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Algal palynomorphs of the Ballagan Formation and their palaeoenvironmental significance

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Contents

Figures

Plates

Summary

The value of spores and pollen from higher vascular land plants is well established in biostratigraphic studies but their value as direct indicators of the immediate environment of deposition is limited because they are mainly dispersed, and hence represent the ecologies of variably distant terrestrial hinterlands. However, simpler spore-producing non-vascular plants such as filamentous algae live in bodies of water like lakes, ponds and lagoons, where deposition occurs, and hence have the potential to be direct indicators of palaeoenvironment.

The purpose of this report is to describe and illustrate some of the algal spores and spore-like propagules present in the palynological assemblages of the Ballagan Formation and to relate them to the four palaeoenvironments and biofacies associations that have been established by ostracod studies (Williams 2002a).

These biofacies associations have been plotted on palynological range and quantitative charts for the Heads of Ayr outcrop section, and the East Dron, Glenrothes, and Spilmersford boreholes (Figures 1-4). The charts bring together most of the palaeontological information gained during joint ostracod/palynology studies in the period 2000-2002. On the left of each chart are the sample positions, while the left hand panels illustrate palynomorph ranges and or quantitative palynological characteristics of each sample. To the right, where available, is ostracod range data.

Four ostracod biofacies associations were determined by Williams (2002a). However, on the whole it is not possible to discriminate four corresponding algal assemblages and hence there are no exact algal palynomorph proxies for these associations. However it is clear, overall, that *Chomotriletes* spp., *Leiosphaeridia* spp, *Leiosphaeridia* sp. A and *Leiosphaeridia* sp. B, 'Monolete spore' of McLean and Neves, *R. chalastus* and *R. catenulatus* are generally present (or abundant) within the stratigraphic range of ostracod biofacies associations 2 and 3, and therefore that such an algal assemblage can be taken as evidence for brackish to freshwater conditions. Information from extant algae, which produce similar spores to some of those above, supports such an inference.

1 Introduction

The value of spores and pollen from higher vascular land plants is well established in biostratigraphic studies but their value as direct indicators of the immediate environment of deposition is limited because they are mainly dispersed, and hence represent the ecologies of variably distant terrestrial hinterlands. However, simpler non-vascular plants such as filamentous algae live in bodies of water like lakes, ponds and lagoons, where deposition occurs, and hence have the potential to be direct indicators of palaeoenvironment. They also produce spores and spore-like propagules during their sexual reproductive phases, and these are similar in size to terrestrial palynomorphs, and are durable enough to be preserved in sediments. The modern 'pondweed' zygnemataceaen alga *Spirogyra*, for example, produces spores by the conjugation of algal filaments. The zygospore so formed has a wall that is composed of a tough substance similar to the sporopollenin of which spores and pollen are composed. In modern *Spirogyra,* the zygospore can withstand considerable drying, but after a period of time immersed in water it germinates and a new filamentous algal chain develops. Thus the zygospore allows the alga to survive periods of desiccation. Most of the Ballagan algal spores described here are probably zygnemataceaen zygospores and their prevalence in the sections might reflect the generally changeable wetting-drying conditions of the Ballagan palaeoenvironment. The filamentous alga that produced the zygospores were probably, like the modern *Spirogyra*, composed of cellulosic material with no preservation potential, so it is not surprising that filamentous algal debris is not preserved in the Ballagan sediments. Other algal bodies present in Ballagan sediments include the tough organic remains of the supporting structure of cells of *Botryococcus*, a well-known colonial green alga (Batten and Grenfell, 1996).

The 'autochthonous' algal palynomorphs from the Ballagan Formation are described from the Heads of Ayr outcrop section [NS 3019], Spilmersford Borehole [NT 4570 6902], East Dron Borehole [NO 1360 1572], Glenrothes Borehole [NO 2561 0314], Blairmullock Borehole [NS 5605 2820] and Birnieknowes Borehole [NT 758 732] (Stephenson, 2002, a, b, c, d).

In this report the results of a study of the 'autochthonous' algal palynomorphs of the Ballagan Formation are presented in figures 1-4 and 6-7. The palynomorphs are described and illustrated and their stratigraphical occurrence is related to palaeoenvironments that have been established by ostracod studies (e.g. Williams 2002a). Using the relationships established, algal palynomorphs alone are used to infer palaeoenvironmental conditions in two well sections for which no ostracod data is available.

2 Description of algal palynomorphs of the Ballagan Formation

2.1 'MONOLETE SPORE' OF MCLEAN AND NEVES (2001)

Probable algal microfossil, large (approximately 100 µm maximum dimension); outline oval, usually dark in colour. Discontinuous marginal fold (or thickening), 5-10 µm wide occurs close to, or coincident with, the margin. Exine approximately 1 µm thick; surface scabrate. A single split or dehiscence in the exine occurs parallel to the long axis, dehiscence mark as long, or slightly longer, than the diameter.

This rare, but very distinctive microfossil is closely similar in morphology to species of *Brazilea* Tiwari and Navale 1967, though it appears be larger and more robust. Very similar specimens were recorded as a 'monolete spore' by McLean and Neves (2001) from the New Farm A Borehole, Perth and Kinross, in the upper Dron Member of the Ballagan Formation. Given its similarity to *Brazilea,* this form is likely of zygnemataceaen algal origin and its presence in an assemblage dominated by other definite algal palynomorphs, such as *Chomotriletes* tends to support this suggestion. The presence of the taxon in the lowest part of the Ballagan Formation, stratigraphically much lower than the Dron Member of the New Farm A Borehole, suggests that it is an opportunistic algal species of little regional correlation significance.

2.1.1 Biological affinity

Unknown but morphologically similar to *Brazilea*, a probable zygnemataceaen alga (van Geel and Grenfell, 1996).

2.2 RUDUVIASPORONITES CATENULATUS

Microfossil, usually forming chains, but also present as pairs of cells or single dispersed cells. Cell outline subcircular or subrectangular; probably originally sub-spherical before compression. Outer cell wall approximately 1 µm thick, smooth; may be irregularly thickened at the margins; no inner body or cell material has been observed. Cells in a chain, and particularly single unattached cells, have regular concentric or subpolygonal fold patterns. Method of cell-to-cell attachment not known, though some chains appear to indicate that the convexity of part of a given cell fits into a corresponding hemispherical concavity in an adjacent cell. No terminal rims are present.

The record of this taxon from Birnieknowes is the earliest known; previous records occur only from the Wordian (Middle Permian) of Oklahoma (Wilson, 1962; Morgan, 1967).

2.2.1 Biological affinity

Unknown, but morphological similarity with *Ruduviasporonites chalastus* (below) suggests an algal, probably zygnemataceaen origin.

2.3 RUDUVIASPORONITES CHALASTUS

Microfossil, usually forming chains but also present as pairs of cells or single dispersed cells. Cell outline subrectangular, rarely oval, irregular or 'Y' shaped, though most cells were probably originally cylindrical in shape before compression. Outer cell wall approximately 0.5 µm to 1.5 µm thick, smooth, may be slightly thickened in the regions of the terminal rims. The inner body commonly has the same shape as the outer cell and may be adpressed to the inner surface of the main cell so that it is difficult to distinguish optically. The inner body may also occupy a smaller part of the cell cavity (possibly through shrinkage) and may be twisted. Detachment of the two walls appears first to occur in the middle parts; usually the termini of the inner body are firmly attached to the inner surface of the terminal rim, though detachment at these points may also occur. Wall of inner body 0.5 to 1 µm thick where observed, smooth, sometimes hyaline in appearance. Dark 'cell material' of amorphous or granulate appearance occurs in many specimens and is often enveloped by the delicate, shrunken inner body. Cell has a number of characteristic folding patterns. The diagonal folding pattern noted by Foster (1979) is caused by twisting of the cell body about the long axis of the cell. Other folds, in either of the cell walls, commonly delineate rectilinear shapes and these may represent areas of residual attachment of the inner and outer cell walls. Commonly, short lunate folds, orientated perpendicular to the long axis of the cell, occur close to the margins of ovoid cells. These are believed to result from the attachment of the termini of the inner body to the inner surface of the outer body and as such may represent parts of a poorly developed terminal rim.

The presence of this probable algal taxon (Foster et al., 2002; Stephenson and Foster, 2002) is interesting partly because this may be one of earliest occurrences of the taxon and partly because this occurrence, alongside a largely algal assemblage, tends to support new interpretations of the palaeoenvironment of the organism (see Foster et al., 2002).

2.3.1 Biological affinity

New work (Stephenson and Foster 2002, Foster et al., 2002) suggests an algal, probably zygnemataceaen origin.

2.4 LEIOSPHAERIDIA SP. D

Probable algal microfossil; small (approximately 35 µm); outline oval or circular, usually dark in colour. Exine thin <1 µm, possibly two layered. A split or dehiscence, with thickened edges resembling lips, occurs in a spiral pattern across the full length of the body.

2.4.1 Biological affinity

Unknown but morphologically similar to *Brazilea*, a probable zygnemataceaen alga.

2.5 LEIOSPHAERIDIA SP. A

Probable algal microfossil; relatively large (approximately 100 µm); outline oval or circular or irregular; probably originally spherical before compression; usually light in colour. Exine thin <1 µm; no split or dehiscence or other aperture present. Exine characteristically net-like (reticulate) in structure. Lumen form openings to the interior of the body; mean width of lumen approximately 1 µm, shape polygonal or circular. Muri relatively robust; approximately 1 µm wide.

This taxon is a distinctive component of Ballagan Formation palynological assemblages. It is most common in assemblages rich in other undoubted algal palynomorphs and hence is likely to be algal in origin. The lack of dehiscence structure or aperture tends to support such an interpretation. The palynomorph bears no relationship to known extant zygnemataceaen zygospores.

Leiosphaeridia sp. A was originally thought (Stephenson et al., 2002), to be indicative of the upper part of the Ballagan Formation but recent records indicate that it occurs throughout the Ballagan Formation, and that it is an opportunistic algal species of little regional correlation significance.

2.5.1 Biological affinity

Unknown.

2.6 LEIOSPHAERIDIA SP. B

Probable algal microfossil; relatively large (approximately 100 µm); outline oval or circular or irregular; probably originally spherical before compression; usually light in colour. Two layered; 'exoexine' very thin <1 µm, diaphanous, smooth, with no split or dehiscence or other aperture present. 'Intexine' present in the form of a variably shrunken inner body loosely enclosed by the 'exoexine'. Features of the 'intexine' difficult to discern, but appears to be smooth.

As with *Leiosphaeridia* sp. A, the lack of a split, dehiscence or other aperture and the occurrence with other algal palynomorphs indicates that this palynomorph is probably of algal origin. This taxon commonly occurs with *Leiosphaeridia* sp. A.

2.6.1 Biological affinity

Unknown.

2.7 LOPHOSPHAERIDIUM SP. A

Probable algal microfossil, without dehiscence structure or split, very small (approximately diameter 20 µm); outline circular. Exine approximately 1 µm thick, surface covered with very fine delicate spines or grana just resolvable under x100 objective; length of ornament elements approximately 0.5µm; width at base approximately 0.5 µm, very densely and evenly distributed over the whole area of the body (approximately 0.5µm apart).

2.7.1 Biological affinity

Unknown.

2.8 OTHER LEIOSPHAERIDIA SPP.

Simple smooth ‘spheres’ of exine-like material are very common in Ballagan Formation palynological assemblages. These probable algal microfossils are relatively large (approximately 100 µm), with an oval or circular or irregular outline; though they were probably originally spherical before compression. They are usually very light in colour reflecting the delicacy and thinness of their walls. Wall exine very thin <0.5 µm, no split or dehiscence or other aperture present. Often tens of folds are present reflecting the delicacy and thinness of the wall exine.

2.8.1 Biological affinity

Unknown.

2.9 CF. PELTACYSTIA SP. 1

Probable algal microfossil; relatively large (approximately 70 µm); outline oval or circular; probably originally spherical or ovoid before compression; usually dark in colour. Exine relatively thick approximately 1 µm, no split or dehiscence or other aperture present. Exine characteristically heavily, but irregularly, ornamented with a variety of small, very densely distributed, variably shaped ornament elements, including bacula and verrucae. An annular fold or thickening conformable with the margin of the body occurs a few microns from the margin.

2.9.1 Biological affinity

Unknown but morphologically similar to *Peltacystia*, a probable zygnemataceaen alga (van Geel and Grenfell, 1996).

2.10 TETRAPORINA SP.,

Algal microfossil; outline sub-rectangular or square with rounded, slightly thickened corners; corners sometimes bear arcuate folds. Exine laevigate, 1 µm or less thick.

2.10.1 Biological affinity

Zygnemataceaen zygospore (van Geel and Grenfell, 1996).

3 Relationship of algal palynomorphs to palaeoenvironments as suggested by ostracods

Williams (2002a) has established a number of ostracod biofacies for the Ballagan Formation based on ostracod assemblages from the Ballagan Formation in Ayrshire and from boreholes at Glenrothes, East Dron and Spilmersford.

The four recurrent biofacies associations are

1. the *Cavellina coela* (Rome), *C. incurvescens* (Jones and Kirkby), *Paraparchites* sp. 1, *Knoxiella* sp. A and cf. *Bairdia jakutika* sensu Robinson (1978) Association occurring in tidal flat facies;
2. the *Shemonaella* sp. A and *Acutiangulata aequalis* Association, often occurring with the bivalve *Modiolus*, and which may indicate brackish water/quasi marine conditions;
3. the *Sulcella* cf. *affiliata* Association, possibly associated with low salinity or freshwater conditions;
4. the *Shemonaella scotoburdigalensis* (Hibbert) Association, possibly indicative of brackish water.

Associations 1-3 are well developed in Ayrshire, whilst the East Dron Borehole sequence is dominated by Association 2. Thus far, Association 4 is found only in the lower part of the Ballagan Formation in the Glenrothes Borehole, where it may be a temporal precursor of Association 2. Association 3 is present in the Spilmersford Borehole and Ayrshire.

For the purposes of this study, these biofacies associations have been plotted on palynological range and quantitative charts for the sections listed above (Figures 1-4). The charts bring together most of the palaeontological information gained during joint ostracod palynology studies in 2000-2002. On the left of each chart are the sample positions, while the left hand panels illustrate palynomorph ranges and/or quantitative palynological characteristics of each sample. To the right, where, available is ostracod range data (Stephenson et al., 2002; Williams, 2001, 2002a, b).

By noting the ranges of autochthonous algal palynomorphs, it has been possible to relate the latter to the palaeoenvironments suggested by ostracods.

3.1 HEADS OF AYR SECTION

The Heads of Ayr section (Figure 1) shows the most continuous sections of biofacies associations as shown by ostracods. Between approximately 235 m and 260 m, Association 1 (tidal flat palaeoenvironment) is present, and this part of the section is shown by a complete absence of autochthonous algal palynomorphs. Between 160 m and 185 m, Association 2 (brackish-quasi marine palaeoenvironment) is present; this is associated with *Chomotriletes* spp., *Leiosphaeridia* spp., *Leiosphaeridia* sp. A and microforaminiferal test linings. Between 92 m and 135 m, Association 3 (low salinity to freshwater environment) is present. This is associated with *Chomotriletes* spp., *Leiosphaeridia* spp., *Botryococcus* spp. and *Leiosphaeridia* sp. A.

The absence of autochthonous algal palynomorphs in the probably fully marine Association 1 palaeoenvironment, might be expected in that the algal palynomorphs present in other parts of the Ballagan Formation, e.g. *Botryococcus* spp. and zygnemataceaen algae, occupy fresh or brackish water environments. Hence the salinity of the water on the tidal flat was probably too high for this type of algae to grow.

The algal palynology, as suggested by the Heads of Ayr section, of Associations 2 and 3 is similar, though *Botryococcus* is present in Association 3 and not in 2, while the converse is true of microforaminiferal test linings. The latter are associated with marine conditions (Stancliffe, 1996) and though their presence may indicate more saline conditions than is suggested by Williams (2002a) for Association 2, the absence of microforaminiferal linings from Association 3 tends to reinforce the evidence of ostracods for Association 2 being more saline than Association 3.

3.1.1 Statistical analysis of palynological and ostracod data in the Heads of Ayr section

Quantitative palynological and presence/absence ostracod data from the Heads of Ayr section was analysed with Principal Components Analysis (PCA) to gain objective definition of possible associations within the ostracod population and between ostracods and autochthonous algal palynomorphs. PCA involves the simplification of multivariate data in which many variables (taxon frequencies) are transformed into a smaller number of composite variables (known as principal components). The method used here to identify associations of taxa is that of Birks and Birks (1980), where the component loadings of the first two unrotated principal components are plotted against each other on a scattergram (Figure 5).

The distribution of ostracod taxa on the scattergram suggests two associations:

1. *Paraparchites* sp. 1, *Cavellina coela*, *Cavellina incurvescens* and *Knoxiella* sp. A.
2. Cf. *Bairdia jakutika,* Large postplete ?paraparchitacean, *Acratia*? sp., *Beyrichopsis*? sp., Robust ?cavellinid, Paraparchitacean sp. B, *Shemonaella* sp. B and *Shemonaella* sp. A. and *Acutiangulata* cf. *aequalis.*

These associations broadly correspond with those established by Williams (2002a), since 1 (above) is similar to Association 1 (tidal flat) of Williams (2002a) and 2 (above) is similar to Association 2 (brackish-quasi marine) of Williams (2002a), however it should be noted that the above PCA includes data from only one section and not four sections as does the analysis of Williams (2002a). Another point of concern is that only presence/absence data is available for ostracods; this may partly account for the rather low variance (31%) accounted for by the first two principal components. Such a low variance indicates low statistical significance for the clustering in the scattergram.

Perhaps most interesting about the distribution of taxa on the scattergram, is the clustering of algal palynomorphs such as *Botryococcus* spp., *Chomotriletes* spp., *Leiosphaeridia* spp. and *Leiosphaeridia* sp. A with the freshwater ostracod *Sulcella* sp. This supports the view that most of the algal palynomorphs of the Ballagan Formation occupied freshwater (to brackish) rather than saline water.

3.2 SPILMERSFORD BOREHOLE

This sequence (Figure 2) shows shorter more discrete sections of ostracod biofacies/palaeoenvironments, than the Heads of Ayr section. The vertical distance between these discrete sections and the lack of many coincident palynological assemblages containing autochthonous algal palynomorphs, makes relationships like those indicated in the Heads of Ayr more difficult to establish in this section. Overall, however, a similar relationship is present; *Chomotriletes* spp., *Leiosphaeridia* spp, *Leiosphaeridia* sp. A and *Leiosphaeridia* sp. B are present within the range of Association 3 and similar taxa are present within the range of Association 2.

3.3 EAST DRON BOREHOLE

This sequence also shows short discrete sections assignable to ostracod biofacies/palaeoenvironments (Figure 3). On the whole, though, the East Dron Borehole shows no evidence, from the ostracods, of the low salinity to freshwater biofacies/palaeoenvironment Association 3, and this may explain the relatively low occurrence of autochthonous algal palynomorphs since low salinity, in general, appears to favour the growth of their parent algae. Within the long section between approximately 53 m and 190 m, which is mainly assigned to Association 2, the following autochthonous algal palynomorphs occur: ?*Deuselites* sp., Cf. *Palambages* sp., *Botryococcus* spp. and *Chomotriletes* spp.

3.4 GLENROTHES BOREHOLE

The yield of ostracods from the Glenrothes Borehole (Figure 4) was poor (Williams, 2001) and this allows only small parts of the section to be assigned to ostracod biofacies/palaeoenvironment associations. The vertical distance between these discrete sections and the lack of many coincident palynological assemblages containing autochthonous algal palynomorphs makes relationships like those indicated in the Heads of Ayr difficult to establish in this section. However, an interesting assemblage occurs at 357.30 m in the Glenrothes Borehole. It contains *Leiosphaeridia* spp., Cf. *Tetraporina*, *Reduviasporonites* spp. and *Leiosphaeridia* sp. D. The sample is 90 cm below another analysed for ostracods that contained the brackish taxon *Shemonaella* cf. *scotoburdigalensis*.

4 Prediction of palaeoenvironment from algal palynomorph assemblages

Figures 6 and 7 illustrate an attempt to predict palaeoenvironment from algal palynomorph assemblages alone.

In the Blairmulloch Borehole (Figure 6), the presence of significant numbers of *Leiosphaeridia* spp., *Leiosphaeridia* sp. A *and Leiosphaeridia* sp. B, as well as the presence of *Botryococcus* spp, *Tetraporina* spp., ?'Monolete spore' of McLean and Neves and *Leiosphaeridia* sp. E between approximately 155 m and 176 m suggest the presence of Association 3 (low salinity to freshwater palaeoenvironment) or Association 2 (brackish-quasi marine palaeoenvironment). Similar environments may also be present around 83.75 m depth in the Blairmulloch Borehole.

Assemblages of algal palynomorphs are not as well developed in the Birnieknowes Borehole as they are in the Blairmulloch Borehole. The presence of *Leiosphaeridia* spp., 'Monolete spore' of McLean and Neves, *R. chalastus* and *R. catenulatus* at 903.4 feet may suggest the presence of Association 3 (low salinity to freshwater palaeoenvironment) or Association 2 (brackish-quasi marine palaeoenvironment) at that level.

5 Conclusions

On the whole it is not possible to discriminate four algal assemblages that correspond directly with the four ostracod biofacies associations determined by Williams (2002a), and hence there are no exact algal palynomorph proxies for these associations. However it is clear, overall, that *Chomotriletes* spp., *Leiosphaeridia* spp, *Leiosphaeridia* sp. A and *Leiosphaeridia* sp. B, 'Monolete spore' of McLean and Neves, *R. chalastus* and *R. catenulatus* are generally present (or abundant) within the stratigraphic range of Associations 2 and 3, and therefore that such an algal assemblage can be taken as evidence for brackish to freshwater conditions. Although many of the palynomorphs described here are of obscure origin, and therefore cannot be directly linked with environment, others, particularly the zygnemataceaen zygospores and *Botryococcus*, were produced by algal taxa that are extant. The modern zygnemataceaen algae and *Botryococcus* are confined to freshwater or brackish bodies of water (Brenner and Foster, 1994; van Geel and Grenfell, 1996; Batten and Grenfell, 1996). Hence the origins of the algae themselves support the interpretation of palaeoenvironme nt from ostracods.

Despite there being no associations of algal palynomorphs consistent with the four ostracod biofacies, at least two associations of algal palynomorphs do occur. The first, which is overwhelmingly dominant is the *Leiosphaeridia* assemblage. Its main taxa are: *Leiosphaeridia* spp., *Leiosphaeridia* sp. A, *Leiosphaeridia* sp. B, *Botryococcus* spp. and *Chomotriletes* spp. It is present in all the sections studied. The second, which has been recorded from only two samples in the Glenrothes and Birnieknowes Boreholes, is the *Reduviasporonites* Assemblage; its main taxa are *Leiosphaeridia* spp., *Reduviasporonites* spp. and *Leiosphaeridia* sp. D. Both these assemblages appear to indicate brackish or freshwater conditions but it is not understood why they differ.

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FIGURES

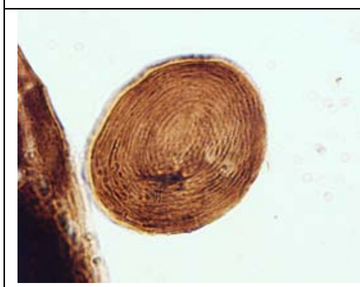
Plates

Algal palynomorphs of the Ballagan Formation

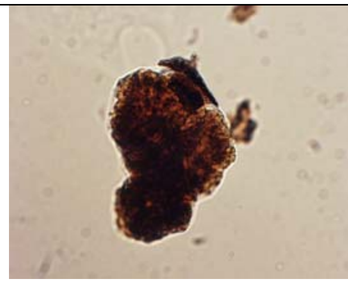
R. chalastus, 019/4, 51101, B

?R. chalastus, F20/2, 51101, B

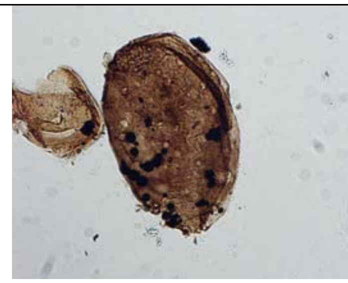
?R. chalastus, F26, 51101, B



Chomotriletes sp. F30, 51101, B



Botryococcus sp. F24/1, 51101, B



?'Monolete spore' of McLean and Neves, H21/2, 51101, B

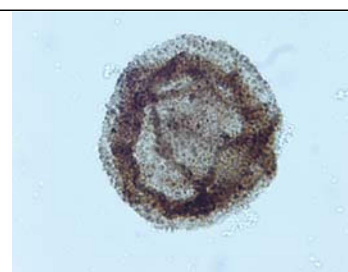
?'Monolete spore' of McLean and Neves, O13/3, 51101, B

?'Monolete spore' of McLean and Neves, Y9, 51101, B

R. catenulatus, U31/4, 51101, B

Leiosphaeridia sp., G3/3, 51101, B

'Monolete spore' of McLean and Neves, Q24, 30030, G



Cf. Peltacystia sp. 1 V9/4, 50654, G

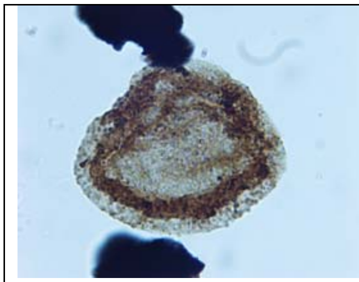
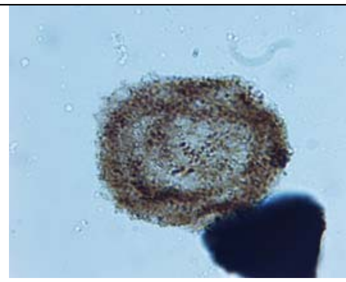
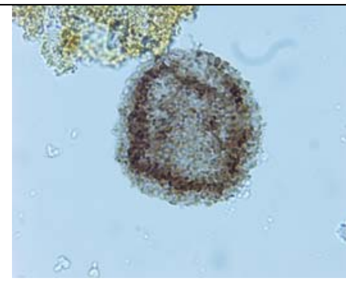
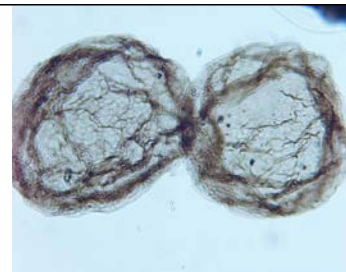
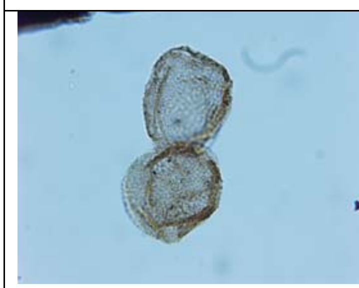
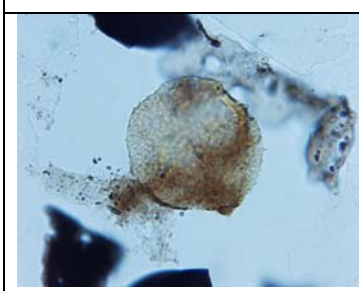
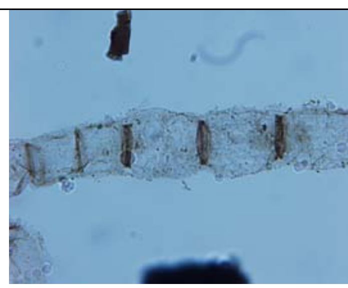
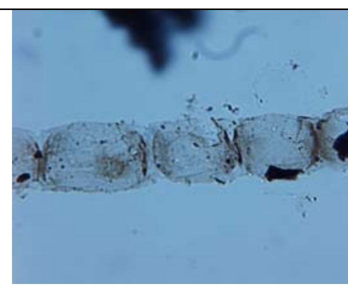
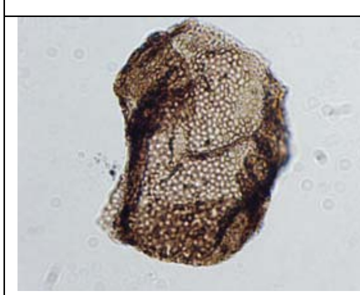
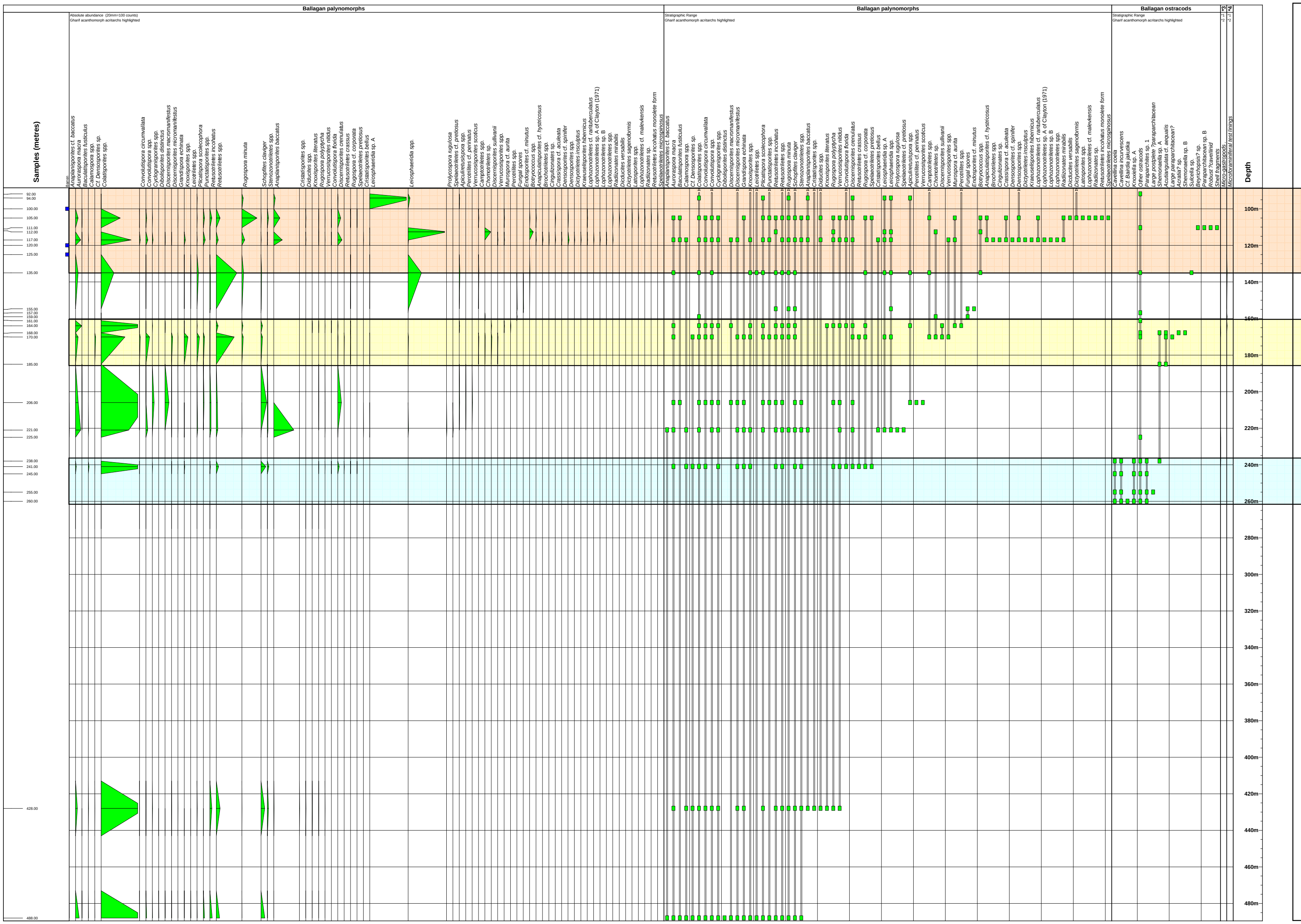
 Cf. Peltacystia sp. 1, U29/1, 50654, G	 Cf. Peltacystia sp. 1, W18/3, 50654, G	 Cf. Peltacystia sp. 1, T9 50654, G
 Leiosphaeridia sp. D, N5/4, 50641, G	 Leiosphaeridia sp. D, U24 50641, G	 Leiosphaeridia sp. L16/2, 50657, G
 Lophosphaeridium sp. A Q18/1, 50654, G	 Lophosphaeridium sp. A, Q29/3, 50654, G	 Lophosphaeridium sp. A U19/1, 50653, G
 Lophosphaeridium sp. A, R20/3, 50653, G	 Reduviasporonites chalastus., J35, 50641, G	 Reduviasporonites chalastus., G29/4, 50641, G
 Leiosphaeridia sp. A, F20, 51039, S		

Fig.1 Stratigraphical relationship between autochthonous algal palynomorphs and palaeoenvironments as determined by ostracods, Heads of Ayr Section



Ostracod palaeoecological associations (See Williams 2002a)	Autochthonous algal palynomorphs
Association 3 Low salinity to freshwater	*Chomotriletes* spp. *Leiosphaeridia* spp. *Leiosphaeridia* sp. A *Botyrococcus* spp.
Association 2 Brackish-quasi marine	*Chomotriletes* spp. *Leiosphaeridia* spp. *Leiosphaeridia* sp. A Microforam linings
Association 1 Tidal Flat	No autochthonous algal palynomorphs

Fig. 2 Stratigraphical relationship between autochthonous algal palynomorphs and palaeoenvironments as determined by ostracods, Spilmersford BH

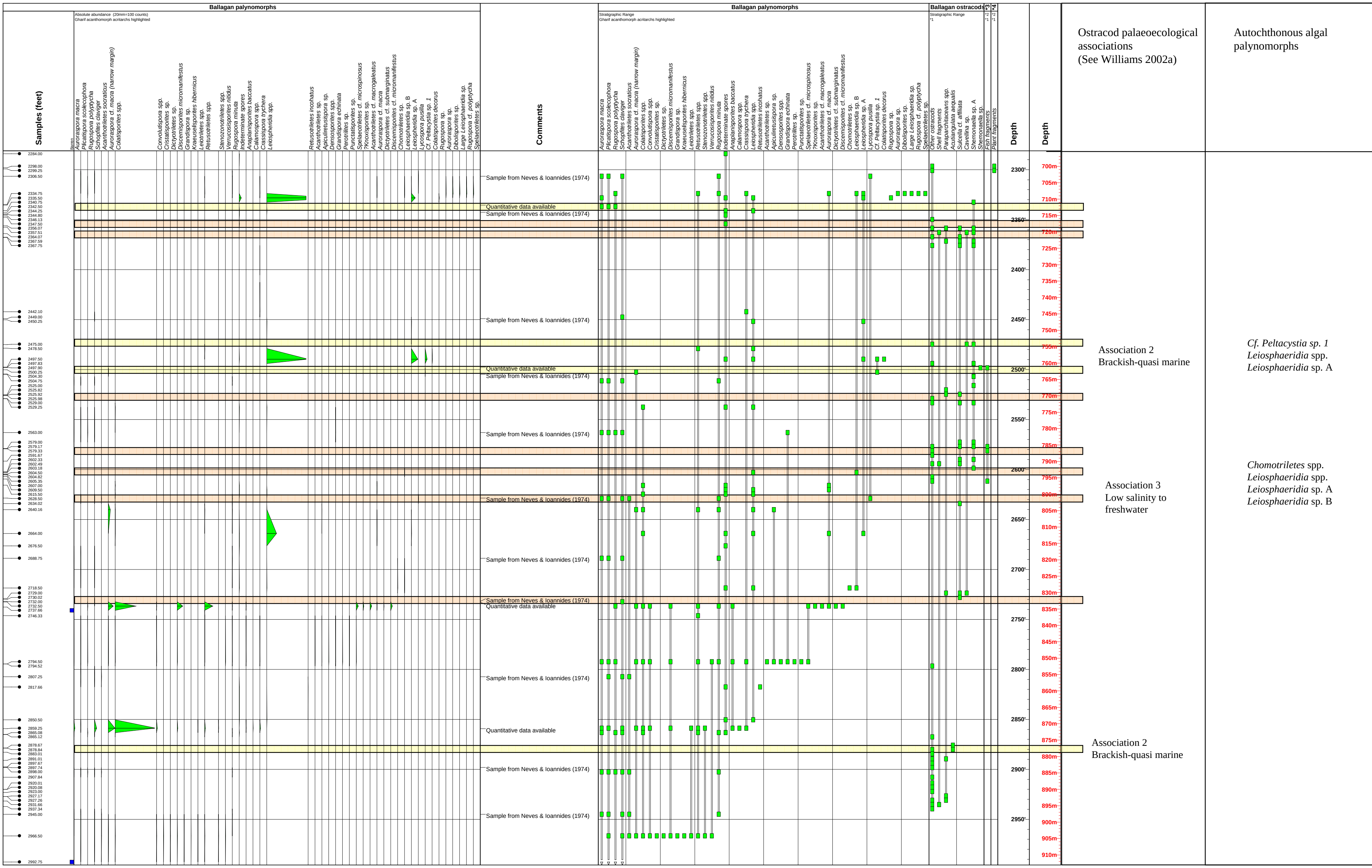


Fig. 3 Stratigraphical relationship between autochthonous algal palynomorphs and palaeoenvironments as determined by ostracods, East Dron BH

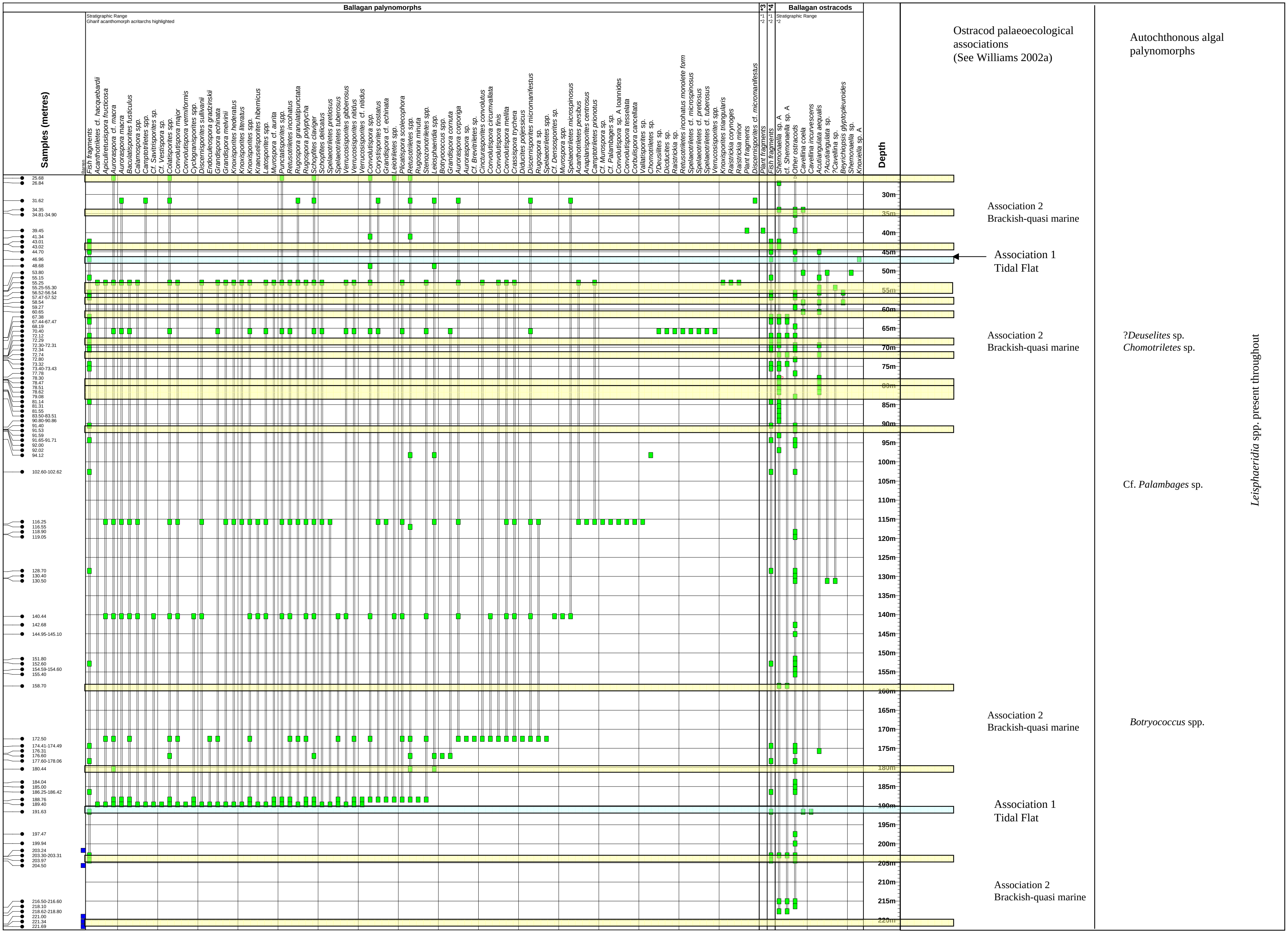


Fig. 4 Stratigraphical relationship between autochthonous algal palynomorphs and palaeoenvironments as determined by ostracods, Glenrothes BH

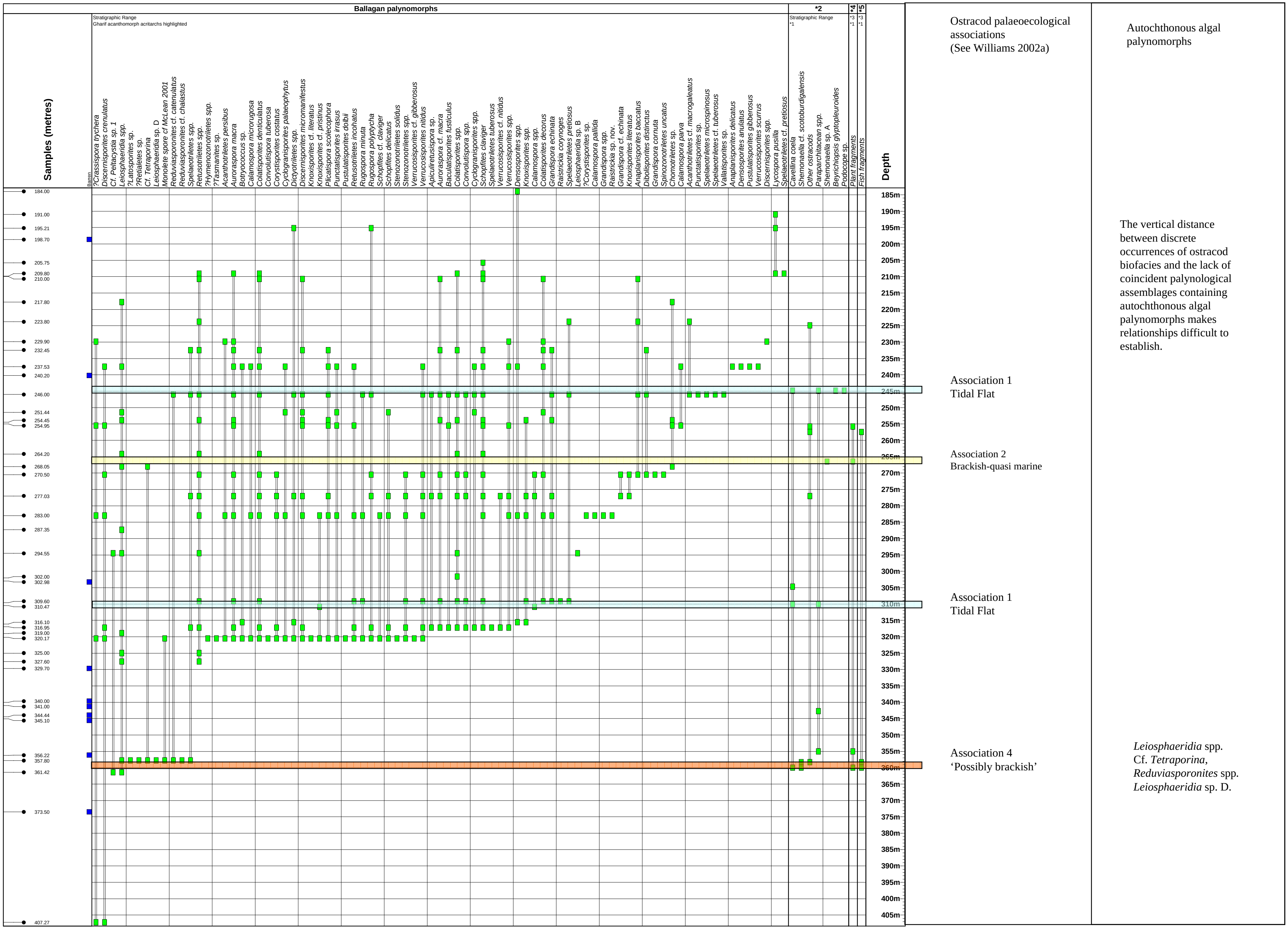


Fig. 6 Predicted palaeoenvironments from autochthonous algal palynomorphs, Blairmulloch BH

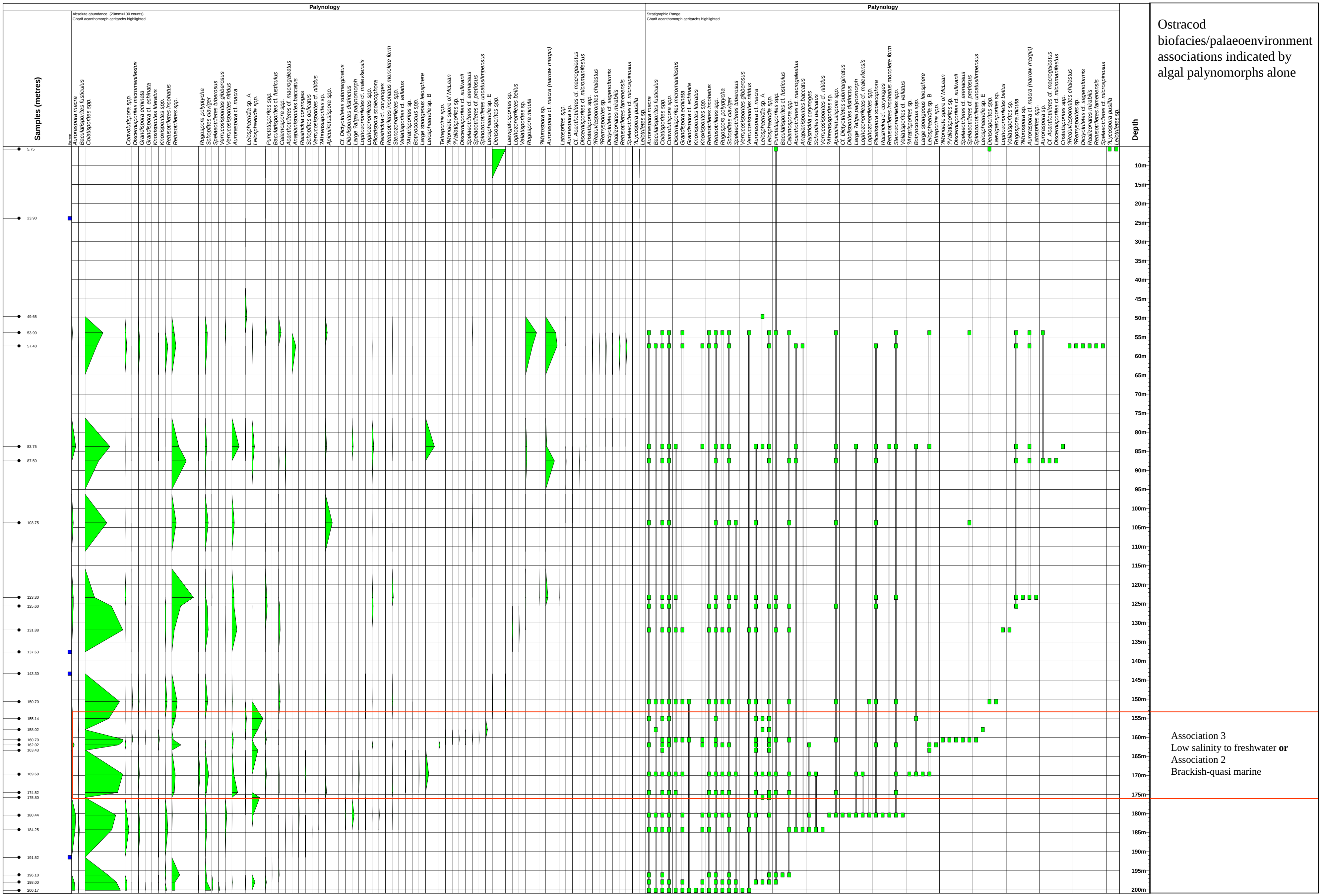


Fig. 7 Predicted palaeoenvironments from autochthonous algal palynomorphs, Birnieknowes BH

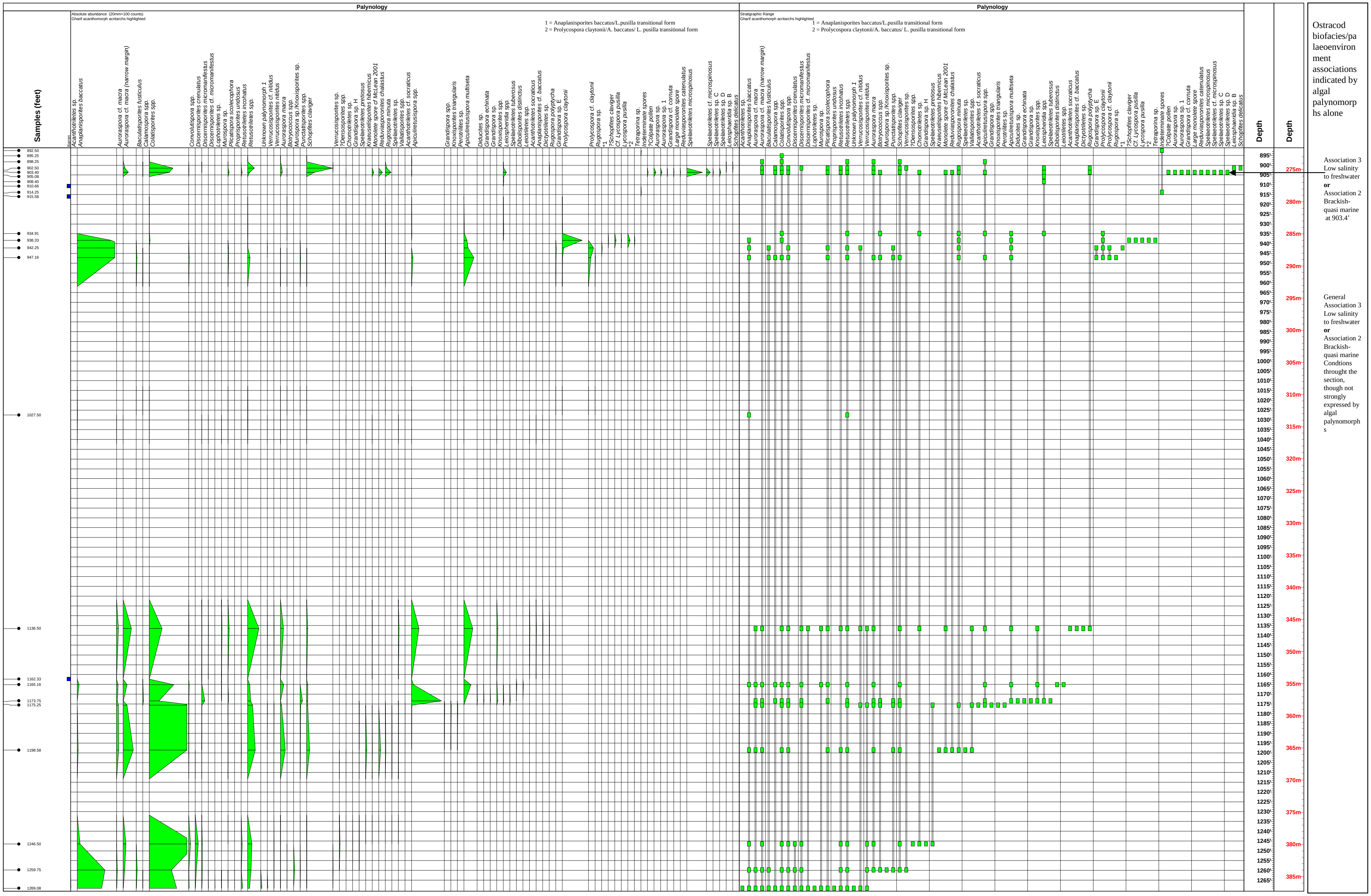


Fig. 5 Heads of Ayr, palynomorphs and ostracods, Variables (axes F1 and F2: 31 %)