesurae indistinct to discernible, radii extending one half to two thirds of spore radius, bordered by labra up to 2 µm wide. Ornamentation of irregular foveae that may produce the effect of an indistinct reticulum. Ornamentation is reduced on proximal face.
SIZE	28 - 38 µm
STRATIGRAPHIC RANGE	<u>'Stormberg' Group:</u> KZN.Clarens Fm 5

TOTAL ABUNDANCE	2 specimens

Foveosporites sp. A Modie 2007 Plate 2 (10)	
DESCRIPTION	Amb sub-circular to roundly triangular. Trilete laesurae distinct, radii thin and extend to spore periphery. Exine 3 µm thick, sculpture of short fossulae and circular foveolae.
SIZE	34 - 37 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63
TOTAL ABUNDANCE	4 specimens

Reticulatisporites bifrons Jones & Truswell 1992 Plate 3 (17)	
DESCRIPTION	Amb sub-circular to oval to roundly triangular. Trilete laesurae indistinct, radii simple and extend two thirds of spore periphery. Both proximal and distal faces ornamented with a coarse reticulum of polygonal muri, muri appear to be formed by folding of the exine. Each murus seems double in optical section with two parallel bands separated by a narrow gap which represents the centre of the upfolded exine. Outline distorted by projecting muri. Exine smooth.
SIZE	48 - 74 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Prince Albert Fm 64, W.Collingham Fm 59
TOTAL ABUNDANCE	4 specimens

Reticulatisporites compactus (Luber & Waltz) Hart 1965 Plate 4 (1)	
DESCRIPTION	Amb circular to oval. Trilete laesurae indistinct, radii simple and bordered by thin labra, extend less than one half of spore periphery. Lumen are distinct and muri form a polygonal pattern.
SIZE	37 - 42 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63 Beaufort Group: KZN.Normandien Fm 22
TOTAL ABUNDANCE	7 specimens

Retitriletes rosewoodensis (de Jersey) McKellar 1974 Plate 4 (2)	
DESCRIPTION	Amb subcircular to convexly subtriangular, apices broadly to narrowly rounded, inter-apical region slightly convex. Trilete laesurae distinct to indistinct, extends almost to spore periphery, bordered by narrow, membranous labra. Exine distally and equatorially sculptured with low muri, lumina polygonal. Proximal face laevigate or sculptured marginally by extension of distal reticulum.
SIZE	21 - 24 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63 Beaufort Group: W.Abrahamskraal Fm 39, E.Koonap Fm 36, E.Katberg Fm 13

TOTAL ABUNDANCE	15 specimens

Retitriletes sp. A van der Hammen *ex* Pierce *emend*. Döring, Krutzsch, Mai & Schulz 1963 Plate 4 (3)	
DESCRIPTION	Amb triangular, apices narrowly rounded, inter-apical region slightly concave. Trilete laesurae indistinct. Exine sculptured with low muri.
SIZE	24 - 29 μm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> E.Upper Ripon Fm 55, E.Fort Brown Fm 52, E.Uppermost Fort Brown Fm 49, E.Waterford Fm 44 <u>Beaufort Group:</u> E.Koonap Fm 35, E.Oudeberg M. 25, KZN.Normandien Fm 24, E.Katberg Fm 13 <u>'Stormberg' Group:</u> KZN.Clarens Fm 6
TOTAL ABUNDANCE	110 specimens

Subinfraturma Rugulati

Ischyosporites volkheimeri Filatoff 1975 Plate 3 (5)	
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight to slightly convex. Trilete laesurae straight to slightly sinuous, radii extending two thirds of spore radius, bordered by labra up to 2

	µm wide. Sculpture of foveae and rugulae with rare verrucae on the distal face, sculpture encroaches onto proximal face at apices.
SIZE	26 - 39 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 24
TOTAL ABUNDANCE	44 specimens

ANTETURMA SPORITES

TURMA TRILETES

SUPRASUBTURMA ACAVATITRILETES

SUBTURMA AURICULATI

Infraturma Laevigati

Cf. *Triquitrites* sp. A of Bharadwaj & Venkatachala 1961 Plate 4 (8)	
DESCRIPTION	Amb roundly triangular with broadly conical auriculae, interapical region slightly concave to lightly convex. Border laevigate, trilete laesurae indistinct. Exine irregularly and densely ornamented with grana or verrucae.
SIZE	25 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 23
TOTAL ABUNDANCE	2 specimens
PREVIOUSLY REPORTED FROM	Carboniferous of Spitzbergen, Pennsylvanian of Iowa

Infraturma Murornati

Appendicisporites sp. Weyland & Krieger 1953 Plate 1 (5)	
SYNONYMY	*Plicatella* Malyavkina 1949
DESCRIPTION	Amb roundly triangular. Cicatricose structure of one or several sets of parallel muri together with exinal appendices in the equatorial radial regions. Trilete laesurae indistinct.
SIZE	26 - 28 μm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 22
TOTAL ABUNDANCE	2 specimens

ANTETURMA SPORITES

TURMA TRILETES

SUPRASUBTURMA LAMINATITRILETI

SUBTURMA ZONOLAMINATITRILETES

Infraturma Cingulicavati

Subinfraturma Laevigati

Limbosporites denmeadii (de Jersey 1962) de Jersey & Raine 1990 Plate 8 (1)	
SYNONYMY	*Lundbladispora denmeadi* (de Jersey) Playford & Dettmann 1965
DESCRIPTION	Amb triangular, apices sharp, inter-apical region slightly to strongly convex. Trilete laesurae indistinct to discernible, radii extend one half of

	spore body radius. Cingulum spongeous and finely punctate. Intexine laevigate. Zona approximately one fourth the width of spore body radius, margin smooth.
SIZE	41 - 44 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Palingkloof M. 14 'Stormberg' Group: KZN.Clarens Fm 4, KZN.Clarens Fm 2
TOTAL ABUNDANCE	53 specimens

Zonotrilete Sp. 1 cf. *Ergonulisporites appendiculatus* Ağrali 1969 Plate 8 (8)	
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region convex. Trilete laesurae indistinct. Zona present but damaged, hence width and form are not possible to ascertain. Intexine laevigate, exoexine laevigate to finely reticulate.
SIZE	Inner body 36 µm, zona > 23 µm in width
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 53
TOTAL ABUNDANCE	2 specimens

Subinfraturma Apiculati

Cf. *Cristatisporites inconstans* Archangelsky & Gamerro 1979 Plate 7 (13)	
DESCRIPTION	Trilete zonate spore with subtriangular amb. Apices

	rounded, inter-apical region strongly convex. Radii distinct and thickened, bordered by thin dark labra. Radii slightly sinuous, extend to spore periphery. Exine approx. 1 μm thick, with well-defined echinate ornamentation on both proximal & distal face. Echinae are 2-3 μm high and randomly orientated.
SIZE	19 - 23 μm
STRATIGRAPHIC RANGE	Beaufort Group: W.Upper Hoedemaker M. 28, W.Oukloof M. 27 'Stormberg' Group: E.Lower Elliot Fm 8
TOTAL ABUNDANCE	37 specimens

Densoisporites psilatus (de Jersey) Raine & de Jersey 1988 Plate 7 (14)	
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight to slightly convex. Trilete laesurae distinct, radii bordered by narrow labra and extend almost to margin of intexine. Cingulum smooth to scabrate, intexine laevigate.
SIZE	28 μm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 22
TOTAL ABUNDANCE	1 specimen

Densosporites vulgaris Neves 1961 Plate 7 (15)	
DESCRIPTION	Amb roundly triangular to sub-angular, outline

	irregular to due to radial folds in the cingulum. Trilete laesurae indistinct to discernible, radii extend to spore periphery, labra present in some specimens. Exoexine 2 - 4 µm, laevigate to infrapunctate on proximal face, verrucate on the distal face. Cingulum laevigate to finely granulate.
SIZE	52 - 64 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Whitehill Fm 62, W.Ripon Fm 57 Beaufort Group: W.Middle to Lower Poortjie M. 32 'Stormberg' Group: KZN.Clarens Fm 6
TOTAL ABUNDANCE	8 specimens

Gondisporites raniganjensis Bharadwaj 1962 Plate 7 (17)	
DESCRIPTION	Amb triangular, apices sharp, inter-apical region slightly convex. Trilete laesurae distinct, radii slightly thickened, arms extend to spore body margin. Body-exine thin and granulate with sporadic baculi. Thin zona with granulate exine, approx. 4 – 6 µm wide, margin undulating to dentate.
SIZE	54 - 61 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 'Stormberg' Group: E.Molteno Fm 9, KZN.Clarens Fm 6
TOTAL ABUNDANCE	16 specimens

Gondisporites variabilis Anderson 1977 Plate 7 (18)	
DESCRIPTION	Amb triangular, apices sharp, inter-apical region slightly to strongly convex. Trilete laesurae distinct, radii bordered by narrow labra, arms extend past spore body margin and onto zona. Intexine granulate with sporadic baculi. Zona approximately one third the width of spore body radius, exoexine granulate, margin smooth to dentate.
SIZE	42 - 60 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42 Beaufort Group: W.Abrahamskraal Fm - Mudstone B 41
TOTAL ABUNDANCE	10 specimens

Kraeuselisporites enormis Segroves 1970 Plate 7 (19)	
DESCRIPTION	Amb triangular, apices broadly to narrowly rounded, inter-apical region convex. Trilete laesurae distinct, radii thin and extend to inner margin of zona. Width of zona approximately one fourth to one half of spore. Exoexine punctate, microreticulate or scabrate. Distal surface ornament of coni and echinae, size of ornaments reduced on the proximal face. Intexine laevigate to finely granulate. Spore periphery strongly dentate.
SIZE	30 - 52 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Vryheid Fm 53,

	KZN.Volksrust Fm 42 Beaufort Group: W.Abrahamskraal Fm 38, W.Middle to Lower Poortjie M. 32 'Stormberg' Group: KZN.Clarens Fm 6
TOTAL ABUNDANCE	27 specimens

Lundbladispora braziliensis (Pant & Srivastava) *emend*. Marques-Toigo & Picarelli 1984 Plate 8 (2a, b)	
DESCRIPTION	Amb sub-circular to roundly subtriangular. Trilete laesurae discernible to distinct, radii extend to spore periphery and onto cingulum. Exoexine granulate, intexine proximally laevigate, punctate to finely granulate, distally verrucate to connate or spinose. Cingulum 5 – 10 μm wide; margin ornamented with coni and spinae, up to 2 μm high.
SIZE	50 - 60 μm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	8 specimens

Zinjisporites congoensis (Maheshwari & Bose) Anderson 1977 Plate 8 (6)	
DESCRIPTION	Amb triangular, apices broadly rounded, inter-apical region straight to slightly convex. Trilete laesurae indistinct, radii slightly thickened and do not extend onto zona. Exine ornamentation of echinae and baculi, both thin and elongated.

	Echinae are recurved.
SIZE	35 - 39 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	6 specimens

Zinjisporites spinosus (Kar & Bose) Anderson 1977 Plate 8 (7)	
DESCRIPTION	Amb roundly triangular, apices broadly rounded, inter-apical region straight to slightly convex. Trilete laesurae indistinct, radii slightly thickened and extends onto inner margin of zona. Proximal face granulate to spinose, distal face ornamented with interconnected cristae.
SIZE	30 µm
STRATIGRAPHIC RANGE	Beaufort Group: W.Abrahamskraal Fm - Mudstone B 41
TOTAL ABUNDANCE	1 specimen

Uvaesporites verrucosus (de Jersey) Helby 1971 Plate 8 (5)	
DESCRIPTION	Amb roundly triangular to circular. Trilete laesurae indistinct Distal face densely granulate to verrucose, projections on proximal face reduced. Narrow band of thinner exine on distal face at inner margin of equatorial zone in well-preserved specimens.
SIZE	21 - 43 µm
STRATIGRAPHIC RANGE	Beaufort Group:

	E.Burgersdorp Fm 11 'Stormberg' Group: E.Molteno Fm 9, E.Lower Elliot Fm 8, E.Upper Elliot Fm 7, KZN.Clarens Fm 2
TOTAL ABUNDANCE	15 specimens

Infraturma Murornati

Duplexisporites gyratus Playford & Dettmann 1965 Plate 7 (16)	
DESCRIPTION	Spores biconvex, distal surface strongly arched. Amb sub-triangular, apices sharp, inter-apical region convex. Trilete laesurae indistinct, extends three fourths of spore radius, bordered by elevated labra. Exine 1-2 µm with sculpture of broad low muri on the distal face that anastamose. Exine laevigate on the proximal face
SIZE	38 - 57 µm
STRATIGRAPHIC RANGE	'Stormberg' Group: KZN.Clarens Fm 6
TOTAL ABUNDANCE	2 specimens

Playfordiaspora crenulata (Wilson) Foster 1979 Plate 8 (3)	
SYNONYMY	*Guthoerlisporites cancellosus* Playford & Dettmann 1965
DESCRIPTION	Amb circular to sub-triangular. Trilete laesurae indistinct. Exine two-layered, consisting of a

	smooth homogenous intexine that is distally and equatorially detached from an enveloping, usually radially folded, finely reticulate exoexine.
SIZE	44 - 47 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Barberskrans M. 17, E.Elandsberg M. 16
TOTAL ABUNDANCE	5 specimens

Tripunctisporis maastrichtiensis (Krutzsch) Herngreen *et al*. 1986 Plate 8 (4)	
DESCRIPTION	Amb roundly triangular. Trilete laesurae indistinct. Exine laevigate with three distinct punctures in central body. Equatorial cingulum present.
SIZE	17 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Katberg Fm 13
TOTAL ABUNDANCE	1 specimen

ANTETURMA SPORITES

TURMA MONOLETES

SUPRASUBTURMA ACAVATOMONOLETES

SUBTURMA AZONOMONOLETES

Infraturma Laevigatomonoleti

Laevigatosporites minimus Dybová & Jachowicz 1957 Plate 5 (15)	
DESCRIPTION	Amb ellipsoidal, monolete laesura widened and extending full length of spore, forming “I” shape.

	Exine thin and laevigate.
SIZE	26 - 40 µm x 21 - 33 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Middle Ripon Fm 56 Beaufort Group: E.Barberskrans M. 17
TOTAL ABUNDANCE	18 specimens

Cf. *Laevigatosporites obscurus* Kosanke 1950 Plate 4 (16)	
DESCRIPTION	Amb broadly oval. Spore outline is irregular due to punctate sculpture of the exine. Monolete laesura extends two thirds to three fourths the radius of spore body, distorted by ornamentation.
SIZE	28 - 37 µm x 22 - 30 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 24 'Stormberg' Group: KZN.Clarens Fm 5
TOTAL ABUNDANCE	48 specimens

Laevigatosporites ovatus Wilson & Webster 1946 Plate 4 (17)	
DESCRIPTION	Amb broadly bean-shaped. Monolete laesura simple, extends three fourths of spore body. Exine laevigate.
SIZE	33 - 39 µm x 22 - 30 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Whitehill Fm 60, W.Ripon Fm 57, E.Fort Brown

	Fm 52, E.Fort Brown Fm 51, E.Waterford Fm 44 Beaufort Group: W.Middle to Lower Poortjie M. 32, E.Barberskrans M. 17, E.Katberg Fm 12 'Stormberg' Group: E.Upper Elliot Fm 7
TOTAL ABUNDANCE	38 specimens

Laevigatosporites vulgaris (Ibrahim *in* Potonié, Ibrahim & Loose) Ibrahim 1933 Plate 4 (19)	
SYNONYMY	*Laevigatosporites colliensis* (Balme & Hennelly) Venkatachala & Kar 1968
DESCRIPTION	Amb bean-shaped to oval. Monolete laesura simple, extends three fourths of spore body. Exine laevigate.
SIZE	35 - 50 µm x 22 - 33 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 34
TOTAL ABUNDANCE	1 specimen

Laevigatosporites sp. Ibrahim 1933 Plate 4 (18)	
DESCRIPTION	Amb oval. Monolete laesura simple, wide, extends full length of spore body. Exine laevigate.
SIZE	17 - 27 µm x 12 - 16 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Barberskrans M. 17 'Stormberg' Group: KZN.Clarens Fm 5

TOTAL ABUNDANCE	2 specimens

Infraturma Apiculatimonoleti

Punctatosporites granifer (Potonié & Kremp) Alpern & Doubinger, 1973 Plate 5 (1)	
DESCRIPTION	Amb circular to sub-circular to weakly oval, outline smooth. Monolete laesura distinct and extending entire diameter of spore, bordered by exinal folds. Exine ornament of fine grana.
SIZE	19 - 39 µm
STRATIGRAPHIC RANGE	<u>Dwyka Group:</u> E.Elandsvlei Fm 65 <u>Ecca Group:</u> E.Upper Ripon Fm 55, KZN.Vryheid Fm 54, KZN.Vryheid Fm 53, KZN.Volksrust Fm 42 <u>Beaufort Group:</u> E.Koonap Fm 34, KZN.Normandien Fm 24, E.Katberg Fm 13 <u>'Stormberg' Group:</u> KZN.Clarens Fm 6
TOTAL ABUNDANCE	105 specimens

Punctatosporites scabratus (Couper) Norris 1965 Plate 5 (2)	
DESCRIPTION	Amb broadly oval. Monolete laesura simple, long, extends full length of spore. Occasional granules scattered over entire exine.

SIZE	19 - 28 µm x 13 - 18 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Waterford Fm - Facies A 46 Beaufort Group: W.Oukloof M. 26, E.Palingkloof M. 14 'Stormberg' Group: KZN.Clarens Fm 6
TOTAL ABUNDANCE	12 specimens

Thymospora ipsviciensis (de Jersey) Jain 1968 Plate 5 (5)	
DESCRIPTION	Amb elliptical to subcircular. Monolete laesura extends two thirds of spore diameter. Exine heavily verrucate to verruco-rugulate.
SIZE	28 - 36 µm x 17 - 21 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Ripon Fm 57, E.Upper Ripon Fm 55, W.Lower Waterford Fm 47 Beaufort Group: W.Abrahamskraal Fm 38, E.Koonap Fm 35, W.Uppermost Abrahamskraal Fm 33, W.Poortjie M. 31, W.Oukloof M. 26, KZN.Normandien Fm 20, E.Barberskrans M. 17, E.Elandsberg M. 16, E.Palingkloof M. 14 'Stormberg' Group: E.Molteno Fm 9, KZN.Clarens Fm 2
TOTAL ABUNDANCE	142 specimens

Thymospora cf. *pseudothiessenii* (Kosanke) Wilson & Venkatachala 1963 Plate 5 (3)	
SYNONYMY	*Polypodiisporites mutabilis* Balme 1970
DESCRIPTION	Amb lenticular, monolete laesura often obscured by ornamentation. When seen, extends approx. half to three fourths the length of spore body. Exine approx. 1 µm thick, irregular but heavy verrucate ornamentation.
SIZE	23 - 30 µm x 21 - 27 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> E.Upper Ripon Fm 55, KZN.Vryheid Fm 54, KZN.Vryheid Fm 53, E.Waterford Fm 44, KZN.Volksrust Fm 43 <u>Beaufort Group:</u> W.Abrahamskraal Fm - Mudstone B 41, W.Middle to Lower Poortjie M. 32, W.Upper Hoedemaker M. 28, W.Oukloof M. 27, E.Oudeberg M. 25, KZN.Normandien Fm 22, E.Elandsberg M. 16, E.Elandsberg/Palingkloof Contact 15, E.Palingkloof M. 14, E.Katberg Fm 12 <u>'Stormberg' Group:</u> KZN.Clarens Fm 6, KZN.Clarens Fm 4, KZN.Clarens Fm 1
TOTAL ABUNDANCE	61 specimens

Cf. *Aratrisporites strigosus* Playford 1965 Plate 4 (13)	
DESCRIPTION	Amb oval, with central body and zona. Monolete laesura distinct and extends central body and onto zona, laesurae grades into zona at narrow ends of the ovaloid, which are elevated and curved in. Membraneous zona is usually narrow and turned up at the ends. Exoexine and intexine granulate, exoexine may carry scattered ornaments of spinae or coni.
SIZE	54 - 57 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 23
TOTAL ABUNDANCE	2 specimens

Aratrisporites tenuispinosus Playford 1965 Plate 4 (14)	
DESCRIPTION	Amb oval, with central body and zona. Monolete laesura distinct and extends full length of central body, does not extend onto zona. Zona is ornamented with spinae and coni.
SIZE	54 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Katberg Fm 13
TOTAL ABUNDANCE	1 specimen

ANTETURMA SPORITES

TURMA ALETES - INAPERTURATES

SUPRASUBTURMA ACAVATALETES

SUBTURMA AZONALETES

Infraturma Laevigati

Balmeella tetragona Pant & Mehra 1963 Plate 5 (4)	
SYNONYMY	*Tetraporina tetragona* (Pant & Mehra) Anderson 1977
DESCRIPTION	Amb quadrilateral, sides convex. Laesurae not apparent. Exine smooth to granular. Central depression bounded by two folds.
SIZE	45 - 60 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63, W.Whitehill Fm 62, E.Collingham Fm 58 Beaufort Group: E.Koonap Fm 35, W.Middle to Lower Poortjie M. 32, E.Oudeberg M. 25 'Stormberg' Group: KZN.Clarens Fm 5, KZN.Clarens Fm 2
TOTAL ABUNDANCE	12 specimens

Brazilea scissa (Balme & Hennelly) Foster 1975 Plate 5 (6)	
DESCRIPTION	Amb circular to lenticular, laesurae not present. Exine very thin and microgranulate / laevigate. Random folds orientated over surface, exine has a tendency to split open (probably due to its

	thinness).
SIZE	24 - 28 µm x 20 - 25 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 37, E.Barberskrans M. 17
TOTAL ABUNDANCE	5 specimens

Dicellaesporites sp. Elsik 1968 Plate 5 (11)	
DESCRIPTION	Amb oval. Two cells, uniseptate, inaperturate. Exine laevigate to scabrate. May be of fungal or algal origin.
SIZE	19 - 29 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Whitehill Fm 61 Beaufort Group: E.Koonap Fm 35, E.Koonap Fm 34, W.Middle Hoedemaker M. 29, KZN.Normandien Fm 19, E.Barberskrans M. 17, E.Katberg Fm 13 'Stormberg' Group: E.Lower Elliot Fm 8, KZN.Clarens Fm 6
TOTAL ABUNDANCE	79 specimens
PREVIOUSLY REPORTED FROM	Palaeocene of Texas

Dictyosporites sp. (Salard-Cheboldaeff & Locquin) Kalgutkar & Jansonius 2000 Plate 5 (12)	
DESCRIPTION	Multicellular smooth-walled fungal bodies. Amb circular to oval, may be compressed or folded.
SIZE	17 - 37 µm

STRATIGRAPHIC RANGE	Ecca Group: E.Fort Brown Fm 52, W.Lower Waterford Fm 47 Beaufort Group: E.Koonap Fm 36, E.Koonap Fm 35, W.Uppermost Abrahamskraal Fm 33, W.Middle to Lower Poortjie M. 32, W.Poortjie M. 31, W.Upper Hoedemaker M. 28, W.Oukloof M. 26, KZN.Normandien Fm 19, E.Elandsberg/Palingkloof Contact 15, E.Katberg Fm 13, E.Katberg Fm 12, E.Burgersdorp Fm 11 'Stormberg' Group: E.Lower Elliot Fm 8, E.Upper Elliot Fm 7
TOTAL ABUNDANCE	59 specimens
PREVIOUSLY REPORTED FROM	Palaeocene of Equatorial Africa

Diporisporites elongatus van der Hammen 1954 Plate 5 (13)	
DESCRIPTION	Amb fusiform with two opposite small pores at the tapered ends. Pores may be modified with atrium, annulus or septum. Laevigate exine.
SIZE	19 - 24 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63, W.Whitehill Fm 62, E.Whitehill Fm 60, E.Uppermost Fort Brown Fm 49 Beaufort Group: W.Abrahamskraal Fm 38, W.Uppermost Abrahamskraal Fm 33, W.Middle to Lower Poortjie M. 32, W.Middle Hoedemaker M. 29, E.Katberg Fm 13 'Stormberg' Group:

	E.Lower Elliot Fm 8, E.Upper Elliot Fm 7
TOTAL ABUNDANCE	57 specimens
PREVIOUSLY REPORTED FROM	Maastrichtian of Colombia

Disectispora lobata Tiwari & Navale 1967 Plate 5 (14)	
DESCRIPTION	Amb quadrilateral to irregularly subcircular with four lobed constructions in one plane. Lobes usually distinctly marked, thus imparting a square outline. Laesurae not apparent. Exine laevigate.
SIZE	32 - 45 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Collingham Fm 59 Beaufort Group: W.Abrahamskraal Fm 39
TOTAL ABUNDANCE	10 specimens
PREVIOUSLY REPORTED FROM	Permian (Upper Carboniferous?) of Brazil

Cf. *Haplocystia pellucida* Segroves 1967 Plate 5 (16)	
DESCRIPTION	Amb circular to sub-circular, alete. Exine is two-layered: outer layer is 3 µm thick with narrow grooves. Inner layer is thin, dark, and laevigate to microgranulate.
SIZE	24 - 30 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65

	Ecca Group: E.Whitehill Fm 60, E.Upper Ripon Fm 55, E.Uppermost Fort Brown Fm 49, W.Lower Waterford Fm 47, E.Waterford Fm 44 Beaufort Group: E.Koonap Fm 36, E.Koonap Fm 35, W.Uppermost Abrahamskraal Fm 33, W.Upper Poortjie M. 30, W.Upper Hoedemaker M. 28, W.Oukloof M. 26, E.Elandsberg M. 16, E.Elandsberg/Palingkloof Contact 15, E.Katberg Fm 13, E.Katberg Fm 12, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 'Stormberg' Group: E.Molteno Fm 9, E.Upper Elliot Fm 7, KZN.Clarens Fm 4
TOTAL ABUNDANCE	130 specimens

Hemisphaerium sp. Hemer & Nygreen 1967 Plate 5 (18)	
DESCRIPTION	Amb circular, grooved along one third to four fifths of test diameter. Exine laevigate. Test often split along and beyond the groove.
SIZE	14 – 19 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: E.Whitehill Fm 61, E.Collingham Fm 58, E.Upper Ripon Fm 55, E.Fort Brown Fm 52, E.Uppermost Fort Brown Fm 49, W.Lower Waterford Fm 47, E.Waterford Fm - Facies A 46, E.Waterford Fm - Facies B 45, E.Waterford Fm 44 Beaufort Group:

	W.Abrahamskraal Fm 39, W.Abrahamskraal Fm 38, E.Koonap Fm 37, E.Koonap Fm 35, E.Koonap Fm 34, W.Poortjie M. 31, W.Upper Hoedemaker M. 28, W.Oukloof M. 26, E.Oudeberg M. 25, KZN.Normandien Fm 19, E.Barberskrans M. 17, E.Elandsberg M. 16, E.Palingkloof M. 14, E.Katberg Fm 13, E.Katberg Fm 12 'Stormberg' Group: E.Molteno Fm 9
TOTAL ABUNDANCE	1497 specimens
PREVIOUSLY REPORTED FROM	Lower Carboniferous of Saudi Arabia

Inaperturopollenites dubius (Potonié & Venitz) Thomson & Pflug 1953 Plate 6 (3)	
DESCRIPTION	Amb subcircular to lenticular, inaperturate. Exine very thin and laevigate to microgranulate, heavily folded. Spores have a tendency to split (likely due to very thin exine).
SIZE	27 - 39 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 35, E.Koonap Fm 34, KZN.Normandien Fm 20
TOTAL ABUNDANCE	10 specimens

Inapertisporites circularis (Sheffy & Dilcher) Kalgutkar & Jansonius 2000 Plate 5 (20)	
DESCRIPTION	Spores inaperturate, thin-walled, laevigate, circular and unicellular.

SIZE	23 - 25 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Whitehill Fm 60
TOTAL ABUNDANCE	4 specimens

Inapertisporites communis Song & Li *in* Song *et al*. 1989 Plate 5 (10)	
DESCRIPTION	Spores inaperturate, subcircular, smooth; spore wall two-layered.
SIZE	52 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65
TOTAL ABUNDANCE	1 specimen

Inapertisporites sp. A van der Hammen 1954 *ex* Rouse 1959 Plate 6 (1)	
DESCRIPTION	Spores inaperturate, subcircular, smooth; spore wall split.
SIZE	52 - 55 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Elandsberg M. 16, E.Katberg Fm 13
TOTAL ABUNDANCE	3 specimens

Cf. *Inapertisporites* sp. B van der Hammen 1954 *ex* Rouse 1959 Plate 6 (2)	
DESCRIPTION	Spores inaperturate, subcircular, smooth; inaperturate.
SIZE	34 - 45 µm

STRATIGRAPHIC RANGE	Ecca Group: E.Uppermost Fort Brown Fm 49, W.Base of the Waterford Fm 48 Beaufort Group: E.Koonap Fm 37, E.Koonap Fm 36, E.Koonap Fm 35, E.Koonap Fm 34, E.Burgersdorp Fm 11
TOTAL ABUNDANCE	395 specimens

Inderites bulbiferus (Malyavkina) Abramova & Marchenko 1964 Plate 6 (4)	
DESCRIPTION	Amb circular to circular-oval. Border 4 µm wide surrounding body of spore. Exine thick and laevigate to infrapunctate. No dehiscence slit observed.
SIZE	45 - 50 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Upper Ripon Fm 55, E.Fort Brown Fm 52 Beaufort Group: E.Barberskrans M. 17
TOTAL ABUNDANCE	11 specimens

Involutisporonites foraminus Clarke 1965 Plate 6 (5)	
DESCRIPTION	Fungal spores planispiral, individual cells lobate, cell wall laevigate. Septa simple, each cell connected by an opening through each septum.
SIZE	20 - 27 µm
STRATIGRAPHIC RANGE	Beaufort Group: W.Abrahamskraal Fm 39, W.Uppermost

	Abrahamskraal Fm 33, W.Middle Hoedemaker M. 29, E.Oudeberg M. 25, KZN.Normandien Fm 24, E.Katberg Fm 13
TOTAL ABUNDANCE	27 specimens
PREVIOUSLY REPORTED FROM	Upper Cretaceous of Colorado

Lacrimasporonites levis Clarke 1965 Plate 6 (6)	
DESCRIPTION	Unicellate smooth-walled fungal spores, mostly medium-sized, spatulate to lacrimate. Flat hilar scar at one end, and a round pore at the opposite end of the spore.
SIZE	22 - 25 µm x 30 - 37 µm
STRATIGRAPHIC RANGE	<u>'Stormberg' Group:</u> E.Lower Elliot Fm 8, E.Upper Elliot Fm 7
TOTAL ABUNDANCE	3 specimens
PREVIOUSLY REPORTED FROM	Palaeocene of Equatorial Africa

Lacrimasporonites sp. A Clarke 1965 Plate 6 (7)	
DESCRIPTION	Unicellate smooth-walled fungal spores, lacrimate.
SIZE	19 - 21 µm x 16 - 18 µm
STRATIGRAPHIC RANGE	<u>Beaufort Group:</u> E.Oudeberg M. 25, E.Burgersdorp Fm 11
TOTAL ABUNDANCE	5 specimens

Lacrimasporonites sp. B Clarke 1965 Plate 6 (8)	
DESCRIPTION	Unicellate smooth-walled fungal spores, spatulate to lacrimate.
SIZE	24 - 29 µm x 15 - 22 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: E.Whitehill Fm 61, E.Whitehill Fm 60, E.Upper Ripon Fm 55 Beaufort Group: W.Abrahamskraal Fm 38, E.Elandsberg M. 16
TOTAL ABUNDANCE	58 specimens

Laevolancis divellomedium Burgess & Richardson 1991 Plate 6 (9)	
DESCRIPTION	Amb circular, inaperturate, proximally hilate. Equatorial to subequatorial crassitude surrounding the hilum. Exine laevigate.
SIZE	18 - 23 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 36, W.Middle Hoedemaker M. 29
TOTAL ABUNDANCE	4 specimens
PREVIOUSLY REPORTED FROM	Emsian of Bashkiria, USSR

Leiosphaeridia sp. Eisenack (1958) *emend*. Downie & Sarjeant (1963) *emend*. Turner (1984) Plate 6 (10)	
DESCRIPTION	Thin-walled, laevigate, originally spheroidal vesicles with common, mainly concentric folds.
SIZE	23 - 29 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 36 'Stormberg' Group: E.Lower Elliot Fm 8
TOTAL ABUNDANCE	6 specimens

Multicellites camerounensis (Salard-Cheboldaeff & Locquin) Kalgutkar & Jansonius 2000 Plate 6 (16)	
DESCRIPTION	Inaperturate laevigate fungal spores of three or more cells, two or more septa, shape variable around a long axis.
SIZE	35 - 43 µm x 12 - 16 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: E.Whitehill Fm 60, E.Fort Brown Fm 52, E.Fort Brown Fm 50 Beaufort Group: W.Middle Hoedemaker M. 29, W.Upper Hoedemaker M. 28, KZN.Normandien Fm 20, E.Elandsberg/Palingkloof Contact 15, E.Katberg Fm 13 'Stormberg' Group:

	E.Upper Elliot Fm 7
TOTAL ABUNDANCE	20 specimens

Papulosporonites sp. Schmiedeknecht & Schwab 1964 Plate 7 (1)	
DESCRIPTION	Spores in irregularly spherical, brown, smooth colonies consisting of an aggregate of angular to polygonal cells appressed together in a compact mass. Septae between cells solid, thickened, and dark.
SIZE	15 - 20 µm x 10 - 13 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Beaufort Group: E.Katberg Fm 13 'Stormberg' Group: E.Lower Elliot Fm 8, E.Upper Elliot Fm 7
TOTAL ABUNDANCE	68 specimens
PREVIOUSLY REPORTED FROM	Cretaceous of Canada

Phycomycites sp. Ellis 1915 Plate 7 (2)	
DESCRIPTION	Fungal sporangia with elongate hyphae attachment. Amb circular to sub-circular to oval, smooth-walled to infrapunctate.
SIZE	28 - 33 µm x 35 - 37 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Uppermost Fort Brown Fm 49

	Beaufort Group: E.Katberg Fm 13 'Stormberg' Group: E.Lower Elliot Fm 8, E.Upper Elliot Fm 7
TOTAL ABUNDANCE	8 specimens

Pilasporites calculus Plate 7 (3)	
DESCRIPTION	Amb lenticular, spore alete. Exine thin and laevigate or with sparse scabrate ornamentation.
SIZE	37 - 46 µm x 25 - 32 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Whitehill Fm 61, E.Uppermost Fort Brown Fm 49, W.Base of the Waterford Fm 48, W.Lower Waterford Fm 47 Beaufort Group: W.Abrahamskraal Fm 39, E.Koonap Fm 35, E.Koonap Fm 34, W.Uppermost Abrahamskraal Fm 33, W.Poortjie M. 31, E.Elandsberg M. 16 'Stormberg' Group: E.Upper Elliot Fm 7
TOTAL ABUNDANCE	95 specimens

Pilasporites plurigenus Balme & Hennelly 1956 Plate 7 (4)	
DESCRIPTION	Amb circular. Laesurae not apparent. Exine approx. 1-2 µm thick and laevigate under LM (likely micropitted under SEM). Small and random folds in exine.

SIZE	30 - 48 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 36, E.Koonap Fm 35, E.Katberg Fm 12 'Stormberg' Group: E.Upper Elliot Fm 7
TOTAL ABUNDANCE	52 specimens

Polycellaesporonites bellus Chandra, Saxena & Setty 1984 Plate 7 (6)	
DESCRIPTION	Capsular fungal spores, one end of spore is rounded while the other gives rise to a tube-like projection. Multi-cellulate, inaperturate, cells arranged in clusters and not in a row or along a single axis. Spore wall laevigate.
SIZE	50 - 54 µm x 10 - 12 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Whitehill Fm 60, E.Upper Ripon Fm 55 Beaufort Group: W.Abrahamskraal Fm 38, W.Middle to Lower Poortjie M. 32, W.Oukloof M. 26, KZN.Normandien Fm 24, E.Barberskrans M. 17, E.Katberg Fm 12
TOTAL ABUNDANCE	9 specimens
PREVIOUSLY REPORTED FROM	Late Quaternary of Arabian Sea

Prasinophyceae sp. Christensen 1962 Plate 7 (5)	
DESCRIPTION	Vesicle circular to roundly oval, inaperturate. Exine very thin and laevigate, easily compressed and randomly folded.
SIZE	32 - 43 µm x 21 - 36 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> W.Prince Albert Fm 64, E.Waterford Fm - Facies B 45 <u>Beaufort Group:</u> E.Koonap Fm 37, W.Middle Hoedemaker M. 29, E.Barberskrans M. 17, E.Elandsberg M. 16, E.Palingkloof M. 14, E.Katberg Fm 13, E.Katberg Fm 12 <u>'Stormberg' Group:</u> KZN.Clarens Fm 1
TOTAL ABUNDANCE	67 specimens

Reduviasporonites chalastus Wilson 1962 *emend*. Foster *et al*. 2002 Plate 7 (7a, b)	
DESCRIPTION	Amb sub-rectangular, flask shaped, ovoid or spherical. Outer cell wall is 0.5 – 1.5 µm thick, exine laevigate to granulate. Inner body present in most specimens, has the same shape as outer cell or is twisted due to shrinkage. Usually forms chains but also present in pair or single cells.
SIZE	26 - 63 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> W.Prince Albert Fm 64, E.Prince Albert Fm 63, E.Whitehill Fm 61, E.Whitehill Fm 60

	Beaufort Group: W.Abrahamskraal Fm 39, W.Abrahamskraal Fm 38, E.Koonap Fm 37, E.Koonap Fm 36, E.Koonap Fm 34, W.Upper Poortjie M. 30, W.Upper Hoedemaker M. 28, KZN.Normandien Fm 24, KZN.Normandien Fm 23, KZN.Normandien Fm 22, KZN.Normandien Fm 20, E.Elandsberg/Palingkloof Contact 15, E.Palingkloof M. 14, E.Katberg Fm 13, E.Katberg Fm 12, E.Burgersdorp Fm 11, E.Burgersdorp Fm 10 'Stormberg' Group: E.Molteno Fm 9, E.Lower Elliot Fm 8
TOTAL ABUNDANCE	137 specimens

Tetraporina horologia (Staplin) Playford 1963 Plate 7 (11)	
DESCRIPTION	Amb quadrilateral, sides may be convex, concave or irregular. Laesurae not apparent. Exine approx. 1-2 µm thick and laevigate with a sparse finely granulate texture.
SIZE	34 - 58 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Middle Ripon Fm 56 Beaufort Group: E.Palingkloof M. 14
TOTAL ABUNDANCE	2 specimens

Infraturma Apiculati

Cerebropollenites mesozoicus Nilsson 1958 Plate 5 (7)	
DESCRIPTION	Amb circular to oval, inaperturate. Exine coarsely and irregularly folded and plicated, ornamented with verrucae to loop-shaped ornaments. Spores have a tendency to split (likely due to very thin exine).
SIZE	27 - 35 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Fort Brown Fm 50 Beaufort Group: KZN.Normandien Fm 22, E.Katberg Fm 13
TOTAL ABUNDANCE	9 specimens

Hemisphaerium inominatum Hemer & Nygreen 1967 Plate 5 (17)	
DESCRIPTION	Amb circular, grooved along one third to four fifths of test diameter. Exine granulate. Test often split along and beyond the groove.
SIZE	17 – 35 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 19
TOTAL ABUNDANCE	6 specimens
PREVIOUSLY REPORTED FROM	Lower Carboniferous of Saudi Arabia

Hilidicellites strangulatus (Salard-Cheboldaeff & Locquin) Kalgutkar & Jansonius 2000 Plate 5 (19)	
DESCRIPTION	Amb oval. Two cells, uniseptate, inaperturate. Exine laevigate to scabrate. Margin dentate.
SIZE	15 - 24 µm
STRATIGRAPHIC RANGE	Beaufort Group: W.Upper Poortjie M. 30
TOTAL ABUNDANCE	7 specimens
PREVIOUSLY REPORTED FROM	Lower Carboniferous of Saudi Arabia

Mehlisphaeridium fibratum Segroves 1967 Plate 6 (13)	
DESCRIPTION	Amb circular, wall two-layered. Body bearing evenly or unevenly disposed, hollow, coarse, conical processes, which are composed of only the outer layer of the wall, which is differentially thickened to form elongate fibres that are confined to and traverse the length of the processes. Grana or subgrana cover remainder of processes or may be restricted to fibres.
SIZE	37 - 43 µm
STRATIGRAPHIC RANGE	Beaufort Group: W.Poortjie M. 31, KZN.Normandien Fm 23, E.Elandsberg/Palingkloof Contact 15
TOTAL ABUNDANCE	36 specimens

Membranosphaera maastrichtica Samoilovich *in* Samoilovich & Mchedlishvili 1961 Plate 6 (15)	
DESCRIPTION	Amb circular to ellipsoidal, easily crumpled. Exine ornamented with small tubercles
SIZE	21 - 39 µm
STRATIGRAPHIC RANGE	<u>Ecca Group:</u> E.Upper Ripon Fm 55 <u>Beaufort Group:</u> W.Abrahamskraal Fm - Mudstone D 40, W.Uppermost Abrahamskraal Fm 33, KZN.Normandien Fm 19 <u>'Stormberg' Group:</u> KZN.Clarens Fm 6
TOTAL ABUNDANCE	67 specimens
PREVIOUSLY REPORTED FROM	Maastrichtian of Western Siberia

Micrhystridium karrooense Anderson 1977 Plate 6 (17)	
DESCRIPTION	Vesicle with circular amb. Distinct outer wall approximately 4 µm thick. Equator ornamented with sporadic elongated baculate-like processes.
SIZE	23 - 24 µm
STRATIGRAPHIC RANGE	<u>Beaufort Group:</u> KZN.Normandien Fm 19
TOTAL ABUNDANCE	2 specimens
PREVIOUSLY REPORTED FROM	Maastrichtian of Western Siberia

Micrhystridium stellatum Deflandre 1942 Plate 6 (19)	
DESCRIPTION	Vesicle polyhedral, thin-walled, smooth, spines slightly curved.
SIZE	13 - 17 µm
STRATIGRAPHIC RANGE	Beaufort Group: W.Upper Hoedemaker M. 28
TOTAL ABUNDANCE	2 specimens
PREVIOUSLY REPORTED FROM	Jurassic of Western Canada

Micrhystridium sp. Modie 2007 Plate 6 (18)	
DESCRIPTION	Vesicle with circular amb; probably originally spheroidal. Distinct outer wall about 1 - 2 µm thick; equator with densely populated processes, 1 µm high, less than 1 µm apart, conate-like to baculate-like.
SIZE	19 - 23 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Beaufort Group: W.Abrahamskraal Fm - Mudstone D 40, W.Uppermost Abrahamskraal Fm 33, E.Oudeberg M. 25
TOTAL ABUNDANCE	7 specimens
PREVIOUSLY REPORTED FROM	Palaeozoic of Botswana

Sphaeroporalites solus Hemer & Nygreen 1967 Plate 7 (9)	
DESCRIPTION	Amb circular, porate, pores simple and circular, pore area often pigmented. Exine microgranulate. Wall thickness 1 - 2 µm.
SIZE	17 – 35 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Lower Waterford Fm 47
TOTAL ABUNDANCE	4 specimens
PREVIOUSLY REPORTED FROM	Lower Carboniferous of Saudi Arabia

Tasmanites sp. Newton 1875 Plate 7 (10)	
DESCRIPTION	Outline circular to sub-circular. Multi-porate or with a perforated texture. Pores commonly circular, occasionally sub-circular to rarely oval or linear; sporadic coarse pores. Wall appears largely smooth and uniform with faint laminae, 2 – 3 µm thick. Pores rarely extend beyond wall structure, but are visible within wall as narrow radial elements.
SIZE	56 - 59 x 44 - 46 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Middle Ripon Fm 56 Beaufort Group: E.Koonap Fm 37 'Stormberg' Group: E.Molteno Fm 9, KZN.Clarens Fm 6
TOTAL ABUNDANCE	83 specimens

PREVIOUSLY REPORTED FROM	Lower Carboniferous of Saudi Arabia

Infraturma Murornati

Circulisporites parvus (de Jersey) Norris 1965 Plate 5 (9)	
DESCRIPTION	Amb circular, no laesurae present. Exine ornamented with multiple concentric ribs that resemble tree rings.
SIZE	30 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63
TOTAL ABUNDANCE	1 specimen

Greinervillites sp. Bose & Kar 1967 Plate 5 (15)	
DESCRIPTION	Amb circular to sub-circular. Exine ornamented with a coarse reticulum on both faces, muri high, thin, flappy, wide at the middle and tapering at the ends, meshes polygonal to rectangular, lumina shallow. Exine between muri laevigate. No dehiscence slit observed. Margin smooth or slightly undulating.
SIZE	19 - 41 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Collingham Fm 58, W.Ripon Fm 57, E.Waterford Fm 44

	Beaufort Group: W.Abrahamskraal Fm 38, E.Koonap Fm 34, W.Upper Poortjie M. 30, W.Oukloof M. 26, E.Barberskrans M. 17, E.Katberg Fm 12, E.Burgersdorp Fm 11
TOTAL ABUNDANCE	52 specimens
PREVIOUSLY REPORTED FROM	Permian of Congo

Maculatasporites eraduensis Anderson 1977 Plate 6 (11)	
DESCRIPTION	Outline circular to sub-circular to slightly quadrilateral. Exine foveolate, foveae are small and just touch, creating a spongy appearance. No dehiscence slit observed.
SIZE	23 - 26 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Beaufort Group: W.Abrahamskraal Fm 39, W.Abrahamskraal Fm 38, E.Koonap Fm 37 'Stormberg' Group: E.Lower Elliot Fm 8, KZN.Clarens Fm 1
TOTAL ABUNDANCE	20 specimens

Maculatasporites gondwanensis Tiwari 1965 Plate 6 (12)	
DESCRIPTION	Amb circular to subcircular. Exine reticulate with polygonal lumina surrounded by uniform muri. No

	aperture visible.
SIZE	37 - 42 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: E.Whitehill Fm 61, E.Whitehill Fm 60, E.Collingham Fm 58 Beaufort Group: W.Middle to Lower Poortjie M. 32, W.Upper Hoedemaker M. 28, W.Oukloof M. 26, E.Palingkloof M. 14
TOTAL ABUNDANCE	77 specimens
PREVIOUSLY REPORTED FROM	Barakar Stage, India

Mehlisphaeridium regulare Anderson 1977 Plate 6 (14)	
DESCRIPTION	Amb sub-circular, finely reticulate on both faces. No dehiscence slit observed.
SIZE	19 - 36 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Collingham Fm 59, E.Fort Brown Fm 50, KZN.Volksrust Fm 42 Beaufort Group: W.Abrahamskraal Fm - Mudstone B 41, W.Abrahamskraal Fm 38, E.Koonap Fm 36, W.Middle to Lower Poortjie M. 32, W.Middle Hoedemaker M. 29, E.Elandsberg/Palingkloof Contact 15, E.Palingkloof M. 14, E.Burgersdorp Fm 11 'Stormberg' Group:

	E.Lower Elliot Fm 8
TOTAL ABUNDANCE	122 specimens

Retialetes radforthii Staplin 1960 Plate 7 (8)	
DESCRIPTION	Amb ellipsoidal, sculpture reticulate, muri approximately 1 µm wide. Sometimes split along a few fine grooves that originate at one end and parallel the long axis, grooves not seen on unbroken specimens.
SIZE	36 - 39 µm x 27 - 34 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 34
TOTAL ABUNDANCE	6 specimens

SUBTURMA ZONALETES

Infraturma Laevigati

Cingulaletes minor (Luber) Hart 1965 Plate 5 (8)	
DESCRIPTION	Amb circular to oval and possessing an equatorial cingulum. Exine laevigate to granulate.
SIZE	30 - 32 µm x 30 - 34 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Fort Brown Fm 52, E.Fort Brown Fm 51
TOTAL ABUNDANCE	3 specimens

Zonoaletes hacquebardii Staplin 1960 Plate 7 (12)	
DESCRIPTION	Amb circular to sub-circular, shape lenticular, equatorially girdled, exine laevigate.
SIZE	51 - 65 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: W.Prince Albert Fm 64, W.Collingham Fm 59, E.Upper Ripon Fm 55, E.Fort Brown Fm 50, KZN.Normandien Fm 22, KZN.Normandien Fm 20, E.Katberg Fm 13, E.Katberg Fm 12 'Stormberg' Group: KZN.Clarens Fm 6
TOTAL ABUNDANCE	15 specimens

ANTETURMA POLLENITES

TURMA PRAEPOLLENITES

SUBTURMA CIRCUMPOLLES

Infraturma Singulipollenites

Duplicisporites granulatus (Leschik) Scheuring 1970 Plate 8 (9)	
DESCRIPTION	Amb circular to subtriangular. Sometimes a small simple trilete laesurae is seen at the proximal pole. Rimula (ring-like exine thinning) in the equatorial zone. Two superimposed spore sacs which are connected to a single spore body at three points. Exine is finely granulate to laevigate.

SIZE	40 - 42 µm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 34
TOTAL ABUNDANCE	5 specimens

TURMA SACCITES

SUBTURMA MONOSACCITES

Infraturma Triletesacciti

Barakarites rotatus (Balme & Hennelly) Bharadwaj & Tiwari 1964 Plate 8 (10)	
DESCRIPTION	Amb sub-circular to oval, rarely roundly sub-triangular. Margin generally smooth, sometimes undulated or possessing crenulations. Corpus outline discernible to distinct, sub-circular to broadly oval. Trilete laesurae poorly displayed, saccus attachment sub-equatorial. Saccus one third to one fourth of corpus radius and is infrapunctate, infrareticulate or infravermiculate.
SIZE	79 - 111 µm largest equatorial diameter (e-d), 60 - 83 µm corpus diameter (c-d)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Volksrust Fm 42
TOTAL ABUNDANCE	12 specimens

Cannanoropollis densus (Lele) Bose & Maheshwari 1968 Plate 8 (11)	
DESCRIPTION	Amb circular to sub-circular. Corpus distinct,

	exoexinal expansion surrounds corpus, exinal surface reticulate. Faint trilete aperture visible in some specimens. Bladder exine reticulate, gently undulate margin. Saccus approx. half the width of the corpus radius.
SIZE	54 - 87 µm (e-d), 31 - 50 µm (c-d)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54 Beaufort Group: W.Poortjie M. 31 'Stormberg' Group: E.Molteno Fm 9
TOTAL ABUNDANCE	14 specimens

Cannanoropollis mehtae (Lele) Bose & Maheshwari 1968 Plate 8 (12)	
SYNONYMY	*Virkkipollenites mehtae* Falcon 1988
DESCRIPTION	Amb circular to sub-circular. Corpus discernible, shape circular to subcircular, margin often indistinct and smooth. Proximal surface finely reticulate. Proximal surface displays discernible to indistinct trilete aperture, laesurae one half to almost full corpus radius in length. Intexine thin and unstructured. Saccus fine to mediumly reticulate with brochi 1 -5 µm in diameter and radially elongate. Saccus strongly frilled, saccus width one third to two thirds of corpus radius. Outline moderately to strongly crenulate and moderately undulate.
SIZE	58 - 95 µm (e-d), 31 - 51 µm (c-d)
STRATIGRAPHIC RANGE	Ecca Group:

	E.Prince Albert Fm 63, KZN.Vryheid Fm 54, KZN.Volksrust Fm 42
TOTAL ABUNDANCE	16 specimens

Cannanoropollis obscurus (Lele) Bose & Maheshwari 1968 Plate 8 (13)	
SYNONYMY	*Virkkipollenites obscurus* Falcon 1988
DESCRIPTION	Amb circular to broadly oval. Corpus circular to oval, exoexine infrareticulate, intexine very thin. Proximal surface displays poorly defined trilete aperture, laesurae one half of corpus radius in length. Saccus 1 - 3 µm thick, intrareticulum fine, densely packed, brochi 1 - 5 µm in diameter and radially elongate.
SIZE	75 - 117 µm (b-d), 53 - 82 µm (c-d)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Volksrust Fm 42
TOTAL ABUNDANCE	26 specimens

Plicatipollenites gondwanensis (Balme & Hennelly) Lele 1964 Plate 8 (15)	
SYNONYMY	*Vestigisporites gondwanensis* (Balme & Hennelly) Anderson 1977
DESCRIPTION	Amb circular, sub-circular to occasionally slightly oval. Margin smooth to slightly undulated. Corpus distinct, circular to sub-circular, following contour of saccus margin. Proximal surface finely reticulate to coarsely granulate, exoexine thickens and may be detached from the intexine near to or at the corpus

	equator. Distally the exoexine thickens at or close to the inner margin of the circular to polygonal folds i.e. subequatorially. Proximal surface displays indistinct to discernible trilete aperture, laesurae one third to one half of corpus radius in length. Intexine thin, unstructured. Saccus width one half to rarely equal to corpus radius. Saccus finely reticulate with brochi 1 - 3 µm in diameter.
SIZE	75 - 117 µm (e-d), 45 - 69 µm (c-d)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 43 Beaufort Group: KZN.Normandien Fm 21
TOTAL ABUNDANCE	30 specimens

Plicatipollenites sp. Lele 1964 Plate 8 (16)	
DESCRIPTION	Amb circular to slightly oval. Corpus distinct. Exhibiting conspicuous intexinal fold system. Saccus finely reticulate.
SIZE	60 µm (e-d), 27 µm (c-d)
STRATIGRAPHIC RANGE	'Stormberg' Group: KZN.Clarens Fm 6
TOTAL ABUNDANCE	3 specimens

Infraturma Aletesacciti

Florinites eremus Balme & Hennelly 1955 Plate 8 (14)	
DESCRIPTION	Amb sub-circular to oval. Corpus subcircular, may be distinct or indistinct with diffused reticulum sometimes exhibiting marginal folding. Saccus punctate and finely reticulate with brochi 1 – 2 µm wide.
SIZE	32 - 104 µm (e-d), 20 - 64 µm (c-d)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Vryheid Fm 53
TOTAL ABUNDANCE	4 specimens

Potonieisporites magnus Lele & Karim 1971 Plate 8 (17)	
DESCRIPTION	Amb elongately oval in the longitudinal direction. Corpus distinct, circular, sub-circular to oval. Proximal surface finely reticulate, exoexinal expansion or thickening subequatorial and in close proximity to the corpus margin. Distally there are two sets of narrow subequatorial folds. Intexine thin and unstructured. Saccus finely to mediumly reticulate with numerous fine radial folds (Specimens have lost sacci).
SIZE	56 µm (c-w), 76 µm (c-h), 76 µm (s-h)
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 21 'Stormberg' Group: E.Molteno Fm 9, KZN.Clarens Fm 6

TOTAL ABUNDANCE	9 specimens

ANTETURMA POLLENITES

TURMA SACCITES

SUBTURMA DISACCITES

Infraturma Disacciatrileti

Chordasporites australiensis de Jersey 1962 Plate 9 (8)	
DESCRIPTION	Amb haploxylonoid with a chorda 4 - 8 µm wide on the proximal surface of the corpus. Corpus sub-circular to quadrilateral in shape. Intexine smooth to faintly reticulate. Chorda extends across entire proximal corpus surface, or almost so. Sacci semicircular in shape, approximately equal to corpus in size, finely reticulate with brochi ± 1.5 - 3 µm in diameter.
SIZE	28 µm (c-w), 34 µm (c-h), 20 µm (s-w), 44 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	9 specimens

Chordasporites endroedii MacRae 1988 Plate 9 (12)	
DESCRIPTION	Amb haploxylonoid with a chorda on the proximal surface of the corpus. Corpus circular, sub-circular to slightly quadrilateral in shape. Intexine ± 2 µm

	thick, may have fine spinae concentrated towards the equator, finely granulate elsewhere. Intexine appears darker in a thin (± 8 µm wide) equatorial region or band. Chorda of two thickened exinal elements with a visible join line in the centre, extends across entire proximal corpus surface and merges with the equatorial darkened band. Sacci semicircular to less than semicircular in shape, smaller than corpus in transverse direction. Cappula wide, three fourths or more of corpus longitudinal direction. Sacci finely reticulate with brochi ± 2 µm in diameter.
SIZE	26 µm (c-w), 33 µm (c-h), 17 µm (s-w), 35 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	3 specimens

Cf. *Jugasporites* sp. 1 MacRae 1988 Plate 10 (7)	
DESCRIPTION	Amb diploxylonoid. Corpus circular to sub-circular. Sacci greater than semicircular in shape and slightly larger than the corpus in the transverse direction, reticulate with radial folds.
SIZE	33 µm (c-w), 38 µm (c-h), 22 µm (s-w), 45 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54
TOTAL ABUNDANCE	2 specimens

Minutosaccus acutus Mädler 1964 Plate 9 (13)	
DESCRIPTION	Amb diploxylonoid. Corpus circular, sub-circular to slightly quadrilateral in shape, thick-walled and dark. Distinct sulcus developed on the corpus. Sacci sub-circular in shape, distinctly smaller than corpus. Sacci finely reticulate.
SIZE	38 µm (c-w), 36 µm (c-h), 35 µm (s-w), 28 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	4 specimens
PREVIOUSLY REPORTED FROM	Lower Triassic of Germany

Platysaccus papilionis Potonié & Klaus 1954 Plate 9 (5)	
DESCRIPTION	Amb strongly diploxylonoid. Corpus discernible to distinct, subcircular to elongately oval in shape. Sacci much larger than corpus, greater than semicircular in shape, finely infrareticulate with superimposed vermiculate, brochi less than 1 µm wide. Narrow cappula approx. 2 µm wide, extending full length of corpus.
SIZE	20 - 24 µm (c-w), 24 - 29 µm (c-h), 18 - 20 µm (s-w), 36 - 41 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Volksrust Fm 42
TOTAL ABUNDANCE	26 specimens

Platysaccus radialis (Leschik) Clarke 1965 Plate 9 (11)	
DESCRIPTION	Amb diploxylonoid with protosaccate infrastructure. Corpus discernible to distinct, longitudinally oval to rhombic in shape. Exoexine of cappa finely infrapunctate, sometimes fractured and divided Into irregular polygonal areas. Intexine 2 µm thick, smooth, darker than exoexine. Sacci larger than corpus, subcircular to broadly reniform in equatorial outline, discrete or overlapping at lateral margins of corpus, distally inclined. Saccus exoexine 1 µm thick, often arranged in radial folds emanating from sacci bases; infrastructure fine or moderately coarse, brochi 0.5 - 2 µm in diameter, sometimes strongly radially elongate. Cappula extending over full length of corpus, breadth less than half that of corpus, often flanked by narrow intexinal folds.
SIZE	19 µm (c-w), 23 µm (c-h), 14 µm (s-w); 32 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Volksrust Fm 42
TOTAL ABUNDANCE	17 specimens

Platysaccus sp. Naumova 1939 *ex* Ishchenko 1952 Plate 9 (10)	
DESCRIPTION	Amb diploxylonoid. Corpus distinct, subcircular to quadrilateral in shape. Sacci approximately equal in size to corpus, semicircular in shape, finely infrareticulate.

SIZE	13 µm (c-w); 14 µm (c-h); 16 µm (s-w); 14 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: E.Middle Ripon Fm 56, KZN.Vryheid Fm 54, KZN.Volksrust Fm 43 'Stormberg' Group: E.Molteno Fm 9, KZN.Clarens Fm 1
TOTAL ABUNDANCE	36 specimens

Pteruchipollenites landianus (Balme 1970) MacRae 1988 Plate 10 (5)	
DESCRIPTION	Amb moderately diploxylonoid. Corpus indistinct to distinct, circular to sub-circular in shape. Exoexine of the proximal surface thin, granulate to finely reticulate. Distal saccus attachment subequatorial with a narrow saccus overlap onto the corpus. Cappula wide, oval to rectangular in shape. Sacci larger than corpus, semicircular to more so in shape, finely reticulate with brochi less than 1 µm in diameter. Lateral bladders narrow to not developed. Sacci may show radial folding near the bases.
SIZE	36 - 60 µm (c-w), 56 - 72 µm (c-h), 40 - 64 µm (t-w), 70 - 130 µm (t-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54 Beaufort Group: KZN.Normandien Fm 23, KZN.Normandien Fm 21
TOTAL ABUNDANCE	51 specimens

Pteruchipollenites sp. Couper 1958 Plate 9 (14)	
DESCRIPTION	Amb haploxylonoid. Corpus indistinct, appears elongately oval in shape. Sacci semicircular in shape.
SIZE	72 µm x 58 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 43 Beaufort Group: KZN.Normandien Fm 22, KZN.Normandien Fm 21, KZN.Normandien Fm 19 'Stormberg' Group: KZN.Clarens Fm 5, KZN.Clarens Fm 3, KZN.Clarens Fm 2
TOTAL ABUNDANCE	42 specimens

Scheuringipollenites ovatus (Balme & Hennelly) Foster 1975 Plate 11 (12)	
SYNONYMY	*Alisporites ovatus* (Balme & Hennelly) Jansonius 1962
DESCRIPTION	Pollen distally sulcate. Amb haploxylonoid, oval in shape. Corpus indistinct to discernible, elongately oval. Sacci semi-elliptical, finely reticulate with brochi about 1 µm wide. Distal saccus attachment sub-parallel, defining margin to a narrow sulcus that extends the full length of corpus.
SIZE	19 - 28 µm (c-w), 29 - 39 µm (c-h), 24 - 41 µm (s-w), 36 - 49 µm (t-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Vryheid Fm 53,

	KZN.Volksrust Fm 43 Beaufort Group: KZN.Normandien Fm 23
TOTAL ABUNDANCE	87 specimens

Cf. *Scheuringipollenites* (*Alisporites*) *ovatus* MacRae 1988 Plate 10 (6)	
DESCRIPTION	Amb haploxylonoid, oval to quadrangular in shape. Corpus indistinct. Proximal exoexine infrapunctate to slightly granulate. Sacci less than semi-circular in shape, finely reticulate. Narrow sulcus formed distally between saccus bases.
SIZE	42 µm x 36 µm
STRATIGRAPHIC RANGE	'Stormberg' Group: KZN.Clarens Fm 2
TOTAL ABUNDANCE	1 specimen

Scheuringipollenites sp. (Balme & Hennelly) Foster 1975 Plate 9 (2)	
DESCRIPTION	Amb haploxylonoid, circular to oval in shape. Corpus distinct, oval in shape. Proximal exoexine punctate. Sacci crescentic in shape, finely reticulate. Narrow sulcus formed distally between saccus bases.
SIZE	64 µm x 56 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 24
TOTAL ABUNDANCE	2 specimens

Vestigisporites rudis Balme & Hennelly 1955 Plate 11 (2)	
DESCRIPTION	Amb haploxylonoid to weakly diploxylonoid. Corpus distinct, circular to sub-circular. Proximal face laevigate. Sacci semi-circular to greater than semicircular in shape and reticulate.
SIZE	30 - 55 µm (c-w), 25 - 59 µm (c-h), 26 - 86 µm (s-w), 45 - 83 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54 Beaufort Group: W.Poortjie M. 31, E.Palingkloof M. 14 'Stormberg' Group: KZN.Clarens Fm 5
TOTAL ABUNDANCE	7 specimens

Bisaccate Sp. 1 Plate 9 (1)	
DESCRIPTION	Amb diploxylonoid. Corpus indistinct, sub-circular to oval. Presumed laevigate due to age (Jurassic). Sacci semi-circular to greater than semicircular in shape and reticulate.
SIZE	40 µm (c-h), 48 µm (s-w), 56 µm (s-h)
STRATIGRAPHIC RANGE	'Stormberg' Group: KZN.Clarens Fm 6
TOTAL ABUNDANCE	2 specimens

Infraturma Striatiti

Corisaccites alutas Venkatachala & Kar 1966 Plate 9 (6)	
DESCRIPTION	Amb diploxylonoid to almost haploxylonoid. Corpus distinct, subcircular to transversely elongate. Cappa relatively thick, scabrate to punctate, bisected transversely into two taeniae by a well-defined narrow cleft having straight to weakly undulant margins, extending continuously to corpus margins. Sacci longitudinally elongate, semicircular in shape, with distal and equatorial attachment to corpus. Narrow, saccus-free distal area comprising cappula consisting of thin intexine.
SIZE	45 - 60 µm (c-w), 38 - 57 µm (c-h), 22 - 32 µm (s-w), 46 - 60 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: W.Collingham Fm 59
TOTAL ABUNDANCE	1 specimen

Hamiapollenites dettmannae Segroves 1969 Plate 9 (7)	
DESCRIPTION	Amb haploxylonoid to slightly diploxylonoid. Corpus circular to oval. Cappa with approximately 5–8 latitudinal taeniae, intexine thin and indistinct. Distal face of corpus with one longitudinal distal taenia; often more prominent than the proximal taeniae. Cappula width 40–60% of the corpus width; extends the length of the corpus. Proximal taeniae 3–10 µm wide, parallel or convergent, with

	narrow striations between (< 0.5 µm wide), distal taenia 5–8 µm. Sacci greater than semicircular in shape, distinctly smaller than the corpus, sacci width approximately half that of corpus. Infrareticulation fine to coarse when discernible (brochi diameter 0.5–2 µm); infrareticulation often not distinct.
SIZE	18 - 24 µm (c-w), 26 - 30 µm (c-h), 18 - 24 µm (s-w), 32 - 40 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Vryheid Fm 53
TOTAL ABUNDANCE	18 specimens

Protohaploxypinus latissimus (Luber *in* Luber & Waltz) Samoilovich 1953 Plate 10 (1)	
DESCRIPTION	Amb haploxylonoid. Corpus distinct, circular to subcircular. Proximal surface finely reticulate to coarsely granulate with 10 longitudinal taeniae. Taeniae of unequal width, separated by narrow clefts. Cappula oval, one third or less so of corpus longitudinal dimension, exine laevigate. Sacci semi-circular to less than so, joined laterally by narrow lateral bladders. Sacci finely reticulate with brochi 0.5 - 2 µm in diameter.
SIZE	55 µm (c-w), 60 µm (c-h), 20 µm (s-w), 60 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54
TOTAL ABUNDANCE	2 specimens

Protohaploxypinus limpidus (Balme & Hennelly) Balme & Playford 1967 Plate 9 (4)	
SYNONYMY	*Pityosporites micros* (Hart) Anderson 1977
DESCRIPTION	Amb haploxylonoid, elongately oval in longitudinal axis of grain. Corpus indistinct to discernible, broadly elongately oval. Proximal cap with 6 – 8 longitudinal taeniae, rarely branched and approx. 1 - 6 μm wide, intexine micro-infrareticulate to micro-granulate. Sacci semi-circular in outline, rarely joined, exoexine finely reticulate with brochi 1 - 3 μm wide, occasionally radial. Discernible narrow cappula, about one fourth to nearly half of corpus breadth, with straight margins, exine faintly structured.
SIZE	27 - 32 μm (c-w), 28 - 45 μm (c-h), 29 - 50 μm (t-a)
STRATIGRAPHIC RANGE	Ecca Group: W.Collingham Fm 59, KZN.Volksrust Fm 43, KZN.Volksrust Fm 42 Beaufort Group: KZN.Normandien Fm 23, KZN.Normandien Fm 21
TOTAL ABUNDANCE	68 specimens

Protohaploxypinus microcorpus (Schaarschmidt) Clarke 1965 Plate 10 (2)	
DESCRIPTION	Amb haploxylonoid to slightly diploxylonoid. Corpus indistinct, oval in shape with elongation in the transverse direction. Proximal surface finely reticulate, brochi 0.5 - 1 μm in diameter with 10 - 18 longitudinal taeniae separated by narrow clefts. Taeniae narrow and of unequal width along their

	length, tapering along the entire length of the corpus or by half the distance in some taeniae. Intexine thin and poorly defined. Cappula one third or less than the corpus longitudinal direction, exine thin and unstructured. Bisaccate, sacci semicircular or greater than so in shape and usually observed joined by narrow lateral bladders. Sacci mediumly to coarsely reticulate with brochi 2 - 6 µm in diameter.
SIZE	48 µm (c-w), 42 µm (c-h), 55 µm (t-w), 83 µm (t-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54
TOTAL ABUNDANCE	2 specimens

Protohaploxypinus sp. Samoilovich *emend*. Morbey 1975 Plate 11 (1)	
DESCRIPTION	Slightly diploxylonoid amb, proximal cap divided into six or more longitudinal taeniae.
SIZE	19 - 26 µm (c-w), 20 - 32 µm (c-h), 56 µm (s-w), 20 – 22 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: W.Collingham Fm 59 Beaufort Group: W.Middle Hoedemaker M. 29, KZN.Normandien Fm 21
TOTAL ABUNDANCE	5 specimens

Cf. *Striatoabieites multistriatus* (Balme & Hennelly) Hart 1964 Plate 9 (3)	
DESCRIPTION	Amb haploxylonoid to weakly diploxylonoid. Corpus distinct, oval to quadrangular. Proximal face consists of 14 – 16 longitudinal taeniae extending full extent of corpus and divided by significantly narrow striations. Sacci finely reticulate (sacci missing in specimens recorded).
SIZE	34 µm (c-w), 52 µm (c-h), 60 µm (l-a), 48 µm (t-a)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 53
TOTAL ABUNDANCE	16 specimens

Striatoabieites sp. Zoricheva & Sedova *ex* Sedova *emend*. Hart 1964 Plate 9 (15)	
DESCRIPTION	Amb haploxylonoid to weakly diploxylonoid. Corpus indistinct to discernible, oval in shape. Multistriate proximal surface, sacci crescentic in shape and finely reticulate, smaller than corpus in size.
SIZE	41 µm x 37 µm
STRATIGRAPHIC RANGE	Beaufort Group: KZN.Normandien Fm 23, KZN.Normandien Fm 21
TOTAL ABUNDANCE	43 specimens

Striatopodocarpites cancellatus (Balme & Hennelly) Hart 1963 Plate 10 (4)	
DESCRIPTION	Amb diploxylonoid. Corpus distinct, circular to

	sub-circular. Proximal cap with 5 – 10 longitudinal taeniae separated by narrow clefts, taeniae of equal width and extend over entire corpus, exine finely micro-reticulate to granulate. Sacci greater than semi-circular in shape, distally inclined, fine to moderately reticulate with brochi about 1 - 4 µm wide. Cappula one fifth of less than the corpus longitudinal dimension, exine thin and showing little or no structure.
SIZE	17 - 29 µm (c-w), 17 - 39 µm (c-h), 20 - 42 µm (s-w), 29 - 47 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: W.Collingham Fm 59, KZN.Vryheid Fm 54, KZN.Vryheid Fm 53, KZN.Volksrust Fm 42
TOTAL ABUNDANCE	58 specimens

Striatopodocarpites fusus (Balme & Hennelly) Potonié 1958 Plate 10 (10)	
SYNONYMY	*Lueckisporites fusus* Balme & Hennelly 1955
DESCRIPTION	Amb strongly diploxylonoid. Corpus distinct, circular to subcircular. Proximal cap with approximately 5 – 11 longitudinal taeniae, 2 – 3 µm wide; finely infrapunctate. Sacci very large, greater than semi-circular in outline, distal attachment convex to straight, finely reticulate with brochi 2 µm wide, radially arranged near base. Cappula constricted or slit-like to very narrow, approximately one tenth of corpus.
SIZE	19 - 26 µm (c-w), 20 - 32 µm (c-h), 30 - 40 µm (s-w), 20 – 22 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group:

	KZN.Vryheid Fm 54, KZN.Volksrust Fm 42
TOTAL ABUNDANCE	15 specimens

Striatopodocarpites cf. *rarus* (Bharadwaj & Salujha) Balme 1970 Plate 10 (8)	
DESCRIPTION	Amb slightly to moderately diploxylonoid. Corpus discernible, sub-circular to oval with elongation in the transverse axis, displays crescentic transverse exinal folds. Proximal surface finely reticulate with 5 - 9 longitudinal taeniae separated by narrow clefts. Taeniae of even width and extend along entire corpus. Sacci greater than semicircular in shape, mediumly reticulate.
SIZE	27 - 56 µm (c-w), 35 - 59 µm (c-h), 44 - 67 µm (s-w), 31 – 67 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: E.Prince Albert Fm 63
TOTAL ABUNDANCE	1 specimen

Striatopodocarpites solitus (Bharadwaj & Salujha) Foster 1979 Plate 10 (14)	
DESCRIPTION	Amb strongly diploxylonoid. Corpus distinct, circular to oval with elongation in the transverse or longitudinal axis. Cappa 1 - 2 µm, finely infrapunctate to infrareticulate, divided into 5 - 10 longitudinal taeniae separated by narrow clefts. Taeniae 2 - 8 µm wide, width of individual taeniae variable, mostly extend along entire breadth of corpus. Sacci semi-circular to almost circular in shape, slightly larger than corpus, distally inclined,

	exoexine 1 - 3 µm thick, finely to coarsely infrastructured. Cappula rectangular, extending over full length of corpus, breadth approximately one third that of corpus, commonly bordered by intexinal folds, exine unstructured and thin.
SIZE	18 - 27 µm (c-w), 21 - 23 µm (c-h), 12 - 19 µm (s-w), 24 – 29 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	11 specimens

Striatopodocarpites sp. Zoricheva & Sedova *ex* Sedova *emend*. Hart 1964 Plate 10 (13)	
DESCRIPTION	Amb diploxylonoid. Corpus discernible to distinct, sub-circular to oval with elongation in the transverse axis. Proximal surface finely reticulate, multistriate. Sacci crescentic to greater than semicircular in shape, mediumly reticulate.
SIZE	10 - 14 µm (c-w), 24 - 48 µm (c-h), 18 - 23 µm (s-w), 23 - 46 µm (s-h)
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42 Beaufort Group: KZN.Normandien Fm 22, KZN.Normandien Fm 21 'Stormberg' Group: E.Lower Elliot Fm 8
TOTAL ABUNDANCE	32 specimens

ANTETURMA POLLENITES

TURMA PLICATES

SUBTURMA COSTATES

Infraturma Costati

Weylandites lucifer (Bharadwaj & Salujha) Foster 1975 Plate 11 (6)	
DESCRIPTION	Pollen taeniate. Amb circular to oval, longitudinally elongated. Taeniae continuous from the proximal to the distal surface and achieve perpendicular orientation when taeniae cross the equatorial margin. Accordingly taeniae appear longitudinal on the proximal face and transverse on the distal face.
SIZE	22 - 55 µm
STRATIGRAPHIC RANGE	Ecca Group: E.Whitehill Fm 61, KZN.Vryheid Fm 54, KZN.Vryheid Fm 53, KZN.Volksrust Fm 43 Beaufort Group: E.Oudeberg M. 25, KZN.Normandien Fm 23, KZN.Normandien Fm 22, KZN.Normandien Fm 21, KZN.Normandien Fm 19
TOTAL ABUNDANCE	71 specimens

SUBTURMA PRAECOLPATES

Marsupipollenites striatus (Balme & Hennelly) Hart 1965 Plate 10 (3)	
DESCRIPTION	Amb circular to subcircular, some grains oval. Outline irregular due to infrasculpture often visible

	along the equatorial plane. Small trilete laesurae on the proximal face, faintly labrate. Sulcus present distally, usually open and extending almost to the periphery of the grains. Exine infragranulate, elements arranged in rows which simulate ribs or taeniae. Apparent curved taeniae generally follow the direction of the laesurae, producing a triangular pattern.
SIZE	24 - 53 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54 Beaufort Group: W.Poortjie M. 31, KZN.Normandien Fm 22, KZN.Normandien Fm 21
TOTAL ABUNDANCE	25 specimens

Marsupipollenites triradiatus Balme & Hennelly 1956 Plate 11 (10)	
DESCRIPTION	Amb oval. Two distinct fields bordering the transverse distal sulcus which extend to the lateral margin on the proximal face. Small distinct trilete aperture on the proximal face. Ornamented with flattened verrucae or grana.
SIZE	42 - 73 µm x 25 - 65 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42 Beaufort Group: KZN.Normandien Fm 20
TOTAL ABUNDANCE	7 specimens

Bennettiteaepollenites sp. Potonié 1958 Plate 10 (9)	
DESCRIPTION	Amb oval, width approx. two thirds of length. Exine smooth to infrapunctate, distal face traversed by two longitudinal folds flanking an inner sulcus, none of which reach the outline. Folds are not homologs of colpi in tricolpate pollen grains.
SIZE	30 - 55 µm
STRATIGRAPHIC RANGE	'Stormberg' Group: KZN.Clarens Fm 5
TOTAL ABUNDANCE	2 specimens
PREVIOUSLY REPORTED FROM	Middle Jurassic of Germany

Cycadopites cymbatus (Balme & Hennelly) Hart 1965 Plate 11 (3)	
DESCRIPTION	Amb elongately oval, length approx. twice width. Sulcus extends full length of grain, narrows across the centre and widens out at each pole. Exine thin with microgranulate sculpture.
SIZE	39 - 65 µm x 20 - 35 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, E.Uppermost Fort Brown Fm 49, KZN.Volksrust Fm 42 Beaufort Group: KZN.Normandien Fm 22
TOTAL ABUNDANCE	24 specimens

Cycadopites follicularis Wilson & Webster 1946 Plate 11 (4)	
DESCRIPTION	Amb ellipsoidal, length approx. twice width. Sulcus extends full length of grain, usually narrows across the centre due to shrinkage and widens out at each pole. Exine laevigate to microgranulate.
SIZE	39 - 42 µm x 18 - 21 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Vryheid Fm 54, KZN.Vryheid Fm 53 Beaufort Group: KZN.Normandien Fm 22 'Stormberg' Group: E.Lower Elliot Fm 8, E.Upper Elliot Fm 7, KZN.Clarens Fm 6, KZN.Clarens Fm 5, KZN.Clarens Fm 3, KZN.Clarens Fm 1
TOTAL ABUNDANCE	79 specimens

Cycadopites glaber (Luber & Waltz) Hart 1965 Plate 11 (5)	
DESCRIPTION	Amb approaching an oval, length approx. one and a half times width. Lateral margin is rounded when sulcus is closed and slightly flattened when it is opened. Exine laevigate.
SIZE	43 µm x 26 µm
STRATIGRAPHIC RANGE	Dwyka Group: E.Elandsvlei Fm 65 Ecca Group: W.Prince Albert Fm 64, E.Whitehill Fm 61, W.Ripon Fm 57, E.Fort Brown Fm 50 Beaufort Group:

	E.Koonap Fm 37, E.Koonap Fm 35, E.Koonap Fm 34, E.Barberskrans M. 17, E.Katberg Fm 13, E.Katberg Fm 12, E.Burgersdorp Fm 10 'Stormberg' Group: E.Lower Elliot Fm 8, E.Upper Elliot Fm 7
TOTAL ABUNDANCE	64 specimens

Cf. *Cycadopites tunguskensis* (Luber & Waltz) Hart 1965 Plate 11 (9)	
DESCRIPTION	Amb elongately oval, lateral margins rounded. Sulcus does not extend to lateral margin and is closed laterally. Exine thin with microgranulate sculpture.
SIZE	55 µm x 30 µm
STRATIGRAPHIC RANGE	'Stormberg' Group: E.Lower Elliot Fm 8
TOTAL ABUNDANCE	1 specimen

Pakhapites fusus (Bose & Kar) Menéndez 1971 Plate 10 (15)	
SYNONYMY	*Fusacolpites fusus* Bose & Kar 1966
DESCRIPTION	Amb longitudinally oval. Exine 1 – 1.5 µm thick, infrapunctate or laevigate, divided into 10 – 14 transverse taeniae, 1 - 2 µm wide. Colpus extending full length of grain, centrally constricted, margins occasionally overlapping, fan-shaped at both extremities.
SIZE	42 µm x 27 µm
STRATIGRAPHIC RANGE	Ecca Group:

	W.Prince Albert Fm 64, W.Whitehill Fm 62, W.Collingham Fm 59, E.Fort Brown Fm 52, W.Base of the Waterford Fm 48, KZN.Volksrust Fm 42 Beaufort Group: E.Koonap Fm 35, W.Oukloof M. 26, KZN.Normandien Fm 23, KZN.Normandien Fm 21, E.Palingkloof M. 14
TOTAL ABUNDANCE	81 specimens

Punctacolpites jamottei Kar & Bose 1967 Plate 10 (12)	
DESCRIPTION	Amb oval to fusiform. Exine proximally punctate, distally laevigate. Colpus extending full length of grain, well-defined, generally open, of uniform width or slightly constricted at the middle.
SIZE	47 μm x 33 μm
STRATIGRAPHIC RANGE	Beaufort Group: E.Koonap Fm 34
TOTAL ABUNDANCE	2 specimens
PREVIOUSLY REPORTED FROM	Permian of Congo

Monosulcate Sp. 1 Plate 11 (11)	
DESCRIPTION	Amb elongately oval. Sulcus does not extend to lateral margin and is closed laterally, bordered by an exinal fold on either side of sulcus Pollen apiculate (has slightly protruding polar caps). Exine

	laevigate.
SIZE	34 - 37 µm x 17 - 21 µm
STRATIGRAPHIC RANGE	Beaufort Group: W.Abrahamskraal Fm 39
TOTAL ABUNDANCE	4 specimens

SUBTURMA POLYPLICATES

Equisetosporites steevesii (Jansonius) de Jersey 1968 Plate 11 (7)	
SYNONYMY	*Gnetaceaepollenites steevesii* Jansonius 1962
DESCRIPTION	Amb oval, broadly oval, or spindle-shaped, at longitudinal ends often distinctly tapering, either pointed or rounded. Approximately 12 ribs, more or less fused near longitudinal ends, wall moderately thick.
SIZE	34 - 50 µm x 15 - 28 µm
STRATIGRAPHIC RANGE	'Stormberg' Group: E.Molteno Fm 9, KZN.Clarens Fm 6
TOTAL ABUNDANCE	23 specimens

Praecolpatites sinuosus (Balme & Hennelly) Bharadwaj & Srivastava 1969 Plate 11 (13)	
SYNONYMY	*Gnetaceaepollenites sinuosus* (Balme & Hennelly) Bharadwaj 1962
DESCRIPTION	Amb oval to fusiform, outline smooth. Exine polyplicate with 2 - 6 longitudinal folds extending almost full length of grain. Ornament of fine grana.

SIZE	70 µm x 30 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Prince Albert Fm 64, W.Whitehill Fm 62 Beaufort Group: E.Koonap Fm 37
TOTAL ABUNDANCE	5 specimens

Vittatina fasciolata (Balme and Hennelly) Anderson 1977 Plate 10 (11)	
DESCRIPTION	Amb roundly oval. Proximal face ornamented with 11 – 14 longitudinal taeniae, taeniae cover entire face. Proximal face surrounded by distinct equatorial rim.
SIZE	30 µm x 37 µm
STRATIGRAPHIC RANGE	Ecca Group: W.Ripon Fm 57, W.Base of the Waterford Fm 48, KZN.Volksrust Fm 42 Beaufort Group: KZN.Normandien Fm 22, KZN.Normandien Fm 21
TOTAL ABUNDANCE	42 specimens

Vittatina multistriata (Balme and Hennelly) Anderson 1977 Plate 11 (8)	
SYNONYMY	*Striatoabieites multistriatus* Falcon 1975
DESCRIPTION	Amb haploxylonoid to weakly diploxylonoid. Corpus distinct, circular to oval. Proximal face is completely covered by 14 – 16 longitudinal taeniae. Sacci crescentic to semi-circular. Cappula indistinct and rectangular in shape.

SIZE	41 - 64 µm x 42 - 45 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	2 specimens

Vittatina sp. Luber *ex* Samoilovich *emend*. Wilson 1962 Plate 11 (14)	
DESCRIPTION	Amb oval. Proximal face striated (broken specimen).
SIZE	37 µm x 18 µm
STRATIGRAPHIC RANGE	Ecca Group: KZN.Volksrust Fm 42
TOTAL ABUNDANCE	2 specimens

INCERTAE SEDIS

Unknown sp. 1 Plate 9 (9)	
DESCRIPTION	Specimens folded - may represent monosaccate pollen or zonotrilete spore.
SIZE	24 - 32 µm
STRATIGRAPHIC RANGE	'Stormberg' Group: KZN.Clarens Fm 6
TOTAL ABUNDANCE	3 specimens

PLATES

Plates of all described species are presented below along with page references to systematic descriptions. Scale bars under each specimen represent 10 µm. All slides are housed in the palynological collection of the Evolutionary Studies Institute, University of the Witwatersrand.

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18. *Hemisphaerium* sp. 233
19. *Hilidicellites strangulatus* 246
20. *Inapertisporites circularis* 234

PLATE 6

Page

1. *Inapertisporites* sp. A 235
2. Cf. *Inapertisporites* sp. B 235
3. *Inaperturopollenites dubius* 234
4. *Inderites bulbiferus* 236
5. *Involutisporonites foraminus* 236
6. *Lacrimasporonites levis* 237
7. *Lacrimasporonites* sp. A 237
8. *Lacrimasporonites* sp. B 238
9. *Laevolancis divellomedium* 238
10. *Leiosphaeridia* sp. 239
11. *Maculatasporites eraduensis* 251
12. *Maculatasporites gondwanensis* 251
13. *Mehlisphaeridium fibratum* 252
14. *Mehlisphaeridium regulare* 252
15. *Membranosphaera maastrichtica* 247
16. *Multicellites camerounensis* 239
17. *Micrhystridium karrooense* 247
18. *Micrhystridium* sp. Modie 2007 248
19. *Micrhystridium stellatum* 248

PLATE 7

Page

1. *Papulosporonites* sp. 240
2. *Phycomycites* sp. 240
3. *Pilasporites calculus* 241
4. *Pilasporites plurigenus* 241
5. *Prasinophyceae* sp. 243
6. *Polycellaesporonites bellus* 242
7. *Reduviasporonites chalastus* 243
    a. Single spore
    b. Cluster
8. *Retialetes radforthii* 253
9. *Sphaeroporalites solus* 249
10. *Tasmanites* sp. 249
11. *Tetraporina horologia* 244
12. *Zonoaletes hacquebardii* 254
13. Cf. *Cristatisporites inconstans* 215
14. *Densoisporites psilatus* 216
15. *Densosporites vulgaris* 216
16. *Duplexisporites gyratus* 221
17. *Gondisporites raniganjensis* 217
18. *Gondisporites variabilis* 218
19. *Kraeuselisporites enormis* 218

PLATE 8

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1. *Limbosporites denmeadii* 214
2. *Lundbladispora braziliensis* 219
    a. Single spore
    b. Tetrad
3. *Playfordiaspora crenulata* 221
4. *Tripunctisporis maastrichtiensis* 222
5. *Uvaesporites verrucosus* 220
6. *Zinjisporites congoensis* 219
7. *Zinjisporites spinosus* 220
8. Zonotrilete Sp. 1 217
9. *Duplicisporites granulatus* 254
10. *Barakarites rotatus* 255
11. *Cannanoropollis densus* 255
12. *Cannanoropollis mehtae* 256
13. *Cannanoropollis obscurus* 257
14. *Florinites eremus* 259
15. *Plicatipollenites gondwanensis* 257
16. *Plicatipollenites* sp. 258
17. *Potonieisporites magnus* 259

PLATE 9

Page

1. Bisaccate Sp. 1 267
2. *Scheuringipollenites* sp. 268
3. Cf. *Striatoabieites multistriatus* 272
4. *Protohaploxypinus limpidus* 272
5. *Platysaccus papilionis* 262
6. *Corisaccites alutas* 268
7. *Hamiapollenites dettmannae* 268
8. *Chordasporites australiensis* 260
9. Unknown sp. 1 284
10. *Platysaccus* sp. 263
11. *Platysaccus radialis* 263
12. *Chordasporites endroedii* 260
13. *Minutosaccus acutus* 262
14. *Pteruchipollenites* sp. 265
15. *Striatoabieites* sp. 272

PLATE 10

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1. *Protohaploxypinus latissimus* 269
2. *Protohaploxypinus microcorpus* 270
3. *Marsupipollenites striatus* 276
4. *Striatopodocarpites cancellatus* 272
5. *Pteruchipollenites landianus* 264
6. Cf. *Scheuringipollenites ovatus* MacRae 1988 265
7. Cf. *Jugasporites* sp. 1 MacRae 1988 261
8. *Striatopodocarpites* cf. *rarus* 274
9. *Bennettiteaepollenites* sp. 278
10. *Striatopodocarpites fusus* 273
11. *Vittatina fasciolata* 283
12. *Punctacolpites jamottei* 281
13. *Striatopodocarpites* sp. 275
14. *Striatopodocarpites solitus* 274
15. *Pakhapites fusus* 280

PLATE 11

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1. *Protohaploxypinus* sp. 271
2. *Vestigisporites rudis* 267
3. *Cycadopites cymbatus* 278
4. *Cycadopites follicularis* 279
5. *Cycadopites glaber* 279
6. *Weylandites lucifer* 276
7. *Equisetosporites steevesi* 282
8. *Vittatina multistriata* 283
9. Cf. *Cycadopites tunguskensis* 281
10. *Marsupipollenites triradiatus* 277
11. Monosulcate Sp. 1 281
12. *Scheuringipollenites ovatus* 267
13. *Praecolpatites sinuosus* 282
14. *Vittatina* sp. 284

6. APPENDIX B

1. Raw Species Counts

	Sample No.															
Species	**65**	**64**	**63**	**62**	**61**	**60**	**59**	**58**	**57**	**56**	**55**	**54**	**53**	**52**	**51**	**50**
Acanthotriletes tereteangulatus			1							28					35	
Altitriletes densus																
Apiculatisporis cornutus		9								1						
Apiculiretusispora sp.													4			
Appendicisporites sp.																
Cf. *Aratrisporites strigosus*																
Aratrisporites tenuispinosus																
Baculatisporites comaumensis																
Balmeella tetragona			1	2				1								
Barakarites rotatus												2				
Bennettiteaepollenites sp.																
Cf. *Biretisporites modestus*																
Bisaccate Sp. 1																
Brazilea scissa																
Brevitriletes bulliensis																
Brijrajisporites distinctus																
Calamospora mesozoica																
Calamospora plicata									8			2		1		
Cannanoropollis densus												12				
Cannanoropollis mehtae			2									10				
Cannanoropollis obscurus												20				

Cerebropollenites mesozoicus																1
Chordasporites australiensis																
Chordasporites endroedii																
Cingulaletes minor														1	2	
Circulisporites parvus			1													
Cf. *Conbaculatisporites* sp.																
Concavisporites bohemiensis												11				
Cf. *Converrucosisporites irregularis*	5					16										
Converrucosisporites micronodosus			9													
Converrucosisporites naumoviae											20				118	
Converrucosisporites pseudoreticulatus													29			
Converrucosisporites sp.																
Convolutispora intrareticulatus											1					
Corisaccites alutas							1									
Cf. *Cristatisporites inconstans*																
Cyathidites minor																
Cycadopites cymbatus												3				
Cycadopites follicularis												6	44			
Cycadopites glaber	6	2			16				4							4
Cf. *Cycadopites tunguskensis*																
Cf. *Cyclogranisporites firmus*																
Cyclogranisporites gondwanensis		44							12		1				1	

Deltoidospora directa	22	29	45	20	1	11	6	5	30	6	11	4		26	2	1
Deltoidospora magna	14		2	12	25	4	2		8							
Densoisporites psilatus																
Densosporites vulgaris				2					4							
Dicellaesporites sp.					2											
Cf. *Dictyophyllidites harrisii*																
Dictyophyllidites mortonii																
Dictyosporites sp.														5		
Diporisporites elongatus			13	20		6										
Disectispora lobata							6									
Duplexisporites gyratus																
Duplicisporites granulatus																
Equisetosporites steevesi																
Florinites eremus												2	2			
Foveosporites moretonensis																
Foveosporites sp. A Modie 2007			4													
Gondisporites raniganjensis	1															
Gondisporites variabilis																
Granulatisporites austroamericanus																
Granulatisporites convexus																
Cf. *Granulatisporites microgranifer*				23	83		9									
Granulatisporites minor	28	1	74	60	22	86	142		16	122	11			8	74	76

Granulatisporites papillosus									2			14				
Granulatisporites sp.	6	2		16	23		2	68	32	72	24		16			69
Granulatisporites sp. MacRae 1988								1								
Granulatisporites trisinus				8			1		2			2			9	
Greinervillites sp.								1	2							
Hamiapollenites dettmannae												10	8			
Cf. *Haplocystia pellucida*	5					1					1					
Hemisphaerium inominatum																
Hemisphaerium sp.	52				16			121			52			146		
Hilidicellites strangulatus																
Horriditriletes filiformis												2				
Horriditriletes ramosus																
Inapertisporites circularis						4										
Inapertisporites communis	1															
Inapertisporites sp. A																
Cf. *Inapertisporites* sp. B																
Inaperturopollenites dubius																
Inderites bulbiferus											2			2		
Interradispora sp.			1													
Involutisporonites foraminus																
Ischyosporites volkheimeri																
Cf. *Jugasporites* sp. 1 MacRae 1988												2				

Kraeuselisporites enormis												8	14			
Lacrimasporonites levis																
Lacrimasporonites sp. A																
Lacrimasporonites sp. B	2				4	1					1					
Laevigatosporites minimus										4						
Cf. *Laevigatosporites obscurus*																
Laevigatosporites ovatus						1			4					5	2	
Laevigatosporites sp.																
Laevigatosporites vulgaris																
Laevolancis divellomedium																
Cf. *Latipulvinites kosankii*																
Leiosphaeridia sp.																
Limbosporites denmeadii																
Cf. *Lobatisporites* sp.		38														
Lophotriletes novicus			4									2	19			
Lophotriletes scotinus																
Lundbladispora braziliensis																
Maculatasporites eraduensis	4															
Maculatasporites gondwanensis	40				2	4		1								
Marsupipollenites striatus												14				
Marsupipollenites triradiatus																
Mehlisphaeridium fibratum																

Mehlisphaeridium regulare							2									1
Membranosphaera maastrichtica											2					
Micrhystridium karrooense																
Micrhystridium sp. Modie 2007	1															
Micrhystridium stellatum																
Minutosaccus acutus																
Monosulcate Sp. 1																
Multicellites camerounensis	1					1								1		1
Neoraistrickia truncata																
Pakhapites fusus		6		1			16							1		
Papulosporonites sp.	2															
Phycomycites sp.																
Pilasporites calculus					2											
Pilasporites plurigenus																
Platysaccus papilionis												8				
Platysaccus radialis												4				
Platysaccus sp.										7		4				
Playfordiaspora crenulata																
Plicatipollenites gondwanensis																
Plicatipollenites sp.																
Polycellaesporonites bellus						2					1					
Potonieisporites magnus																

Praecolpatites sinuosus		2		1												
Prasinophyceae sp.		19														
Protohaploxypinus latissimus												2				
Protohaploxypinus limpidus							2									
Protohaploxypinus microcorpus												2				
Protohaploxypinus sp.							1									
Pteruchipollenites landianus												8				
Pteruchipollenites sp.																
Punctacolpites jamottei																
Cf. *Punctatisporites minutus*																
Punctatisporites gretensis																
Cf. *Punctatisporites obliquus*	1					3								2		
Cf. *Punctatisporites parvus*																
Punctatisporites sp. A	4	3					8	1	14		6				1	39
Punctatosporites granifer	1										4	18	4			
Punctatosporites scabratus																
Pustulatisporites distinctus										5						
Reduviasporonites chalastus		6	10		1	1										
Retialetes radforthii																
Reticulatisporites bifrons		3					1									
Reticulatisporites compactus			6													
Retitriletes rosewoodensis			9													

Retitriletes sp. A											1			50		
Scheuringipollenites ovatus												10	14			
Cf. *Scheuringipollenites ovatus* MacRae 1988																
Scheuringipollenites sp.																
Schopfites dimorphus																
Cf. *Secarisporites lobatus*									6					1		1
Sphaeroporalites solus																
Cf. *Striasporis striatus*												8				
Cf. *Striatoabieites multistriatus*													16			
Striatoabieites sp.																
Striatopodocarpites cancellatus							6					20	29			
Striatopodocarpites fusus												6				
Striatopodocarpites cf. *rarus*			1													
Striatopodocarpites solitus																
Striatopodocarpites sp.																
Tasmanites sp.										5						
Tetraporina horologia										1						
Thymospora cf. *pseudothiessenii*											2	8	2			
Thymospora ipsviciensis									8		2					
Toripustulatisporites hokonuiensis																
Tripunctisporis maastrichtiensis																
Cf. *Triquitrites* sp. A Bharadwaj & Venkatachala 1961																

Unknown Sp. 1																
Uvaesporites verrucosus																
Verrucosisporites andersonii																
Verrucosisporites polygonalis			2			8					1					2
Verrucosisporites sp. A	2			80			6		20		49					2
Verrucosisporites sp. MacRae 1988												6				
Vestigisporites rudis												2				
Vittatina fasciolata									6							
Vittatina multistriata																
Vittatina sp.																
Weylandites lucifer					1							4	3			
Zinjisporites congoensis																
Zinjisporites spinosus																
Zonoaletes hacquebardii	1	1					1				1					2
Zonotrilete Sp. 1													2			
SAMPLE TOTALS	**199**	**206**	**185**	**245**	**198**	**149**	**212**	**199**	**180**	**251**	**193**	**236**	**206**	**249**	**244**	**199**

	Sample No.															
Species	**49**	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**40**	**39**	**38**	**37**	**36**	**35**	**34**
Acanthotriletes tereteangulatus							46				4					
Altitriletes densus	32					5		2								
Apiculatisporis cornutus																
Apiculiretusispora sp.																

Appendicisporites sp.																
Cf. *Aratrisporites strigosus*																
Aratrisporites tenuispinosus																
Baculatisporites comaumensis																1
Balmeella tetragona															1	
Barakarites rotatus								10								
Bennettiteaepollenites sp.																
Cf. *Biretisporites modestus*																
Bisaccate Sp. 1																
Brazilea scissa													1			
Brevitriletes bulliensis																
Brijrajisporites distinctus												1				
Calamospora mesozoica								6								
Calamospora plicata				3				4								
Cannanoropollis densus																
Cannanoropollis mehtae								4								
Cannanoropollis obscurus								6								
Cerebropollenites mesozoicus																
Chordasporites australiensis								9								
Chordasporites endroedii								3								
Cingulaletes minor																
Circulisporites parvus																
Cf. *Conbaculatisporites* sp.																
Concavisporites bohemiensis																
Cf. *Converrucosisporites irregularis*																

Converrucosisporites micronodosus																
Converrucosisporites naumoviae				230	165			4		126					4	
Converrucosisporites pseudoreticulatus															4	2
Converrucosisporites sp.																
Convolutispora intrareticulatus															1	
Corisaccites alutas																
Cf. *Cristatisporites inconstans*																
Cyathidites minor																
Cycadopites cymbatus	1							19								
Cycadopites follicularis																
Cycadopites glaber													3		2	1
Cf. *Cycadopites tunguskensis*																
Cf. *Cyclogranisporites firmus*								2								
Cyclogranisporites gondwanensis													2			
Deltoidospora directa	10	14	9	4	24	3		25	6		28	11	3	1	9	66
Deltoidospora magna	9					1			2	6	12	6		24		2
Densoisporites psilatus																
Densosporites vulgaris																
Dicellaesporites sp.															2	1
Cf. *Dictyophyllidites harrisii*																
Dictyophyllidites mortonii																
Dictyosporites sp.			5											3	2	
Diporisporites elongatus	1											2				
Disectispora lobata											4					
Duplexisporites gyratus																

Duplicisporites granulatus																5
Equisetosporites steevesi																
Florinites eremus																
Foveosporites moretonensis																
Foveosporites sp. A Modie 2007																
Gondisporites raniganjensis																
Gondisporites variabilis								6	4							
Granulatisporites austroamericanus								3								
Granulatisporites convexus																
Cf. *Granulatisporites microgranifer*			29						4					2	1	
Granulatisporites minor	9	160	47			4				3	32	2		38	17	2
Granulatisporites papillosus		19														
Granulatisporites sp.		29	4	7		9				31	20	15		66		
Granulatisporites sp. MacRae 1988																
Granulatisporites trisinus														41		
Greinervillites sp.						3						6				1
Hamiapollenites dettmannae																
Cf. *Haplocystia pellucida*	3		12			1								2	3	
Hemisphaerium inominatum																
Hemisphaerium sp.	6		108	5	6	129					16	138	91		84	54
Hilidicellites strangulatus																
Horriditriletes filiformis								3								
Horriditriletes ramosus								3								
Inapertisporites circularis																
Inapertisporites communis																

Inapertisporites sp. A																
Cf. *Inapertisporites* sp. B	108	17											75	2	98	83
Inaperturopollenites dubius															1	7
Inderites bulbiferus																
Interradispora sp.																
Involutisporonites foraminus											8					
Ischyosporites volkheimeri																
Cf. *Jugasporites* sp. 1 MacRae 1988																
Kraeuselisporites enormis								2				1				
Lacrimasporonites levis																
Lacrimasporonites sp. A																
Lacrimasporonites sp. B												1				
Laevigatosporites minimus																
Cf. *Laevigatosporites obscurus*																
Laevigatosporites ovatus						2										
Laevigatosporites sp.																
Laevigatosporites vulgaris																1
Laevolancis divellomedium														2		
Cf. *Latipulvinites kosankii*																
Leiosphaeridia sp.														5		
Limbosporites denmeadii																
Cf. *Lobatisporites* sp.																
Lophotriletes novicus								6		21		5				
Lophotriletes scotinus		4								3						
Lundbladispora braziliensis								8								

Maculatasporites eraduensis											5	1	4			
Maculatasporites gondwanensis																
Marsupipollenites striatus																
Marsupipollenites triradiatus								5								
Mehlisphaeridium fibratum																
Mehlisphaeridium regulare								3	95			2		1		
Membranosphaera maastrichtica										60						
Micrhystridium karrooense																
Micrhystridium sp. Modie 2007										3						
Micrhystridium stellatum																
Minutosaccus acutus								4								
Monosulcate Sp. 1											4					
Multicellites camerounensis																
Neoraistrickia truncata												9	17			1
Pakhapites fusus		2						3							1	
Papulosporonites sp.																
Phycomycites sp.	1															
Pilasporites calculus	32	1	6								33				1	1
Pilasporites plurigenus														1	2	
Platysaccus papilionis								18								
Platysaccus radialis								13								
Platysaccus sp.							12									
Playfordiaspora crenulata																
Plicatipollenites gondwanensis							4									
Plicatipollenites sp.																

Polycellaesporonites bellus												1				
Potonieisporites magnus																
Praecolpatites sinuosus													2			
Prasinophyceae sp.					2								1			
Protohaploxypinus latissimus																
Protohaploxypinus limpidus							29	7								
Protohaploxypinus microcorpus																
Protohaploxypinus sp.																
Pteruchipollenites landianus																
Pteruchipollenites sp.							3									
Punctacolpites jamottei																2
Cf. *Punctatisporites minutus*																
Punctatisporites gretensis													23			
Cf. *Punctatisporites obliquus*						20										
Cf. *Punctatisporites parvus*						1										
Punctatisporites sp. A						6	34		8	3	7				6	2
Punctatosporites granifer								4								2
Punctatosporites scabratus				1												
Pustulatisporites distinctus																
Reduviasporonites chalastus											4	12	3	4		3
Retialetes radforthii																6
Reticulatisporites bifrons																
Reticulatisporites compactus																
Retitriletes rosewoodensis											3			1		
Retitriletes sp. A	29					8									1	

Scheuringipollenites ovatus							14									
Cf. *Scheuringipollenites ovatus* MacRae 1988																
Scheuringipollenites sp.																
Schopfites dimorphus																
Cf. *Secarisporites lobatus*	3		1													
Sphaeroporalites solus			4													
Cf. *Striasporis striatus*																
Cf. *Striatoabieites multistriatus*																
Striatoabieites sp.																
Striatopodocarpites cancellatus								3								
Striatopodocarpites fusus								9								
Striatopodocarpites cf. *rarus*																
Striatopodocarpites solitus								11								
Striatopodocarpites sp.								3								
Tasmanites sp.													2			
Tetraporina horologia																
Thymospora cf. *pseudothiessenii*						2	4		1							
Thymospora ipsviciensis			22									27			5	
Toripustulatisporites hokonuiensis														1		
Tripunctisporis maastrichtiensis																
Cf. *Triquitrites* sp. A Bharadwaj & Venkatachala 1961																
Unknown Sp. 1																
Uvaesporites verrucosus																
Verrucosisporites andersonii								4								

Verrucosisporites polygonalis						1			1					6		
Verrucosisporites sp. A		2							78			8				
Verrucosisporites sp. MacRae 1988																
Vestigisporites rudis																
Vittatina fasciolata		3						2								
Vittatina multistriata								2								
Vittatina sp.								2								
Weylandites lucifer							12									
Zinjisporites congoensis								6								
Zinjisporites spinosus									1							
Zonoaletes hacquebardii																
Zonotrilete Sp. 1																
SAMPLE TOTALS	**244**	**251**	**247**	**250**	**197**	**195**	**158**	**224**	**200**	**256**	**180**	**248**	**227**	**200**	**245**	**243**

	Sample No.															
Species	**33**	**32**	**31**	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**
Acanthotriletes tereteangulatus												14	10			
Altitriletes densus																
Apiculatisporis cornutus				1								6				
Apiculiretusispora sp.																
Appendicisporites sp.												2				
Cf. *Aratrisporites strigosus*											2					
Aratrisporites tenuispinosus																
Baculatisporites comaumensis																
Balmeella tetragona		2							2							
Barakarites rotatus																

Bennettiteaepollenites sp.																
Cf. *Biretisporites modestus*																
Bisaccate Sp. 1																
Brazilea scissa																
Brevitriletes bulliensis										2						
Brijrajisporites distinctus																
Calamospora mesozoica																
Calamospora plicata														1	4	
Cannanoropollis densus			1													
Cannanoropollis mehtae																
Cannanoropollis obscurus																
Cerebropollenites mesozoicus												1				
Chordasporites australiensis																
Chordasporites endroedii																
Cingulaletes minor																
Circulisporites parvus																
Cf. *Conbaculatisporites* sp.																
Concavisporites bohemiensis						2										
Cf. *Converrucosisporites irregularis*		4				4										
Converrucosisporites micronodosus																
Converrucosisporites naumoviae	76			2	32										60	
Converrucosisporites pseudoreticulatus																
Converrucosisporites sp.																
Convolutispora intrareticulatus									1							
Corisaccites alutas																

Cf. *Cristatisporites inconstans*						8	26									
Cyathidites minor																
Cycadopites cymbatus												1				
Cycadopites follicularis												1				
Cycadopites glaber																
Cf. *Cycadopites tunguskensis*																
Cf. *Cyclogranisporites firmus*																
Cyclogranisporites gondwanensis								8				21		20		
Deltoidospora directa	38	20	9	12	4	6	10	29	52			9		32	4	
Deltoidospora magna		4	1	2	4	12	8	32	59	10						
Densoisporites psilatus												1				
Densosporites vulgaris		1														
Dicellaesporites sp.					2										2	
Cf. *Dictyophyllidites harrisii*																
Dictyophyllidites mortonii															2	
Dictyosporites sp.	1	2	1			2		4							4	
Diporisporites elongatus	1	1			2											
Disectispora lobata																
Duplexisporites gyratus																
Duplicisporites granulatus																
Equisetosporites steevesi																
Florinites eremus																
Foveosporites moretonensis																
Foveosporites sp. A Modie 2007																
Gondisporites raniganjensis																

Gondisporites variabilis																
Granulatisporites austroamericanus																
Granulatisporites convexus																
Cf. *Granulatisporites microgranifer*		70					40	18		74					16	
Granulatisporites minor		39	77	85	20	28	22	26	4			113		76	40	134
Granulatisporites papillosus																
Granulatisporites sp.	10	5	7	48	16		56	16		4		4		6	36	20
Granulatisporites sp. MacRae 1988												1				
Granulatisporites trisinus		23				4		6			4					1
Greinervillites sp.				12				6								
Hamiapollenites dettmannae																
Cf. *Haplocystia pellucida*	44			1		4		8								
Hemisphaerium inominatum															6	
Hemisphaerium sp.			98			60		4	94						8	
Hilidicellites strangulatus				7												
Horriditriletes filiformis																
Horriditriletes ramosus																
Inapertisporites circularis																
Inapertisporites communis																
Inapertisporites sp. A																
Cf. *Inapertisporites* sp. B																
Inaperturopollenites dubius														2		
Inderites bulbiferus																
Interradispora sp.																
Involutisporonites foraminus	1				8				3	4						

Ischyosporites volkheimeri										44						
Cf. *Jugasporites* sp. 1 MacRae 1988																
Kraeuselisporites enormis		1														
Lacrimasporonites levis																
Lacrimasporonites sp. A									1							
Lacrimasporonites sp. B																
Laevigatosporites minimus																
Cf. *Laevigatosporites obscurus*										24						
Laevigatosporites ovatus		5														
Laevigatosporites sp.																
Laevigatosporites vulgaris																
Laevolancis divellomedium					2											
Cf. *Latipulvinites kosankii*																
Leiosphaeridia sp.																
Limbosporites denmeadii																
Cf. *Lobatisporites* sp.					46											
Lophotriletes novicus											23	15		6		4
Lophotriletes scotinus			1								9					
Lundbladispora braziliensis																
Maculatasporites eraduensis																
Maculatasporites gondwanensis		6				6		8								
Marsupipollenites striatus			3									2	6			
Marsupipollenites triradiatus														2		
Mehlisphaeridium fibratum			3								16					
Mehlisphaeridium regulare		2			2											

Membranosphaera maastrichtica	2														2	
Micrhystridium karrooense															2	
Micrhystridium sp. Modie 2007	2								1							
Micrhystridium stellatum						2										
Minutosaccus acutus																
Monosulcate Sp. 1																
Multicellites camerounensis					2	2								1		
Neoraistrickia truncata		1			2									6		
Pakhapites fusus								2			20		28			
Papulosporonites sp.																
Phycomycites sp.																
Pilasporites calculus	1		1													
Pilasporites plurigenus																
Platysaccus papilionis																
Platysaccus radialis																
Platysaccus sp.																
Playfordiaspora crenulata																
Plicatipollenites gondwanensis													26			
Plicatipollenites sp.																
Polycellaesporonites bellus		1						1		1						
Potonieisporites magnus													2			
Praecolpatites sinuosus																
Prasinophyceae sp.					13											
Protohaploxypinus latissimus																
Protohaploxypinus limpidus											18		12			

Protohaploxypinus microcorpus																
Protohaploxypinus sp.					1								3			
Pteruchipollenites landianus											4		39			
Pteruchipollenites sp.												1	20		2	
Punctacolpites jamottei																
Cf. *Punctatisporites minutus*												2			10	
Punctatisporites gretensis				8												
Cf. *Punctatisporites obliquus*																
Cf. *Punctatisporites parvus*			1		2			2								
Punctatisporites sp. A	1	11		1		52	4	22	10		58		2	53		
Punctatosporites granifer										64						
Punctatosporites scabratus								4								
Pustulatisporites distinctus									11						10	
Reduviasporonites chalastus				6		2				2	5	2		2		
Retialetes radforthii																
Reticulatisporites bifrons																
Reticulatisporites compactus												1				
Retitriletes rosewoodensis																
Retitriletes sp. A									3	14						
Scheuringipollenites ovatus											49					
Cf. *Scheuringipollenites ovatus* MacRae 1988																
Scheuringipollenites sp.										2						
Schopfites dimorphus																
Cf. *Secarisporites lobatus*								2								

Sphaeroporalites solus																
Cf. *Striasporis striatus*																
Cf. *Striatoabieites multistriatus*																
Striatoabieites sp.											6		37			
Striatopodocarpites cancellatus																
Striatopodocarpites fusus																
Striatopodocarpites cf. *rarus*																
Striatopodocarpites solitus																
Striatopodocarpites sp.												4	23			
Tasmanites sp.																
Tetraporina horologia																
Thymospora cf. *pseudothiessenii*		2				4	2		5			2				
Thymospora ipsviciensis	15		6					2						12		
Toripustulatisporites hokonuiensis																
Tripunctisporis maastrichtiensis																
Cf. *Triquitrites* sp. A Bharadwaj & Venkatachala 1961											2					
Unknown Sp. 1																
Uvaesporites verrucosus																
Verrucosisporites andersonii																
Verrucosisporites polygonalis			1													
Verrucosisporites sp. A	27		2	65	46		30					2		5	22	43
Verrucosisporites sp. MacRae 1988																
Vestigisporites rudis			1													
Vittatina fasciolata												4	27			

Vittatina multistriata																
Vittatina sp.																
Weylandites lucifer									4		34	1	10		2	
Zinjisporites congoensis																
Zinjisporites spinosus																
Zonoaletes hacquebardii												1		2		
Zonotrilete Sp. 1																
SAMPLE TOTALS	**223**	**200**	**213**	**250**	**204**	**198**	**198**	**200**	**250**	**245**	**250**	**211**	**245**	**226**	**232**	**202**

	Sample No.															
Species	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Acanthotriletes tereteangulatus							1					25		34		9	34
Altitriletes densus									13								
Apiculatisporis cornutus					1												1
Apiculiretusispora sp.																	
Appendicisporites sp.																	
Cf. *Aratrisporites strigosus*																	
Aratrisporites tenuispinosus					1												
Baculatisporites comaumensis										1							
Balmeella tetragona													2			1	
Barakarites rotatus																	
Bennettiteaepollenites sp.													2				
Cf. *Biretisporites modestus*															2	3	
Bisaccate Sp. 1												2					
Brazilea scissa	4																
Brevitriletes bulliensis																	

Brijrajisporites distinctus																	
Calamospora mesozoica																	
Calamospora plicata									1			12	5				
Cannanoropollis densus									1								
Cannanoropollis mehtae																	
Cannanoropollis obscurus																	
Cerebropollenites mesozoicus					7												
Chordasporites australiensis																	
Chordasporites endroedii																	
Cingulaletes minor																	
Circulisporites parvus																	
Cf. *Conbaculatisporites* sp.										3							
Concavisporites bohemiensis																	
Cf. *Converrucosisporites irregularis*																	
Converrucosisporites micronodosus																	
Converrucosisporites naumoviae																	
Converrucosisporites pseudoreticulatus									2								
Converrucosisporites sp.											10						
Convolutispora intrareticulatus																	
Corisaccites alutas																	
Cf. *Cristatisporites inconstans*										3							
Cyathidites minor											50	104	11		2	3	1
Cycadopites cymbatus																	
Cycadopites follicularis										5	5	6	7		2		3
Cycadopites glaber	6				2	4		10		3	1						

Cf. *Cycadopites tunguskensis*										1							
Cf. *Cyclogranisporites firmus*																	
Cyclogranisporites gondwanensis				2						3							
Deltoidospora directa	24	19	16	18	14	33	3	10	41	1							
Deltoidospora magna		12	37	9		14	55	28	48	20							
Densoisporites psilatus																	
Densosporites vulgaris												1					
Dicellaesporites sp.	61				3					2		4					
Cf. *Dictyophyllidites harrisii*											7						
Dictyophyllidites mortonii	4					2			4	13				1			
Dictyosporites sp.			1		14	2	1			1	11						
Diporisporites elongatus					3					1	7						
Disectispora lobata																	
Duplexisporites gyratus												2					
Duplicisporites granulatus																	
Equisetosporites steevesi									13			10					
Florinites eremus																	
Foveosporites moretonensis													2				
Foveosporites sp. A Modie 2007																	
Gondisporites raniganjensis									12			3					
Gondisporites variabilis																	
Granulatisporites austroamericanus										11	1						8
Granulatisporites convexus				38													
Cf. *Granulatisporites microgranifer*			6		6		17	12		35	2						
Granulatisporites minor	10	2	58	7	14	19	41	58	9	77	7	42	28	60	56	62	89

Granulatisporites papillosus																	
Granulatisporites sp.	4		38	78	1	26	75	81	1	79		12		88	79	38	15
Granulatisporites sp. MacRae 1988																	
Granulatisporites trisinus						7	19	4		4			4				
Greinervillites sp.	14					5	2										
Hamiapollenites dettmannae																	
Cf. *Haplocystia pellucida*		7	8		5	13	1	4	1		5			1			
Hemisphaerium inominatum																	
Hemisphaerium sp.	37	61		5	90	13			3								
Hilidicellites strangulatus																	
Horriditriletes filiformis																	
Horriditriletes ramosus																	
Inapertisporites circularis																	
Inapertisporites communis																	
Inapertisporites sp. A		1			2												
Cf. *Inapertisporites* sp. B							12										
Inaperturopollenites dubius																	
Inderites bulbiferus	7																
Interradispora sp.										5			1			1	
Involutisporonites foraminus					3												
Ischyosporites volkheimeri																	
Cf. *Jugasporites* sp. 1 MacRae 1988																	
Kraeuselisporites enormis												1					
Lacrimasporonites levis										1	2						
Lacrimasporonites sp. A							4										

Lacrimasporonites sp. B		49															
Laevigatosporites minimus	14																
Cf. *Laevigatosporites obscurus*													24				
Laevigatosporites ovatus	10					1					8						
Laevigatosporites sp.	1												1				
Laevigatosporites vulgaris																	
Laevolancis divellomedium																	
Cf. *Latipulvinites kosankii*													11				
Leiosphaeridia sp.										1							
Limbosporites denmeadii				2										2		49	
Cf. *Lobatisporites* sp.																	
Lophotriletes novicus				14									23			54	4
Lophotriletes scotinus																	
Lundbladispora braziliensis																	
Maculatasporites eraduensis										5							1
Maculatasporites gondwanensis				10													
Marsupipollenites striatus																	
Marsupipollenites triradiatus																	
Mehlisphaeridium fibratum			17														
Mehlisphaeridium regulare			6	1			1			6							
Membranosphaera maastrichtica												1					
Micrhystridium karrooense																	
Micrhystridium sp. Modie 2007																	
Micrhystridium stellatum																	
Minutosaccus acutus																	

Monosulcate Sp. 1																	
Multicellites camerounensis			1		4						6						
Neoraistrickia truncata								2		3							
Pakhapites fusus				1													
Papulosporonites sp.					10					1	55						
Phycomycites sp.					2					4	1						
Pilasporites calculus		2									15						
Pilasporites plurigenus						3					46						
Platysaccus papilionis																	
Platysaccus radialis																	
Platysaccus sp.									2								11
Playfordiaspora crenulata	2	3															
Plicatipollenites gondwanensis																	
Plicatipollenites sp.												3					
Polycellaesporonites bellus	1					1											
Potonieisporites magnus									1			6					
Praecolpatites sinuosus																	
Prasinophyceae sp.	3	11		5	1	11											1
Protohaploxypinus latissimus																	
Protohaploxypinus limpidus																	
Protohaploxypinus microcorpus																	
Protohaploxypinus sp.																	
Pteruchipollenites landianus																	
Pteruchipollenites sp.													4		1	11	
Punctacolpites jamottei																	

Cf. *Punctatisporites minutus*													74				
Punctatisporites gretensis			15		2		6		2								
Cf. *Punctatisporites obliquus*	1					2		2			1						
Cf. *Punctatisporites parvus*	3				22												
Punctatisporites sp. A		4	7	12		16	9	4	15				53	63	62	1	6
Punctatosporites granifer					1							7					
Punctatosporites scabratus				2								5					
Pustulatisporites distinctus																	
Reduviasporonites chalastus			37	1	4	5	9	2	2	14							
Retialetes radforthii																	
Reticulatisporites bifrons																	
Reticulatisporites compactus																	
Retitriletes rosewoodensis					2												
Retitriletes sp. A					2							2					
Scheuringipollenites ovatus																	
Cf. *Scheuringipollenites ovatus* MacRae 1988																1	
Scheuringipollenites sp.																	
Schopfites dimorphus		7															
Cf. *Secarisporites lobatus*	1				1												
Sphaeroporalites solus																	
Cf. *Striasporis striatus*																	
Cf. *Striatoabieites multistriatus*																	
Striatoabieites sp.																	
Striatopodocarpites cancellatus																	

Striatopodocarpites fusus																	
Striatopodocarpites cf. *rarus*																	
Striatopodocarpites solitus																	
Striatopodocarpites sp.										2							
Tasmanites sp.									72			4					
Tetraporina horologia				1													
Thymospora cf. *pseudothiessenii*		12	6	2		2						2		1			2
Thymospora ipsviciensis	29	2		8					3							1	
Toripustulatisporites hokonuiensis										2	3						2
Tripunctisporis maastrichtiensis					1												
Cf. *Triquitrites* sp. A Bharadwaj & Venkatachala 1961																	
Unknown Sp. 1												3					
Uvaesporites verrucosus							1		1	2	10					1	
Verrucosisporites andersonii																	
Verrucosisporites polygonalis		2															
Verrucosisporites sp. A	5	4	4	20		17	1		2	2							22
Verrucosisporites sp. MacRae 1988																	
Vestigisporites rudis				1									3				
Vittatina fasciolata																	
Vittatina multistriata																	
Vittatina sp.																	
Weylandites lucifer																	
Zinjisporites congoensis																	
Zinjisporites spinosus																	

Zonoaletes hacquebardii					2	3						1					
Zonotrilete Sp. 1																	
SAMPLE TOTALS	**244**	**198**	**257**	**237**	**222**	**199**	**258**	**217**	**249**	**311**	**253**	**258**	**255**	**250**	**204**	**235**	**200**

2. Supplementary Information - Figure 3.10

Correlations in Figure 3.10 were made on the basis of taxa common to both the Main Karoo Basin (this study) and previous palynological studies in the MKB. Shared taxa for each formation are listed below. Species recovered in previous studies that correspond to taxa only identified to generic level in this work have a question mark before the species name.

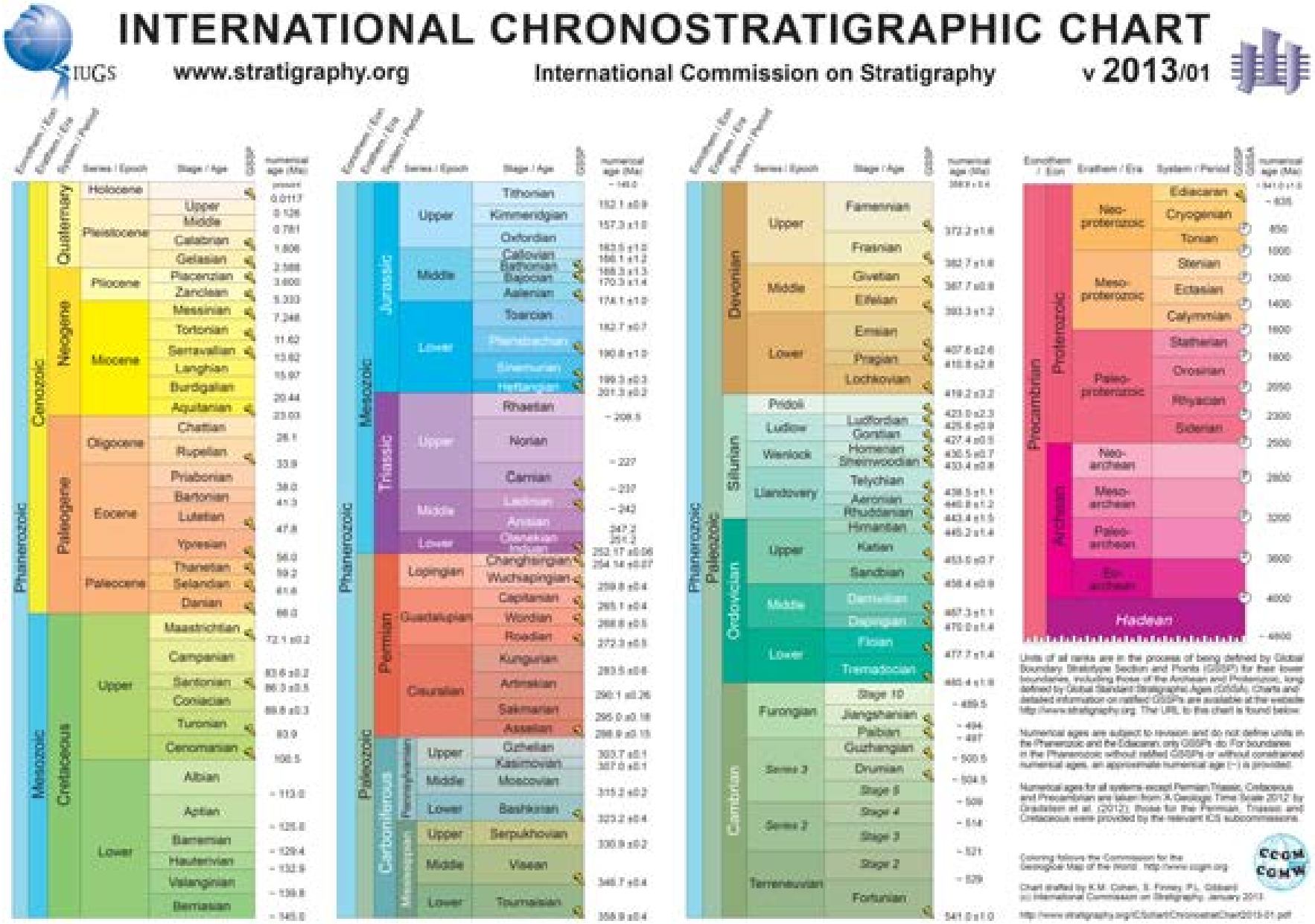
Vryheid Formation microflora of this study		
- No. 2 seam, Witbank coalfield (Falcon, 1988, 1989)	**- No. 5 seam, Witbank coalfield (Aitken, 1993, 1994)**	**- Bottom, Middle and Top Seams, Vereeniging (Millsteed, 1994, 1999)**
Apiculatisporis filiformis (Horriditriletes filiformis)	*Alisporites ovatus*	*Barakarites rotatus*
Calamospora plicata	*Barakarites rotatus*	*Deltoidospora directa*
Cycadopites cymbatus	*Calamospora plicata*	*Granulatisporites trisinus*
Deltoidospora directa	*Cannanoropollis densus*	*Lophotriletes novicus*
Florinites eremus	*Cannanoropollis obscurus*	*Marsupipollenites striatus*
Sulcatisporites ovatus	*Cycadopites cymbatus*	*Pseudoreticulatispora pseudoreticulata (Converrucosisporites pseudoreticulatus)*
Verrucosisporites pseudoreticulatus (Converrucosisporites pseudoreticulatus)	*Cycadopites follicularis*	*Scheuringipollenites ovatus*
Virkkipollenites mehtae (Cannanoropollis mehtae)	*Deltoidospora directa*	*Striatopodocarpites cancellatus*
Virkkipollenites obscurus (Cannanoropollis obscurus)	*Florinites eremus*	*Striatopodocarpites fusus*
	Granulatisporites papillosus	*Weylandites lucifer*
- Biozones I - V of Aitken (1998)	*Granulatisporites trisinus*	
Calamospora plicata	*Kraeuselisporites enormis*	**- Zone B & C of MacRae (1988)**
Cannanoropollis densus	*Lophotriletes novicus*	*Calamospora plicata*
Converrucosisporites pseudoreticulatus	*Marsupipollenites striatus*	*Cannanoropollis densus*
Cycadopites cymbatus	*Platysaccus papilionis*	*Cannanoropollis mehtae*
Cycadopites follicularis	*Platysaccus radialis*	*Cannanoropollis obscurus*
Deltoidospora directa	*Protohaploxypinus latissimus*	*Jugasporites sp. 1 of MacRae (1988)*

Florinites eremus	*Protohaploxypinus microcorpus*	*Converrucosisporites pseudoreticulatus*
Granulatisporites papillosus	*Punctatosporites granifer*	*Cycadopites follicularis*
Granulatisporites trisinus	*Striatopodocarpites cancellatus*	*Deltoidospora directa*
Kraeuselisporites enormis	*Striatopodocarpites fusus*	*Florinites eremus*
Lophotriletes novicus	*Thymospora pseudothiessenii*	*Granulatisporites papillosus*
Marsupipollenites striatus	*Weylandites lucifer*	*Kraeuselisporites enormis*
Platysaccus papilionis		*Platysaccus papilionis*
Platysaccus radialis		*Platysaccus radialis*
Protohaploxypinus microcorpus		*Protohaploxypinus latissimus*
? Pteruchipollenites landianus		*Pteruchipollenites landianus*
Punctatosporites granifer		*Punctatosporites granifer*
Scheuringipollenites ovatus		*Scheuringipollenites ovatus*
Striatopodocarpites cancellatus		*Striatopodocarpites fusus*
Striatopodocarpites fusus		*Thymospora pseudothiessenii*
Thymospora pseudothiessenii		*Verrucosisporites sp. MacRae 1988*
Weylandites lucifer		*Vestigisporites rudis*
		Weylandites lucifer

Witbank and Vereeniging seams (Aitken, 1993, 1994; Falcon, 1988, 1989; Millsteed, 1994, 1999)		
- Prince Albert Formation (this study)	**- Whitehill Formation (this study)**	**- Collingham Formation (this study)**
Acanthotriletes tereteangulatus	*Balmeella tetragona*	*Balmeella tetragona*
Apiculatisporis cornutus	*Granulatisporites trisinus*	*Corisaccites alutas*
Balmeella tetragona	*Maculatasporites gondwanensis*	*Deltoidospora directa*
Cannanoropollis mehtae	*Pakhapites fusus*	*Granulatisporites trisinus*
Circulisporites parvus	*Pilasporites calculus*	*Maculatasporites gondwanensis*
Cyclogranisporites gondwanensis	*Praecolpatites sinuosus*	*Pakhapites fusus*
Deltoidospora directa	*Weylandites lucifer*	*Protohaploxypinus limpidus*
Interradispora sp.		*Protohaploxypinus sp.*
Lophotriletes novicus	**- Fort Brown Formation (this study)**	*Striatopodocarpites cancellatus*
Pakhapites fusus	*Acanthotriletes tereteangulatus*	
Praecolpatites sinuosus	*Calamospora plicata*	**- Waterford Formation (this study)**
Striatopodocarpites rarus	*Converrucosisporites naumoviae*	*Calamospora plicata*
	Cycadopites cymbatus	*Converrucosisporites naumoviae*
- Ripon Formation (this study)	*Cyclogranisporites gondwanensis*	*Deltoidospora directa*
Acanthotriletes tereteangulatus	*Deltoidospora directa*	*Granulatisporites papillosus*

Apiculatisporis cornutus	*Granulatisporites trisinus*	*Lophotriletes scotinus*
Calamospora plicata	*Pakhapites fusus*	*Pakhapites fusus*
Converrucosisporites naumoviae	*Pilasporites calculus*	*Pilasporites calculus*
Convolutispora intrareticulatus		*Thymospora cf. pseudothiessenii*
Cyclogranisporites gondwanensis		
Deltoidospora directa		
Granulatisporites papillosus		
Granulatisporites trisinus		
Platysaccus sp.		
Punctatosporites granifer		
Thymospora cf. pseudothiessenii		
Zone I of Aitken (1998) - the No. 2 seam, Witbank coalfield (Falcon, 1988, 1989)		
Calamospora plicata	*Limitisporites monstruosus*	*Scheuringipollenites ovatus*
Cannanoropollis mehtae	*Neoraistrickia ramosa*	*Sulcatisporites splendens*
Cannanoropollis obscurus	*Potonieisporites novicus*	*Verrucosisporites naumovai*
Cyclogranisporites verrucosus	*Protohaploxypinus amplus*	*Verrucosisporites pseudoreticulatus*
Deltoidospora directa	*Punctatisporites gretensis*	*Vestigisporites gondwanensis*
Florinites eremus		
Biozones VI and VII of Aitken (1998), Zone 4 of Anderson (1977), Volksrust Formation microflora of this study		
- Ripon Formation (this study)	**- Fort Brown Formation (this study)**	**- Waterford Formation (this study)**
Acanthotriletes tereteangulatus	*Acanthotriletes tereteangulatus*	*Altitriletes densus*
Apiculatisporis cornutus	*Altitriletes densus*	*Calamospora plicata*
Calamospora plicata	*Calamospora plicata*	*Converrucosisporites naumoviae*
Converrucosisporites naumoviae	*Converrucosisporites naumoviae*	*Deltoidospora directa*
Deltoidospora directa	*Cycadopites cymbatus*	*Granulatisporites papillosus*
Granulatisporites papillosus	*Deltoidospora directa*	*Lophotriletes scotinus*
Granulatisporites trisinus	*Granulatisporites trisinus*	*Pakhapites fusus*
Platysaccus sp.	*Mehlisphaeridium regulare*	*Punctatisporites sp. A*
Punctatosporites granifer	*Pakhapites fusus*	*Thymospora cf. pseudothiessenii*
Thymospora cf. pseudothiessenii		*Vittatina fasciolata*
Vittatina fasciolata		
	- Zone D, E and F of MacRae (1988)	
- Abrahamskraal Formation (this study)	*Acanthotriletes tereteangulatus*	*Plicatipollenites gondwanensis*

Acanthotriletes tereteangulatus	*Calamospora plicata*	*Pteruchipollenites sp.*
Converrucosisporites naumoviae	*Chordasporites endroedii*	*Protohaploxypinus limpidus*
Deltoidospora directa	*Converrucosisporites naumoviae*	*Punctatosporites granifer*
Gondisporites variabilis	*Deltoidospora directa*	*Punctatisporites sp.*
Kraeuselisporites enormis	*Horriditriletes ramosus*	*? Scheuringipollenites ovatus*
Lophotriletes novicus	*Kraeuselisporites enormis*	*Striatopodocarpites cancellatus*
Lophotriletes scotinus	*Lophotriletes novicus*	*Striatopodocarpites fusus*
Mehlisphaeridium regulare	*Platysaccus papilionis*	*Thymospora cf. pseudothiessenii*
Thymospora cf. pseudothiessenii	*Platysaccus radialis*	*Weylandites lucifer*
Clouston Farm (Prevec *et al*., 2009) + Wapadsberg Pass (Prevec *et al*., 2010) - *Dicynodon* AZ of this study		
Alisporites ovatus	*Cyclogranisporites gondwanensis*	*Protohaploxypinus sp.*
?Alisporites tenuicorpus	*?Granulatisporites papillosus*	*?Striatopodocarpites cancellatus*
Apiculatisporis cornutus	*Lophotriletes novicus*	*Striatopodocarpites sp.*
Calamospora plicata	*Protohaploxypinus limpidus*	*Weylandites lucifer*


INTERNATIONAL CHRONOSTRATIGRAPHIC CHART
IUGS
www.stratigraphy.org
International Commission on Stratigraphy
v 2013/01
Eonothem / Eon
Erathem / Era
System / Period
Series / Epoch
Stage / Age
GSSP
numerical age (Ma)
Phanerozoic
Cenozoic
Quaternary
Holocene
Pleistocene
Upper
Middle
Calabrian
Gelasian
Neogene
Pliocene
Piacenzian
Zanclean
Miocene
Messinian
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
Paleogene
Oligocene
Chattian
Rupelian
Eocene
Priabonian
Bartonian
Lutetian
Ypresian
Paleocene
Thanetian
Selandian
Danian
Mesozoic
Cretaceous
Upper
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Lower
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Jurassic
Upper
Tithonian
Kimmeridgian
Oxfordian
Middle
Callovian
Bathonian
Bajocian
Aalenian
Lower
Toarcian
Pliensbachian
Sinemurian
Hettangian
Triassic
Upper
Rhaetian
Norian
Carnian
Middle
Ladinian
Anisian
Lower
Olenekian
Induan
Paleozoic
Permian
Lopingian
Changhsingian
Wuchiapingian
Guadalupian
Capitanian
Wordian
Roadian
Cisuralian
Kungurian
Artinskian
Sakmarian
Asselian
Carboniferous
Pennsylvanian
Upper
Gzhelian
Kasimovian
Middle
Moscovian
Lower
Bashkirian
Mississippian
Upper
Serpukhovian
Middle
Visean
Lower
Tournaisian
Devonian
Upper
Famennian
Frasnian
Middle
Givetian
Eifelian
Lower
Emsian
Pragian
Lochkovian
Silurian
Pridoli
Ludlow
Ludfordian
Gorstian
Wenlock
Homerian
Sheinwoodian
Llandovery
Telychian
Aeronian
Rhuddanian
Ordovician
Upper
Hirnantian
Katian
Sandbian
Middle
Darriwilian
Dapingian
Lower
Floian
Tremadocian
Cambrian
Furongian
Stage 10
Jiangshanian
Paibian
Guzhangian
Series 3
Drumian
Stage 5
Series 2
Stage 4
Stage 3
Terreneuvian
Stage 2
Fortunian
Proterozoic
Neo-proterozoic
Ediacaran
Cryogenian
Tonian
Meso-proterozoic
Stenian
Ectasian
Calymmian
Paleo-proterozoic
Statherian
Orosirian
Rhyacian
Siderian
Archean
Neo-archean
Meso-archean
Paleo-archean
Eo-archean
Hadean
Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSAs). Charts and detailed information on ratified GSSPs are available at the website http://www.stratigraphy.org. The URL to this chart is found below.
Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.
Numerical ages for all systems except Permian,Triassic, Cretaceous and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012). Those for the Permian, Triassic and Cretaceous were provided by the relevant ICS subcommissions.
Coloring follows the Commission for the Geological Map of the World: http://www.ccgm.org
Chart drafted by K.M. Cohen, S. Finney, P.L. Gibbard
(c) International Commission on Stratigraphy, January 2013
http://www.stratigraphy.org/ICSchart/ChronostratChart2013-01.pdf

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