

Master Thesis, Department of Geosciences

Palynofacies and Palynological Analysis of Late Triassic Sediments from the Kentish Knock-1 Well (Northern Carnarvon Basin, NW Australia)

Reconstruction of vegetation history, interpretation of climate and sea level changes and placement in regional zonation.

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ABSTRACT

This study has integrated palynofacies and palynological analyses of samples from the Northern Carnarvon Basin (NCB) to ascertain sea level, vegetation and climate variations of the North West Australian shelf during the Late Triassic, as well as correlating the sediments with a major bioevent within the regional stratigraphy. The sediments were found to be deposited in an environment grading between floodplain, marginal marine and oxic shelf settings. Using the palynological assemblages, mostly dominated by *Falcisporites australis*, the section was found to fall in the Middle *M. Crenulatus* spore-pollen zone of Norian age, deposited in the Mungaroo Formation in the Northern Carnarvon Basin. The palynological data were assigned to botanical affinities and manipulated to be used in a Sporomorph Eco Group (SEG) study. This enabled the reconstruction of vegetation history, the interpretation of sea level based on available niche areas for different ecological groups, and the interpretation of climate based on changes in flora within an ecological group. Climate oscillated, but overall showed a shift towards warmer and drier conditions. Sea level was determined by both palynofacies and SEG results, and found to slowly fall for most of the section, except for at the event associated with the oxic shelf conditions and the major bioevent: *H. balmei* Microplankton zone.

1. INTRODUCTION

1.1 THIS STUDY

Palynological analyses of sediments allow the reconstruction of past vegetation patterns and subsequently give clues on palaeoclimatic and palaeogeographical conditions. Palynology is frequently used to determine regional scale vegetation patterns, but the development of large scale vegetation models make it possible to explore the relationships and feedback between climate and regional vegetation zones.

The aim of this study is to use palynology and palynofacies to reconstruct the vegetation pattern, sea level changes and climate changes of the North West Australian continent in the Late Triassic, as well as pinpointing the stratigraphy of the Kentish Knock-1 Well sediments within regional biozones. Palynofacies analysis will provide information on the depositional setting of the sediments, sea level changes, and may aid in interpreting vegetational and climate results. The development of sporomorph eco-groups (SEGs) for Mesozoic vegetation by Abbink, Van Konijnenburg-Van Cittert and Visscher (2004) has provided a way to gain insight into sea level and climate changes based on variations between, and within the composition of, the SEGs. This tool will be utilised with the results from this study.

It is hoped that this information can then be used as a data point from which large scale climate versus vegetation models can be constructed.

1.2 PALAEOGEOGRAPHY

By the Late Triassic, the splitting of Pangaea into Laurasia and Gondwanaland was well under way and these two landmasses formed arcs almost symmetrically around the equator (Kutzbach and Gallimore 1989, Sellwood and Valdes 2006). They were connected near the equator on the western side and separated by the Tethys Ocean on the east (Kutzbach and Gallimore 1989). Their land mass stretched almost pole to pole (See Figure 1 (Backhouse and Balme 2002)) which had implications for the global circulation patterns and climate.

At this time, the Australian continent was on the south side of the Tethys Ocean, its northwest border, at approximately 30° south, in contact with India to the west and land that later joined up with Asia to the north (Veevers 1988, Metcalfe 1996, 1998). This land broke apart from present-day Australia during the late Jurassic, and according to Veevers (1988), it is possible that the margin may have experienced some precursor tectonics during the Late Triassic.

Because land still lay to the north of the Exmouth Plateau during the Late Triassic (Nicoll and Foster, 1998), this area formed an intracontinental basin; the southern, paralic margin of which is present-day Northern Carnarvon Basin.

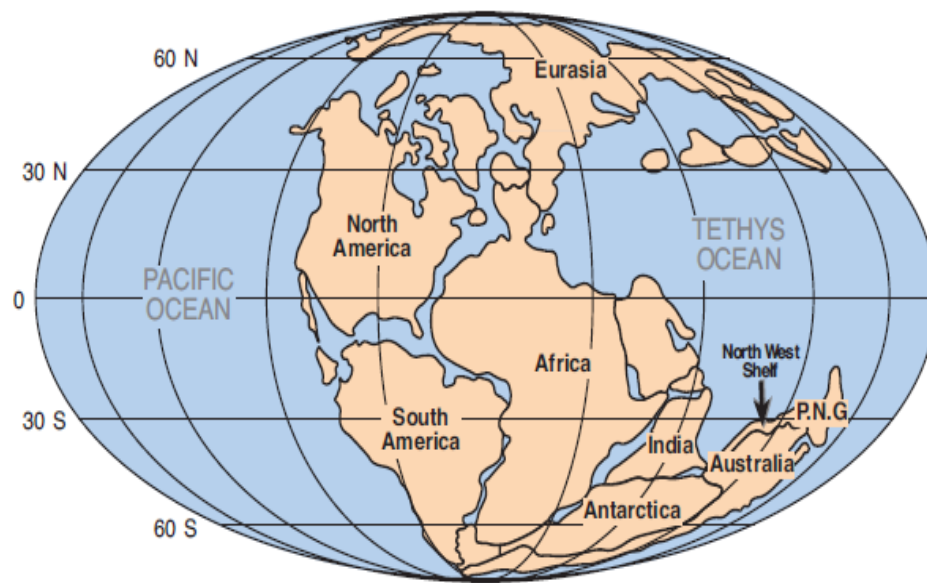


FIGURE 1: PALAEOGEOGRAPHY DURING THE LATE TRIASSIC. NORTH WEST AUSTRALIAN SHELF INDICATED WITH AN ARROW. (SOURCE: BACKHOUSE & BALME, 2002)

1.3 STRATIGRAPHY AND ZONATION

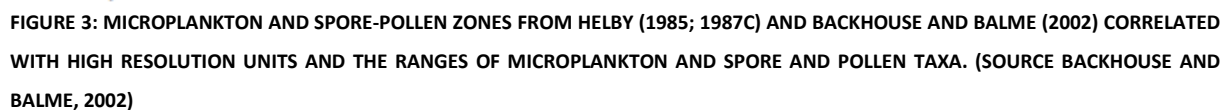
1.3.1 STRATIGRAPHY AND SEDIMENTATION

In the Carnarvon Basin, the megasequence of Jablonski (1997) spans from the base of the Triassic until the transgressive surface at the Pliensbachian of the early Jurassic. The majority of these sediments were deposited without any influence from tectonics; the major tectonic features were emplaced afterwards while the Early Synrift megasequence was deposited (Jablonski 1997). The main unconformity, which sees Triassic and Early Jurassic sequences overlain by Early Cretaceous sediments, was formed by subsequent substantial erosion. In terms of reservoir potential, the Lower Cretaceous shales here act as a seal to the Upper Triassic and Lower Jurassic sandstone reservoir (Backhouse and Balme 2002).

Within the megasequence of Jablonski (1997), the Mungaroo Formation (Figure 2) was informally introduced in lithostratigraphic nomenclature by Parry (*in* Jones 1967, in Backhouse and Balme 2002), and formalised by Playford *et al.* (1975, in Backhouse and Balme 2002). These beds represent a fluvio-deltaic sequence which was deposited under the influence of a large fluvial system in the scale of the present-day Mississippi or Amazon systems (Jablonski 1997). The Mungaroo Formation is overlain by the Brigadier Formation and is predominantly sandstone.

1.3.2 SPORE-POLLEN ZONATION

Backhouse and Balme (2002) after Helby, Morgan and Partridge (1987) describe the *Minutosaccus crenulatus* Spore-pollen Zone within the Mungaroo Formation.



q. are all present at levels within the middle *M. crenulatus* subzone. The *M. crenulatus* zone has been correlated with microplankton zones. Specifically, the *Hebecysta balmei* Microplankton Zone covers a short interval in the Middle *M. crenulatus* subzone. The *Wanneria listeri* Microplankton Zone correlates to the *M. crenulatus* zone, but due to the low number of marine intervals encountered in this section, it is rarely found.

1.33 MICROPLANKTON ZONATION

The *Hebecysta Balmei* Microplankton Zone is described by Backhouse and Balme (2002), after modification from the *Heibergella Balmei* Zone of Helby *et al.* (1987). In the NCB, this zone is usually only present over 30 metres or less, and often just represented in a single sample.

In the NCB, the zone is defined by the first and last appearances of *H. balmei*. As well as *H. balmei*, *Hebecysta* sp. A can be abundant in some samples; *Noricysta* sp B and *Wanneria listeri* are usually rare.

1.4 TRIASSIC CLIMATOLOGY

Using the knowledge of its tectonics, the Triassic's global circulation (Sellwood and Valdes 2006) and climate (Kutzbach and Gallimore 1989) have been modelled. Both investigations gave similar results regarding temperature and precipitation. In Sellwood and Valde (2006)'s model, the continents were shown to have extreme variability in summer and winter temperatures. Despite winter temperatures often getting as low as -20°C, permanent ice was prevented from forming since the summer temperatures often reached high values (around 24°C). Most of the rainfall was convection driven and consequently fell over the ocean or the coast; little reached the continental interior. Kutzbach and Gallimore (1989)'s model results were similar; they describe the landmasses' climate as exhibiting 'extreme continentality' with hot summers and cold winters. Most of the precipitation in their model was of monsoon nature and consequently restricted to coastal areas. Continental interiors were also modelled as arid, except polewards of 40°. Kutzbach and Gallimore (1989) ran models with differing values for variables to test if altitude, snow cover or greenhouse heating changes made a difference. In each scenario, the results were similar. The results require verification by climate proxy data such as the vegetation patterns, which is discussed in 1.5 below.

1.5 TRIASSIC VEGETATION PATTERNS

Sellwood and Valdes (2006) compared their circulation model results with globally derived data, including terrestrial plant biomes that were arranged by Ziegler *et al.* (1993) for the Triassic of Eurasia. The southern hemisphere was not covered in this study but its results still shed light on the vegetation patterns at a global scale, so are described here. Ziegler *et al.* (1993) found an indistinct latitudinal gradient beginning at the dry subtropical, where microphyllous conifers dominated. Polewards from here the vegetation graded to warm and cool temperate biomes. The cool temperate biome was characterised by abundant deciduous ginkgophytes and broadleaved conifers; the warm by high diversity and abundance of ferns, cycads and seedferns, as well as the conifers of the dry subtropical and the ginkgoes of the cool temperate biomes. During

the Late Triassic, the warm temperate biome, common to highly seasonally influenced areas, was very extensive. It was dominant between 30° and 50° and had occasional occurrences even further north than 70°. To the south (in Europe), there was mixing of this biome with dry, subtropical flora and to the north (in North China), some cool, temperate flora appeared, but neither biome was nearly as extensive as the warm, temperate flora. Since the palaeolatitude of the NCB was 30°S in the Late Triassic, the reconstructed vegetation in this study is expected to correspond to a mix between the warm temperate and the dry subtropical biomes.

1.6 THE END TRIASSIC MASS EXTINCTION AND PRECURSORY EVENTS

Near the Triassic/Jurassic (T-J) boundary, 200Ma, Central Atlantic Magmatic Province (CAMP) volcanism began, spilling $\sim 2.3 \times 10^6$ km³ of lava (Marzoli *et al.* 2004) in its entirety. The ejection of this lava and its associated toxic gases is often proposed as the direct or indirect cause of a large biotic turnover occurring at this time (Bonis and Kürschner 2012, van de Schootbrugge *et al.* 2009, Lindström *et al.* 2012, Götz, Ruckwied, Palfy and Haas 2009, Hesselbo, Robinson, Surlyk and Piasecki 2002). There was a 42% decrease in the number of terrestrial tetrapod families (Olsen, Shubin and Anders 1987) and marine invertebrate families decreased by 23% (Sepkoski 1984 in Fowell, Cornet and Olsen 1994). In the terrestrial realm, the data are controversial, and there is a debate on how sudden this turnover occurred. Some authors have reported a gradual transition (eg. Bonis and Kürschner 2012, Hallam 2002, Cirilli 2012), and others a sudden, extensive shift (eg. van de Schootbrugge *et al.* 2009, Fowell, Cornet and Olsen 1994).

Backhouse and Balme (2002) describe the T-J boundary interval in the Northern Carnarvon Basin. They report little lithostratigraphic difference, and a large and rapid palynological change. Assemblages from the upper Triassic are dominated by the pollen *Falcisporites australis*, but the assemblage changes dramatically to be dominated by *Classopollis* pollen in less than a metre. Grice, Backhouse, Alexander, Marshall and Logan (2005) also report a sudden change between assemblages dominated by these two pollen types over the boundary. Conflicting records of the severity of the shift are present in the Southern Hemisphere, though, with Zhang and Grant-Mackie (2001) finding the vegetational turnover recorded in sediments from New Zealand to be gradual.

Before the Rhaetian, there is yet little evidence for prominent climatic changes during the Late Triassic (Preto, Kustatscher and Wignall 2010), although some climatic episodes have been reported from the Norian-Rhaetian boundary and into the Rhaetian. Hallam (1984) reported a transition from gypsiferous red beds to plant rich and coal-bearing strata in rocks from Western Europe and attributed it to an increase in humidity. Ahlberg, Arndorff and Guy-Ohlson (2002) also noted this shift to higher humidity shown by the beginning of coal and gleysol deposition in present day Sweden. Sephton *et al.* (2002) claim that the Late Triassic had more than one extinction event, finding evidence for a major $\delta^{13}\text{C}$ excursion and extinction of deep-water invertebrate fauna at the Norian-Rhaetian boundary. Cirilli *et al.* (2009) suggest that CAMP basalt emplacement in Nova Scotia, and consequently to other CAMP areas, all occurred within the Rhaetian. In the Norian, the evidence for major climatic change is so far restricted to the marine realm, in which the number of ammonite genera decreased from 150 to 90 (Teichert, 1986).

2. MATERIALS AND METHODS

2.1 SAMPLES

Samples were taken by Wolfram Kürschner during a visit to the Geological Survey of Western Australia in Perth, in 2010. The samples span 45m between 2355 and 2310m depth in the Kentish Knock-1 well. This well was drilled to a total of 2.53km by Chevron in the Northern Carnarvon Basin 300kms from the Western Australia Coast (See Figure 4) at 1.219kms water depth (Chevron, 2009).

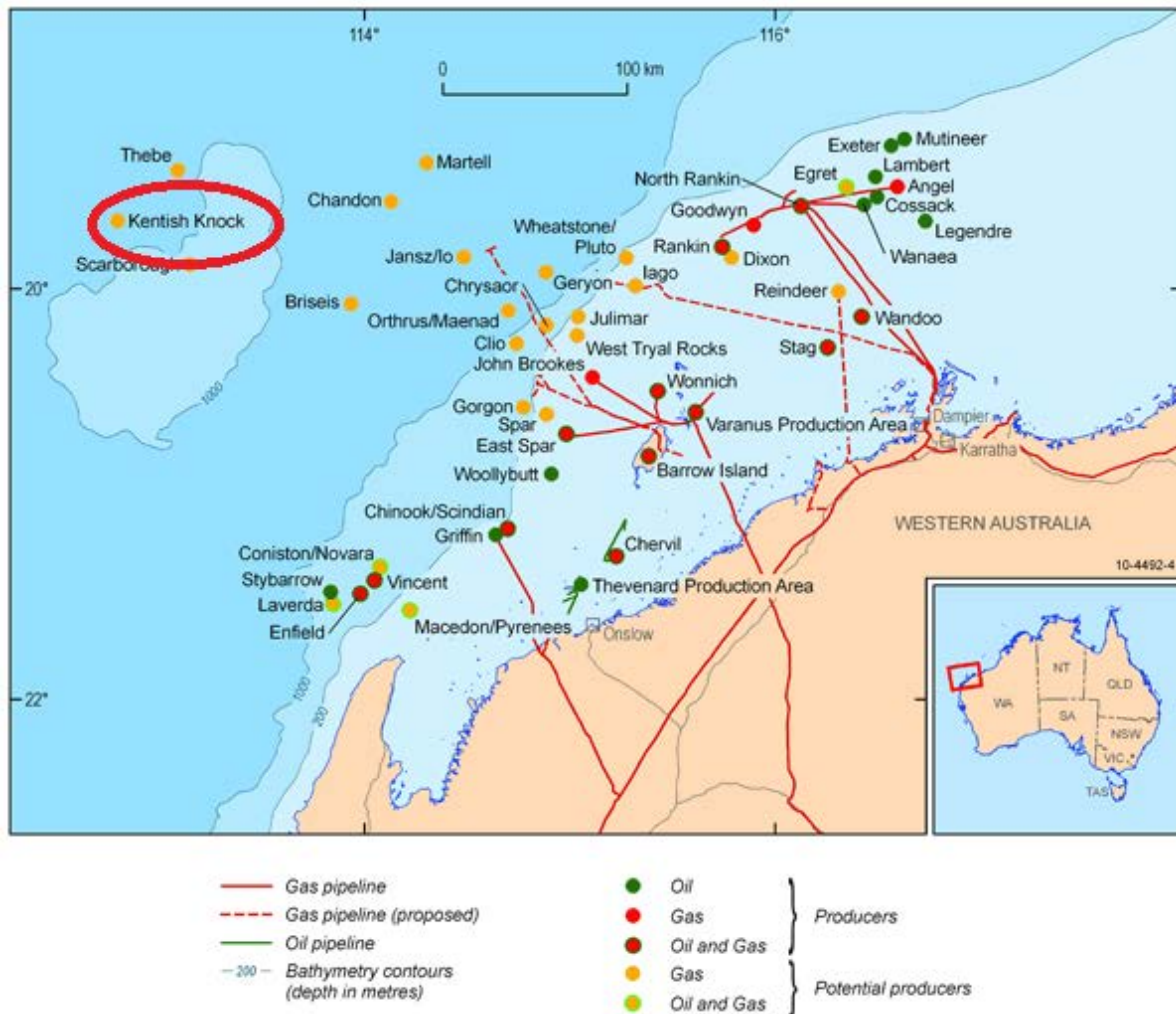


FIGURE 4: WELLS AND PIPELINES IN THE NORTHERN CARNARVON BASIN WITH KENTISH KNOCK WELL CIRCLED. (SOURCE: GEOSCIENCE AUSTRALIA, 2010)

2.2 SLIDE PREPARATION

The uppermost six samples were prepared at the University of Oslo. The resulting slides were used for the palynological analyses of the samples 2309.95m -2315.4m depth. Here:

1. Samples were crushed and 3g of each were collected in a plastic bottle to undergo acid treatment.
2. The samples underwent acid treatment:

- a. 10% HCl was added to the plastic bottles, and let sit for some days with regular shaking in order to remove carbonate.
 - b. Each bottle was decanted, filled with tap water and left to settle.
 - c. Step 2b was repeated until the decanted liquid had a neutral pH.
 - d. 40% HF was added to the plastic bottles which were placed and left in a 70°C water bath for some days, being shaken regularly.
 - e. Decanting was performed on each sample until a neutral pH was achieved.
3. The samples were sieved through a 15µm mesh.
 4. The residue was then mounted to microscopy slides on a hot plate, using glycerin gel.

All 24 samples were prepared at Applied Petroleum Technology. The resulting slides were used for the palynological analyses of the samples 2317.66m – 2354.35m depth, and the palynofacies analyses of all samples. Here:

1. Samples were cleaned with liquid soap to remove contaminants
2. The samples underwent acid treatment:
 - a. Carbonate was removed with HCl treatment
 - b. Each sample underwent decanting until neutral.
 - c. Siliceous material was removed with HF treatment
 - d. Each sample underwent decanting until neutral.
 - e. Some of the material was oxidised with nitric acid.
3. The samples were sieved through an 18µm mesh.
4. Both the oxidised and non-oxidised material was mounted onto separate microscopy slides using resin.

2.3 ANALYSIS

Each slide then underwent palynofacies and palynological analyses. In the palynofacies analysis, the particulate organic material (POM) was categorised into amorphous organic material (AOM), and structured organic material (including charcoal, brown translucent material, cuticles, bisaccate pollen, non-bisaccate pollen, spores, dinoflagellate cysts, acritarchs and other algae). Material in each category was counted until 300 palynomorphs were reached. The palynological analysis consisted of identifying palynomorphs to species or, if not possible, genus level. Counts were made until the total palynomorphs reached 300. Diagrams of the results from both analyses were made using Tilia and annotated with Adobe Illustrator.

3. PALYNOFACIES

3.1 ORIGIN AND NATURE OF PALYNOFACIES COMPONENTS

PHYTOCLASTS

Phytoclasts are pieces of plant derived structured organic material (Tyson, 1993). In this research, they are divided into three categories: opaque organic material (charcoal), brown translucent material and cuticles.

Opaque organic material is made up of either charcoal or biochemically oxidised wood. It originates from the oxidation of organic material, either during forest fires, repeated degradation or thermal maturation. It is easily recognisable by its completely black and opaque nature.

Brown translucent material is fragments of wood. Holes or stripes can often be seen on the clasts.

Cuticles are light coloured, translucent leaf cuticles. They are recognisable by their transparent nature and their cellular structure.

AMORPHOUS ORGANIC MATTER

Amorphous Organic Matter (AOM) can have either a terrestrial or aquatic origin. Terrestrially, higher plants can secrete AOM as intra-/extra-cellular resins or it can be a product of the decomposition of higher plants (Tyson, 1993). Aquatically, faecal pellets from zooplankton, aggregates of flocculated dead organic matter (DOM) or bacteria can form AOM (Tyson, 1993). AOM is recognisable by its unstructured appearance. It is usually grey, translucent and can have a bubbly texture.

PALYNOMORPHS

Palynomorphs are all organic microfossils, either plant or animal derived. They include spores and pollen; acritarchs and algae remains, including dinoflagellate cysts.

Spores and pollen are the terrestrial component of this category. They are produced during the life cycle of land plants: spores by the bryophytes and ferns, pollen by the gymnosperms and angiosperms (Traverse, 2007a).

Land plants have a lifecycle comprising two alternating generations. The gametophyte generation consists of sexual reproduction of male and female gametes, the male of these developing inside a pollen grain. The sporophyte generation is asexual and produces spores (Traverse, 2007b).

Spores generally germinate in damp environments. They can be trilete, monolete or alete, referring to the number of laesurae they have. The laesurae separate the surfaces where the spores were in contact with each other (Traverse, 2007c).

In higher land plants, the pollination mechanism varies from plant to plant. Many pollen grains have air sacs to increase their buoyancy, and hence their dispersal reach. However, there are also many pollen grains without these features. Hence, bisaccate, monosaccate and non-saccate pollen grains are produced. In this research, the pollen has been grouped simply into bisaccate and non-bisaccate.

Dinoflagellate cysts are the resting cysts of the algae dinoflagellates. Dinoflagellates are marine, single celled organisms that are important primary producers. Their motile cells have two flagella for propulsion, one longitudinal and one transverse. Part of the lifestyle of some species of dinoflagellates involves the formation of a resting cyst, which can have one or multiple layers. It is this cyst which is fossilised, since it is composed of dinosporin (organic material resistant to decay) (Traverse, 2007a). Dinocysts can be recognised by their plated surface and their apical and antapical horns and processes.

Acritarchs encompass all single celled, organic walled microfossils that have unknown biological affinity. Many are thought to be resting cysts of marine algae, and almost all are likely algal in origin (Traverse, 2007a). Hence acritarchs probably represent the remains of very important phytoplanktonic primary producers.

3.2 PALYNOFACIES ANALYSIS

Palynofacies analysis can give an indication of the depositional environment. The analysis consists of studying all the organic matter in a sample, including amorphous material, phytoclasts and palynomorphs. The relative distribution of the organic matter can then be used to recognise facies and to reconstruct palaeoenvironments. The significance of various palynofacies parameters are described below summarised from Tyson (1993).

PHYTOCLASTS

A relative abundance of phytoclasts within a sample can indicate three different scenarios.

Firstly, they can indicate a depositional environment that was proximal to the parent flora. In this case, limited sorting of composition and size would be evident since insufficient transport occurred to do this job. Particles which often would not be preserved after transportation, for example large leaf fragments, could be present within a facies of this description.

Secondly, they can indicate the degree of relative preservation. They are often the only organic material to survive in highly oxidised environments.

Thirdly, they can often be found concentrated in coarse silt or very fine sand because of their similarity in grain size to these materials.

FLUORESCENT AMORPHOUS MATTER

Amorphous organic matter often has enhanced preservation, and hence will be dominant in an assemblage under reducing conditions, for example highly disoxic bottom waters. This is especially the case when the top

layers are high in primary production. They can also be relatively dominant in sediments that are removed from terrestrial influence.

PALYNOMORPHS

The relative abundance of palynomorphs is usually dependent on the concentration or dilution of other organic material. Therefore, in general, they are relatively abundant within an assemblage away from fluvial sources, in arid climates with little vegetation, and in moderately oxidising conditions. Sorting may also play a role in that palynomorphs may be preferentially selected by sediments of similar grain size, ie: medium to fine silt. However, within the palynomorph group, the relative proportions of the sporomorph (pollen and spore) and fossilising organic walled microplankton components can be more enlightening on the palynofacies present.

PERCENT SPOROMORPHS OF TOTAL PALYNOMORPHS

High percentages of sporomorphs reflect low energy, distal, moderately oxidising environments, especially when bisaccate pollen is favoured. Since dinocysts peak in production on the continental slopes, a relatively high sporomorph count could reflect an oceanic setting.

RATIO DINOCYSTS: ALL PALYNOMORPHS

A high dinocyst: other palynomorph ratio means areas of high marine primary productivity, for example within coastal upwelling zones. Areas of coastal upwelling are also often associated with arid terrestrial conditions, so in this way, phytoclast abundance is limited, increasing the relative proportion of dinocysts to all organic matter.

PERCENTAGE DINOCYSTS OF ALL PLANKTON

A high percentage of dinocysts can reflect temperate to subtropical shelf facies, since dinocysts are able to adapt to unstable regimes. When dinocysts percentage is lowered by partial replacement by acritarchs, brackish and hypersaline conditions are reflected. In general, the percentage of dinocysts increases offshore but declines again in basinal pelagic or hemipelagic facies.

PERCENTAGE ACRITARCHS OF ALL PLANKTON.

Acritarchs only play a significant role in shallow marginal marine settings, where dinocysts have been inhibited by brackish water, since acritarchs are the most tolerant marine phytoplankton. Because of their small size, however, they can often be overlooked or sieved out of the sample.

3.21 STYLISTED MARINE PALAEOFACIES DIAGRAM

Tyson (1989, in Tyson 1993) has constructed a stylised triangle diagram assigning paly-assemblages to marine palaeofacies (Figure 5). The marine facies found in this research is mud-dominated oxic shelf (V). This facies generally has low-moderate AOM, and abundant palynomorphs. The spores to bisaccate ratio is usually low, and dinocysts are the dominant microplankton.

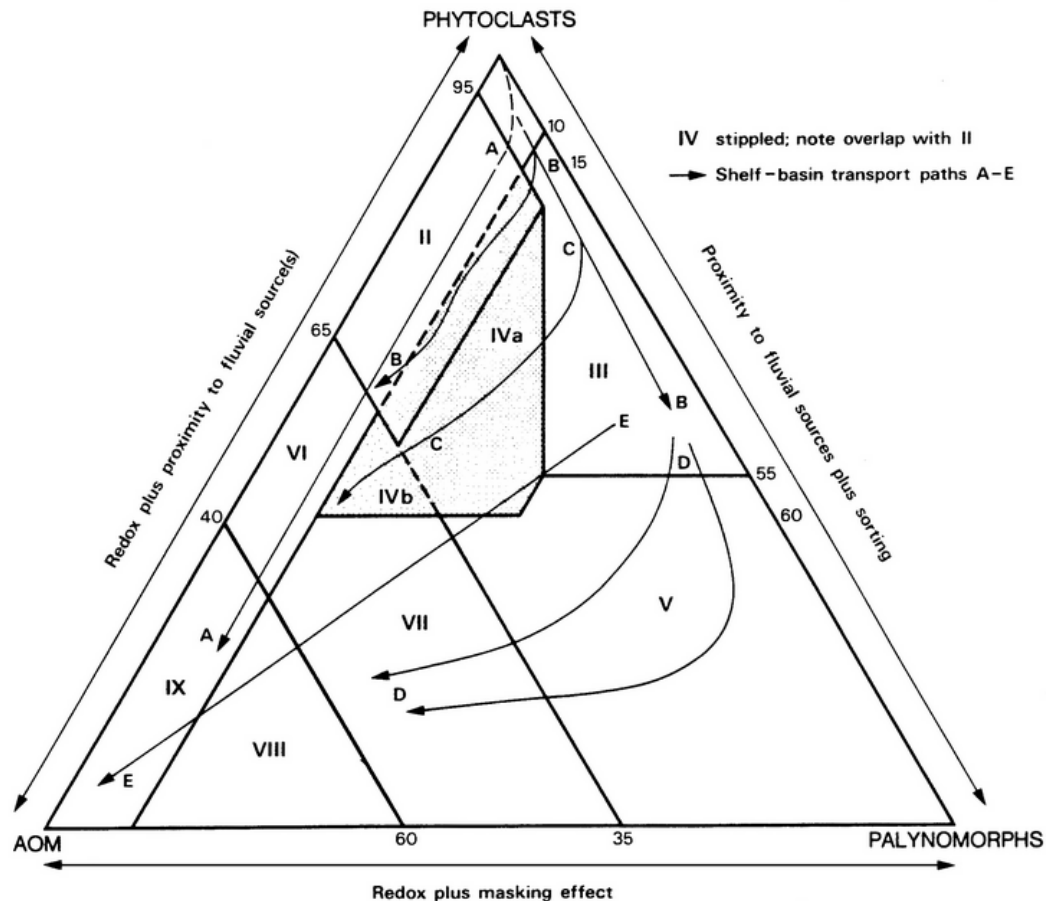


FIGURE 5: STYLED TRIANGLE DIAGRAM SHOWING POM CONTENT OF I: HIGHLY PROXIMAL SHELF OR BASIN, II: MARGINAL DYSOXIC-ANOXIC BASIN, III: HETEROLITHIC OXIC SHELF ('PROXIMAL SHELF'), IV: SHELF TO BASIN TRANSITION, V: MUD-DOMINATED OXIC SHELF ('DISTAL SHELF'), VI: PROXIMAL SUBOXIC-ANOXIC SHELF, VII: DISTAL DYSOXIC-ANOXIC 'SHELF', VIII: DISTAL DYSOXIC-ANOXIC SHELF, IX: DISTAL SUBOXIC-ANOXIC BASIN. PRIMARILY DESIGNED FOR LATE JURASSIC MARINE SHALE PALYNOFACIES (AFTER TYSON 1989, IN TYSON 1993).

3.23 PALYNOFACIES SPECIFIC TO THE NORTHERN CARNARVON BASIN

Backhouse and Balme (2002), drawing on Bint and Helby (1988), have summarised the characteristics of the specific palynofacies found in the Northern Carnarvon Basin. Their analysis does not take organic detritus into consideration, which according to some authors (Batten 1996), makes it incomplete. However, an overview of the significance of organic detritus has been discussed above, and it is also useful to look in more detail at the significance of palynomorphs specific to the study area. In their analysis, they note that the changes between the palynofacies occur quickly, especially within the swamp palynofacies. Their analysis describes the following palynofacies:

FRESHWATER

This palynofacies is rarely found in the study area, and only first identified by Backhouse and Balme, 2002. It consists of freshwater or brackish algal cysts, most commonly *Plaesiodictyon* and *Botryococcus*. *F. australis* is reduced in relative abundance.

SWAMP

Six swamp or swamp margin environments are identified, described as strongly to weakly characterised swamp facies. All have high counts of selected spore and algal species, and a low count of *F. australis*. Typically, these palynofacies have low spore and pollen diversity. Dinocysts are not common, nor are spinose acritarchs, but where these are present, they indicate marine influence, and hence a weakly characterised swamp palynofacies. The algal cyst *Bartenia communis* is sometimes common.

CHANNEL

The channel palynofacies typically has low diversity of spores and pollen, although it is noted that this may be influenced by the lower yield of channel sediments. *F. australis* dominates.

FLOODPLAIN

Floodplain sediments typically give a large yield, which may influence the high spore-pollen diversity seen in this palynofacies. Spinose acritarchs and dinocysts are not present. There is a gradient of increasing diversity from channel to floodplain palynofacies.

BRACKISH TO MARGINAL MARINE

F. australis is dominant in this high diversity spore-pollen palynofacies. Spinose acritarchs of the *Veryhachium* spp. and *Micrhystridium* spp. are present in extremely low counts, and no dinocysts are present.

MARGINAL MARINE

F. australis is dominant. Dinocysts are present, accounting for up to 10% of the assemblage. This palynofacies is very common in both the *R. rhaetica* and lower *D. priscum* zones. Where present in the *A. Reducta* zone, the small, monolet spore *Thymospora ipsviciensis* increases in abundance.

OXIDISED

Oxidation during, for example, the emergence of floodplains, has removed organic material.

4. SPOROMORPH ECO GROUPS

Sporomorphs (pollen and spores) are often used to determine local and regional scale environmental changes in Quaternary studies, but this becomes more difficult and is less commonly done in older sections. This is due to several reasons. Firstly, nearly all of the sporomorphs within Quaternary studies are able to be correlated to a parent plant since they correspond to extant flora. The proportion of sporomorphs coming from extant flora declines as the samples get older, leaving fewer to be assigned botanical affinities. This also makes it more difficult to assign the sporomorph to an ecological group, even where it has been found in situ with macrofossils and can be assigned a parent plant, since the ecological preferences of the parent plant can never be known as accurately as that of an extant plant. Despite this, Abbink, Van Konijnenburg-Van Cittert & Vischer (2004), note that with just partially extant sporomorph assemblages from the neogene and palaeogene, palaeoecological communities have been able to be identified, and these create a good basis for working even further back in time into the Mesozoic.

When attempting to reconstruct vegetation patterns by using sporomorphs, it is first imperative to take into account some influencing factors. Firstly, different plants produce different amounts of sporomorphs. For example, a *Rumex acetosa* (sorrel) anther can produce almost 150 times the amount of pollen that a *Trifolium pratense* (clover) anther does (Moore, Webb and Collinson 1991), so a majority of sorrel pollen does not necessarily mean that sorrel was dominant. Thus, absolute counts of sporomorphs have to be corrected for these biasing factors. However changes between abundances of sporomorphs can provide direct information on changes between vegetation types.

Secondly, varying dispersal mechanisms of different sporomorphs means their distribution ranges are affected. Pollination by insects began only with the spread of the angiosperms in the Jurassic (Sanderson, Thorne, Wikström and Bremer 2004). Consequently all the sporomorphs within this study relied on wind and water currents for their dispersal. Some (eg. bisaccate pollen) are more morphologically adapted to travel long distances by these methods than others, and a sporomorph assemblage reflects this. In a setting where water dispersal is dominant, for example a marginal marine setting, the Neves effect (Figure 6, described by Chaloner and Muir 1968) can be used to describe the distribution of the sporomorphs. This is where the relative proportions of sporomorphs is inversely proportional to the distance from their source. For example, hinterland vegetation often includes gymnosperms with bisaccate pollen. Because of its high buoyancy, it can travel long distances from shore before sedimentation, and is consequently usually the dominant sporomorph in marine assemblages. On the other hand, spores from mosses, which may be growing closer to the shoreline are less morphologically adapted to travel long distances, so will be out-numbered by bisaccates once distance from the parent plant is achieved.

Abbink *et al.* (2004) have developed a palaeocommunity model based on ecological groups defined by sporomorph composition for the European Jurassic- Lower Cretaceous. Despite the area and age difference to

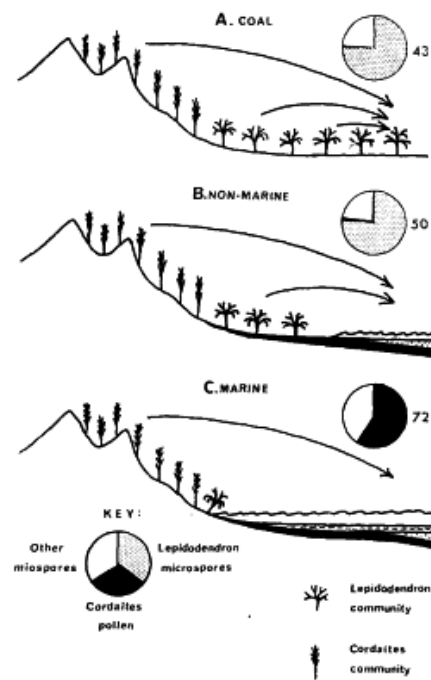


FIGURE 6: DIAGRAM ILLUSTRATING 'NEVES EFFECT'. WHERE THE PROPORTION OF HINTERLAND SPORES BECOMES PROGRESSIVELY LARGER MOVING OFFSHORE. SOURCE: CHALONER AND MUIR, 1968.

this study, it is thought to be relevant enough to be used because of the following argument: In terms of area, the main difference arising between North West Europe and Australia will be the sporomorph assemblages, rather than changing ecological behaviour of parent plants. The age difference is considered insignificant since this study comes from the latest Triassic, and Abbink *et al.* (2004)'s model applies from the Jurassic, the next period of time. Hence these authors' model has been used and will be described here.

Each sporomorph eco group (SEG) consists of a floral community that reflects a particular ecological environment. The SEGs are listed below.

Upland: Includes plants that grew well above the water table and that were never submerged;

Lowland: Includes plants that grew on plains or in swamps. They could be periodically submerged by fresh water;

River: Communities of vegetation frequently exposed to submergence and erosion;

Pioneer: Includes plants that grow on newly available eco spaces;

Coastal: Vegetation that grows near the sea and is constantly subject to sea spray, although never submerged;

Tidally-influenced: Vegetation that underwent regular submergence by sea water and was influenced by the tide daily.

The driver of shifts between the relative proportions of SEGs has been attributed to sea level change. Generally, when a sea level rise occurs, the increase in marine influence results in the encroachment of the Coastal and Tidal SEGs into the zone once occupied by the Lowland SEG. The boundary between the Lowland and Upland SEGs is much more stable. Consequently the Lowland SEG loses much of its niche area and the relative contributions of the Lowland to the Coastal and Tidal SEGs, which often increase in abundance with sea level rise, give an indication of relative sea level rise and fall.

On the other hand, when the changes are within the SEGs, a changing climate is the cause. Climatic changes result in variations of water, light and nutrient availability. These shifts alter the competitive strategy of plants. Consequently, the relative abundances of different constituents of a SEG are significantly altered, especially within the Lowland SEG where the sole plant strategy is competitive. The Coastal and Upland SEGs also experience internal shifts but the River and Tidal SEG are not notably altered.

5. RESULTS

5.1 PALYNOFACIES

The palynofacies results are displayed in Figures 7 and 8.

For most of the sampled section (See Figures 7 and 8), phytoclasts dominate the assemblage. Brown translucent material is almost exclusively the dominant material, usually ranging between 25% and 45% of all particulate organic matter (POM) and cuticles are consistently high, usually between 15% and 30% of POM. Charcoal is in high supply in the upper 20m of the section (Zones 5, 4, 3 and the top half of Zone 2), where it charts between 15 and 30%, but its contribution reduces to generally less than 10% in the lower 20m (Zone 1 and lower half of Zone 2). All phytoclasts have lower contributions around 2315m where a large dinocyst influence is present.

Terrestrial palynomorphs generally contribute between 20% and 30%, but two peaks are identifiable in the section. One peak is five metres above the base of the section (in Zone 1) where terrestrial palynomorphs make up almost 45% POM, and corresponds to a decrease in brown translucent material. Another peak to almost 50% POM occurs in Zone 3 just below the influx of dinocysts, and again corresponds with a decrease in brown translucent material. Since spores and non-bisaccate pollen are fairly consistent throughout the section, making up about 10% and 3% POM respectively, these peaks are driven by increases in bisaccate pollen, which is the dominant terrestrial palynomorph at all levels.

Aquatic palynomorph contributions are generally very low and scattered. Dinocysts appear in very low counts twice near the base of Zone 1 and more frequently from 2320m upwards. At about 2315m, in Zone 4, there are two samples containing very large proportions of dinocysts. They reach between 40% and 50% in both samples. Above this again there are just two sporadic very low counts of dinocysts. Acritarchs first appear in the section at 2320m but only ever offer very low to low contributions, the highest being about 3% where dinocysts dominate. Other algae (solely the fresh or brackish water *Bartenia* spp.) show very low counts in six samples scattered throughout the section. Four of these are at or below 2340m, and the two others are at or above the dinocyst influx at 2315m.

Amorphous organic matter only occurs in low percentages of less than 5% below 2330m (half way through Zone 2). Above this however, it is more dominant, usually making up between 5% and 10% of POM. One large peak at 2314m (in Zone 5) and one small peak at 2316m (in Zone 4) are present, where AOM makes up 25% and 15% POM, respectively.

Using a Cluster Analysis, the diagram was divided into five zones, here named Zones 1-5.

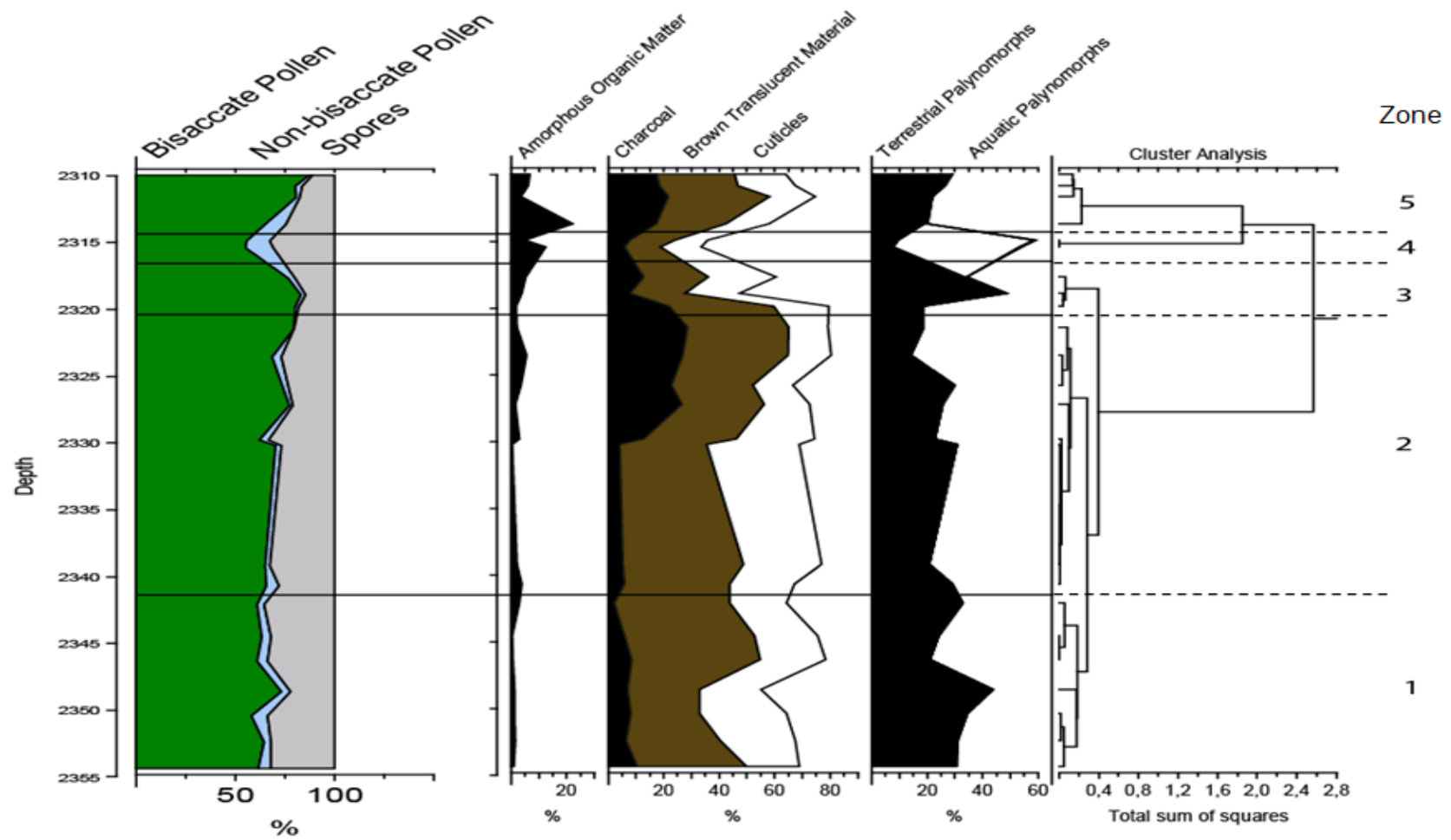


FIGURE 7: RATIO DIAGRAM BETWEEN SPOROMORPH TYPES CORRELATED WITH DIAGRAM OF ORGANIC DETRITUS STACKED INTO GROUPS. CLUSTER ANALYSIS FROM WHICH ZONES WERE DETERMINED SHOWN TO THE RIGHT (VERTICAL SCALE IN METRES).

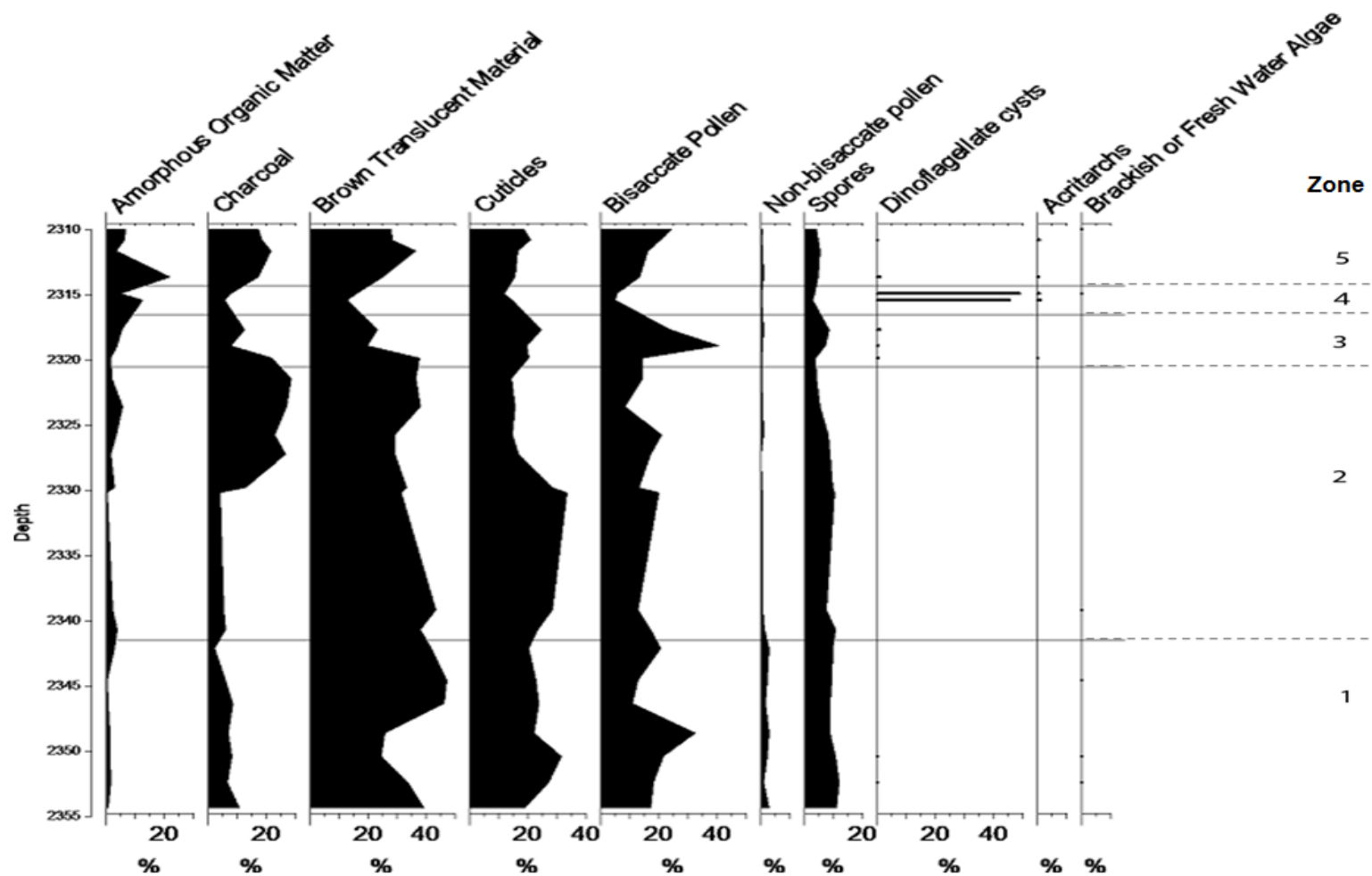


FIGURE 8: PALYNOFACIES DIAGRAM WITH ZONES SHOWING ALL DETRITUS GROUPS (VERTICAL SCALE IN METRES)

ZONE 1 (2355M-2342M)

This lowermost zone is characterised by the low proportions of amorphous organic matter and charcoal. Otherwise, brown translucent material is easily dominant; cuticles consistently make up 20-30% POM, bisaccates 15-25% (except for the peak at 2348m), non-bisaccates consistently low counts under 2%, spores consistently ~10%. Acritarchs are absent, as are dinocysts, except for two very low counts near the base. Very low counts of *Bartenia* spp. are scattered throughout this section.

ZONE 2 (2342M-2321M)

The zone above (2330m-2317m) is characterised by its increase in charcoal to ~20% POM and amorphous organic material to 5-10% at 2330m. Brown translucent material remains the most dominant material overall; and together phytoclasts make up almost 80% of POM. Terrestrial palynomorphs make up between 10 and 30%. Aquatic palynomorphs are absent except for one occurrence of *Bartenia* spp. at the base of the zone.

ZONE 3 (2321M-2317M)

A peak in terrestrial palynomorphs to almost 55% POM characterises this zone. Phytoclasts experience a dip here, and AOM rises steadily through the zone from 2-5%. Dinocysts are consistently present in low counts throughout the zone.

ZONE 4 (2317M-2314M)

The assemblage in this zone is dominated by dinocysts which make up almost 50% POM. Acritarchs are present in low counts. Terrestrial palynomorphs dip below 10%, all types experiencing a decrease, but especially bisaccate pollen. Phytoclasts dip to under 40% altogether, but here AOM experiences its small peak to 13%.

ZONE 5 (2314M-2310M)

At the base of this zone, AOM has its large spike to over 20%, but this zone is again dominated by brown translucent material and phytoclasts, which altogether contribute 65-70% POM. Terrestrial palynomorphs make up ~30% POM. Dinoflagellate cysts and acritarchs are present with very low counts in two samples and *Bartenia* spp. is present in very low counts in the uppermost sample.

5.2 PALYNOLOGY

A list of the taxa found in this research is provided in Table 1, and their relative abundances shown in Figure 9. Photographs are presented in Plates 1-5.

5.2.1 BOTANICAL AFFINITIES OF SPORES AND POLLEN

The spores and pollen found in this study are below presented with their botanical affinity and summarised in Table 2.

TABLE 1: TAXA IDENTIFIED IN THE SAMPLES IN THIS RESEARCH.

Pollen	Spores	Dinocysts
<i>F. australis</i>	<i>C. tener</i>	<i>H. balmei</i>
<i>A. reducta</i>	<i>Punctatisporites</i> spp.	<i>W. Listeri?</i>
<i>V. signatus</i>	<i>D. harrisii</i>	
<i>S. speciosus</i>	<i>Dictyophyllidites</i> sp. A	Acritarchs
<i>P. queenslandii</i>	<i>A. pristidentatus</i>	<i>Micrystridium</i> spp.
<i>Elongatosaccites</i> spp.	<i>A. globosus</i>	<i>M. dendroidium</i> c.f.
<i>H. insculptus</i>	<i>Baculatisporites</i> sp. A	
<i>E. densus</i>	<i>C. cameronii</i>	Other Algae
<i>E. vogens</i>	<i>L. bauhinae</i> c.f.	<i>Bartenia</i> spp.
<i>M. crenulatus</i>	<i>N. taylorii</i>	
<i>C. meyeriana</i>	<i>U. verrucosus</i>	
<i>C. follicularis</i>	<i>L. argenteaeformis</i>	
<i>Chasmatisporites</i> sp. A	<i>S. perforatus</i>	
<i>E. macistriatus</i>	<i>P. mooniensis</i>	
	<i>D. problematica</i>	
	<i>P. velata</i>	
	<i>Leschikisporis</i> spp.	
	<i>Thymospora</i> spp.	
	<i>T. aberdarensis</i>	
	<i>P. walkomii</i>	
	<i>A. astigosus</i>	

BISACCATE POLLEN

Falcisporites australis

Townrow, 1965 (in Balme 1995) described a specimen which was found borne on the frond of a peltasperm plant. The specimen was referred to by Balme (1995) as *Falcisporites australis*.

Vitreisporites signatus

The *Vitreisporites* genus was assigned to the Caytoniales order of pteridosperms (Bonis and Kuerschner 2012).

Platysaccus queenslandii

In Bonis and Kuerschner (2012), the *Platysaccus* genus has been placed as a Voltziaceae within conifers.

Samaropollenites speciosus

This species has been assigned to either a conifer or seed fern parent plant by Breda *et al.* (2009).

Ashmoripollis reducta

Ashmoripollis reducta is simply described as having natural affinity to a gymnosperm mother plant in the New Zealand catalogue of fossil spores and pollen (Raine, Mildenhall, Kennedy, 2011). Its morphology lends itself to

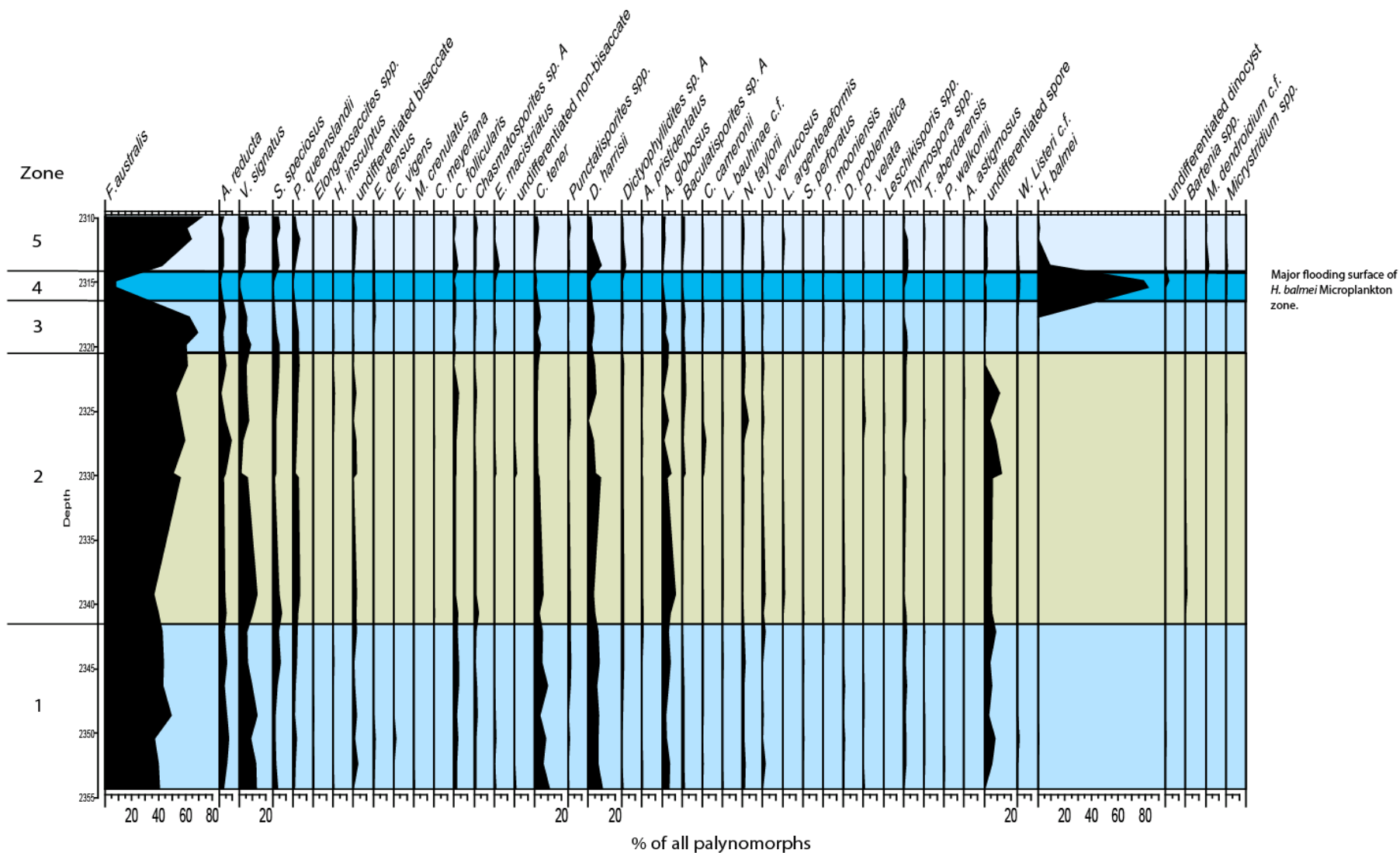


FIGURE 9: DIAGRAM SHOWING ALL TAXA IDENTIFIED IN THIS STUDY. ZONES DETERMINED BY CLUSTER ANALYSIS AND DISTINGUISHED BY PALYNOFACIES ANALYSIS (VERTICAL SCALE IN METRES)

either a cycadophyte or seed fern but has never been found in situ (H. van Konijnenburg pers. comm, March 21st, 2013).

No information could be found on the botanical affinities of bisaccates *Elongatosaccites* spp., *Minutosaccus crenulatus* and *Hamiapollenites insculptus*.

NON-BISACCATE POLLEN

Enzonasporites densus and *Enzonasporites vigens*

Leschik, 1956 (in Balme, 1995), attributed the *Patinasporites* genus to conifer parent plants, and Balme (1995) has equated the *Patinasporites* and *Enzonasporites* genera.

Classopollis meyeriana

Bonis and Kuerschner (2012) have listed *Classopollis meyeriana* as a Cheirolepidaceous conifer.

Cycadopites follicularis

Cycadopites-type pollen can be from a Cycadophyta, Ginkgoales or Peltaspermales parent plant (Bonis and Kuerschner, 2012).

Chasmatosporites sp. A

The *Chasmatosporites apertus* c.f. *Chasmatosporites* sp. A was listed as coming from Cycadophyta gymnosperms by Bonis and Kuerschner (2012).

Ephedripites macistriatus

The *Ephedripites* spp. were listed as Gnetales gymnosperms by Bonis and Kuerschner (2012)

SPORES

Calamospora tener

Bonis and Kuerschner (2012) attribute *Calamospora tener* to a horsetail parent plant.

Punctatisporites spp.

Traverse (2007d) summarises the different parent plants *Punctatisporites* has been assigned to. Notably it is assigned as a spore to several ferns ((Millay and Rothwell 1983; Millay 1979, 1982; Millay and Taylor 1982) in Traverse 2007d), but also as a pollen grain or pre pollen to Cycadofilicales seed-ferns ((Eggert and Taylor 1968; Stidd 1978) in Traverse 2007d). Since the *Punctatisporites* found in this study is a spore, it has been assigned to a fern parent plant.

Dictyophyllidites spp.

Species of *Dictyophyllidites* spores including *D. nilssonii* (c.f. *D. harrisii*) were produced by Dipteridaceae ferns (Balme 1995).

Anapiculatisporites pristidentatus

Millay and Taylor (1982), Good (1979) and Meyen (1987) (in Balme, 1995) described a spore that Balme (1995) has placed in *Anapiculatisporites* as having affinity to the fern-like Botryopteridales.

Apiculatisporis globosus

Wagner et al. (1985) (in Balme, 1995) recovered and described a spore that Balme (1995) has called *Apiculatisporis*. They assigned it to the parent flora of a Marattiales fern.

Baculatisporites spp.

The *Baculatisporites* spp. has been assigned to an Osmundales fern parent plant by Bonis and Kuerschner (2012).

Converrucosisporites cameronii

A spore of the *Converrucosisporites* genus has been assigned to the Filicales fern by Bonis and Kuerschner (2012).

Lophotriletes bauhiniae c.f.

A spore of the *Lophotriletes* genus has been assigned as having a fern parent plant by Bonis and Kuerschner (2012).

Neoraistrickia taylorii

Abbink et al. (2004) has affiliated this spore with the Lycopodiales. They also specifically place it within the River SEG.

Uvaesporites verrucosus

This spore is assigned to the Lycopods in the New Zealand Catalogue of Fossil Spores and Pollen (Raine et al., 2011)

Leptolepidites argenteaeformis

The *Leptolepidites* spp. has been attributed to a clubmoss parent flora (Bonis and Kuerschner, 2012).

Stereisporites spp.

A moss parent plant has been assigned to spores of the *Stereisporites* genus by Bonis and Kuerschner, (2012).

Polycingulatisporites mooniensis

This spore is assigned to the bryophytes in the New Zealand Catalogue of Fossil Spores and Pollen (Raine *et al.*, 2011)

Playfordiaspora velata

This spore is tentatively assigned to a Lycopsid parent plant in the New Zealand Catalogue of Fossil Spores and Pollen (Raine *et al.*, 2011)

Leschikisporis spp.

Millay (1979) and Millay and Taylor (1984) (in Balme, 1985) described a spore from a Marattiales fern that Balme (1985) has compared to the *Leschikisporis* spp.

Thymospora spp.

Pant and Misra (1976) in Balme (1995) described a spore from a fern that Balme (1995) has placed in the *Thymospora* genus.

Punctatosporites walkomii

Brousicmiche (1979; in Balme 1995) describe a spore belonging to a fern parent plant. Balme (1995) places this spore in the *Punctatosporites* genus.

Duplexisporites problematica

Abbink *et al.* (2004) place this spore within the Pteridaceae ferns.

Aulisporites astigmosus

The spore coming from the cycadopsid *Williamsonianthus keuperianus* shows remarkable similarity to *Aulisporites astigmosus*. Although it is unconventional for a gymnosperm to produce a spore, *Aulisporites astigmosus* has been tentatively placed as having affinity to the bennettitales (cycadopsids) (Balme, 1995).

5.22 PLACEMENT OF PLANT GROUPS WITHIN SEGs

The botanical groups with identified constituents from this study are below described in terms of their affinity to certain SEGs, and summarised in Table 2.

MOSSES

Mosses usually prefer humid conditions, but some types rather dry environments. They can withstand long droughts and it is impossible to use Mesozoic spores to distinguish between these types (Abbink *et al.*, 2004).

However, they mostly grow near water and therefore have been assigned by Abbink *et al.* (2004) to the River SEG, but with the sidenote that they could also occur in the Lowland SEG as well. *Stereisporites* spp. has been specifically assigned to the River SEG.

CLUBMOSSES

The extant species of Lycopside (the group which includes clubmosses) mostly favour tropical conditions but can be found in temperate or occasionally polar environments (Abbink *et al.*, 2004). Abbink *et al.* (2004) have placed them by extant occurrences, but only tentatively, within the Lowland, River or Tidally-influenced SEGs. The *Uvaesporites* genus and *Neoraistrickia taylorii* have been more specifically, but still tentatively, assigned to the River SEG.

HORSETAILS

The only sporomorph from an equisetale parent plant in this study is *Calamospora tener* which, according to Abbink *et al.* (2004) belongs in the Lowland SEG.

FERNS

Ferns, which generally prefer humid and warm conditions, have been assigned to the Lowland or River SEG by Abbink *et al.* (2004). According to these authors, this association is especially strong for *Baculatisporites* and *Punctatisporites*. *Duplexisporites problematicus* is listed specifically in the Lowland SEG.

SEED FERNS (PTERIDOPHYTES)

Abbink *et al.* (2004) do not assign seed ferns as a group to an ecogroup. However, it has been attempted here to separately assign *Falcisporites* and *Vitreisporites* to an ecogroup each. *Vitreisporites* come from the Caytoniales group of pteridophytes (Bonis and Kuerschner, 2012). Since Caytoniales prefer deltaic environments, they have been assigned by Abbink *et al.* (2004) to the River SEG. Apart from this and one other taxa, the authors group most alele bisaccates into the Upland SEG. However, *Falcisporites* has an affinity to Peltasperms (Balme, 1995), which have a habitat described by DiMichele, Phillips & Pfefferkorn, (2006). While acknowledging that the Peltasperms are a highly diverse group, DiMichele *et al.* (2006) describe their broad preferences to be stream-side, periodically dry to quite dry substrate. Judging by this description, the Peltasperms environment would be best encompassed in the Lowland SEG.

GINKGOALES, CYCADALES, BENNETTITALES

These plants generally grew in lowland environments so the pollen for these has been grouped in the Lowland SEG (Abbink *et al.* 2004), and the main constituent of this botanical group in this study (*Chasmatosporites*) is specifically listed in the Lowland group.

TABLE 2: SUMMARY OF SPOROMORPHS FOUND IN THIS STUDY ASSIGNED TO A PRODUCER AND A SEG

Producer	Sporomorph	SEG
Seed ferns	<i>Falcisporites australis</i>	Lowland
	<i>Vitreisporites signatus</i>	River
Conifers	<i>Classopollis meyeriana</i>	Coastal
	<i>Platysaccus queenslandii</i>	Upland
	<i>Enzonalsporites densus</i>	Upland
	<i>Enzonalsporites vigens</i>	Upland
Cycadales, bennettitales	<i>Chasmatosporites</i> sp. A	Lowland
	<i>Aulisporites astigosus</i>	Lowland
Gnetale	<i>Ephedripites macistriatus (gnetale)</i>	River
Seed fern or conifer	<i>Samaropollenites Speciosus</i>	Upland?
Cycadophyta, Ginkgoales or Peltaspermales	<i>Cycadopites follicularis</i>	Lowland
Other or unspecified gymnosperms	<i>Ashmoripollis reducta</i>	Upland?
	<i>Elongatosaccites</i> sp. c.f. <i>E. triassicus</i>	Upland?
	<i>Hamiapollenites insculptus</i>	Upland?
	<i>Minutosaccus crenulatus</i>	Upland?
Bryophytes	<i>Stereisporites</i> spp.	River
	<i>Polycingulatisporites mooniensis</i>	River (or possibly Lowland)
Horsetails	<i>Calamospora tener</i>	Lowland
Clubmosses	<i>Anapiculatisporites pristidentatus</i>	Lowland, River or Tidally influenced
	<i>Uvaesporites verrucosus</i>	River?

	<i>Leptolepidites argenteaeformis</i>	Lowland, River or Tidally influenced
	<i>Neoraistrickia taylorii</i>	River
	<i>Playfordiaspora velata</i>	Lowland, River or Tidally influenced
Ferns	<i>Punctatisporites</i> spp.	River or Lowland
	<i>Dictyophyllidites</i> spp.	River or Lowland
	<i>Apiculatisporis globosus</i>	River or Lowland
	<i>Baculatisporites</i> spp.	River or Lowland
	<i>Converrucosisporites cameronii</i>	River or Lowland
	<i>Lophotriletes bauhinae</i> c.f.	River or Lowland
	<i>Leschikisporis</i> spp.	River or Lowland
	<i>Thymospora</i> spp.	River or Lowland
	<i>Punctatosporites walkomii</i>	River or Lowland
	<i>Duplexisporites problematicus</i>	Lowland

CONIFERS

While the *Classopollis* spp. is specifically listed in the Coastal SEG, the rest of the sporomorphs from conifers in this study are less certainly assigned, although Vakhrameev (1991, in Abbink *et al.* 2004) states that in general, conifers in the Mesozoic would have inhabited upland forests, and thus are placed in the Upland SEG in this report. *Samaropollenites speciosus*, which was assigned to either a conifer or seed fern parent plant, is here tentatively placed in the Upland SEG. This has been judged as the most apt placement since conifers have been placed here, and if it is not a conifer, it is still an alete bisaccate pollen, most of which, according to Abbink *et al.* (2004), belong in the Upland SEG. Since *Ashmoripollis reducta*, *Elongatosaccites* spp., *Hamiapollenites insculptus* and *Minutosaccus crenulatus* are also alete bisaccates, and since no specific information has been found on their botanical affinities, they are here also tentatively placed within the Upland SEG.

GNETALES

Crane and Upchurch (1987) describe the megafossil *Drewria potomacensis* genus from the Lower Cretaceous. As this is one of the only definite Mesozoic megafossil records of gnetales, their interpretation of its habitat is here used as the rule for all Mesozoic gnetales. They describe the palaeoecology of this low-lying herbaceous

or shrubby plant to be streamside, so the gnetales, of which *Ephedripites macistriatus* is the sole representative in this research, are placed in the River SEG in this report.

CHANGES BETWEEN SEGS.

Originally, a diagram was made with the sporomorphs grouped under either a certain (eg. Lowland) or uncertain (eg. Lowland, River or Tidally Influenced) SEG (Figure 10). This diagram was then used to compare the certain and uncertain SEGs in order to test whether a pattern was present which could aid in more definite classification of those plant groups with more than one possible habitat. Patterns were identified, especially strongly between 'Lowland, River or Tidally Influenced' and 'River', but also between 'River or Lowland' and 'River'. (See discussion of patterns in caption to Figure 10). In this way, the SEG groups were confined to Coastal, Lowland, River, Upland and Unknown (Figure 11).

Since *Falcisporites australis* has been placed in the Lowland SEG, this SEG is dominant throughout the section. The River SEG is the next most influential, a large number of ferns having been placed here. Upland has an approximate 10% influence, represented mostly by alele bisaccates. The Coastal SEG is only represented by *Classopollis Meyeriana*, and appears sporadically, at very low contributions. Since the Coastal SEG is very low in its contribution, and the Tidally Influenced SEG is absent, the Lowland SEG cannot be plotted against these to determine sea level changes. Instead, the Lowland SEG has been compared to the River and Upland SEGs, which are much less prone to changes from sea level variations, and hence will provide a stable comparative to the fluctuating Lowland SEG.

The lower part of the section is fairly constant, the most significant being two small peaks in the Upland SEG between 2351m and 2344m either side of a trough, which is compensated by a small peak in the Lowland SEG. From 2330m down, an increase in the base level of the Lowland SEG can be seen, while the River SEG decreases (accentuated with green lines in Figure 11). At 2327m, a trough in the River SEG corresponds to a peak in the Lowland and a small peak in the Upland SEG. At this point there is one of only two occurrences of the Coastal SEG.

From this point, the three SEGs remain fairly constant until 2318m, where a peak in the Lowland SEG and trough in both River and Upland are followed by a decrease to a sharp trough in the Lowland and an increase to a sharp peak in the River SEG (circled in green). From here, the Lowland SEG recovers so that it reaches its highest point at the top of the section, and the River SEG decreases sharply, while the Upland SEG remains fairly constant.

CHANGES WITHIN SEGS

Because of the varying plant strategies within the different SEGs, only some experience internal shifts with changing climatic conditions. Lowland is the SEG with the assemblage most subject to internal changes, and the

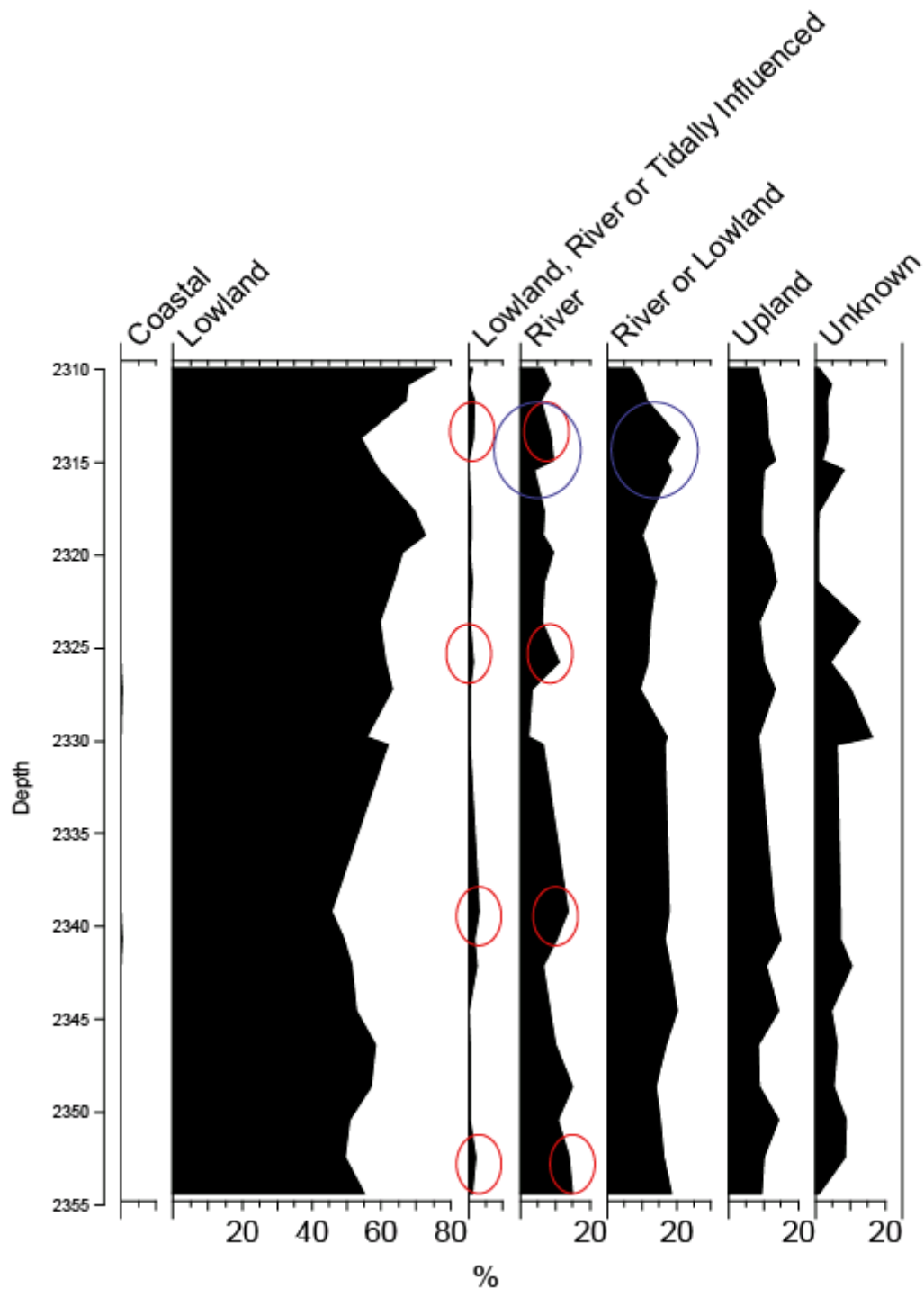


FIGURE 10: SPOROMORPHS GROUPED INTO CERTAIN OR UNCERTAIN SPOROMORPH ECO-GROUPS. THE 'LOWLAND, RIVER OR TIDALLY INFLUENCED' SEG SHOWS STRONG ALIGNMENT WITH THE 'RIVER' SEG, BOTH SHOWING FOUR PATCHES OF HEIGHTENED INFLUENCE (CIRCLED IN RED, FROM 2354M, 2342M, 2327M AND 2315M). THE 'RIVER OR LOWLAND' IS LESS STRONGLY CORRELATED BUT STILL SHOWS A CLOSER ALIGNMENT TO 'RIVER' THAN 'LOWLAND', SINCE IT EXPERIENCES A BASE LEVEL DECREASE OVER THE SECTION AND INCREASES AROUND 2315M (PURPLE CIRCLES) WHERE THERE IS A SHARP DECREASE IN THE 'LOWLAND' SEG, BUT A SLIGHT INCREASE IN THE 'RIVER' SEG. (VERTICAL SCALE IN METRES)

Upland SEG is also internally altered, but the River SEG is not (Abbink *et al.*, 2004). Therefore, the variations in the results from the Lowland (Figure 12) and Upland (Figure 13) SEGs will now be explored.

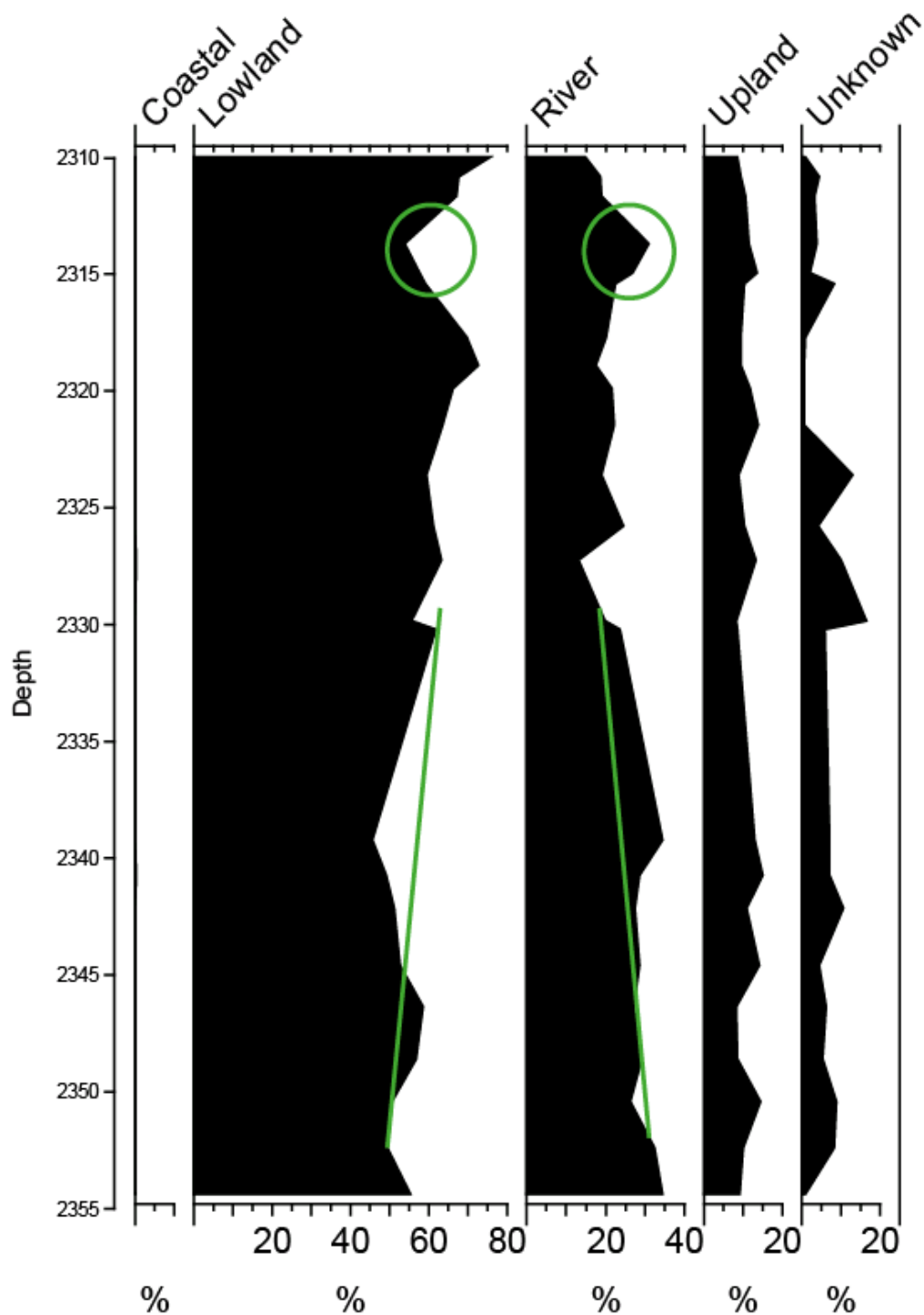


FIGURE 11: GRAPH COMPARING SEG DOMINANCE. MAJOR SHIFTS CIRCLED OR FOLLOWED IN GREEN. (VERTICAL SCALE IN METRES)

LOWLAND

Overall, the horsetails plant group (exclusively *Calamospora tener*) is subject to a base level decrease over the section. At the base, they make up 20% of the Lowland SEG, but by the top represent less than 5%. They peak

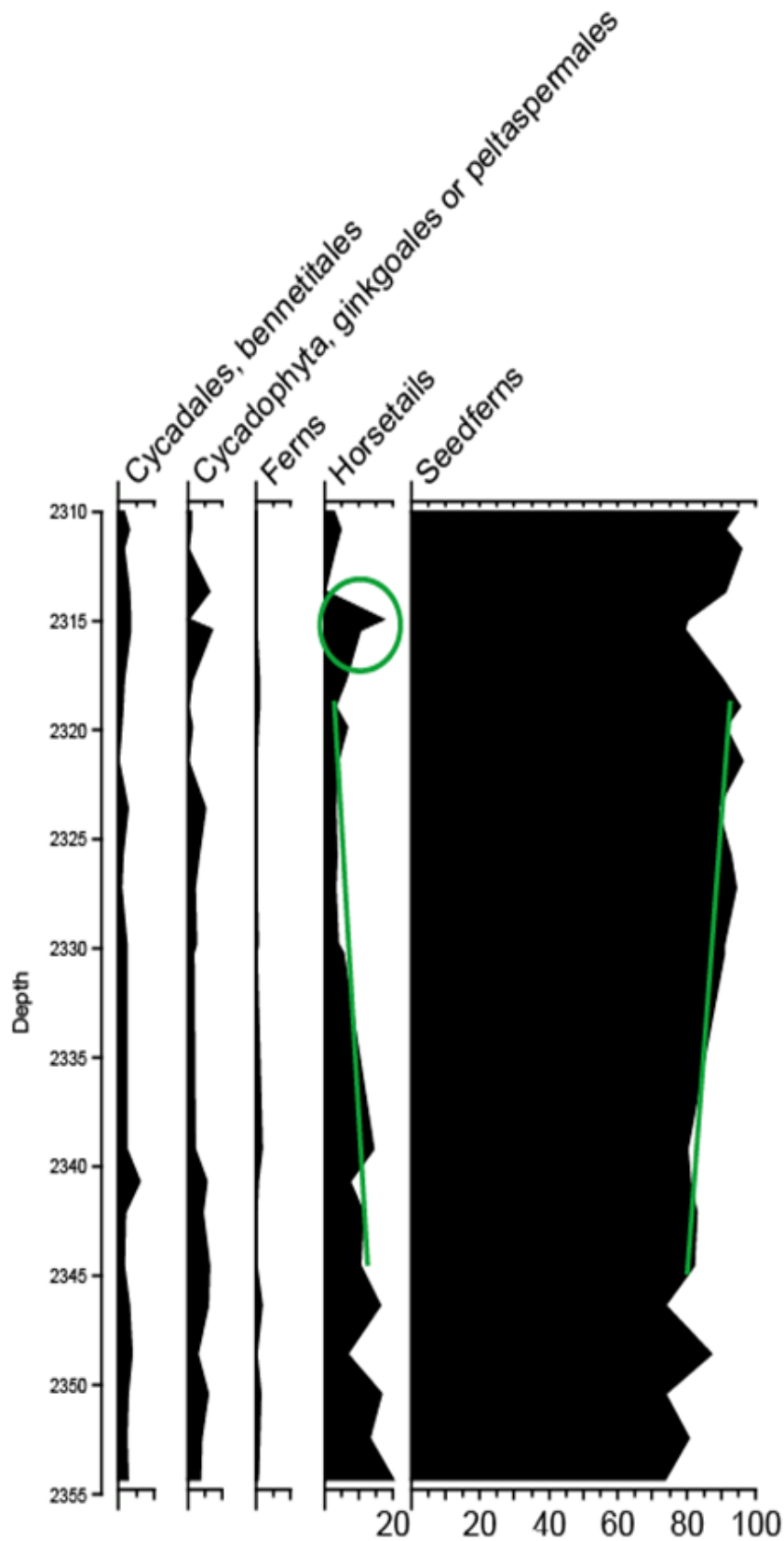


FIGURE 12: CHANGES BETWEEN THE PLANT GROUPS WITHIN THE LOWLAND SEG WITH MAJOR SHIFTS ACCENTUATED IN GREEN (VERTICAL SCALE IN METRES)

twice near the bottom of the section, at 2351m and 2347m. An isolated peak occurs at 2316m, when they constitute between 15 and 20% of the SEG. In contrast, the Lowland seedferns (exclusively *Falcisporites australis*) experience a base level increase over the section, starting at about 75%, and reaching ~95% at the

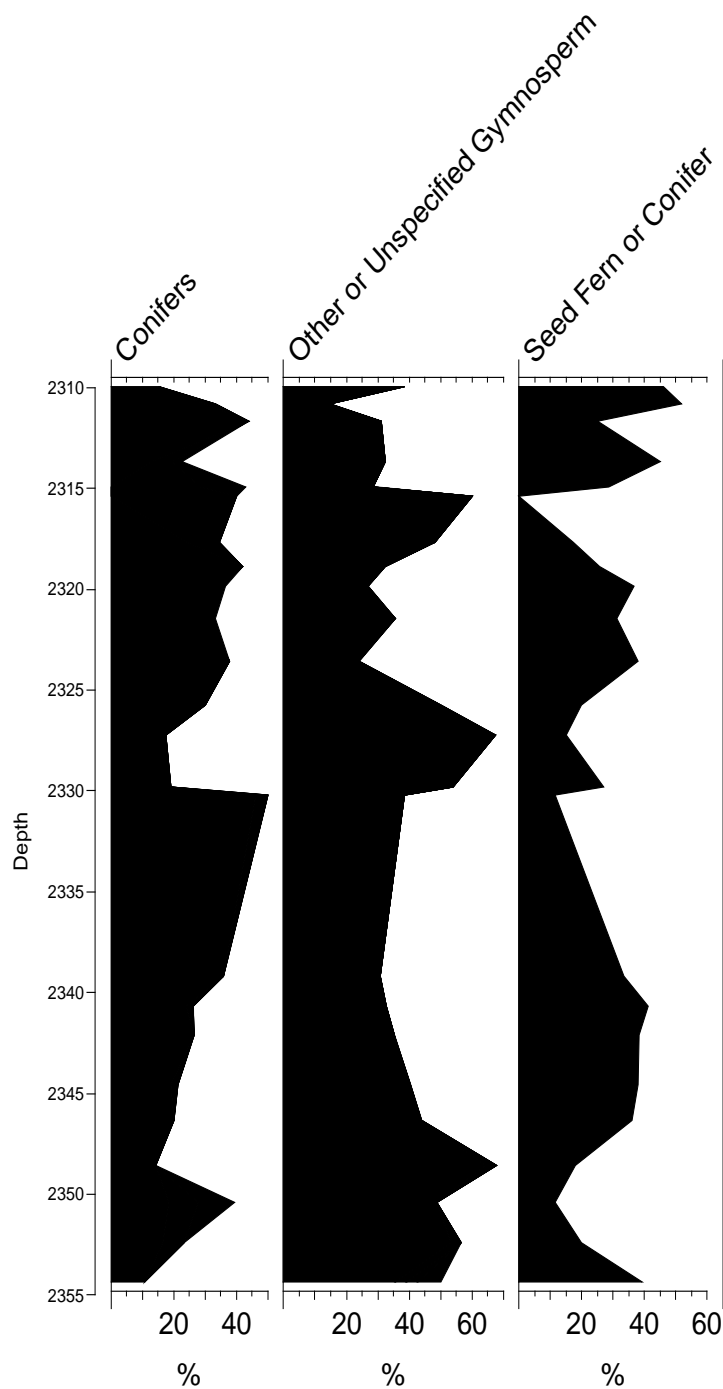


FIGURE 13: PLANT GROUPS WITHIN THE UPLAND SEG (VERTICAL SCALE IN METRES)

top of the section. They have a peak at 2348m, and an isolated trough at 2316m, correlating with the peak of horsetails.

The ferns in the Lowland SEG are low numbered but are slightly less common at the top of the section. Cycadales and bennetitaes and cycadophyta, ginkgoales or peltaspermales experience little change over the section, although the base level of the latter does decrease slightly towards the top, and there are two sudden peaks surrounding a trough at 2315m in the cycadophyta, ginkgoales or peltaspermales.

UPLAND

The Upland SEG is more difficult to draw results from due to the uncertainty in the plant groups it includes. Conifers are one clear distinction, however the ambiguity of the other two groups: 'Other or unspecified gymnosperm' and 'seed fern or conifer' means that the Conifer group is probably not complete. The results appear erratic which may also be an indication of the false separation of the graphs. Since this is the furthest it has been possible to get in terms of confining the plant groups, the climate interpretation from changes within SEGs will be left to those within the much clearer Lowland SEG.

6. DISCUSSION

6.1 PALYNOFACIES

An interpretation of the palynofacies results is provided in Figure 14.

ZONE 1

The presence (albeit small) of dinocysts in this zone signifies a marine environment. However, the dominance of phytoclasts suggests proximity to a terrestrial source. Hence a marginal marine facies is decided. The peak of bisaccates/trough of phytoclasts mid zone could correspond to a reduction in fluvial influence at that time.

ZONE 2

Since Zone 2 is devoid of dinocysts and acritarchs, it is determined to be non-marine. Since the spore-pollen diversity continues to be high, this sample is thought to be deposited in a floodplain setting. The increase in the charcoal component of the phytoclasts in the upper half of this zone is unlikely to be due to a facies change, since the proportions of phytoclasts as a group remains fairly similar. Rather, it is likely that the increase of charcoal in the sediment is due to an increase in its supply. Greater numbers of forest fires are therefore likely to be the reason behind the observed increase. This could in turn suggest a drying of the continent.

ZONE 3

The presence of dinoflagellate cysts and acritarchs in this zone means the depositional setting was again marginal marine. While phytoclasts are still dominant, their decrease and the corresponding increase in terrestrial palynomorphs could reflect a shift towards lower vegetation levels, or simply a reduction in fluvial input. The spore:bisaccates ratio is at its lowest here, possibly reflecting the parent vegetation's reaction to the drying climate, as suggested by the increased charcoal observed in Zone 2. The drying climate could also result in lower vegetation levels, supporting the former interpretation of the decrease in phytoclasts.

ZONE 4

The overwhelming dominance of dinocysts in this zone suggests it was deposited on a flooding surface. The proportion of dinocysts is too high for this zone to be marginal marine. On a stylised diagram from Tyson 1989 (in Tyson 1993) (Figure 5), it can be placed within a mud-dominated oxic shelf ('distal shelf'). The description given by Tyson for this facies type matches well with the results since dinocysts are the dominant microplankton and the spore: bisaccate ratio is higher than in other zones, but still low-moderate. It is counter-intuitive that the spore:bisaccate ratio increases in what appears to be a flooding surface, since a sea level rise corresponds with a distal shift of the depositional setting. As discussed, dilution of spores and non-bisaccate pollen should then reduce their relative abundance compared to the morphologically tailored bisaccates. An explanation must be sought in the source of the POM, and this will be explored within the SEG discussion.

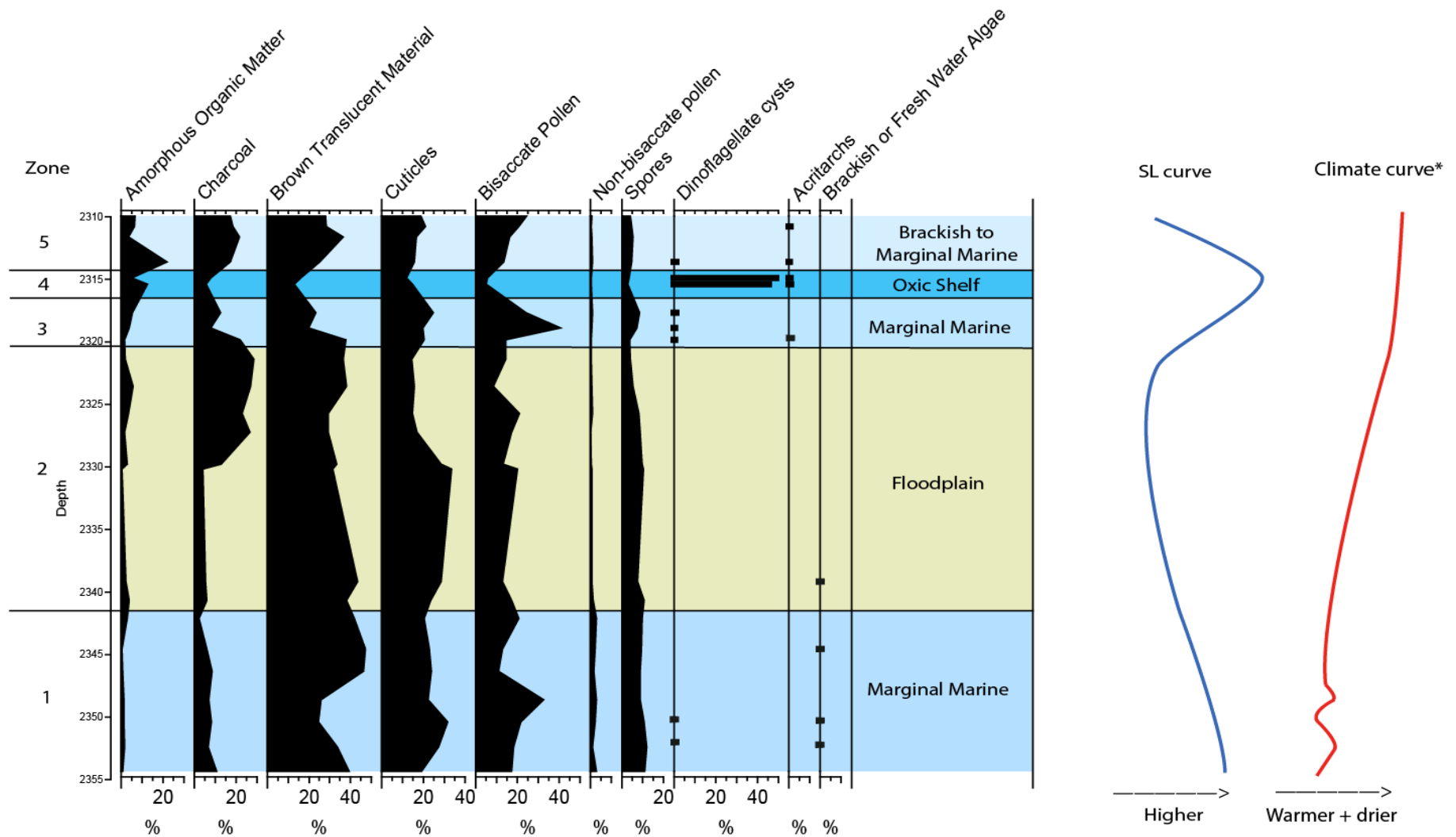


FIGURE 14: PALYNOFACIES DIAGRAM WITH FACIES INTERPRETATION AND IMPLIED SEA LEVEL AND CLIMATE CURVE TO THE RIGHT. *CLIMATE CURVE INFERRED FROM SEG RESULTS (FIGURE 15) (VERTICAL SCALE IN METRES)

ZONE 5

The presence of dinoflagellates in this zone means that it represents a marine environment. However, the comparative proportions of dinoflagellates with acritarchs mean brackish water is playing a role in inhibiting the dinocysts distribution. Therefore the setting was brackish to marginal marine. Phytoclasts were once again dominant, suggesting a recovery of vegetation and a high proximity to the terrestrial source. The peak in AOM at the base of this zone could suggest that the bottom waters were somewhat reducing.

PALYNOFACIES SHIFTS

Altogether, the palynofacies results suggest the section begins with sediments deposited in a marginal marine setting. A relative sea level fall then shifted the setting to floodplain. During this time, increased forest fires are evident from the increased proportion of charcoal, and could suggest a drying climate that is reflected in a trough in the spores:bisaccates ratio. From here, a sea level rise means the depositional environment was once more marginal marine. A flooding surface at 2317m reflects a large sea level rise, the depositional setting shifting from marginal marine to an oxic shelf. A brackish to marginal marine setting with less oxic bottom waters and a high proximity to a terrestrial source replaced this as sea level fell again.

To make the interpretation of sea level change as thorough as possible in this study, the information given by the results obtained by the palynofacies analysis will be later discussed and compared with the variations in SEG dominance (In Section 6.2).

6.2 SPOROMORPH ECO GROUPS

SEA LEVEL CHANGE

The first shift in the SEG diagram (Figure 15) with sufficient magnitude to be significant is the increase in base level of the Lowland SEG and the decrease in base level of the River SEG over the 9 metre sample gap between 2339 and 2330m. It is likely then, that the unsampled section would record sediments from a slowly regressing sea, since the area available for the Lowland ecological niche appears to be increasing.

This result corresponds to the palynofacies results, which suggest a marginal marine environment at the base of the section is replaced upwards by a non-marine floodplain. Another possibility could be that the results are biased by the vast majority of *Falcisporites australis* making up the Lowland SEG, and its increase could reflect the same climate shift discussed in the palynofacies results towards a drier climate favouring seed producers.

The decrease in the Lowland SEG and increase in the River SEG, beginning at 2318m, is the next sustained change between SEGs. The sharpness of the graphs here suggests a rather rapid sea level rise as the area for the Lowland SEG is submerged. This result is in support of the palynofacies results, where an influx of dinocysts suggests a flooding surface at this level. The confusing result of the increasing spore:bisaccate ratio at a

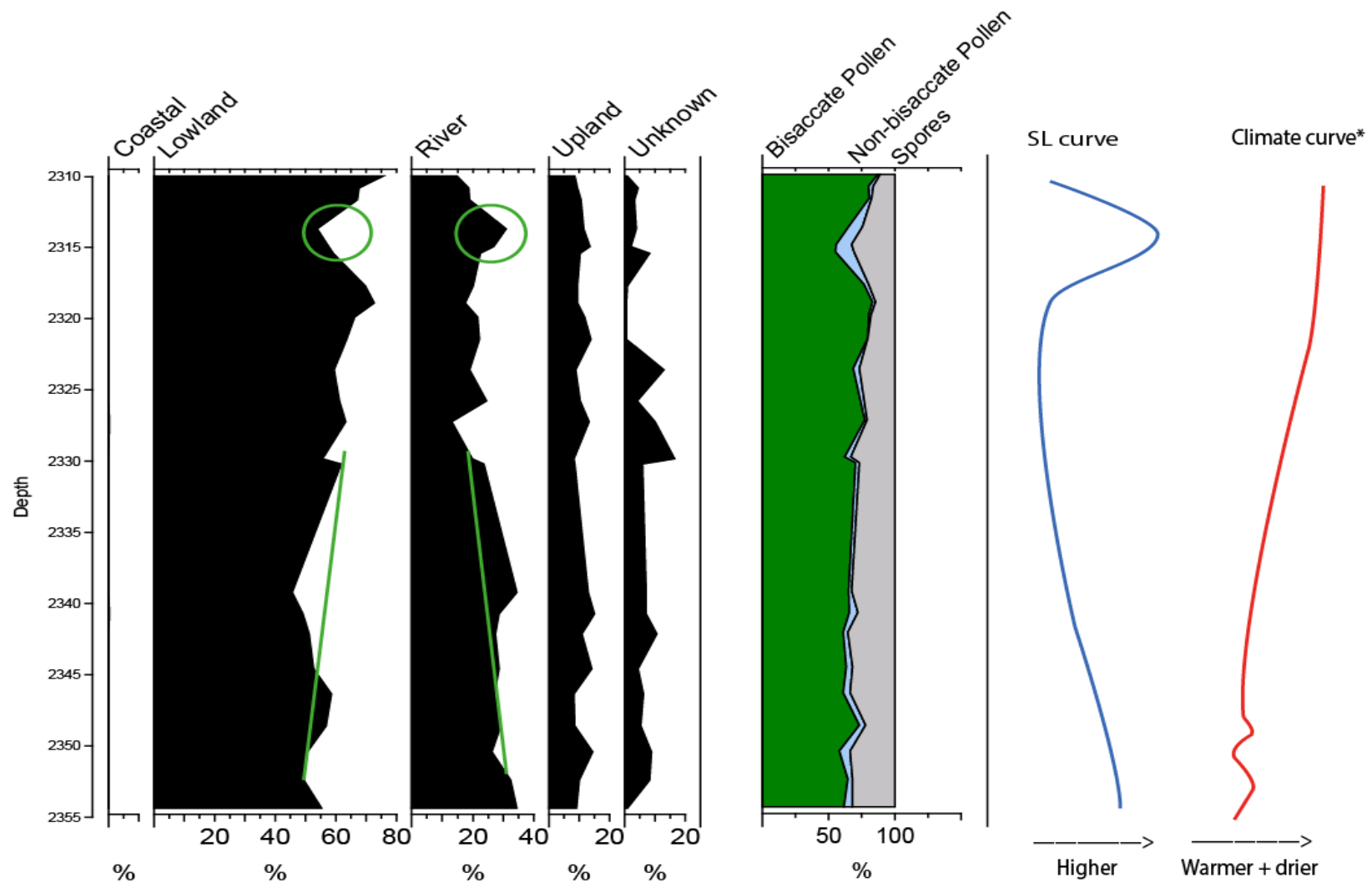


FIGURE 15: GRAPH COMPARING SEG DOMINANCE THROUGHOUT THE SECTION AND RATIOS OF BISACCATES, NON-BISACCATES AND SPORES. STRAIGHT GREEN LINES INDICATE THE INFERRED SLOW SEA LEVEL FALL AS THE LOWLAND SEG INCREASES AND THE RIVER SEG INCREASES. GREEN CIRCLES HIGHLIGHT THE DECREASE OF LOWLAND AND INCREASE OF RIVER FLORA WITH THE MARINE INCURSION. INFERRED SEA LEVEL CURVE (DERIVED FROM PALYNOFACIES AND THIS DIAGRAM) AND CLIMATE CURVE ON THE RIGHT. *CLIMATE CURVE INFERRED FROM FIGURE 13. VERTICAL SCALE IN METRES.

flooding surface can therefore be explained at the source by the decrease in the Lowland vegetation, mainly represented by the Peltasperm bearing *Falcisporites australis*.

The very low proportions or complete absence of the Coastal SEG could indicate an eco-system without vegetation. However, knowing that coastal vegetation bearing *Classopollis* pollen becomes much more dominant after the Late Triassic (Backhouse and Balme, 2002), it is more likely that this ecological niche was covered by other plants that can also grow, and have here been placed, in the Lowland or River SEGs.

CLIMATE VARIATION

Since in the Lowland SEG, the horsetails group is solely composed of *Calamospora tener*, the seedferns of *Falcisporites australis*, and the ferns of *Duplexisporites problematicus*, the preferences of these sporomorphs can be used in this interpretation. According to Abbink *et al.* (2004), a shift towards a higher proportion of *Calamospora* spp. indicates a change to wetter and warmer climate conditions. On the other hand, in their NW Australian study of the Triassic-Jurassic, Grice *et al.* (2005), note the synchronised appearance of abundant *Falcisporites australis* in samples containing combustion markers indicate their preference for a warm and dry climate. *Duplexisporites problematicus* marks a transition to drier and warmer conditions.

The notable and prolonged changes of the seedferns and horsetails in the Lowland SEG (Figure 16), therefore point towards a drying of the continent, as *Falcisporites australis* and *Calamospora tener* increase and decrease respectively. The results from *Duplexisporites problematicus* contradict this, but since its overall contribution is very low, this could be accounted for by bias within the counting. This result is consistent with the palynofacies results, where a substantially higher percentage of charcoal is present in the upper part of the section. The alternating peaks in horsetails and seedferns are interpreted to be due to small oscillations in the climate.

Above this, the recovery of the Lowland SEG, accompanied by the decrease of the River SEG suggests that the sea level then fell. The results from the AOM in the palynofacies results support this, as they return to low levels after a large peak just after the flooding surface, however the phytoclast results are less clear. They initially increase after the flooding surface, in agreement with a regression, but they drop off in the upper two samples of the section. This may be due to a reduction in the fluvial input, however.

Although within the diagram comparing plant groups within a SEG, the peak of horsetails at 2315m, corresponding to the trough in seedferns and cycadophyta, ginkgoales or peltaspermales, is probably due to sea level change rather than climate variation. As an ingression occurs, the fresh water within rivers is pushed landwards and it is common therefore for a river to expand in breadth (W. Kuerschner pers. comm, April 16th). The habitat for horsetails, lowland floodplains, is hence magnified, so within the reducing Lowland niche area, the horsetails habitat is increased.

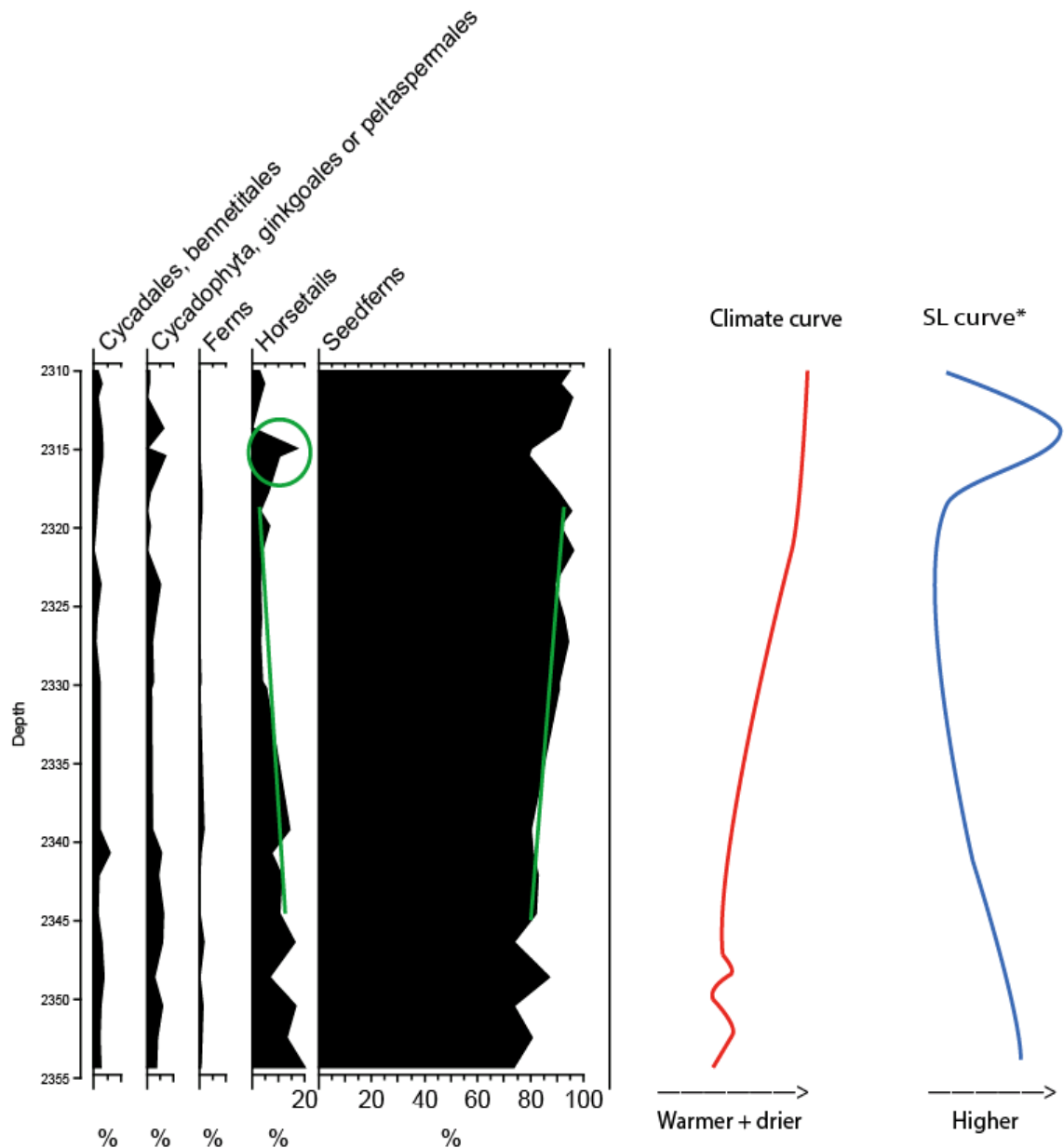


FIGURE 16: PLANT GROUPS WITHIN THE LOWLAND SEG. GREEN LINES HIGHLIGHT THE BASE LEVEL DECREASE OF HORSETAILS AND INCREASE OF SEEDFERNS. GREEN CIRCLE INDICATES THE PEAK IN HORSETAILS WHICH, ALONG WITH THE CORRESPONDING TROUGHS IN OTHER SEGS, HAS BEEN EXPLAINED BY SEA LEVEL, RATHER THAN CLIMATE CHANGES. INFERRED CLIMATE CURVE AND SL CURVE ON THE RIGHT. *SL CURVE DERIVED FROM FIGURES 13 AND 14 IN PALYNOFACIES AND SEG DISCUSSIONS. VERTICAL SCALE IN METRES.

Altogether, the SEG results point towards an initially oscillating climate with a very slow sea level fall, followed by a warming and drying climate recorded over 25m of sedimentation as sea level dropped slightly faster. The SEGs suggest that by 2315m, the climate had mostly levelled, but here a large sea level rise occurred but was quickly reversed at 2314m.

7. ZONATION

In this research, *M. crenulatus* was present only at the base of the zone, *Aulisporites astigmosus* was extremely rare and *C. stonei* and *A. banksii* were not found. These four taxa are distinctive in appearance and consequently it is unlikely that they were present but overlooked. *E. macistriatus* is rare at the base of the studied section, but becomes more common towards the top. The algal species *Bartenia* is present but rare and in very low counts. *F. australis* dominates. *Thymospora* and *Enzonalosporites* spp. are consistent and common, and *Leschikisporis* spp. is consistent but in low counts. Despite the inconsistencies, the *M. crenulatus* Zone was considered the most fitting for the samples in this study. It is suggested that the absence of some expected taxa is due to facies regulation, as according to Backhouse and Balme (2002), the Middle *M. crenulatus* Zone is highly facies controlled. The placement of these samples in this zone is especially fitting when considering the microplankton zonation.

H. balmei was the overwhelmingly dominant dinocyst. The only other dinocyst present was *W. listeri*. This places the samples clearly within the *H. balmei* Microplankton zone. This information, along with the absence of *Duplicisporites* and the presence of *Ephedripites macistriatus* was, can more specifically place these samples in the Middle *M. crenulatus* subzone (See Figure 17).

7.1 BIOEVENT

Backhouse and Balme (2002) describe five high resolution subzones in the NCB sediments which they refer to as Tr units. One of these (named Bioevent 5 or Tr7Aiib) is the *H. balmei* Microplankton zone, which, as discussed above, is present in this research. This Tr unit represents a major flooding surface, reinstating fully marine conditions in the NCB for the first time since the early Triassic. With this information, the studied section can be pinpointed stratigraphically: the section between 2317m and 2314m (Zone 4, Figure 17) represents Backhouse and Balme (2002)'s Bioevent 5.

8. CONCLUSION

This study has integrated palynofacies and palynology to ascertain the vegetation, climate and sea level changes in the Late Triassic recorded in the Northern Carnarvon Basin. It has also placed the sediments of the Kentish Knock-1 well within the regional stratigraphy.

A diverse and stable palynological assemblage dominated by the bisaccate *Falcisporites australis* was found to be present at most levels; only at one interval did a flooding surface result in an assemblage dominated by dinocysts.

Palynofacies analysis was paired with the utilisation of sporomorph eco-groups to develop a rough vegetational, climatic and sea level history over the sampled section. The results indicated that deposition began in a marginal marine setting with an oscillating climate. A slow sea level fall shifted the depositional environment to a floodplain. At the same time a significant, though gradual, warming and drying of the continent, resulting in a Lowland increase of seedferns and decrease of horsetails occurred. This drying appeared to intensify with a sudden increase in charcoal, likely resulting from forest fires.

A marginal marine setting returned with a slight sea level rise, which was then accelerated with a flooding surface as an oxic shelf setting was implaced. This sea level rise meant the Lowland vegetational setting was encroached upon by the ocean, and hence lost much of its influence in the palynological assemblage. The sea retreated after less than 4m of sedimentation and the setting changed back to marginal marine with close proximity to the terrestrial source. The Lowland vegetation recovered as the low-lying planes were once again available.

Stratigraphically, the sediments can be placed in the Middle *M. crenulatus* zone from the Norian, since *E. macistriatus* was present, but *Duplicisporites* was not. The dinocyst taxa observed also aided in the pinpointing of the stratigraphy, since *H. balmei* is only present in the *H. balmei* microplankton zone, in the Middle *M. crenulatus* spore-pollen zone. The flooding surface evident in this research can be correlated with Bioevent 5 from Backhouse and Balme (2002). The presence of *Hebecysta balmei* and *Wanneria Listeria* are evidence of this.

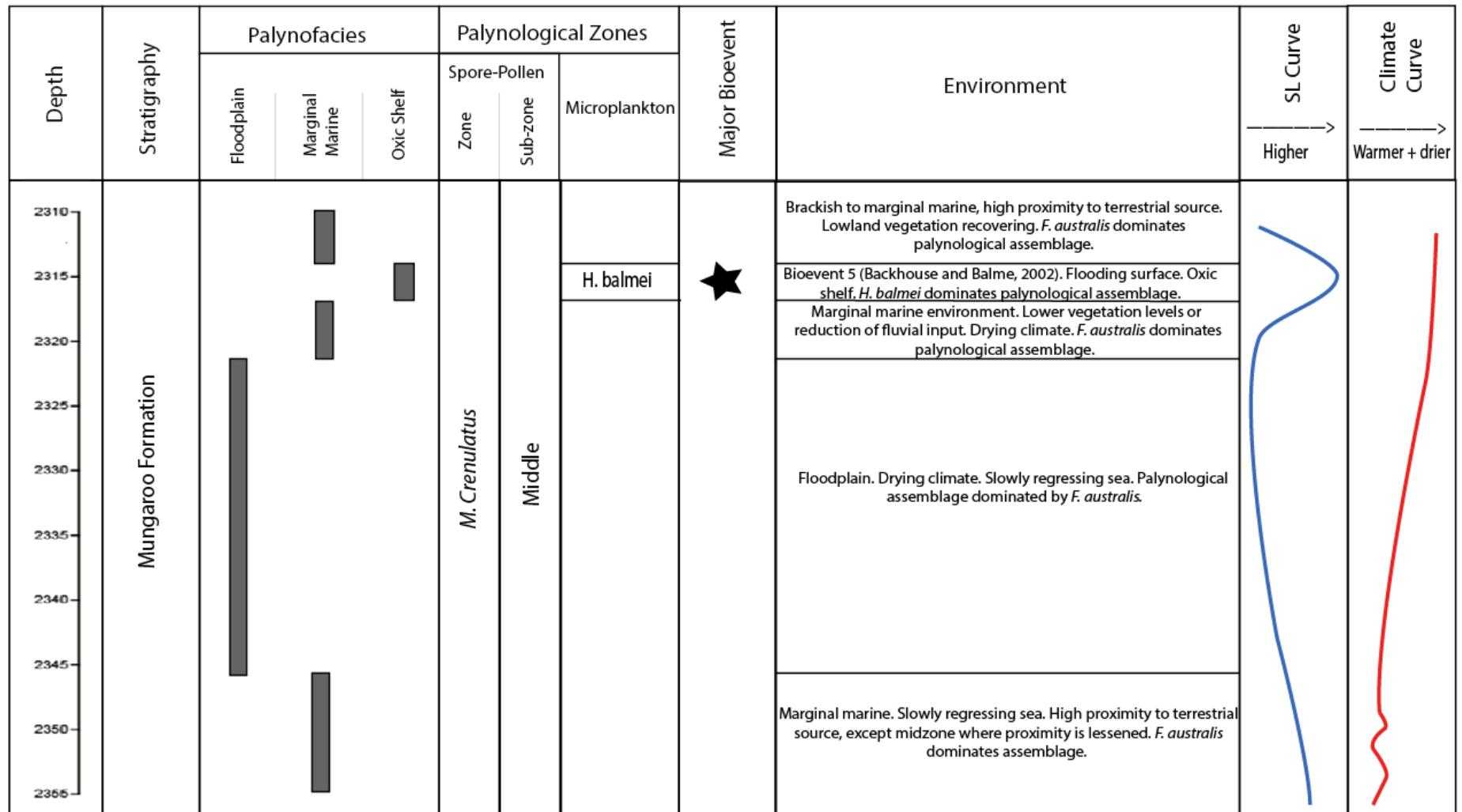


FIGURE 17: SAMPLED SEDIMENTS FROM THIS STUDY SHOWING REGIONAL STRATIGRAPHY, PALYNOFACIES, PALYNOLOGICAL ZONES, MAJOR BIOEVENTS, DEPOSITIONAL ENVIRONMENTS AND SEA LEVEL AND CLIMATE VARIATIONS WITH DEPTH (IN METRES)

9. FUTURE WORK

It is hoped that the information on sporomorphs, given their biological affinities, and their placement within sporomorph eco-groups can be useful in future studies involving large scale vegetation and climate patterns. By using this section as one of many data sets, regional vegetation patterns for the Late Triassic can be established and compared with climate and circulation models for the time. Specifically, this research could be used in close collaboration with a proposed PhD, 'Reconstructing Late Triassic vegetation patterns and environmental change: a data-model comparison', to be supervised by Wolfram Kürschner at the Department of Geosciences, University of Oslo.

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APPENDICES

APPENDIX 1. TAXA PHOTOGRAPHS. PLATE 1 - SPORES

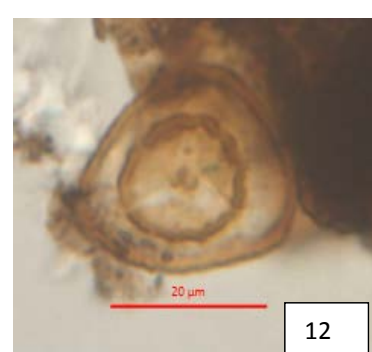
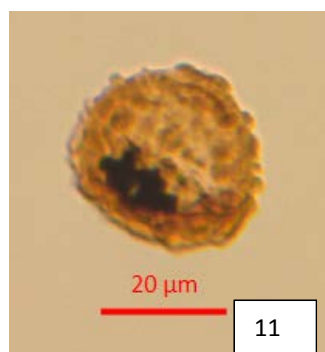
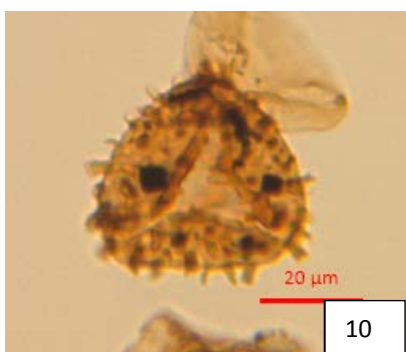
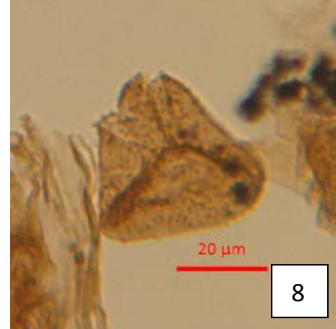
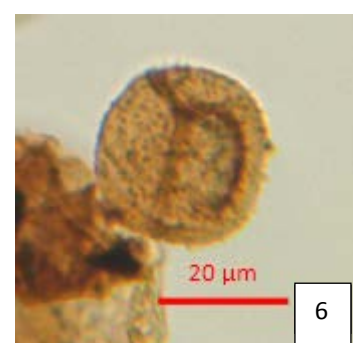
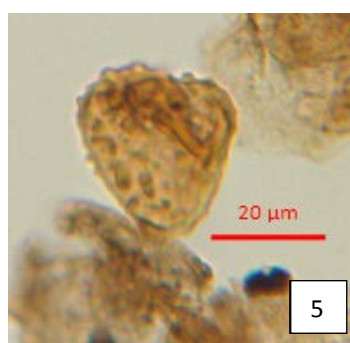
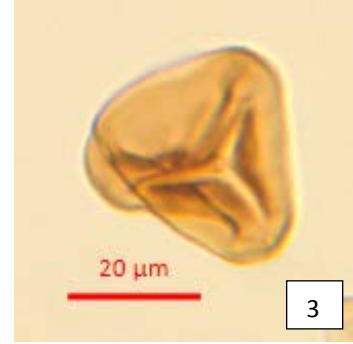
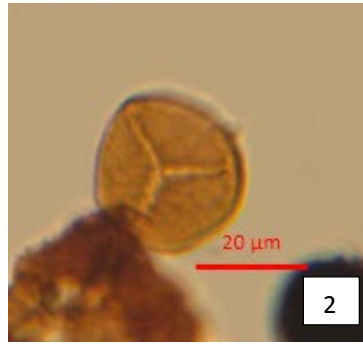


PLATE 1 – SPORES

1. *Calamospora tener*
2. *Puncatisporites* spp.
3. *Dictyophillidites harrisii*
4. *Dictyophillidites* sp. A
5. *Anapiculatisporites pristidentatus*
6. *Apiculatisporis globosus*
7. *Baculatisporites* sp. A
8. *Converrucosisporites cameronii*
9. *Lophotriletes bauhinae* c.f.
10. *Neoraistrickia taylorii*
11. *Uvaesporites verrucosus*
12. *Polycingulatisporites mooniensis*

PLATE 2 - SPORES

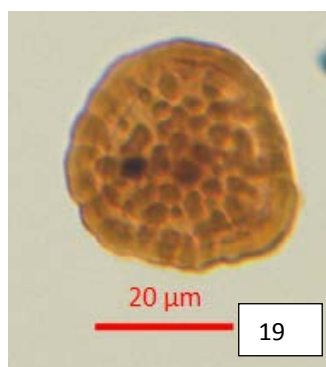
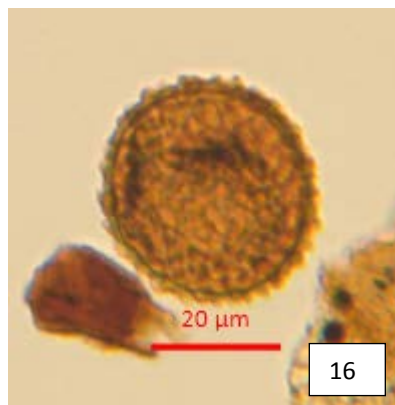


PLATE 2 – SPORES

13. *Striatella seebergensis*
14. *Stereisporites perforatus*
15. *Leschikisporis* spp.
16. *Thymospora* spp.
17. *Punctatosporites walkomii*
18. *Aulisporites astigosus*
19. *Duplexisporites problematica*

PLATE 3 - POLLEN

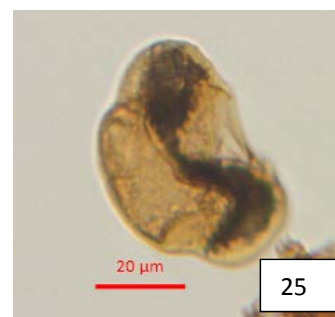
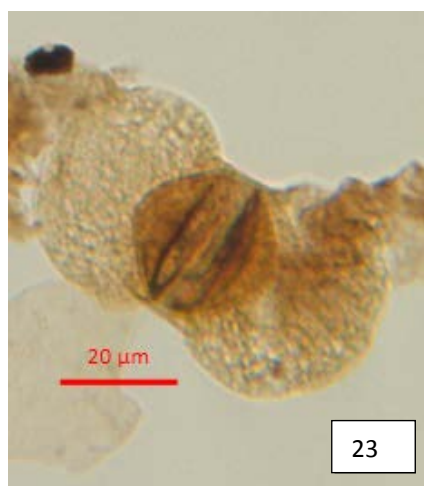


PLATE 3 – POLLEN

20. *Ashmoripollis reducta*
21. *Falcisporites australis*
22. *Vitreisporites signatus*
23. *Platysaccus queenslandii*
24. *Elongatosaccites spp.*
25. *Samaropollenites speciosus*
26. *Minutosaccus crenulatus*
27. *Enzonasporites densus*
28. *Enzonasporites vigens*

PLATE 4 - POLLEN

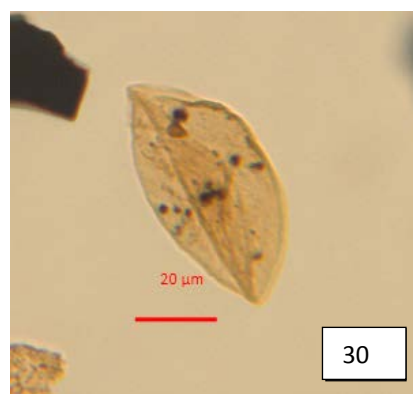
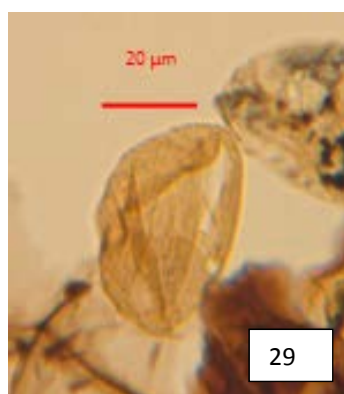


PLATE 4 – POLLEN

- 29. *Ephedripites macistriatus*
- 30. *Cycadopites follicularis*
- 31. *Chasmatosporites?* sp. A
- 32. *Classopollis meyeriana*

PLATE 5 – AQUATIC PALYNOMORPHS

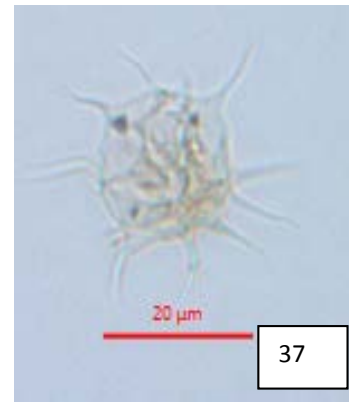
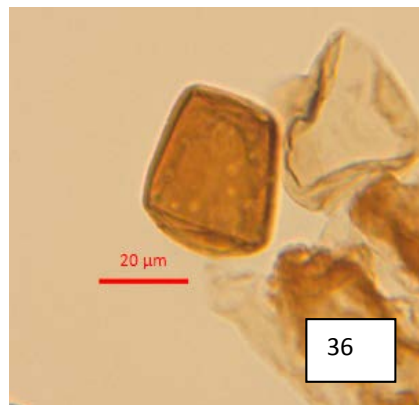
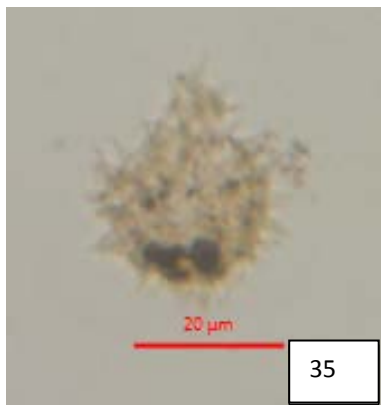


PLATE 5 – AQUATIC PALYNOMORPHS

- 33. *Hebecysta balmei*
- 34. *Wanneria listeri*?
- 35. *Multiplicisphaeridium dendroidium* c.f.
- 36. *Bartenia* spp.
- 37. *Micrhystridium* spp.

APPENDIX TWO. ABSOLUTE PALYNOLOGICAL COUNTS

Taxa \ Depth	2309,95	2310,8	2311,65	2313,65	2314,9	2315,4	2317,66	2318,9	2319,85	2321,43	2323,55	2325,75	2327,22	2329,8	2330,2	2339,2	2340,7	2342,1	2344,55	2346,35	2348,6	2350,4	2352,4	2354,35
<i>F. australis</i>	216	179	193	133	24	23	195	228	207	199	173	111	178	158	168	109	122	133	128	128	160	112	119	122
<i>A. reducta</i>	10	4	10	10	2	3	14	9	10	16	4	9	27	14	10	12	15	12	16	11	18	21	16	10
<i>V. signatus</i>	18	20	14	13	1	0	17	16	28	16	18	14	8	3	18	40	30	17	18	27	43	26	37	38
<i>S. speciosus</i>	12	14	8	14	2	0	5	8	15	14	11	4	6	7	3	13	19	13	16	9	5	5	6	11
<i>P. queenslandii</i>	4	8	14	4	0	0	7	13	14	14	11	6	7	5	12	14	11	9	8	5	4	8	5	3
<i>Elongatosaccites</i> spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
<i>H. insculptus</i>	0	0	0	0	0	0	0	1	1	0	3	1	0	0	0	0	0	0	1	0	0	0	0	1
undifferentiated bisaccate	3	7	5	3	0	1	0	0	1	0	5	0	5	7	0	6	5	7	1	2	7	2	9	0
<i>E. densus</i>	0	1	0	2	2	2	3	0	0	0	0	0	0	0	1	0	1	0	1	0	0	4	2	0
<i>E. vigens</i>	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0
<i>M. crenulatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
<i>C. meyeriana</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
<i>C. follicularis</i>	2	2	0	9	0	2	3	0	3	0	10	4	4	4	3	3	8	7	10	10	5	9	6	6
<i>Chasmatosporites</i> sp. A	3	6	3	4	1	1	3	2	1	0	5	1	1	4	4	3	9	3	2	5	7	4	3	4
<i>E. macistriatus</i>	1	2	1	11	2	2	1	4	0	0	0	0	0	3	0	1	0	1	1	0	2	3	0	3
undifferentiated non-bisaccate	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	3
<i>C. tener</i>	6	9	6	0	5	3	13	7	15	8	6	4	6	7	10	19	11	18	16	28	12	25	19	33
<i>Punctatisporites</i> spp.	1	4	1	3	0	0	1	0	1	1	3	3	1	1	2	4	4	4	5	4	0	3	0	1
<i>D. harrisii</i>	5	8	9	30	4	4	13	12	8	15	18	0	11	16	27	11	15	23	24	18	25	22	21	31
<i>Dictyophyllidites</i> sp. A	1	3	2	9	1	1	3	2	0	5	3	2	3	3	3	4	4	4	4	3	2	0	0	3
<i>A. pristidentatus</i>	2	0	1	1	0	0	1	1	1	2	1	0	1	0	1	1	3	2	0	0	0	0	1	1
<i>A. globosus</i>	7	5	6	2	0	2	9	7	15	13	2	9	3	20	11	30	19	14	18	14	8	10	17	15
<i>Baculatisporites</i> sp. A	4	4	5	0	0	1	7	3	6	6	8	2	2	7	2	0	1	1	2	3	3	4	3	4
<i>C. cameronii</i>	0	1	2	1	0	0	3	1	0	0	1	1	7	3	0	2	2	2	2	2	1	0	1	0
<i>L. bauhiniae</i> c.f.	0	0	0	0	0	0	1	1	2	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1
<i>N. taylorii</i>	1	3	3	0	0	0	3	2	4	6	2	8	2	1	2	0	1	3	5	3	2	2	5	4
<i>U. verrucosus</i>	1	0	0	2	0	0	1	0	0	2	0	1	0	1	0	5	1	5	0	0	1	0	5	0
<i>L. argenteaeformis</i>	0	0	4	0	0	0	0	1	0	0	0	0	0	0	0	3	1	1	0	0	0	1	0	0
<i>S. perforatus</i>	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0
<i>P. mooniensis</i>	1	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>D. problematica</i>	0	0	0	0	0	0	2	2	1	0	0	0	0	1	0	2	1	0	0	3	0	2	1	1
<i>P. velata</i>	0	0	0	1	0	0	0	1	1	0	1	2	0	0	0	0	0	0	0	1	1	0	0	2
<i>Leschikisporis</i> spp.	1	1	0	1	0	0	0	0	0	1	0	1	0	2	0	0	1	1	1	0	1	1	0	0
<i>Thymospora</i> spp.	2	1	8	9	4	1	1	6	8	5	5	3	1	1	5	1	5	6	3	6	3	5	5	1
<i>T. aberdarensis</i>	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	2	1	1	0
<i>P. walkomii</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
<i>A. astigosus</i>	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
undifferentiated spore	0	6	5	7	1	3	3	2	1	2	37	8	25	40	18	15	17	26	12	16	10	24	16	0
<i>W. Listeri</i> c.f.	0	0	0	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0

<i>H. balmei</i>	0	4	0	28	239	246	1	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
undifferentiated dinocyst	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
<i>Bartenia</i> spp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
<i>M. dendroidium</i> c.f.	0	2	0	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Micrystridium</i> spp.	0	0	0	3	2	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0

APPENDIX THREE. SOURCE OF BOTANICAL AFFINITIES TO IDENTIFIED TAXA.

Source Taxa	Traverse (2007d) (with original citation in brackets)	Balme (1995) (with original citation in brackets)	Bonis and Kuerschner (2012)	Raine, Mildenhall and Kennedy (2011)	Breda <i>et al.</i> (2009)	Abbink et al. (2004)
Pollen						
F.australis		peltasperm (Townrow, 1965)				
A. reducta				gymnosperm		
V. signatus			seed fern			
S. speciosus					conifer or seed fern	
P. Queenslandii			other conifer			
E. densus		conifer (Leschik 1956)				
E. vigens		conifer (Leschik 1956)				
C. meyeriana			cheirolepidaceous conifer			
C. follicularis			Cycadophyta, Ginkgoales or Peltaspermales			
Chasmatosporites sp. A			cycadophyte			
E. macistriatus			gnetale			
Spores						
C. tener			horsetail			
Punctatisporites spp.	fern (eg. Millay and Taylor, 1982, Millay 1979)					
D. harrisii		fern				
Dictyophyllidites sp. A		fern				
A. pristidentatus		fern-like botryopteridales (Millay and Taylor 1982, Good 1979, Meyen, 1987)				

A. globosus		fern (Wagner et al. 1985)				
Baculatisporites sp.A			fern			
C. Cameronii			fern			
L. bauhinae			fern			
N. taylori						lycopodiales
U. verrucosus				lycopsid		
L. argenteaeformis			clubmoss			
Stereisporites spp.			moss			
S. perforatus			moss			
Polycingulatisporites mooniensis				bryophyte		
P. velata				lycopsid		
Leschikisporis spp.		fern (Millay 1979, Millay and Taylor 1984)				
Thymospora spp.		fern (Pant and Misra 1976)				
P. walkomii		fern (Brousmiche 1983)				
Duplexisporites problematica						fern
A. astigmosus		cycadopsid				