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A palynological investigation of the offshore Cretaceous sequence on the south-west coast of South Africa

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CHAPTER 8

DISCUSSION

8.1 INTRODUCTION

The main body of the research consists of systematic, descriptive palynology where identification to species level where possible was undertaken on all trilete spores, pollen grains, algae and fungal spores encountered. Palaeoenvironmental and palaeoclimatic interpretations are based on the results of the palynofacies analysis and the pollen diagram results. Each pollen diagram is divided into zones, and each of these divisions characterize the essential changes in the palaeovegetational history of the Cape Basin. The palynomorphs present in each pollen zone determined an age range not only for the pollen zones present at each site but also for each palynomorph present. These age ranges are comparable to established stratigraphic events. The variations within the palaeoflora's over time are discussed within the context of the overall palaeoenvironment.

8.2 THE CAPE BASIN, AN EARLY CRETACEOUS STAGNANT BASIN: A COMPARISON WITH SITE DSDP 361.

Site DSDP 361 was cored to a depth of 1314 m and the oldest lithologies intersected at its base were Aptian in age (Bolli *et al*., 1975). Offshore Sites C-B1 and O-A1 were cored to a depth of 1914 m and 4398 m respectively. The oldest lithologies that were intersected for Offshore Site C-B1 was of metamorphosed quartzite basement rock of pre-Cretaceous age and Offshore Site O-A1 penetrated basalt also of pre-Cretaceous age (Figure 1.3).

Offshore Sites C-B1 and O-A1 both intersected Barremian aged lithologies but this period will not be discussed as Site DSDP 361 did not intersect it.

The Aptian of from Site DSDP 361 consisted of sapropelic shales interbedded with siltstones and massive silty-sandstones found at the base (Bolli *et al*., 1975). These sapropelic sediments are rich in pyrite and plant debris i.e. wood chips (now coal) up to 10 cm long, indicating humid conditions with luxuriant plant growth in the source area (Bolli *et al*., 1975). No mention was

made as to the presence of a noticeable limestone interval at this site during this stage. Lithologies of the same age (Aptian Stage) cored from Offshore Site C-B1 consisted of a 61 m thick interval consisting predominantly of thick glauconitic sandstone with inclusions of ligite and carbonaceous fragments at the base of this unit. This glauconitic sandstone grades into a thick claystone package with occasional siltstone and sandstone interbeds. A limestone layer, 1.5 m thick caps the claystone interval and is followed by more glauconitic sandstone. Offshore Site O-A1 consists of a 203 m thick package that begins with 86 m of interbedded sandstone and claystone with rare interbedded limestone stringers. A limestone layer, 1.5 m thick caps the interval and is followed by a 117 m thick claystone unit.

Shale and sandstones filled the Cape Basin at this time, at an incredible rate of 70 m per million years (Bolli *et al.*, 1975). Bottom water was so acidic that all but the most resistant calcareous microfossils were dissolved before burial, and as a result most of the shales are barren of microfossils (Bolli *et al*., 1975). These sediments indicate that totally stagnant euxinic conditions persisted through much of the Early Cretaceous in the Cape Basin (Bolli *et al*., 1975). Euxinic conditions result in the deposition of black carbonaceous, pyritic mud. The presence of dark grey-brown siltstone may suggest that euzinic conditions existed at Offshore Sites C-B1. Offshore Site O-A1 consists of large packages of claystone that graded from light to dark grey and dark brown-grey in places suggesting that euxinic conditions may also have affected this site to some degree.

By the end of the Aptian Stage, as the South Atlantic widened, circulation patterns allowed oxygenation of bottom water at Site DSDP 361 and Offshore Sites O-A1 and C-B1 respectively.

The Albian to Coniacian stages at Site DSDP 361 consist predominantly of shale (Bolli *et al.,* 1975) so little if any comparison to the Albian to Cenomanian stages of Offshore Sites C-B1 and O-A1 can be made.

At Offshore Site C-B1 the Albian Stage consisted of a 60 m thick sedimentary package consisting of sandstone at the base and grading into claystone. Limestone stringers can be found

higher up in the sequence. Offshore Site O-A1 consists of a 70 m thick claystone interval with common sandstone and limestone stringers.

The Cenomanian Stage at Offshore Site C-B1 includes a 90 m thick claystone layer with glauconitic sandstone lenses occurring at intervals throughout. Pyrite and limestone stringers occur at intervals throughout the sequence. No Cenomanian Stage was preserved in Offshore Site O-A1.

Offshore Site C-B1's Turonian Stage consists of a 140 m thick claystone package with limestone stringers and pyrite occurring throughout the interval. The Turonian of Offshore Site O-A1 comprises a 99 m thick claystone interval with minor sandstone and occasional limestone stringers.

The Coniacian Stage of Offshore Site C-B1 consists of a 200 m thick claystone interval whereas Offshore Site O-A1 consists of a 786 m thick claystone interval with a 1 m thick limestone layer occurring 235 m from the bottom of this unit.

By the Santonian / Campanian stages, the South Atlantic had achieved a state of inter-change of shallow and deep water masses, allowing for the normal accumulation of pelagic and calcareous sediments (Bolli *et al.*, 1975). The terriginous influx into the Cape Basin waned sharply during the Late Cretaceous, reflecting a decline in the rate of denudation of the African continent (Bolli *et al*., 1975). With this decline, the kind of sediments that accumulated at Site DSDP 361 reflect mainly the depth of the sites with respect to the carbonate-compensation depth (CCD) at any given time (Bolli *et al*., 1975). Pelagic clays, marly chalks, chalks and calcareous oozes dominate the Late Cretaceous and Cenozoic lithologies at all sites (Bolli *et al*., 1975).

The Santonian Stage of Offshore Site C-B1 consists of an 80 m thick claystone package and was extremely fossiliferous with shelly and calcareous inclusions and *Inoceramus* fragments while the Santonian Stage of Offshore Site O-A1consists almost exclusively of a 93 m thick package of claystone.

The Campanian Stage of Offshore Site C-B1 consists entirely of a 78 m claystone interval with no interbeds or stringers of any kind. At Offshore Site O-A1 the Campanian Stage includes a 30 m interval consisting of dark grey-green to olive-green claystone with glauconitic and shelly inclusions occur throughout and a single limestone stringer occurs at the top of the sequence.

Bolli *et al*., 1975 discussed the Maastrichtian and Palaeocene stages in detail however these stages are not discussed in this thesis.

The above comparison of Cape Basin sites (Site DSDP 361, Offshore Sites C-B1 and O-A1) reveal that their basic geologies are comparable, even though they are a considerable distance apart from each other and the thicknesses of individual units may vary (Offshore Site C-B1 is 243 km away from Offshore Site O-A1; Site C-B1 is 274 km away from Site 361 and Site O-A1 is 252 km from Site 361). This overall similarity in part is due to the western continental margin of South Africa having undergone most of its development early in its history and sedimentation rates on the continental shelf since the Late Cretaceous Period has been relatively uniform in the Cape Basin (Bolli *et al.,* 1975).

8.3 POLLEN ZONES

The west coast sites do not fit into any established pollen zonation so new pollen zones were established for this thesis. Zones are used to designate each Offshore Site into divisions that characterize the essential changes in the vegetational history. They are introduced here to divide the history of the palaeoflora in the Cape Basin. Offshore Site C-B1 consists of 5 zones and four subzones, while Offshore Site O-A1 is comprised of 5 zones.

South Africa has been systematically geographically isolated over a period of approximately 120 million years from the rest of Gondwana. From a palaeovegetational viewpoint, South Africa belongs to the Southern Gondwana Province, however the *Northofagus* species, one of the Southern Gondwana Provinces most important members was not found. Other South African researchers such as Scott (1971 & 1976), McLachlan & Pieterse (1978), Coetzee (1978), Scholtz (1985) and de Villiers (1997) were not able to compare their findings to the Australian and New Zealand zonations or Germeraad *et al's* (1968) tropical zonation due to the absence of this

specimen at their research sites. Most of the zonations erected rely on the presence of this species. Locally, the complexity of the geology of these two Offshore Sites makes the correlation of these zones from places to place extremely tentative. On a global scale, distance, provincialism, limited age-definition in relation to depth and problems with taxonomic identification and differentiation have all added to the difficulty of making long-distance correlations.

8.3.1 DOES THE MICROFLORA FROM OFFSHORE SITES C-B1 AND O-A1 REFLECT THE SAME FLORAL PROVINCE? – A COMPARISON OF ZONES

Two text figures (Figures 8.1 and 8.2) have been generated to aid this discussion. Each figure consists of three diagrams:

- A summary pollen diagram reflecting the most dominant taxa at each Offshore Site situated on the far left.
- A dendogram that has been generated by the Tillia program to help identify the numerous pollen zones (middle diagram).
- A Principal Components Analysis (PCA) diagram based on twenty eight selected, prominent taxa of the pollen diagrams. Data from both Offshore Sites were combined in the analysis.

The PCA values in Figures 8.1 and 8.2 are based on an analysis of the combined data for Offshore Sites C-B1 and O-A1 that allows a comparison between boreholes. Each PCA diagram consists of three curves, PC1, PC2 and PC3 with a cumulative variance of 35.4 %. The total percentage variance required to generate these two figures is included in the table that follows.

The loadings in the first PC column contrast strongly from top to bottom. The Early Cretaceous group includes *Classopollis torsus, Balmeiopsis limbatus, Classopollis* cf. *C. echinatus, Zonalapollenites dampieri* etc. (positive loadings at the top of the table) against *Osmundacidites wellmanii, Camarozonosporites cretaceous, Undulatisporites microcutis,* and *Stereisporites electoides* (negative loadings at the bottom of the table). These loadings are illustrated and discussed in Figures 8.1 and 8.2 and the pages that follow.

PRINCIPLE COMPONENT LOADINGS	**PC1**	**PC2**	**PC3**
Classopollis torsus	0.887	-0.032	-0.113
Balmeiopsis limbatus	0.182	-0.069	0.199
Classopollis cf. *C. echinatus*	0.168	-0.049	0.046
Zonalapollenites dampieri	0.120	-0.191	0.077
Biretisporites potonei	-0.051	0.098	-0.167
Cyathedites rimulis	-0.093	0.294	-0.247
Exesipollenites tumulus	-0.143	0.109	-0.266
Gleicheniidites circindites	-0.183	-0.114	0.670
Cicatricosisporites hughesii	-0.189	0.100	-0.261
Ghoshiatriletes gondwanensis	-0.191	-0.156	-0.044
Gleicheniidites peregrinus	-0.216	-0.161	0.586
Podocarpidites sp.	-0.282	0.611	-0.288
Ceratosporites echinatus	-0.349	0.164	0.129
Microcacryidites antarcticus	-0.357	0.683	-0.016
Tetracolporites ixerboides	-0.367	-0.181	-0.519
Cicatricosisporites australis	-0.379	-0.445	-0.185
Cyathedites australis	-0.425	0.090	0.037
Interulobites algoensis	-0.430	-0.176	0.339
Cyathedites minor	-0.437	0.349	0.161
Gleicheniidites rasilis	-0.439	0.456	0.461
Gleicheniidites senonicus	-0.443	-0.240	0.441
Luberisporites luberii	-0.468	0.155	-0.185
Taurocusporites reduncus	-0.486	-0.522	0.163
Microreticulatisporites parviretis	-0.504	0.720	0.042
Stereisporites electoides	-0.533	-0.419	-0.290
Undulatisporites microcutis	-0.552	-0.177	-0.091
Camarozonosporites cretaceous	-0.571	-0.478	-0.266
Osmundacidites wellmanii	-0.593	-0.151	-0.258
EIGEN VALUE	**4.6**	**3.0**	**2.3**
% VARIANCE	**16.3**	**10.8**	**8.3**
CUMULATIVE %	**16.3**	**27.1**	**35.4**

Table 8. 1. PC1, PC2 and PC3 loadings with cumulative variances based on twenty eight selected and most prominent taxa of the summary pollen diagrams.

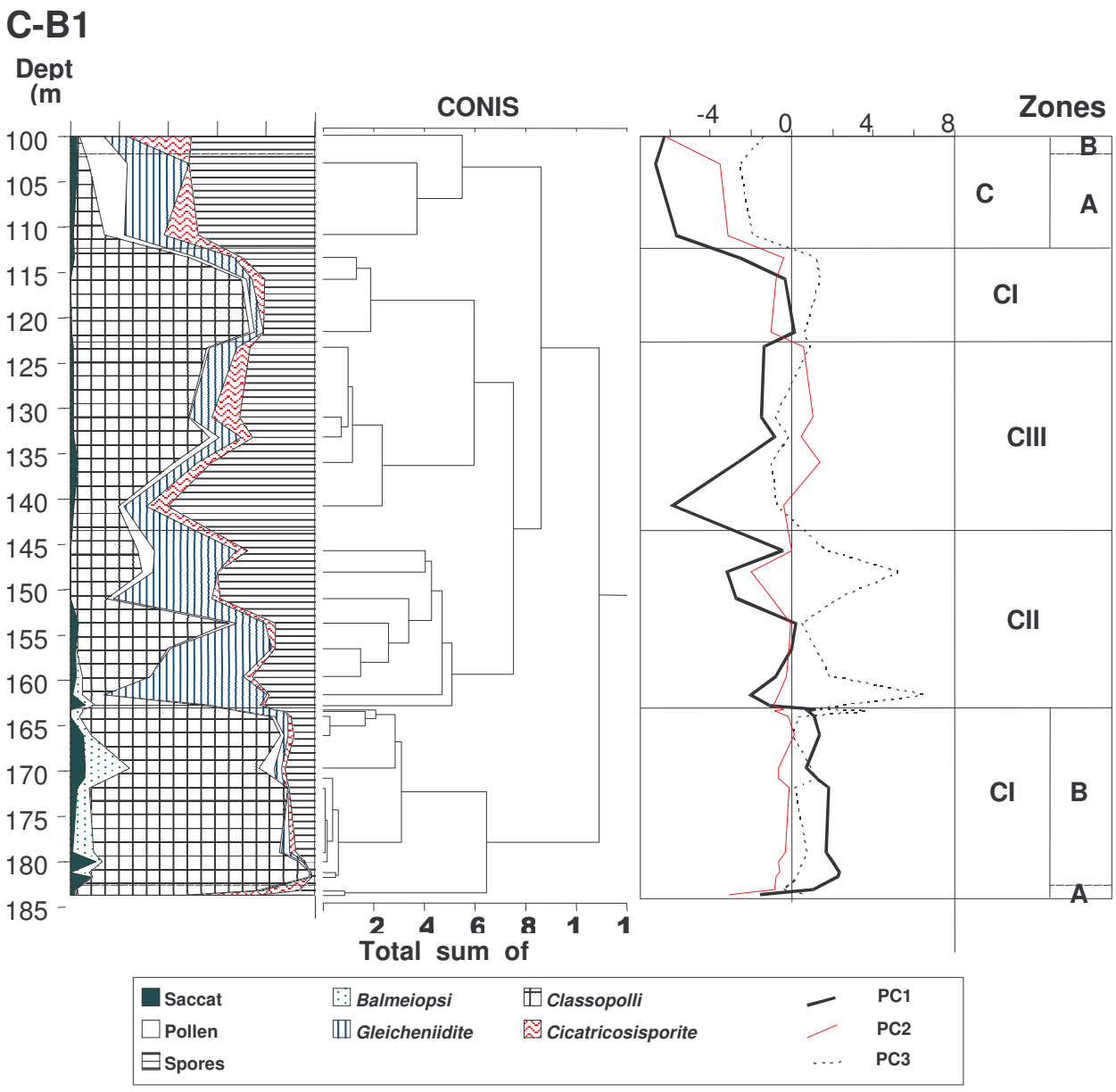


Figure 8.1. Summary pollen diagram and PCA diagram for Offshore Site C-B1.

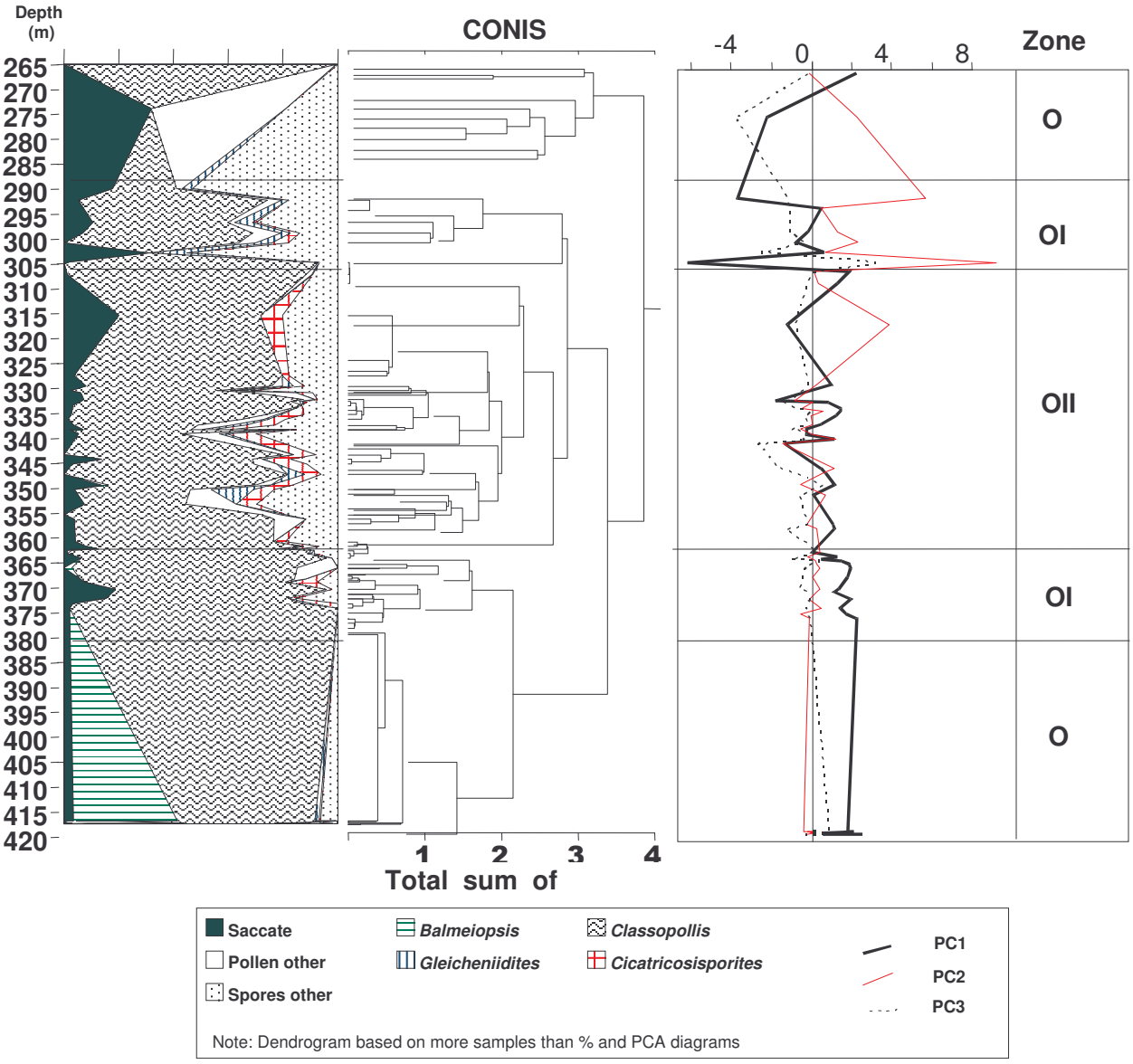


Figure 8.2. Summary pollen diagram and PCA diagram for Offshore Site O-A1.

8.3.1.1 COMPARING ZONES CI (INCLUDES SUBZONES CI - A AND CI - B) AND ZONE OI

Zones CI and OI both represent the Barremian to start of the Aptian stages and both zones come to a close during the Aptian stage either before or after the Aptian regressive event.

Both these zones consist of Early Cretaceous vegetation that represents the Southern Gondwana microfloral province. Gymnosperms continue to dominate the palaeoflora with *Balmeiopsis limbatus* and *Classopollis torsus* dominating the microflora at both offshore sites and this can be seen in the summary pollen diagrams. Ferns and mosses still occur in greater abundance than the conifers do. The most prevalent fern and moss species in these zones are *Cicatricosisporites australiensis, Cyathedites minor, Gleicheniidites senonicus* and *Interulobites algoensis.*

Zone C-I's PCA diagram consists of curves PC-1 and PC-3 both weighing positively while curve PC-2 weighs negatively. The fluctuations of these curves are within a value of ± 1 and therefore the dominant flora that these curves represent is considered relatively stable for the entire zone. The peaks and valleys within these curves are gentle suggesting a generally stable environment.

The PCA curves for Zone OI have a similar overall position to that of Zone CI, however the majority of this zone studied were barren. Only the strata at the start and end of this zone contained microflora and palynodebris, with the result the microfloral content for virtually the entire zone is not known hence the straight lines of curves PC-1, PC-2 and PC-3.

8.3.1.2 COMPARING ZONES CII TO ZONE OII

Zone CII includes the remainder of the Aptian Stage, the Albian, the Cenomanian and start of the Turonian stages. Zone OII also comprises the remainder of the Aptian Stage, Albian and the start of the Turonian Stage. The Cenomanian Stage is not preserved at this Offshore Site and was possibly eroded away by the regressive events of the Turonian Stges.

As mentioned when discussing the pollen diagrams, Zone CII represents the crossover between the Early and Late Cretaceous periods. The transition occurs at ca. 1540 m and is registered in the flora of this zone as a sharp peak specifically in *Classopollis torsus,* still the most dominant

of the conifers, and *Cicatricosisporites.* Ferns and mosses still occur in abundance however this zone represents the first time that they truly start to diversify and flourish. Zone OII includes only the Early Cretaceous Period.

Regressive events in the Aptian, Cenomanian and Turonian stages have impacted significantly on the flora of Zone CII. This can be seen in both the summary pollen and the PCA diagrams. Numerous fluctuations within the microflora of the summary pollen diagram suggest continually changing environmental conditions, possibly a result of either drought or xeric conditions brought on by the numerous regressive events and changing topography, a result of rifting and drifting. The PCA diagram reflects the same numerous fluctuations in PC curves supporting the response of the microflora to a changing environment. The PC-1 curve now weighs negatively in comparison to its previous position in Zone CI, however the PC-2 curve has retained its negative weighting. Both these curves represent the most prominent taxa present. The PC-3 curve represents the least prominent of all the taxa present and appears to be flourishing as it carries a very strong positive weight. *Balmeiopsis limbatus,* one of the most prominent members of the Early Cretaceous flora disappears during the early stages of this zone.

No regressive events occurred in Zone OII, however the summary pollen diagram does show numerous minor fluctuations within the dominant flora present possibly as a result of the palaeoflora adapting to a dry climate brought on by the Aptian regressive event. *Classopollis torsus* remained one of the most dominant members of the microflora at both offshore sites and this can be seen in the summary pollen diagrams. The PCA diagram shows the same minor fluctuations in the PC curves. The PC-1 curve continues to weigh positively and the PC-2 curve has increased in value from an initial negative weight at the start of this zone to end with a low but positive weight. Both these curves represent the most prominent taxa present. The PC-3 curve represents the least prominent of all the taxa and carries a low positive weight. As with Zone CII *Balmeiopsis limbatus* disappears during the early stages of this zone.

8.3.1.3 COMPARING ZONES CIII AND ZONE OIII

Both Zones CIII and OIII include the remainder of the Turonian to the start of the Coniacian stages and represent both the Late Cretaceous Period and its flora.

The Turonian Stage appears to have been represented by an ongoing regressive event that made little impact on both Offshore Sites. This can be seen in the geology of both Offshore Sites with both zones exhibiting the same claystone package with numerous limestone stringers occurring throughout and, the impact on the Turonian regression on the microflora is minimal. This can be seen in summary pollen diagrams and the PCA diagrams for both sites. No regressive events occurred during the Coniacian Stage transgressive seas.

Offshore Site C-B1 experienced igneous intrusions between 1400 m and 1250 m and this affected the microflora as can be seen in the PC-1 and PC-3 curves of Zone CIII. Both these curves are negatively weighted whereas curve PC-2 responds with a positive weight for the first time at this site. All three PC curves weigh constantly positive or negative for the entire zone, even though a few fluctuations do occur to each PC curve. Zone CIII is a continuation of palaeoflora that has already established in previous zones, with a few exceptions. In comparison to Zone OIII, this zone experienced gradual events and this can be seen in the very few fluctuations within the PC curves.

No intrusive episodes can be found in the geology of Zone OIII of Offshore Site O-A1. The entire of Zone OIII reflects an unstable period and this can be seen in the numerous jagged peaks and valleys of both summary and PCA diagrams. The microflora of this period has responded by maintaining a fairly constant path. The PC-1 and PC-2 curves that reflect the most prominent taxa present, have fluctuated between fairly low positive and negative weightings for the entire zone, possibly suggesting that the palaeoflora was experiencing an ongoing cycle of adapting and coping with the dry conditions of the Late Cretaceous Period.

8.3.1.4 COMPARING ZONES CIV AND ZONE OIV

Both Zones CIV and OIV include most of the Coniatian Stage. A Late Cretaceous flora, including ferns and mosses, still dominates the palaeoflora. *Classopollis torsus* continues to dominate the microflora at both Offshore Sites however a change in the palaeoflora, both in abundance and diversity is visible as a result of long-ranging angiosperm flora starting to establish itself.

Zone CIV continues to experience gradual environmental events and this can be seen in the flat peaks and resulting gentle fluctuations within both the summary pollen diagram and PC curves. Both PC-I and PC-II curves weigh negatively, and fluctuate within a value of -1 for most of this zone. Curve PC-3 continues to carry a low positive value for the entire zone. All three curves do however taper off sharply before entering Zone CV.

Numerous minor regressive events appear to have occurred throughout Zone OIV. This conclusion is based on the presence of numerous limestone stringers in the geology of this zone and their position links up with the peaks and valleys of the summary and PCA diagrams for Zone OIV.

The weighting of the PC curves fluctuate heavily between positive and negative values within Zone OIV. Curve PC-1 as mentioned earlier represents the most dominant taxa present and weighs negatively for most of this zone, crossing over into positive territory on two occasions only. Curve PC-2 in comparison seems to have flourished in this zone as it carried a fluctuating positive weighting for the entire zone. The curve representing the least dominant taxa, curve PC-3, initially carried a positive weighting and then slipped into negative territory for the remainder of this zone.

8.3.1.5 COMPARING ZONES CV (INCLUDING SUBZONES CV-A AND CV-B) AND ZONE OV

Zones CV and OV both encompasses the close of the Coniacian as well as the Santonian and Campanian stages. Both zones end during the Campanian Stage.

These zones document the last remnantces of Late Cretaceous vegetation. As can be seen particularly in Zone CV's summary pollen and PC diagram, the Cretaceous flora is systematically disappearing to make way for a Tertiary flora.

Zone CV is a continuation of previous zones and continues to experience gradual environmental changes that can be seen in the flat peaks and corresponding negative fluctuations within both the summary pollen diagram and PC curves. All the PC curves in Zone CV now weigh

negatively, in comparison to previous zones where at least one PC curve weighed in positive territory. These curves up to this point represent the most prominent taxa present of the established flora however they are slowly being replaced by the next generation (Tertiary) of flora

In comparison, Zone OV's summary pollen diagram has peaked, suggesting either an adapting or different palaeofloral make-up to that of Offshore Site C-B1. The PC curves for this zone also suggests a positive change in environmental conditions possibly suggesting the onset of wetter conditions. Curve PC-2 continues its positive weighting as it has done since Zone OIII, however this curve takes a steep downward trend for the entire zone. Curves PC-1 and PC-3 continue to weigh negatively for the first half of this zone and then during the second half of this zone suddenly increase sharply into positive territory.

8.3.1.6 FINAL COMPARISON OF OFFSHORE SITES C-B1 AND O-A1

If the PCA diagrams of Zones CI and OI are compared, it can be seen that superficially the PC-1, PC-2 and PC-3 curves all have similar trends. Due to the lack of preservation of microfloral information in Zone OI, only an assumption can be made with regards to how comparable these two zones are. Taking into considering that both these zones represent the very Early Cretaceous and that the palaeoflora at this time was fairly uniform in composition at both Offshore Sites, it can be concluded that these two zones are comparable.

Zone OII's PCA curves show a gradual decrease over time in response to the close of the Early Cretaceous, that is the boundary line between Zones OII and OIII. Zone C-II's summary pollen zone and PCA diagrams shows erratic behavior probably in response to the numerous climatic and vegetational changes. If the PCA diagrams are compared for both sites it can be seen that the PC-1, PC-2 and PC-3 curves are not similar as they do not follow the same trends.

These zones cannot be compared due to their differing geology and the fluctuations within the PC diagrams which suggest that Zone OIII experienced a far harsher climate in comparison to Zone CIII situated further south.

Neither Zones CIV nor OIV can be compared due to the differences in palaeoflora in the corresponding summary pollen diagram, and the PC curves do not follow similar trends.

Zones CV and OV follow the same trends as the previous zones in that they cannot be compared due to the differing trends within both the palaeoflora and the weighting of the PC curves for both PCA diagrams.

Only Zones CI and OI can be compared to each other, and that is based on the assumption that the Early Cretaceous flora has the same basic palaeofloral components at both Offshore Sites, and that both these zones belong to the Early Cretaceous Southern Gondwana microfloral province. Zones CII to CV and OII to OV cannot be compared to each other. The palaeo-vegetational structure and quantity differs noticeably in each offshore site after the Early Cretaceous possibly suggesting that each offshore site represents a different microfloral province. This change in vegetational character supports a possible divergence of a single microfloral province during the Early Cretaceous into two separate microfloral provinces during the Late Cretaceous Period. This separation coincides with the appearance of angiosperm vegetation, that in some instances appeared to be Tertiary in origin.

8.4 THE COMPOSITION OF THE PALYNODEBRIS AND THE REFERECES IT MAKES TO A NEARBY TERRIGENOUS SOURCE

8.4.1 OFFSHORE SITE C-B1

The environment as reflected by the composition of the palynodebris diagram for Offshore Site C-B1 was warm and dry for most of its history, and this is reflected in the plant material and cuticle curves. A low but constant quantity of plant and cuticle material in general reflects stable dry conditions terrestrially (Batten, 1996). Cuticle fragments, all be it in tiny quantities, occur throughout Facies CB – D1 to part of Facies CB – D4 (Figure 5.2) and suggest near shore deposition (Batten, 1996). The presence of amorphous organic material (AOM) in all the facies suggests a terrigenous source associated with shallow fresh to brackish water of lagoons and swamps (Batten, 1996). Resins occur throughout all four facies indicating a stable, flourishing community of angiosperms and gymnosperms. These were the most prolific producers of resin at the time (Batten, 1996). The presence of marine palynomorphs supports deposition in a marginal

marine or saline esturine marsh environment (Farr, 1989). The sporomorph and fungi component remained low in value in all facies, however it does reflect a great diversity of hinterland vegetation.

8.4.2 OFFSHORE SITE O-A1

The environment, as reflected by the composition of the palynodebris diagram for Offshore Site O-A1 (Figure 5.3) was much drier and possibly warmer than Offshore Site C-B1as it was further north in position, this is again reflected in the plant material and cuticle curves. A constant representation of plant and cuticle material continues to reflect stable dry conditions terrestrially. Cuticle fragments are far more abundant at this site and occur throughout all four facies (Figure 5.2) and suggest the same-near shore depositional environment (Batten, 1996). The dominance of AOM in all the facies suggests a terrigenous input in association with the shallow fresh to brackish water of lagoons and swamps (Batten, 1996). Resins occur throughout the palynofacies assemblage, again indicating a stable, flourishing community of angiosperms in the vicinity. Marine palynomorphs show deposition in a marginal marine or saline esturine marsh environment (Farr, 1989) and the sporomorph and fungi component reflect a great diversity of palaeoflora. Green algae in the form of *Schizosporos reticulatus* is one of the most common forms at this site and infers that a freshwater influence was present.

The palynodebris results illustate a terrigenous to inner neritic accumulation over time for each Offshore Site.

8.4.3 THE RELATIVE POSITIONS OF PALAEO-SHORELINE OVER TIME

From the descriptions of the zones from each graph in Chapter 5 (Figures 5.2 and 5.3), the following can be concluded.

The relative position for Offshore Site C-B1 as a result of continental rift, drift and terrigenous accumulation over time is:

- Facies CB – D1 represent the shallowest environments because they are comprised almost exclusively of terrestrially derived organic material, with only a very limited marine influence. This group accumulated in the littoral (non marine) zone.

- Facies CB – D2 and 75 % of CB – D3 has a strong terrestrial influence but is also combined with a marine influence. These assemblages probably accumulated in a proximal littoral to shallowest of inner neritic zone environment.
- Facies CB – D4 probably also accumulated in a proximal littoral to inner neritic zone environment.

The relative position for Offshore Site O-A1 as a result of continental rift, drift and terrigenous accumulation over time is:

- Facies OA – D1 and ca. 60 % of OA – D2 represent the shallowest of environments as it is comprised almost exclusively of terrestrially derived organic material and the AOM in this group is terrestrially derived. This group possibly accumulated in the littoral to shallowest regions of the inner neritic zone.
- The remainder of Facies OA – D2, Facies OA – D3 and Facies OA – D4 are terrestrially based and combined with a marine influence. These assemblages like those in Offshore Site C-B1 probably accumulated in the inner neritic zone.

8.5 PALAEOENVIRONMENTAL RECONSTRUCTION

During the Early Cretaceous, the South Atlantic and Indian Ocean Basins started to open up thereby disrupting the southern monsoon rain pattern (Parrish & Doyle, 1984). By the Late Cretaceous, continental dispersion had reached a maximum and the monsoonal circulation that had dominated the palaeoclimatic history during the pervious 250 million years had disappeared (Parrish, 1987).

The environment of the emerging South Atlantic is generally considered to have been arid once the rift formed (Arthur & Natland, 1979; Doyle *et al.*, 1982). Temperature estimates for the Aptian to early part of the Cenomanian stages are uncertain because the vegetation was evolving rapidly and because there are no modern analogs to compare the mid-Cretaceous vegetation (Upchurch & Wolfe, 1987). If Southern Hemisphere leaf-margin percentages are used, then the mean annual temperature at the lower-middle paeolatitudes averaged 20° C (Upchurch & Wolfe, 1987).

8.5.1 PALAEOENVIRONMENTAL OVERVIEW FOR OFFSHORE SITE C-B1

The environment of Offshore Site C-B1 during the Early Cretaceous was probably humid and tropically warm with conditions starting to shift, as shown by the presence of *Classopollis* and *Ephedripites* (xerophytic, dry climate indicators), towards becoming semi-arid and warm to hot. The environment during the Early / Late Cretaceous crossover was less tropical, moist and warm and more one reflecting warmer, semi-arid conditions. These conditions continued almost to the close of the Late Cretaceous Period however from the Cenomanian Stage environmental conditions shifted back to warm, moist and wet.

The microflora adapted and flourished to all the conditions that prevailed but the most noticeable change was the slow replacement of Cretaceous with Tertiary flora.

8.5.2 PALAEOENVIRONMENTAL OVERVIEW FOR OFFSHORE SITE O-A1

The environment that prevailed during the accumulation of early-rift sediments during the Early Cretaceous of Offshore Site O-A1 was wet, humid and warm however by the close of the Early Cretaceous, the conditions had changed towards warmer and more semi-arid. By the start of the Late Cretaceous period the environment was becoming hotter and more arid. As with Offshore Site C-B1, environmental conditions shifted back at the close of the Late Cretaceous back to warm, moist and wet.

The microflora adapted and flourished to a greater extent at this site than at Offshore Site C-B1. The most noticeable change in the flora started during the Turonian Stage (Late Cretaceous Period) with the slow replacement of gymnosperm flora with angiosperms.

Environmental conditions in the higher latitude regions of both Offshore Sites remained stable, cool and temperate throughout the entire Cretaceous Period.

8.6 GEOCHRONOLOGY

8.6.1 AGE BRACKETS

Every species identified was arranged in order of its first occurrence within each Offshore Site (Figures 6.3 and 6.4). The interpretations concerning the age and correlation of each zone is

based mainly on the entrance levels of stratigraphically significant species. The age ranges of the palynomorphs present have provided a general Cretaceous age for both Offshore Sites, with only a few specimens tentatively age-defining the depth they were found at i.e. A tricolpate pollen grain with columellate semi-tectate sculpture could possibly isolate Subzone CI - A specifically to the Barremian Stage and *Gleicheniidites radiatus* and *Gleicheniidites rasilis* that are both present in this zone and are known to make their first appearances during the Aptian Stage. On more than one occasion Tertiary palynomorphs were located in the early part of the Cretaceous Period. Their presence is probably a result of contamination that occurred during the drilling, maceration or preparation of slides process.

8.7 PALAEOFLORA

8.7.1 PHYSICAL SETTING, VEGETATION AND COMMUNITY STRUCTURE OVER TIME

The Cretaceous palaeoflora of these two Offshore Sites consist predominantly of gymnosperms and ferns and to a lesser extent angiosperms. If we take the findings of Chapter 7 into account i.e. physical setting, vegetation and community structure over time, and compare it to the detrended correspondence analysis diagram below, then the landscape and the distribution of the vegetation within it would consist of the following:

Twenty eight palynomorphs were used for this detrended correspondence analysis (DCA) and their criteria for selection was based on their prominance in the summary pollen diagrams. The interpretation of this DCA diagram was done primarily on the basis of the spatial position of each species (Figure 8.3) along the first and second order axes.

Figure 8.3 identifies trends based on the position of the palynomorph groups along Axis 1 and 2. It is not possible to assign a specific palynomorph gradient along Axis 1 due to lack of knowledge of the parent plants that produced them, however, Axis 2 may tentatively represent the coastal to high latitude gradient. It is however, not expected to find environmental gradients as evolutionary gradients are more likely to be expressed.

8.7.1.2 DETRENDED CORRESPONDENCE ANALYSIS GROUPINGS

- **GROUP A**

  Group A consists of five members that include *Balmeiopsis limbatus, Classopollis echinatus, Classopollis torsus, Cicatricosisporites hughesii* and *Zonalapollenites dampieri,* of these five members, four are gymnosperms and one is a fern. This group is positioned in the bottom left hand corner of the above diagram. If it is taken into consideration that these four gymnosperms are known to have occurred in low latitude woodlands that probably hugged the west coast coastline and *Cicatricosisporites hughesii,* a member of the Schizaeceae family that is almost exclusively tropical in modern flora (Brenner, 1963), probably formed part of the woodland ground cover then this bottom left hand corner could possibly represent the coastal boundary of both Offshore Sites.

- **GROUP B**

  Group B is an outlier with only one member, *Cicatricosisporites australiensis.* Its position within the DCA diagram suggests that of a low-latitude, slightly further inland dweller that possibly formed part of the outskirts of the woodland ground cover.

- **GROUP C**

  Group C includes four members *Undulatisporites microcutis, Stereisporites electoides, Camarozonosporites cretaceous* and *Taurocusporites reduncus.* The position of this group in the diagram suggests a low latitude, slightly further inland position, possibly associated with a water source. This is suggested by to the presence of *Stereisporites electoides* and *Taurocusporites reduncus*, both mosses.

- **GROUP D**

  Group D consist of four members that include *Gleicheniidites circindites, Gleicheniidites peregrinus. Gleicheniidites senonicus* and *Osmundacidites wellmanii.* These are typically tropical ferns (Brenner, 1963) and their orientation in the diagram suggests an inland middle to high latitude position possibly forming high latitude forest ground cover.

- **GROUP E**

  Group E consists of six members, three of which are gymnosperms (*Podocarpidites, Exessipollenites tumulus* and *Microcachryidites antarcticus*). These are known members of high altitude forests. *Gleicheniidites rasilis* and *Biretisporites* possibly formed the understorey ground cover. The position of this group in the DCA diagram suggests an inland high latitude position

- **SCATTERED FOLIAGE**

  Between groups A – D is a scatter of spores and a single angiosperm pollen grain that have not been included into any grouping. These palynomorphs consists of a combination of tree ferns mosses and unknown affinities. This scatter possibly formed the undergrowth on the side of a valleys or mountain ranges.

GROUP A. *Classoechin = Classopollis echinatus, Classotor = Classopollis torsus, Balmeioplimb = Balmeiopsis limbatus, Cichug = Cicatricosisporites hughesii.*
GROUP B. *Cicaust = Cicatricosisporites australis.*
GROUP C. *Undulatimicr = Undulatisporites microcutis, Stereimaas = Stereisporites maastrichtiensis, Camarocret = Camarozonsporites cretaceous, Tauroredun = Taurocusporites reduncus.*
GROUP D. *Gleichcirc = Gleicheniidites circindites, Gleichper = Gleicheniidites peregrinus. Osmunwel = Osmundacidites wellmanii, Gleichsen = Gleicheniidites senonicus.*
GROUP E. *Exesiptum = Exesisporites tumulus, Podocarpites = Podocarpidites Microcachrant = Microcachryidites antarcticus, Gleichras = Gleicheniidites rasilis, Microretpar = Biretipot = Biretisporites potonie.*
SCATTERED FOLIAGE. *Cyathrim = Cyarhedites rimulus, Cyathmin = Cyathedites minor, Cyathaustr = Cyathedites australis, Ceratechin = Ceratosporites echinatus, Ghoshigon = Ghoshia , Tetracolpixer = Tetracolpites ixerboides, Interuloalg = Interulobites algoensis, Luberilub = Luberisporites luberi.*

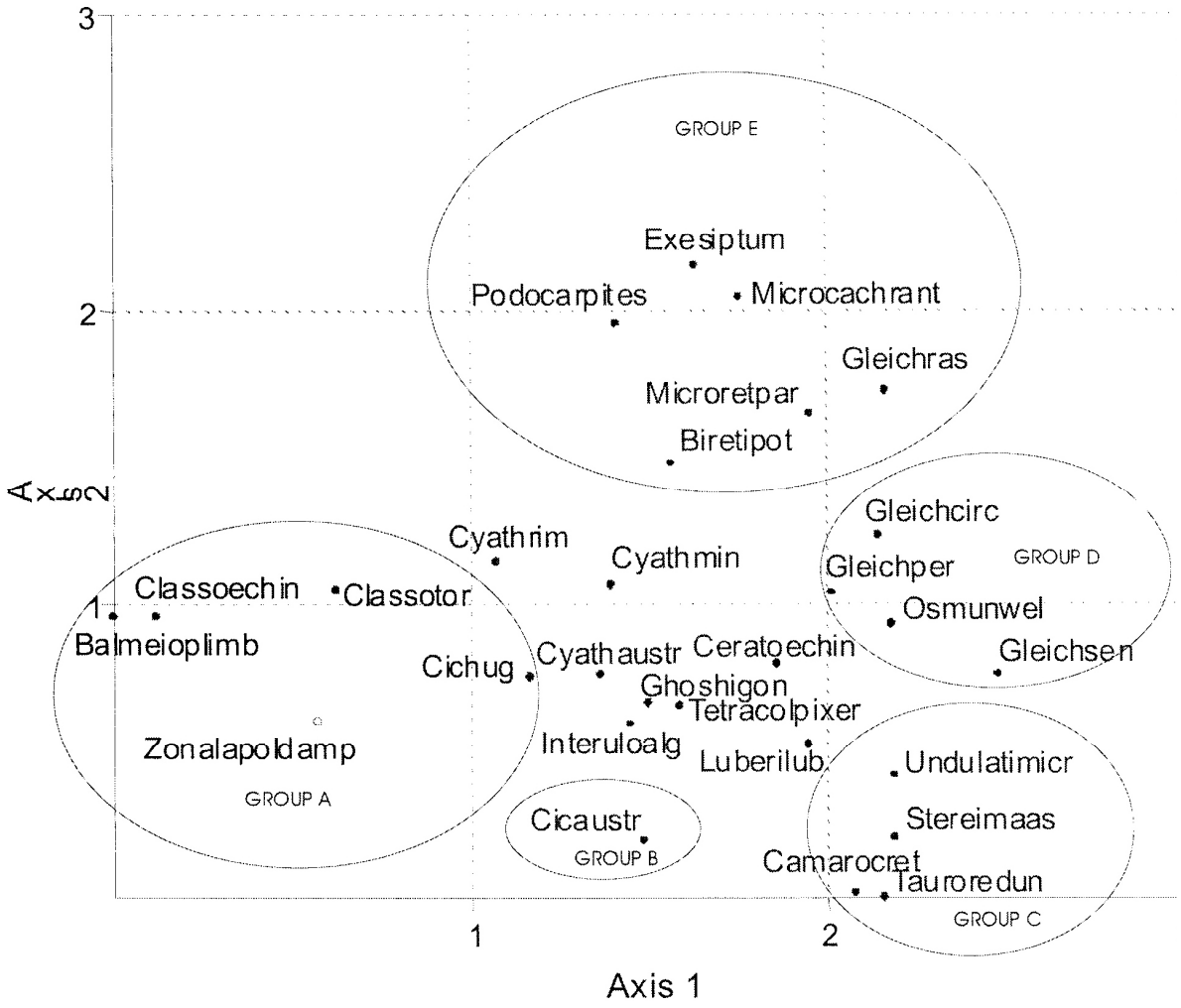


Figure 8.3. A scatter diagram has been generated of the detrended correspondence analysis of samples from Offshore Sites C-B1 and O-A1

Also Figure 8.3 is a compilation of vegetation common to both offshore sites and they were dominant for the majority of the Cretaceous Period. Both sites reflect a very high composition of gymnosperms and ferns in relation to the angiosperm content. Most of the 28 palynonorphs present are long-ranging components with the exception of *Balmeiopsis limbatus* that died out at both sites either during or after the Aptian regressive event. Regionalism is evident at both offshore sites with both overstorey (high latitude forests) and understorey (woodlands, ferns and mosses) vegetation, and this is primarily a result of climate (Dettmann *et al.*, 1992).

8.7.2 PALAEOFLORA SUMMARY

The Cretaceous west coast microflora is represented by communities that include coastlines dominated by woodlands and high latitude forests of evergreen podocarps. Angiosperm communities first appeared in both offshore sites in low numbers during the Barremian stage and later became a conspicuous element of the palaeoflora during the Late Cretaceous Period. The abundance of *Cyathedites minor, Cicatricosisporites australis* and *Gleicheniidites senonicus* reflect the importance of Cyatheaceae, Gleicheniaceae and Schizaeaceae at the time. These fern families would have supported a luxuriant undergrowth that would have included members that thrived on tree trunks to ground dwellers to tall tree ferns. The gymnosperms of the Cretaceous forests were primarily members of the Podocarpaceae and to a lesser extent Araucariaceae. The copius quantities of *Classopollis* suggest the importance and dominance of the *Brachyphyllum*m (cheirolepidacean conifer).

The close of the Cretaceous Period saw the start of the Palmae Province. The cheirolepidacean conifer dominated woodlands had diminished to the point where they were of little significance in the palaeoflora and the sudden decrease in the diversity of ferns and mosses along with a change in the composition of the higher latitude forests suggests that the west coast flora was being replaced by new Tertiary vegetation that included angiosperms as the dominant vegetation inhabiting the moist lowlands.

8.8 PLANT GROUPS

8.8.1 IMPORTANT PLANT FAMILIES REPRESENTED

Very few of the plant families identified from both offshore sites exist in the area today. The modern scenario consists mostly of semi-arid adapted fynbos that contrasts greatly with the Cretaceous palaeoflora. The majority of the plant families identified occur not only in other parts of Africa but throughout the world. A few of the important South African families are discussed below.

8.8.1.1 FERNS

Dettmann (1981) found that the fertile fronds of *Conioperis hymenophylloides* and *Adiantites lindsayoides* Seward yielded *Cyathedites* and *Dictyophyllidities* spores. Balme (1957) found that

spores of this type occurred among the Cyathaceae and similar types are found in the Dicksoniaceae and Polypodiaceae similar to *Microlepia setosa* Alston in Selling (1946). Of the spores of recent New Zealand species it is similar to those of *Cyathea smithii, Cyathea colensoi* and *Cyathea novae-zealandiae,* but it is larger, has more broadly rounded apices, and is not so distinctly concave between apices in polar view (Couper, 1953).

Skarby (1964) views *Gleicheniidites* as having a general affinity to Gleicheniaceae, *Gleichenia* or *Dicranopteris.* Cookson (1953) showed that the species *Gleicheniidites circindites* was comparable to the spores *Gleichenia circinata* Swartz.. The spores of the modern *Gleichenia circinata* Swartz and *Gleichenia laevissima* Christ. are morphologically comparable to *Gleicheniidites* (Dettmann, 1963).

The ornamentation of the species *Cicatricosisporites cooksonii* resemble that found in certain schizeaceous ferns and *Cicatricosisporites* grouping resembles some modern spores of Aneimia Swartz eg. *Aneimia jaliscana* Maxon and *Aneimia dregeana* Kunze (Dettmann, 1963).

Today these species are almost exclusively tropical in habitat, however during the Cretaceous Period, their presence supported the interpretation of a probable tropical to sub-tropical climate around the coastline and in the high latitude forests.

8.8.1.2 GNETALEAN POLLEN

Research by Wood *et al*., (1997) found that the *Ephedra*-like pollen which entered the geological record in the Late Hauterivian to Early Barremian stages are morphologically similar to pollen of some extant species of xerophytic gnetalean *Ephedra* and *Welwitschia*. Their presence supports the interpretation of a probable arid to semi-arid climate from the rift valleys of the Early Cretaceous to the modern deserts of Namibia where the species *Welwitschia* occurs.

8.8.1.3 PALMAE POLLEN

Four pollen types have been associated with the Palmae namely *Andreisporis mariae*, *Constantinisporis jacquei, Dorreenipites sp.* and *Victorisporis robertii*. The presence of a Late Cretaceous palm-rich pollen zone supports the conclusion that the climate had reverted back to

that of warm, wet and moist. The modern palmae of today eg. *Sclerosperma mannii*, usually occurs in tropical to sub-tropical climates (Traverse, 1988) and even though the Late Cretaceous palm types were probably more hardy, they were forms that even then characterised tropical to sub-tropical conditions.

8.8.1.4 MODERN ANALOGY

If an attempt is made to make a modern analogy with the Cretaceous west coast microfloras, a similarity can be found between the forests of podocarps that covered South Africa during the Cretaceous Period (Coetzee, 1993) and the relict forests that remain today such as those found in Knysna. A noticeable similarity can be found with the flora of the warm temperate rain forests of New Zealand. The forests specifically of North Island consist of amongst others *Podocarpus dacrydioides* and *Dacrydium cupressinum.* The undergrowth includes varieties of *Cyathea* and *Dicksonia,* modern analogs of the *Cyathedities* grouping. The Schizaeceae and *Gleichenia* that produces spores comparable to *Gleicheniidites* are exclusicely tropical in the modern flora of New Zealand today. Both these families were well represented in the west coast palaeoflora.

8.9 A COMMON DENOMINATORS TO BOTH OFFSHORE SITES

Figure 8.4 has been generated using the same DCA that generated Figure 8.3 with the aim of identifying what is common to both Offshore Sites. In this diagram, however, the samples from the two boreholes are shown on both axes instead of the species.

8.9.1 COMMON DENOMINATORS IN DETRENDED CORRESPONDENCE ANALYSIS

Each grouping of the groupings that follow reflects a major disappearance or transition event.

- **GROUP 1**

  Group 1 has isolated 4 samples that are all Barremian in age and correspond closely with palynomorphs in Group A (Figures 8.3 and 8.4). These include one sample from Offshore Site C-B1 (1812m) and three samples from Offshore Site O-A1 (4168.95 m, 4165.6 m and 4164.9 m). These four samples are characterized by very high values of *Classopollis torsus* and *Balmeiopsis limbatus* that make up no less than 80 % of the microfloral

component of each site. They all reflect disappearance events that at this Early Cretaceous stage are not connected to sea level trans- or regressions but to the geology of the region.

Sample 1812 m is situated at the end of a 10.5 m thick mostly barren interval between 1820 m and 1809.5 m. This interval consists of clay, which being basic in nature does not readily preserve cellulose-rich spores and pollen grains. The resulting disappearance event due to low preservation potential can be seen above and below the stippled line in the bottom right-hand corner of the biostratigraphic distribution diagram in Figure 6.1 (Chapter 6).

Samples from 4168.95 m, 4165.6 m and 4164.9 m all occur before the break in preservation in Subzone CI - B of Offshore Site O-A1. The Pollen diagram (Figure 4.2) and the biostratigraphic distribution diagram (Figure 6.2) for Offshore Site O-A1 shows that between 4169.65 m and 4164.90 m, a rich assemblage of microfloraflora existed and then between 4150 m and 3800 m a barren sequence occurs. The geology over this interval (4150 m to 3800 m) has been affected by igneous activity (Petroleum Agency, SA researchers). It was also noted by previous Petroleum Agency, SA geologists that the interval from 3793 m to 3755 m consisted of “weathered volcanic products” and heat from this intrusion would have metamorphosed and destroyed any organic debris in the surround rock, thereby registering as a barren sequence.

Therefore these four samples have been isolated into Group 1 due to their common microfloral composition and the resulting barren interval that either follows or is a part of their sampling position.

Sample 1837 m is situated at the start of a 12 m thick fine-grained grey sandstone and shows no geological disturbances. The only connection that can be seen with the other sites within this grouping is that of a high *Classopollis* content and this sample depth registers the first of many disappearance events. This can be seen below the stippled line in the bottom right-hand corner of the biostratigraphic distribution diagram in Figure 6.1

where the first three species disappear.

Two magma intrusions appear in Zone CIII of Offshore Site C-B1, the location of three of the four samples. The first intrusion occurs between 1400 m and 1375 m and the second intrusion occurs between 1300 m and 1250 m. As a result two barren metamorphosed zones have been formed and samples 1360 m, 1310 m and 1233 m occur on either side of the intrusions / within the metamorphosed zones. A series of very noticeable step-like disappearance events can be seen at the end of Zone CIII in biostratigraphic distribution diagram in Figure 6.3 where 13 species have disappeared.

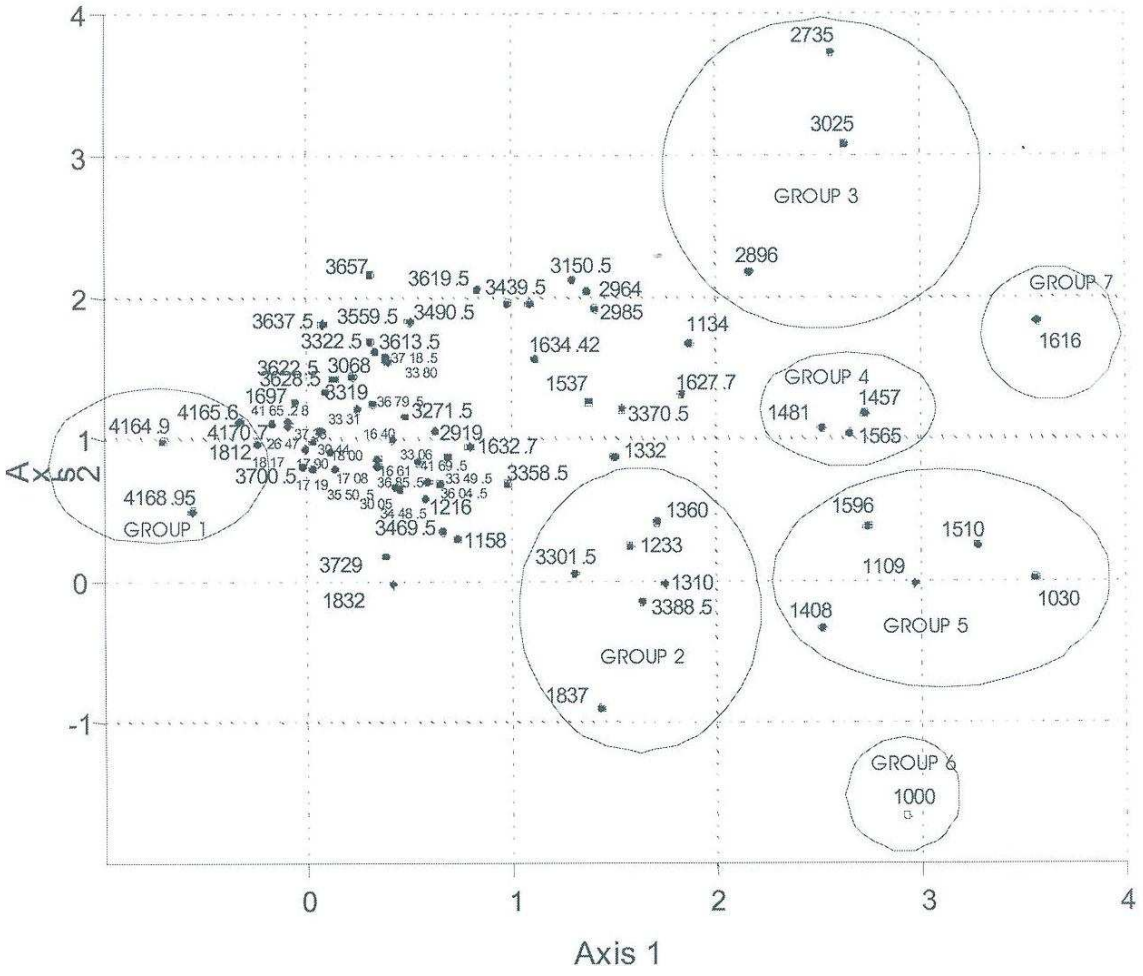


Figure 8.4. Common DCA denominators to both Offshore Sites.

- **GROUP 2**

  Sites 3387 - 90 m (Group 2 as 3388.5) and 3300 - 03 m (Group 2 as 3301.5) occur in Zone OIII of Offshore Site O-A1 (Figure 5.3). This zone represents the Turonian to the middle part of the Coniatian stages and consists of a 560 m thick claystone interval with minor sandstone and occasional limestone stringers. Twenty one species disappeared over this interval.

- **GROUP 3**

  Group 3 consists of three samples all of Coniacian age (3025, 2896 m and 2735 m) and all from Offshore Site O-A1. These three sites are characterized by very high values of *Microcachryidites antarcticus, Podocarpidites* sp.and *Cyathedities minor* that makes up no less than 18 % of the microfloral component of each site. These samples reflect major disappearance / transition events.

  Zones OIV and OV include all three sites and appear to be the 'cut-off' zones for most Cretaceous-based species. Species that appear to be well-established Cretaceous palaeoflora suddenly disappear over these two zones. Large step-like disappearance events can be seen throughout both zones in the biostratigraphic distribution diagram in Figure 6.2 and 40 species systematically disappeared over that interval.

- **GROUP 4**

  Group 4 consists of three samples all of varying ages (1565, 1481 m and 1457 m) all of which are from Offshore Site C-B1. These three samples are characterized by very high values of *Classopollis torsus, Gleicheniidites senonicus* and *Cyathedites minor* that makes up no less than 47 % of the microfloral component of each site. These samples reflect disappearance / transition events of increasing magnitudes.

  All three samples occur in Zone CIII and have been influenced in some way by regressive episodes. *Balmeiopsis limbatus* disappears at 1565 m. This species could be a possible marker species for the Albian regressive event as it dies out either during or shortly after the regression. A second regressive event occurred during the Cenomanian

Stage at 1475 m (See Figure 5.3). This regressive event has impacted negatively on sites 1481 m and 1457 m by resulting in another disappearance event although on a much smaller scale.

- **GROUP 5**

  Group 5 includes five samples (1596 m, 1510 m, 1408 m, 1109 m & 1030 m) of varying ages all from Offshore Site C-B1. All five sights are characterized by a high value of *Gleicheniidites senonicus* that makes up no less than 20 % of the microfloral component of each site. These samples reflect major disappearance / transition events. These five samples reflect disappearance / transition events of increasing magnitudes.

  Samples 1596 m, 1510 m and 1408 m are minor events with only a few species disappearing and are concentrated in and just above Zone CII. This zone includes many mini-disappearance events. Samples 1109 m and 1030 m are found in Group CV – A. This zone is noted for large magnitude disappearance events related to changes in flora (See Figure 6.3).

- **GROUP 6**

  Group 6 consists of a single outlying sample from Offshore Site C-B1 (1000 m) that is Cenomanian in age. This was the last site sampled and therefore reflects a large disappearance event.

- **GROUP 7**

  Group 7 consists of a single outlying sample from Offshore Site C-B1 (1616 m) that is Aptian in age and coincides with the Aptian regressive event. This regression ended at the 1600 m level and affected the palaeoflora in three ways. This regression had a drying effect on land with the result that some of the flora flourished in the dry conditions while other flora drastically diminished and in some cases died out altogether. Following the same trend as Zone CIII, Zone CII has a series of step-like disappearance events that can be seen in the middle bottom right-hand corner of the biostratigraphic distribution diagram in Figure 6.3 (Chapter 6).