High resolution comparative palynostratigraphy and palaeoecology of Oligocene sequences in the terrestrial basins of the Western British Isles and the marine North Sea Basin.

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Volume I

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Summary

Oligocene sediments from six terrestrial basins in western Britain and two boreholes from the North Sea Basin were studied. These Oligocene sequences are dominated by claystones with silts, sands, conglomerates and lignites. From these sediments 116 samples were processes for a quantitative palynological study. Taxa encountered included 142 genera and 264 species.

Using palynological associations and the ranges of taxa the two North Sea Basin sections could be correlated with the data from the western British Isles basins. A fall in sea level at the Rupelian/Chattian boundary was evident from the data enabling absolute ages to be defined for the correlative events between the marine sequences. Upto now the ages of the terrestrial Oligocene sediments in western Britain have been poorly constrained. It was found that the pollen and spore events of the marine sequences could be seen in the data from the western British Isles allowing, for the first time, a high resolution comparative palynostratigraphy for the Oligocene sequences of North and West Britain.

The distribution of the taxa encountered and statistical tests on the data indicate a fall in sea level at the Rupelian/Chattian boundary and three local transgressive events (two in the Upper Rupelian and one in the Upper Chattain).

The Rupelian palaeoecology suggests mixed mesophytic forests surrounding floodplain areas with floodplain swamp development. This changes into the Chattian with secondary dryland and primary forests taking over from the mixed mesophytic forests. The fall in sea level and associated fall in base level generates instability leading to fluctuating floodplain swamp environments. A similar situation is envisaged for eastern England where the dominance of mixed mesophytic forests and coastal littoral swamp environments changes to more open, drier forests and unstable coastal swamps.

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CHAPTER 1

AIMS AND INTRODUCTION

AIMS

Previous studies have been undertaken on the sedimentology and palynology of UK terrestrial Oligocene sediments. These include Chandler (1957) on the Bovey Basin, Herbert-Smith (1972) on the Mochras Borehole Cardigan Bay, Watts (1970) on the Lough Neagh material, Evans *et al.* (1979 & 1991) on Sea of the Hebrides material and Boulter & Craig (1979) on the Stanley Bank Basin. The work of Wilkinson (1979 unpub. PhD thesis) and Wilkinson & Boulter (1980) working on Bovey Basin, Cardigan Bay and Lough Neagh provided a more detailed palynological study and comparison of this material. But despite the efforts of Wilkinson & Boulter between 1977 and 1980, no clear understanding of the stratigraphical distribution of the Western British Isles sediments either relative to each other or in relation to the marine Oligocene of the British Isles and to the European stages, was attained.

The aims of this project are to redress these problems, so as to be able to date the western British Isles sequences more accurately. A detailed Palynological investigation undertaken firstly; using binomial taxon (rather than the Form groups of Boulter (1979) and Wilkinson & Boulter (1980)) and secondly; analysing marine sections containing both dinoflagellates and pollen and spores, from the North Sea, along side terrestrial sections of a similar Oligocene age containing only pollen and spores from western Britain, to achieve the objectives.

It was realised that some pollen and spore events would differ from one side of the country to the other, from the terrestrial sections on the west to the marine sections on the east of the country, as they are in different facies. But it was anticipated that the controlling factors of climate, evolution and sea level changes would be reflected in the palynological records from both east and west Britain.

An initial subsidiary aim of the project was to deduce local sea level conditions and to assess the distribution of different vegetational types in the period initially prior to the onset of the first significant Antarctic glaciation.

INTRODUCTION

To resolve the problems outlined in the aims of this project, material for palynological processing was collected from a number of known, or suspected, Oligocene deposits in the Western British Isles and the North Sea. Wilkinson & Boulter (1980) concentrated their worked on Oligocene deposits in the Bovey Basin, Cardigan Bay Basin, the Lough Neagh Basin, the Stanley Bank Basin and the Canna Basin (figure 3.1). In this project three areas of Oligocene sediments from offshore

Scottish boreholes drilled by the British Geological Survey (BGS) were sampled. Two sections from the Little Minch Basin in the Sea of the Hebrides were sampled. Firstly, core samples from 80/14 were taken following the initial observations of Jolley in Evans *et al.* (1991) and secondly core samples from 88/12, a problematical borehole adjacent to 80/14 were taken. Core samples taken from the Canna Basin, 78/1, previously studied by Wilkinson in Evans *et al.* (1979) was re-examined here. Borehole 77/7 was drilled through sediments of an unknown age on the flank of the Solan Bank High, and core samples were taken from this section. Also core samples from a one small section, well 28, from the western side of the Lough Neagh Basin were examined.

Material was made available by UNOCAL from two North Sea wells namely 16/16b-4 and 21/28b-7 from the South Viking Graben and the Outer Morray Firth (figure 3.11). These samples were in the form of ditch cuttings; wireline log information was also provided.

A significant aim of this project is to correlate the terrestrial and marine sequences examined from the Western and Eastern British Isles. Later in the study, the potential importance of marine influences documented in the Stanley Bank Basin and the Teiffe Basin (Boulter & Craig, 1979 and Tappin *et al.*, 1994 respectively) was seen. This was followed by a second period of sampling, time constraints allowed only one of these areas to be sampled, it was decided a section from the Stanley Bank Basin previously examined by Boulter & Craig (1979) would be collected to enable a direct comparison of their work to the results of this project. Here core samples were taken from the deepest borehole penetrating this basin namely, 73/36.

An outline of the work involved after the material was collected is given below:

1) Familiarisation with the terrestrial palynomorphs of the Oligocene and collecting detailed palynological data from six terrestrial sections examined
2) Defining 'associations' and 'pollen and spore events' for the six terrestrial sections examined
3) Relative dating of the six terrestrial sections examined
4) Familiarisation with the marine palynomorphs of the Oligocene and collecting detailed palynological data from the two marine sections examined both for dinoflagellate and pollen and spore information
5) Relative and absolute dating of the marine sequences
6) Comparison of the marine pollen and spore data to the terrestrial pollen and spore data
7) Absolute dating of the pollen and spore events
8) Palynofloral conclusion and associated palaeovegetation, palaeotemperature and palaeoenvironmental interpretations

The marine sequences which were expected to be relatively poor in pollen and spores were actually, surprisingly rich. This enabled an accurate and direct correlation of pollen and spore "associations" between the marine and terrestrial sequences, constrained by an 'absolute' time framework provided from the dinoflagellate study. This calibrated the terrestrial and marine records for the British Oligocene, defining what were once arbitrary and dubious ages for the Oligocene boundaries in the Western British Isles.

Subsequent to sampling of the offshore Sea of the Hebrides Basins at BGS Edinburgh and the kind help of Dan Evans, seismic and gamma ray log information relating to the area was unexpectedly made available. This extra information has enabled a more detailed correlation between the sections both lithologically and seismically and to look at the basin structures both sedimentologically and palynologically.

Thesis Layout

To give continuity to the presentation of the results and the interpretations laid up on them, this thesis is split into two volumes. The first volume consists of the aims and introduction followed by the descriptive work, then the interpretations and conclusions. It is hoped this will give continuity to the reader and allow the development of the arguments in a logical order. The second volume consists of the laboratory methods for the preparation of palynological slides and the systematical treatment and description of the palynomorphs encountered in this project, this is followed by a list of references used and the appendix. Finally volume three contains illustrations, in the form of colour plates, of the taxa described in the project.

CHAPTER 2

OLIGOCENE EPOCH AND SUCCESSIONS OF NW EUROPE

AIMS

The scope of this project focuses on Oligocene aged sediments. The Oligocene successions of NW Europe and the general position of the Oligocene within the Tertiary period (figure 2.1) along with the range of time that this epoch is thought to represent are discussed.

The relative position of the base of the Oligocene sequences over NW Europe is discussed and the sequence of Oligocene continental beds in southern England, which are restricted to a Lower Oligocene age, are described. This is followed by a description of the equivalent and more continuous Oligocene marine sequences from the North Sea. Figures 2.2 and 2.3 present an illustrative correlation of Oligocene stratigraphical divisions, firstly throughout NW Europe and secondly throughout the British Isles, to give an overall view of the sedimentary beds and units at this time.

TIME SCALES

The Oligocene epoch occurs within the Tertiary time period. In the literature numerous time scales have been proposed, a selected few are summarised in figure 2.1, focusing on the Palaeogene period. In this work the author is using the Cande & Kent (1992, 1995) time scale, which is based on isotope dated magnetostratigraphy from the South Atlantic. From this it can be seen that the Oligocene epoch is thought to account for an approximate time interval of 10.3 Ma.

Period		Epoch	Stage	Harland et al 1990	Cande & Kent 1992 & 1995	Haq et al. 1987
TERTIARY	Neogene	Pliocene	Piacenzian	1.64Ma	1.8Ma	1.65Ma
			Zanclian	5.2Ma	5.5Ma	5.2ma
		Miocene	Messinian			
			Tortonian			
			Serravallian			
			Langnian			
			Burdigalian			
			Aquitanian	23.3Ma	24.23Ma	25.2Ma
	Palaeogene	Oligocene	Chattian	29.3Ma	28.26Ma	30Ma
			Rupelian	35.4Ma	33.05Ma	36Ma
		Eocene	Priabonian			
			Bartonian			
			Lutetian			
			Ypresian	56.5Ma	55Ma	54Ma
		Palaeocene	Thanetian			
			Danian	65Ma	66Ma	65.5Ma

Figure 2.1 To show the position of the Oligocene within the Tertiary time period

OLIGOCENE DEPOSITS AND CORRELATION OF NW EUROPE

The material studied in this work was chosen with the aim of closely correlating the material from minor terrestrial Tertiary basins that have developed along the Western British Isles, namely, the Sea of the Hebrides Basin, the Canna Basin, the Rona Basin and the Stanley Bank Basin. The sediments encountered in these basins were collected from numerous BGS Boreholes in these areas mentioned above which have been suggested to be Oligocene in age. Marine North Sea sediments of this Oligocene age were also sampled and processed in an attempt to correlate the marine sections with the various terrestrial sections from the Western British Isles, to more accurately date the sediments in these basins, than has been possible in the past. The uncertainty of the precise ages of the sediments from these basins studied in this work is shown in figure 2.3. This figure is compiled from the available literature, the question marks at the boundaries of the sedimentary sequences show that definite, more precise age ranges have been unobtainable upto now.

A detailed discussion and synthesis of Tertiary stratigraphy (including the Oligocene) and correlations between NW European sediments is found in Curry *et al.* (1978, 1992). His suggestions are tabulated along with more recent work to give an overall review of the Oligocene stratigraphy in NW Europe (figures 2.2 and 2.3).

The term Oligocene was created by Beyrich (1854) in Germany for the marine Latdorf sands which form the lowest unit of the Oligocene series, the Lattorfian (Mayer-Eymar, 1893). The distinct mollusc faunas of the Latdorf are closely similar to those of the Brockenhurst beds in the British Isles and thus the base of the Oligocene was traditionally taken here. However the Nannoplankton work of Martini (1971) showed the Brokenhurst Beds to be NP20 which is distinctly older than the Latdorf Sands (which are regarded as NP21) and are therefore actually Late Eocene in age (See figure 2.2 for NP biozones).

As the facies of the British and German successions are very different, it is difficult to locate the base of the Oligocene, but it is proposed to occur between the marine Middle Headon Beds (Brokenhurst Beds) and the later Upper Hamstead Beds. The Bembridge Oyster Beds of the Bouldnor Formation occur in this position and are therefore regarded as the base Oligocene in the UK, where present, although no faunal evidence supports this.

Continental Beds

The Bouldnor Formation in southern England starts with a restricted marine incursion from the east (Curry, 1992), this is characterised by the lowest unit of the Bembridge Marls Member, the Bembridge Oyster Beds. These Oyster Beds occur as thin sands with flint pebbles and mollusc faunas and are best developed on the Isle of Wight. The remainder of the Bembridge Marls Member consists of dominantly grey clays with subordinate sands which Daley (1973) suggests are formed in brackish lagoons or floodplains. Next in the succession is the Hamstead Member, the lowest units are clays with freshwater mollusc, plant and mammal remains. This passes up into monotonous grey green marls which have layers of freshwater and brackish mollusc faunas and dinoflagellate cyst floras. Above this is the Cranmore Member which is the highest unit of the Bouldnor Formation, it is composed of thin clays which are dominated by esturine faunas at the base, these become increasingly saline although never reach marine salinities. It is suggested (Curry, 1992) that the terrestrial Oligocene succession ends at this level with a time gap of about 25 Ma, when only North Sea marine sediments were been deposited, until the Late Miocene when continental deposition began again with the Lenham Beds.

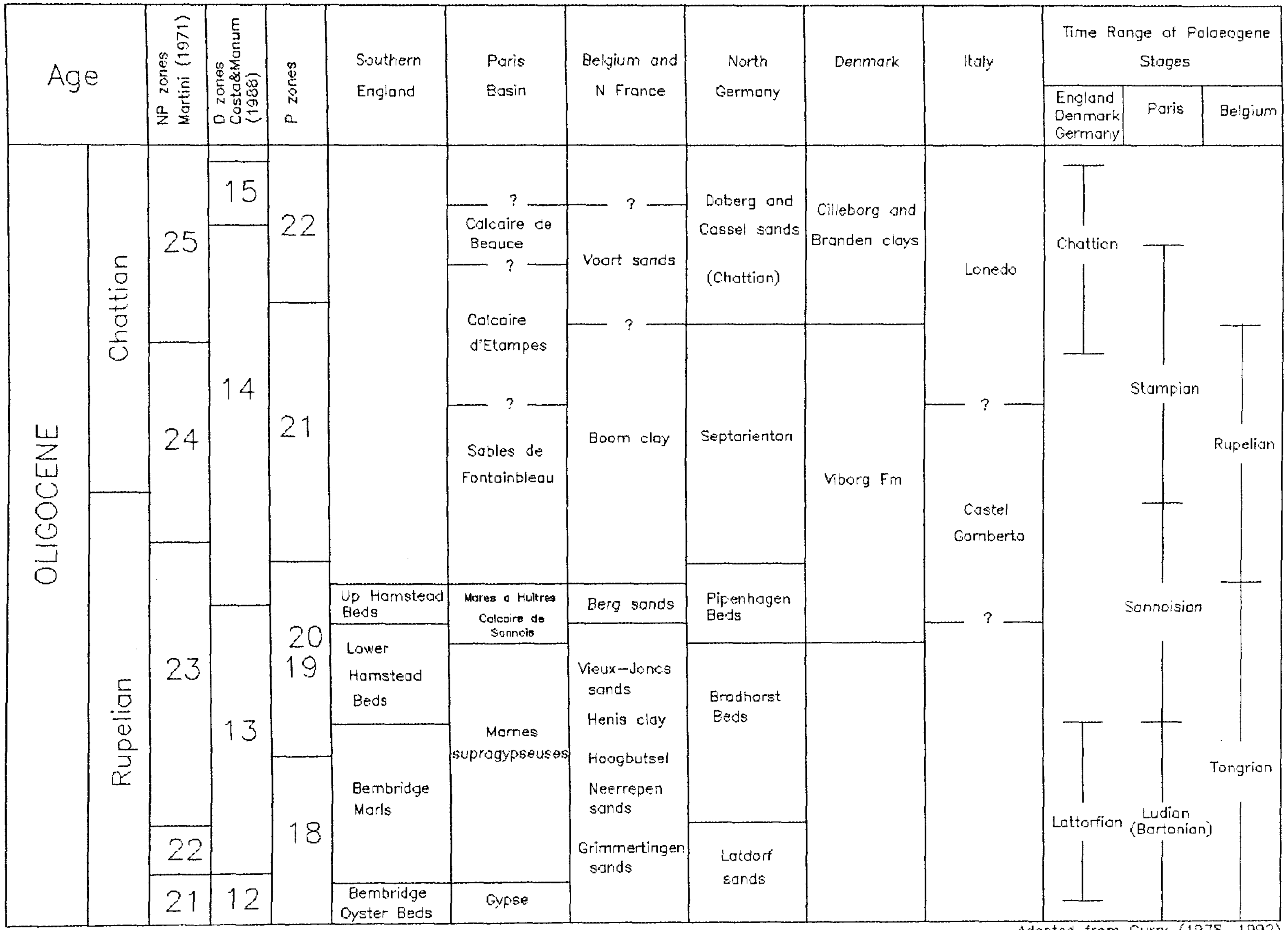
Minor Continental Deposits

During the time of deposition of the Oligocene continental deposits and the 25 Ma time gap, mentioned above, minor continental sedimentary sequences were deposited along western Britain in fault controlled basins such as Bovey, Stanley Bank, Petrockstow and basins associated with lava plateau regions such as Lough Neagh and Sea of the Hebrides. It is these deposits that are poorly constrained on the time scale (figure 2.3), being hesitantly assigned to the Middle to Late Oligocene by some authors (e.g. Evans *et al.*, 1979 1991; Chandler, 1957; Herbert-Smith, 1979 and Boulter & Craig, 1979). It is the aim of this project to examine these deposits and to determine the relative timing of deposition of these various basin sediments.

North Sea Marine Sequence

A different story is seen in the North Sea Basin where subsidence and deposition occurred relatively uninterrupted through the Oligocene to the present day. The sediments deposited in these sequences were formally described as the undifferentiated Hordaland Group (Deegan & Scull, 1977) and they ranged from the Late Eocene to Miocene and consisted of marine grey brown soft fossiliferous shales with thin limestones, with localised sandstones in the Viking Graben area, the Grid Sandstone. This sandstone is Late Eocene to Early Oligocene in age, it is fine to medium grained and blocky in appearance. Derivation is suggested by Isaksen & Tonstad (1989) to be from the East Shetland Platform. Another localised sandstone is the Skade Formation which is fine to medium grained. This sandstone is Late Oligocene in age and is thought to represent an environment showing a reduction in sea level.

The 1992 UKOOA report on the Palaeogene of the Central North Sea revised the work of Deegan & Scull (1977), replacing their undifferentiated Hordaland Group with the Stronsay and Westray groups. The Westray group sediments represent an Early Oligocene to Early Miocene age and are described as brown mudstones with glauconite, deposited in symmetrical fill basin tectonics, with relatively shallow water conditions of deposition being suggested (Andrews *et al.*, 1990). Two formations occur within this group (figure 2.3). The Skade Formation (Isaksen & Tonstad, 1989) is dominated by shelf sand facies (inner shelf) with glauconitic siltstones and sandstones. The sandstone is fine to coarse grained and is shelly. The sandstones of the Skade pass eastwards into grey brown mudstones of the Lark Formation. The Lark Formation (UKOOA, 1992) represents distal shelf sediments, these are monotonous grey brown mudstones with silty patches which grade up into the Skade Sandstones.



Adapted from Curry (1978, 1992)

Figure 2.2 Oligocene stratigraphical divisions of NW Europe

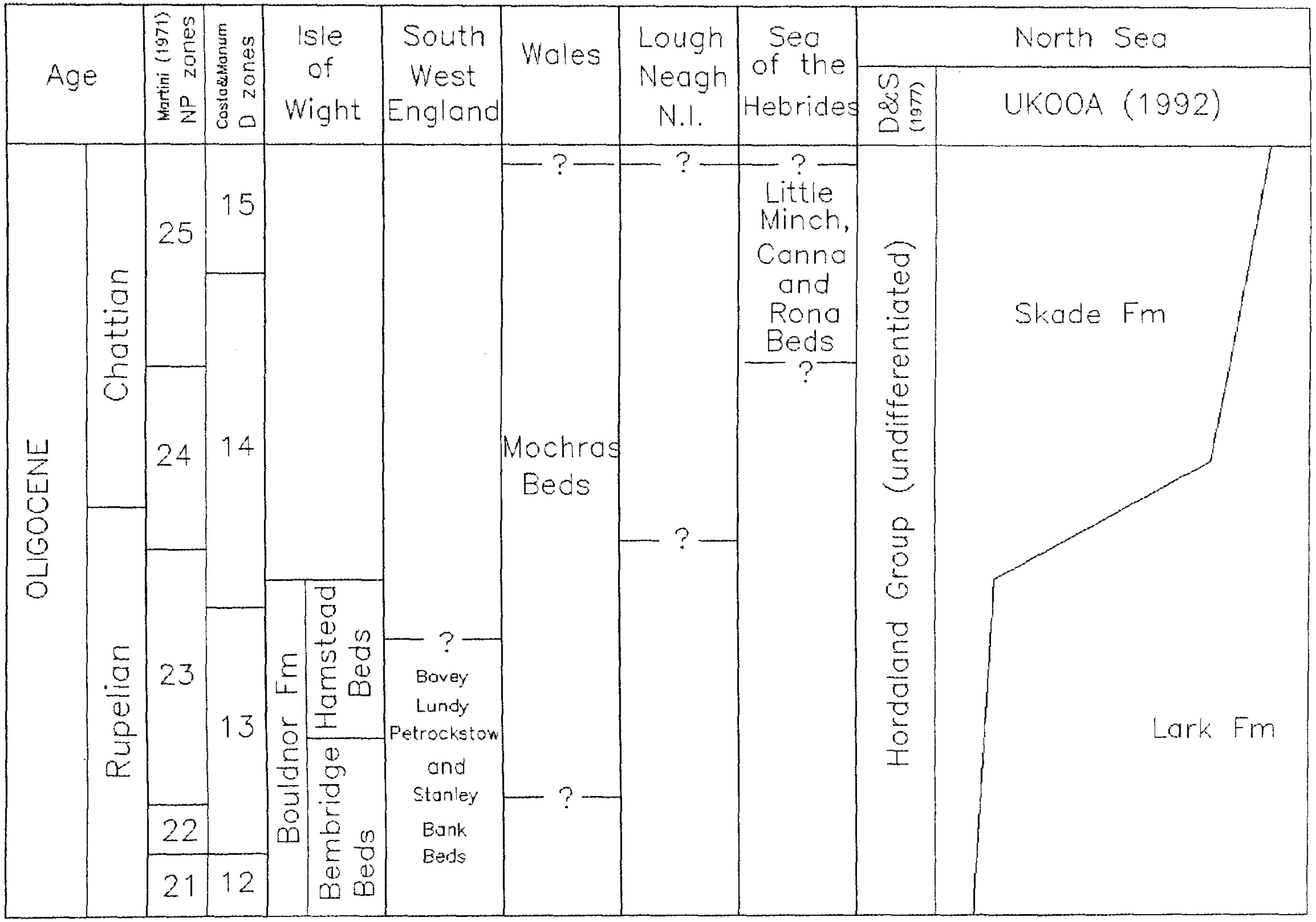


Figure 2.3 Oligocene stratigraphical divisions in the British Isles

CHAPTER 3

TERTIARY BASINS IN THE WESTERN BRITISH ISLES

Several isolated Tertiary basins occur along the Western British Isles (figure 3.1). These include the basins from which material has been worked on by the author for this project such as; the Little Minch Basin, and the Canna Basin from the Sea of the Hebrides, the Rona Basin and Solan Bank High, the Stanley Bank Basin, the Lough Neagh Basin in Northern Ireland and the North Sea Basin. Before any descriptive or interpretive results from this work can be presented, it is important to consider the general geology and setting of each of the basins involved. Also a brief account of other important Tertiary basins along the Western British Isles such as; the Cardigan Bay Basin, the Bovey Basin and the Petrockstowe Basin, which have been studied by other workers and not in this current work. These have been included to give a more complete picture of what is happening during this time period over the area and to enable any data from these basins to be used as a detailed comparative, to the work of this study.

SEA OF THE HEBRIDES AREA

The Sea of the Hebrides Basin and Little Minch Basin lie between the Outer Hebrides, to the west, and the Isle of Skye and the Scottish Mainland to the east, figure 3.2 shows the locations of the boreholes sampled from this area in this project. Offshore geological mapping of the area has been carried out by the BGS and is well documented in the literature. Most of this work was done in the 70's and early 80's as part of the BGS offshore mapping programe by McQuillin & Binns (1973), Binns *et al.* (1975), McQuillin *et al.* (1975), Smythe & Kenolty (1975), Chesher *et al.* (1983) and more recently Fyfe *et al.* (1993) using such methods as;

1. Areomagnetics
2. Deep seismic refraction and reflection
3. Gravity and Magnetic surveys
4. Shallow coring

Evidence shows that the Pre-Quaternary Geology of the area is controlled by two principle faults, the Minch Fault and the Camasunary-Skerryvore Fault. These form the western margins to a set of NE-SW trending parallel deep asymmetric sedimentary basins. These basins are floored by downfaulted Precambrian and Palaeozoic rocks.

The largest of these basins is the Sea of the Hebrides Basin this extends SW from beneath the Skye Tertiary Lavas until it wedges out against the Minch Fault (figure 3.3). This fault separates the basin from the extensive platform of Lewisian Gneiss to the west which forms the footwall of the fault. The Little Minch sedimentary Basin is the northerly extension of the Sea of the Hebrides Basin. The Little Minch Basin finishes to the north against a Precambrian (Torridonian) structural high (figure 3.3) which crosses the Little Minch to the NE of the Shiant Isles. To the north of this structural high lies the North Minch Basin, this is bounded to the east by an outcrop of Precambrian rocks of the mainland (as the Camasunary-Skerryvore Fault does not appear to continue north of Rassay) and bounded to the west by the Minch Fault. The North Minch Basin opens out northwards into Basin 'G' of Bott & Watts (1970) and Watts (1971).

Sea of the Hebrides Basin

The Sea of the Hebrides Basin is the most extensive of the basins described here, it extends southwest from beneath Skye where it is at its deepest (about 2-3km), to the Minch Fault. This fault forms the western margin to the basin and is a controlling factor in its geometry and development giving this basin the style of a classic half graben. The basin is seen by a negative Bouguer gravity anomaly to the north of Skye, and the Minch fault can be traced by the steep gravity gradient on the Bouguer anomaly map (Binns *et al.*, 1975; Fyfe *et al.*, 1993). The fault runs along the east coast of Harris and continues parallel to the eastern coastline of the Outer Hebrides. Along its length the Minch Fault closely follows the Outer Isles Thrust trend and occurs as a complex system of normal Faults (Chesher *et al.*, 1983) and is believed to be a normal shortcut fault to the Outer Isles Fault (Stein, 1988; O'Neill & England, 1994). However to the north of Lewis the main fault has no close association with the Outer Isles Thrust.

The Minch Fault has a long and complex history, it is described in McQuillan & Binns, (1973) and O'Neill & England (1994). It was initiated as a Caledonian structure, was reactivated by Hercynian stresses and reactivated again during Mesozoic and Tertiary tension.

It was suggested by Smythe *et al.*, (1972) and Chesher *et al.*, (1983) that the basins in the Sea of the Hebrides are floored by Late Precambrian and Palaeozoic rocks. Torridonian sediments were preserved by Devonian movements along the Minch Fault, which was related to the extensional collapse of the Caladonian Orogeny (O'Neill & England, 1994). The 7 km of Torridonian sediments (Stewart, 1988) were deposited as conglomerates and sandstones. A thin wedge of Carboniferous (Westphalian) deltaic sediments have been reported by O'Neill & England (1994). The Mesozoic Basins then developed by downfaulting in an area of extensive Mesozoic, Permo-Triassic and Jurassic, sedimentation. To the west of the Minch Fault these Mesozoic sediments lie unconformibly on 4 to 8 km of (Torridonian) Lewisian (Smythe *et al.*, 1972).

Sedimentation started with the reactivation of the Minch Fault in New Red Sandstone times (Steel, 1971) this gave deposition of red Permo-Triassic sediments, mudstones and sandy mudstones in an allivial fan, floodplain environment and braided stream deposits (Steel, 1971,1974; O'Neill & England, 1994). These Permotriassic sediments are regarded as synrift sediments (O'Neill & England, 1994). The Lower and Middle Jurassic is represnted by shallow marine deposits, such as the Great Esturine series of the Upper Bajocian to Upper Bathonian. The Jurasssic sediments are thicker in the centre of the basin and are interpreted as post rift, thermal subsidence sequences of sediments (O'Neill & England, 1994). Absence of Upper Jurassic and Lower Cretaceous sediments in the Sea of the Hebrides is noted by Chesher *et al.* (1983). During this period of non depositional or erosion prior to the cenomonian transgression, the deposition of Greensand outliers occur throughout the Hebrides area. Although the gravity and seismic modeling of O'Neill & England (1994) suggests thin, discontinuous outcrops of Cretaceous sediments.

Tertiary rocks in the area are mainly volcanics (Binns *et al.*, 1975). These Palaeogene igneous rocks are associated with five plutonic centres (South Skye, Rhum, Ardnamurchan, Mull and Blackstones). Throughout NW Europe this igneous activity came to an end during the Late Palaeocene and Early Eocene. Extensive remnants of this Palaeogene lava cover, of which upto 1.8 km, remain. These are locally downwarped to accomodate Palaeogene sediments. The sediments are produced from the rapid erosion after volcanic ceasation, (Smythe & Kenolty, 1975) and the development of the secondary basins of Oligocene age superimposed on the Sea of the Hebrides Basin, e.g. the Canna Basin and the Little Minch Basin.

The Tertiary history in this inner continental shelf area is similar to that of the continental margin and Rockall trough, where Eocene/Oligocene unconformaty was followed by rapid Oligocene subsidence. This hiatus in sedimentation appears as a prominant seismic reflector (Smythe & Kentoly, 1975) which can be traced from the mid-Atlantic Ridge to the continental margin of Western Britain. Above this reflector all the sediments are Oligocene in age these restricted sediments follow from the Oligocene extensional faulting described by O'Neill & England (1994). Tertiary sediments occur as relatively steeply dipping reflectors at about 20°, dipping towards the centre of the basin (O'Neill & England, 1994).

In this area two main basins are of principle interest to this work. The Little Minch Basin, which is a northerly continuation of the Sea of the Hebrides Basin and the Canna Basin which is a secondary basin within the Sea of the Hebrides Basin (figure 3.3).

Little Minch Basin

The Little Minch Basin is a northerly extension of the Permo-Triassic and Jurassic aged Sea of the Hebrides Basin, which has additional accumulations of Tertiary sediments on its western margin. The extent of the Little Minch Basin, from the 1:250000 OS Little Minch 57N 08W sheeet, shows an elongate basin 27 km by 4 km in size and 250 m in depth, trending NE-SW. In cross section, the Little Minch Basin is trough shaped; O'Neill & England (1994) suggest this is due to extension in the intrabasinal faults which are linked to the Outer Isles Fault at depth. In the Little Minch Basin the sediments are dated as Oligocene (Evans *et al.*, 1991; Fyfe *et al.*, 1993) and occur adjacent to the Minch Fault (figures 3.4a and b). These sediments appear to be fault controlled in structure and dip towards the fault itself (figure 3.4b), sedimentation was helped by rapid Oligocene subsidence (Haq *et al.*, 1987). In BGS borehole 80/14 (figure 3.2) 44.4m of Oligocene clays, sands, lignites occur under a 34.6 m Quaternary cover and form part of this research.

The basin and its sediments are closely associated with the Minch Fault, this is shown by the dominantly conglomeratic sediments from borehole 88/12 (figure 3.2) situated adjacent to the fault although their exact relationship is unknown. It is possible other small Tertiary basins occur along the Minch Fault, but have not been discovered during the offshore mapping of the area by the BGS. Similar structures to these have been found on the NW side of the Tow Valley Fault, in Northern Ireland, where three small Oligocene basins of Lough Neagh group types have been identified on the downthrown side of the fault (Evans *et al.,* 1991).

Canna Basin

The Canna Ridge SE of Skye is a submarine platfrom formed by the Skye Palaeocene Basalt Lavas, on top of which the Isle of Canna sits. NW of the Isle of Canna a small steep sided post lava sedimentry basin is present, the Canna Basin. This basin is similar in structure to the Lough Neagh Basin, Northern Ireland, but half its size. It is described by Smythe & Kentloy (1975) as an ovoid basin 8 km by 20 km in size and greater than 1 km thick. It is an accumulation of sediment on an area of downwarped lava NW of Canna and the Canna Lava Ridge (figure 3.5a and b). The Canna Basin forms part of the Sea of the Hebrides Basin, on the unfaulted downwarped lava pile NW of the Isle of Canna on which sediment of Late Oligocene (Chattian) age (Evans *et al.* 1979) has accumulated and subsided. Gravity and seismic work of O'Neill & England (1994) on the Canna Basin suggests the presence of a fault on the NW side of the Canna Basin and this fault controlled the ramp/flat geometry of the basin. This fault was thought to be active during the Triassic rifting and gave Triassic and Jurassic sediments deposited as a syn rift sequence, it was also active during the Oligocene NW-SE extensional episode (England, 1994), this extension leading to the warping of the lava pile and the development of the Canna

Basin involving fault movement on the Canna Fault under the lavas. This warped lava pile was overlain by the later Oligocene aged sediments (figure 3.5a and b).

NORTH RONA BASIN AND THE SOLAN BANK HIGH

The North Rona Basin lies 100km north of Cape Wrath, ENE of the Islands of North Rona. It is about 35 km by 25 km in size and over 1 km deep (figure 3.1). The Basin was first described by Bott and Watts (1970) and Watts (1971) who identified a series of local negative gravity anomalies and interpreted these as sedimentary basins, 'C' to 'H'. Of these anomalies Basin 'C' and 'D' corrispond to the Stack Skerry Basin and North Rona Basin, respectively these two basins are separated by a NNE trending high, the Solan Bank High (figure 3.6a and b). This high is a belt of shallow Lewisian basement, that passes between the basins encompassing the Islands of North Rona and the Skerries, (Nisbett 1961; Bott 1975) and is one of several NE trending basement highs on the shelf north of Scotland (Stoker *et al.*, 1993). This high is bounded by steep normal faults.

Both the North Rona Basin and Stack Skerry Basin developed in Permo-Triassic times following the change to an extensional regime at that time leading to the development of these half graben basins. The basins are well defined by low Bouguer gravity anomalies and are considered to have a synrift Permo-Triassic infill (Evans *et al.*, 1981).

In the northern part of the North Rona Basin the earlier Permo-Triassic infills were followed by a thin Jurassic sequence, Lower and Upper Cretaceous and Palaeocene sediments. Then, after renewed and more widespread subsidence, the unconformable deposition of post rift Oligocene to Miocene sediments occurred overstepping the older formations and faults and pinching out over the Solan Bank High and thickening towards the slope west of Shetlands (figure 3.6b). The borehole 77/7 (figure 3.1) is located on the north west flank of the Solan Bank High, through the post-rift drape of Oligo-Miocene sediments on this basement high.

CARDIGAN BAY BASIN

The Cardigan Bay Basin is situated offshore and to the west of Wales between the Llyn Peninsula and Pembroke (figure 3.1). The general geological structure is that of an arc of Precambrian and Lower Palaeozoic rocks around a post Palaeozoic sedimentry basin (figure 3.7). The BGS are responsible for the majority of investigative geological work done in this area, with shallow and deep seismic surveys (Bullerwell & McQuillin, 1969) and further geophysical work (Woodland, 1971). Other structural, sedimentology and stratigraphic studies, based mainly on the Mochras and Tonfanau boreholes were done by workers such as O'Sullivan (1971;

1979), Herbert-Smith (1979), Barr *et al.*, (1981), Dobson, Evans & Whittington (1973) and Dobson & Whittington (1987).

The Cardigan Bay Basin is separated from the structurally similar St Georges Channel Basin to the SW by a basement ridge, St Tudwel's Arch. It is possible that the Cardigan Bay Basin may have been continuous with the St Georges Channel Basin for much of its history (Dobson *et al.*, 1973) but is now separated by this arch of Precambrian rocks elevated in later structural movements. A smaller subsiduary Tertiary basin occurs in the NW corner of the Cardigan Bay Basin, the Tremadoc Bay Basin, while a second small elongate basin, the Teife basin occurs between the St Georges Channel Basin and the Welsh mainland (figure 3.7). The structure of the Cardigan Bay Basin interpreted from deep seismic by Bullerwell and McQuillin (1969) changes from a half graben structure in the NE where the sediment horizons dip eastward towards the coastal fault complex, to a southern boundry fault, the Bala Fault system which delimits the edge of the Cardigan Bay Basin (figure 3.7). This complex faulted margin is not associated with the deepest part of the basin, as the sediments thicken away from the fault. The geological history of the basin begins with Carboniferous sediments infilling the basin on a Precambrian/Lower Palaeozoic basement. Permo-Triassic rocks were then deposited unconformably in the SW extremities of the basin and were succeeded again unconformably by Jurassic sediments, volumetrically these are the most significant rocks in Cardigan Bay, infilling the central areas of the basin. These Jurassic rocks are dominated by Middle Jurassic marginal marine sediments. Cretaceous sediments are not found in Cardigan Bay, but it is probable they were deposited and only remain further west in the axial zone of the North Celtic Sea Basin.

Tremadoc Bay Basin

Tertiary sediments are found predominantly in the NE corner of the Cardigan Bay Basin, in the Tremadoc Bay area, where they lie unconformably on the Lower Palaeozoic and Mesozoic sediments, described above. These sediments are restricted to a broad, shallow half graben basin, faulted along its eastern margin by a coastal fault complex, formed by the Mochras, Mawddach and Tonfanau Faults. The Tremadoc Bay Basin, is clearly seen on the Bouguer gravity anomaly map (Tappin *et al.*, 1994, figure 14) as a closed gravity low in the Tremadoc and Barmouth Bay area, with gentle gradients extending west onto St Tudwal's Arch. The Mochras Fault which forms the eastern edge to the basin is indicated by the steep gravity gradient on the Bouguer anomaly map at Mochras. This fault is downthrown to the west by 4500m (Woodland, 1971) and trends NNW-SSE extending south to the Mawddach estuary where it meets the Mawddach Fault trending NE-SW. The Mawddach Fault continues southwest and terminates against the NNE-SSW trending Tonfanau Fault, this extends south to the line of the Bala Fault system marking the southern edge of the Cardigan Bay Basin. The Tertiary sediments extend as a tongue to the south at Tonfanau and are seen as a kink on the Gravity map (Tappin *et al.,* 1994) to the west of Towyn.

Evidence of the general structure of the Tremadoc Bay Basin (Bullerwell & McQuillin, 1969 and Dobson *et al.*, 1973) indicates that Tertiary sediments were deposited in a half graben structure in the northeastern corner of the Cardigan Bay Basin. The sediment horizons dip at 12°-15° into the coastal fault complex, and to the north unconformably overstep the Lias and Permo-Triassic to rest directly on the Lower Palaeozoic basement. This overstepping relationship continues to the west and southwest where the Tertiary deposits extend over Lias and Middle Jurassic sediments. The southern margin of the basin is formed by the Mawddach Fault which downthrows the Tertiary against the Lower Palaeozoic, with the exception of a small tongue of Tertiary sediment, adjacent to the Tonfanau Fault, which extends southwards.

The Tertiary sediments are composed of slits, clays and conglomerates with a maximum thickness of about 500m (Dobson and Whittington, 1987) and are dated by palynology as Oligocene to Miocene (Herbert-Smith, 1972; 1979; Wilkinson & Boulter, 1980). The oldest Tertiary sediments here are thought to be early Oligocene in age (Dobson and Whittington, 1987) as deposition is penecontemporaneous with the final phase of uplift of the Welsh Massif along the active Mochras Fault, with conglomeratic sediments detailing ten phases of fault movement. The detailed sedimentology and palynology of this basin will be described in full later. When seeing if any comparison can be drawn from the published data of the Cardigan Bay Basin compared to the sections currently under analysis in this project (Chapter 10).

Boreholes in adjacent areas have penetrated small outliers of Tertiary sediments such as in the St Georges Channel Basin, commercial wells, 107/21-1, 107/16-1 and 106/24-1 are reported to penetrate undifferentiated Eocene to Oligocene sediments (Barr *et al.*, 1981). Also Eocene/Oligocene aged sediments are seen to occur in the axis of the South Celtic Sea Basin which is penetrated by BGS borehole 89/10 (Tappin *et al.*, 1994).

Teife Basin

The Teife basin is a small elongate basin 19 km by 2.5 km, trending NE-SW positioned between the St Georges Channel Basin and the Welsh Mainland. This basin is possibly fault controlled, with a fault forming its NW margin and sedimentation restricted to a synclinal structure in the southeast. Two BGS boreholes, 72/66 and 74/21, have cored this basin. These boreholes show Eocene to Middle Oligocene sediments (Tappin pers. comm. 1994) of green brown laminated clays with plant fragments and lignites within which glauconite occurs, indicating periodic marine influnces. This is important as it probably represent the most northerly marine incursion encountered in Oligocene sediments along the western British Isles. Marine incursions have been picked up to the south of this, in the Stanley Bank Basin (Boulter & Craig, 1979).

TERTIARY BASINS ALONG THE STICKLEPATH-LUSTLEIGH FAULT ZONE

For hundreds of years, a number of Tertiary accumulations have been recognised along the Sticklepath-Lustleigh Fault Zone (SLFZ), both onshore in Devon; the Bovey Basin, the Petrockstowe Basin, and the Dutson Basin (Freshney *et al.*, 1982) and offshore; the Stanley Bank Basin of Fletcher (1975). Furthermore a possible NW continuation of the Fault reaches the Welsh coast at Flimston where another Tertiary accumulation occurs, described by Murchison (1839), and Dixon (1921). A close genetic relationship between the faulting and basin formation along the SLFZ can be recognised.

Structure

The major NW-SE trending SLFZ can be described as a left stepping en echelon fault zone, running northwards from the English Channel through Devon, the Bristol Channel and extending as far north as Pembrokeshire. A small number of Tertiary basins have developed on the NE side of this fault zone. A net dextral displacement of 4.8 km between Carboniferous rocks of the Crackington and Bude Formations in Devon, and a 1.3 km displacement on the southern margin of the Dartmoor granite, (Holloway & Chadwick, 1986) evidence this. The two on-shore basins, are deep relative to their width, having steep margins and are infilled with thick sequences of fluvial and lacustrine sediments (Edwards, 1976; Freshney *et al.*, 1982). This geometry suggests the onshore basins are pull-apart basins, formed by overlapping side stepping transcurrent faults (Rodgers 1980, Reading 1980). In this case the left stepping nature of the faults would require sinistral strike-slip movement to produce the tension and downwarping needed to form a pull apart basin (Clayton, 1966; Rodgers, 1980; Mann *et al.*, 1983) and such a situation is illustrated in figure 3.8b.

The apparent dextral sense of movement seen on the SLFZ could not have produced pull-apart basins from the fault geometry seen. Holloway & Chadwick (1986) explained this conflicting evidence by suggesting that the principle dextral sense of movement of the fault was produced in the compressional tectonic regime of the Variscan orogeny. In the late Variscan age, strike-slip movement on the SLFZ was in a dextral sense, giving a total displacement of about 10 km. Extensional reactivation in Permo-Triassic times led to subsidence in the Credition Trough and the dextral offset of the adjacent Heatherleigh outlier (Holloway & Chadwick, 1986).

Reactivation in the early Tertiary extensional regime, which occurred over SW England and the SW Approaches at this time, gave 6 km of Tertiary sinistral movement on the SLFZ producing these small pull apart basins. This sinistral movement reduced the net dextral offset seen on the fault leaving only the pull-apart basin as an indication of sinistral reactivation. This was followed in the Middle Tertiary by minor dextral movement on SLFZ leading to the formation of reverse faults (Riedel Shears) on the margins of the Tertiary basins (Holloway & Chadwick, 1986). The Bovey and Petrockstow Basins were infilled with Eocene to Oligocene aged sediments, deposition in both these basins was confined to narrow valleys and linear basins along the SLFZ.

Bovey Basin

The sediments of the Bovey Basin have been well documented, notably from the earlier of authors such as Reid (1913). The popularity of this area for study at this time was largely due to the economic importance of the deposits, as they were extensively extracted and used as a major source of ball clay for the pottery industry. The geometry of the Bovey Basin was described as two parts by Edwards (1976). Firstly, the Bovey Basin which is a rhomd-shaped basin 6.5 km by 4.3 km, trending NW-SE from the Bovey Tracey area to the Newton Abbott area, with a span of 11 km. Secondly a smaller subcircular basin called the Decoy Basin occurs to the south of Newton Abbott (figure 3.8a), southeast of the main basin.

A gravity survey by Fasham (1971) indicated a maximum depth for the basin of 1245 m, of which only the upper 350 m are known from surface exposures and boreholes. As explained above, the Bovey Basin is a pull-apart basin situated between left stepping en echelon faults of the SLFZ, in north Devon. The western margin of the basin is formed from a splay fault off the SLF and dips to the east. Within the Bovey Basin, an eastern master fault connects the Torquay Fault system with the Bovey Tracey Fault. This fault is marked by the presence of minor en echelon faults to the north and east of the basin. These probably reflect movement in the basement, their distribution indicates they are Riedel Shears and represent post-depositional dextral movement along this underlying master fault (Holloway & Chadwick, 1986).

The 1200 m of Tertiary sediments infilling this basin are composed of kaolinitic clays, silty clays, lignites and sands. These form the Bovey Formation of Edwards (1969). The age of this Bovey Formation has been suggested as Eocene to Middle Oligocene using plant macrofossils, Chandler (1957) and more recently with plant microfossils, pollen and spores, Wilkinson and Boulter (1980). A very detailed lithostratigraphy of the Bovey Formation has been described, Vincent (1974), Edwards and Freshney (1982) and Edwards (1976).

The Bovey Basin overlies, on its eastern side, Carboniferous sands and silts, Cretaceous Upper Greensands and the Eocene Aller Gravels. Elsewhere the sediment is faulted against, or rests unconforambly on Devonian and Carboniferous rocks. In the Decoy Basin, the sediments of the Bovey Formation overlie, or are faulted against Permian breccias, Cretaceous Greensands and the Eocene Aller Gravels. The Bovey and Decoy Basin are almost separated by an E-W trending ridge of Devonian Slate (Edwards & Freshney, 1982).

Sedimentation in the Bovey Basin occurred in two phases (Edwards, 1976). Phase I is wholly fault controlled. Here an estimated 900 m of sediments were deposited in a central subsiding trough area, these sediments have yet to be sampled or penetrated by boreholes. In phase II the faulting was less active, so sedimentation was greater than subsidence. This led to sedimentation spreading out and occuring over a wider area, especially to the N and E, (the Abbrook Member was the first deposited in this phase of sedimentation). The Decoy Basin contains sediments laid down during phase II only, with no representation of phase I.

The provenance of the sediments in the Bovey Basin is a much debated subject, but it is now agreed they are derived from both the Dartmoor Granite (which form the Blatchford Sands, in the upper part of the Bovey Formation) and also from weathered mantle developed on Carboniferous rocks in the Early Tertiary (forming the pre-Blatchford Sands in the lower part of the Bovey Formation, in the southern parts of the basin), Bristow (1968).

In the Early Eocene through to the Oligocene times, Devon was situated in a sub-tropical to tropical climate belt. This is evident from the floras of Bovey Basin at this time, such as, palms, ferns, heathers and swamp vegetation which are characteristic of such environments and climates (Chandler 1957; 1967; Collinson *et al.*, 1981).

Sedimentation of the Bovey Formation occurred largely in river flood plains, and short lived lakes, as clastic deposits in these fault controlled subsiding basins, with the river systems envisaged to discharge into the English Channel area, (Edwards and Freshney, 1982). Shallow water lake deposition is evident from brecciated horizons and the desiccation of clays on the floodplain. The lignites and clays represent floodplain deposition with a back swamp developing (as seen in the Southacre, Twinyeo and Brimley Members). The majority of lignites in the Bovey Basin are derived from dense *Sequoia* Forests growing on upland areas to the north and west of the basin, with flooding transporting the *Sequoia* fragments into the basin with overbank clays (Chandler, 1957; Wilkinson & Boulter,1980). Also some channel sands are present, such as the Chudleigh-Knighton Member. To summarise the sedimentollogy encompasses a complex interplay of floodplain, lacustrine and alluvial fan environments.

Petrockstow Basin

A second smaller Tertiary basin occurs in north Devon, the Petrockstow Basin (figure 3.8a). It has a similar structural development and setting to Bovey Basin, being another pull-apart basin lying between left stepping, en echelon faults, namely the Greencliffe and the Sticklepath faults, (Edwards & Freshney, 1982), with downwarping occuring in the intervening ground. Over 780 m of Tertiary sediments have been described Freshney (1970) and Fasham (1971). These Tertiary deposits are gently folded with only some of the re-activated Carboniferous faults breaking through. The structural geometry shows a deep but narrow steep sided basin 5 km by 2 km in size, trending NW-SE and flanked by marginal shelves. Details of this basin are described in Edwards & Freshney (1982), and are summarised below.

Along the trend of the basin axis a broad asymmetric synclinal structure can be seen with its deepest part towards the NW of the basin. A cross section across the basin, in its NW part, shows a narrow, deep faulted trough flanked by a shelf to the NE, another shelf can also be seen to the SW. The sediments deposited in the Petrockstow Basin are similar to those of the Bovey Basin and are composed of clays, sands and silts rich in clays, gravels and some lignites. These sediments have been dated using palynology by C. Turner in Edwards & Freshney (1982) and by Wilkinson & Boulter (1980). The top 260 m gave a Lower to Upper Oligocene age, but samples from 260-780 m gave poor yields of pollen and spores, and have not been accurately dated. It can be assumed by the laws of superposition to be older and are probably Eocene.

A marked cyclicity in the sedimentation was described by Freshney (1970) evident by fining upward sequences. This cyclicity has been attributed both to alluvial floodplain sedimentation on the fine scale and on a larger scale to the tectonic controls of subsidence and sedimentation. The gradational reduction of grain size NW along the basin axis indicates alluvial sedimentation occurred with a river flowing along the basin from Dartmoor in the SE to the Bristol Channel in the NW, Edwards & Freshney (1982).

A variety of depositional environments have been suggested for the different types of sediments occurring. These include lag gravels, point bar sands, levee/crevasse splay sands, floodplain clays, backswamp clays and lignites and (restricted to the NW axial area) laminated silts and sands with leaf fragments representing lacustrine environments. Edwards & Freshney (1982) suggested that these sediments were derived from Carboniferous successions with some New Red Sandstone and Mesozoic rocks. Both the Bovey Basin and the Petrockstowe Basin floras have been regarded as indicating sub tropical to tropical climates (Chandler, 1957).

Stanley Bank Basin

The Stanley Bank Basin occurs 10 km east of Lundy Island in the Bristol Channel. The SLFZ forms the western margin to this large elongate sedimentary basin, 32 km by 16 km, trending NW-SE. The sediments in the basin rest uncomformably on Upper Palaeozoic and Mesozoic rocks. The structural setting of the Stanley Bank Basin is closely similar to Bovey Basin and Petrockstow Basin, but is much larger in size. The solid geology of the Bristol Channel floor on which the Stanley Bank Basin is formed was first described by Lloyd *et al.* (1973). The southern half of the Channel is largely floored by Jurassic rocks, which are folded into a synclinal structure, 'the Bristol Channel Syncline'. The syncline is asymmetrical, the north limb dipping at 5-10° and the south limb dipping at about 20°, also subsidiary folds and flexures occur on the northern limb (Brooks & Thompson, 1973). The syncline trends ESE from NE of Lundy eastwards towards Minehead and contains 1600m of predominantly argillaceous Jurassic rocks with some Triassic sediments, these lie uncomformably on Upper Palaeozoic (Carboniferous) strata. The Lower Lias, Middle and Upper Jurassic rocks are dominated by shales and silts with thick sands. The Kimmeridge clays (Upper Jurassic) are the youngest rocks in the syncline (Brooks & James, 1975). In the central Bristol Channel area, on the northern limb of the syncline, a major E-W zone of strike-slip faulting occurs. In the Camathern and Barnstaple Bay area the Bristol Channel Syncline gives way to a series of complex local folds partially concealed under sediment. The Jurassic succession is dislocated by the SLFZ which passes through the Barnstaple area east of Lundy.

As part of the regional mapping program in the early 1970's, the BGS drilled several boreholes to confirm the presence of and delimit the Stanley Bank Basin (figure 3.9), after the initial early gravity and seismic investigations had been carried out over the area (Brooks & Thompson, 1973; Brooks & James, 1975 respectively). This early seismic, indicated 340 m of Tertiary sediments infilling the basin. A three layer infill structure is seen to the NW and a two layer structure to the SE. The sediments are thicker towards the N and W margins and both thin and dip towards the S and E. It forms in a half graben developed along the SLFZ, which forms its western edge. This is in the form of a single fault with several minor flexures. Splay faults upto 5-6 km long develop from these flexures on the SW side of the fault, incorporating slices of displaced Oligocene floodplain sediments. Although over 340 m of sediments infill this basin the deepest borehole only penetrates to 33.85 m. The sediments from this borehole (73/36, figure 3.9), which has been worked on in detail in this study are Middle Oligocene pale grey clays, silts, lignitic clays and lignites upto 5 m thick (Boulter & Craig, 1979). This is a marked contrast to the sediments of the Mochras and Tonfanau boreholes where no lignites over 15 cm in thickness were recorded (O'Sullivan, 1971) but are similar to the sediments from the upper parts of the Bovey and Petrockstow Basins.

Three seismic facies have been recognised in the Stanley Bank Basin by Davies (1987). Firstly an unsampled basal unit that is restricted to the S and E margins of the basin, this is Facies 'B' of Davies. It is 80 m thick in the south and this facies progrades towards the centre of the basin and is interpreted as a braided sand and gravel channel network. Secondly the major part of the succession, facies 'A' is widespread over the basin and is deposited in a braided channel floodplain system overlying facies 'B' where it occurs, and elsewhere lies unconformably on an Upper Palaeozoic and Mesozoic erosional surface. The sediments dip towards the faulted western margin of the basin. Boulter & Craig (1979) interpreted these sediments as distal floodplain deposits laid down in a back swamp/shallow lagoon environment. Extensive lignite development (upto 5 m thick) and intercalated grey clays indicate reducing conditions, this is backed up with the palynological evidence of spores indicating a swamp environment. Floodplain drainage is suggested to be to the northwest by Davies (1987).

A marine incursion in the NW part of the basin is indicated by the presence of microplankton at a depth of 18.75m in BGS borehole 73/36, by Boulter & Craig (1979) is the most northerly published record of marine Oligocene in the western British Isles. Also further BGS boreholes in the SE, 74/44 and 72/45, are reported to contain red beds which also indicate oxidation conditions in the area. Overlying facies 'A' unconformably in the northern area of the Stanley Bank Basin, two sub basins can be seen. These contain alluvial and bar deposits, facies 'C' of Davies (1987). The sub basins are formed due to subsidence associated with later movement along two N-S trending faults in the northern part of the basin and are thought to be Pleistocene in age (Tappin *et al.*, 1994).

TERTIARY BASINS IN NORTHERN IRELAND

The Oligocene Tertiary deposits in Northern Ireland are mainly confined to the Lough Neagh area. These deposits have been known since the 1700's and the clays and lignites exploited for economic reasons. For this reason the majority of previous work has concentrated on these lignites and clays, consequently much work remains to be done on other areas such as structure and geological evolution.

Brief Geological History of the Lough Neagh area, Northern Ireland

The foundations of the region are the metamorphic Dalradian and Moinian rocks. They outcrop in NE Antrim and disappear under the Tertiary lava pile and reappear to the west in the Sperrin mountains.

Both volcanic and sedimentary rocks were deposited throughout the Ordovician and Silurian. Erosion of the Caladonian uplands was the main source of the Devonian foreland sediments. Carboniferous rocks occur with their greatest thickness to the

NW, the downthrown side of the reactivated Highland Boundary Fault. The delta facies of the earliest Carboniferous, Tournaisian, were followed by Visean shelf limestone deposits, Namurian Yoredale sequences and grits, topped with the Westphalian Coal Measures. Earth movements associated with the Hercynian Orogeny produced gentle NE-SW folds and faulting over the area. Permo-Triassic rocks were deposited in fault grabens on Carboniferous and older rocks in arid conditions, starting with breccias and some dune sands. The Permian saw shallow saline sea deposits (Zechstein equivalents) which into the Triassic were associated with salt formation. This was followed with further variations in sea levels, such as the Rhaetic transgression. In Northern Ireland the Jurassic period is represented only by Lower Jurassic sediments (Wilson, 1972) he also suggested that subsidence in the Lough Neagh Basin area started in the Jurassic period. The Cretaceous started with a long period of non-deposition (possibly accounting for the erosion of the upper part of the Jurassic). These Cretaceous deposits include Cenomonian/Turonian Greensands and Senonian (Late Cretaceous) White Limestones and Chalks.

The dominant feature in NE Ireland is the Antrim Plateau Lavas. These have acted as a protective cover over the softer Upper Palaeozoic and Mesozoic rocks which outcrop around the edges of the Plateau Lavas. The extrusive volcanic activity started in Palaeocene/Eocene times and probably flowed from fissures and volcanic vents. They were erupted as part of a wide arc of volcanic activity stretching from Greenland through Iceland and the Inner Hebrides to NE Ireland. The Antrim Lavas are comparable to the Mull sequence and are assumed to be about 1800 m thick compared to 7500 m in Iceland (Wilson, 1972). The composition of the lava is mainly basalt particularly Olivine Basalts, with Tholeiitic Basalts, Trachytes and Mugerites occuring only locally. Some tuff horizons have been found in the lower lava sequence and have been traced over 7 km, Wilson (1972). Interbasaltic beds are common and show weathering giving thin laterite soil horizons in places. After cessation of the lava outpouring, large scale warping and subsidence of the lava occurred around the Lough Neagh area. Subsidence in this area is thought to have occurred since Jurassic times (Wilson, 1972). The faulting and subsidence continued and began to initiate a tectonic basin which then developed into the Lough Neagh Basin, which simultaneously filled with Tertiary Oligocene sediments, the Lough Neagh Clays.

A trio of intrusive Tertiary complexes occur to the south of the lava plateau (associated with the Lower Tertiary acid magmatism), namely; the Slieve Gullion ring complex, the Carlington gabbro complex and the Mourne granite. Other Tertiary igneous features present in the area include agglomerates, plugs, sills and dykes.

Lough Neagh Basin

The Tertiary Lough Neagh Basin is another example of a terrestrial Tertiary basin that has formed in the Western British Isles, and its sediments are of interest in this current work. The Lough Neagh Clays extend over an area of 500 km^2 of which 300 km^2 lie under Lough Neagh itself. They outcrop underneath glacial drift and form an irregular arc around the southern end of the Lough (figure 3.10).

The sediments in the Lough Neagh Basin where first described by Barton in 1757, later in 1829 they were named the Lough Neagh Clays by Griffith who also suggested a Tertiary age and compared them to the Bovey Tracey deposits in Devon. In 1837 a further comparison was made by Scouler to the Rhine Basin sediments.

The extent of the outcrop of the Lough Neagh Group was determined with the aid of boreholes. In total 28 boreholes were drilled around Lough Neagh by the Geological Survey and Commercial Companies. Commercial Companies were interested in the extent of the Lough Neagh Clays due to the economic value of the Group which contain lignites (especially to the east of Lough Neagh where an estimated 10-20 million tonnes of lignite reserves are present) and white clays to the SW of Lough Neagh which are used in the pottery and tile industry. It is from this area that material studied by the author was obtained from. From boreholes it can be seen that the greatest thickness of these deposits are upto 350 m, in the Washing Bay borehole, and consist of pale clays, silts, sands and lignites.

The Lough Neagh Basin is a group of sub basins from Ballymoney in the north to Lough Neagh in the south (figure 3.10). The basin formed on the subsiding Antrim Plateau lavas after the cessation of volcanic activity, probably in the Eocene (Wilkinson *et al.*, 1972). This subsidence was accompanied by block faulting in an extensional tectonic regime. The basin was constrained by NNW-SSE faulting (normal to extension) and the reactivated Hercynian NE-SW faults as strike slip faults (Parnell & Shukla 1989). Large scale fault related subsidence occured in the Lough Neagh Basin. Sedimentation must have been contemporaneous with faulting which allowed the thick accumulation of sediments to occur here.

Lough Neagh Group sediments also occur to the north of Lough Neagh in the Ballymoney area (figure 3.10). They were also deposited in a similar extensional tectonic regime forming fault bounded, asymmetrically filled, sub basins along the Tow Valley Fault Zone (Parnell *et al.*, 1989; Evans *et al.*, 1991).

Parnell *et al.* (1989) described four main lithologies in the Lough Neagh Group.

1. Conglomerates; these occur near the base of the sequence and contain clasts of basalt and chalk. Thin conglomerates do occur higher up the sequence and have additional clasts of dolomite, quartzite and Carboniferous Limestones.
2. Sandstone occurs at all levels, interbedded with the other lithologies.

3. Mudrocks/Siltstones form the majority of the sequence. They vary greatly from green, brown, grey to black and are organic rich. They contain finely disseminated plant matter with some fresh water macrofossils.
4. Lignites are interbedded with the other lithologies and grade into dark mudstones. Two types were seen; woody lignites and non woody lignites.

Three main areas of lignites occur; Coagh, Crumlin and Ballymoney (figure 3.10). Studies on the lignites indicate burial depths of less than 1 km by vitrinite reflectance (Parnell *et al.*, 1989). In general the sequences are all interbedded lignite, mudstone and sandstone and they cannot be consistently divided lithologically. Wilkinson *et al.* (1972) suggested in general, a lower basal conglomerate with pebbles scattered through a paler clay, passing up into an upper darker clay with lignite beds. In places, such as in Coagh a definite lithological sequence can be seen, this sequence was also correlated using palynology (Shukla, 1989).

Thick pebble beds at the base of sequences can be seen in the boreholes in the area SW of Lough Neagh, indicating a major influx of material into the basin from a river source from a westerly direction. This is further supported by a lack of coarse sediments in the boreholes to the east of Lough Neagh (Boulter, 1980). Evidence of smaller rivers flowing in from the NE can be seen in Crumlin as sands cutting lignites.

Provenance of the sediments in the basin have been determined with the use of geochemistry and heavy mineral analysis by Shukla (1989). Provenance is dominated by the basalts of the Antrim Lava Group. This can also be seen by the thick weathering profiles in the upper part of the Antrim Basalts, which have been extensively weathered to kaolinite clays. And these clays are the dominant clays in the sediments of the Lough Neagh Group. Other sources for the sediments include Dalradian metamorphic rocks, the Ordovician Tyrone Igneous Complex and the Tertiary Mourne Granites. Provenance showed that through time the drainage system eroded into older rocks below the basalt, Parnell *et al.* (1989).

A warm tropical climate was envisaged for the depositional setting of the Lough Neagh Clays. After a palynological investigation on the Lough Neagh Clays, both Wilkinson *et al.* (1980) and Hubbard & Boulter (1983) suggested palaeofloras indicated lowland swamp cypress and fagaceous shrubs and fern prairie, under a conifer upland in a warm temperate climate, with a more tropical climate prior to this in the Eocene. This would give ideal conditions for the deep tropical weathering of the large volumes of basalts into kaolinite. Also giving a time gap after the eruption of the Antrim Basalts to allow the erosion and transport of these sediments into the basin and thier deposition as the Lough Neagh Clays. Palaeoenvironmental interpretation is difficult due to the lack of outcrop and limited borehole data available.

Since the suggestion by Portlock (1834) a lacustrine origin has been postulated for the Lough Neagh Clays by the more recent work of Parnell *et al.* (1989). Deposition occurred in a lake much larger than the present day postglacial Lough Neagh. The lignite and organic rich mudstone developed in a swamp mudflat environment at the margin of the lake (Parnell & Shukla, 1989). They described autocthonous lignites developed on these lake margin swamps as peat, developed *in situ* on raised swamps, with occasional burials and rapid drownings. Parautochthonous lignites developed in open lake environments with deposits containing plant debris being washed in and accumulating to form lignites. Also sediments were transported into the lake basin by fluvial mechanisms and formed river delta systems into the lake. The majority of this fluvial input was from the west, indicated by pebble beds from Carboniferous siltstones and clay in the western part of Lough Neagh Group.

The basin has been known as a Tertiary deposit since Wright (1924) suggested the Lough Neagh Clays were derived from weathered Palaeocene/Eocene basalts making them post Eocene in age. Wilkinson & Boulter (1980) suggested a Middle to Late Oligocene age from pollen and spore evidence, confirming the earlier dubious pollen and spore study of Watts (1962) of an Eocene to Early Oligocene age.

NORTH SEA BASIN

General Geology

Over the last 30 years an extensive geological data base has been built up for the North Sea area since the first discoveries of the reserves of oil and gas. The present North Sea Basin is flanked by Britain to the west and Scandinavia to the east, its southern margin is marked by the northern limb of the Alpine foreland from the Netherlands to Germany and its northern limit is the continental margin of the NNE trending Atlantic margin. Five major basins have been recognised beneath the North Sea, the South Permian Basin, North Permian Basin, Moray Firth Basin, Viking-East Shetland Basin and Horda Platform (Stord Basin)

Pre-Permian

The North Sea area has a complex history due to its location relative to ancient plate boundaries. The metamorphic basement rocks of the North Sea are important in understanding the geology, as often structural weaknesses that developed during these times, such as Precambrian Lineaments and Caledonian NE-SW trending structures were subsequently reactivated by later tectonic events.

A series of grabens and half grabens developed over NW Europe in Late Carboniferous and Early Permian times. In the Carboniferous buoyant positive areas and subsiding basins were related to Precambrian and Devonian granites.

Two east-west trending Permian Basins; namely the South Permian Basin and the North Permian Basin, are separated by a buried high, the Mid North Sea High, which affects sedimentation into the Tertiary period. Cutting the Permian Basins, a series of zig zag, north-south trending grabens developed; the Viking and Central Graben systems. These are associated with the break up of Pangea and contained a more complete Permian to Recent stratagraphic sequence than the flanking areas. The initiation of subsidence in the Moray Firth Basin also started in the Early Permian. The Permian succession in the North Sea is dominated by sea level changes, the Lower Permian deposits are the sandy Rotliegendes, these were followed by a marine transgression in the Late Permian which gave the Upper Zechstein sequence which is dominated by marine evaporites.

Post Permian

Graben subsidence was rapid in the Triassic, leading to the development of the Stord and East Shetland Basin, which resulted in graben controlled sequences of thick continental clastics. Mobility of Zechstein salt sequences greatly complicated the tectonics in the North Sea and led to the variation in thickness of the Tertiary deposits that can be seen today.

The Upper Triassic transgression of the Rhetic Sea was associated with the opening of Tethys and the re-splitting of Pangea. Graben subsidence had stopped by the Late Jurassic to Early Cretaceous possibly coincident with fracture and crustal extension now being concentrated along Rockall-Shetland-Faeroe Trough. The Jurassic system is very important in the North Sea, accounting for the deposition of the source rocks important for the development of oil in the province. In the early Jurassic a transgression re-established marine conditions and gave deposits of shales, mudstones and delta sediments. The Middle Jurassic was dominated by a broad domal uplift which was caused by volcanism and a hot spot associated with the failed arm of a triple junction. A temporary regression led to the erosion of these uplifted areas and the deposition of fluvial delta sediments, with erosion centred on the axis of the central graben. Transgression and subsidence in the Late Jurassic led to argillaceous sediments e.g. Kimmeridge clays and local fault related coarse clastics on the western margins of the South Viking Graben. The tilted fault blocks that developed earlier in the Mesozoic continued into the Early Cretaceous. Early Cretaceous times were characterised by shallow marine carbonates resulting from a major transgression. Cretaceous subsidence in the Viking Graben and Central Graben is related to the lithological cooling after the Middle to Late Jurassic rifting phase (McKenzie, 1978; Sclater & Christie, 1980). This subsidence increased due to the isostatic response to sedimentary loading. In the Late Cretaceous block faulting died out and was replaced with general downwarping and open marine conditions which prevailed over NW

Europe at this time with a general increase in relative Sea Level, despite Haq (1981) who has described a reduced global eustatic sea level in the Turonian/Maastrictian, this gave a topography blanketed with chalk (south of 59°N) grading northwards into the argillaceous Shetland Group in relatively quiet tectonic times. At the end of the Late Cretaceous the start of coarse clastic deposition indicated the renewal of tectonic activity associated with the opening of the North Atlantic (Rochow, 1981), this continued into the Palaeocene.

North Sea Tertiary

During the Tertiary, subsidence varied greatly (King, 1983), the slow subsidence in the Danian was followed by rapid subsidence in the later Palaeocene, slowing again in the Eocene. Water depth fell through the Oligocene, by the end of which the depositional basin was at its smallest extent. The Palaeocene/Eocene depocentre was in the Viking Graben area, this moved south to the Central Graben area (figure 3.11) in Oligocene to Miocene times (Lovell, 1990). Early Danian sedimentation described by King (1983) was a continuation of Late Cretaceous carbonates. This sedimentary regime was terminated by a major uplift and reactivation of Mesozoic graben zones namely, the Viking, Central and Moray Firth Grabens. Coarse clastics were deposited in the late Danian due to tectonic activity (active rifting) associated with the opening of the North Atlantic and accompanying reduction in global sea levels which led to the rejuvenation of the surrounding source areas to the north and west. Thanetian sediment supply was from the northwest (Zeigler, 1975; Deegan & Scull, 1977 and Morton, 1977) from the Moray Firth area and the Scottish Mainland into the Central Graben and Forties area, and from the East Shetland Platform into the Viking Graben. Palaeocene and Eocene clastics in the grabens consisted of mainly mudstones with density flow sand bodies, these sands form some important reservoirs (e.g. Forth, Alba and Forties). Early Ypresian sedimentation prograded east infilling the basin from the west, this led to the development of a new sedimentary regime of shallow marine to delta deposition (the Dornoch Formation). Sands formed a delta shelf along the Scottish coast and basin margins and developed into deepwater turbidite tongues and lobes in deep basin parts (Zeigler, 1975). Deegan & Scull (1977) described delta sedimentation culminating in widespread lignite deposition in the Moray Firth Basin and Viking Graben (the Beauly Member). Volcanic eruption was intermittent through the Palaeocene (Deegan & Scull, 1977) giving dominantly basaltic ash deposits (the Balder Formation) over the North Sea, with the main volcanic centre being located on the East Greenland Margin to the west and north of Britain. The Early Eocene Balder Formation is a distinctive unit of tuffaceous claystones and sands associated with laminated shales, with low salinity marine environments (King, 1983).

Deegan & Scull (1977) suggested more downwarping of the basin associated with the volcanism, leading to a major Eocene transgression giving marine muds over the basin with the exception of marginal areas such as the East Shetland Platform where littoral sheet sand deposition occured. During this period density-flow sands continued to be deposited in the grabens (e.g. the Frigg, Grid and Skade Members) particularly in the Middle Eocene continuing into the Oligocene in some areas. Late Eocene sediments are thin and restricted to the deeper graben areas e.g. the South Viking Graben. For the remainder of the Tertiary, the Oligocene to Pliocene, Deegan & Scull (1977) envisaged monotonous fine grained clastic sedimentation of marine clays, silts and sands being deposited, associated with the continued downwarping of the basin. In Lower Oligocene times a low relative sea level led to claystone deposition in the grabens with glauconitic turbidite sands. The change in sea level in the Late Oligocene times gave predominantly claystones, often as thin veneers over the Tertiary sands in the Moray Firth and South Viking Grabens (figure 3.11). Miocene times saw generally lower sea levels again, (with no representation on land except for minor deposits) giving shallow marine sediments including a prominant foraminifera rich sand.

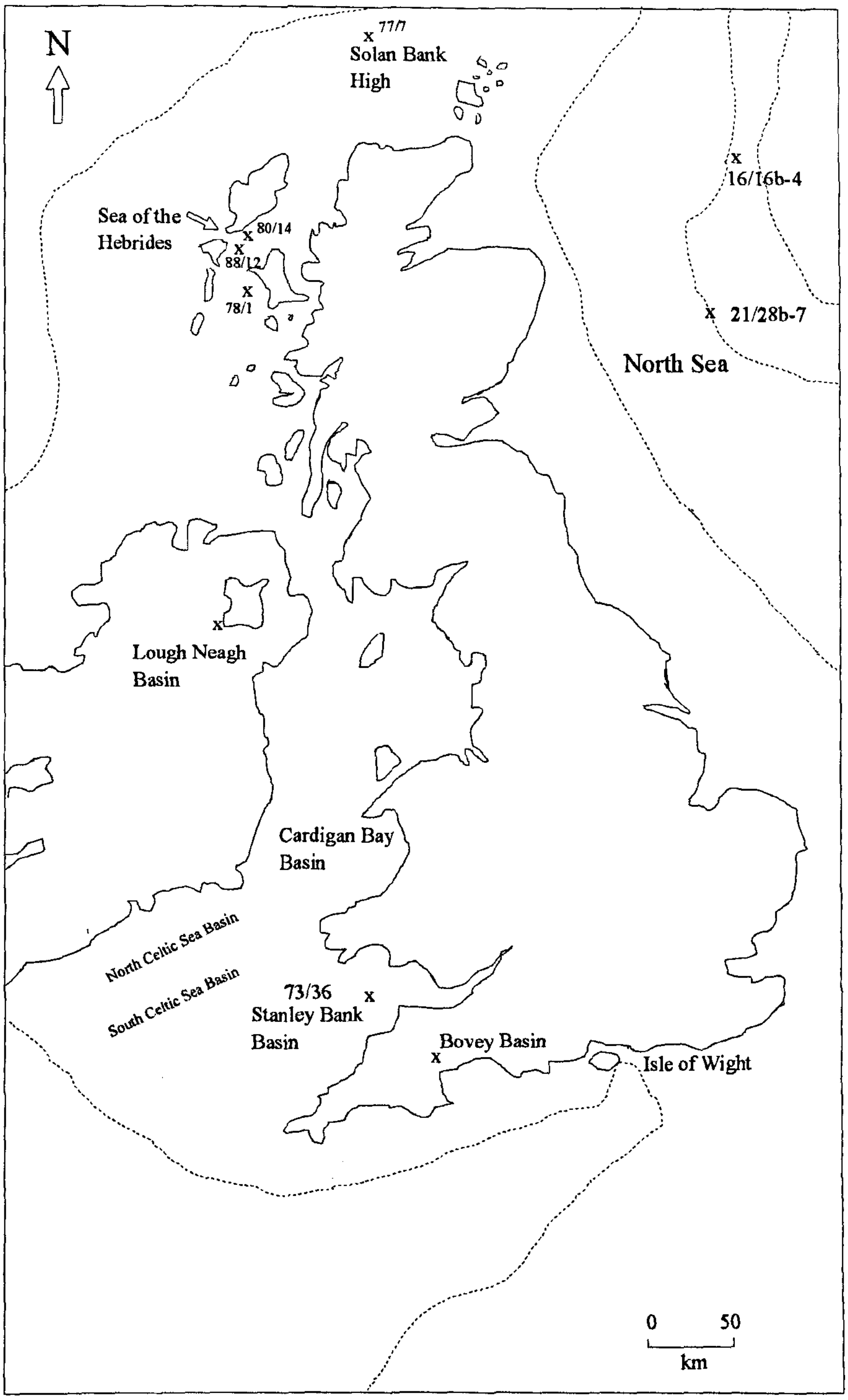


Figure 3.1 Map showing the locations of basins discussed in the text, the dotted line indicates the extent of marine conditions, after Cope et al. (1992).

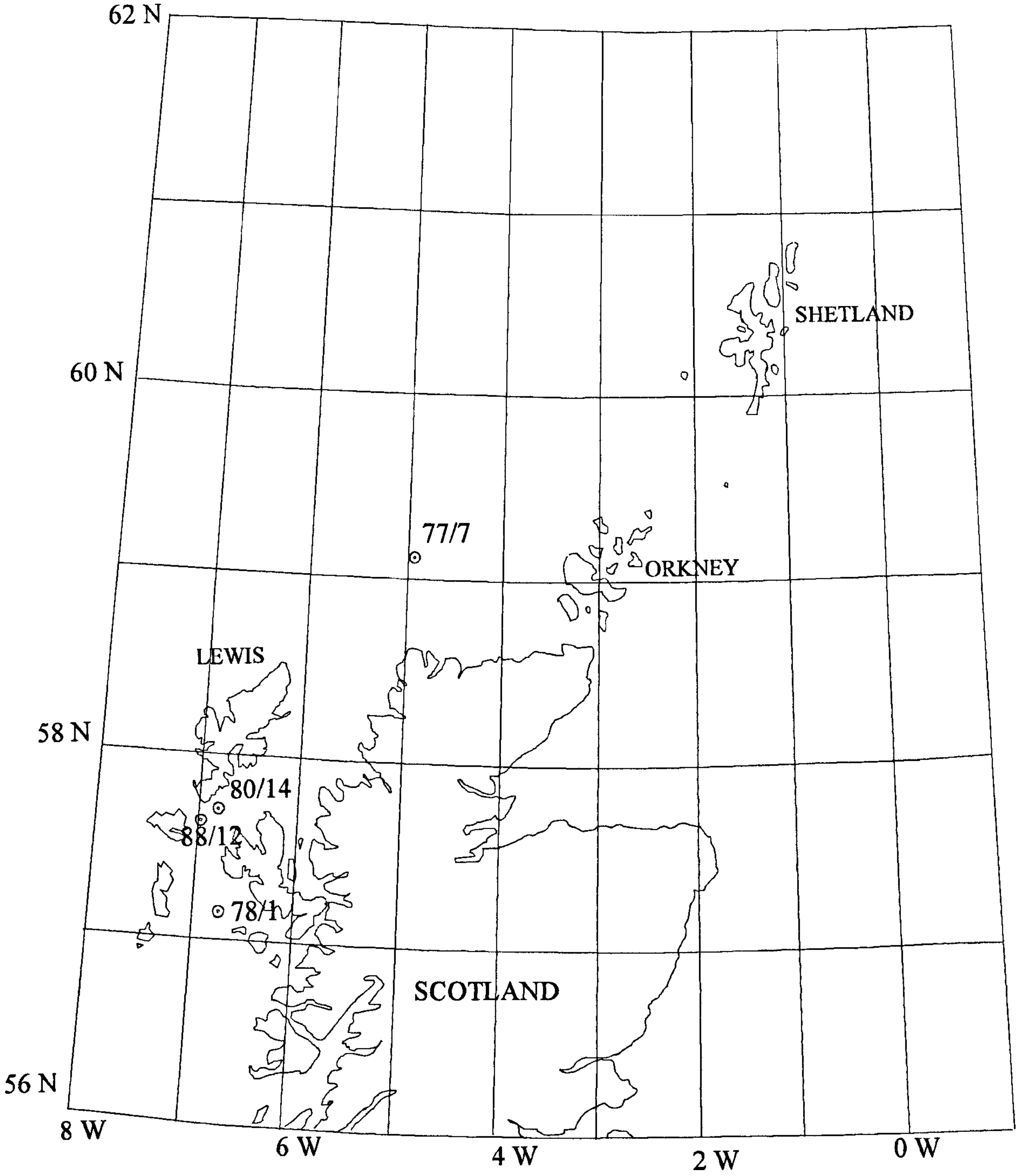


Figure 3.2 Map showing location of the material sampled from offshore Scottish boreholes, adapted from IGS Report 79/12

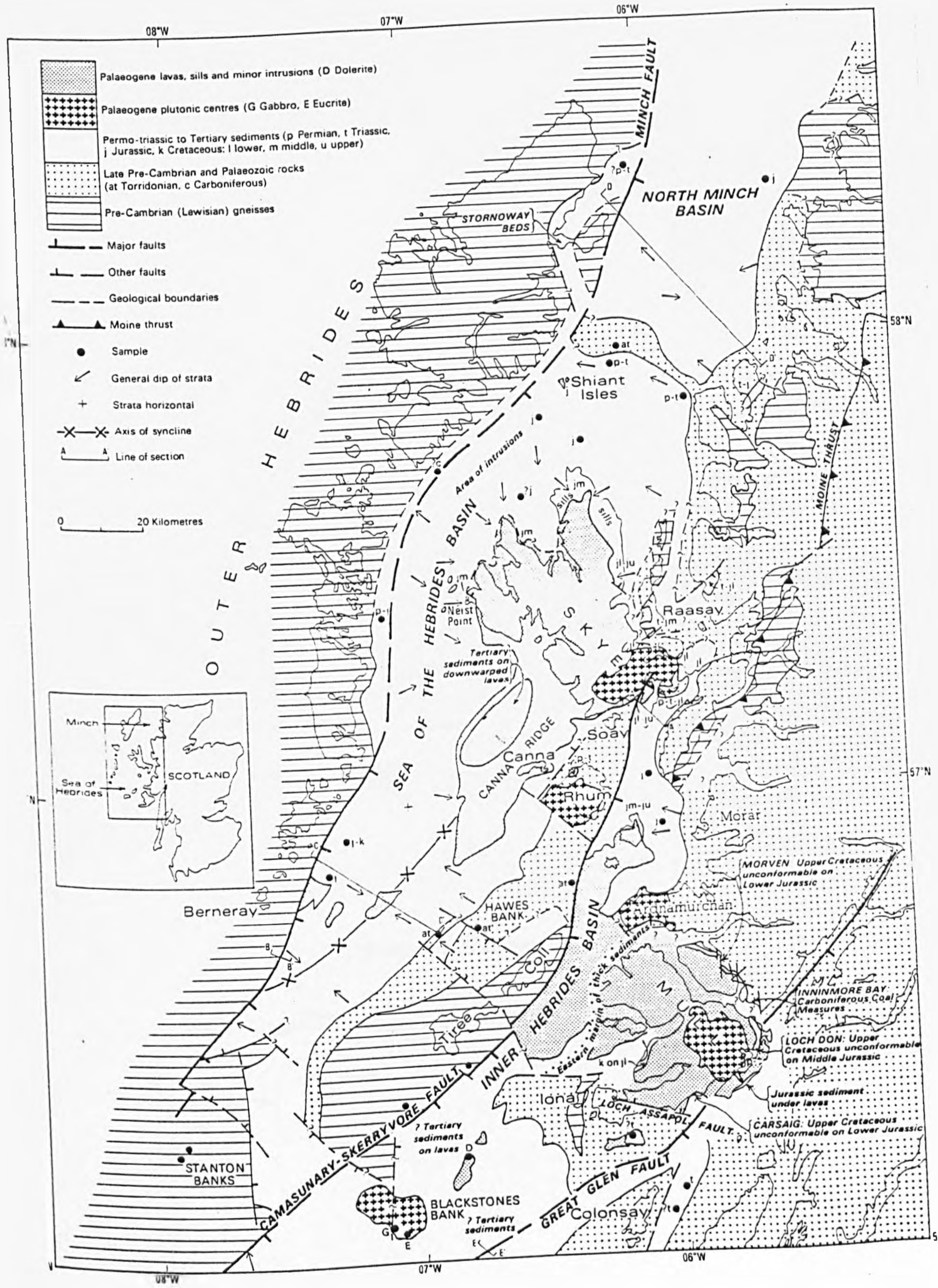
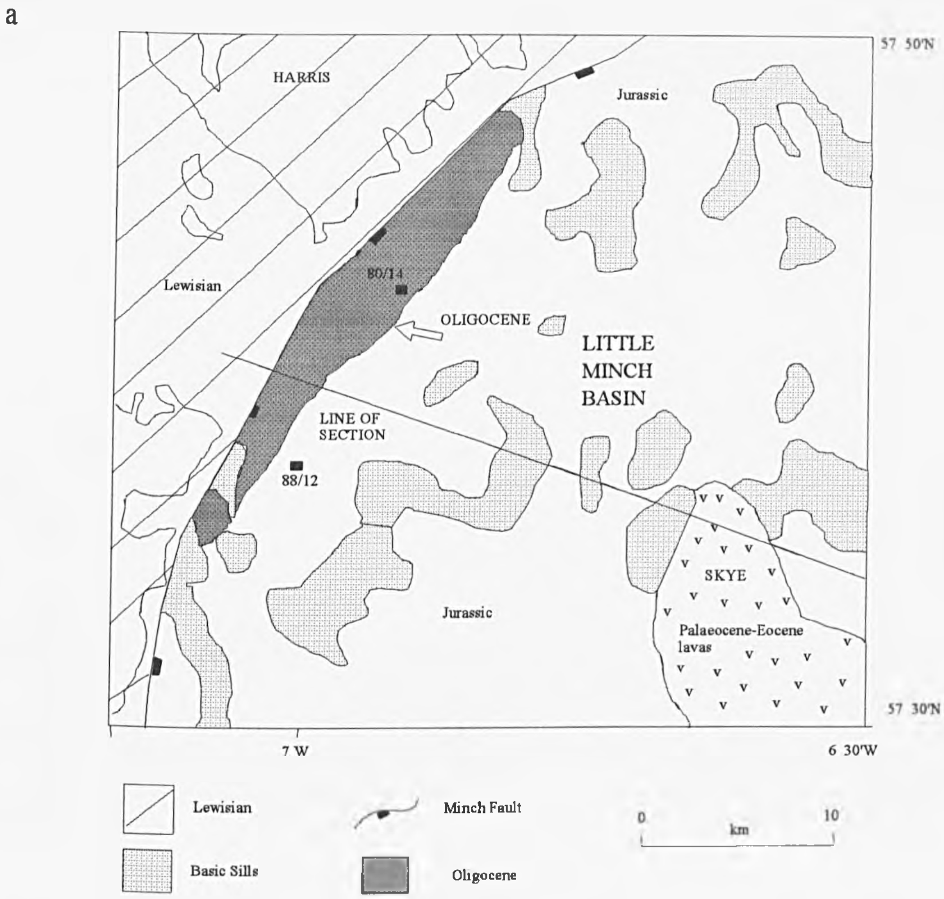


Figure 3.3 Geology map of the Hebrides and W. Scotland. After Binns *et al.*, (1975).



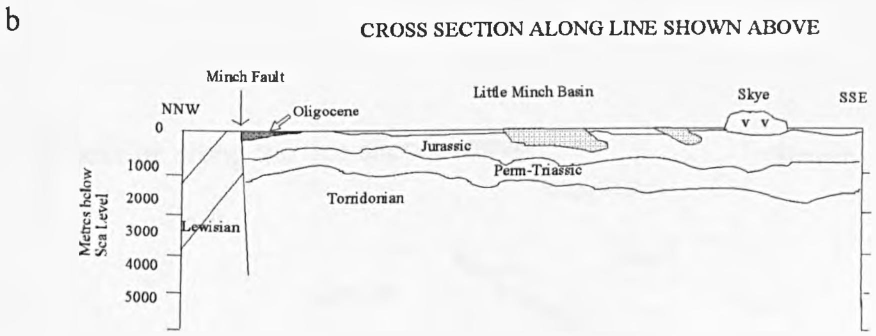
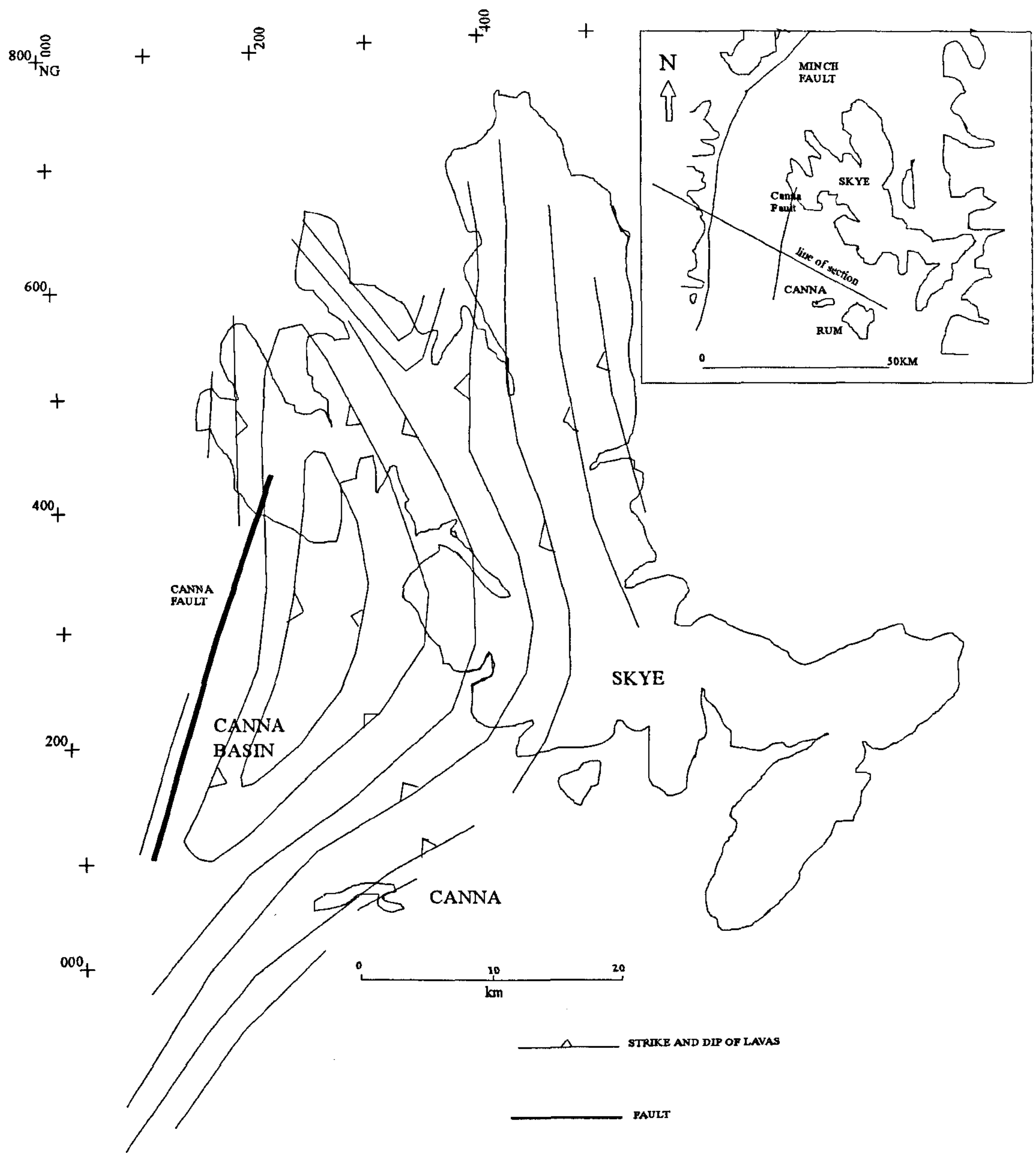


Fig. 3.4a Simplified geological map of the Little Minch Basin and b a schematic geological cross section through the Little Minch Basin

a



b Cross section along the line shown above

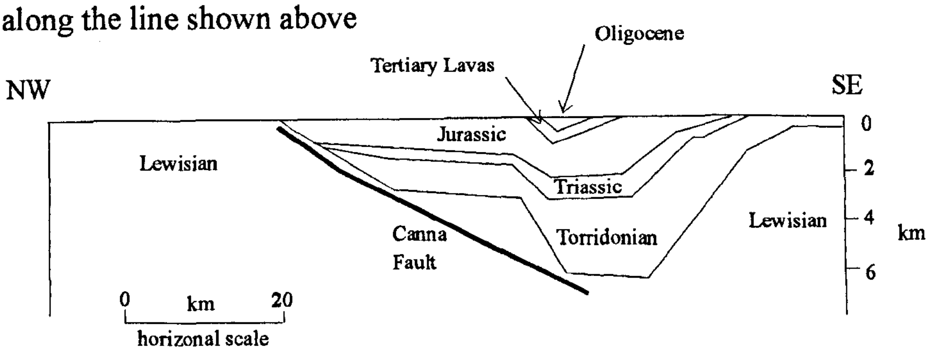
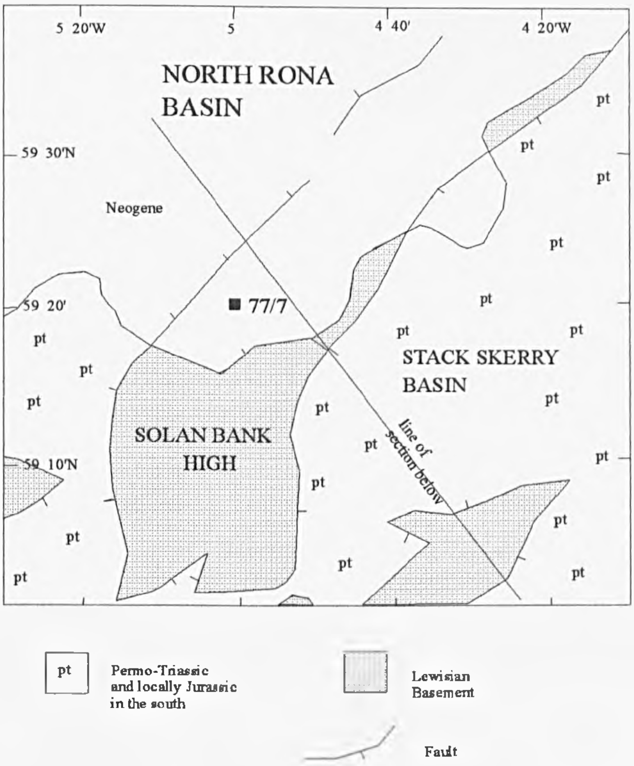


Fig. 3.5a Structural map of the Palaeocene lava field around Canna (after England, 1994) and b simplified geological cross section through the Canna Basin (after O'Neill & England, 1994)

a



b Cross section along the line shown above

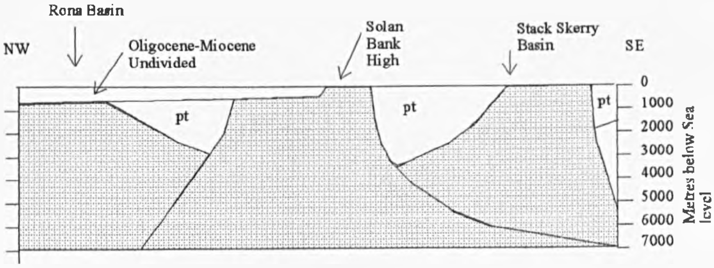


Figure 3.6a geological map and b schematic cross section of the Rona Basin and the Solan Bank High.

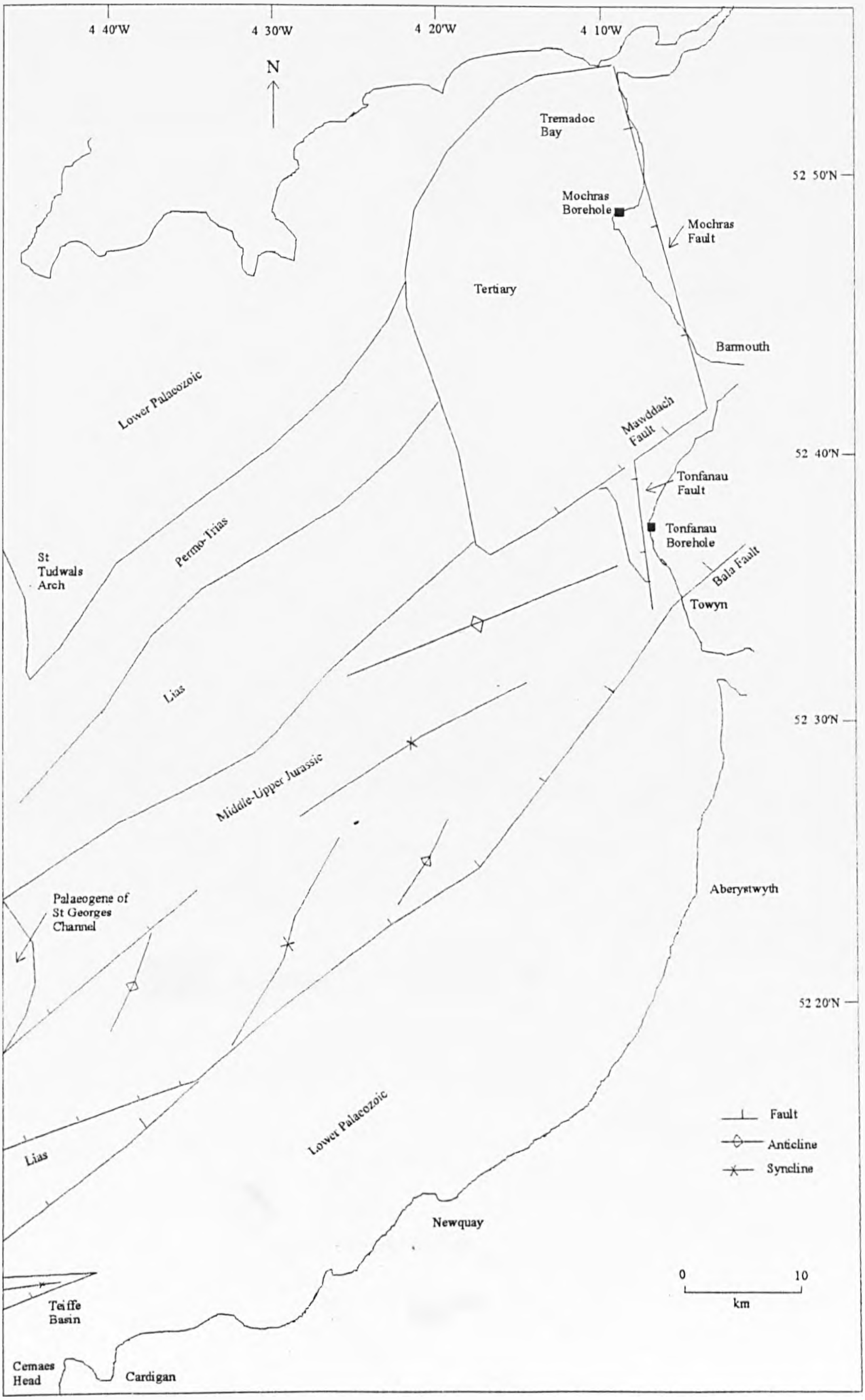


Fig 3.7 Simplified geological map of Cardigan Bay and Tremadoc Bay after Wilkinson (1979).

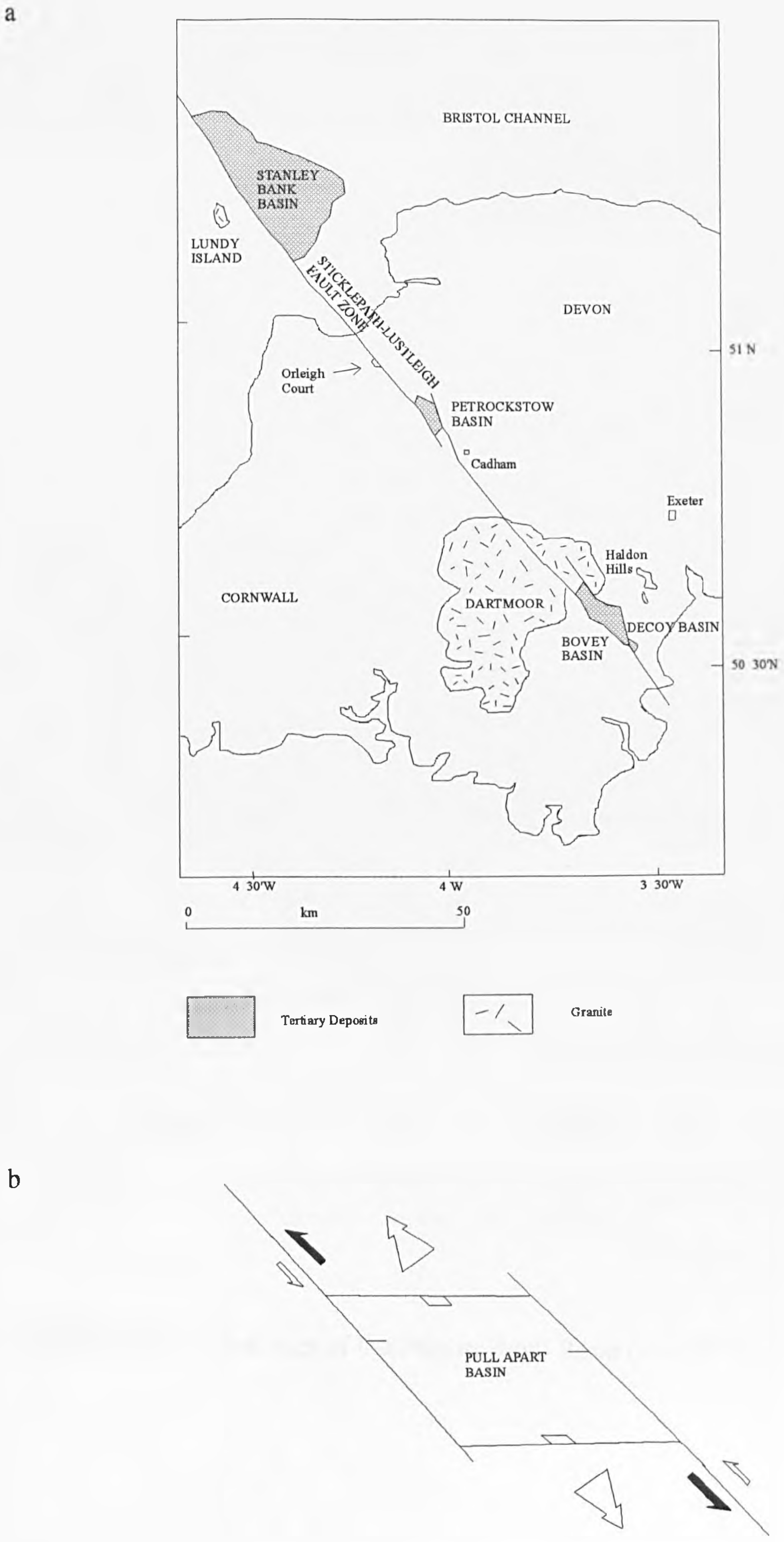


Figure 3.8a The location of the Tertiary Basins along the Sticklepath-Lustleigh Fault Zone and b the structural formation of a Pull Apart Basin.

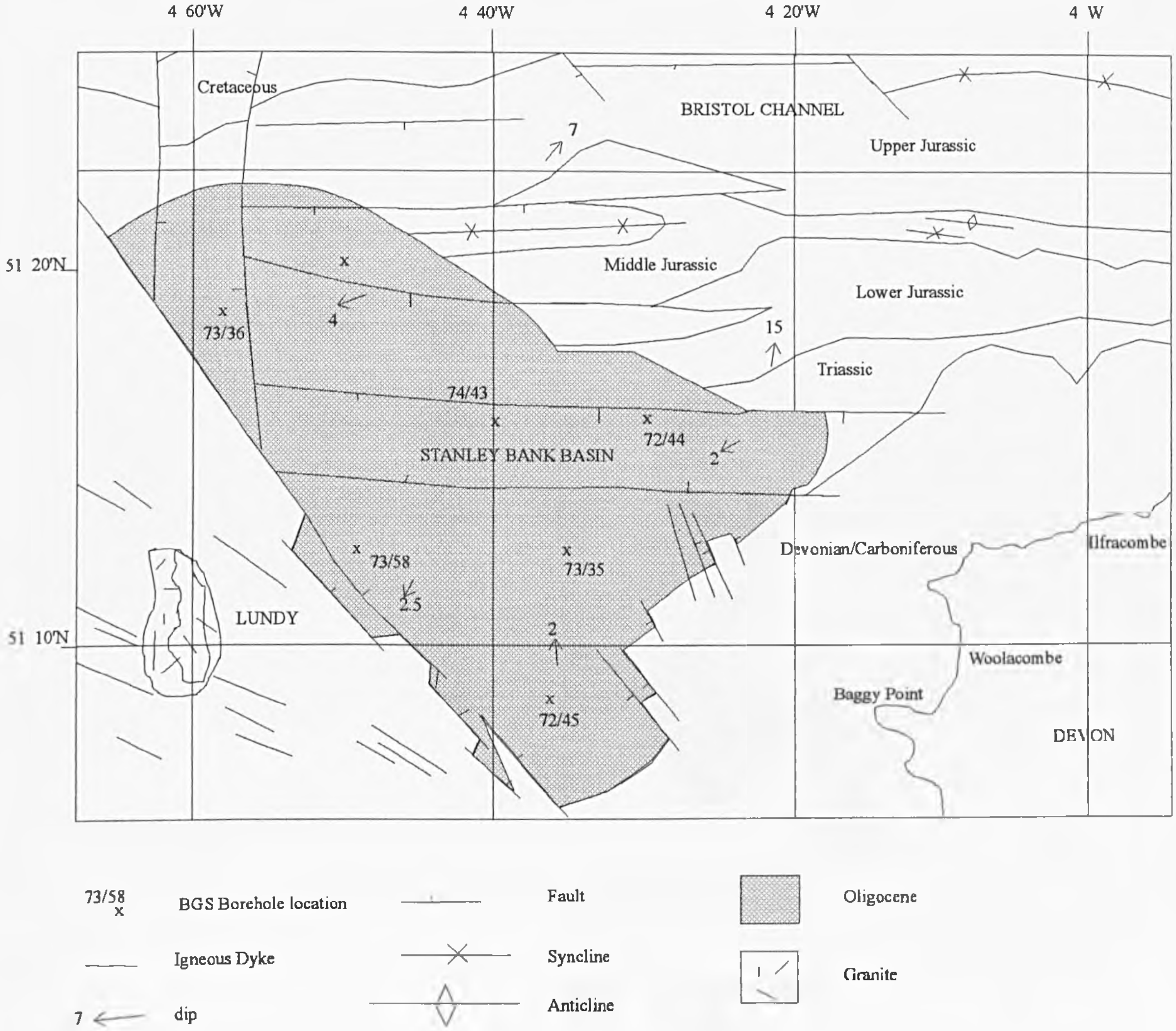


Figure 3.9 Simplifed geological map of the Stanley Bank Basin (after IGS sheet 51N 06W).

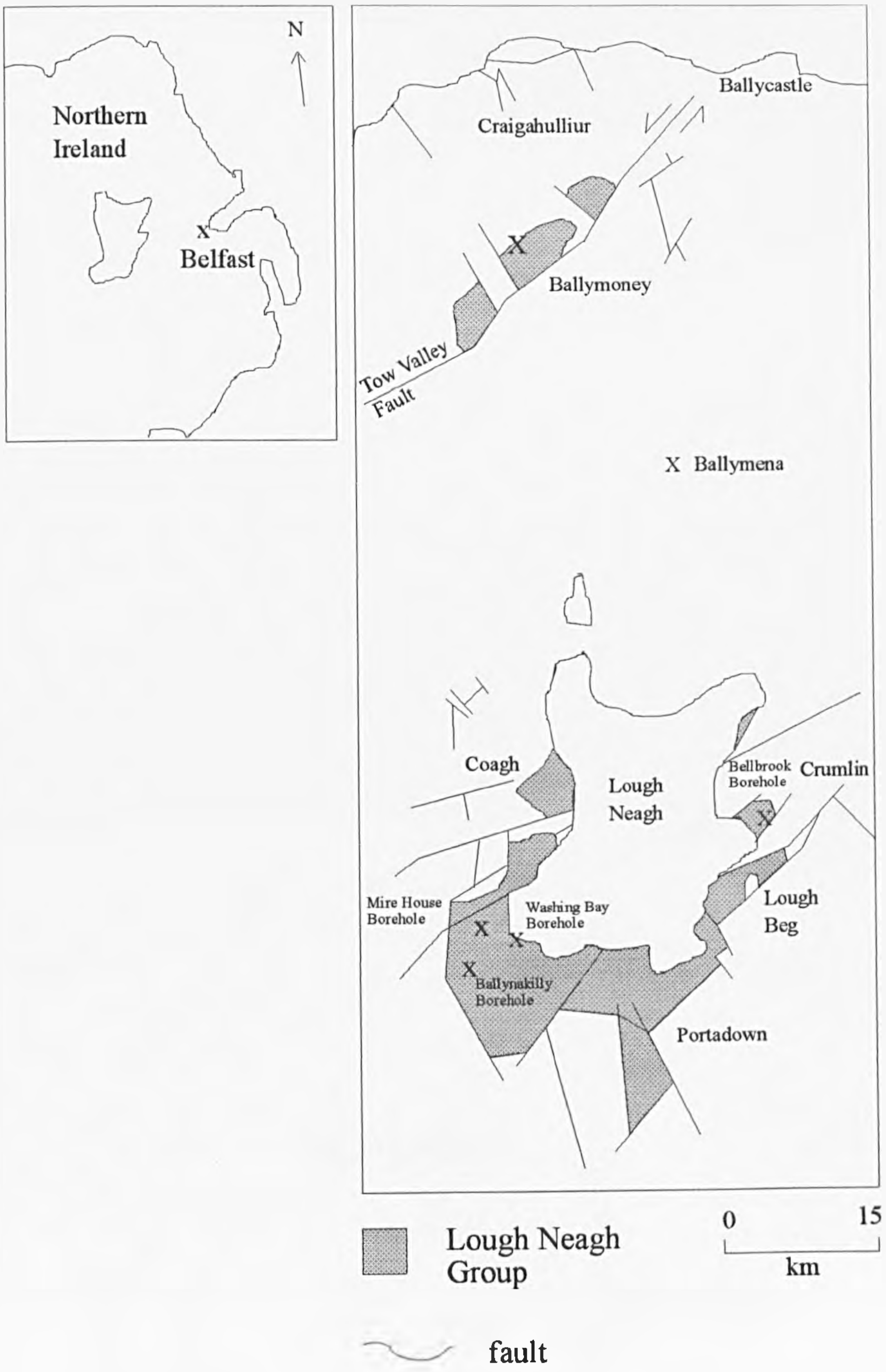


Figure 3.10 Map showing the location of the Lough Neagh Group sediments in Northern Ireland (after Parnell & Shukla, 1989)

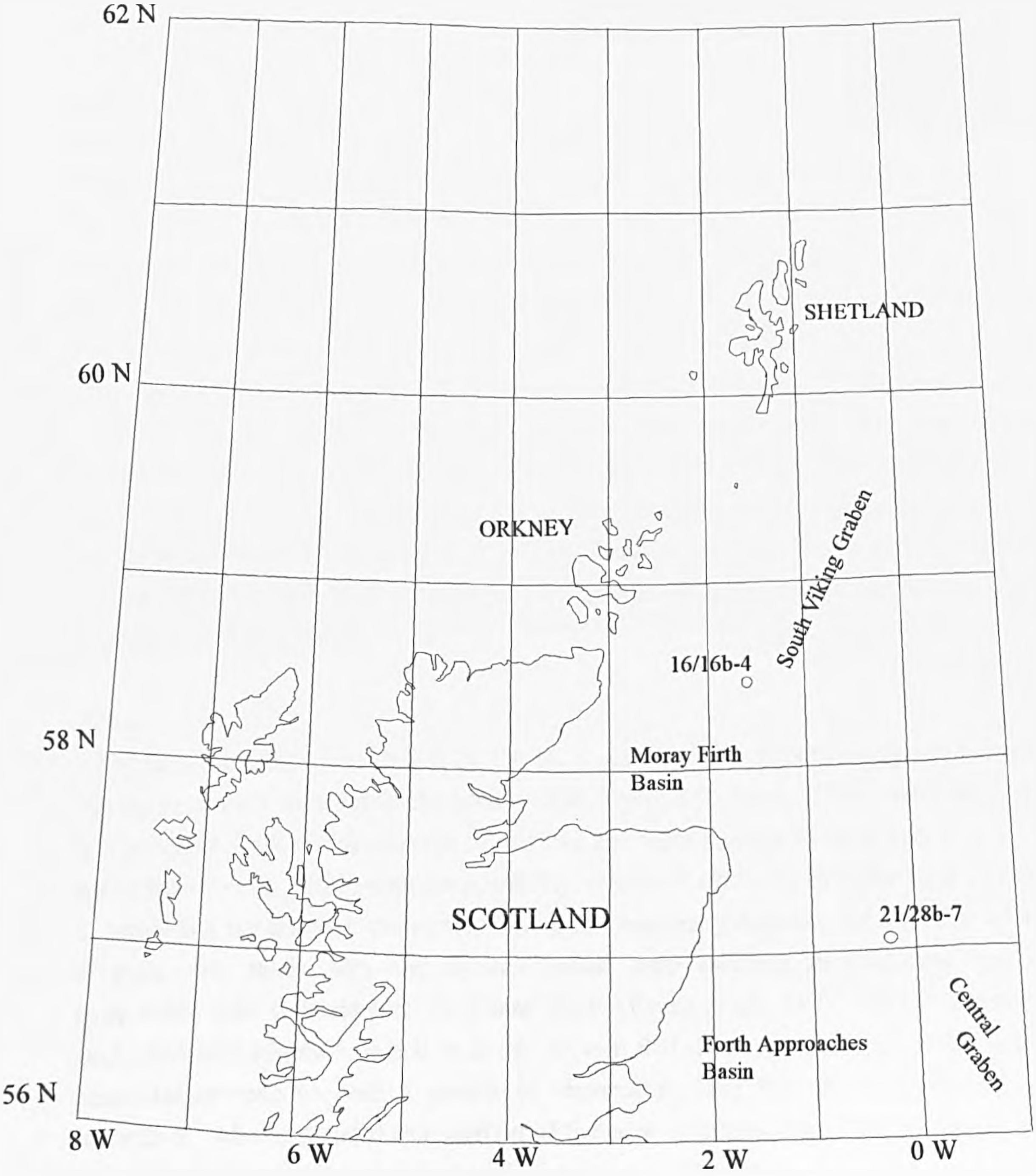


Figure 3.11 Map showing borehole locations of the two marine sections from the North Sea

CHAPTER 4

SEDIMENTOLOGY

Sediments are important to the study of palynology as they determine whether palynomorphs are present and if so which type of palynomorph is likely to occur. Prior to studying in detail the palynological data from the sections examined in this project, the sedimentary sequences from the sections in question must be described. Different lithofacies are more or less productive of palynomorphs; for example finer sediments deposited in low energy environments such as clays and silts, contain more palynomorphs than coarser sands, grits and conglomerates which contain fewer due to the higher energies at the time of deposition. Also, oxidised red beds are likely to be barren of palynomorphs, as oxidation destroys any organic material occurring in the sediments. Therefore it is important to understand the sedimentary sequences from which the palynomorphs are obtained, in order to attain a clearer understanding of the results.

All the samples taken for palynological investigation are listed and described in Appendix 1.1 to 1.7 for every section. Each sample taken is denoted as a small circle on figures 4.1 to 4.7 for the respective sections. The details of the processing techniques for the samples collected is described in full in Chapter 11. The closest possible sample spacing, lithology and time permitting, was used in order to obtain the most detailed palynological data possible.

80/14

The borehole 80/14 was drilled by the BGS with the aim of penetrating the westerly dipping sediments adjacent to the Minch Fault (figure 3.2, 3.4a). These sediments were first indicated from seismic surveys of the area and were thought to be largely Jurassic in age (Chesher *et al.*, 1983) with the possibility of some Carboniferous (Eden *et al.*, 1973). In actual fact the borehole penetrated 34.6m of Quaternary deposits and a further 44.4m of clays with sands, silts and lignites, which were assigned an Oligocene age by comparison with sediments of the Canna Basin (Evans *et al.*, 1979; 1991). From the geological map (figure 3.4a and b) it can be seen that these sediments are fault related, penecontemporaneous with a period of movement along the Minch Fault, dipping towards it. After a detailed examination of the core, a graphic log of the sediments and structures of this section was produced (figure 4.1). Three fining upwards units on the gamma ray log have been marked by arrows (figure 4.1).

The lithology is predominantly claystone, these are not mottled, suggesting perennial water logging or swamp conditions, with the lack of palaeosols indicating a high water table. Theses sediments are comparable to the 'Transitional Unit' and the 'Lignite and Clay Unit' described from the Mochras borehole (O'Sullivan, 1979) and facies A of Dobson & Whittington (1987) from Stanley Bank, although the rootlets described by these authors are not always seen to be present. The claystones are grey in colour with carbonaceous fragments and plant remains being common. Several listric surfaces or slickensides are seen to occur and rootlets are preserved below thin lignite layers at a depth of 73.5m. Iron staining in the basal sandstone of the section is noted at 78.70m. The upper part of the section (60-70m) contains claystones with lignite bands upto 1m thick whereas the lower part (70-80m) contains very thin lignite layers, 10cm thick, which are interbedded with coarser grained clastic material such as conglomerates (71.6m) and grits (75.5m).

The clay mineralogy (Evans *et al.*, 1991) varies through the section from 55-80% kaolinite & chlorite and 15-45% smectite with gibbsite also present near the base of the section. The percentage of kaolinite & chlorite decrease to 50-60% upsection and smectite increases to 30-40% upsection.

The interbedded sandstones are relatively poorly sorted (possibly crevasse splays, O'Sullivan, 1979) they contain quartz, kaolinite (originally feldspar), unaltered feldspar and detriatal clays. The heavy mineral content epidote, garnet and amphibole (Evans *et al.*, 1991) indicates an origin from a crystalline basement source. This is probably the Lewissian basement from the western side of the Minch Fault (figure 3.3 and 3.4a). The high proportions of kaolinite and gibbsite indicate intense acid weathering, either from the source or during exposure on floodplains prior to deposition. The increase in smectite and reduction of gibbsite up through the section has been suggested to represent unroofing of deeply weathered profiles into more immature material.

Jurassic reworking and glaucony grains (Evans *et al.*, 1991) originate from the Jurassic sediments in the Minch and Skye areas (figure 3.3) either due to subsidence drainage from these areas or the Jurassic sediments once present to the west on the outer Hebrides and beyond.

From this section 19 samples were processed and used for this palynological investigation. These 19 samples are listed and described in Appendix 1.1 and shown on figure 4.1 as small circles. The samples were taken from predominantly claystone and siltstone lithologies in preference to the sandstone, conglomerate and lignite layers as trial and error showed the latter lithologies to yield poorer palynological assemblages.

88/12

The objective of the borehole 88/12 drilled by the BGS in September 1988 was to examine the possibility of Carboniferous rocks in the Little Minch Basin. The succession from 0m to 31.5m was found to represents Quaternary sediments. It is the succession from 31.5m to 54.25m that represents the sediments of interest in this study (figure 4.2). The outcome of an initial study of these sediments by the BGS indicated these sediments to be of Palaeocene or younger age rather than Carboniferous. The conglomerates, interbedded mudstones and siltstones that comprise the interval of interest are in fact sediments of Oligocene age.

As in 80/14 the sedimentary sequence here is thought to be fault related, although the conglomeratic nature of these sediments suggest this section is in a more proximal setting on an alluvial fan developed on the active Minch Fault (figure 3.4a and b) The conglomerates are green to grey in colour and poorly sorted. They are massive in structure with no bedding or grading being seen. The clasts are large up to 7cm in diameter and are generally well rounded, some are noted to have weathered rims. The conglomerate is composed of polymictic clasts the majority of which are basalt. It varies from clast supported to matrix supported with a fine to coarse sandy matrix and some lignitic fragments. Interbedded between the conglomerates are thinner sandstone, mudstone and lignite layers. The sandstones are dark grey in colour, poor to moderately sorted, massive and silty to coarse grained with plant fossil remains and black carbonaceous rich layers. The claystones and silty claystones occur in a relatively thick layer close to the top of this sequence between 32.63m to 33.68m in depth. The dark grey claystones are silty in places and contain carbonaceous patches, listric structures and rare plant fragments. The predominant conglomerate lithology of this section differs drastically from all the other sections studied which are claystones interbedded with sandstones, siltstones and lignites.

Eight samples were taken for palynological study from the 20m section (figure 4.2 and appendix 1.2). Due to the nature of the sediments the thin claystone and siltstone interbeds were sampled in preference to the conglomerates. Although three samples from conglomerate lithologies were taken to lessen gaps in the section occurring between the more suitable lithologies, these were processed very carefully and were found to yield some palynomorphs.

78/1

The Canna Basin formed on a downwarped basalt lava pile to the NW of Canna which lies over the Sea of the Hebrides and Little Minch Trough (figure 3.5a and b). By analogy with the Lough Neagh area Smythe & Kenolty (1975) proposed the Canna Basin to contain Tertiary sediments probably of Oligocene age. In 1978 the BGS drilled a borehole into the sediments of the Canna Basin, namely borehole 78/1. The initial results of the investigation are published in Evans *et al.* (1979) which proved the sediments found to be the most northerly presence of terrestrial Oligocene deposits in the Western British Isles.

In all, 141.40m of sediments were cored from this section and after a detailed examination of the core material, a graphic log of the sediments and structures of this section was produced (figure 4.3). The Quaternary succession occurs from 0m to 123m and consists of soft to stiff clays which are often gravely or pebbly. A general reduction in the gamma ray response at a depth of about 120m indicates the change over from soft to stiff Quaternary clays to the underlying very stiff overconsolodated claystones of the Tertiary sequence. The sparker section through this borehole shows two seismic facies the upper relatively flat Quaternary sediments which are underlain by a facies that is slightly more steeply dipping to the SW (Evans *et al.*, 1979).

Underlying the Quaternary sediments a thinner sequence of Oligocene sediments occur from 123m to 141.4m and consist of dark green brown claystones. These claystones are often carbonaceous with lignite, plant fragments and occasional mica and feldspar fragments. Paler coloured orientated clay pellets of less than 1 mm in diameter are also noted to occur within the claystone. Coarse grained sand and grit layers are recorded from 127.50m to 128.14m and at 128.20m, the green red colour of this unit could be an indication of the presence of chlorite, glauconite or oxidation with brown stained quartz grains also noted here. A coarse grained pebble bed at 136.40m to 136.60m is recorded and consists of extraformational clasts of a basic igneous origin. Evans *et al.* (1979) suggest these Oligocene sediments are indicative of brackish near shore or lacustrine depostional environments with abundant influxes of plant debris and coarse sediments.

From this 20m section eleven samples were taken for palynological investigation these samples are listed and described in Appendix 1.3 and shown as small circles on figure 4.3 from wholly claystone lithologies at a spacing of 1m to 2m intervals.

77/7

This section was drilled in 1977 by the BGS with the aim of sampling seismically variable units which were thought to be Quaternary in age with the underlying well bedded, onlapping Tertiary sequences in the Rona Basin and Solan Bank High areas. Here the Tertiary sediments occur dipping towards the centre of the basin away from the basement highs (figure 3.6a and b). The initial results of the BGS investigation are published in Evans *et al.* (1981) and a more recent examination of the data is published in Evans *et al.* (in press).

After a detailed examination of the core material a graphic log of the sediments and structures of the section was produced (figure 4.4). The sediments encountered at the top of this section from 47.5m to 110.2m represent a Lower Miocene age (Evans *et al* , in press) and are composed of dominantly dark green calcareous, sandy siltstone interbeds with sandstone and mudstone layers which contain bioclasts including bivalves. Underlying this is a highly glauconitic unit consisting of a fine grained muddy sandstone with mollusc bioclastic debris (bivalves and gastropods) and interbedded sandstones. These sediments are generally unlithified with a carbonate cemented horizon noted at a depth of about 100m. The base of this unit grades into a buff silty mudstone. These sediments represent an Upper or Lower Miocene age.

The interval from 110.2m to 112.2m is described as a Mudstone Unit and is composed of finely laminated buff siltstones which grade into very dark carbonaceous claystones at the base with colour bands and thin partings of silt or fine sand and plant fragments. Underlying this unit is a Carbonaceous Unit from 112.5m to 123.5m. Here chocolate brown mudstones occur at the top of the sequence with fine buff sandstones at the base (figure 4.4). These sandstones are highly carbonaceous, with vertical rootlets visible. Lignite interbeds occur in bands which are highly sulphurous and show yellow encrustations. A Kaolinitic Unit from 123.5m to 138m is characteristically a pale to buff coloured claystone with a kaolinitic matrix, here kaolinite is present with the virtual exclusion of other clay minerals in the matrix (Evans *et al.*, in press) and fragments of quartz and feldspar (microcline and orthoclase) along with carbonaceous spots are common at the top of this unit. A thin grit band and conglomerate layer are noted to occur between 127m and 128m. A basement unit from 138m to the termination of drilling consists of a dark green amphibolite schist. The upper part of which is very deeply weathered resulting in the top being difficult to define.

It is the Mudstone, Carbonaceous and Kaolinitic Units that are of interest in this study. In all ten samples were taken from these varying lithologies such as siltstones, claystones, lignites and a sand. These samples are listed and described in Appendix 1.4 and are shown on the graphic log, figure 4.4.

73/36

The borehole 73/36 was the deepest of three shallow boreholes drilled by BGS in 1973 in the Stanley Bank Basin (figure 3.9) as part of a regional mapping programme of the continental shelf (Fletcher, 1975). A detailed examination of the core material from this section was undertaken and a graphic log of the sediments and structures occurring has been produced, figure 4.5. The interval from 0m to 4m is composed of gravel and sands and represents Quaternary aged sediments. While the interval from 4m to 33.88m represents the Tertiary aged part of the section and is composed of lignites with plant fragments and interbedded brown grey claystones, sandstones and siltstones. The sediments in the basin lie unconformably on Upper Palaeozoic and Mesozoic rocks and are seen to dip towards the western faulted margin of the basin (figure 3.9). Boulter & Craig (1979) suggest these Tertiary sediments to be Middle Oligocene in age and to represent distal floodplain deposits in back swamp to shallow lagoonal environments. The extensive lignites and grey clays along with the spores recorded were thought to be indicative of reducing conditions with a floodplain drainage postulated to be NW (Davies, 1987).

While a marine incursion at 18.95m noted by Boulter & Craig (1979) along with red siltstone facies are thought to be indicative of other oxidation conditions affecting the sediments of the area. It was this reported marine incursion that was the reason for sampling this material as part of this study. This material was looked at with the aim of giving direct evidence of marine microplankton within a terrestrial sequence providing a direct calibration to the North Sea sequence.

Three distinct sedimentological units have been recognised within the Tertiary sequence. From 33.88m to 24.82m sandstone layers with interbedded siltstone and claystones occur. Red, hard sands and orange/red siltstones are noted within this unit and a possible ganister, a claystone with what appears to be *in situ* rootlets are seen. Upsection from 24.82m to 16.74m is a predominantly grey claystone lithology with carbonaceous and plant fragments with some fine siltstone and sand laminations. A red siltstone is also recorded from within this unit. The top most unit of this Tertiary section occurs from 16.74m to 8m and contains predominantly lignite and dirty lignite lithologies with interbedded mudstones occurring.

From this 30m sequence 22 samples have been analysed in detail for palynological content and the associations defined from the data are described in Chapter 7. The samples have been taken at less than 3m intervals up the section from a variety of lithologies such as claystones, siltstones, lignites and lignitic claystones and are listed and described in Appendix 1.5 and shown on the graphic log, figure 4.5.

Well 28

A number of samples were acquired from the sediments of the Lough Neagh Basin in Northern Ireland. The samples were taken from a 12m section in the Coagh area on the western side of Lough Neagh. The lithologies of the samples indicate that the sediments represent the middle of the Lough Neagh clays sequence being dominantly woody lignites with interbedded blocky claystone layers.

The main aims of studying this section was to provide a comparison of both taxonomic data and stratigraphical and environmental evidence gathered from the offshore Scottish basins and the Stanley Bank Basin. Of the samples acquired 14 were processed and logged for palynology study, of these 13 were found to yield well with only one barren sample being encountered. The lignites proved difficult to process due to the very woody nature of the residues produced after acid digestion which were problematic, as they blocked up the sieves used in processing (see Chapter 11 for a detailed discussion of processing techniques) and gave strew mounts with very high densities of woody fragments. Despite this the pollen and spores encountered were a good representation of the taxa present. An Oligocene age for the Lough Neagh sediments has been postulated by Parnell *et al.* (1989) and Hubbard & Boulter (1983) with the Lough Neagh Group envisaged as being deposited in a lacustrine environment (Portlock, 1834, Parnell *et al.*, 1989) and the lignites and dark claystones deposited in a swamp mudflat environment at the margin of the palaeolake (Parnel & Shukla, 1989).

16/16b-4

This is the most northerly of the two North Sea marine sections examined as part of this study, it was drilled into sediments on the southern limb of the South Viking Graben of the British North Sea, as part of oil exploration in the area (figure 3.11). A total depth of 8088 ft was drilled in December 1991, this penetrated a Permian sequence from 7900 ft to 8088 ft, a Cretaceous sequence from 7700 ft to 7900 ft and a Tertiary sequence from 1250 ft to 7700 ft. In the graben areas in the North Sea a time of almost continuous sedimentation throughout the Tertiary has been envisaged accounting for the large thicknesses seen in this section. Within this Tertiary sequence an undifferentiated Oligocene to Recent aged section is seen to occur from 4250 ft to 1250 ft and this is the part of the section of interest in this study. Twenty one samples were processed for palynological investigation between 4320 ft and 3440 ft, these were taken at 20 ft to 80 ft intervals, depending on lithology which, it was hoped would sample the Oligocene aged sediments. These samples are listed and described in Appendix 1.6.

The 900 ft 'Oligocene' section is composed of predominantly claystones and siltstones with interbeds of sands and calcareous sediments (figure 4.6). The claystones are buff to grey/brown in colour and contain patches of silt, sand, pyrite, lignite, glauconite, shelly fragments and calcareous material. The siltstones are grey/brown in colour and contain micas in varying abundances with local sandy or clayey patches and thin limestone bands. Lignites occur in thin layers, they are brown to black in colour and brittle to crumbly in texture. The lignites are more abundant towards the top of the section along with more carbonaceous fragments.

Figure 4.6 shows two Type 2 sequence boundaries (*sensu* Van Waggoner). These have been identified by a characteristic shift to the right on the gamma ray curve. Firstly the Rupelian/Chattian boundary occurs at a depth of 3874 ft occurring between two coarsening upwards sequences. Secondly the Oligocene/Miocene boundary can be seen occurring at a depth of 3580 ft again at the top of a coarsening up unit.

21/28b-7

This well section was drilled in the Outer Moray Firth area of the British North Sea and was drilled as part of oil exploration (figure 3.11). A total depth of 6590 ft was drilled in September 1991 and penetrated a Triassic sequence from 6590 ft to 5820 ft, a Cretaceous sequence from 5820 ft to 4830 ft, a Tertiary sequence from 4830 ft to 1800 ft and a Quaternary sequence from 1800 ft to 293 ft. Of the Tertiary sequence Oligocene aged sediments were thought to occur in the interval between 3200 ft to 2770 ft. Eleven samples were taken at 30 ft to 60 ft spacing, depending on lithology, these samples are listed and described in Appendix 1.7.

This 400 ft 'Oligocene' aged section is composed of predominantly claystones and siltstones with subordinate layers of sandstone and limestone with an unconformaty in the sequence marked at 3030 ft (figure 4.7). The claystones are grey to green in colour, soft, slightly calcareous and contain characteristic loose quartz fragments. The siltstones are brown in colour, they occur predominantly in the lower part of this section and contain sandy and micaceous patches. Also in the lower part of the section buff to brown limestones are common and they occur as angular crystalline sediments. Interbeds of fine sandstone occur in the upper part of the section, these are quartzose sandstones with glauconite and shelly fragments No lignitic patches or carbonate fragments are seen to occur in this section.

One Type 2 sequence boundary has been identified in this section (figure 4.7) by the characteristic shift in the gamma ray response curve to the right. This corresponds to the Rupelian/Chattian boundary in this section occurring at a depth of 3030 ft which is at the top of a coarsening up unit.

At this point it should be noted it is beyond the scope of this project to define parasequences for the two marine sections here, although it is possible given the wire line log information and lithologies. Both the widely spaced nature of the samples studied and the caving associated with these cuttings make it difficult to relate floral associations to parasequences. Moreover the driller to logger depth discrepancies varies from 18 ft in 21.28b-7 to a vast 60 ft in 16/16b-4 making the delimitation of accurate palynoflora to parasequence relationships difficult.

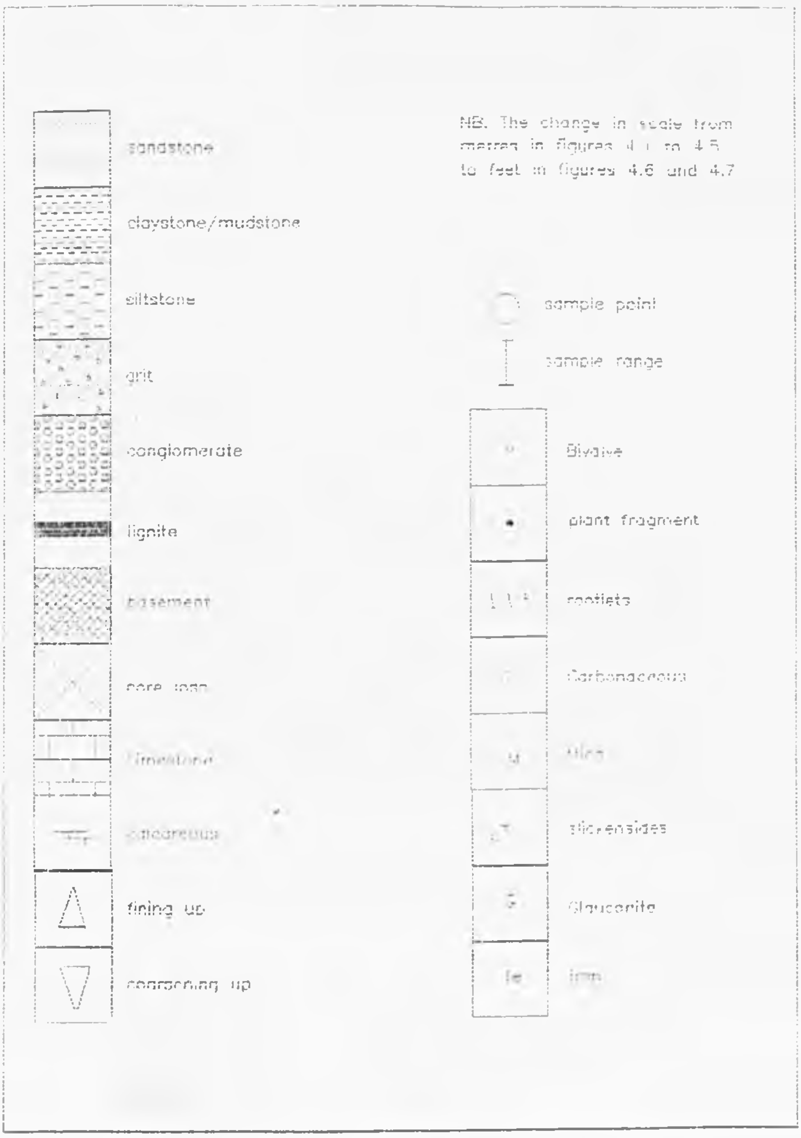


Figure 4 Key to the symbols used in Figures 4.1 to 4.7

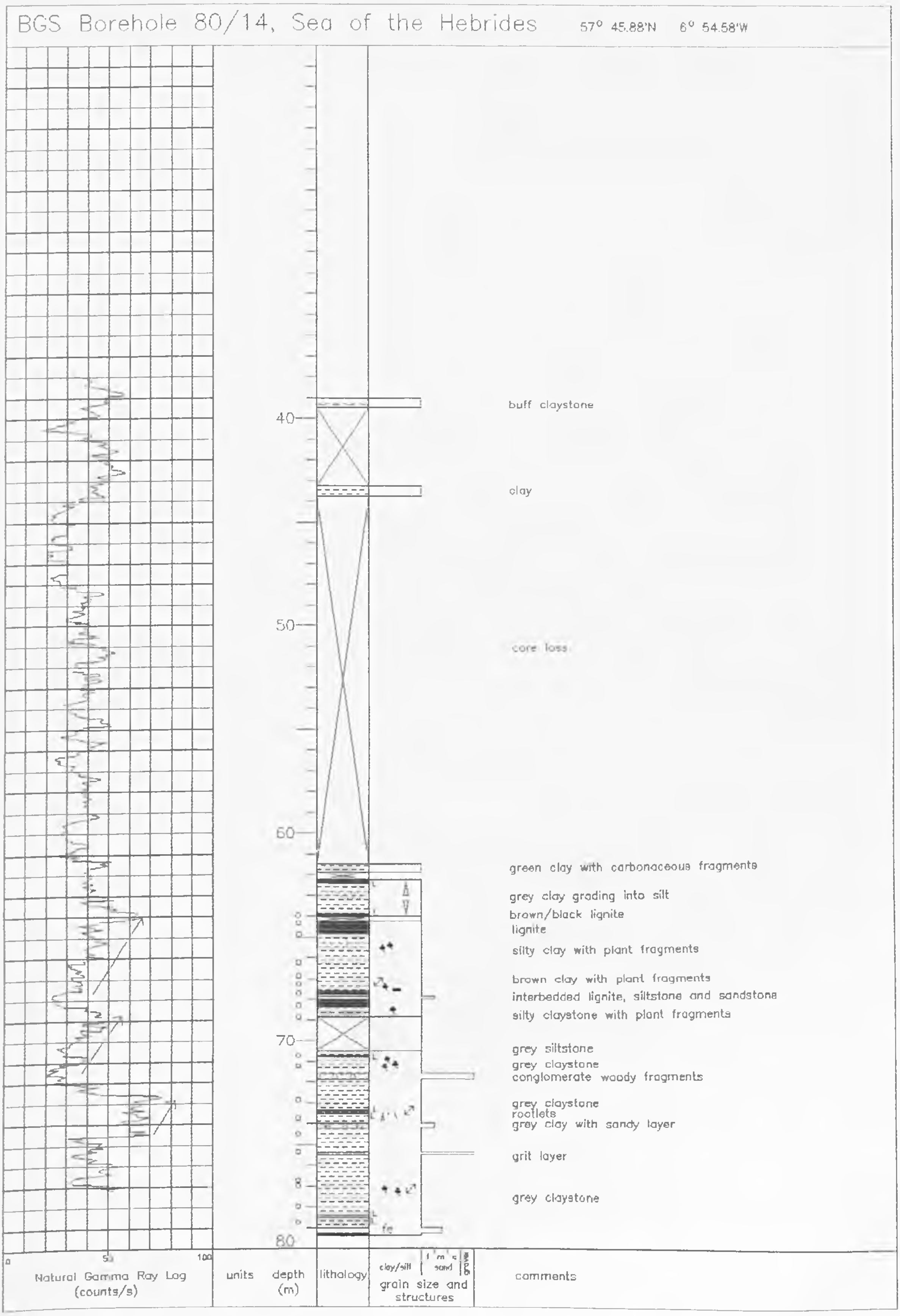


Figure 4.1 A graphic log of the sediments and structures seen from the 80/14 core material.

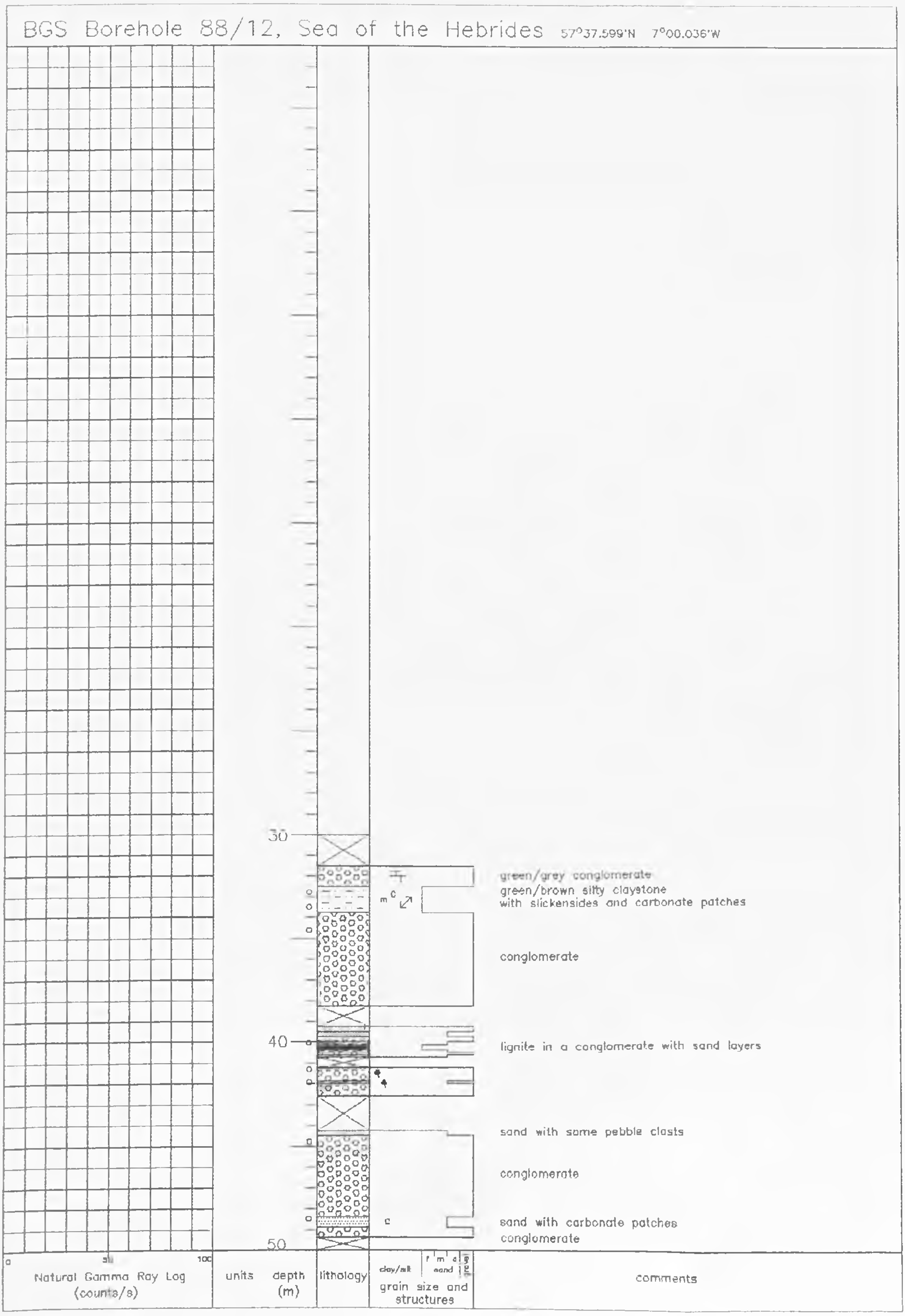


Figure 4.2 A graphic log of the sediments and structures seen from the 88/12 core material.

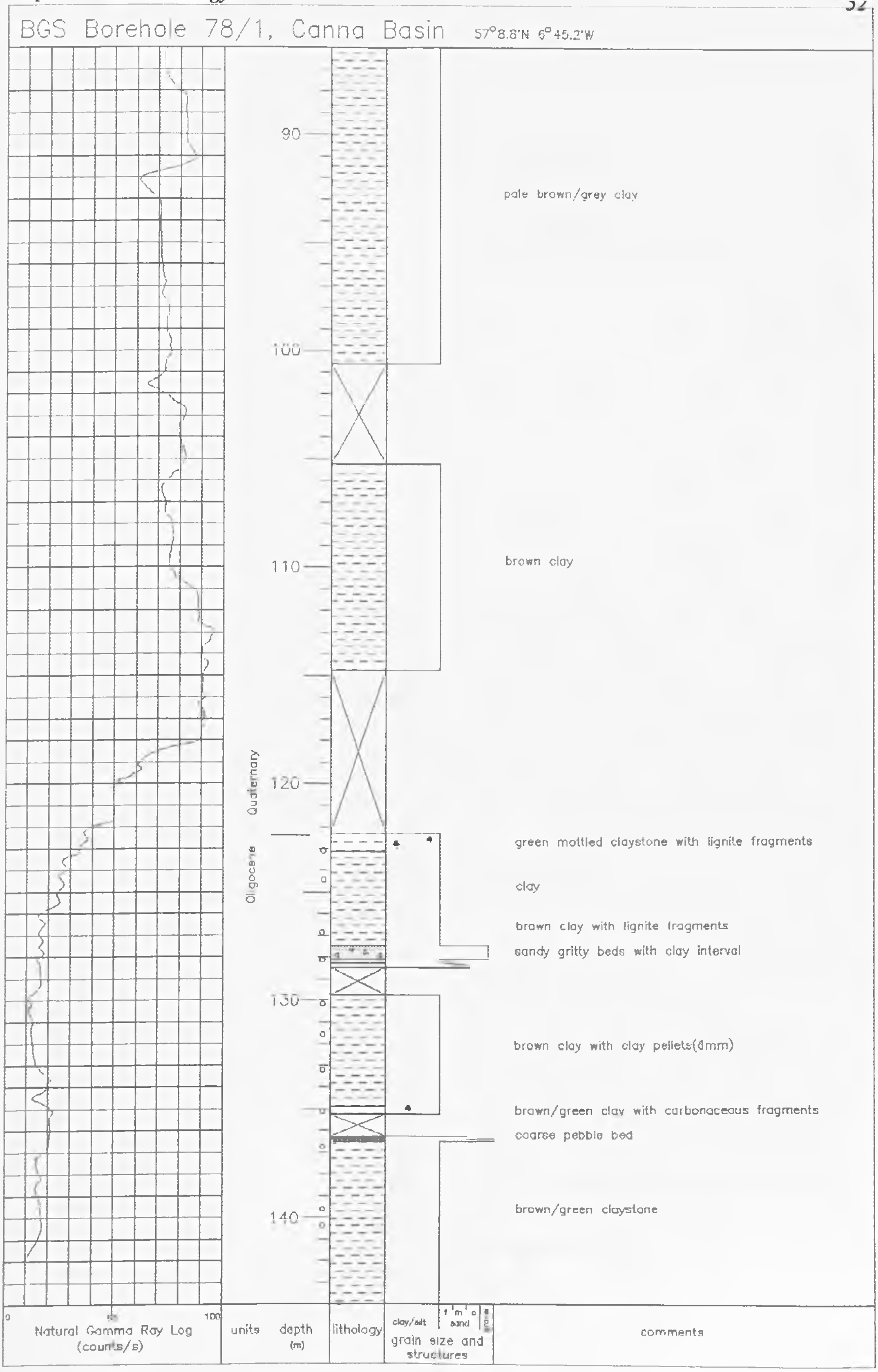


Figure 4.3 A graphic log of the sediments and structures seen from the 78/1 core material.

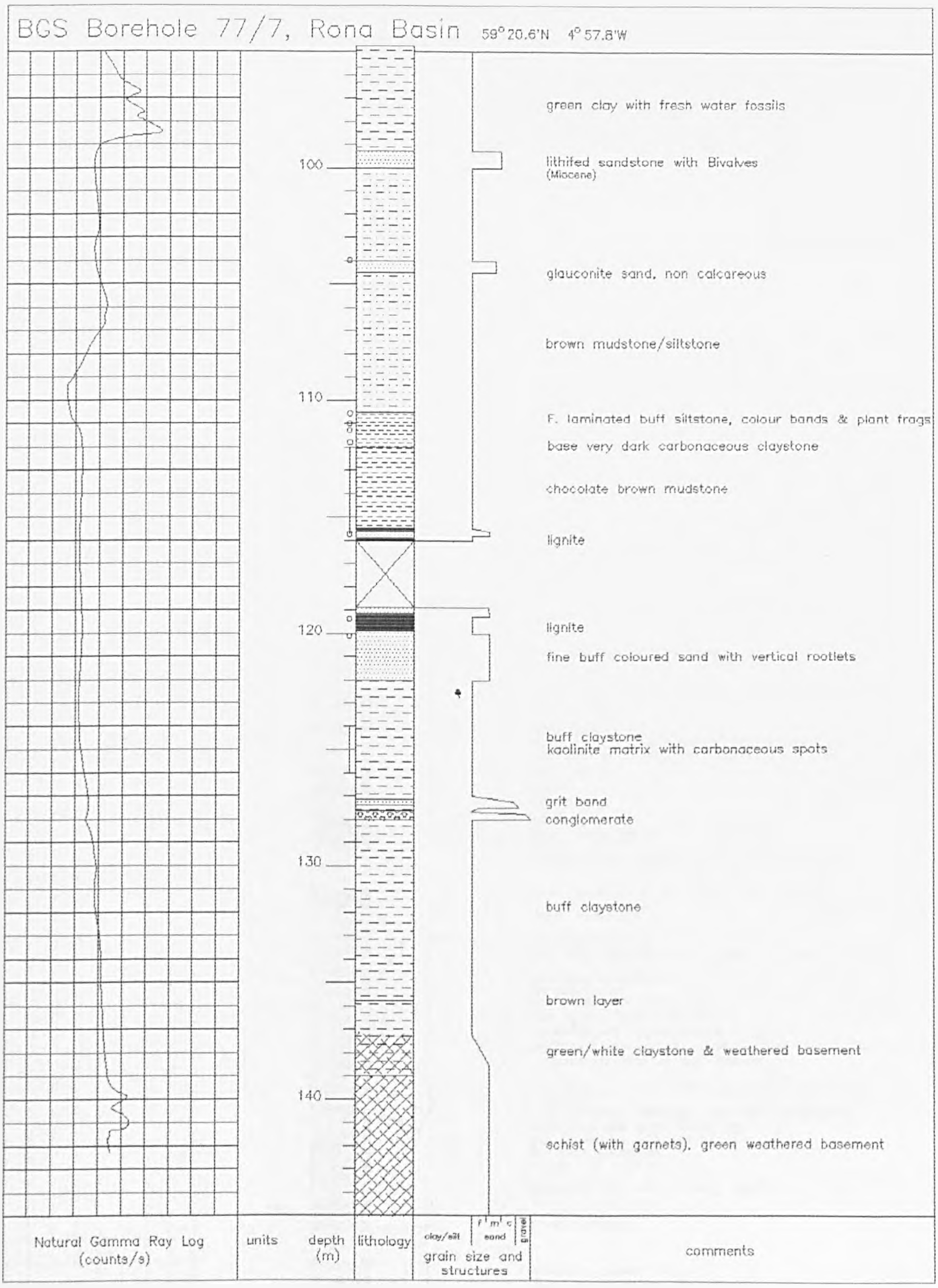


Figure 4.4 A graphic log of the sediments and structures seen from the 77/7 core material.

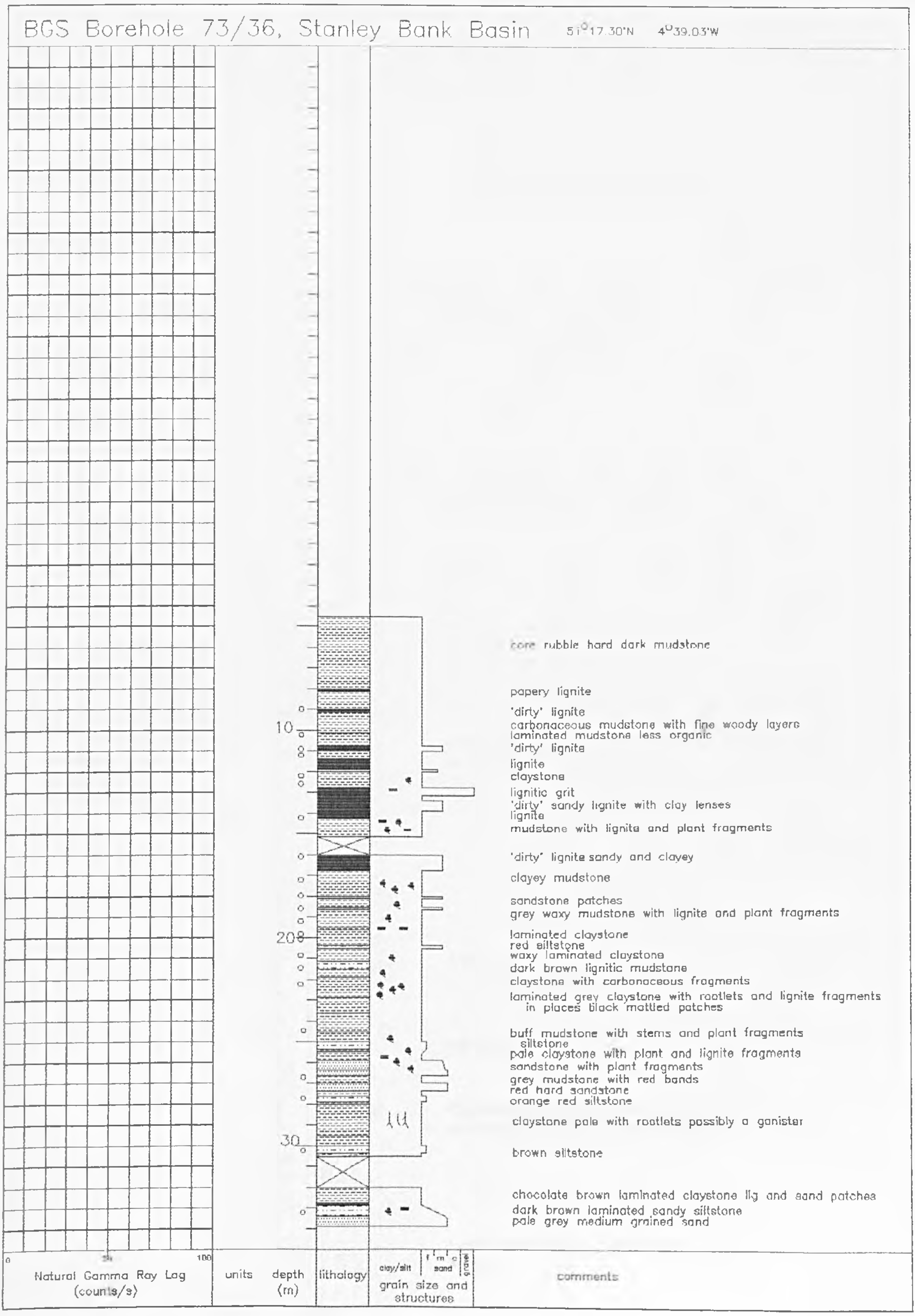


Figure 4.5 A graphic log of the sediments and structures seen from the 73/36 core material.

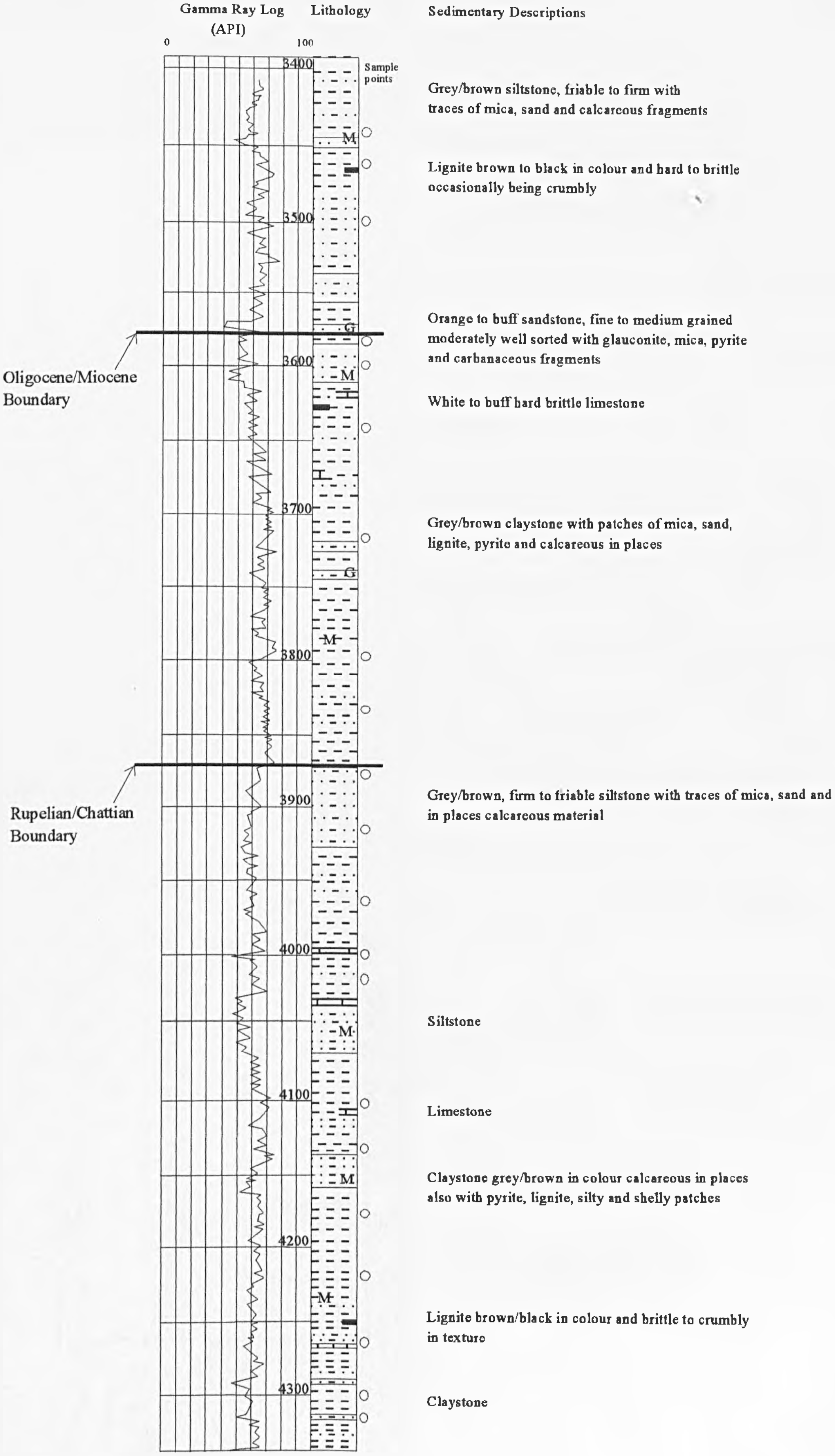


Figure 4.6 A sedimentary log of the 16/16b-4 section (adapted from UNOCAL well log data, 1992)

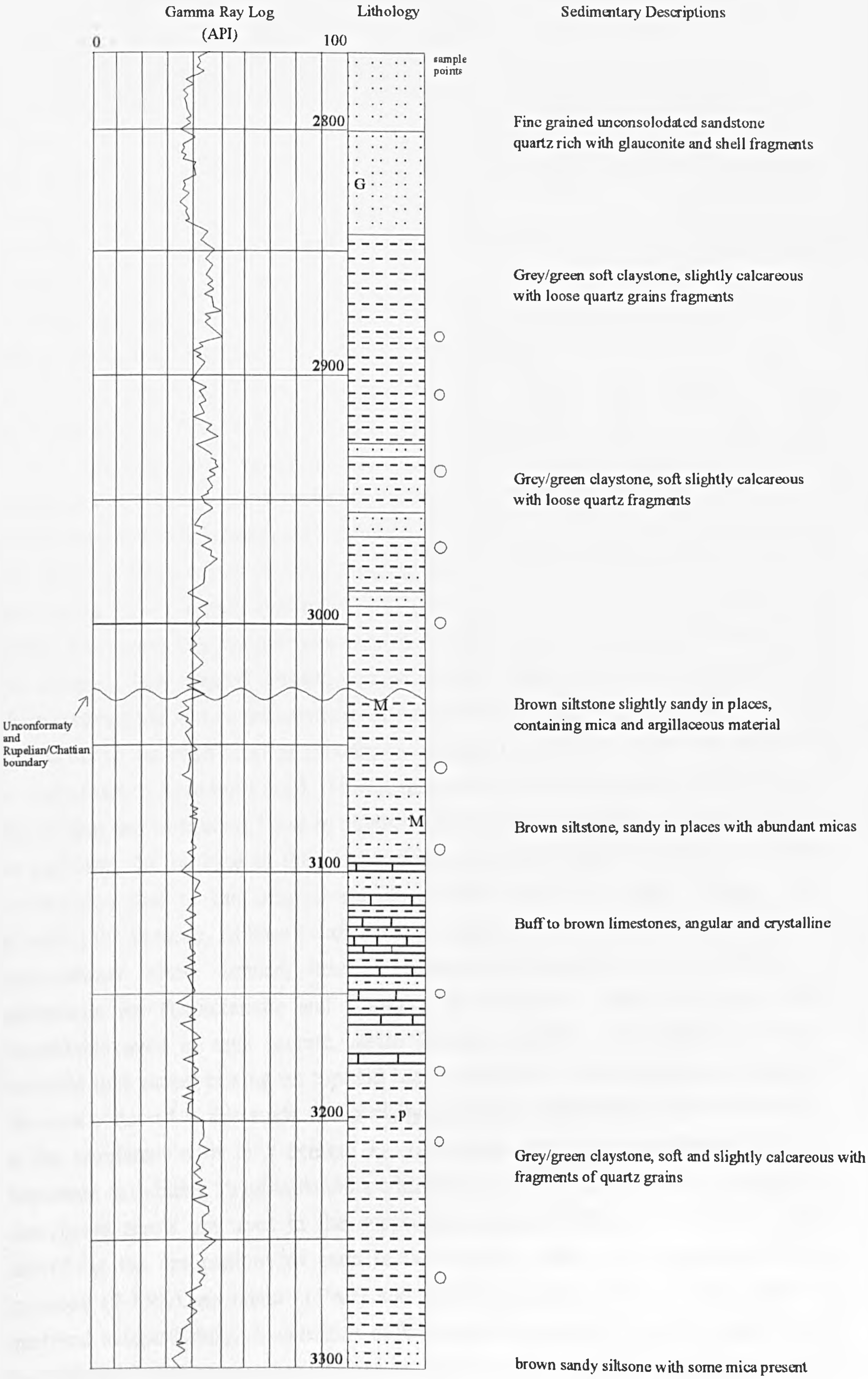


Figure 4.7 A sedimentary log of the 21/28b-7 section (adapted from UNOCAL well log data)

CHAPTER 5

DATA COLLECTION AND ANALYSIS

The palynological analysis of the six terrestrial sections forms an important focus for this project. The terrestrial palynomorphs encountered in these sections, pollen and spores, were recorded in counts of 250 palynomorphs per sample, with the rest of the slide being scanned for other taxa present not recorded in the count. This data was then entered into the 'Tilia' spreadsheet and graphical package, where the quantitative data could be displayed graphically and the data statistically manipulated. Extra taxa (above the count) recorded in the scan are noted with the symbol in parentheses (+) on the Tilia charts (enclosures 1 to 10). A figure of 250 for the standard count is regarded as an optimum figure to pick up the diversity of taxa in any particular sample. In some cases where taxa are sparse, a count of 250 palynomorphs per sample is not obtainable. In these circumstances as many palynomorphs as possible are counted and only samples with counts over 100 are regarded as statistically viable. The two marine sections analysed contain both dinoflagellate cyst and pollen and spore taxa. To maintain continuity with the terrestrial sections counts of 250 (+) pollen and spores per sample were recorded along with 250 (+) dinoflagellate cysts per sample. This enabled detailed comparisons between the pollen and spores from the terrestrial and marine sediments to be compared in a proportionate manner.

In order to establish detailed correlation between the sections studied in this work, two approaches have been used. Firstly, that of top and base occurrences of taxa up the section and comparing these to published zonation schemes which feature the taxa in question. In the case of the marine data, particular attention is paid to the top occurrences due to the original sample material which was ditch cuttings, thus affecting the accuracy of base occurrences by caving. Secondly a number of units or 'associations' where defined, here associations are described in an attempt to summarise the characteristic and common assemblages of taxa that occur within identifiable units in each section, *sensu* Lockley (1983). Associations are more versatile than purely relying on top and base occurrences. The quantitative nature of the data collected in this study is especially conducive to the use of associations, as it is the combination of taxa present in conjunction with their abundances that are important in defining identifiable units within the sections. The following quantitative descriptive terms are used in the succeeding chapters (Chapters 6 and 7) when describing the associations of each section studied, rare (0-3%), present (3-7%), common (7-15%), abundant (15%+) and highly abundant (40%+). Each section is analysed independently, associations defined and described in Chapter 6 and 7, with the top and base occurrences for each association used for general dating purposes. For each section the major features and findings are discussed for all the available data and palaeoenvironmental conclusions are made. Once associations have been defined for each section, they can be compared to the other sections to see if a correlation is possible.

A number of statistical procedures on the individual data sets was undertaken. It is important to treat the data numerically as it provides an objective method of interpretation. This is thought necessary in order to both aid interpretation (e.g. variance) and to test or to quantify the subjective interpretations of the data (e.g. Cluster Analysis).

STATISTICAL PROCEDURES

It has been shown that simple statistical methods applied to a data set can be used to infer palaeoenvironmental conditions (Goodman, 1979; Harland, 1983 and Davies *et al.*, 1982). This line of thought is followed here and a number of statistical procedures are applied to the data sets in this study.

Diversity and numbers of palynomorphs per gram

The diversity of a sample is easily defined, simply as the numbers of different species recorded in each sample. As the samples for each palynological preparation were quantitative, actual numbers of palynomorphs i.e. palynomorphs per gram could be calculated. Muller (1953) showed the diversity and numbers of pollen and spores in a marine sample increase with proximity to land surfaces. This has been furthered by Harland (1983) who concludes that dinoflagellate diversity is maximum in the outer neritic, shelf slope break area and reduces from this location both inshore and offshore. A prominent low in the diversity of palynofloras is associated with inner neritic zones. Davies *et al.* (1982) described this low diversity as being associated with stressed environments where only a few adaptive species are present.

Variance and standard deviation

Further to diversity values and number of palynomorphs per gram, variance and standard deviation values are calculated for the data. Both are a measure of the degree to which individual values in the data set vary from the mean (average) of all the values. Variance being defined as the average of the squared deviations from their mean and standard deviation being the positive square root of the variance. Variance and standard deviation values are most accurate for large numbers of observations, which is definitely the case in this study. The lower the variance/standard deviation the less a samples individual values vary from the mean and a variance/standard deviation of zero indicates all the values in the sample are equal to the mean, therefore a higher value indicates a greater variation from the mean. Furthermore, where a number of taxa show particular dominance in a sample the result will be a high or peak in the variance/standard deviation value. Therefore these calculations are an indicator of dominance within a sample. This method to indicate dominance is used in preference to the various dominance index calculations that are published e.g. Goodman (1979), which is calculated from the sum of the two most abundant species divided by the diversity of the sample. This assumes that only two taxa of equal dominance occur whereas in reality a larger number of 'dominant' taxa is more likely.

From the marine microplankton sections variance is interpreted as an indication of dominance. Lower variance values i.e. many species with higher numbers or maximum diversity, are characteristic of outer shelf environments with high nutrients and general conditions able to support a wide range of taxa. High values of variance i.e. more dominance of few species with high numbers is characteristic of proximal, near shore environments or stratified oceanic, bathyal environments which result from transgressive events. Here only a few tolerant taxa can thrive due to low salinities, high energy conditions or other stressed conditions.

The variance trends from the marine pollen and spore data must be interpreted in a different way due to the nature of transportation and deposition of the floras compared to the microplankton. Here the variance is an indication of the terrestrial input into a depositional environment. Therefore the closer the depositional environment is to the shoreline the greater the diversity of taxa will be present, resulting in a low variance value. Conversely the further the depositional environment is from the shoreline the fewer the number of taxa that can be transported a long distance, such as bisaccate pollen. This situation will result in an increase in dominance and therefore higher variance values.

Variance data from terrestrial pollen and spore sections again must be interpreted differently. A variety of factors affect this value and the terrestrial variance figures are therefore interpreted and discussed individually for each section (see Chapter 7).

Multivariate techniques

Multivariate statistical techniques are important in geology as virtually all geological data is naturally multivariate. Cluster analysis is a multivariate analysis tool which is used to summarise and determine relationships between samples in large data sets. It has been suggested (Swan & Sandilands, 1995) that cluster analysis is the best and only objective way to classify such data and it is the method chosen by the author, on the marine sections especially to try and quantify the data and the interpretations which have been made by studying the data with only the tool of an 'educated' eye.

Cluster analysis is a very complex mathematical procedure involving many variations in technique as the user has a choice of methods within similarity coefficients, clustering algorithms, partitioning, linkage methods and phenon lines. Variations on the above methods mentioned can produce many different results from the same data. This problem is overcome by choosing a method arbitrarily, or in this case on a recommendation from the literature (Grimm, 1987), before the analysis is run on the data (so as a particular methodology is not picked which is seen to fit the data or the assessors preconceptions) and to use the same method on all of the data to maintain continuity. For the rationale behind the methodology see Swan & Sandilands (1995). Recent studies indicate that with frequency pollen/palynomorph data the incremental sum of squares method of clustering performs well (Birks, Webb & Berti, 1975 and Grimm, 1987) so this method was chosen for the analysis. The analysis was performed using the Coniss cluster analysis package (for detailed program specifications see Grimm, 1987). This cluster analysis program bases its calculations of numerical similarity between each sample in turn giving a dissimilarity coefficient based on distance coefficients (Euclidean distance matrixes) and the sum of squares is incremented after each successive stage. Most importantly the cluster analysis is stratigraphically constrained i.e. only stratigraphically adjacent clusters are considered when the calculations are performed. This type of constrained clustering has previously been successfully used for biostratigraphy by palaeontologists (Birks & Gordon, 1985 and Kovach, 1993).

The results of cluster analysis are displayed in the form of a dendrogram which as the name implies has a branching tree like construction. The horizontal axis represents the similarity coefficient in this case the incremental sum of squares. The vertical axis represents the sample linkages which are connected by vertical bars which link the appropriate clusters/samples at the appropriate similarity value. Therefore the dendrogram illustrates the hierarchical relationship of the clusters defined by the analysis. Samples are joined singularly to another sample or to a cluster, the closer the junction is to the origin of the X axis, the more similar the two samples are (See Tilia Charts, enclosures 3 to 10).

A useful way of defining zones or clusters on the dendrogram is by using phenon lines. These are vertical lines drawn at a specific similarity value which cuts the dendrogram branches and isolates clusters or zones (for example see figure 6.2 a and b). These clusters will than have a similarity greater than the specific value within the cluster and less than the specific value between the clusters. A phenon line drawn close to the origin on the X axis indicates a very high similarity and at the opposite end only one or broad scale clusters or similarities are picked out. The choice of Phenon line can be subjective when placed to fit preconceived zones or clusters but the placing of this line must be flexible due to the different requirements of the user for various purposes. Often the best method to follow for the most objective way to place this line is that of natural solutions i.e. gaps between the linkages, these are an obvious location for the phenon line.

As the dendrogram represents the hierarchical relationship of the clusters defined it is often necessary to have a hierarchy or tiering of phenon lines on one diagram. This tiering could give an idea, in this case, of the magnitude or levels of the clusters. In a geological sense cut-offs can pick out different stratigraphical levels i.e. from clusters at geological stages, sub stages down to assemblage zones or association clusters. (figure 6.2).

CHAPTER 6

MARINE PALYNOSTRATIGRAPHY

The quantitative palynological data obtained from the two marine sections during this study is presented in the form of Tilia diagrams (enclosures 1 to 10). These graphically show the frequency of each genus and species noted to be present within the samples. After a detailed examination of the data a number of associations have been defined. In the case of the marine sections, both dinoflagellate associations and pollen and spore associations have been defined and described (Chapter 6). The latter enabling comparison to the pollen and spore associations defined for the terrestrial sections (Chapter 7). The original sample material for the two marine sections was in the form of dried ditch cuttings, therefore 'top down' associations are described, so that any caved material will not affect the results. Within each association defined, the top and base occurrences of any taxa within the association are listed and a calibration to the published literature and zonation schemes (figure 6.1) is discussed, for those taxa which are regarded to be of stratigraphical significance.

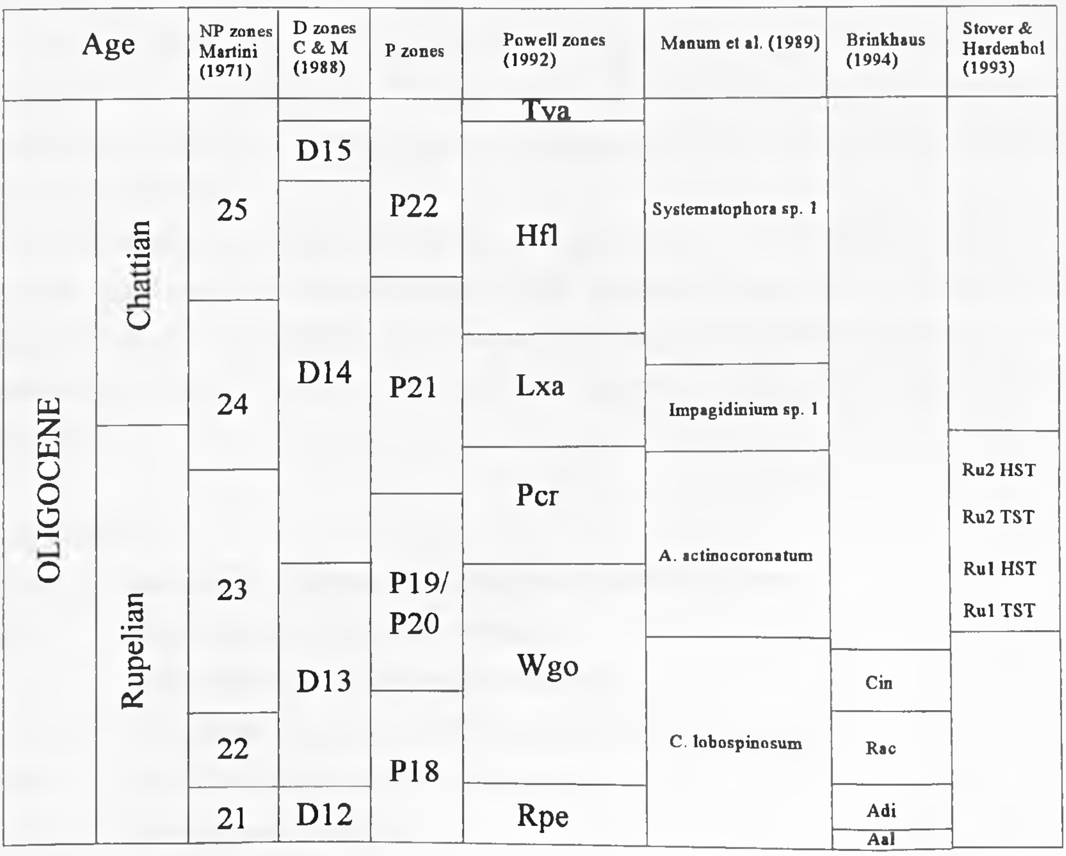


Figure 6.1 Showing the relative positions of selected zonation schemes in the Oligocene.

MICROPLANKTON SECTION 16/16b-4

ASSOCIATION A

This association is seen from 4140 ft to 4320 ft, the lithologies present in this interval (figure 4.6) comprise of light to medium buff coloured claystones. These are soft, firm to blocky in character with common silty sandy patches with traces of pyrite, lignite and glauconite being present.

Characteristic palynological features

The distinguishing and characteristic taxa of this association change downhole, with an increase of *Cordosphaeridium cantharellum* to common frequencies and a peak of *Spiniferites ramosus* subsp. *ramosus*, an increase in *Homotryblium tenuispinosum* from present to common, an increase in numbers of *Hystrichostrogylon membranophorum*, a reduction in the numbers of *Homotryblium floripes* and relatively lower numbers of *Achomosphaera ramulifera* compared with the rest of the section. Consistent abundances of *Areoligera semicirculata* are observed in this association and the presence of taxa such as *Phthanoperidinium geminatum*, *Membranophoridium aspinatum*, *Wetzeliella symmetrica* and *W. gochtii* is noted. Overall the numbers of peridinioid dinoflagellate cysts is higher in this association than in the rest of the sequence.

Comments

One sample within this association (4300 ft) is statistically unviable having a microplankton sum of less than 100 and as such must be taken into account when interpreting the data as these low counts generate artificially high abundances when the data is normalised.

Within this association standard deviation and variance are low. Also the number of grains per gram are low when compared with the rest of the section. These low numbers do have environmental significance indicating more marine conditions (for discussion see later). Peak diversity in this section is seen at the top of this Association.

Tops and Bases

Within this association a number of taxa appear for the last time;

4320ft	top *Adnatosphaeridium vittatum*
	top *Phthanoperidinium alectelophum*
4300ft	last major occurrence of *Deflandrea heterophlycta*
4180ft	top *Cordosphaeridium funiculatum*
	top *Fromea fragilis*

A number of taxa are recorded for the first time within this association;

4260ft	base *Wetzeliella gochtii*
	base *Chiropteridium partispinosum*
4220ft	base *Polysphaeridium subtile*
4180ft	base *Nematosphaeropsis lemniscata*
4140ft	base *Chiropteridium mespilanum*

Application and calibration to published zonation schemes

Costa & Manum (1988) and Manum *et al.* (1989) regard *Areosphaeridium diktyoplokus* as appearing for the last time at the top of the Late Eocene (top D12) and Williams, Stover & Kidson (1993) record this taxa for the last time at the Eocene/Oligocene boundary. It is possible that the section in this study is poor in *Areosphaeridium diktyoplokus,* or that the environment does not favour the presence of the taxon in question, accounting for its absence. This absence cannot be assumed to indicate a level younger than the range top of the species, but it does suggest an Early Oligocene age. The presence of *Areosphaeridium arcuatum* indicates this association to be Early Oligocene, Rupelian, in age falling within the Rpe zone, Late Eocene to Early Oligocene, of Powell (1992), and Late Eocene to Early Oligocene of Brinkhuis (1994) and Manum *et al.* (1989).

The last occurrence of *Cordosphaeridium funiculatum* here also places this association within the Rpe biozone, Late Eocene of Powell (1992) although *Thalassiphora fenestrata* present in Powell's biozone does not appear until Association D in 16/16b-4 in this study and is in low numbers. The suggested range of *Cordosphaeridium funiculatum* by Powell (1992) is problematic, as in this study this taxa has a much longer range recorded upto Association D of 21/28b-7 (Rupelian/Chattian boundary). This taxon is also recorded occurring for the last time in the Oligocene, in the Gse zone (Brinkhuis, 1994). The first appearance of *Wetzeliella gochtii* and the presence of *Wetzeliella symmetrica* within this association correlates to the Wgo biozone of Powell (1992), base D13 of Costa & Manum (1988) and Early Oligocene of Stover & Hardenbol (1993).

At the top of this association the first uphole appearance of *Chiropteridium mespilanum* occurs, this appearance is suggested by Powell (1992) to represent his Pcr zone which is Rupelian in age. The first appearance of *Chiropteridium partispinosum* recorded in this association, extends the range of this taxa into older sediments than suggested by published zonation schemes, although the range of this taxon could be affected by caving. Costa & Manum (1988) record the first occurrence of *Chiropteridium partispinosum* at the base of zone D14 and Powell (1992) places its first appearance in biozone Pcr, both of which suggest a middle to late Rupelian age. Although Manum (1976) indicates a Late Eocene age and Manum *et al.* (1989) indicates an Early/Late Oligocene age for the base of *C. partispinosum.*

Deflandrea heterophlycta is seen to have a substantially larger range than is suggested in the literature. Costa & Manum (1988) indicate this species tops at the Eocene/Oligocene boundary (their D12 to D13), but in this section extends into Association E, which is Late Oligocene, Chattian in age.

The combined presence of *Phthanoperidinium amoenum*, *Svalbardella cooksoniae*, *Wetzeliella gochtii* and *Deflandrea phosphoritica* are all recorded in the D13 zone of Costa & Manum (1988), although they see the base of *Areoligera semicirculata* in the middle of D13 whereas in the sections 16/16b-4 and 21/28b-7, *Areoligera semicirculata* is seen to be present in all of the samples in both sections suggesting an older first appearance with its base being Rupelian, probably lower Rupelian, lower D13 of Costa & Manum (1988), although the effects of caving cannot be ruled out. In the literature this species is seen to have a restricted occurrence. Brinkhuis (1994) show it as being confined to his Adi zone, Lower Oligocene and Williams, Stover & Kidson (1993) also have it restricted to the Early Oligocene, Rupelian. *Adnatosphaeridium vittatum* is recorded from the base of this association only, published occurrences of this taxa suggest a top occurrence in the *A. arcuatum* zone, Late Eocene of Manum *et al.* (1989). Also *Phthanoperidinium alectrolophum* recorded from the base of this association is suggested by Brinkhuis (1994) to have a last occurrence in the Late Eocene.

INTERPRETED AGE: **Early Rupelian,** Lower Oligocene, based on *Areosphaeridium arcuatum, Wetzeliella symmetrica, Wetzeliella gochtii, Phthanoperidinium alectrelophum, Svalbardella cooksoniae* and *Deflandrea phosphoritica.*

ASSOCIATION B

This Association occurs from 4000 ft to 4100 ft in depth. The sediments within this interval are composed of pale grey brown claystones grading up into grey brown siltstones. Patches of thin bands of brittle white cryptocrystalline limestone are present (figure 4.6).

Characteristic palynological features

This association is marked by a downhole change in *Achomosphaera ramulifera* from abundant to present, this is coincident with a downhole increase in *Homotryblium tenuispinosum* from rare to present and a downhole increase in *Spiniferites ramosus* subsp. *ramosus* from being present to common. *Palaeocystodinium golzowense* also increases slightly downhole and *Impletosphaeridium insolitum* shows a continued steady downhole reduction into this association. The top of this association coincides with the first consistent downhole appearance of *Phthanoperidinium geminatum* and a general downhole increase in the numbers of peridinioid dinoflagellate types.

Comments

Diversity remains high in number at the base of this association declining upsection. The variance is low but is seen to increase up section. Standard deviation is also low, as expected, and increases up section. The grains per gram figures show a marked increase, by half again, in this association compared to the association below.

Tops and Bases

Within this association a number of taxa appear for the last time;

4000ft	top *Areosphaeridium? actinocoronatum*
4020ft	top *Areosphaeridium arcuatum*
4100ft	top *Spiniferites* sp. 1 of Manum *et al.* (1989)
	top *Microdinium* sp. 1 of Chateauneuf (1980)
	top *Distatodinium ellipticum*

Within this association a number of species appear for the first time;

4020ft	base *Svalbardella cooksoniae*

Application to published zonation schemes

Areosphaeridium? actinocoronatum appears for the last time in this association. The known ranges for this species vary greatly. N. American material (Williams, Stover & Kidson, 1993) record this species with a top occurrence in the Pliocene. Manum (1989) records this species up to the Late Miocene. Whereas NW European studies such as Stover & Hardenbol (1993) on Belgium material give a top occurrence in the Lower Oligocene and Brinkhuis (1994) on Italian material gives a Lower Oligocene, top Gse zone, for the last uphole occurrence of this species.

Towards the base of this association *Distatodinium ellipticum* is seen to have its last occurrence. This appears to be higher than the published zonation schemes which suggest a last occurrence at the Eocene/Oligocene boundary Manum *et al.* (1989) and Lower Oligocene, Adi zone, of Brinkhuis (1994).

The last occurrence of two important taxa here is noted, namely *Spiniferites* sp. 1 of Manum *et al.* (1989) and *Microdinium* sp. 1 of Chateauneuf (1980). These two taxa appear to be a consistent and accurate 'marker' as have been recorded (figure 6.3) as disappearing at the same level and this was dated as Early Oligocene, D13. Also the two taxa in question have a last occurrence together in the 21/28b-7 section.

Areosphaeridium arcuatum occurs for the last time near the top of this association. This taxon is well documented in the literature and published schemes with its top occurring from the Late Eocene of Brinkhuis (1994), the Early Oligocene, Rpe zone of Powell (1992), the Early Oligocene of Manum *et al.* (1989) up to the Rupelian/Chattian boundary of Williams, Stover & Kidson (1993). Figure 6.3 places the top of *A. arcuatum* in the middle Rupelian, D13. Importantly Manum *et al.* (1989) places the top of *A. arcuatum* stratigraphically above the *Spiniferites* sp. 1 of Manum *et al.* (1989) apparent occurrence. The base of *Svalbardella cooksoniea* occurs within this association, this species shows a more restricted range than seen from known ranges from other areas, such as Manum *et al.* (1989) who place its base occurrence at the Eocene/Oligocene boundary.

INTERPRETED AGE: **Rupelian**, Lower Oligocene, based on *Areosphaeridium actinocoronatum, Areosphaeridium arcuatum, Spiniferites* sp. 1 of Manum *et al.* (1989), *Microdinium* sp. 1 (Chateauneuf, 1980) and *Distatodinium ellipticum.*

ASSOCIATION C

This association occurs from 3880 ft to 3960 ft in depth. The sediments from this interval are grey brown siltstones. They vary from being friable to firm with traces of mica, argillaceous, calcareous and sandy patches with local fine grained sandstone and claystone layers.

Characteristic palynological features

This association is easily recognised by the characteristic influx of *Areoligera semicirculata*. Other characteristics of this association are the downhole reductions in the numbers of *Homotryblium tenuispinosum* and *H. floripes* to rare/present. *Cordosphaeridium cantharellum* shows peak to common abundances in this association and *C. minimum* shows reducing numbers downhole. *Lingulodinium machaerophorum* shows a distinct reduction downhole at the top of this association, this is a very important environmentally (see later).

In general *Operculodinium* species show a reduction in numbers downhole from the top of this association. The association contains the last consistent occurrences of *Wetzeliella*, *Phthanoperidinium* and *Svalbardella* species seen within this sequence. A distinct increase in the numbers of *Achomosphaera ramulifera* from present to abundant at the base and throughout this association is seen. *Systemotophora placacantha* shows an increase in numbers downhole at the top of this association. In general the stratigraphical sequences within and below this association show an increase in peridinioid dinoflagellate cyst types. Relative to adjacent associations the numbers of chorate dinoflagellates cysts is low, this is due to the shift in importance of the *Cordosphaeridium* and *Homotryblium* genera particularly.

Comments

Both the standard deviation and especially the variance is relatively low at the base but increases vastly towards the top of the association, this is due to the influx and dominance of *Areoligera semicirculata* here. The top of this association is important as this influx or peak at 3920 ft is regarded as a maximum flooding surface.

Tops and Bases

Within this association two taxa are recorded for the last time;

3880ft	last major occurrence *Wetzeliella symmetrica*
	last major occurrence *Svalbardella cooksoniae*
3920ft	top *Wetzeliella gochtii*
	top *Svalbardella* sp. 1

Application to published zonation schemes and known ranges

The distinctive feature of this association is the influx of *Areoligera semicirculata*. This is shown in figure 6.3 and occurs stratigraphically higher than the top of *Areoligera arcuatum* and *Phthanoperidinium comatum* .

In both the North Sea sections studied in this work, *Areoligera semicirculata* occurs throughout the sequences. This indicates a much longer range than the literature suggests. Brinkhuis (1994) shows *Areoligera semicirculata* to be restricted to his Adi zone, which is Rupelian in age. Stover & Hardenbol (1993) place the base of *Areoligera semicirculata* at the base Rupelian, Powell (1992) suggests a base in his Lxa zone, which is Chattian in age. Costa & Manum (1988) record the first appearance of this species at the base of D13, Rupelian. Benedek (1972) also shows a first appearance in the Lxa zone of Powell (1992) stratigraphically before the first appearance of *Apteodinium spiridoides*. This is not seen in this study as both species in question occur throughout the sections.

A more accurate indication of age is given by the top occurrence of *Wetzeliella gochtii* which occurs within this association. The range of this species is well known, Costa & Manum (1988) have a last occurrence of this species at the top of their D14 zone, which is Chattian, Stover & Hardenbol (1993) suggest a top above their Ru2 HST zone, which is base Chattian. The range for *W. gochtii* shown in figure 6.3 is consistent with these known ranges suggesting a Lower Chattian age. At the top of this association both *Wetzeliella symmetrica* and *Svalbardella cooksoniae* show their last significant presence in the section. The last occurrence of *Svalbardella cooksoniae* can be correlated to the middle Rupelian, the Wgo/Pcr zone boundary of Powell (1992) and middle D14 (Lower Chattian) of Costa & Manum (1988) and the *C. lobospinosum* zone (Lower Oligocene) of Manum *et al.* (1989). The top occurrence of *Wetzeliella symmetrica* suggests a restricted range in this section when compared to the literature. Previously recorded ranges of this species give top occurrences in the top D14, Chattian, of Costa & Manum (1988), the Hfl zone, Middle Chattian, of Powell (1992) and the top Rupelian of Stover & Hardenbol (1993).

INTERPRETED AGE: **Top Rupelian**, Lower Oligocene, based on *Wetzeliella gochtii, W. symmetrica* and *Svalbardella cooksoniae.*

ASSOCIATION D

This association is seen from 3800 ft to 3840 ft. The lithology of this interval is of grey to grey brown, soft to blocky claystones. These are commonly silty, finely sandy and calcareous with traces of pyrite, lignite, shell fragments, mica and glauconite being recorded.

Characteristic palynological features

This association contains the last significant occurrences of *Lingulodinium machaerophorum* which occur only in rare numbers downhole from the base of this association. This occurrence of *Lingulodinium machaerophorum* is environmentally significant (see below). *Areoligera semicirculata* is increases in numbers downhole in this association to abundant levels, as it lies stratigraphically above Association C which is characterised by a flood influx of *Areoligera semicirculata*. The record of *Achilliodinium biformoides* is restricted to this association. This species is included on many published zonation schemes but as it is rare in this section and is not present in the other marine section studied, its stratigraphical use here is limited. *Homotryblium floripes* and *Homotryblium tenuispinosum* occur in present to common numbers respectively in this association. The number of *Apectodinium spiridoides* although rare to present, reduce downhole from the top of this association. Again the numbers of *Pentadinium laticinctum* are rare but appear to become more frequent in this association and up section. The presence of *Palaeocystodinium* sp. A of Costa & Downie (1979) in this association is noted.

Comments

Diversity increases towards the top of this association. Standard deviation decreases slightly and variance decreases upwards through this association from about 8 at the base to about 7 at the top, this decrease in variance possibly indicates a reduction in sea level. Also the numbers of grains per gram in this association significantly increase into the base of this association upsection from Association C.

Tops and Bases

Within this association a number of last occurrences are recorded;

3840ft	only occurrence of *Achilliodinium biformoides*

3800ft	top *Phthanoperidinium comatum*
	top *Phthanoperidinium amoenum*
	top *Diphyes colligerium*
	top *Melitisphaeridium asterigium*
	top *Impletosphaeridium implicatum*

Within this association a number of taxa occur for the first time;

3840ft	base *Thalassiphora fenestrata*
3800ft	base *Impagidinium* spp.

Application to published zonation schemes and known ranges

The last appearance of *Achilliodinium biformoides* at the base of this association allows correlation to base D14, Pcr zone, upper Rupelian of Powell (1992), the base of Ru2 HST of Stover & Hardenbol (1993) and the Middle Oligocene, *Areosphaeridium actinocoronatum* zone, of Manum *et al.* (1989). The first occurrence of *Thalassiphora fenestrata* is seen in this association, the range of this species is relatively restricted when compared with known ranges which suggest a first occurrence in the Late Eocene, Rpe zone of Powell (1992) and Late Eocene, *A. arcuatum* zone of Manum *et al.* (1989).

The top of this association sees a number of taxa occurring for the last time. *Phthanoperidinium amoenum* and *Phthanoperidinium comatum* have first downhole occurrences at this level. This can be correlated to figure 6.3 which shows all *Phthanoperidinium* species as having their last occurrence in the Lower Chattian, Upper Oligocene. Powell (1992) shows the top of *Phthanoperidinium amoenum* in his Wgo zone, top D13, Rupelian and the top of *Phthanoperidinium comatum* in his Pcr zone, top Rupelian, D14. Costa & Manum (1988) show a higher range of *Phthanoperidinium comatum* up to top D14, Lower Chattian.

The top occurrence of *Diphyes colligerum* within this association shows an expanded range compared with records in the literature. Manum (1976) and Williams, Stover & Kidson (1993) place top *D. colligerum* at a level in the Middle Eocene and Eocene/Oligocene boundary respectively. Brinkhuis (1994) places the top of this species in his Gse zone (Lower Oligocene), Powell (1992) in his Wgo zone, Rupelian and Manum *et al.* (1989) place this in his *A. actinocoronatum* zone, Early/Late Oligocene.

The last occurrence of *Melitisphaeridium asterigium* correlates to Stover & Hardenbol (1993) Ru1 TST zone in the Boom Formation of Belgium which is considerably lower stratigraphically than the studied section here. The top of this association also see the base of *Impagidinium* spp. this possibly correlates to the base of the *Impagidinium* sp. zone of Manum *et al.* (1989) which is Lower Chattian.

INTERPRETED AGE: **Lower Chattian**, Upper Oligocene, based on *Phthanoperidinium comatum, Diphyes colligerium* and *Impagidinium* spp.

ASSOCIATION E

This association occurs from 3600 ft to 3720 ft. The base of this interval is composed of grey claystones, these are commonly silty, finely sandy and calcareous with traces of pyrite, lignite and shell fragments. These coarsen upwards into a grey brown siltstones with common mica and calcareous patches.

Characteristic palynological features

Downhole *Cordosphaeridium cantharellum* shows an increase at the top of this association from being rare to present. This increase is mirrored by an increase in *Homotryblium tenuispinosum* at this level. The characteristic feature of this association is the first significant occurrence of *H. floripes* at the top of this association which continues downsection. Here *H. floripes* peaks to abundant numbers at the top of this association. The numbers of *Hystrichokolpoma cinctum, Hystrichosphaeridium patulum* and *Impletosphaeridium insolitum* show a downhole reduction in numbers from the top of this association downwards.

In general *Operculodinium* species, especially *Operculodinium* sp. 1 and *O.* sp. 2 show a slight reduction in number compared with the associations stratigraphically above and below. Also an absence of *O.* sp. of Piasecki (1980) is noted except for a single specimen recorded at the top of this association. *Lingulodinium machaerophorum* is present in this association and shows an increase in numbers downhole. Reduced numbers of *Systematophora placacantha* to present/common are seen within this association compared to the common/abundant numbers recorded from the adjacent associations both uphole and downhole. *Areoligera semicirculata* increases in number downhole from the top of this association where numbers are absent/rare to the base where common to abundant numbers are reached. *Achomosphaera ramulifera* occurs in common to abundant numbers and remains constant throughout this association. Both *Chiropteridium mespilanum* and *Membranophoridium aspinatum* occur in this association. In general lower numbers of proximochorates are recorded and fewer peridinioid or proximate cysts are seen within this association. Whereas an increase in the numbers of chorate cysts is seen, with a peak at 3640 ft, this coincides with and is a result of the peak *Homotryblium floripes* at this level and probably represents a maximum flooding surface.

Tops and Bases

A large number of taxa are recorded for the last time within this association;

3720ft	top *Phthanoperidinium geminatum*

	top *Apteodinium trinovantium*
	top *Deflandrea heterophlycta*
	top *Chiropteridium lobospinosum*
3640ft	top *Impagidinium* spp.
3600ft	top *Lentinia wetzelli*
	last major occurrence of *Homotryblium floripes*
	top *Homotryblium vallum*
	top *Deflandrea phosphoritica*

No base or first occurrences have been seen within this association.

Comments

The relative low diversity seen within this association could indicate an inner neritic marine environment. The standard deviation and variance show an increase upsection through this association again with a peak at the 3640 ft level resulting from the *Homotryblium floripes* peak and representing a maximum flooding surface. The number of grains per gram increase vastly upsection to greater than 90 000, these higher numbers suggest increases in sea level and are significant environmentally (see later).

Application to published zonation schemes

The base of this association sees a number of last occurrences. *Phthanoperidinium geminatum* occurs for the last time here, its range in this section is much greater than that suggested in the literature, Manum *et al.* (1989) gives a Middle Eocene age for the top of this species, although figure 6.3 shows *Phthanoperidinium* species to be present into the Chattian. *Deflandrea heterophlycta* was originally thought to be an important species with its last occurrence coinciding with the Eocene/Oligocene boundary (Costa & Manum, 1988) or going into the earliest Oligocene, the Adi zone of Brinkhuis (1994). In this section the range of *Deflandrea heterophlycta* is seen to be much longer, extending into the Chattian, Late Oligocene.

The top of *Chiropteridium lobospinosum* which occurs near the base of this association seems a much more reliable species to enable comparison with other zonation schemes for example this compares with the top of the Hfl zone of Powell (1992) which is top Chattian and the top of the *Impagidinium* sp. 1 zone of Manum *et al.* (1989) which is Chattian, Late Oligocene. This also corresponds to the last occurrence of *Impagidinium* spp. within this association which can again be compared to the top *Impagidinium* sp. 1 zone of Manum *et al.* (1989).

The last occurrence of *Homotryblium vallum* occurs at the top of this association this compares to the Cin zone of Brinkhuis (1994) and the Ru2 HST of Stover & Hardenbol (1993) which are both Lower Oligocene, Rupelian in age and is even recorded upto the late Miocene of Manum *et al.* (1989). In this section the last occurrence of this species probably falls between these ages and is Chattian, Late Oligocene.

Deflandrea phosphoritica has its last occurrence near to the top of this association. When compared to the published literature a Late Oligocene, Chattian age can easily be inferred. It compares to the base of the Hfl zone of Powell (1992), top D14, Chattian, the *A. actinocoronatum* zone of Manum *et al.* (1989), early Oligocene, the top of D14 zone of Costa & Manum (1988), above the Cin zone of Brinkhuis (1994) and the Ru2 HST of Stover & Hardenbol (1993). Figure 6.3 places the top of this taxa in the Late Oligocene and Williams, Stover & Kidson (1993) shows it ranging into the Early Miocene.

INTERPRETED AGE: **Chattian**, Late Oligocene, based on *Phthanoperidinium geminatum, Chiropteridium lobospinosum, Impagidinium* spp., *Deflandrea phosphoritica* and *Homotryblium vallum.*

ASSOCIATION F

This association occurs at a depth of 3580 ft and is represented by one sample only. This association is regarded as the top Oligocene in this section. This interval is composed of a grey brown claystone which grade into a fine to medium grained loose sandstone. Patches of glauconite, mica, carbonaceous material and pyrite are common. It is possible this level is affected by caving indicated by the peak in the calliper trace at this level.

Characteristic palynological features

This association seems to be a transitional zone between association E and G. *Impletosphaeridium insolitum* and *Impletosphaeridium ligospinosum* decline in numbers downhole from the top of this association as do many of the *Operculodinium* species especially *Operculodinium* sp. 1, *O.* sp. 2, *O. bellulum* and *O.* sp. of Piasecki (1980). Conversely *Lingulodinium machaerophorum* shows an increase in numbers from rare to present downhole through this association. *Systematophora placacantha* shows a downhole reduction from abundant numbers in the association stratigraphically above this level, to common. The first downhole occurrence of *Areoligera semicirculata* is recorded at the top of this association, this increases in numbers downhole through the section. The last occurrence of *Chiropteridium partispinosum* occurs within this association.

Tops and Bases

A number of taxa appear for the last time within this association. It is an important interval as it is regarded as the top Oligocene in this section this accounts for the large number of taxa showing their first downhole occurrence at this level.

3580ft top *Membranophoridium aspinatum*
top *Dinopterygium fehmarnense*
top *Areoligera semicirculata*
top *Chiropteridium partispinosum*
top *Areoligera* cf. *semicirculata*
top *Thalassiphora pelagica*
top *Callaiosphaeridium* spp.

Comments

A slight decline in the standard deviation and variance figures from the association above is seen. Although the numbers of grains per gram show a drop off downhole from the middle of Association G and throughout this association.

Application to published zonation schemes

Areoligera semicirculata is one of the most significant first downhole occurrences seen in this North Sea section. Although discussed earlier (see Association A and C) *Areoligera semicirculata* seems to have a longer range than the published literature suggests. The last occurrence of *Areoligera semicirculata* here can be correlated to the top Hfl zone of Powell (1992), upper Chattian, the top D14 of Costa & Manum (1988), upper Chattian and the top of Ru2 HST of Stover & Hardenbol (1993), Rupelian/Chattian boundary.

Membranophoridium aspinatum is seen for the last time within this association. This top occurrence can be compared to Powell (1992) who places this event at the Oligocene/Miocene boundary and Costa & Manum (1988) in their D15 zone which is top Chattian. Stover & Hardenbol (1993) place their last occurrence of this taxon stratigraphically lower in the Ru2 HST zone. The top of *Dinopterygium fehmarnense* is not as significant as the previous taxa. The only published record of this taxon in this area is of Liengjarern *et al.* (1980) who gives a Lower Oligocene age for the top of this species. *Chiropteridium partispinosum* occurs for the last time at the top of this association. This can be compared to the *Systematophora* sp. 1 zone of Manum *et al.* (1989) which is aged topmost Late Oligocene, top of the D15 zone of Costa & Manum (1988) which is top Chattian and the Hfl/Tva zone boundary of Powell (1992).

Thalassiphora pelagica although only ever seen as rare occurrences in this section has its last appearance in this association. The last occurrence of the taxa correlates with the Tva zone of Powell (1992), Late Oligocene/Lower Miocene and the D16 zone of Costa & Manum (1988), Early Miocene. Although Manum *et al.* (1989)

records a more restricted range of this taxa with a last occurrence in the *A. actinocoronatum* zone, Early/Late Oligocene.

INTERPRETED AGE: **Top Chattian,** Latest Oligocene, based on *Areoligera semicirculata, Membranophoridium aspinatum, Chiropteridium partispinosum* and *Thalassiphora pelagica*.

ASSOCIATION G

This association occurs from 3440 ft to 3500 ft. The sedimentary sequence recorded from this interval is of grey brown siltstones which are argillaceous with traces of mica and calcareous patches. These grade locally into fine to medium grained micaceous sandstones. Lignitic layers are also present.

Characteristic palynological features

Various algae and acritarchs are present in slightly greater numbers in this association compared with the rest of the sequence downhole.

The number of *Cordosphaeridium cantharellum* is rare and they increase downhole from the base of this association becoming common in number. *C. minimum* is present. No significant occurrences of *Homotryblium tenuispinosum* or *H. floripes* occur in this association but are seen to increase drastically downhole from the base of this association. A lack of *Areoligera semicirculata* also characterises this association along with a lack of the majority of *Chiropteridium* species and *Phthanoperidinium* species. The numbers of *Hystrichokolpoma cinctum, Hystrichosphaeridium patulum* and *Hystrichosphaeridium latirictum* are present to common and their numbers are seem to reduce downhole from the base of this association. This association shows higher numbers of *Impletosphaeridium insolitum* and *I. ligospinosum* than the association stratigraphically below. *Lingulodinium machaerophorum* is consistently present throughout this association along with *Operculodinium bellulum, O.* sp. 2 and *O.* sp. 1.

Hystrichostrogylon membranophorum appears slightly more abundantly in this association and is rare downhole throughout the rest of the section. *Apteodinium spiridoides* shows a similar distribution to this. The only presence of *Hystrichostrogylon* sp. 1 of Manum *et al.* (1989) at the top of this association must be noted. *Systematophora placacantha* is abundant at the top of this association and shows a reduction in numbers downhole to common at the base.

The presence of new taxa appearing for the first time in this section namely, *Aoria* spp. and *Tuberculodinium vancampoae* are important. In general the numbers of chorate cysts is low due to the lack of *Cordosphaeridium* and *Homotryblium* species which occur more abundantly downhole. This is mirrored by an increase in the numbers of proximochorate cysts recorded in this association due to the higher numbers of *Systematophora placacantha* and *Operculodinium* species.

A clear change can be seen in this association summarised by the lack of taxa present below such as *Phthanoperidinium* species, *Chiropteridium* species, *Areoligera semicirculata, Homotryblium floripes* and *H. tenuispinosum.* Also the introduction of new taxa previously not recorded downhole, these are the characteristic Miocene species *Tuberculodinium vancampoae* and *Aoria* spp.

Tops and Bases

A number of taxa appear for the last time within this association;

3500ft top *Homotryblium tenuispinosum*
top *Thalassiphora fenestrata*
top *Paralecaniella indentata*
rogue appearances of *Wetzeliella symmetrica* and *Svalbardella cooksoniae*

A number of taxa appear for the first time within this association;

3460ft base *Tuberculodinium vancampoae*
3440ft base *Hystrichosphaeridium* sp. 1 of Manum *et al.* (1989)
base *Aoria* spp.

Comments

Diversity reduces slightly up through this association and standard deviation and variance show an overall trend of continued or slight increase upwards through the association. The numbers of grains per gram peak at the base of this association with numbers greater than 80 000 then decline to about 55 000 at the top of the association.

Calibration to published zonation schemes

Homotryblium tenuispinosum appears for the last time within this association. Costa & Manum (1988) record the last occurrence of this species at the top of their D16 zone which is Early Miocene in age. Stover & Hardenbol (1993) place the top of this species at the top of their Ru2 HST zone which is much more restricted than seen by Costa & Manum (1988).

Paralecaniella indentata is recorded for the last time in the middle of this association. Few published records include this taxa, figure 6.3 places its last occurrence in the Lower Miocene at the same level as the top occurrence of *Homotryblium floripes.* In this section although the numbers of *Thalassiphora fenestrata* have been low, the range of this taxa is greatly extended. The published ranges place the top of this taxa in the middle to Late Eocene, *A. arcuatum* zone of Manum *et al.* (1989) and the Rpe zone, Late Eocene of Powell (1992).

The base occurrence of *Tuberculodinium vancampoae* occurs near to the top of this association, many authors have used this taxa for correlation. Powell (1992) places this event in his Tva zone, at the Oligocene to Miocene boundary. Costa & Manum (1988) place this in their D16 zone, Lower Miocene and Manum *et al.* (1989) places this in his *A. granosa* zone which is Early Miocene in age. The base of *Hystrichosphaeridium* sp. 1 of Manum *et al.* (1989) occurs at the top of this association. This correlates to a late Early Miocene age in the *E. spiridoides* zone of Manum *et al.* (1989). Also at this level the first occurrence of *Aoria* spp. occurs which places this association in the Early Miocene (figure 6.3).

It should be noted that a spurious presence of *Svalbardella cooksoniae* and *Wetzeliella symmetrica* are recorded in the data at 3500m within this association. These points are regarded as spurious and the last major occurrence of these taxa are regarded as the significant feature and are therefore discussed at that appropriate level (Association C).

INTERPRETED AGE: **Lower Miocene,** based on *Homotryblium tenuispinosum, Paralecaniella indentata, Tuberculodinium vancampoae, Aoria* spp. and *Hystrichosphaeridium* sp. 1 of Manum *et al.* (1989).

INTERPRETATION OF THE 16/16B-4 DINOFLAGELLATE SECTION

Originally it was thought only the correlation of the sections to the published literature would provide dating for the section. But further to this comparisons with Haq *et al.* (1987) and magnitostratigraphy/chronostratigraphy have enabled absolute ages to be assigned to certain levels in the sections.

In this section two clear boundaries can be seen, firstly the Oligocene/Miocene boundary occurs between 3580 ft and 3500 ft and secondly the Rupelian/Chattian boundary at a depth between 3880 ft and 3840 ft. The basis of these divisions is on both the associations defined, the occurrence of a number of what are regarded as 'important stratigraphical' taxa and some of the statistical data gathered. Association F in 16/16b-4 represents the top most Oligocene from this section. The age was based on the last occurrence of a number of taxa such as *Membranophoridium aspinatum, Areoligera semicirculata* and *Thalassiphora pelagica*. These are regarded in the published literature as stratigraphically significant taxa, marking the Oligocene/Miocene boundary. Moreover a number of 'traditionally' Miocene taxa are recorded for the first time in the association upsection from this, Associaiton G, namely, *Tuberculodinium vancampoae, Aoria* spp. and *Hystrichostrogylon* sp. 1 of Manum *et al.* (1989). Also the last occurrence of *Homotryblium tenuispinosum* and

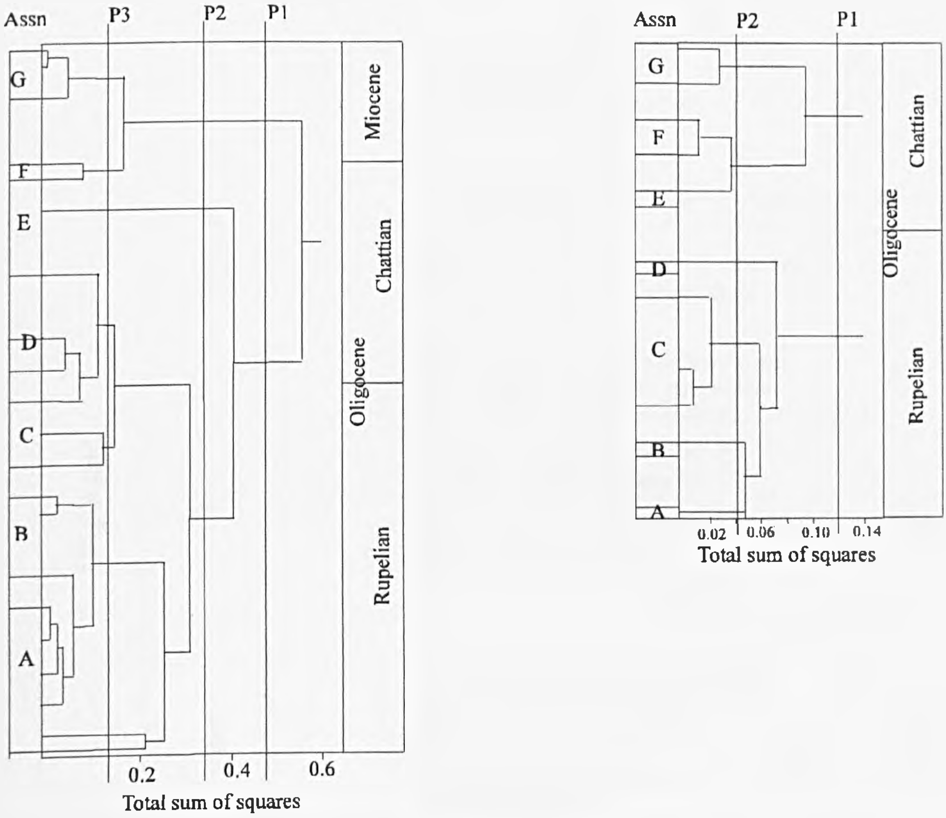
Paralecaniella indentata are important indicating this association reaches up into the Lower Miocene.

At the level of the Oligocene/Miocene boundary, the sedimentary log (figure 4.6) shows a marked lithological change corresponding to the top of a coarsening up unit of claystones into siltstones which then grade into the thin fine to medium grained glauconitic sandstones of the Miocene strata above. This coarsening up is also picked up on the gamma ray response curve which reduces uphole from c. 70 API to c. 50 API.

The top of Association C marks the top most Lower Oligocene, Rupelian aged sediments in this section. This age was based on the top occurrences of a number of stratigraphically important taxa namely, *Wetzeliella gochtii, W. symmetrica, Svalbardella cooksoniae* and *S.* sp. 1.

At this level the sedimentary log indicates a more discrete coarsening up sequence from claystones below into siltstones at this level although the gamma ray response does not pick this up as clearly as the Oligocene/Miocene boundary, and it remains at a constant 60 API. A sharp dip in the sonic response at this level is also noted.

The cluster analysis dendrograms also give an indication of the two major boundaries picked out in this section. As discussed earlier (Chapter 5) a dendrogram illustrates a hierarchical relationship of clusters defined using the consiss analysis. Clusters or in this case associations are defined by the placing of a phenon line, cutting the dendrogram vertically at a given height or heights, this practice is useful for defining zones and provides a 'quantitative characterisation of the zones/clusters defined' (Grimm, 1987). Zones and subzones are defined by the use of phenon lines, these are the lines cutting the dendrogram (Fig. 6.2a, P1, P2 and P3) in order to describe a hierarchy of clusters. P1 is at a level of 0.48 and defines two broad clusters, these are interpreted as the Oligocene and Miocene parts of the section. So at a relatively high level the cluster analysis is seen to pick out the major boundaries between geological epochs in the section. Moving closer to the origin of the dendrogram (P2) a phenon line placed at a level of 0.32 results in three clusters becoming apparent, those corresponding to the Oligocene and Miocene clusters are seen again but a further clustering of the Oligocene into two zones is seen at 3880 ft, this is interpreted as representing the Rupelian and Chattian aged parts of the section. Still closer to the origin a phenon line drawn at a level of 0.12, results in further subdivisions of these clusters/zones being seen. These compare very closely to the associations already defined for this section and are labelled A to G (Figure 6.2). This tiering of Phenon lines gives a tiering of clusters from geological epochs to geological stages and finally to the level of associations.



a) 16/16b-4

b) 21/28b-7

Figure 6.2 Diagram showing the cluster analysis dendrograms and their relationship to geological boundaries and the defined Associations, for the microplankton sections a) 16/16b-4 and b) 21/28b-7.

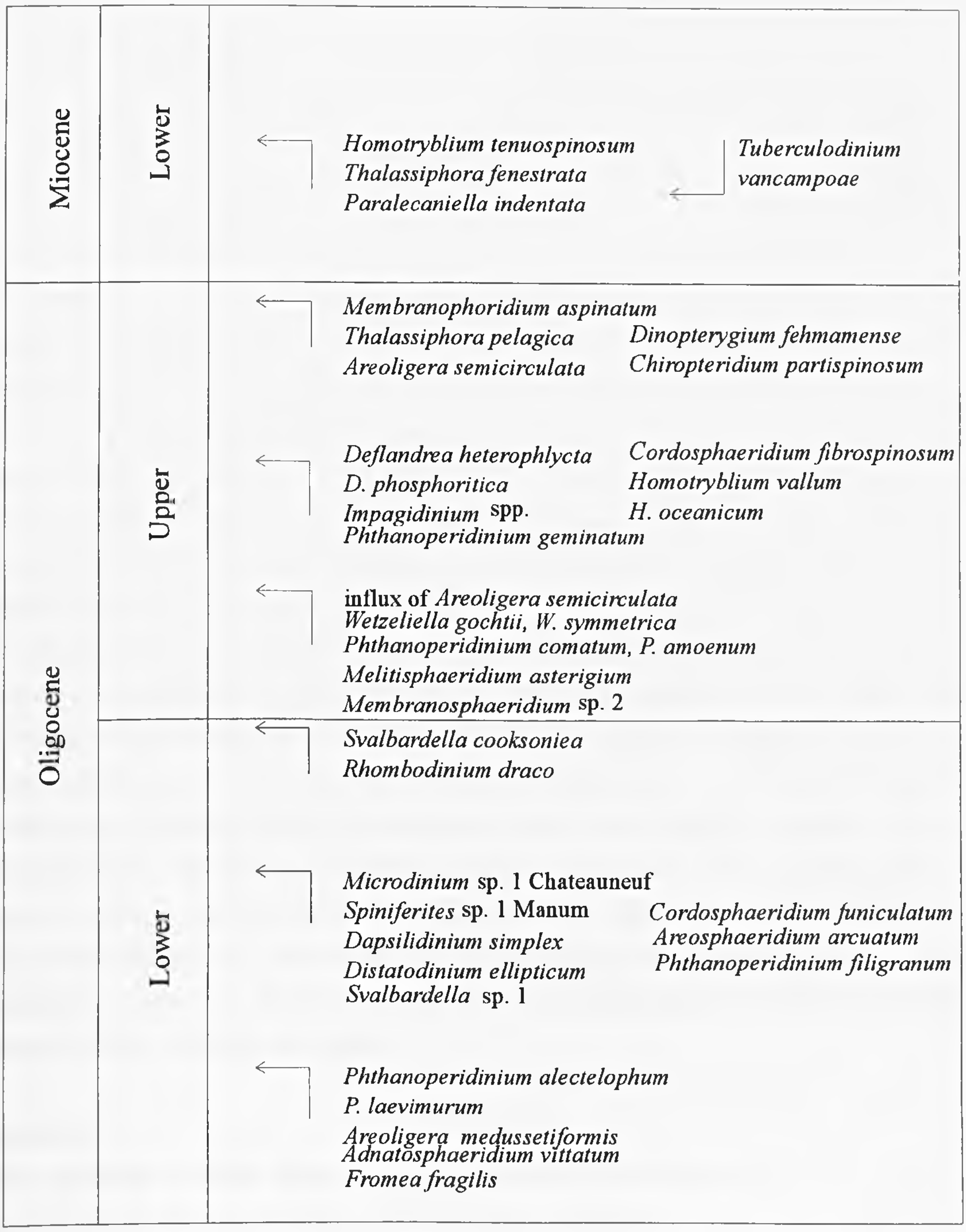


Figure 6.3 A diagram showing the sequence of dinoflagellate events as interpreted from the data in the sections studied.

MICROPLANKTON SECTION 21/28b-7

ASSOCIATION A

This association occurs from 3270 ft downwards to the base of the section. This association is defined on one sample only and is the basal sample of this section. The lithologies of this interval (figure 4.7) are composed of grey green soft claystones which are slightly calcareous with common loose fine to medium quartz grains present.

Characteristic palynological features

As this is the basal unit of this section it is difficult to see any trends that may be present. Downhole an increase in the number of *Cordosphaeridium cantharellum* to common and an increase in the numbers of *Systematophora placacantha* to abundant, into the top of this association can be seen. The numbers of *Homotryblium tenuispinosum* reduce downhole to present and *H. floripes* reduces downhole to rare at the top of this association. Other species such as *Areosphaeridium arcuatum, Cordosphaeridium minimum,* the majority of *Operculodinium* species, *Areoligera medussetiformis, Deflandrea phosphoritica, Distatodinium craterium* and *Palaeocystodinium golzowense* are noted to occur in this association but in rare numbers. *Lingulodinium machaerophorum* which was a species that was seen to be important in the 16/16b-4 microplankton section, is reducing in numbers to the top of this association and is rare. Constant numbers of *Achomosphaera ramulifera* which is common and constant numbers of *Areoligera semicirculata* which is present occur in this association. *Spiniferites multibrevis, S. pseudofurcatus* and *S. ramosus* subsp. *ramosus* occur in this association and their numbers reduce downhole. Other rare occurrences within this association are *Hystrichostrogylon membraniphorum* and *Wetzeliella symmetrica*. In general the number of proximochorate cysts show a slight increase at the top of this association.

Comments

The standard deviation increases from the top of this association up the section. The variance at the top of this association is at its lowest value for the section at about 5, and is seen to increase upwards from the top of this association. The numbers of grains per gram in this association show a marked increase from over 40 000 in the association above to over 100 000 at the top of this association.

Tops and Bases

No definite base occurrences of taxon occur within this association and no first downhole occurrences of taxon are recorded in this association.

Application to published zonation schemes

As no tops and bases are recorded to occur within this association no comparisons can be made to the published zonation schemes which rely on them and few other distinguishing features are noted for comparison.

INTERPRETED AGE: **Rupelian,** Lower Oligocene, based on *Areoligera semicirculata, Areosphaeridium arcuatum, Systematophora placacantha* and *Wetzeliella symmetrica.*

ASSOCIATION B

This association occurs at a depth of 3210 ft. This interval is composed of grey green claystones which are soft and slightly calcareous with common loose quartz grains.

Characteristic Palynological Features

This association is defined from one sample only. Downhole from the top of this association the numbers of *Cordosphaeridium cantharellum* and *Systematophora placacantha* increase. *Homotryblium floripes* and *H. tenuispinosum* both show a downhole decrease in numbers. A slight increase in the numbers of *Hystrichokolpoma cinctum* is mirrored by a slight reduction in the numbers of *Hystrichokolpoma rigaudiae. Hystrichosphaeridium patulum* also shows a slight increase in numbers downhole. *Lingulodinium machaerophorum* reduces in numbers downhole from the top of this association and *Spiniferites ramosus* subsp. *ramosus* reduces downhole from abundant at the top of this association to common at the base. Numbers of *Achomosphaera ramulifera* and *Areoligera semicirculata* are constant and common in this association. The presence of *Areosphaeridium arcuatum, Achomosphaera crassipellis, Melitisphaeridium asterigium* and the majority of *Operculodinium* species is noted. In general the downhole reduction in numbers of proximochorate group cysts is due to the reduced numbers of *Achomosphaera* species and *Spiniferites* species in this association.

Comments

The standard deviation and variance show a reduction downhole. Grains per gram occur in relatively low numbers of over 40 000, at the top of the association.

Tops and Bases

A number of taxa occur for the last time within this association;

3210ft	only occurrence of *Phthanoperidinium amoenum*
	top *Areoligera medussetiformis*

A large number of taxa within this association are recorded for the first time:

3210ft base *Nematopshaeropsis lemniscata*
base *Chiropteridium mespilanum*
base *Chiropteridium partispinosum*
base *Rhombodinium draco*
base *Dapsilidinium pastielsii*
base *Membranophoridium aspinatum*
base *Amiculosphaera umbracula*
base *Thalassiphora fenestrata*
base *Thalassiphora pelagica*
base *Deflandrea heterophlycta*
base *Lentinia wetzeli*
base *Phthanoperidinium geminatum*
base *Spiniferites* sp. 1 of Manum *et al.* (1989)
base *Svalbardella cooksoniae*
base *Achomosphaera crassipellis*

Application to published zonation schemes

The top occurrence of *Phthanoperidinium amoenum* occurs in this association, (figure 6.3) shows the majority of *Phthanoperidinium* species as having their last occurrence in the Lower Chattian, Powell (1992) shows the top of this species in his Wgo zone, which is Rupelian and Costa & Manum (1988) has its top occurrence in their D13 zone which is also Rupelian.

The base occurrences of the taxa in this association show wide variation in ranges, possibly due to the varying affects of caving. This is especially important in this study as the samples are ditch cuttings.

The base of *Nematosphaeropsis lemniscata* occurs in this association, this correlates to the Eocene/Oligocene boundary of Williams, Stover & Kidson (1993). Both *Chiropteridium mespilanum* and *C. partispinosum* have there base occurrence in this association. The former correlates to the Pcr zone of Powell (1992) which is Rupelian and the Chattian of Manum *et al.* (1989). The latter correlates to the Pcr zone of Powell (1992) which is Rupelian, the base of the D14 zone of Costa & Manum (1988) which is Middle to Late Rupelian, the Late Eocene of Manum (1976) and the Early to Late Oligocene of Manum *et al.* (1989).

The base of *Rhombodinium draco* in this section shows a much more restricted range than in the literature which indicates Middle Eocene bases by Powell (1992), Costa & Manum (1988) and Williams, Stover & Kidson (1993). Stover & Hardenbol (1993) show the more restricted range here with a first occurrence in their Ru1 TST zone. The D10 zone, Middle Eocene of Costa & Manum (1988) is one of the few published bases for *Deflandrea heterophlycta*, this is much lower than what is seen here.

The base of *Membranophoridium aspinatum* occurs at the top of this association. Powell (1992) records a base for this taxa in his Gin zone which is Middle Eocene, Brinkhuis (1994) in his Aal zone, which is Late Eocene, Costa & Manum (1988) in their D10 zone, which is Middle Eocene and Williams, Stover & Kidson (1993) at the Eocene/Oligocene boundary. The base occurrence of *Thalassiphora fenestrata* in this association shows a much more restricted range when compared with the literature. Powell (1992) places the base of this taxon in his Rpe zone which is Late Eocene, Manum *et al.* (1989) places it in their *A. arcuatum* zone, which is Late Eocene, Costa & Manum (1988) in their D12 zone which is also Late Eocene and Liengjarern *et al.* (1980) in the Eocene. *Thalassiphora pelagica* is similar to the above, Costa & Manum (1988) show the base of this taxon in the Eocene, Manum (1976) places it in the Early Eocene, Manum *et al.* (1989) in the Early/Late Oligocene and in the Cfu zone of Brinkhuis (1994).

The base of *Phthanoperidinium geminatum* again is recorded as Middle Eocene from Manum *et al.* (1989) and Powell (1992) in his Gin zone, which is Eocene. The base of *Svalbardella cooksoniae* in this section is much more restricted than the published literature suggests. Powell (1992) places the base of this taxon in his Rpe zone, Upper Eocene, Costa & Manum (1988) in their D10 zone which is Middle Eocene and Manum *et al.* (1989) at the Eocene/Oligocene boundary.

Conversely the base of *Amiculosphaera umbracula* in this section is more extended than the published literature suggests with Powell (1992) placing the base of this taxon in his Aum zone which is Late Miocene and Costa & Manum (1988) in the D19 zone which is Middle Miocene. The extended range of this taxa in the present study probably reflects the effects of caving.

INTERPRETED AGE: **Rupelian**, Early Oligocene, based on *Phthanoperidinium amoenum, Chiropteridium mespilanum* and *C. partispinosum*.

ASSOCIATION C

This association occurs from 3090 ft to 3180 ft. The sedimentology of this interval is of grey green claystones at the base with loose fine to medium quartz grains, grading up into brown tan crystalline limestone layers which are interbedded with brown slightly sandy to argillaceous siltstones.

Characteristic Palynological Features

Downhole from the top of this association *Cordosphaeridium minimum* shows a slight increase in numbers while *C. cantharellum* shows consistent relatively low numbers when compared to the rest of the section. The numbers of *Homotryblium floripes* and *H. tenuispinosum* show a continued reduction downhole through this association. The number of *H. tenuispinosum* reduce from abundant at the top to common at the base of the association. The presence of *Areosphaeridium arcuatum* is noted. *Homotryblium vallum* appears for the first time in this section with low numbers at the top of this association. The numbers of *Operculodinium* species remain relatively constant downhole through this association with a final reduction towards the base. The numbers of *Systematophora placacantha* remain common throughout this association, while a downhole increase of *Achomosphaera ramulifera* at the top of this association from rare to common can be seen. *Nematosphaeropsis labryinthea* is present along with single occurrences of *N. lemniscata*. *Spiniferites* sp. 1 of Manum *et al.* (1989) and *Microdinium* sp. 1 (Chateauneuf, 1980) occur here. The numbers of *Spiniferites ramosus* subsp. *ramosus* increase downhole from common at the top of this association to abundant at the base. A similar downhole increase in the numbers of *Spiniferites multibrevis* and *S. pseudofurcatus* is also seen. The numbers of *Areoligera semicirculata* reduce downhole from the top of this association and remain present throughout the association. Other taxa present include *Chiropteridium* species, *Deflandrea* species, *Phthanoperidinium* species, *Svalbardella* species and *Wetzeliella* species. The base of *Wetzeliella gochtii* occurs near the base of this association and shows a slight peak in relative numbers.

In general the number of chorate cysts reduces downhole in this association due to reductions in the numbers of *Cordosphaeridium* species, *Homotryblium* species and *Areoligera* species. While the numbers of proximochorate cysts increases towards the base of this association due to the increase in numbers of *Spiniferites* species here. Peridinioid cysts also seem more diverse within this association.

Comments

Association C is seen to show the highest diversity in this section with a peak of over 60. The standard deviation increases up through this association. The variance also increases from 7 at the base to 8 at the top of the association. Conversely the numbers of grains per gram fall to a low point of the section in this association to about 25 000 from an average of about 65 000. The cluster analysis data also shows clustering for this association with a phenon line drawn at a level of 0.02 (figure 6.2b).

Tops and Bases

A number of taxa occur for the last time within this association;

3090ft	top *Fromea fragilis*
	top *Areosphaeridium arcuatum*
	only occurrence of *Pentadinium laticinctum*
3150ft	top *Wetzeliella gochtii*

	top *Thalassiphora pelagica*
	only occurrence of *Phthanoperidinium filigranum*
	only occurrence of *Phthanoperidinium laevimurum*
3180ft	top *Deflandrea* spp.

A number of taxa appear for the first time within this association;

3090ft	base *Homotryblium oceanicum*
	base *Homotryblium vallum*
	base *Svalbardella* sp. 2
3150ft	base *Microdinium* sp. 1 of Chateauneuf (1980)
	base *Nematosphaeropsis labrynthea*
	base *Svalbardella* sp. 1
3180ft	base *Chiropteridium lobospinosum*
	base *Apteodinium spiridoides*
	base *Apteodinium trinovantium*
	base *Fromea fragilis*
	base *Wetzeliella gochtii*

Application to published zonation schemes

The top occurrence of taxa give a more reliable indication of age when the original samples are ditch cuttings, therefore it is these that will be looked at first. In the middle of this association a number of last occurrences of taxa are recorded. *Phthanoperidinium filigranum* and *P. laevimurum* have there top occurrence at this level. The former species correlates to the top of Stover & Hardenbol (1993) Ru2 TST zone which is top Rupelian.

The top occurrence of *Thalassiphora pelagica* is seen here and is well documented in the literature. Powell (1992) places this event in his Tva zone, which is Late Oligocene to Lower Miocene, Costa & Manum (1988) in their D16 zone which is Early Miocene, Manum *et al.* (1989) in their *A. actinocoronatum* zone which is Early/Late Oligocene and Manum (1976) in the Late Eocene.

Importantly the top of *Wetzeliella gochtii* occurs at this level. In the literature this is seen to have a much more restricted range than the previous species discussed. Costa & Manum (1988) place the top of this species in their D14 zone which is Chattian, Powell (1992) at the top of his Pcr zone which is Rupelian, and Stover & Hardenbol (1993) above their Ru2 HST zone, which is Rupelian.

At the top of this association *Areosphaeridium arcuatum* is seen to occur for the last time. From the published literature Brinkhuis (1994) places this event in the Late Eocene, Powell (1992) in his Rpe zone which is base Rupelian, Manum *et al.* (1989) in the Early Oligocene and Williams, Stover & Kidson (1993) at the

Rupelian/Chattian boundary. Manum *et al.* (1989) place the top of *A. arcuatum* above the *Spiniferites* sp. 1 of Manum *et al.* (1989) top but this sequence of events is not seen here.

The only occurrence of *Pentadinium laticinctum* is recorded at the top of this association. The stratigraphical range of this species from the published literature extends from the Early Eocene to the Middle Miocene (Powell, 1992; Manum *et al.*, 1989 and Costa & Manum, 1988).

A number of taxa are recorded for the first time within this association and are compared only briefly. In the middle of the association the base of *Chiropteridium lobospinosum* correlates to the *C. lobospinosum* zone of Manum *et al.* (1989) which is Early Oligocene. *Apteodinium spiridoides* correlates to the *Impagidinium* sp. 1 zone of Manum *et al.* (1989) which is the base of the Late Oligocene, the base of the D14 zone of Costa & Manum (1988) which is Rupelian and the top of the Ru1 HST zone of Stover & Hardenbol (1993).

The base of *Wetzeliella gochtii* occurs at this level, this shows a very restricted range of this species in this section as its occurrence is confined to within Association C. The majority of the published literature show the base occurrence of this species in the Rupelian. Powell (1992) places this event at the base of his Wgo zone, Brinkhuis (1994) at the base of his Cin zone and Costa & Manum (1988) in their D13 zone.

Stratigraphically above this the base occurrence of *Nematosphaeropsis labrynthea* occurs, this is poorly recorded in the literature although Manum *et al.* (1989) suggests a Middle Eocene age for this event. The base of *Microdinium* sp. 1 of Chateauneuf (1980) also occurs at this level, it has a suggested base occurrence in the Eocene by Chateauneuf (1980). The base occurrence of *Svalbardella* sp. 1 is seen here in this section and can only be correlated to the 16/16 microplankton section in which this species is restricted to its Association C, which is top Rupelian.

At the top of this association the base of *Homotryblium oceanicum* occurs, Costa & Manum (1988) place this event in their D9 zone which is Middle Eocene and Powell (1992) places it in his Pcr zone which is also Middle Eocene. The base of *H. vallum* is compared to a wide range of suggestions in the literature, Brinkhuis (1994) places this event in his Adi zone which is Rupelian and Stover & Hardenbol (1993) also have a Rupelian base whereas Manum *et al.* (1989) place this event in their *I. patulum* zone which is Early Miocene.

INTERPRETED AGE: **Rupelian**, Early Oligocene, based on *Phthanoperidinium filigranum, Thalassiphora pelagica, Wetzeliella gochtii, Chiropteridium lobospinosum* and *Apteodinium spiridoides.*

ASSOCIATION D

This is a small association occurring at 3060 ft. The sedimentary sequence of this interval starts with a brown slightly sandy to argillaceous siltstone with abundant mica flecks and fines upwards into a claystone with a few calcareous patches. Stratigraphically above this interval at 3030 ft an unconformity occurs in the section.

Characteristic Palynological features

This association sees the downhole reduction in numbers of *Cordosphaeridium cantharellum* and *Homotryblium floripes* and slight reduction of *Cordosphaeridium minimum*. *Homotryblium tenuispinosum* shows a significant increase in numbers at the top of this association from rare to common. *Lingulodinium machaerophorum* occurs in numbers less than 5 and is rare. *Operculodinium* sp. 2 reduces in number at the top of this association and *Operculodinium bellerum* occurs in constant numbers. *Systematophora placacantha* shows a downhole decrease in numbers to the top of this association. *Achomosphaera ramulifera* shows a drastic increase from rare to abundant into the association below.

Hystrichostrogylon membranophorum, Spiniferites sp. 1 of Manum *et al.* (1989) and *Microdinium* sp. 1 of Chateauneuf (1980) are present in this association. *Spiniferites ramosus* subsp. *ramosus* reduces in number downhole from the top of this association into Association C as does *Areoligera semicirculata*. *Chiropteridium partispinosum, C. mespilanum, Deflandrea phosphoritica* and *D. heterophlycta* are rare but present in this association. Importantly the top of a number of *Phthanoperidinium* species occur in this association.

In general the number of peridinioid cysts are lower compared with the associations stratigraphically below. A switch in dominance from *Areoligera semicirculata* above association to *Homotryblium tenuispinosum* below is seen. This association probably represents a sequence boundary, a maximum flooding surface.

Comments

The diversity in this association remains relatively high before reducing upsection. The variance increases downhole from 6 at the top of this association to 8 at the top of Association C below. The number of grains per gram at the top of this association is about 75 000, this decrease, downhole to 55 000 at the top of the association below. The results of the cluster analysis indicate that the top of this association is more closely related to the associations below than those above. It is the conclusion here in this study that the associations A-D that are all regarded as representing Rupelian aged strata.

Tops and Bases

A number of first downhole occurrences of taxa are recorded from this association;

3060ft	top *Microdinium* sp. 1 of Chateauneuf (1980)

top *Spiniferites* sp. 1 of Manum *et al.* (1989)
top *Phthanoperidinium comatum*
top *Rhombodinium draco*
top *Svalbardella* sp. 1
top *Svalbardella* sp. 2
top *Lentinia wetzeli*
top *Cordosphaeridium funiculatum*
only occurrence of *Dapsilidinium simplex*

Application to published zonation schemes

In this association first downhole occurrences of nine taxa are seen. The last occurrence of *Rhombodinium draco* occurs at the top of this association. This correlates to the Lxa zone of Powell (1992) which is Chattian, the D14 zone of Costa & Manum (1988) which is Chattian and the Rupelian/Chattian boundary (figure 6.3). *Cordosphaeridium funiculatum* was recognised as an important taxa for indicating a Late Eocene age when analysing and comparing this section to 16/16b-4. Although Brinkhuis (1994) places this in his Gse zone which is Early Oligocene, other authors such as Powell (1992) place this in his Rpe zone which is Upper Eocene and Williams, Stover & Kidson (1993) at the Eocene/Oligocene boundary, showing this taxa extending further up the stratigraphical sequence in this section.

Two taxa which are noted as important in Association B of 16/16b-4 microplankton section also occur here. *Spiniferites* sp. 1 of Manum *et al.* (1989) and *Microdinium* sp. 1 of Chateauneuf (1980) have their last occurrence recorded together in both of the microplankton sections studied here. Figure 6.3 places this event in the Rupelian for both of the taxa in question and Manum *et al.* (1989) places the top of *Spiniferites* sp. 1 of Manum *et al.* (1989) in their *C. lobospinosum* zone, which is also Early Oligocene.

Phthanoperidinium comatum has its first downhole occurrence at the top of this association. This can be correlated with the top of the D14 zone of Costa & Manum (1988) which is Chattian, the Pcr zone of Powell (1992) which is at the Rupelian/Chattian boundary and (figure 6.3) where this event is placed in the Lower Chattian.

Dapsilidinium simplex is only recorded from this association in this section. This correlates to the Cin zone of Brinkhuis (1994) which is Lower Oligocene. The distinctive species *Svalbardella* sp. 1 is recorded for the last time upsection in this association, this compares with the last occurrence of this species at the top of Association C of the 16/16b-4 section, which is Rupelian in age. *Svalbardella* sp. 2 also occurs for the last time in this section at this level. These taxa cannot be correlated to the 16/16b-4 microplankton section as is not present there.

INTERPRETED AGE: **Late Rupelian**, late Early Oligocene, based on *Rhombodinium draco, P. comatum, Spiniferites* sp. 1 of Manum *et al.* (1989), *Microdinium* sp. 1 (Chateauneuf, 1980) and *Dapsilidinium simplex.*

ASSOCIATION E

This association occurs at 3000 ft in depth. The sedimentary sequences of this interval comprise of grey to green soft, calcareous claystones with medium to fine quartz grains being common. This sequence is not conformable, as an unconformity is recorded at a depth of 3030m. This unconformity is shown clearly by a downhole reduction in Gamma Ray response and a reduction in sonic response.

Characteristic Palynological Features

The number of *Homotryblium floripes* reduces downhole from the top of this association and *H. tenuispinosum* occurs in rare numbers at the top of this association and increases drastically downhole to abundant at the top of Association D. *Hystrichokolpoma rigaudiae* also reduces downhole from the top of this association and *Hystrichosphaeridium patulum* is rare to absent but increases downhole into the top of the association below. *Cyclopsiella* sp. A and *C.* sp. B reduce slightly downhole from the top of this association. *Paucisphaeridium* cf. *invesibuccinum* shows constant numbers throughout the majority of this section. *Dapsilidinium pastielsii* has a peak occurrence in this association but is still rare and reduces in number both downhole and uphole from here. The numbers of *Lingulodinium machaerophorum* are rare in this association and account for the lowest numbers of this species within this section. *Operculodinium* sp. 1 is absent from this association. *Systematophora placacantha* shows common occurrences throughout this association while *Achomosphaera ramulifera* drops in number from abundant in Associations F, G and C to rare within this association which is very characteristic.

Hystrichostrogylon membraniphorum is present as is *Cordosphaeridium cantharellum, C. minimum* and *Distatodinium paradoxum.* The number of *Spiniferites ramosus* subsp. *ramosus* drops off slightly at the top of this association, then increases downhole into the next association. Another very characteristic feature of this association is the increase in *Areoligera semicirculata* at the top to abundant and forms the peak occurrence or 'influx' of this species in this section. When compared with the influx in the 16/16b-4 microplankton section, it is noted here that the influx is seen over a much broader depth.

Thalassiphora fenestrata, Deflandrea heterophlycta, D. phosphoritica and *Palaeocystodinium golzowense* are present although in low numbers and the first downhole occurrence of *Wetzeliella symmetrica* is noted. No *Phthanoperidinium* species are recorded in this association or upsection from this level. In general the number of chorate cysts is low compared to numbers downhole.

Comments

The top of this association is marked by a drop of diversity while the standard deviation remains relatively constant, only increasing slightly. The variance shows a marked increase at the top of this association compared with the top of Association D. The number of grains per gram show a marked peak in this association to a level of over 120 000. The cluster analysis results indicate a separation of the section above and below this association. It picks out the similarities between Associations A, B, C and D and between Associations E, F and G while suggesting these two groups are overall different in character from each other. This correlates well to the presence of an unconformity at a 3030 ft level between these associations.

Tops and Bases

A number of taxa are seen to occur for the last time in this association;

3000ft	top *Wetzeliella symmetrica*
	top *Nematopshaeropsis labrynthea*
	top *Wetzeliella* spp.
	only occurrence of *Cyclopsiella vieta*
	influx of *Areoligera semicirculata*

Application to Published Zonation Schemes

The top of *Wetzeliella symmetrica* occurs at the top of this association, this event correlates to the top of the D14 zone of Costa & Manum (1988) which is Chattian in age, the Hfl zone of Powell (1992) which is Middle Chattian and the top Rupelian of Stover & Hardenbol (1993). This also correlates to the top of *Wetzeliella* spp. recorded at this level in this study.

The top of *Nematosphaeropsis labrynthea* occurs in this association and displays a more restricted range than recorded in the literature. Previous work sees this taxa extending into the Late Miocene, the *A. andalousiensis* zone of Manum *et al.* (1989).

The only specimen of *Cyclopsiella vieta* recorded from this section occurs in this association. This can be correlated to occurrences recorded by Liengjarern *et al.* (1980) in the Lower Oligocene and the top of Association D in the 16/16b-4 which is Lower Chattian.

The distinctive feature of this association is the peak occurrence or influx of *Areoligera semicirculata*. This correlates to the Association C of the 16/16b-4 which is Rupelian. Overall the range of *Areoligera semicirculata* is greatly extended when compared to previous published records in the literature. Brinkhuis (1994) shows this species restricted to his Adi zone which is Rupelian. Powell (1992) and Benedek

(1972) record a base for this species in the Chattian and Costa & Manum (1988) and Stover & Hardenbol (1993) place the last downhole occurrence of *Areoligera semicirculata* in the Rupelian. Therefore it is clear that the range of this species in this section and in 16/16b-4 extends throughout the Rupelian and Chattian, to a last occurrence at the Oligocene/Miocene boundary.

INTERPRETED AGE: **Chattian**, Upper Oligocene, based on *Wetzeliella symmetrica.*

ASSOCIATION F

This association occurs from 2940 ft to 2970 ft. In this interval grey green claystones occur. These are soft and slightly calcareous or silty with common loose quartz grains present. Two definite sandstone bodies occur within this dominantly claystone unit.

Characteristic Palynological features

Cordosphaeridium cantharellum and *C. minimum* are present in this association with slight downhole increases and decreases respectively through this unit. A distinctive and characteristic increase in *Homotryblium floripes* downhole to the top of this association is seen while the inverse is seen with *H. tenuispinosum* which shows a marked reduction in numbers downhole to rare from common and abundant numbers above and below. *Hystrichokolpoma rigaudiae* shows an increase in numbers from the top to base of this association while *Hystrichosphaeridium patulum* declines in number. *Operculodinium bellerum* increases downhole and *O.* sp. 2 reduces in number downhole from the top of this association. *Lingulodinium machaerophorum* occurs with its lowest numbers seen throughout the section.

Systematophora placacantha occurs in common numbers and *Achomosphaera ramulifera* decreases in numbers downhole from abundant at the top of this association to present at the top of the association below. *Hystrichostrogylon membraniphorum* occurs as single specimens through this association and *Nematosphaeropsis lemniscata* has its first downhole occurrence within this association.

Spiniferites ramosus subsp. *ramosus* is common throughout this association and *Areoligera semicirculata* occurs in common to abundant numbers indicating this is still within the influx zone of this species which is noted at the top of Association E. The *Impletosphaeridium* species are present in this association as are *Chiropteridium mespilanum, C. lobospinosum, C. partispinosum, Membranophoridium aspinatum, Amiculosphaera umbracula, Apteodinium spiridoides, Thalassiphora fenestrata, Deflandrea heterophlycta, D. phosphoritica, Palaeocystodinium golzwense, P.* sp. A of Costa & Downie (1979) and *Areosphaeridium actinocoronatum*. No *Wetzeliella* species are recorded in this association or above.

Comments

Diversity remains relatively constant at about 50. The standard deviation peaks at the top of this association and reduces downhole, this is also seen in the variance figures but is more marked, it reduces downhole from 9 to about 6.5. The number of grains per gram show a marked and steady increase from 70 000 at the top of the association downhole to about 120 000 at the top of the next association below. The cluster analysis in this section is very clear, picking out the unconformity at 3030 ft. It also picks out this association showing the samples here to be more similar to each other than to the samples in Association G or E or to those below the unconformity.

Tops and Bases

A number of taxa are recorded for the last time within this association;

2970ft	only occurrence of *Palaeocystodinium* sp. A of Costa & Downie (1979)
	top *Nematosphaeropsis lemniscata*
2940ft	top *Operculodinium microtriainum*
	top *Paralecaniella indentata*
	top *Achomosphaera crassipellis*
	top *Cordosphaeridium fibrospinosum*
	top *Homotryblium vallum*
	top *Homotryblium oceanicum*
	top *Impagidinium patulum*
	top *Nematosphaeropsis* spp.
	top *Apteodinium trinovantium*
	influx of *Areoligera semicirculata*
	last significant occurrence of *Deflandrea heterophlycta*

Application to Published Zonation Schemes

The middle of this association sees the only occurrence of *Palaeocystodinium* sp. A of Costa & Downie (1979) within this section. The published literature gives relatively large ranges for this taxa. Costa & Manum (1988) suggest a range from their D14 to D19 zones which is Rupelian to Late Miocene, Powell (1992) has a base in the Hfl zone which is Chattian up to his Uaq zone which is Middle Miocene and Manum *et al.* (1989) suggest a range from Early to Late Miocene. The top of *Nematosphaeropsis lemniscata* is also recorded at this level, it can be correlated to the Late Miocene of Manum *et al.* (1989) and the Pleistocene of Williams, Stover &

Kidson (1993). This species is showing a restricted range in this section possibly due to environmental factors.

At the top of this association a number of taxon occur for the last time. Although *Paralecaniella indentata* is recorded in very few of the published records in this area (figure 6.3) places the top of this species in the Lower Miocene at the same level as the top of *Homotryblium floripes*, but the top of *H. floripes* is not recorded here but its numbers do appear to reduce markedly into the next association upsection, Association G.

Cordosphaeridium fibrospinosum occurs for the last time at the top of this association. This species appears to have a much larger range than the published literature suggests. Powell (1992) places its top in his Aar zone which is Middle Eocene and Costa & Manum (1988) place it in their D9 zone which is also Middle Eocene with Stover & Hardenbol (1993) and Williams, Stover & Kidson (1993) suggesting an Early Oligocene age for this event.

The last occurrence of *Homotryblium vallum* can be correlated to the Late Eocene of Manum *et al.* (1989), the Early Oligocene of Brinkhuis (1994) in his Cin zone and the base of Stover & Hardenbol (1993) Ru2 HST zone which is Rupelian, giving a much more restricted range than is suggested in this section. A second species of *Homotryblium, H. oceanicum* is seen for the last time at the top of this association. While Powell (1992) places this event in his Rpe zone which is Upper Eocene and Costa & Manum (1988) in the Late Eocene, Liengjarern *et al.* (1980) has recorded this species up into the Lower Oligocene. In this section its range is extended further into the Chattian.

The top of *Achomosphaera crassipellis* in this association shows a very restricted occurrence in this section compared with the 16/16b-4 section in which it ranges throughout all of the Associations from A to G. The influx of *Areoligera semicirculata* occurs at the top of this association as well as at the top of Association E. The top of *Impagidinium patulum* in this association is not regarded as important stratigraphically as the majority of authors e.g. Williams, Stover & Kidson (1993), Costa & Manum (1988) and Powell (1992) suggest this species ranges into the Recent, although environmental significance could be placed on it having a last occurrence in this section.

The last occurrence of *Operculodinium microtriainum* at the top of this association can be correlated with the Adi zone of Brinkhuis (1994) which is Rupelian and the top of Stover & Hardenbols (1993) Ru1 HST zone which is also Rupelian. *Apteodinium trinovantium* occurs very rarely in this section and is seen to occur for the last time at the top of this association, this is very different to the 16/16b-4 section, in which this species occurs slightly more frequently and ranges from Association B to E, which is much longer than seen here.

The last significant occurrence of *Deflandrea heterophlycta* is recorded at the top of this association. Few records of this species are recorded in the published literature. Costa & Manum (1988) place this event at the Eocene/Oligocene boundary and Brinkhuis (1994) records this species up into his Gin zone which is Early Oligocene.

INTERPRETED AGE: **Chattian**, Upper Oligocene, based on *Deflandrea heterophlycta, Areoligera semicirculata* and *Apteodinium spiridoides*.

ASSOCIATION G

This association occurs from 2880 ft to 2910 ft. This interval comprises of predominantly grey green claystones which are soft and slightly calcareous and argillaceous in places with common quartz grains. One layer of sandstone occurs within this claystone near to the base of this association. The top of this association is marked by a reduction in Gamma Ray response (figure 4.7) and a reduction in the sonic response.

Characteristic Palynological Features

A slight increase in the numbers of *Cordosphaeridium minimum* compared to below and lower numbers of *Homotryblium floripes* are recorded in this association. While the numbers of *Homotryblium tenuospinosum* are common at the top of this association they reduce markedly downhole. *Hystrichosphaeridium patulum* again increases in numbers up through this association to the top of the section. A slight peak of *Impletosphaeridium insolitum* and *Lingulodinium machaerophorum* is seen at the top of this association and the reduction in numbers downhole from this is noted. In general the numbers of *Operculodinium* are low and show a marked increase in numbers to the top of the association below.

The numbers of *Systematophora placacantha* in this association are higher than those seen below and the numbers of *Achomosphaera ramulifera* increase slightly downhole from the top of this association. An increase in the numbers of *Hystrichostrogylon membraniphorum* is seen at the top of this association. The numbers of *Spiniferites ramosus* subsp. *ramosus* and *Areoligera semicirculata* both decrease upsection from the top of Association F to the top of Association G. The presence of *Chiropteridium mespilanum, C. partispinosum, C. lobospinosum, Membranophoridium aspinatum, Microdinium* sp. 2, *Thalassiphora fenestrata, Deflandrea phosphoritica, Phthanoperidinium geminatum* and Dinocyst sp. 4 of Manum (1976) are noted.

Comments

Diversity remains at a constant level of about 50 in this association. The standard deviation shows an increase from the top of this association downhole to the top of Association F. The same is seen from the variance figures but it is more marked increasing from 5.5 at the top of Association G to 9 at the top of the association below. The numbers of grains per gram are very varied from over 90 000 at the top of this association falling to over 40 000 in the middle then increasing to 70 000 at the top of association F. The cluster analysis data picks out this association showing the samples within it are similar to each other and distinct from the samples in the associations below.

Tops and Bases

As this is the upper most association in this section difficulty in deciding on which taxa have their last occurrence at this level or continue up through the section was found.

A number of taxa are recorded for the last time within this association;

2910ft	top *Membranophoridium aspinatum*
	top *Impletosphaeridium ligospinosum*

A number of taxa are recorded for the first time within this association;

2880ft	base *Ascostomocystis granulatus*
	only occurrence of *Kallosphaeridium* spp.
	only occurrence of *Operculodinium* sp. of Piasekei (1980)

Application to Published Zonation Schemes

In this unit the top of *Membranophoridium aspinatum* occurs. This is an important species in the stratigraphical sense as its top occurrence is quite well recorded in the literature. Costa & Manum (1988) place this event in their D15 zone which is Chattian, just below the top of *Homotryblium floripes*, this is possibly seen here as *H. floripes* is seen to be reducing in number towards the top of this association, this relationship is also recorded in the 16/16b-4 section. Powell (1992) places the top of *Membranophoridium aspinatum* at the Oligocene/Miocene boundary and Williams, Stover & Kidson (1993) record this species up into the Early Miocene.

At the top of this association the base of *Ascostomocystis granulatus* is seen. This correlates to the D15 zone of Costa & Manum (1988) which is Chattian, the Oligocene/Miocene boundary of Manum *et al.* (1989) and the Hfl zone of Powell (1992) which is Chattian, Late Oligocene in age.

The only specimen of *Operculodinium* sp. of Piaseki (1980) is recorded in this association. The range of this species from the literature suggests a long range. For example from the *A. granosa* zone of Manum *et al.* (1989) which is Early to Late Miocene and the Tva zone to the Mch zone of Powell (1992) which is Early Miocene to Pliocene. This suggests that this specimen recorded here represents caving or an extended basal range of the taxa in Question.

INTERPRETED AGE: **Late Chattian**, Late Oligocene, based on *Membranophoridium aspinatum* and *Ascostomocystis granulatus.*

INTERPRETATION OF THE 21/28B-7 DINOFLAGELLATE CYST DATA SECTION

In this section a clear boundary can be seen at a depth of 3030 ft. From the sedimentary log an unconformity occurs at this depth and is the basis of the boundary discussed. The top of Association D represents the top most Rupelian aged sediments in this section, this age was based on the last occurrences of a number taxa such as *Microdinium* sp. 1 of Chateauneuf (1980), *Spiniferites* sp. 1 of Manum *et al.* (1989), *Deflandrea phosphoritica, Phthanoperidinium comatum, Rhombodinium draco* and *Svalbardella* species, these are regarded as stratigraphically significant taxa and indicate the top Rupelian in this section. Above the unconformity in Association E the top of taxa such as *Wetzeliella symmetrica* indicate a Lower/Middle Chattian age for this association.

The cluster analysis is studied to try and pick out or even quantify this boundary in the section. The Phenon line P1 (figure 6.2b) defines two clusters very clearly at a level of 0.12. These two clusters are regarded as representing the Rupelian and Chattian aged sediments in the section. A phenon line P2 at a level of 0.04 further subdivides these two clusters into six smaller clusters which are seen to correlate closely to the Associations A to G previously identified and described. It must be noted that caving will disrupt some of the associations compared to the clusters defined therefore not resulting in exact correlations.

It must be stressed that no comparison can be made of the level of clustering between the two sections involved here i.e. number of total sum of squares between sections because each section is composed of different variables which in turn will give different results that do not allow comparison.

COMPARISON OF THE DINOFLAGELLATE CYST DATA IN THE NORTH SEA WELL SECTIONS

After studying the two North Sea dinoflagellate sections, 16/16b-4 and 21/28b-7 individually, it was necessary to compare the two section together as both represent sections located in the middle of the North Sea sedimentary basin they should record similar if not the same sequences of events.

Correlation

A number of correlative events between the two sections have been shown to occur, these are illustrated in figure 6.4. The 16/16b-4 section in this study represents a 880 ft sedimentary interval whereas section 21/28b-7 in this study represents a 390 ft sedimentary interval. The much shorter latter sequence represents a less complete sequence compared to the 16/16b-4 section, this is recognised not only by an unconformity in 21/28b-7 at the base of Association E (3030 ft) but also by the lack of Unit M III which is recorded in 16/16b-4 as Association C. The schematic diagram (figure 6.4) details the correlation between the two sections based on the previously defined and discussed associations in each.

The most distinct correlative level is the top of Association B in 16/16 with the top of Association D in 21/28, at this level in both sections a switch in abundance of *Homotryblium floripes* downhole to abundant *H. tenuispinosum* is marked and a switch from abundant *Areoligera semicirculata* downhole to abundant *Cordosphaeridium cantharellum* and *Systematophora placacantha*. Also importantly at this level, the top of the M II unit, the taxa *Spiniferites* sp. 1 of Manum *et al.* (1989) and *Microdinium* sp. 1 of Chateauneuf (1980) have their first downhole occurrence, with the top occurrence of *Areosphaeridium arcuatum* occurring below this level in both sections.

The unconformity at the base of association E in 21/28b-7 (base of M IV) accounts for the fact that Association C in 16/16b-4 which is equivalent to M III is not represented in 21/28b-7. The unconformity in 21/28b-7 represents an approximate 1 ma time gap in deposition here, as inferred from figure 7.2.

The next correlative level is the top of Association D in 16/16b-4 with the top of Association E in 21/28b-7. This marks the top of the M IV unit. This is based on *Hystrichokolpoma rigaudea* which reduces in abundance downhole and *Homotryblium floripes* which also reduces in numbers downhole.

Association E in 16/16b-4 can be correlated to Associations F and G in 21/28b-7 this is the M V biozone. The correlation here is based on a number of features. A clear peak of *Homotryblium floripes* in 16/16b-4 correlates to the high numbers of this species in 21/28b-7. The numbers of *H. tenuispinosum* are relatively low compared to the rest of the sections and the numbers of *Operculodinium* species in both sections remain relatively high. *Hystrichosphaeridium patulum* increases uphole within this unit and abundant numbers of *Areoligera semicirculata* are characteristic but these reduce drastically up the section to rare/present numbers. The taxa *Membranophoridium aspinatum* and *Deflandrea phosphoritica* are present in this unit and the last major occurrence of *Chiropteridium* species occurs here and the lack of *Wetzeliella* species in this unit is noted. A peak in variance occurs in this unit, this is important as it represents a time of regressive sea levels at the basin margins and is recognised in the two sections studied here. All the taxa representing these environments are transported into the middle of the basin where these sections are located. This ties into the coarsening up sequences of the sediments recorded here (figures 4.6 and 4.7) making this feature a good correlative event across the two sections.

A tentative correlation between Association A in 16/16b-4 and Association A and B in 21/28b-7 is made, corresponding to the MI unit. This is based on the slight peaks of *Cordosphaeridium cantharellum* and *Homotryblium tenuispinosum* recorded here along with lower numbers of *H. floripes*. *Spiniferites ramosus* subsp. *ramosus* also shows a slight peak across this unit. The variance for this unit in the sections is at its lowest point along with lower numbers of grains per gram.

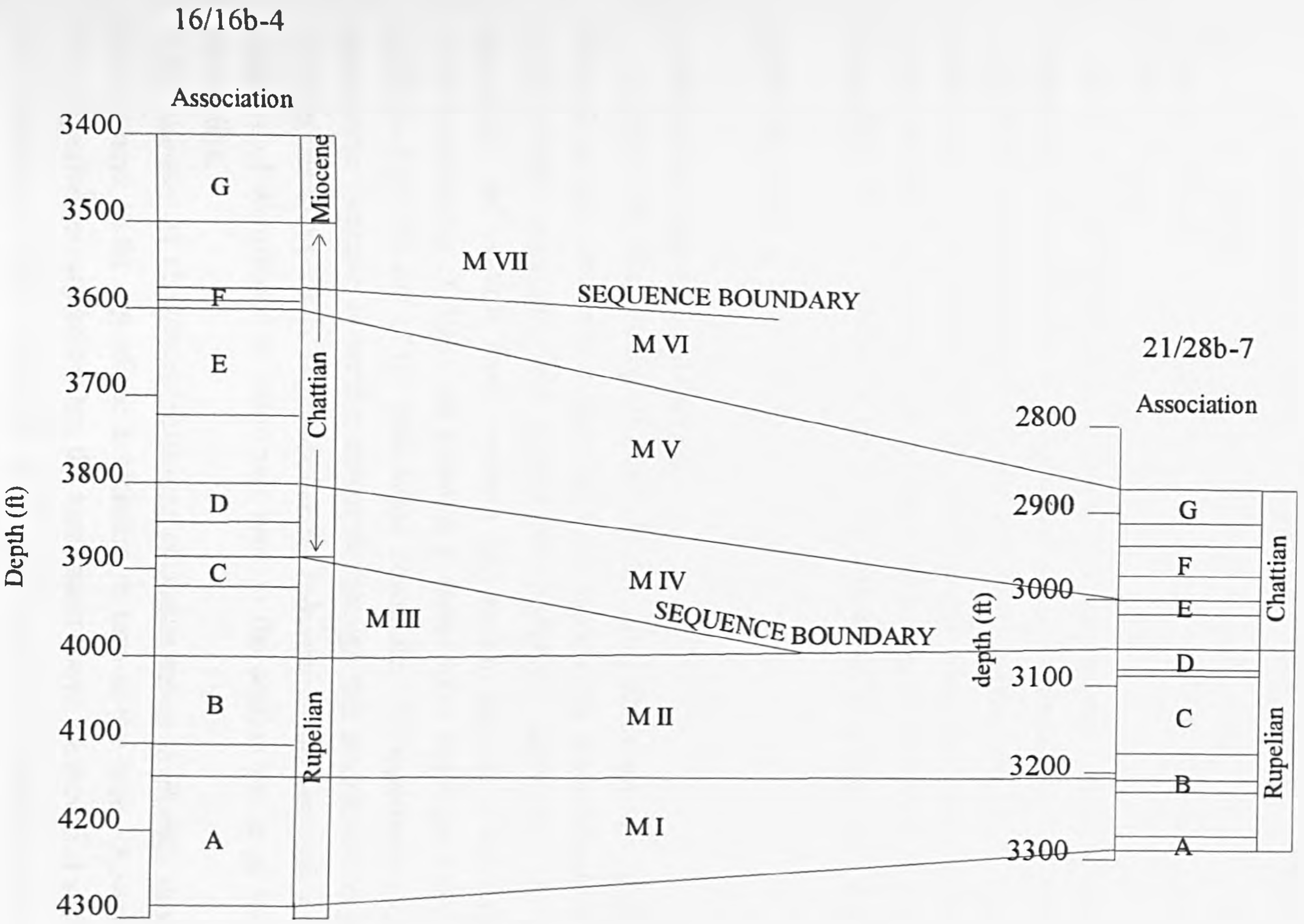


Figure 6.4 Schematic diagram showing the correlation of the two North Sea marine sections 16/16b-4 and 21/28b-7. The lines connecting the two sections are lines of correlation and the units MI to MVII are the correlatable units (the letters A to G are individual Associaton lables and are NOT correlatable).

SECTION 16/16B-4 POLLEN ASSOCIATIONS

The dinoflagellate sections were analysed in detail, particular attention was paid to the top and base occurrences of taxa in each association. These were then correlated to the published zonation schemes in order to establish some datable events in the sections. This was done rigorously as dinoflagellate cysts are established and recognised as a good tool for the basis of biozonation and the relative and absolute dating of marine sequences. Although dinoflagellate cysts are affected by environmental factors and some degree of facies control they are regarded as good zonation fossils.

The pollen and spore floras seen in both the marine and terrestrial sections must be interpreted with a view to the climatic and the environmentally restricted nature of the floras from which pollens and spores are derived. As the presence of pollen and spore taxa is very localised it is difficult to follow any zonation schemes, even pollen and spore zonations for NW Europe, as floras tend to be localised rather than widespread depending on local climate and conditions making such schemes very limited.

ASSOCIATION A

Characteristic palynological features

Numbers of *Inaperturopollenites hiatus* are abundant to highly abundant throughout the whole section and within this association, while *Momipites coryloides, Graminidites annulatus* and *Liquidambarpollenites stigmosus* are rare in this association and occur in fewer numbers than seen in the rest of the section. Present *Tricolpopollenites* cf. *hians* and common *T. hians* occur and show a slight increase in numbers from the top of the association downhole. *Nyssapollenites kruschi* subsp. *analepticus* increases in number downhole through this association to common, and corresponds to a peak in *Triporopollenites robustus* in this association. The highest numbers of *Retitricolpites retiformis* seen in the section occur at the top of this association.

The number of *Cupuliferoipollenites cingulum* subsp. *oviformis* drops downhole from present at the top of the association to rare at the base. Lower numbers of *Triporopollenites coryloides* than the association above are recorded and the numbers of *Tricolporopollenites edmundi* show a reduction in numbers in this association when compared to the rest of the section. The highest numbers of *Cicatricosisporites chattensis* for the section are recorded in this association but still remain rare. Slight downhole increases in the numbers of *Deltoidospora maxoides* to rare and *Deltoidospora wolffi* to common are seen. *Baculatosporites primarus* and *Stereisporites (Stereisporites) stereoides* show a slight increase in presence downhole while *Verrucatosporites favus, Laevigatosporites discordatus* and *L. haardti* occur in constant numbers. Bissacate numbers reduce from highly abundant at the top to abundant at the base of this association.

Comments

Standard deviation and variance in general reduce downhole through this association. Although a sharp drop in both at 4300 ft is as a result of the low numbers of grains per gram recorded in this sample. This low pollen sum is over 100 and is therefore is statistically viable but as the count is much lower than the standard 250 count for the section the result appears spurious. Overall the numbers of grains per gram in this association are the lowest with numbers at about 45 000 to 50 000, again the sample at 4300 ft shows a marked drop in numbers per gram to less than 10 000.

Tops and Bases

A number of last occurrences of taxa within this section are recorded from this association:

4260ft	top *Pterocarya* spp.
	only occurrence of *Dicolpopollis kockeli*
4200ft	top *Caryapollenites spp.*
4180ft	only occurrence of *Tricolporopollenites spinus*
	top *Veryhacium spp.*
	only occurrence of *Trilites* sp. 1

The first uphole occurrence of a number of taxa are recorded within this association

4260ft	base *Graminidites annulatus*
4180ft	base *Tetracolpites reticulatus*
	base *Trivestibulopollenites betuloides*
	base *Polypodaceoisporites marxheimensis*
4140ft	base *Momipites tenuipollis*
	base *Nyssapollenites kruschi* subsp. *accessorius*

Application to published zonation schemes

The top occurrence of a number of taxa are recorded for the last time in this association. Taxa such as *Caryapollenites* spp. and *Pterocarya* type are recorded for the last time here, but in the literature occurrences of these species are recorded into the Pleistocene (Vinken *et al.*, 1988). *Dicolpopollis kockeli* is a distinctive taxon and has a top occurrence ranging from the Lower Oligocene of Chateauneuf (1980) and Ollivier-Pierre (1980) up to the Lower Miocene of Vinken *et al.* (1988). Importantly

Wilkinson & Boulter (1980) record this species commonly occurring in the Oligocene of the Western British Isles.

The range of *Tricolporopollenites spinus* is similar to that suggested from the Eocene of Chateauneuf (1980) to the Lower Oligocene of Ollivier-Pierre (1980). It is considered to be present only in the Middle Oligocene sediments of Central Europe (Krutzsch, 1967c).

The base of several taxa are recorded from this association; *Trivestibulopollenites betuloides* is seen to range from an Eocene to Oligocene age, (Chateauneuf, 1980). *Graminidites annulatus* is recorded from the Lower Oligocene of Germany by Krutzsch (1966). This species is rare in the Oligocene sediments of Europe and is more abundant from Miocene and Pliocene sediments (Krutzsch, 1967c) but it is never seen to reach such abundances in these sections.

INTERPRETED AGE: **Lower Oligocene**

ASSOCIATION B

Characteristic palynological features

The first consistent but still rare occurrences of *Graminidites annulatus* is recognised in this association. A slight peak in numbers of *Momipites coryloides* is recorded along with a similar peak of *Nyssapollenites kruschi* subsp. *accessorius, Tricolporopollenites edmundi, Microthallites spp., Pluricellaesporites* spp., *Micrhystridium fragile* and *Tasminites.* It is noted that the numbers of *Micrhystridium fragile* characteristically reduce up section from this association.

The abundances of both *Alnipollenites verus* and *Triplanosporites spp.* are reduced in this association. Only occurrences of *Sparganiaceaepollenites polygonalis, Triatriopollenites rurensis* and *Tricolporopollenites* sp. 1 are seen in this association. A marked downhole increase in numbers of *Nyssapollenites kruschi* subsp. *analeptics* from present to common occurs in this association. The numbers of *Ilexpollenites iliacus* increase into the top of the association from rare to common and reduce again at the base. The opposite is seen with *Sciadopityspollenites serratus, Deltoidospora wolffi* and *Stereisporites (Stereisporites) stereoides* which fall off in number at the base then increase upsection to the base of the next association. *Retitricolpites retiformis* increases markedly downhole through this association from present to common.

Highly abundant bissacates pollen is seen, *Laevigatosporites haardti* are common in number and the presence of *Arecipites* is noted. No *Monocolpopollenites tranquillus* or *Baculatosporites primarus* are recorded here.

Comments

Generally slight increases in the variance and standard deviation are seen downhole through this association, while the numbers of grains per gram drop off markedly from about 70 000 at the top to over 40 000 at the top of the next association.

Tops and Bases

A number of taxa are recorded for the last time in this association;

4100ft	only occurrence of *Triatriopollenites rurensis*
	only occurrence of *Pompeckjoidaepollenites subhercynicus*
	top *Pluricellaesporites* spp.
	only occurrence of *Sparganiaceaepollenites polygonalis*
4020ft	only occurrence of *Cupanieidites* spp.
	only occurrence of *Tricolporopollenites* sp. 1

The first appearance of two taxa are recorded from this association:

4000ft	base *Erecipites* spp.
	base *Verrucatosporites histiopteroides*

Application to published zonation schemes

The only recorded occurrence of *Triatriopollenites rurensis* in this section falls within this association, Chateauneuf (1980) suggests a restricted range of this species to the Lower to Upper Oligocene. A top occurrence of *Sparganiaceaepollenites polygonalis* is seen in the base of the Upper Oligocene by Ollivier-Pierre (1980) while the range suggested by Chateauneuf (1980) is from the Upper Eocene to Lower Oligocene. A similar range is seen for the distinctive species *Pompeckjoidaepollenites subhercynicus* in which Ollivier-Pierre (1980) suggests a top occurrence in the Middle Eocene and Chateauneuf (1980), Vinken *et al*. (1988) and Krutzsch (1967c) indicate a top occurrence in the Upper Eocene, therefore the presence of this species here indicates a longer ranging occurrence than previously recorded, into the Lower Oligocene. *Verrucatosporites histiopteroides* occurs for the first time in this association. This can be correlated to the data of Krutzsch (1966) who regards this species as being rare in the Middle Oligocene increasing to present in the Upper Oligocene. The lowest occurrence of the species *Cupanieidites eucalyptoides* can be compared to an Upper Eocene age (Chateauneuf, 1980) and to a Lower Oligocene age (Krutzsch, 1966).

INTERPRETED AGE: **Lower Oligocene**

ASSOCIATION C

Characteristic palynological features

The top of this association shows a number of distinct changes in character. The abundances of a number of taxa are reduced downhole from the top of the association. Taxa such as *Polyatriopollenites carpinoides, Momipites coryloides, Tricolpopollenites* cf. *hians, Sequoiapollenites polyformosus* and *Echinosporis echinatus* are more significant in the top of the association, these taxa then characteristically reduce in relative numbers downhole. A significant change in abundance of *Retitricolpites retiformis* occurs at this level. It increases in abundance downhole from rare at the top of the association to present at the base and marks an overall change from rare in the upper parts of the section to common in the lower parts of the section. Slight peaks in a number of taxa occurring in this association can be seen, *Alnipollenites verus, Verrucatosporites favus* and *Baculatisporites primarus* all peak to present numbers here. The numbers of *Inaperturopollenites hiatus* reduces downhole from the top of the association to the base, although remain highly abundant. While the numbers of *Laevigatosporites haardti* increase downhole from present at the top to abundant at the base. A clear peak in the numbers of bisaccate pollen to greater than 60 in this association is seen. *Tricolpopollenites hians* and *Nyssapollenites kruschi* subsp. *analepticus* are common in this association with the numbers of the latter being relatively lower compared to their numbers in the rest of this section. The top of this association marks the change from rare *Triporopollenites robustus* above to present/common below. The occurrence of *Trivestibulopollenites betuloides* is rare, the top of this association marks the last consistent occurrence of this species. The presence of *Erecipites* spp. and *Gleicheniidites senonicus* is noted.

Comments

Standard deviation and variance increase to a peak at the base of this association. This peak is important as it possibly indicates a transgressive event. The numbers of grains per gram remain relatively constant.

Tops and bases

A number of taxa occur for the last time downhole:

3920ft	base *Tricolporopollenites baculoferus*
	base *Polypodiaceoisporites* spp.
	only occurrence of *Cicatricosisporites* spp.
3880ft	base *Caryapollenites simplex*
	base *Caryapollenites imparalis*
	base *Trilites corruvallatus*

One taxa occurs for the first time downhole in this association:

3880ft	top *Cupuliferoipollenites cingulum* subsp. *fusus* top *Retitricolpites anguloluminosus*

Application to published zonation schemes

The base occurrence of a number of taxa are recorded in this association such as *Caryapollenites imparalis* and *C. simplex*. Wilkinson & Boulter (1980) found the former species to be rare in the British Oligocene.

The base occurrence of *Tricolporopollenites baculoferus* can be correlated to the Late Eocene of Chateauneuf (1980) and to the Oligocene of Wilkinson & Boulter (1980) who record the last occurrence of this species. The top of *Cupuliferoipollenites cingulum* subsp. *fusus* is seen to occur in this association. This taxa has no stratigraphical significance in the literature and has been widely recorded throughout the Tertiary (Wilkinson & Boulter, 1980; Krutzsch, 1966).

INTERPRETED AGE: **Lower Oligocene, Rupelian**

ASSOCIATION D

Characteristic palynological features

A downhole decline in the numbers of *Sequoiapollenites polyformosus* from present to common in and above this association to rare in the association below is seen. *Triporopollenites robustus* is rare within this association and above, but increases in number downhole to common.

The numbers of *Retitricolpites retiformis* changes downhole from rare in and above this association to common in the association below. A change is also noted from present numbers of *Laevigatosporites haardti* in this association and the association up section to common/abundant numbers below from the base of this association. A change downhole from rare *Alnipollenites verus* and rare but constant *Graminidites annulatus* to present *Alnipollenites verus* and less constant rare to single specimens of *Graminidites annulatus* is seen. The taxon *Polyatriopollenites carpinoides, Liquidambarpollenites stigmosus* and *Tricolpopollenites* cf. *hians* reduce in number downhole from present at the top to rare at the base of this association.

The decrease in the numbers of *Momipites coryloides* downhole from present to none is similar to the downhole decrease in *M. tenuipollis*. Single specimens of *Arecipites* spp. are noted in this association along with *Echinosporis* sp. 1, *Trilites multivallatus, Trivestibulopollenites betuloides* and *Gleicheniidites senonicus*. Other rare occurrences include *Deltoidospora maxoides* and *Ilexpollenites iliacus*. The restricted occurrence of *Erecipites* spp. to associations C, D and E in this section and the constant but rare occurrence of *Monocolpopollenites tranquillus* is noted.

An increase in the numbers of *Micrhystridium* spp. from the base of this association upsection is characteristic for this part of the section. Slight increases in number to present in this association are recorded for *Porocolpopollenites vestibulum, Echinosporis echinatus* and *Botryococcus. Nyssapollenites kruschi* subsp. *analepticus* is common in occurrence and bisaccate pollen are abundant in this association and occur with *Piceapollis* spp. and a slight peak of *Sciadopityspollenites serratus.*

Comments

Variance and standard deviation are low and increase downhole while the numbers of palynomorphs per gram decline downhole.

Tops and Bases

A number of taxa have their first downhole occurrences within this association:

3840ft	top *Quercoidites microhenrici*
	top *Microthallites* spp.
3800ft	top *Caryapollenites imparalis*
	top *Cyrillaceaepollenites megaexactus*

One taxa is recorded as occurring for the first time upsection within this association:

3800ft	base *Momipites anellus*

Application to published zonation schemes

The only stratigraphically significant taxa which has its top occurrence in this association is *Quercoidites microhenrici.* This taxa is suggested to have its last occurrence from the Late Oligocene (Chateauneuf, 1980) to the Upper Miocene (Vinken *et al.*, 1988). And the top occurrence of *Cyrillaceaepollenites megaexactus* at this level can be compared to Chateauneuf (1980) who regards this species as having its top occurrence in the Upper Oligocene, whereas Vinken *et al.* (1988) have shown this taxa ranging up into the Pliocene. The top occurrence of *Caryapollenites imparalis* can be compared to Krutzsch (1966) who places the top of this taxa in the Late Oligocene, although Chateauneuf (1980) regards this event to be Upper Oligocene in age and Vinken *et al* (1988) places this event in their sp8 zone which is Upper Oligocene.

INTERPRETED AGE: **lower Upper Oligocene, Lower Chattian**

ASSOCIATION E

Characteristic palynological features

The characteristic features of the association indicate rare specimens of *Alnipollenites verus* and rare but constant *Graminidites annulatus* which changes downhole to present numbers of *Alnipollenites verus* and single specimens to no *Graminidites* being present. The numbers of *Liquidambarpollenites stigmosus* reduce downhole from the base of this association and the numbers of *Polyatriopollenites carpinoides* increase downhole through this association to present. The numbers of *Inaperturopollenites hiatus* decrease downhole through this association. A peak of bisaccates occurs near the top of the association to highly abundant, this corresponds to a reduction in the number of *Sciadopityspollenites serratus* in this association to rare and the peak in the number of *Laevigatosporites haardti* to common, near the top of the association. Other slight peaks of occurrence are noted, *Echinosporis echinatus* peaks near the top of the association. The peak of *Nyssapollenites kruschi* subsp. *analepticus* at the top of this association occurs after the last occurrence of *Nyssapollenites kruschi* subsp. *accessorius* and *Tricolporopollenites edmundi* is seen to peak to present.

The middle of the association sees the numbers of *Sequoiapollenites polyformosus* peaking to common. The numbers of *Momipites coryloides* decrease downhole from common to rare and *Deltoidospora wolffi* from abundant to common with rare *D. apheles* and *D. maxoides* occurring. *Monocolpopollenites tranquillus* increases downhole through this association from single specimens to rare numbers and relatively low numbers of *Retitricolpites retiformis* are seen. The numbers of *Triporopollenites coryloides* are also low compared with the association above and below.

Finally the presence of a number of species are noted, *Tetracolpites reticulatus, Trivestibulopollenites betuloides, Tricolporopollenites pseudocingulum* and *Cicatricosisporites chattensis.* In general the numbers of swamp vegetation and montane taxa decrease downhole in this association due to the reduction in *Inaperturopollenites* and bisaccate pollen recorded.

Comments

The standard deviation and especially variance decrease downhole through this association, the latter reduces from 44 to 22. This decline corresponds to the peak in palynomorphs per gram at this level, to the highest numbers recorded in the section at over 90 000.

Tops and bases

A large number of taxa are recorded for the last time within this association:

3720ft	top *Momipites anellus*
	top *Nyssapollenites kruschi* subsp. *accesorious*

	top *Erecipites* spp.
3640ft	top *Arecipites* spp.
	top *Deltoidospora apheles*
	top *Echinosporis echinatus*
	only occurrence of *Verrucatosporites megabalticus*
	only occurrence of *Corsinipollenites oculusnoctis*
3600ft	top *Fenestrites spinosus*
	top Hyphae spp.
	top *Torosporis* spp.
	top *Echinosporis* sp. 1
	top *Cupuliferoipollenites cingulum* subsp. *pusilus*
	only occurrence of *Caryapollenites triangulus*
	only occurrence of *Corrusporis tuberculatus*
	only occurrence of *Pediastrum*

Application to published zonation schemes

A large number of species with stratigraphical significance are seen to occur for the last time within this association. The spores indicate a relatively narrow age range for this association. *Torosporis* spp. is recorded from the Oligocene of Wilkinson & Boulter (1980) and the Lower/Middle Oligocene of Chateauneuf (1980). *Deltoidospora apheles* is regarded as having its last occurrence in the Middle Oligocene (Chateauneuf, 1980). *Corrusporis tuberculatus* is stratigraphically restricted and its top occurrence correlates to the Upper Oligocene of both Wilkinson & Boulter (1980) and Krutzsch (1967a), the latter postulates that this species is restricted to the brackish marine sediments in Germany. The top of a distinctive species *Verrucatosporites megabalticus* can be correlated to the Late Oligocene of Wilkinson & Boulter (1980) but is seen to range up into the Lower Miocene in Germany (Krutzsch, 1967a). The last occurrence of *Echinosporis echinatus* can also be correlated to the Lower Miocene of Krutzsch (1967a). The only occurrence of *Caryapollenites triangulus* is seen in this association, this species is regarded as having its top occurrence in the Upper Eocene of Chateauneuf (1980) to the Eocene/Oligocene boundary of Vinken *et al.* (1988). While the occurrence of *Corsinipollenites oculusnoctis* in this association is more restricted and is significant as its top occurrence correlates to the Upper Oligocene of Wilkinson & Boulter (1980) and Chateauneuf (1980), upto the Oligocene/Miocene boundary of Pacltova (1960).

INTERPRETED AGE: **Upper Oligocene, Upper Chattian.**

ASSOCIATION F

Characteristic palynological features

This association occurs from 3580 ft to 3600 ft and is represented by only one sample. It is characterised by a peak in *Inaperturopollenites hiatus* at the top of the association to highly abundant which is a maximum for this section. Both *Triporopollenites coryloides* and *Cupuliferoipollenites cingulum* subsp. *oviformis* show increases uphole from the association below into this association. The majority of other taxa decrease uphole into this association. *Nyssapollenites kruschi* subsp. *analepticus* and *Tricolpopollenites hians* decline in number up into this association. *Momipites coryloides* and *M. tenuipollis* also reduce in numbers uphole into this association, with bisaccate pollen and *Sciadopityspollenites serratus* numbers reducing slightly into this association. Spores such as *Deltoidospora wolffi* and *Laevigatosporites haardti* are seen to decline in number uphole into this association, this is especially marked in the former. The presence of *Liquidambarpollenites stigmosus, Graminidites annulatus, Cicatricosisporites paradorogensis* and *Alnipollenites verus* are noted.

Comments

A peak in standard deviation and variance figures are seen in this association, both show maximum value for this section. The numbers of grains per gram reduce uphole into this association to a level of over 75 000.

Tops and bases

The last occurrence of a number of taxa is within this association is seen:

3580ft top *Intratriporopollenites ceciliensis*
top *Favitricolporites microreticulatus*
top *Tricolporopollenites baculoferus*
top *Cicatricosisporites paradorogensis*
top *Trilites* spp.
top *Botryococcus* spp.
only occurrence of *Tricolpopollenites* cf. *discus*

Application to published zonation schemes

The last occurrence of *Favitricolpites microreticulatus* and *Cicatricosisporites paradorogensis* in this association confirm an Oligocene age, Chateauneuf (1980) reports the presence of both of these species upto the Lower Oligocene. Wilkinson & Boulter (1980) regard the presence of *Cicatricosisporites paradorogensis* along with *C. chattensis* indicative of an Upper Oligocene age here. This association represents the topmost Oligocene in the section.

INTERPRETED AGE: **Upper Oligocene, Upper Chattian**

ASSOCIATION G

Characteristic palynological features

A change in floras is noted in this association. The previous dominance of *Inaperturopollenites hiatus* throughout the lower part of the association is seen to decrease in number into this association although remains highly abundant. This also corresponds to a slight uphole reduction in the numbers of bisaccate pollen in this association and an increase in the numbers of *Sciadopityspollenites serratus* to common. Conversely the numbers of *Momipites coryloides, Tricolpopollenites* cf. *hians, Nyssapollenites kruschi* subsp. *analepticus, Triporopollenites coryloides, Cupuliferoipollenites cingulum* subsp. *oviformis* and *Deltoidospora wolffi* increase in number uphole into this association. The presence of *Liquidambarpollenites stigmosus, Polyatriopollenites carpinoides* and *Verrucatosporites favus* are also noted.

Comments

Standard deviation and variance both show decreases into the base of this association with a final increase at the top of the section. While the number of grains per gram increase at the base of this association to over 80 000 and then drop off at the top of the section to less than 60 000.

Tops and bases

A small number of taxa are recorded for the last time uphole within this association:

3500ft	top *Gleicheniidites senonicus*
	only occurrence of *Momipites triradiatus*

Application to published zonation schemes

Both the taxa above are of little stratigraphical value either occurring widely in the Tertiary or not reported in the published literature.

INTERPRETED AGE: **Lower Miocene**

16/16 POLLEN SUMMARY AND CALIBRATION TO THE DINOFLAGELLATE CYST DATA

In the pollen and spore record from this section a number of distinct associations or events can be seen. The Rupelian aged part of the section includes Association A to C. The abundant or characteristic taxa in these associations are *Inaperturopollenites hiatus, Retitricolpites retiformis, Nyssapollenites kruschi* subsp. *analepticus, Laevigatosporites haardti*, bisaccate pollen, *Micrhystridium fragile, Triporopollenites robustus, Arecipites* spp., *Tricolporopollenites edmundi* and *Cicatricosisporites chattensis*. The abundance of these taxa are a feature of Oligocene sediments (Wilkinson & Boulter, 1980). The more specific Rupelian age is confirmed from the presence of other taxa in the samples such as the top occurrence of *Dicolpopollis kockeli, Tricolporopollenites spinus, Sparganiaceaepollenites polygonalis, Pompeckjoidaepollenites subhercynicus* and *Retitricolpites anguloluminosus*. This age is also confirmed from the microplankton data.

The Chattian aged part of the section includes Associations D, E and F. The abundant or characteristic taxa in these associations include *Inaperturopollenites hiatus, Tricolpopollenites hians, T.* cf. *hians, Nyssapollenites kruschi* subsp. *analepticus, Deltoidospora wolffi, Polyatriopollenites carpinoides, Liquidambarpollenites stigmosus, Porocolpopollenites vestibulum, Sciadopityspollenites serratus, Trivestibulopollenites betuloides* and bisaccate pollen. The presence of these taxa indicate Oligocene aged sediments (Wilkinson & Boulter, 1980). Taxa which confirm a more specific Chattian age are the top occurrences of *Quercoidites microhenrici, Cyrillaceaepollenites megaexactus, Corrusporis tuberculatus, Verrucatosporites megabalticus, Corsinipollenites oculusnoctis* and *Echinsporis echinatus* and the presence of *Cicatricosisporites paradorogensis* and *C. chattensis*. This more specific age is corroborated by the microplankton data.

The Miocene aged part of the section includes Association G only. The abundant or characteristic taxa of this association include *Inaperturopollenites hiatus, Momipites coryloides, Tricolpopollenites hians, Nyssapollenites kruschi* subsp. *analepticus*, and increases in the numbers of *Cupuliferoipollenites cingulum* subsp. *oviformis, Triporopollenites coryloides, Trivestibulopollenites betuloides* and *Sciadopityspollenites serratus*. At the Oligocene/Miocene boundary here no great changes in assemblage characteristics is recorded with no first uphole occurrences of specific 'Miocene' taxa. This accounts for the cluster analysis picking out the Oligocene/Miocene boundary (enclosure 3) at a lower level of clustering than the Rupelian/Chattian boundary. The floras do not show as great a difference in assemblage character at the more major boundary of the Oligocene/Miocene when compared to the Rupelian/Chattian boundary. This is expected because this section is marine, therefore the microplankton will be more sensitive than the floral composition of the assemblages in question. The hierarchy of the clustering for the Oligocene/Miocene and Rupelian/Chattian boundaries is picked out in the correct order the cluster analysis dendrogram for the 16/16b-4 microplankton data set (see figure 6.2a).

SECTION 21/28 POLLEN ASSOCIATIONS

ASSOCIATION A

Characteristic palynological features

This association occurs at the base of the section and is described from one sample only. Abundant to highly abundant numbers of *Inaperturopollenites hiatus,* bisaccate pollen and *Nyssapollenites kruschi* subsp. *analepticus* are recorded here. These taxa are regarded as characteristic of Oligocene sediments in the UK (Wilkinson & Boulter, 1980). Although the numbers of usually more common taxa such as *Laevigatosporites haardti* are lower in this association. Other characteristic taxa within this association include relatively low numbers of *Alnipollenites verus* the numbers of which increase upsection and *Tricolpopollenites hians* which increases in numbers upsection to abundant from the top of this association where it is rare. Numbers of *Deltoidospora wolffi* are relatively constant throughout the section although they are the highest in this association and decrease slightly upsection. *Stereisporites (Stereisporites) stereioides* occurs in this association in rare numbers along with other taxa such as *Ilexpollenites iliacus, Retitricolpites anguloluminosus, R. retiformis* and *Polyatriopollenites carpinoides.* While the presence of *Echinosporis echinatus* is noted and the lack of *Graminidites, Cupuliferoipollenites* and *Cupuliferoidaepollenites* species and *Porocolpopollenites vestibulum* is apparent.

Comments

The standard deviation and variance are the highest calculated for the section, the latter being greater than 35. High numbers of grains per gram are also apparent at the top of this association.

Tops and bases

As this association is the base sample in the section no tops or bases are proposed or are recognised here.

Application to published zonation schemes

With the lack of top and base occurrences of taxa it is very difficult to assign an age to this association. Although the association includes dominant *Inaperturopollenites hiatus,* bisaccate pollen and *Nyssapollenites kruschi* subsp. *analepticus* which correlates to the palynological assemblages recovered from the Oligocene sediments of Wilkinson & Boulter (1980).

INTERPRETED AGE: **Lower Oligocene**

ASSOCIATION B

Characteristic palynological features

Abundant taxa within this association include *Inaperturopollenites hiatus* and bisaccate pollen with other important taxa such as *Nyssapollenites kruschi* subsp. *analepticus* declining in number uphole from abundant to common in this association. *Laevigatosporites haardti* is present at the top of this association and increases uphole to common. A peak of the acritarch *Micrhystridium fragile* to present is characteristic of this association. *Retitricolpites retiformis* is seen to increase uphole into this association but is still rare. The abundant occurrence of *Tricolpopollenites hians* is also seen to increase uphole through this association while *T.* cf. *hians* is rare. *Baculatisporites primarius* peaks to rare occurrences in this association and *Stereisporites (Stereisporites) stereioides* reduces in number downhole, from present to rare. *Triporopollenites robustus* is constant but rare in number, other rare taxa include *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis, Cupuliferoipollenites cingulum* subsp. *oviformis, Trilites multivallatus, Alnipollenites verus, Polyatriopollenites carpinoides, Porocolpopollenites vestibulum* and *Echinosporis echinatus.* No *Graminidites annulatus* is recorded in this association.

Tops and bases

A number of apparent first uphole occurrences of taxa are noted to occur within this association:

3210ft	base *Momipites coryloides*
	base *Nyssapollenites kruschi* subsp. *accessorious*
	base *Cupuliferoidaepollenites liblarensis* subsp. *fallax*
	base *Cupuliferoipollenites cingulum* subsp. *oviformis*
	base *Porocolpopollenites vestibulum*
	base *Tricolporopollenites* sp. 1
	base *Trilites multivallatus*
	only occurrence of *Stereisporites* sp.1
	base *Verrucatosporites favus*
	base *Laevigatosporites discordatus*
	base *Piceapollis* spp.
	base *Sciadopityspollenites serratus*

base *Botryococcus* spp.
base *Micrhystridium* spp.

Application to published zonation schemes

A number of 'apparent' base occurrences of taxa are noted from this association. The base occurrence of *Nyssapollenites kruschi* subsp. *accessorious* can be correlated to Association A in 16/16b-4. Although in general as these samples are from original ditch cutting material, the base ranges of taxa are regarded as less useful due to the effects of caving. The dominant taxa present indicate Oligocene aged sediments other species such as *Trilites multivallatus* and *Echinosporis echinatus* also suggest an Oligocene age (Wilkinson & Boulter, 1980).

The base of *Verrucatosporites favus* can be correlated to the Middle Oligocene of Krutzsch (1967a) which it is remembered that caving can result in the presence of such taxa being present further downhole than their ranges suggest, but Chateauneuf (1980) regards this species as extending into the Upper Eocene. The base of taxa such as *Porocolpopollenites vestibulum* and *Sciadopityspollenites serratus* are regarded as having their base occurrence in the Middle and Upper Eocene respectively therefore in this section the full range of the discussed taxa is not present, only localised occurrences of these are seen.

INTERPRETED AGE: **Lower Oligocene**

ASSOCIATION C

Characteristic palynological features

This association shows a similar dominance of taxa to those recognised throughout the section. Highly abundant species include *Inaperturopollenites hiatus* which is seen to reduce slightly uphole through the association. *Tricolpopollenites hians* is abundant but occurs with two peaks within the association. Bisaccate pollen are also abundant in number. Common taxa include *Nyssapollenites kruschi* subsp. *analepticus* and *Deltoidospora wolffi* the numbers of both remain relatively constant throughout this association. *Retitricolpites retiformis* is common near the base of the association and declines in number uphole to rare which is very characteristic. *Stereisporites (Stereisporites) stereioides* occurs in common numbers with peaks in occurrence at the top and base of the association whereas the numbers of *Laevigatosporites haardti* are seen to increase upsection from present to common.

Another important characteristic is the numbers of *Micrhystridium fragile* which are present within this association and the association downsection but are seen to reduce in number up section to rare in the association above. Other taxa noted to occur within the association include single specimens of *Gothanipollis gothanii, Tricolporopollenites spinus* and *Tricolporopollenites viburnoides. Echinosporis echinatus* occurs in rare numbers which increase slightly to the top of the association and *Triporopollenites robustus* which shows a slight peak in numbers in the middle of this association to rare. Only rare occurrences of *Cupuliferoidaepollenites* and *Cupuliferoipollenites* species are recorded in this association, this contrasts to the upper part of the section where higher frequencies and more diversity of these species are recorded. *Alnipollenites verus, Polycolpopollenites carpinoides, Momipites tranquillus, Trilites multivallatus,* Algae sp. 1 and *Graminidites annulatus* occur in rare numbers. The only occurrence of *Tricolporopollenites edmundi* and *Pesavis tagluensis* are also recorded in this association.

Comments

The standard deviation and variance show a reduction in value in the middle of the association and increases both uphole and downhole from here.

Tops and bases

A large number of taxa occur for the last time upsection within this association:

3090ft	only occurrence of *Caryapollenites veripites*
	top *Gothanipollis gothanii*
	only occurrence of *Pesavis tagluensis*
	only occurrence of *Micrhystridium oceanicum*
3150ft	only occurrence of *Favitricolpites microreticulatus*
	top *Tricolporopollenites edmundi*
	only occurrence of *Tricolporopollenites spinus*
	top Algae sp. 1
3180ft	top Hyphae spp.

A large number of taxa occur for the first time upsection within this association:

3150ft	base *Arecipites* spp.
	base *Caryapollenites* spp.
	base *Tricolporopollenites viburnoides*
	base *Deltoidospora apheles*
	base *Graminidites annulatus*
3180ft	base *Momipites tenuipollis*
	base *Nyssapollenites satzveyensis*
	base *Cupuliferoipollenites cingulum* subsp. *pusillus*
	base *Monocolpopollenites tranquillus*
	base *Quercoidites microhenrici*

base *Tricolporopollenites edmundi*
base *Cicatricosisporites chattensis*
base *C. paradorogensis*
base Algae sp. 1
base *Veryhachium* spp.
base *Gothanipollis gothanii*
base *Pluricellaesporites* spp.

Application to published zonation schemes

Despite the large number of first and last occurrences of taxa recorded, only limited correlations to the published literature can be made due to the lack of pollen and spore data published. Restricted taxa such as the top occurrence of *Tricolporopollenites spinus* indicates a Middle Oligocene age when compared to the data of Krutzsch (1962), Wilkinson & Boulter (1980) and Ollivier-Pierre (1980). The top occurrence of *Tricolporopollenites edmundi* is placed in the Upper Eocene by Chateauneuf (1980) upto the Middle Oligocene by Ollivier-Pierre (1980).

The base occurrences of a number of taxa in this association suggest a larger range of ages due to caving. The base of *Gothanipollis gothanii* is placed in the Lower Eocene by Krutzsch (1966) and the base of *Trivestibulopollenites betuloides* is placed ranging from the Middle Eocene of Chateauneuf (1980) to the Lower Oligocene of Ollivier-Pierre (1980). This is a similar range to the base of *Cicatricosisporites paradorogensis* which is placed from the Middle Eocene of Chateauneuf (1980) to the Oligocene of Wilkinson & Boulter (1980).

Graminidites species are still quite rare within the Oligocene (Wilkinson & Boulter, 1980) so the base could be placed here. More precise bases are gained by stratigraphically restricted taxa such as *Cicatricosisporites chattensis* which is limited to the Middle Oligocene (Wilkinson & Boulter, 1980; Krutzsch, 1966).

INTERPRETED AGE: **upper Lower Oligocene, Upper Rupelian**

ASSOCIATION D

Characteristic palynological features

The dominant taxa of this association are *Inaperturopollenites hiatus* and bisaccate pollen. Common abundances of *Nyssapollenites kruschi* subsp. *analepticus, Tricolpopollenites hians* and *Laevigatosporites haardti* occur, the latter is seen to increase in number upsection from the top of this association. A number of marked changes occur at the top of this association. The occurrences of *Alnipollenites verus* are still rare in this association and are seen to increase uphole from here. Rare numbers of *Momipites tenuipollis* occur although this association marks their first consistent occurrence which continues upsection. A marked change upsection from the top of this association in the numbers of *Tricolpopollenites* cf. *hians* occurs and shows an increase from rare to present/rare and a decrease in the numbers of *Tricolpopollenites hians* from abundant below to common within and upsection from this association. The occurrence of *Retitricolpites retiformis* reduces steadily uphole from the top of this association. The top of this association also marks the change in numbers of *Stereisporites (Stereisporites) stereioides* from present to rare upsection.

An important change is seen in the numbers of *Micrhystridium fragile* which reduce uphole from present to single specimens in this association. Other important rare taxa which occur in this association such as *Polyatriopollenites carpinoides, Cyrillaceaepollenites megaexactus, Trivestibulopollenites betuloides, Momipites tenuipollis* and *Verrucingulatisporites treplinensis* are noted.

Comments

The values of standard deviation and variance both show increases to the top of the association then decreases uphole from this into Associations E and F. The numbers of grains per gram increase upsection to the top of this association.

Tops and bases

A number of taxa are recorded to occur for the last time upsection within this association:

3060ft top *Caryapollenites simplex*
top *Momipites annelus*
top *Ilexpollenites margaritatus*
top *Cicatricosisporites paradorogensis*
only occurrence of *Camerzonosporites heskemsis*
only occurrence of *Verrucingulatisporites treplinensis*

A number of taxa are recorded for the first time upsection from this association:

3060ft base *Cyrillaceaepollenites megaexactus*
base *Tricolporopollenites pseudocingulum*
base *Gleicheniidites senonicus*

Application to published literature

The top occurrences of the taxa recorded in this association help to give an idea of the age of this unit. Chateauneuf (1980) and Krutzsch (1966) place the top occurrence of *Caryapollenites simplex* at the top of the Oligocene but Vinken *et al.* (1988) has recorded this species into the Pliocene. The top occurrence of spores such as *Cicatricosisporites paradorogensis* are quite well recognised in the literature being consistently placed in the top most Lower Oligocene by Chateauneuf (1980) and Wilkinson & Boulter (1980) to the Upper Oligocene by Krutzsch (1966). The top occurrence of *Camerozonosporites heskemsis* is regarded by Krutzsch (1963a) as being characteristic of the Lower to Middle Oligocene and by Wilkinson & Boulter (1980) as characteristic of a Middle Oligocene age. Another stratigraphically significant top occurrence is that of *Verrucingulatisporites treplinensis* which is placed in the Upper Oligocene of Wilkinson & Boulter (1980).

The base occurrence of *Gleicheniidites senonicus* in this association has little stratigraphical significance, as it ranges into the Pliocene. Although the base occurrence of *Tricolporopollenites pseudocingulum* recorded from this association suggests a Middle to Upper Oligocene date by Vinken *et al.* (1988). The base occurrence of *Cyrillaceaepollenites megaexactus* is recorded in this association and is indicative of a pre Upper Oligocene age (Vinken *et al.*, 1988) and the rare occurrence of specimens indicate the section has not passed into the Miocene where numbers of this species are seen to increase.

INTERPRETED AGE: **Lower Oligocene, Upper Rupelian**

ASSOCIATION E

Characteristic palynological features

Abundant *Inaperturopollenites hiatus* and bisaccate pollen dominate this association with the former decreasing in numbers uphole to the top of this association. Common taxa include *Nyssapollenites kruschi* subsp. *analepticus* and *Laevigatosporites haardti* which increase slightly in number upsection to the top of this association, while the numbers of *Tricolpopollenites hians* remain relatively constant. *Alnipollenites verus* is present with its numbers showing a slight peak in this association. The numbers of *Tricolpopollenites* cf. *hians* increase upsection from rare to present. The numbers of *Retitricolpites retiformis* reduce upsection to the top of this association and are rare. The rare numbers of *Triporopollenites robustus, Micrhystridium* spp., *Cupuliferoidaepollenites liblarensis* subsp. *fallax* and *Cupuliferoipollenites cingulum* subsp. *oviformis* show a marked increases above the top of this association. While *Stereisporites (Stereisporites) stereioides* numbers continue to reduce upsection to the top of this association and further uphole. Other rare taxa include *Momipites tenuipollis, Monocolpopollenites tranquillus, Porocolpopollenites vestibulum* and *Echinosporis echinatus.*

Comments

The numbers calculated for standard deviation and variance are seen to decrease upsection to the top of the association while the numbers of grains per gram are at their maximum value for the section, at greater than 100 000.

Tops and bases

One species is seen to occur for the only time within this association:

3000ft only occurrence of *Echinatisporis echinoides*

Two taxa are seen to occur for the first time upsection in this association:

3000ft base *Plicatopollis plicata*
base *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis*

Application to published zonation schemes

The top occurrence of *Echinatisporis echinoides* is regarded as characteristic of the Chattian to Oligocene/Miocene boundary (Krutzsch, 1963b) also Wilkinson & Boulter (1980) record this species as being restricted to the Chattian. The base occurrence of *Plicatopollis plicata* is placed much lower in the section than recorded here by Krutzsch (1967c) and Ollivier-Pierre (1980) in the Eocene. Therefore the only localised range of this taxa is being picked up here.

INTERPRETED AGE: **Upper Oligocene, Lower Chattian**

ASSOCIATION F

Characteristic palynological features

Inaperturopollenites hiatus and bisaccate pollen both occur in abundant numbers within this association. The numbers of *Nyssapollenites kruschi* subsp. *analepticus* increase upsection from common to abundant at the top of this association. *Laevigatosporites haardti* and *Tricolpopollenites hians* occur in common numbers, at the base of this association a slight peak to common in the number of *Tricolpopollenites* cf. *hians* occurs. From the base of this association *Triporopollenites robustus* increases in numbers from rare to present and *Deltoidospora wolffi* reduces upsection from present to rare, this reduction continues into the associations upsection from here. *Sciadopityspollenites serratus* is present and peaks slightly in this association.

The numbers of *Momipites tenuipollis* and *Polyatriopollenites carpinoides* increase slightly to the top of this association but are rare. *Triporopollenites coryloides* and *Stereisporites (Stereisporites) stereioides* reduce in number into this association and continue reducing in number into Association G. A characteristic change is noted with the occurrence of *Cupuliferoidaepollenites* and *Cupuliferoipollenites* species which are rare but constant compared to the patchy occurrences of these taxa downhole. Also characteristically the numbers of *Micrhystridium* spp. increase and *Micrhystridium fragile* decrease upsection although are rare. All *Verrucatosporites* species found are present within this association but are rare in number. Other important taxa include *Tetracolpites reticulatus, Porocolpopollenites vestibulum, Retitricolpites anguloluminosus* and *Echinosporis echinatus,* these occur in rare numbers in this association.

Comments

In this association the lowest values of standard deviation and variance occur and then increase slightly upsection. The numbers of grains per gram reduce upsection from a maximum at the top of Association E.

Tops and bases

A large number of taxa are noted to occur for the last time upsection in this association:

2970ft	only occurrence of *Fenestrites spinosus*
	top *Lycopodiumsporites* spp.
	only occurrence of *Microfoveolatosporis pseudodentatus*
	top *Verrucatosporites alienus*
	only occurrence of *Verrucatosporites histiopteroides*
	top *Botryococcus* spp.
	top *Veryhachium* spp.
2940ft	only occurrence of *Caryapollenites circulus*
	only occurrence of *Momipites* spp.
	top *Intratriporopollenites microreticulatus*
	only occurrence of *Tetracolpites reticulatus*
	only occurrence of *Cupuliferoipollenites cingulum* subsp. *fusus*
	top *Quercoidites microhenrici*
	top *Deltoidospora maxoides*
	top *Gleicheniidites senonicus*
	top *Baculatisporites nanus*
	top *Verrucatosporites balticus*

One species is noted to occurs for the first time upsection in this association:

2970ft	base *Torosporis* spp.

Application to published zonation schemes

Despite the large number of top occurrences of taxa seen to occur within this association only a few are shown to have any stratigraphical significance when compared to the published literature. The top occurrence of spores such as *Verrucatosporites balticus* can be correlated with Chateauneuf (1980) and Krutzsch (1967a) who both regard this event as being in the Chattian, Upper Oligocene. At the same time the top occurrence of *Verrucatosporites alienus* is placed in the Oligocene by Wilkinson & Boulter (1980) but up into the Lower Miocene of Krutzsch (1967a). Some indication of age can be interpreted from certain pollen taxa. The top occurrence of *Intratriporopollenites microreticulatus* has been placed in the Oligocene by Wilkinson & Boulter (1980). The Upper Miocene is regarded as the top occurrence of *Quercoidites microhenrici* by Vinken *et al.* (1988) which is much higher ranging than seen here but is placed in the Upper Oligocene of Chateauneuf (1980). The top occurrence of *Cupuliferoipollenites cingulum* subsp. *fusus* also has a range of suggested ages. It is placed in the Lower Miocene by Vinken *et al.* (1988) whereas Chateauneuf (1980) places this event in the Upper Oligocene. Importantly the only occurrence of *Fenestrites spinosus* occurs in this association. This is regarded as a Miocene pollen species by Van De Hammen (1956). Caving could account for the presence of this species in the Upper Oligocene, or its presence here could represent the range of the taxa, being extended to an older age than is currently reported in the literature.

The only occurrence of *Tetracolpites reticulatus* in this section occurs within this association. This species has only been recorded from the Cretaceous of N. America (Srivastava, 1966).

INTERPRETED AGE: **Upper Oligocene, Chattian**

ASSOCIATION G

Characteristic palynological features

The abundant numbers of *Inaperturopollenites hiatus* and bisaccate pollen show increases up section into this association and *Nyssapollenites kruschi* subsp. *analepticus* numbers reduce upsection from abundant in Association F to common in this association. *Tricolpopollenites hians* increases in number upsection from 9 to 15 in this association and the numbers of *Laevigatosporites haardti* are common but reduce slightly towards the top of the association. Slight peaks in the numbers of *Alnipollenites verus* and *Triporopollenites robustus* from rare to present are seen in this association and a peak in *Momipites coryloides* from none to present is noted. The numbers of *Inaperturopollenites distichiforme* increase to present upsection into the base of this association. Numbers of *Deltoidospora wolffi* reduce upsection from present to rare and the numbers of *Micrhystridium* spp. are present, only rare numbers of *Micrhystridium fragile* occur. *Polyatriopollenites carpinoides* is rare in number but peaks slightly at the base of the association then reduces in number again to the top of the section. Other important rare taxa occurring here are *Echitricolporites spinosus, Tricolporopollenites pseudocingulum, Trilites multivallatus* and *Echinosporis echinatus* with single specimens of *Porocolpopollenites vestibulum* occurring.

Comments

Standard deviation and variance show values increasing into this association form Association F and then reducing upsection to the top of this association, while the converse is seen in the numbers of grains per gram which reduce into the base of this association then increase towards the top of the section.

Tops and bases

A number of taxa are recorded for the last time upsection in this association:

2910ft top *Caryapollenites* spp.
top *Sequoiapollenites polyformosus*
top *Arecipites* spp.
top *Monocolpopollenites tranquillus*
top *Retitricolpites anguloluminosus*
top *Cicatricosisporites chattensis*
top *Tricolporopollenites viburnoides*
top *Echinosporis echinatus*
only occurrence of *Echitricolporites spinosus*
only occurrence of *Dicolpopollis kockeli*

Only one taxa occurs for the first time upsection within this association:

2910ft base *Microfoveolatosporites* spp.

Application to published zonation schemes

The number of top occurrences of taxa within this association enable comparisons to be drawn from other work within the literature. Species such as *Sequoiapollenites polyformosus* are recorded upto the Pliocene by Krutzsch (1971) therefore this top occurrence here can be regarded as a localised event. The top occurrence of *Retitricolpites anguloluminosus* is regarded as Eocene in age by Ollivier-Pierre (1980). Similarly the top occurrence of *Tricolporopollenites viburnoides* is documented as Eocene by Gruas-Cavagnetto (1978) therefore their ranges can be extended up section into the Chattian, Upper Oligocene in the British Isles. Krutzsch (1970) regards the top occurrence of *Monocolpopollenites tranquillus* seen here as

Miocene. The top occurrence of *Dicolpopollis kockeli* is placed in the Lower Oligocene of Chateauneuf (1980) and Wilkinson & Boulter (1980) but up into the Miocene by Krutzsch (1970).

The spores also seem to indicate some level of stratigraphical significance. Here the topmost occurrence of *Echinosporis echinatus* correlates to the Miocene of Krutzsch (1967c) whereas the top occurrence of *Cicatricosisporites chattensis* correlates to the Middle to Upper Oligocene of both Krutzsch (1967c) and Wilkinson & Boulter (1980) which is very significant. *Echitricolporites spinosus* has its only recorded occurrence in this association and is generally thought of as a Miocene taxa but is possibly caved or has an extended range into the Upper Chattian here.

INTERPRETED AGE: **Upper Oligocene, Upper Chattian**

21/28 POLLEN AND SPORE SUMMARY AND CALIBRATION TO THE DINOFLAGELLATE CYST DATA

Overall the pollen and spore records from this section indicate a number of distinct events. The Rupelian aged part of the section includes Associations A to D. The abundant and characteristic taxa in these units are *Inaperturopollenites hiatus, Tricolpopollenites hians, Nyssapollenites kruschi* subsp. *analepticus, Laevigatosporites haardti* and bisaccate pollen. The presence and abundances of these taxa are a feature of Oligocene sediments (Wilkinson & Boulter, 1980). A more specific Rupelian age is indicated by the presence of other taxa such as *Tricolporopollenites spinus, Cicatricosisporites chattensis, Camerozonosporites haskemsis* and greater relative numbers of *Retitricolpites retiformis, Stereisporites (Stereisporites) stereoides, Micrhystridium fragile* and *Porocolpopollenites vestibulum.* This Rupelian age is confirmed by the dinoflagellate cyst data.

The Chattian aged part of the section includes Associations E to G. The abundances or characteristic taxa of these associations include *Inaperturopollenites hiatus, Alnipollenites verus, Nyssapollenites kruschi* subsp. *analepticus, Momipites tenuipollis, Tricolpopollenites* cf. *hians, Triporopollenites robustus, Polyatriopollenites carpinoides, Sciadopityspollenites serratus, Micrhystridium* spp. and bisaccate pollen indicating Oligocene aged sediments (Wilkinson & Boulter, 1980). Taxa which confirm the more specific Chattian age is the top occurrence of *Verrucatosporites balticus, Verrucatosporites alienus* and *Echinosporis echinatus.* This Chattian age is also confirmed by data from the microplankton section.

COMPARISON OF THE NORTH SEA POLLEN AND SPORE SECTIONS

Correlatable Events

The comparison of the dinoflagellate cyst data from the North Sea well sections indicated a number of correlative levels. These have been picked out using both top and base occurrences of taxa along with association characteristics, as multi event picks.

The pollen and spore data for each sections is extensive but does not allow the same level of clarity for correlation as shown by the dinoflagellate results because the sections in question are marine therefore any changes and events will be more clearly picked up by the dinoflagellate floras with the terrestrial floras forming a background overprint. However pollen and spore characteristics are more discretely indicated and such events can be recognised from the data. The pollen and spore events here are also more representative of general climatic conditions rather than localised vegetation events as the transportation of the grains leads to a mixing of the floras.

The most distinctive correlative level displayed by the data is the top of Association B in 16/16 with the top of Association D in 21/28, this corresponds to the top of the proposed MII unit (figure 6.4). At this level the numbers of *Micrhystridium fragile* characteristically reduce upsection from present to rare. Other trends noted include a slight increase uphole in the numbers of *Alnipollenites verus* and *Sciadopityspollenites serratus*. The diagnostic reduction in numbers of *Retitricolpites retiformis* uphole from common/present to rare is especially important. Also a slight peak in the numbers of *Tricolporopollenites edmundi* in Association B of 16/16 and Association C of 21/28 (MII unit) is recognised and thought to be characteristic also.

The next clear correlative level is the top of Association E in 16/16 and the top of Association G in 21/28, this corresponds to the top of the MV unit (figure 6.4). This correlation is based on the top occurrence of the key taxa *Echinosporis echinatus* which occurs at this level in both of the sections. Downsection from the top of this unit is characterised by a relative peak in the numbers of *Polyatriopollenites carpinoides* and *Momipites coryloides.*

The top of Association D in 16/16 can be tentatively correlated to the top of Association E in 21/28 and both correspond to the top of the MIV unit (figure 6.4). This level is characterised by the initiation of the uphole increase in numbers of *Micrhystridium* spp. and *Tricolpopollenites* cf. *hians.* Also at this level in both sections *Gleicheniidites senonicus* occurs in rare numbers compared to the rest of the sections where generally only sporadic occurrences are recorded.

A tentative correlation of Association A in 16/16 to Association A and B in 21/28, the MI unit, is indicated by the base occurrence of *Nyssapollenites kruschi* subsp. *accessorius* in this unit.

PALAEOENVIRONMENTAL CONCLUSIONS FROM THE MARINE MICROPLANKTON, POLLEN AND SPORE SECTIONS

Introduction

Indicators of palaeoenvironment can be gathered form numerous lines of evidence such as sedimentology, statistical tests and the individual species themselves. The distribution of modern dinoflagellate cyst populations are controlled by water masses and surface climatic conditions (Wall *et al.*, 1977). Therefore by closely studying the composition of the dinoflagellate assemblages, palaeoenvironmental conditions can be deciphered. This involves both inferences of dinoflagellate cyst affinities to modern groups and sedimentary conditions. In general, the majority of palynomorph assemblages have undergone transportation before deposition and thanetocoenesis. Speculation involved in relating fossil dinoflagellate cysts to modern groups has resulted in relatively few workers theorising as to the environmental preferences of different taxa.

The statistical procedures carried out on each data set for the two North Sea sections can also give an indication of palaeoenvironmental conditions (see Chapter 5). Standard deviation and variance in essence show the same trends in the data, although the variance values give a much clearer picture and are therefore easier to use. The general trends of the variance results are used here with additional information from sedimentology and the actual dinoflagellate cysts themselves to suggest palaeoenvironmental conditions. It is important to remember here that the variance values from the marine microplankton data must be interpreted differently to the variance values from the marine pollen and spore data (for discussion see Chapter 5).

16/16: PALAEOENVIRONMENTAL CONCLUSIONS

In this section the most direct suggestion of palaeoenvironments comes from the microplankton taxa. Some degree of transportation and sorting (thanetoconesis) will effect the assemblages and facies control can effect the composition of the assemblage. However the environmental preferences of certain taxa can be established and such preferences have been suggested in the literature, often by work comparing fossil species to modern species and distributions.

The section has previously been divided into 3 units which are thought to represent the Rupelian, Chattian and the Miocene. A number of environmentally important taxa have been recognised in the Rupelian part of the section. *Cordosphaeridium cantharellum* occurs in higher numbers here compared with upsection this is thought to be a characteristic species of open marine shelf environments (Liengjarern *et al.*, 1980 and Islam, 1983). Islam (1983) stresses the length of spines in *Homotryblium* species is a reflection of environmental conditions. Here *Homotryblium* *tenuispinosum* occurs in greater numbers in the Rupelian part of the section again indicating an open marine environment. Moreover the greater numbers of *Spiniferites ramosus* subsp. *ramosus* in the Rupelian are thought to indicate a general open marine neritic environment (Brinkhuis, 1994).

Upsection into the Chattian/Miocene aged sediments *Operculodinium* species are seen to occur in much greater numbers. These are thought to be characteristic of more restricted marine environments i.e. shallower waters or shelf slope conditions (Brinkhuis, 1994; Islam, 1983). Furthermore Wall & Dale (1973) regarded *Operculodinium* species as being euryhaline, withstanding low salinitys, which are characteristic of such restricted marine environments. Importantly *Lingulodinium machaerophorum* occurs in greater numbers in this top part of the section, this species is also characteristic of shallower brackish inner shelf, more restricted marine environments (Islam, 1983; Harland, 1983). The shorter spined form of *Homotryblium, H. floripes* which peaks near the top Chattian is also characteristic of brackish inner shelf environments as are *Cyclopsiella* species (Chateauneuf, 1980; Brinkhuis, 1994). In general the palaeoenvironmental picture suggested by the individual microplankton species indicates deeper water conditions in the Rupelian this changes markedly at the base of the Chattian to shallower water conditions which continue up to the top of the studied section.

The diversity of taxa in the section also reflects these findings. As a general rule, greatest diversity in microplankton sections occurs in deeper water, outer neritic environments, where environmental conditions and light conditions enable a large number of taxa to thrive. Both inshore and out towards deep marine, oceanic environments diversity is seen to drop off because in these stressed environments only a few tolerant species predominate. In this section the average diversity of the Rupelian is slightly greater than the average diversity of the Chattian and Miocene indicating the Chattian to be shallower than the Rupelian. It should be noted that this general reduction in sea level or shallowing at the Rupelian/Chattian boundary is similar to the reduction in relative sea levels recorded in the work of Haq *et al.* (1987) on eustatic sea level changes (figure 6.5).

Superimposed over the general change from deeper to shallower water conditions upsection are a number of local transgressive events, these are indicated by the variance results for the sections. The Rupelian aged part of the section shows increasing variance upsection with a significant increase near the top. This variance spike occurs in the M III Unit and is not interpreted as an indication of proximity i.e. near shore stressed environments, which result in higher numbers of a few tolerant species but is interpreted as a local transgressive event (T1, figure 6.6) where low salinities occur due to water stratification in deeper waters. Here it is possible to get one tolerant taxon becoming dominant. This is confirmed by looking at the favoured environments of the dominant taxa in question, in this case *Areoligera semicirculata*.

Brinkhuis (1994) suggests this taxa is indicative of marginal marine settings and Islam (1983) suggests this taxa predominates in turbid open marine low salinity environments. Also at this level a distinct increase in the numbers of peridinioid cysts is recorded. This group of cysts in general are characteristic of increasingly stressed environments (Harland, 1983). This transgressive event is also corroborated from the sedimentology which shows a discrete coarsening up sequence of claystones to siltstones over this interval.

Upsection into the Chattian part of the sequence the variance declines and is followed by a significant increase, to a peak variance, near the top of Association E which then declines again to the top of the Chattian. This trend represents a slight local increase in distal deposition followed by a low salinity open marine environment. The peak variance (T2) results from a peak in the taxon *Homotryblium floripes* which Brinkhuis (1994) and Islam (1983) suggest is characteristic of restricted and open marine environments respectively. This restricted transgressive environment is also indicated by the abundance of *Lingulodinium machaerophorum* in these associations.

The variance from the pollen and spore data from this marine section gives a clear but different story. Overall two local trends or cycles are apparent from the variance results. The variance is seen to increase upsection through the Rupelian to a significant peak near the top of the Rupelian in the section. This peak represents a distinct dominance, which is a result of increasing distance from the source resulting in fewer pollen and spores being able to be transported the longer distances. This can be interpreted as a local transgressive effect with deep water resulting from increases in local sea levels (T1). This is followed by a reduction in variance thought to indicate a falling sea level and probably implies a break in section here or a sequence boundary (characterised by a change from deep to shallow water in sequence stratigraphy, 3rd order). This correlates to the level of the Rupelian/Chattian boundary previously defined on biostratigraphical and cluster analysis methods. Upsection into the Chattian aged part of the section variance increases indicating an increase in local sea levels. The peak variance at the top of the Chattian again marks a local transgressive event or deepening (T2). The base of Association G shows reducing sea level as indicated by the reducing variance, this shallowing again marks the sequence boundary that corresponds to the previously defined Oligocene/Miocene boundary.

The palynomorphs per gram data at first appears to show a rather back to front and confusing picture. For the marine part of the study the palynomorphs per gram data is composed of both the pollen, spores and microplankton numbers per gram, in the case of both of the marine sections it is the pollen and spore numbers that make up the majority of the total figure. Once this has been established the data can be interpreted easily. It is possible to use this data to indicate water depths i.e. the greater the numbers of pollen and spores (palynomorphs per gram) is indicative of a closer proximity to the shore line, because larger numbers of these can be transported over the shorter distances. But with increasing distance from the shore, fewer floral palynomorphs can be transported over the longer distances therefore the numbers per gram will be lower. In this case the low numbers per gram indicate deeper water at the base of the section which is Rupelian in age. This changes upsection from the Rupelian/Chattian boundary to shallower water conditions indicated by substantially higher numbers per gram.

21/28: PALAEOENVIRONMENTAL CONCLUSIONS

A similar change in conditions to those recorded from 16/16 are also indicated from the data in this section. Deeper water is seen in the lower, Rupelian part of the section which is followed by shallower water conditions upsection into the Chattian aged part.

The stratigraphical depth at which the sea level changes is coincident with the break in section marked by an unconformity. This reduction in sea level corresponds to a sequence boundary which marks the change from Rupelian to Chattian aged sediments previously defined.

The Rupelian aged associations have greater numbers of taxa which predominate in outer nertic, open marine environments. Islam (1983) suggests the greater numbers of *Homotryblium tenuispinosum* here are characteristic of such environments and *Spiniferites pseudofurcatus* recorded here is suggested by Brinkhuis (1994) to be characteristic of marginal marine settings with *Spiniferites ramosus* subsp. *ramosus* also an outer neritic, open marine indicator (Wall *et al.*, 1977; Brinkhuis, 1994; Harland, 1983).

While upsection in the Chattian aged associations, a shallower environment is indicated by the presence of a number of environmentally significant taxa which occur in greater numbers than seen elsewhere in the section. The presence of *Homotryblium floripes* in greater numbers in this part of the section is thought to represent near shore, inner shelf environments (Islam, 1983). Also the presence of *Operculodinium* species here in greater numbers is indicative of restricted/marginal marine environments (Islam, 1983; Wall *et al.*, 1977; Brinkhuis, 1994). *Cyclopsiella* species occur in slightly greater numbers in this part of the section and their presence is regarded as characteristic of near shore, inner neritic environments (Brinkhuis, 1994). *Areoligera semicirculata* has also been described as characteristic of marginal marine and inner neritic environments by Brinkhuis (1994) and occurs in greater numbers in the upper part of the section.

Diversity can also be interpreted as a reflection of palaeoenvironments, in the microplankton section it is greatest in the deeper water (Rupelian aged) part of the section reaching to a value over 60 compared with a lower diversity recorded in the shallower water (Chattian aged) part of the section where this value falls to about 40. This reduction in sea level results in the reduction of the diversity figures here.

The palaeoenvironmental interpretation of deeper water followed by a shallowing upsection into the Chattian corresponds closely to the results discussed for the 16/16b-4 section. This similarity would be expected due to the relative close proximity in location of the two sections studied within the North Sea Basin (figure 3.11).

Superimposed over this deep to shallow sea level sequence are a number of localised transgressive events. These can be interpreted from the variance data from the microplankton marine section. At the base of the Rupelian sequence variance shows two onlapping sequences. Near to the top of the Rupelian in the section (M II) a relatively small transgressive event is recognised by the peak in variance, (T1a, figure 6.6). This does not correspond to T1 as this occurs in the M III unit. The presence of the transgressive event T1a can also be inferred from the 16/16b-4 pollen and dinoflagellate variance figures which have a discrete increase at a comparable level to that seen in the 21/28b-7 section in the M II Unit. A shallowing is represented by a reduction in variance at the top of the Rupelian implying a sequence boundary at this level. This corresponds to the previously defined Rupelian/Chattian boundary and the unconformity in the sedimentary log at this level.

In the Chattian part of the section two small onlapping sequences can be recognised from the variance with a relative shallowing between the two. Close to the top of the Chattian a localised transgressive event is recorded, (T2, figure 6.6) in the MV Unit. This is followed by a reduction in variance indicating a shallowing up to the top of the section studied. This shallowing could represent a sequence boundary marking the Oligocene/Miocene boundary just uphole from the top of the section studied. Both transgressive events are marked by an increase in numbers of peridinioid cysts present. Harland (1983) and Davies, Bujak & Williams (1982) suggest these cysts types predominate or favour stressed low salinity environments.

The variance results from the pollen and spore data from this marine section give a clear picture. Two peaks in variance can be seen one at the top of the Rupelian and one near the top of the Chattian, both represent a relative deepening of water or a transgressive phase. These transgressive phases are preceded by environmental conditions of shallower water.

The magnitude of the variance figures, that indicate the transgressive events, are in the order of two fold lower in the 21/28b-7 section when compared to the 16/16b-4 section. This could possibly suggest a more proximal setting for the 21/28b-7 section in the basin resulting in a lesser influence of the transgression here.

The palynomorph per gram data again as in the 16/16b-4 section, shows lower figures in the Rupelian part of the section and higher figures in the Chattian part of the section with a peak in Association E to over 120 000 grains per gram, this again illustrates shallower water conditions prevailing upsection from deeper water conditions below.

ABSOLUTE DATING OF EVENTS IN THE MARINE SECTIONS

The relative dating of these two marine sections has been fully discussed earlier in this Chapter and graphically illustrated in figure 6.4. With the aid of both palaeoenvironmental interpretations and the relative dating that has been proposed for these two marine sections comparisons to the work of Haq *et al.* (1987) has been possible and has enabled the absolute age dating of the two sections studied here to be determined.

Haq *et al.* (1987) proposed a series of eustatic sea level changes and coastal on-lap curves constrained using detailed magnetostratigraphy and biostratigraphy. For the Oligocene time period a marked decline in sea level at the Rupelian/Chattian boundary is described. This is very important as it correlates to the interpreted sea level fall described from sections in this current study. In this study the fall in sea level has been based on the preferred environments of certain microplanktonic taxa along with variance, diversity and grains per gram data from the sections. Haq *et al.* (1987) postulated a date of 30Ma for this fall in sea level event, this corresponds to a date of 28.28Ma on the updated Cande & Kent (1995) timescale (figure 6.5). The Oligocene/Miocene boundary placed at 25.5Ma by Haq *et al.* (1987) is suggested to represent an age of 24.23Ma by Cande & Kent (1995). Following this, a number of other correlative events occurring between the two sections can also be compared to Haq *et al* (1987) and can give absolute dates (figure 6.6).

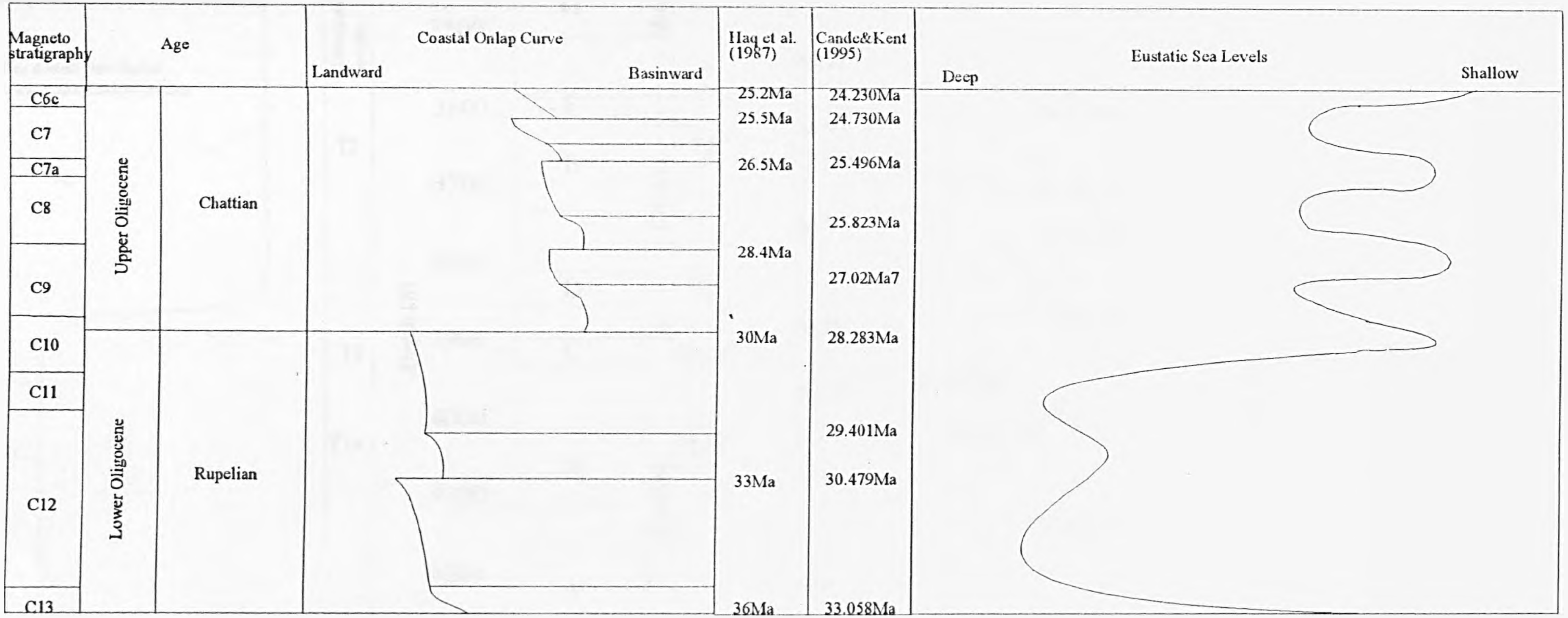


Figure 6.5 Diagram showing the eustatic sea level and onlap curves of Haq et al. (1987) with the comparative ages of Haq et al. (1987) and Cande & Kent (1995).

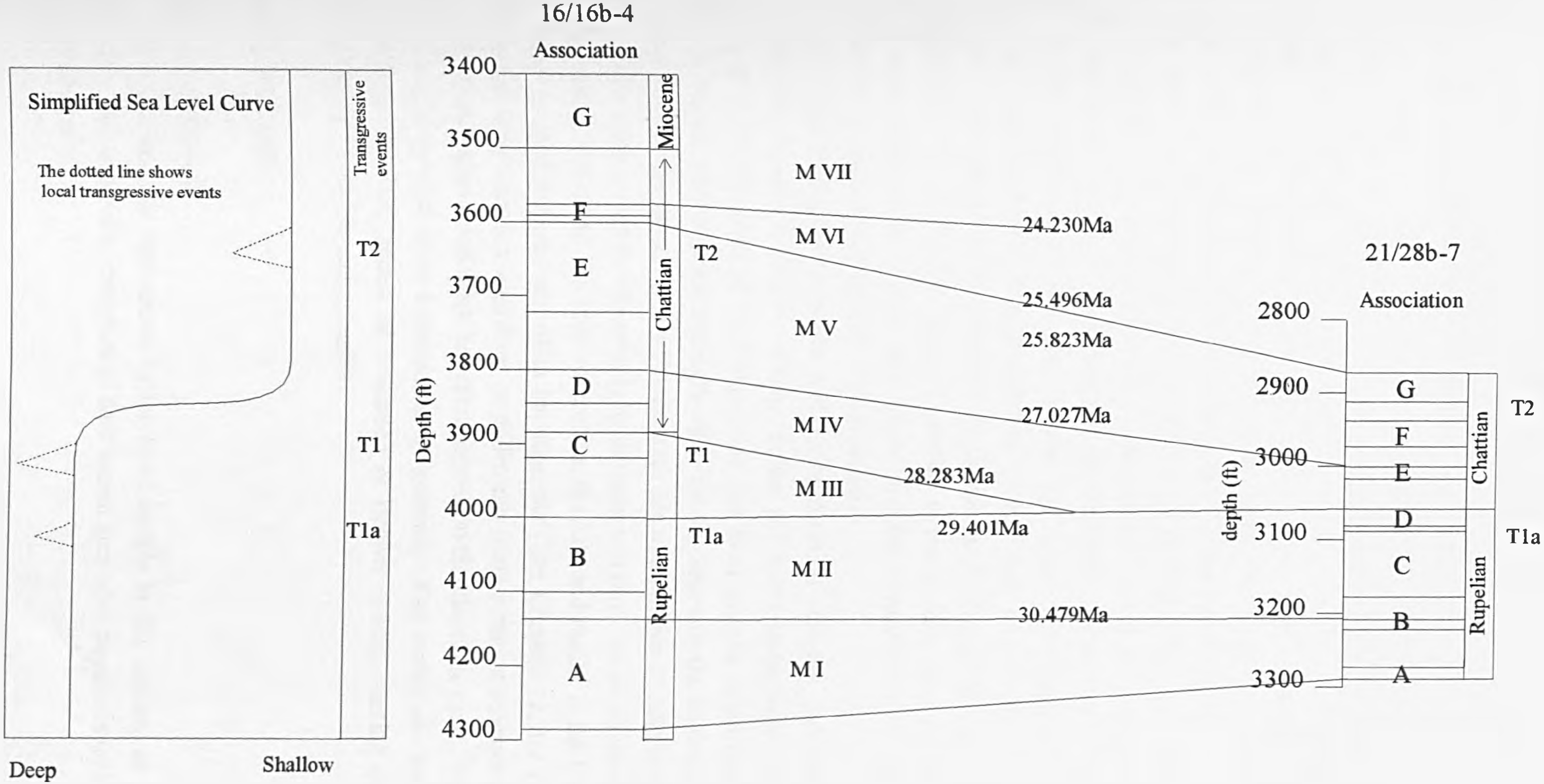


Figure 6.6 Schematic diagram showing the correlation between the two North Sea marine sections 16/16b-4 and 21/28b-7 with Absolute dates derived for these correlative events indicated. Also a simplified sea level curve estimated for the time of deposition of the sediments is shown (three local transgressive events are labled).

CHAPTER 7

TERRESTRIAL PALYNOLSTRATIGRAPHY

The data and results from the terrestrial sections (enclosure 5 to 10), sampled from a number of Tertiary basins from the British Isles are discussed in the following section. The samples taken from the sections were all core material. Such cored samples are not affected by the problems of caving that were encountered with the ditch cutting samples from the marine sections 16/16b-4 and 21/28b-7.

For each section a number of associations are defined. For each association the characteristic palynological features are described and the top and base occurrences of taxa are listed. It must be noted here that the associations described for the terrestrial palynostratigraphical section are 'bottom up' (first stratigraphical occurrence) associations which are slightly different to the 'top down' (last stratigraphical occurrence) associations described for the marine palynostratigraphical sections. This difference is due to the core material sampled in the former. Discussion of the top and base occurrences of taxa and where possible comparisons to the published literature are discussed at the end of each section.

The literature regarding pollen and spore zonation schemes and top and base occurrences of taxa is limited. Firstly, pollen and spore assemblages are generally thought to be indicators of local vegetation and local climatic conditions, therefore having limited stratigraphical value (Boulter, 1986). Secondly the literature regarding Tertiary pollen and spores is in a chaotic state due to a number of different taxonomic approaches being used simultaneously by different workers. As no consistent method of systematic taxonomy has been adhered to, the data and results in the literature are difficult to interpret, and are often incompatible (See Chapter 12, for discussion). Moreover little work has been done on pollen and spore zonation schemes as the bulk of such biostratigraphical work has concentrated on dinoflagellate cysts. Furthermore studies of pollen and spore assemblages are generally of an inadequate level of detail needed i.e. the form genera of Wilkinson & Boulter (1980), making only limited comparisons to the literature possible.

SECTION 80/14

ASSOCIATION A

This association is represented by the basal sample in this section, at a depth of 78.93m. This interval is composed of dark brown grey silty claystones which are very carbonaceous.

Characteristic Palynological Features

This association is characterised by abundant numbers of *Inaperturopollenites hiatus, Alnipollenites verus* and *Retitricolpites retiformis* all of which decrease in number upsection from the base of this association. A number of taxa occurring in present numbers also decrease uphole these include *Tricolpopollenites hians, T.* cf. *hians* and *Monocolpopollenites tranquillus.* While *Laevigatosporites haardti* is present, it shows increasing numbers uphole from the top of this association. *Nyssapollenites kruschi* subsp. *analepticus* also occurs in present numbers and constant common numbers of reworked *Classopollis* pollen are recorded. In this association several taxa are seen to reduce in number to rare/absent levels such as *Tricolporopollenites pseudocingulum, Deltoidospora wolffi, Verrucatosporites favus, Microfoveolatisporis tuemmlitzensis, Microfoveolatosporis pseudodentatus* and bisaccate pollen. A single specimen of *Intratriporopollenites microreticulatus* occurs in this association along with rare numbers of *Echinosporis echinatus* and *Echinosporis* sp. 1.

Comments

The sample representing this association is anomalous in its peak numbers of palynomorphs per gram of over 3 750 000 compared to the much lower average of 1 140 558 for the section. Although the diversity of species is more consistent at about 51.

Tops and Bases

As this association is composed of one sample only, the basal sample of the section, it is difficult to identify any accurate base occurrences of taxa. Although an number of taxa appear for the only time in the section within this association:

78.93m	only occurrence of *Ulmipollenites undulosus*
	only occurrence of *Trilites corruvallatus*
	only occurrence of *Veryhacium* spp.

ASSOCIATION B

This association is represented by only one sample and occurs at a depth of 77.96m. This interval is composed of relatively pale grey claystones which contain lignite and quartz fragments.

Characteristic palynological features

This association is dominated by abundances of *Laevigatosporites haardti* which increase from present in the association below to abundant up into this association.

Other common taxa include *Inaperturopollenites hiatus* and *Verrucatosporites favus* both of which reduce in number upsection from this association and *Retitricolpites retiformis* which is seen to increase in number into Association C. Taxa occurring in present numbers include bisaccate pollen, *Nyssapollenites kruschi* subsp. *analepticus, Tricolporopollenites pseudocingulum* and *Retitricolpites anguloluminosus.* While rare taxa such as *Polyatriopollenites carpinoides, Alnipollenites verus, Tricolpopollenites hians* and *T.* cf. *hians* are recorded and they increase in number upsection from this association. Other rare taxa to note include *Echinosporis echinatus, Trilites multivallatus, Quercoidites microhenrici, Porocolpopollenites vestibulum, Trivestibulopollenites betuloiodes, Cupuliferoidaepollenites* species and *Cupuliferoipollenites* species.

Tops and Bases

Although no last uphole occurrences of taxa can be recognised in this association because it is so close to the base of the section studied , a number of taxa are recorded which have their only occurrence in the section, within this association:

77.96m	only occurrence of *Tricolporopollenites* sp. 1
	only occurrence of *Corrusporis granotuberculatus*

A number of taxa occur for the first time uphole within this association:

77.96m	base *Dicolpopollis kockeli*
	base *Gleicheniidites senonicus*
	base *Verrucatosporites histiopteroides*
	base *V. alienus*

ASSOCIATION C

This association occurs in the interval from 77.0m to 74.47m. This interval is composed of predominantly grey claystones below a thin coarse grained sandy layer (at 74.10 to 74.14m) which has green chlorite crystals visible. A thin grey grit layer with subrounded feldspars (plagioclase) and quartz fragments less than 5 μm in size, in a clay matrix occurs from 75.22 to 75.44m. The grey claystone which dominate throughout this section is very clayey with slickensides or listric structures and black lignitic and quartz fragments. The coarse grained sandy layer is important as it probably represents a break in section.

Characteristic Palynological Features

Laevigatosporites haardti and *Retitricolpites retiformis* occur abundantly in this association, the former increasing in number towards the top of the association and the latter reducing slightly in number towards the top of this association.

Inaperturopollenites hiatus increases from common to abundant at the top of this association. The numbers of *Alnipollenites verus* decrease upsection from common to present.

Nyssapollenites kruschi subsp. *analepticus* is present in this association and its numbers reduce upsection to the top of this association. *Triporopollenites pseudocingulum, Tricolpopollenites hians* and *T.* cf. *hians* reduce in number upsection from present to rare, while *Porocolpopollenites vestibulum* increases in number from the base of this association. A slight peak to present in the number of *Corrusporis tuberculatus* is noted near the top of this association. Other taxa occurring in present numbers include *Verrucatosporites favus* and *Ovoidites* spp. Present to rare occurrences of *Polyatriopollenites carpinoides* show increasing numbers into the next association upsection, Association D. A large number of taxa occur in rare numbers, the more important rare taxa include *Graminidites annulatus, Boehlensipollis hohli, Cupanieidites eucalyptoides, Tricolporopollenites spinus, Intratriporopollenites microreticulatus, Favitricolporites microreticulatus, Deltoidospora apheles* and *Tasminites* spp.

Comments

Diversity varies from over 50 to less than 40 within this association. Palynomorphs per gram reduce in number up through this association. The variance value varies from 5 to 15 through this association.

Tops and Bases

A number of taxa have their only occurrence within the section within this association or are recorded for the last time upsection in this association:

77.0m	top *Schizosporis* spp.
	only occurrence of *Tricolporopollenites spinus*
76.73m	only occurrence of *Boehlensipollis hohli*
	only occurrence of *Nyssapollenites kruschi* subsp. *instructus*
74.47m	only occurrence of *Graminidites annulatus*

A large number of taxa are recorded for the first time upsection:

77.0m	base *Plicatopollis* spp.
	base *Cupanieidites eucalyptoides*
	base *Tricolporopollenites baculoferus*
	base *Deltoidospora maxoides*
	base *Baculatisporites nanus*
	base *Verrucatosporites balticus*

	base *Ovoidites* spp.
76.73m	base *Liquidambarpollenites stigmosus*
	base *Triporopollenites coryloides*
	base *Ilexpollenites iliacus*
	base *Triatriopollenites rurensis*
	base *Toroisporis* spp.
	base *Corrusporis tuberculatus*
	base Algae sp. 1
75.20m	base *Momipites coryloides*
	base *Favitricolporites microreticulatus*
	base *Triporopollenites* cf. *plectosus*
	base *Lycopodiumsporites* spp.
74.47m	base *Baculatisporites primarius*
	base *Verrucatosporites megabalticus*

ASSOCIATION D

This association occurs from 73.77m to 72.95m. The sedimentology of this interval is composed of grey claystones above the important coarse sandstone layer at 74.10m to 74.14m which represents a break in section. In this interval the pale grey claystone grades upsection to mid grey claystones and dark brown grey siltstones. The lower claystone contains large rootlets, slickensides and lignitic bands. Towards the top of this association a friable gritty conglomerate occurs which is composed of quartz, feldspar, mica and large wood fragments. The silty claystones overlying this conglomerate contain superb plant leaf fossils.

Characteristic Palynological Features

Abundant numbers of *Inaperturopollenites hiatus* are recorded in this association and are seen to increases in number upsection. The numbers of *Laevigatosporites haardti* also increase upsection but to highly abundant numbers. *Retitricolpites retiformis* although occurs in abundant numbers at the base of this association, it decreases in number to present upsection into Association E. Common taxa include *Polyatriopollenites carpinoides* which increases in number upsection from the base of this association and *Alnipollenites verus* which increases upsection from present to common within this association. Bisaccate pollen and a peak in the taxa *Ovoidites* spp. occur in numbers up to present. While *Tricolpopollenites hians* and *T.* cf. *hians* decrease in number from present to rare upsection from the base of this association. A large number of taxa occur in rare numbers. *Nyssapollenites kruschi* subsp. *analepticus, Porocolpopollenites vestibulum, Verrucatosporites alienus, V. balticus* and *V. favus* are rare and are seen to reduce in numbers slightly upsection. While

Monocolpopollenites tranquillus and *Sciadopityspollenites* spp. are rare but seen to increase slightly in number upsection. Other rare taxa to be noted include *Liquidambarpollenites stigmosus, Stereisporites (Stereisporites) stereoides, Echinosporis echinatus, Trilites multivallatus, Polypodiaceoisporites marxheimensis* and *Cupanieidites eucalyptoides.*

Comments

Diversity increases upsection through this association as does variance. The numbers of palynomorphs per gram show a significant increase upsection from the base of the association. The cluster analysis dendrogram picks out an important division in the section at the base of Association D.

Tops and Bases

A number of taxa have their only occurrence within the section within this association or are recorded for the last time upsection in this association:

73.77m	only occurrence of *Triplanosporites* spp.
72.95m	only occurrence of *Micrhystridium stellatum*
	only occurrence of *Pediastrum* spp.
	top *Liquidambarpollenites stigmosus*

A number of taxa occur for the first time upsection within this association:

73.77m	base *Cicatricosisporites chattensis*
	base *Polypodiaceoisporites marxheimensis*
	base *Stereisporites (Stereisporites) stereoides*

ASSOCIATION E

This association occurs between 71.28 to 70.75m. Sedimentologically this interval comprises of a dark grey brown silty claystone with mica and wood fragments at the base grading up through a thin lignite band into a grey claystone with carbonaceous and wood fragments.

Characteristic Palynological Features

This association is characterised by abundant numbers of *Inaperturopollenites hiatus* and *Laevigatosporites haardti*, these taxa are shown to increase upsection from the base of this association. Common occurrences of *Retitricolpites retiformis* are recorded here although their numbers characteristically decrease upsection from the base of this association. Bisaccate pollen peaks in occurrence to common at the base of this association and then reduces in number upsection. Numbers of

Polyatriopollenites carpinoides are seen to increase in number upsection to common in this association. An increase in the number of *Baculatisporites nanus* to present is seen at the base of this association. While *Tricolpopollenites hians* and *T* cf. *hians* numbers reduce upsection from the base of this association from present to rare. A peak in the numbers of *Micrhystridium* spp. to present at the base of this association is seen and this reduces upsection to rare. Other characteristic rare taxa occurring in this association include *Inaperturopollenites distichiforme, Nyssapollenites kruschi* subsp. *analepticus, Plicatopollis* spp., *Cicatricosisporites chattensis*, *Stereisporites (Stereisporites) stereoides*, *Echinosporis echinatus, Pesavis tagluensis* and a peak of *Microthallites* spp. *Alnipollenites verus* occurs in rare numbers in this association but is seen to increase drastically upsection to abundant into the base of Association F.

Comments

Again diversity figures increase upsection from the base of this association along with the variance results and numbers of palynomorphs per gram.

Tops and Bases

One taxa has its only occurrence in this section within this association and one taxa is recorded for the last time upsection in this association:

71.28m	only occurrence of *Caryapollenites imparalis*
	top Hyphae spp.

The first uphole occurrence of three taxa are noted to occur in this association:

71.28m	base *Cyrillaceaepollenites megaexactus*
	base *Trilites* spp.
70.75m	base *Triatriopollenites aroboratus*

ASSOCIATION F

This association occurs from 68.96m to 67.21m. Sedimentologically this interval is composed of, a grey silty claystone containing plant fragments, this is overlain by interbedded lignites dark lignitic siltstones and sandstones then overlain by brown claystones with plant fragments and listric features, slickensides.

Characteristic Palynological Features

The abundant taxa characterising this association include *Laevigatosporites haardti* and *Inaperturopollenites hiatus* which decrease in number from the base of this association upsection and *Alnipollenites verus* which shows a marked increase upsection from the base of this association. *Polyatriopollenites carpinoides* occurs in abundant numbers at the base of this association and reduces to common upsection.

The numbers of *Retitricolpites retiformis* and bisaccate pollen increase upsection from present at the base of the association to common. The rare occurrence of a number of taxa in this association is noted. *Nyssapollenites kruschi* subsp. *analepticus, Retitricolpites anguloluminosus, Baculatisporites nanus* and *Corrusporis tuberculatus* occur in rare numbers. Slight increases in the numbers of *Arecipites* spp. and *Micrhystridium* spp. are recorded. Also constant but rare occurrences of *Verrucatosporites alienus* and *V. balticus* are seen but in relatively higher numbers than in the other associations in this section and the rare occurrence of *V. megabalticus* is noted.

Comments

The statistical data shows an initial increase in diversity from the base of the association which then decreases towards the top. A similar pattern is noted for the palynomorphs per gram numbers. Variance values are seen to decline upsection from the base of the association then increase towards the top of the association.

Tops and Bases

A number of taxa occur for the last time upsection in this association:

68.96m	top *Deltoidospora apheles*
67.75m	top *Cupuliferoipollenites cingulum* subsp. *oviformis*
	top *Cupuliferoipollenites cingulum* subsp. *pusillus*
	top *Trilites* spp.
	top *Verrucatosporites* spp.
	only occurrence of *Tricolporopollenites viburnoides*
67.21m	top *Gleicheniidites senonicus*

ASSOCIATION G

This association occurs from 66.88m to 66.19m in depth. This interval is composed of green brown claystones with slickensides, quartz, feldspar and plant fragments occurring in it. This claystone grades upwards into a pale grey claystone containing coarse grained gritty fragments. The base of the next association upsection is composed of a greater than 1m thick lignite layer.

Characteristic Palynological Features

The characteristic abundant taxa recorded in this association include *Laevigatosporites haardti* which increases in number upsection from the base of the association. *Inaperturopollenites hiatus* is also abundant and *Alnipollenites verus* is abundant with its peak occurrence at the base of the association, this then declines upsection. Both *Retitricolpites retiformis* and *Polyatriopollenites carpinoides* occur in common numbers with *R. retiformis* declining slightly upsection. *Nyssapollenites kruschi* subsp. *analepticus* occurs in present numbers and bisaccate pollen is recorded to occur from present to rare in this association. Rare taxa recorded include *Cupanieidites eucalyptoides, Cupuliferoidaepollenites* species, *Tricolporopollenites edmundi, Cicatricosisporites chattensis, Trilites multivallatus, Echinosporis echinatus, Verrucatosporites megabalticus* and *Micrhystridium* spp.

Comments

While the value of diversity increases upsection in this association the number of palynomorphs per gram declines. The variance values initially reduce then increase upsection.

Tops and Bases

A number of last occurrences of taxa are recorded within this association:

66.88m	top *Favitricolporites microreticulatus*
	top *Retitricolpites anguloluminosus*
	top *Verrucatosporites megabalticus*
66.19m	top *Triatriopollenites aroboratus*
	top *Quercoidites microhenrici*
	top *Dicolpopollis kockeli*
	only occurrence of *Tricolpopollenites discus*

Only one taxa is recorded as having its first uphole occurrence within this association:

66.19m	base *Trilites* sp. 1

ASSOCIATION H

This association occurs from 64.95m to the top of the section at 63.97m. This interval is dominated by a lignite layer about 1m in thickness. The lignite is laminated with dark green grey silty claystones which characteristically contain woody fragments and carbonaceous spots. In places an orange red staining has been noted in the lignite. The top of the lignite is brittle, hard and very light weight. As the pure lignite layers were not found to yield palynomorphs well, it is the layers of silty clays between which were prepared for palynological preparation.

Characteristic Palynological Features

The abundant taxa within this association are *Inaperturopollenites hiatus* and *Laevigatosporites haardti,* the latter is seen to increase in number to highly abundant at the top of this association. The numbers of *Alnipollenites verus* are reduced upsection into this association to present from common. *Polyatriopollenites carpinoides* is present and occurs in lower numbers than the levels recorded in the association below. Bisaccate pollen occur in present numbers and *Microthallites* spp. numbers show a slight peak from rare to present in this association. A large number of taxa occur in rare numbers, these include *Platycaryapollenites* spp., *Intratriporopollenites ceciliensis, Gothanipollis gothanii, Cupuliferoidaepollenites* species, *Tricolporopollenites baculoferus, Corrusporis tuberculatus, Echinosporis* sp. 1, *Diporicellaesporites* spp. and *Tasminites* spp.

Comments

Diversity reduces upsection and the palynomorphs per gram reduce at first then increase upsection. The variance value increases upsection with a significant increase being seen at the top of this association.

Tops and Bases

A number of taxa are recorded for the last time within this association or are recorded for the only time within the section:

64.95m	top *Trivestibulopollenites betuloides*
	top *Polypodiaceoisporites marxheimensis*
	top *Fusiformisporites* spp.
	only occurrence of *Gothanipollis gothanii*
	only occurrence of *Intratriporopollenites ceciliensis*
64.26m	top *Momipites coryloides*
	only occurrence of *Platycarya* type
	only occurrence of *Diporicellaesporites*
63.97m	only occurrence of *Polypodiaceoisporites* spp.

OVERALL AGE COMPARISON OF THE 80/14 SECTION TO THE PUBLISHED LITERATURE

The predominantly claystone and lignite sedimentology of this borehole section is similar to the sedimentology of the other Oligocene terrestrial basin sediments described from the Western British Isles. This section has previously been dated as Oligocene (Evans *et al.*, 1991) on pollen and spore evidence.

The associations in this section are dominated by *Laevigatosporites haardti, Inaperturopollenites hiatus, Alnipollenites verus, Retitricolpites retiformis* and *Polyatriopollenites carpinoides* with subordinate numbers of *Nyssapollenites kruschi* subsp. *analepticus, Monocolpopollenites tranquillus, Porocolpopollenites vestibulum, Tricolpopollenites hians* , *T.* cf. *hians, Verrucatosporites* species and bisaccate pollen. The presence of stratigraphically significant taxa such as *Echinosporis echinatus* and *Cicatricosisporites chattensis* along with the abundances of the taxa listed above, indicate these sediments to be of Oligocene age (Wilkinson & Boulter, 1980).

Precise dating of the associations described in this sequence is difficult because few of the published zonation schemes are of any use, as they do not feature many of the taxa in question here. Although a few stratigraphically significant tops and bases have been noted and can be correlated to the published literature.

The base occurrence of *Verrucatosporites alienus* and *V. histiopteroides* in Association B are regarded by Krutzsch (1966) to represent ages of Lower Oligocene and Middle Oligocene respectively. The only occurrence of *Corrusporis granotuberculatus* in this association is regarded as being comparable to the Upper Oligocene of Krutzsch (1966) and Wilkinson & Boulter (1980).

The tops and bases of a number of stratigraphically significant taxa are recorded from Association C. The base of *Triatriopollenites rurensis* correlates to the Lower Oligocene of Chateauneuf (1980), the base of *Corrusporis tuberculatus* to the Middle Oligocene (Krutzsch, 1962 and Wilkinson & Boulter, 1980) and the occurrence of *Tricolporopollenites spinus* indicates a Middle Oligocene age (Krutzsch, 1962; Wilkinson & Boulter, 1980; Ollivier-Pierre, 1980). The 'marker taxa' *Boehlensipollis hohli* is regarded as indicating Middle Oligocene aged sediments (Krutzsch, 1966; Wilkinson & Boulter, 1980; Chateauneuf, 1980; Vinken *et al.*, 1988) and is recorded in this association.

The base of *Cicatricosisporites chattensis* in Association D indicates a Middle Oligocene age or younger for this part of the sequence (Krutzsch, 1966; Wilkinson & Boulter, 1980). The base occurrence of *Cyrillaceaepollenites megaexactus* recorded in Association E is regarded as indicating Upper Oligocene age sediments (Vinken *et al.*, 1988).

Association F sees the top occurrence of *Deltoidospora apheles* which compares to the Middle Oligocene of Chateauneuf (1980). The top occurrence of *Trilites* spp. can be correlated to Association F in 16/16 which is Upper Oligocene in age.

In Association G the top occurrence of *Verrucatosporites megabalticus* is regarded as occurring in the Late Oligocene of Wilkinson & Boulter (1980). Also the top occurrence of *Tricolpopollenites discus* can be correlated to Association F of 16/16 which is Upper Oligocene. Chateauneuf (1980) regards the top occurrence of *Favitricolporites microreticulatus* and *Quercoidites microhenrici* as correlating to an Upper Oligocene age. Finally Association H sees the only occurrence of *Intratriporopollenites ceciliensis* this is correlated to Association F in 16/16 which is Upper Oligocene in age.

In conclusion by comparison to the published literature the lower part of the section, Associations A to C, is suggested to represent a Lower Oligocene age (Rupelian) and the upper part of the section, Association D to H, is suggested to be representative of Upper Oligocene aged sediments (Chattian).

SECTION 88/12

Terrestrial sequences differ from marine sequences in that a large number of associations can be defined in each sequence due to the nature of floras i.e. quick changes with changes in environment and depositional setting. In this section all the associations are defined from one sample only, with the exception of the top most association where the top sample is statistically unviable therefore is unsuitable to be used to define an association alone.

ASSOCIATION A

This association is defined from the sample at a depth of 48.50m and is the basal sample of the section.

Characteristic palynological features

Inaperturopollenites hiatus is the most abundant taxa within this association, with common numbers of *Tricolpopollenites* cf. *hians* and *Cupuliferoipollenites cingulum* subsp. *oviformis* occurring. A number of taxa occur in present numbers such as *Nyssapollenites kruschi* subsp. *analepticus, Monocolpopollenites tranquillus, Deltoidospora wolffi, Microthallites* spp. and Hyphae spp.

Rare taxa occurring within this association include *Alnipollenites verus, Retitricolpites retiformis, Polyatriopollenites carpinoides, Triporopollenites robustus, Dicolpopollenites kockeli, Porocolpopollenites vestibulum, Cupuliferoidaepollenites* species, *Cicatricosisporites chattensis, Baculatisporites nanus* and *Echinosporis echinatus.*

Comments

This association is characterised by low numbers of palynomorphs per gram, under 20 000, relatively low variance values at over 10 and medium to high diversity values. Although the pollen and spore sum is under the standard 250 count its value of over 145 in this sample is regarded as being statistically viable.

Tops and bases

The only occurrence of a number of taxa within this section is recorded in this association:

48.50m only occurrence of *Sequoiapollenites polyformosus*
only occurrence of *Favitricolporites microreticulatus*
only occurrence of *Cupuliferoipollenites cingulum subsp. oviformis*
only occurrence of *Laevigatosporites discordatus*
only occurrence of Algae sp. 1

ASSOCIATION B

This association is defined from one sample at a depth of 44.75m

Characteristic palynological features

This association is characterised by an uphole increase in the numbers of *Inaperturopollenites hiatus* to highly abundant. The numbers of bisaccate pollen are also seen to increase uphole to abundant into this association. The numbers of *Laevigatosporites haardti* and *Monocolpopollenites tranquillus* increase uphole to common in this association and *Inaperturopollenites dubius* occurs commonly at this level. The rare occurrence of a large variety of taxa are recorded within this association. These include *Nyssapollenites kruschi* subsp. *analepticus, Retitricolpites retiformis, Cupuliferoipollenites cingulum* subsp. *pusillus* and *Cyrillaceaepollenites megaexactus*. Importantly an absence of *Tricolpopollenites hians* and *T.* cf. *hians* is noted in this association, along with rare numbers of *Retitricolpites retiformis*.

Comments

Upsection into this association the value of diversity reduces to under 30 and the numbers of palynomorphs per gram significantly reduce to about 10 000. A peak in variance occurs in this association to a value greater than 25.

Tops and bases

Two taxa are recorded for the last time upsection in this association and one taxa is recorded which is not seen from any other association within this section:

44.75m top *Cupuliferoidaepollenites liblarensis* subsp. *fallax*
top *Echinosporis echinatus*
only occurrence of *Schizosporis* spp.

A large number of taxa are recorded for the first time upsection within this association:

44.75m base *Tricolporopollenites pseudocingulum*
base *Polypodiaceoisporites marxheimensis*
base *Torosporis* spp.
base *Triplanosporis* spp.

base *Verrucatosporites favus*
base *Cyrillaceaepollenites megaexactus*
base *Micrhystridium* spp.

ASSOCIATION C

This association is defined from one sample at a depth of 41.70m.

Characteristic Palynological Features

The abundant taxa characterising this association is *Inaperturopollenites hiatus*, this declines in number uphole into this association from highly abundant below to abundant in this association. Commonly occurring taxa include *Tricolpopollenites* cf. *hians* and *Laevigatosporites haardti* which increase to common uphole into this association. Numbers of bisaccate pollen drastically reduce upsection to common into this association from abundant and the last common occurrence of *Monocolpopollenites tranquillus* is seen, which reduces in number upsection to present/rare from here. *Retitricolpites retiformis* is recorded in present numbers and *Trilites multivallatus* and *Microthallites* spp. peak to present numbers in this association. A large number of taxa occur in rare numbers these include *Nyssapollenites kruschi* subsp. *analepticus, Tricolpopollenites hians, Tricolporopollenites viburnoides, Polypodiaceoisporites marxheimensis* and *Triplanosporites* spp. The last rare occurrence of *Deltoidospora wolffi* is seen in this association and from here upsection its numbers increase to present/common. Both *Triporopollenites coryloides* and *T. robustus* increase in number slightly in this association to rare.

Comments

The diversity reduces upsection into this association and the numbers of palynomorphs per gram increase upsection to over 15 000. The variance value reduces upsection from the peak recorded in the association below. It must be noted here that the pollen sum of 102 recorded for this association is marginal with regards to its statistical viability.

Tops and Bases

One taxa is recorded for the last time upsection in this association:

41.70m	top *Triporopollenites robustus*

A number of taxa occur for the first time uphole in this association:

41.70m	base *Tricolporopollenites viburnoides*

base *Stereisporites (Stereisporites) stereoides*
base *Cupuliferoipollenites cingulum* subsp. *fusus*
base *Triporopollenites coryloides*
base *Trivestibulopollenites betuloides*

ASSOCIATION D

This association has been defined from one sample at a depth of 41.25m.

Characteristic Palynological Features

Inaperturopollenites hiatus is the characteristic abundant taxa in this association and it declines in number upsection from here. Common taxa include bisaccate pollen and *Tricolpopollenites* cf. *hians*, the latter is seen to decline in number upsection. *Deltoidospora wolffi* is seen to increase upsection from rare to common in this association and *Laevigatosporites haardti* increases in number upsection from here. The taxa *Polypodiaceosporites marxheimensis* shows a slight peak in occurrence to present numbers in this association and *Nyssapollenites kruschi* subsp. *analepticus* increases upsection to present here while the numbers of *Microthallites* spp. reduce upsection to present. A large number of taxon occur in rare numbers these include *Retitricolpites retiformis, Polyatriopollenites carpinoides, Trivestibulopollenites betuloides, Cyrillaceaepollenites megaexactus, Cicatricosisporites chattensis, Pluricellaesporites* spp., *Deltoidospora maxoides* and *Corrusporis tuberculatus*. *Monocolpopollenites tranquillus* is seen to reduce in number from common/present to rare in this association and above.

Comments

A sharp increase in diversity in this association is seen and more than a two fold increase in the numbers of palynomorphs per gram to over 40 000 are recorded here. The variance value remains at a constant value upsection.

Tops and Bases

A number of taxa are recorded for the last time upsection in this association or are not recorded from any other association within this section:

41.25m top *Trivestibulopollenites betuloides*
top *Cupuliferoipollenites cingulum* subsp. *fusus*
top *Cupuliferoipollenites cingulum* subsp. *pusillus*
only occurrence of *Momipites tenuipolus*
only occurrence of *Corrusporis tuberculatus*
only occurrence of *Pluricellaesporites* spp.

only occurrence of *Cleistosphaeridium* sp. 1 of Manum *et al.* (1989)

The first uphole occurrence of one taxa is recorded from this association:

41.25m base *Deltoidospora maxoides*

ASSOCIATION E

This association is defined from the sample at a depth of 40.02m.

Characteristic Palynological Features

Inaperturopollenites hiatus occurs abundantly in this association although numbers are seen to reduce upsection. *Laevigatosporites haardti* increases from common to abundant up into this association. Common taxa occurring in this association include *Nyssapollenites kruschi* subsp. *analepticus* and *Retitricolpites retiformis* both of which are seen to increase from present and rare respectively, upsection from the association below. While the numbers of *Tricolpopollenites* cf. *hians* remain constant in number. The fungi *Diporicellaesporites* spp. and *Microthallites* spp. occur in present numbers in this association. The numbers of *Polyatriopollenites carpinoides* increase upsection from rare to present here and the number of bisaccate pollen reduce upsection from common to present in this association. A number of taxa occur in rare numbers in this association, these include *Intratriporopollenites microreticulatus, Monocolpopollenites tranquillus, Quercoidites microhenrici, Trilites multivallatus, Baculatisporites* spp. and *Micrhystridium* spp. which increase in number to rare in this association.

Comments

The diversity values show a slight uphole decline, while a marked increase in the numbers of palynomorphs per gram in this association, to a peak value for the section, to a number in excess of 70 000. The variance value reduces uphole to the lowest point seen for the section, at a value of less than 10.

Tops and Bases

A number of taxa are recorded for the last time upsection in this association or are recorded for the only time within this section:

40.02m top *Nyssapollenites satzveyensis*
top *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis*
top *Microthallites* spp.
only occurrence of *Plicatopollis* spp.
only occurrence of *Ilexpollenites iliacus*

only occurrence of *Retitricolpites anguloluminosus*

A number of taxa are recorded to occur for the first time upsection in this association:

40.02m	base *Intratriporopollenites microreticulatus*
	base *Microfoveolatosporis pseudodentatus*
	base *Verrucatosporites balticus*
	base *Diporicellaesporites* spp.

ASSOCIATION F

This association is defined from one sample at a depth of 34.60m.

Characteristic Palynological Features

Inaperturopollenites hiatus is the only abundant taxa recorded from this association. Commonly occurring taxa include *Laevigatosporites haardti* which decreases in number from abundant upsection into this association and bisaccate pollen which increases in number upsection from present to common into this association. While both *Retitricolpites retiformis* and *Tricolpopollenites* cf. *hians* are shown to have their last common occurrence in this section and they decrease to rare/absent in the association at the top of the section. Present taxa include *Inaperturopollenites magnus, Quercoidites microhenrici* and *Deltoidospora wolffi*. At this level a peak in the occurrence of *Piceapollis* spp., *Baculatisporites primarius* and *B.* spp. from rare/absent is also shown.

A number of rare taxa are recorded in this association, these include *Nyssapollenites kruschi* subsp. *analepticus* which is seen to reduce upsection from common to rare. Also *Monocolpopollenites tranquillus* and *Baculatisporites nanus* occur in rare numbers. Slight peaks to rare occurrences in the numbers of *Tricolporopollenites viburnoides, Lycopodiumsporites* spp. and *Stereisporites (Stereisporites) stereoides* are seen.

Comments

Diversity is seen to increase upsection into this association to a value of over 45 while a significant reduction in the numbers of palynomorphs per gram are recorded falling from over 60 000 to numbers less than 5 000. Variance is seen to increase only slightly upsection into this association.

Tops and Bases

A number of taxa are recorded for the last time upsection in this association or are recorded for the only time within this association:

34.60m top *Retitricolpites retiformis*
top *Tricolpopollenites hians*
top *Nyssapollenites kruschi* subsp. *analepticus*
top *Intratriporopollenites microreticulatus*
top *Alnipollenites verus*
top *Polyatriopollenites carpinoides*
top *Tricolporopollenites pseudocingulum*
top *Stereisporites (Stereisporites) stereoides*
top *Verrucatosporites favus*
top *Diporicellaesporites* spp.
only occurrence of *Abiespollenites* spp.
only occurrence of *Inaperturopollenites distichiforme*
only occurrence of *Caryapollenites* spp.
only occurrence of *Arecipites* spp.
only occurrence of *Triatriopollenites subtriangulus*

One taxa is recorded to occur for the first time upsection within this association:

34.60m base *Inaperturopollenites magnus*

ASSOCIATION G

This association occurs over the interval from 33.50 to 32.78m and is the top most association defined in this section. The top most sample has been included within this association as its pollen sum is under a value of 100 which is not statistically viable, therefore it would be unsuitable to define an association for this sample above so it is included into this final Association G.

Characteristic Palynological Features

The abundant taxa in this association include *Inaperturopollenites hiatus* and *Laevigatosporites haardti* which increase from common to abundant into this association. Also bisaccate pollen are abundant and are seen to increase uphole from common. No taxa occur in common numbers, but present taxa include *Deltoidospora wolffi* which increases in number from the base of this association then declines to rare at the top of the section and *Trilites multivallatus* which increases in number upsection into this association. A large number of taxa occur in rare numbers within this association. These include *Tricolpopollenites* cf. *hians, Porocolpopollenites vestibulum, Cyrillaceaepollenites megaexactus, Cicatricosisporites chattensis,* *Polypodiaceoisporites marxheimensis, Torosporis* spp. and a slight peak of *Micrhystridium* spp. *Inaperturopollenites magnus* is seen to decline in number up section from rare at the base of this association to absent at the top. Other absent taxa to note include *Alnipollenites verus, Nyssapollenites kruschi* subsp. *analepticus* and *Retitricolpites retiformis.*

The top of this association is characterised by the abundant and only occurrence of Spore sp. 88 and an increase in the numbers of *Polypodiaceoisporites marxheimensis* from rare to abundant uphole. An increase in the numbers of *Trilites multivallatus* in this section is seen. Rare occurrence of *Dicolpopollenites kockeli* and *Triporopollenites coryloides* are noted. The top part of this association differs slightly from the base of this association. These differences cannot be regarded as significant enough to define this sample as a different association as the pollen sum is less than 100 and the results are therefore statistically unviable. The normalisation of the data in such cases can also be the cause of marked changes in the 'apparent' abundances of certain taxa.

Comments

A high diversity is recorded at the base of this association with figures over 40. Low numbers of palynomorphs per gram are recorded and variance is seen to increase in value to under 20 at the base of this association.

Tops and Bases

One taxa is recorded for the last time upsection in this association and a number of taxa have been recorded for the only time within this association in this section:

33.50m	top *Inaperturopollenites magnus* only occurrence of *Liquidambarpollenites stigmosus* only occurrence of *Gleicheniidites senonicus* only occurrence of *Undulatisporites sculpturis* only occurrence of *Verrucingulatisporites treplinensis* only occurrence of *Veryhacium* spp.

Two taxa are recorded occurring for the first time uphole within this association:

32.78m	base *Trilites* sp. 2 base Spore sp. 88

OVERALL AGE COMPARISON OF THE 88/12 SECTION TO THE PUBLISHED LITERATURE AND THIS WORK

The associations in this section are dominated by *Laevigatosporites haardti* and *Inaperturopollenites hiatus* with subordinate numbers of *Nyssapollenites kruschi* subsp. *analepticus, Monocolpopollenites tranquillus, Retitricolpites retiformis, Tricolpopollenites* cf. *hians* and *Porocolpopollenites vestibulum.* The presence of stratigraphical significant taxa such as *Cicatricosisporites chattensis, Echinosporis echinatus, Polyatriopollenites carpinoides, Corrusporis tuberculatus* and *Verrucatosporites* species along with abundances of the taxa mentioned above indicate these sediments to be of an Oligocene age (Wilkinson & Boulter, 1980; Krutzsch, 1966).

Precise dating of the associations described in this section is limited by the poor quality and content of the published zonation schemes. Although some stratigraphically significant tops and bases have been noted in this section and can be correlated to other sections.

The only occurrence of a number of taxa is noted from Association A. *Laevigatosporites discordatus* here can be correlated to Association B in 21/28 which is Rupelian in age but this species has been recorded from the Late Palaeocene (Gruas-Cavagnetto, 1976) to the Miocene of (Thomson & Pflug, 1953). While the only occurrence of Algae sp. 1 correlates to Association A of 16/16 (Lower Rupelian) and Association C of 21/28 (Rupelian).

Association B is characterised by the apparent top occurrence of *Echinosporis echinatus*, this can be correlated to the Lower Miocene of Krutzsch (1967c) and the Upper Chattian of Association F of 16/16 and Association E of 21/18. The base of a number of taxa are recorded in this association these include *Tricolporopollenites pseudocingulum* the base of which is reported to occur in the Palaeocene (Thomson & Pflug, 1953), the Middle Oligocene of Europe (Vinken *et al.,* 1988; Wilkinson & Boulter, 1980) and Association D of 21/28 (Rupelian). The base occurrence of *Verrucatosporites favus* can be compared to the Middle Oligocene of Krutzsch (1967c) and the Oligocene of Wilkinson & Boulter (1980) and Evans *et al* (1991). While the base of *Polypodiaceosporites marxheimensis* can be correlated to the Palaeocene (Krutzsch & Vanhoorne, 1977; Kedves, 1963) and to Association A of 16/16 (Rupelian) and Association D of 80/14 (Chattian).

Association C sees the top occurrence of *Triporopollenites robustus* this correlates to a range of Late Palaeocene to Oligocene recorded by Thomson & Pflug (1953). The base occurrence of *Triporopollenites robustus* can also be correlated to Association C of 21/28 (Rupelian) and to an only occurrence in Association F of 80/14 (Chattian). While the base of *Triporopollenites coryloides* correlates to Association C of 80/14 (Rupelian). *Trivestibulopollenites betuloides* is reported by Chateauneuf (1980) as having its base occurrence in the Eocene but by Ollivier-Pierre (1980) in the Lower Oligocene. The base of this taxa is also recorded from

Association A in 16/16 (Rupelian) and Association C of 21/28 (Rupelian). The base of *Stereisporites (Stereisporites) stereoides* correlates to Association D of 80/14 (Chattian).

Association D has a number of stratigraphically significant top and base occurrences within it. The top occurrence of *Trivestibulopollenites betuloides* correlates to Association H of 80/14, the top of *Cupuliferoipollenites cingulum* subsp. *fusus* to Association F of 21/28 (Chattian) and the top of *Cupuliferoipollenites cingulum* subsp. *pusillus* to Association E of 16/16 (Chattian) and Association F of 80/14 (Chattian). While the only occurrence of *Momipites tenuipolus* can be compared to a range of Late Eocene to Early Oligocene suggested by Thomson & Pflug (1953). The only occurrence of *Corrusporis tuberculatus* in this association is important as it correlates to the Upper Oligocene of Wilkinson & Boulter (1980) and Krutzsch (1967c) and also to Association E of 16/16 (Chattian) and Association C of 80/14 (Rupelian). The only occurrence of *Cleistosphaeridium* sp. 1 of Manum *et al.* (1989) is suggested to be of a Lower Miocene age (Manum *et al.*, 1989) but has been recorded in Association A of 16/16 (Rupelian). The fungi *Pluricellaesporites* spp. has its only occurrence here, this is comparable to Association B of 16/16 (Rupelian) and Association C of 21/28 (Rupelian).

Association E sees the base occurrences of *Diporicellaesporites* spp. which can be correlated to Association H of 80/14. Also the base of *Verrucatosporites balticus* correlates to an Oligocene age (Wilkinson, 1979; Wilkinson & Boulter, 1980; Evans *et al.*, 1991), a Middle Oligocene (Wilkinson & Boulter, 1980; Krutzsch, 1966) and Association F in 21/28 (Chattian) and Association C of 80/14 (Rupelian). The only occurrence of *Retitricolpites anguloluminosus* can be compared to the top occurrences of this taxa recorded from Association C of 16/16 (Rupelian), Association G of 21/28 (Chattian) and Association G of 80/14 (Chattian).

Association F in this section sees the top occurrence of *Retitricolpites retiformis*, this event correlates to a Middle Oligocene age from Thomson & Pflug (1953). The top of *Intratriporopollenites microreticulatus* correlates to the Oligocene of Wilkinson & Boulter (1980) and to Association F in 21/28 (Chattian). The top of *Tricolporopollenites pseudocingulum* is higher in the sequence than Association D of 21/28 (Rupelian) where the base of this taxa is seen. The top occurrence of *Verrucatosporites favus* corresponds to an older age than Middle Oligocene which Krutzsch (1967c) regards as the base of this species and the Upper Eocene which Chateauneuf (1980) records as the base of this species. The top occurrence of *Diporicellaesporites* spp. can be correlated to Association H in 80/14 (Chattian). The only occurrence *Arecipites* spp. is recorded in this association and can be correlated to the top occurrence of this species in Association E of 16/16 (Chattian) and

Association G of 21/28 (Chattian) and to the base occurrence of this species in Association C in 21/28 (Rupelian).

Association G sees a few taxa that enable correlation to other sections. The only occurrence of *Liquidambarpollenites stigmosus* can be suggested to be of an older age than the recorded top occurrence of the taxa in the Miocene (Thomson & Pflug, 1953) and a top occurrence in Association D of 80/14 but younger than the base occurrence recorded from Association C in 80/14 (Rupelian). The only occurrence of the important taxon *Verrucingulatisporites treplinensis* in this association suggests an age older than the recorded top occurrence of Upper Oligocene by Wilkinson & Boulter (1980), and can be correlated to Association D in 21/28 (Rupelian). The only occurrence of the acritarch, *Veryhacium* spp. can be correlated to an age older than the top occurrences of this taxa recorded in Association A in 16/16 (Rupelian) and Association F of 21/28 (Chattian).

In conclusion the basal part of the section, Association A to C is thought to represent a Rupelian age. And the upper part of the section, Association D to G is thought to represent a Chattian age.

SECTION 78/1

ASSOCIATION A

This association is defined from the basal sample of this section at 141.2m in depth.

Characteristic Palynological Features

The abundant taxa characterising this association include *Laevigatosporites haardti,* bisaccate pollen and *Inaperturopollenites hiatus* the latter of which is seen to increase in number up section to a peak at the base of Association B. Common but constant numbers of *Alnipollenites verus* occur and the numbers of *Nyssapollenites kruschi* subsp. *analepticus* are common but seen to reduce upsection from this association. *Tricolpopollenites hians* and *T.* cf. *hians* occur in present numbers. *Retitricolpites retiformis* and *Polyatriopollenites carpinoides* occur in present numbers although increase upsection while *Triporpollenites robustus* and *Deltoidospora wolffi* numbers are present but decline upsection. A large number of rare taxa are seen to occur in this association these include *Liquidambarpollenites stigmosus, Trivestibulopollenites betuloides, Intratriporopollenites microreticulatus, Cyrillaceaepollenites megaexactus, Stereisporites (Stereisporites) stereoides, Echinosporis echinatus* and *Diporicellaesporites* spp.

Comments

This association is characterised by a high diversity of over 60 which is the highest in the section. This is mirrored by a moderately low variance figure of less than 75.

Tops and bases

A number of taxa have their only recorded occurrence in the section from this association:

141.2m only occurrence of *Plicatopollis* spp.
only occurrence of *Cicatricosisporites chattensis*
only occurrence of *Trilites* sp. 1

ASSOCIATION B

This association has been defined from three samples between 139.57m and 134.92m in depth.

Characteristic Palynological Features

The taxa *Inaperturopollenites hiatus* occurs in abundant numbers at the base of this association and decreases to common upsection. While both *Polyatriopollenites carpinoides* and *Laevigatosporites haardti* markedly increase upsection from common at the base of this association to abundant at the top of the association. The numbers of *Alnipollenites verus* increase from common to abundant in the middle of the association then reduce to common again at the top of the association. *Retitricolpites retiformis* and bisaccate pollen remain in constant common numbers through the association and *Deltoidospora wolffi* reduces in number from the association below to present here in Association B. A number of rare taxa are encountered from this association, these include *Nyssapollenites kruschi* subsp. *analepticus, Tricolporopollenites edmundi* and *Echinosporis echinatus*. *Intratriporopollenites microreticulatus* is rare but increases in number slightly upsection while a slight peak of *Triplanosporites* spp. to rare is seen at the base of this association.

Comments

The numbers of grains per gram varies greatly through this association while the pollen sum decreases upsection through this association. The variance increases to a peak value of greater than 75 near the top of the association. This peak in variance corresponds to a peak in diversity seen within this association. Plant fragments are recorded to occur more commonly from the samples with the highest diversity values.

Tops and Bases

A number of taxa have been recorded for the only time in the section from within this association:

139.57m	only occurrence of *Intratriporopollenites ceciliensis*
	only occurrence of *Triatriopollenites bituitus*
136.6m	only occurrence of *Stereisporites (Cingulitrilites)* spp.
134.92m	only occurrence of *Scolecosporites* spp.
136.6 - 134.92m	only occurrence of *Polypodiaceoisporites marxheimensis*
	only occurrence of *Stereisporites* sp. 1

A number of first uphole occurrences of taxa occur within this association:

139.57m	base *Cupuliferoipollenites cingulum* subsp. *oviformis*
	base *Cupuliferoipollenites cingulum* subsp. *pusillus*
	base *Favitricolporites microreticulatus*
	base *Baculatisporites nanus*
	base *Lycopodiumsporites* spp.
136.6m	base *Corrusporis tuberculatus*
134.92m	base *Fusiformisporites* spp.
	base *Microfoveolatosporites pseudodentatus*

ASSOCIATION C

This association is defined from two samples from 133.1m to 131.5m.

Characteristic Palynological Features

Inaperturopollenites hiatus increases in number upsection from common at the base of this association to abundant at the top. While the converse is seen for *Laevigatosporites haardti* which occurs in abundant numbers at the base of the association and reduces to common upsection through this association. A peak in the numbers of *Alnipollenites verus* to abundant from present is seen at the top of the association A significant increase in the numbers of *Polyatriopollenites carpinoides* from present to abundant upsection through this association is characteristic. Bisaccate pollen occurs in common numbers and *Retitricolpites retiformis* is common and seen to increase in numbers upsection. *Nyssapollenites kruschi* subsp. *analepticus* and *Deltoidospora wolffi* occur in present numbers. Both *Tricolpopollenites hians* and *T.* cf. *hians* occur in present numbers and show a peak in occurrence at the base of the association, then decline upsection from this level. Taxa occurring in rare numbers include *Trivestibulopollenites betuloides*, *Diporicellaesporites* spp., *Arecipites* spp. and *Porocolpopollenites vestibulum*. Also a slight peak to rare of the taxa *Microthallites* spp. is recorded from this association.

Comments

Low numbers of grains per gram between 68 000 to 72 000 are recorded from the samples of this association. The diversity values are relatively high at about 50 and a relatively low variance value of over 50 is recorded.

Tops and Bases

The last uphole occurrence of a number of taxa are recorded from within this association:

133.1m top *Cupuliferoidaepollenites liblarensis* subsp. *fallax*
top *Echinosporis echinatus*
top *Microfoveolatosporis pseudodentatus*
only occurrence of *Echinosporis miocenicus*
131.5m top *Cupuliferoipollenites cingulum* subsp. *oviformis*
top *Cupuliferoipollenites cingulum* subsp. *pusillus*
top *Stereisporites (Stereisporites) stereoides*
top *Fusiformisporites* spp.
only occurrence of *Micrhystridium* spp.

The first uphole appearance of a number of taxa are seen to occur within this association:

133.1m base *Torosporis* spp.
base *Trilites multivallatus*
base Algae sp. 1
base *Cupuliferoipollenites cingulum* subsp. *fusus*
base *Cleistosphaeridium* sp. 1 of Manum *et al.* (1989)
base *Micrhystridium fragile*
133.5m base *Tricolporopollenites* sp. 1

ASSOCIATION D

This association has been defined from one sample at a depth of 130.1m.

Characteristic Palynological Features

The abundant taxa characterising this association include *Inaperturopollenites hiatus* and *Laevigatosporites haardti*. A marked upsection increase in the numbers of *Polyatriopollenites carpinoides* from common to abundant into the base of this association is characteristic and a marked decline in the numbers of *Alnipollenites verus* from abundant to present at the base of this association is seen. Commonly occurring taxa include *Retitricolpites retiformis* and bisaccate pollen which are both seen to decline significantly in number upsection from the base of this association into the next association uphole. *Nyssapollenites kruschi* subsp. *analepticus* occurs in present numbers in this association, *Deltoidospora wolffi* is also present but its numbers are seen to increase upsection into Association E. A large number of taxa occur in rare numbers in this association these include *Triporopollenites robustus, Monocolpopollenites tranquillus, Porocolpopollenites vestibulum, Tricolporopollenites edmundi* and *Verrucatosporites balticus.* Also occurring in rare numbers are *Tricolpopollenites hians* and *T.* cf. *hians* these both decline in number upsection into the base of this association. A single specimen of *Cyrillaceaepollenites megaexactus* is noted.

Comments

The number of grains per gram recorded in this association show a significant increase upsection from 72 000 below to nearly 800 000 at the base of this association. Diversity values remain relatively constant at about 50 and the variance results show an increase from over 50 below to 75 into the base of this association.

Tops and Bases

A number of taxa are seen to occur for the last time upsection in this association:

130.1m top *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis*
top *Cupuliferoipollenites cingulum* subsp. *fusus*
top *Cleistosphaeridium* sp. 1 of Manum *et al.* (1989)
top *Micrhystridium fragile*
only occurrence of *Reevesiapollis triangulus*

ASSOCIATION E

This association is defined from one sample at a depth of 128.2m.

Characteristic Palynological features

This association is characterised by a significant upsection peak in the numbers of *Laevigatosporites haardti* from abundant to highly abundant and a peak in the numbers of *Deltoidospora wolffi* upsection from rare/present to abundant at the base of this association. Conversely the numbers of *Polyatriopollenites carpinoides* decline from abundant below to present at the base of this association and a slight decline in the numbers of *Inaperturopollenites hiatus* is seen. Taxa occurring in present numbers include *Alnipollenites verus* and bisaccate pollen. The latter is seen to decline in number upsection from abundant below to present at the base of this association. A large number of rare taxa are seen to occur within this association. Single specimens of *Nyssapollenites kruschi* subsp. *analepticus, Trivestibulopollenites betuloides* and *Porocolpopollenites vestibulum* are recorded. A significant reduction in the numbers of *Retitricolpites retiformis* from common below to rare in this association and a slight peak to rare in the occurrence of *Microfoveolatisporis tuemmlitzensis* is seen. Other rare taxa include *Tetracolpites reticulatus, Tricolporopollenites pseudocingulum, Tricolporopollenites viburnoides, Corrusporis tuberculatus, Verrucatosporites alienus* and *V. favus*. No fungi or microplankton occur within this association.

Comments

Grains per gram show a significant reduction from about 800 000 to less than 5 000. The diversity value is seen to reduce from about 50 to 40 and the variance value shows a marked and significant increase from about 60 to about 170 upsection in the base of this association.

Tops and Bases

Three taxa occur and have their only occurrence in the section recorded from this association and four taxa occur for the last time uphole in this association:

128.2m top *Torosporis* spp.
top *Trilites multivallatus*
top *Inaperturopollenites dubius*
top *Trivestibulopollenites betuloides*
only occurrence of *Trilites* spp.
only occurrence of *Corrusporis granotuberculatus*

One taxa is recorded for the first time uphole in this association:

128.2m base *Intratriporopollenites pseudoinstructus*

ASSOCIATION F

This association is defined from two samples and occurs between the depth of 126.9m to 124.37m.

Characteristic Palynological features

The abundant numbers of *Inaperturopollenites hiatus* in this association are seen to decrease slightly. The numbers of bisaccate pollen increase from present below to abundant through this association. A significant reduction in the numbers of *Laevigatosporites haardti* from highly abundant below to abundant at the base of, and through this association occurs. A characteristic increase upsection in the numbers of *Retitricolpites retiformis* from rare below to common into this association is noted. The numbers of both *Alnipollenites verus* and *Nyssapollenites kruschi* subsp. *analepticus* increase from below this association to present numbers upsection into the base of this association. The numbers of *Polyatriopollenites carpinoides* are present and increase only slightly upsection. A characteristic downhole reduction in the numbers of *Deltoidospora wolffi* to present in this association from abundant is seen. A slight peak to rare for *Microthallites* spp., *Pesavis tagluensis, Pluricellaesporites* spp. and Hyphae spp. in this association is seen. Other rare taxa include *Graminidites annulatus, Cyrillaceaepollenites megaexactus, Ilexpollenites iliacus, Echinosporis* sp. 1, *Tricolporopollenites edmundi, Verrucatosporites alienus* and *V. favus.*

Comments

A significant increase in the numbers of grains per gram from 5 000 in the association below to nearly 1 000 000 into the base of this association is seen, this then falls off upsection through this association. Diversity values of between 40 to 50 are seen in this association and increase slightly upsection. Variance values decline significantly from a peak of 170 below this association upsection to about 65 in the base of this association. This value then increases upsection to about 80 at the top of the association.

Tops and Bases

A number of taxa occur for the last time upsection within this association:

126.9m	top *Nyssapollenites kruschi* subsp. *accessorius*
	top *Tricolporopollenites* sp. 1
	top *Tricolporopollenites viburnoides*
124.37m	top *Nyssapollenites satzveyensis*
	top *Cyrillaceaepollenites megaexactus*
	top *Ilexpollenites margaritatus*
	top *Quercoidites microhenrici*
	top *Monocolpopollenites tranquillus*
	top *Tetracolpites reticulatus*
	top *Deltoidospora maxoides*
	only occurrence of *Graminidites annulatus*
	only occurrence of *Ulmipollenites* spp.
	only occurrence of *Verrucatosporites megabalticus*

One taxa is seen to occur for the first time uphole in this association:

126.9m base *Tasmanites* spp.

ASSOCIATION G

This association is the top most association in this section and it is defined from one sample at 123.04m

Characteristic palynological features

Abundant numbers of *Laevigatosporites haardti* occur in this association. *Inaperturopollenites hiatus* numbers decline upsection to common in this association from abundant below and the numbers of *Retitricolpites retiformis* increase to abundant from common below. Both the numbers of *Alnipollenites verus* and *Polyatriopollenites carpinoides* increase upsection from present in the association below to common into this association. Bisaccate pollen are seen to decline in numbers upsection to common into this association from abundant numbers below. Present taxa include *Nyssapollenites kruschi* subsp. *analepticus* and *Intratriporopollenites microreticulatus*. The rare taxa occurring in this association include *Arecipites* spp., *Sequoiapollenites polyformosus, Favitricolporites microreticulatus, Deltoidospora wolffi, Corrusporis tuberculatus, Diporicellaesporites* spp., Algae sp. 1 and *Verrucatosporites histiopteroides.*

Comments

The numbers of grains per gram decline from 400 000 to under 300 000 upsection into this association. Variance values also show a reduction in number upsection from about 80 to less than 60 at the base of this association.

Tops and Bases

A number of taxa have their only recorded occurrence in the section from this association:

123.04m only occurrence of *Nyssapollenites kruschi* subsp. *pseudolaesus*
only occurrence of *Verrucatosporites histiopteroides*

BRIEF AGE COMPARISONS OF 78/1 TO THE PUBLISHED LITERATURE AND OTHER SECTIONS IN THIS STUDY

Association A sees the only occurrence of *Cicatricosisporites chattensis* in this section. This is an important stratigraphic taxa as it is restricted to the Oligocene.

From Association B the base occurrence of *Favitricolporites microreticulatus* is seen, this is regarded as indicating a pre Oligocene age (Chateauneuf, 1980). This taxa can also be correlated to the Rupelian aged parts of other sections in this study, Association C of 80/14, Association A of 88/12, Association B of 77/7 and Association C of 21/28. The base of *Cupuliferoipollenites cingulum* subsp. *pusillus* is also recorded from Association C in 21/28 which is Rupelian in age. The base occurrence of *Corrusporis tuberculatus* is important here as Krutzsch (1962) and Wilkinson & Boulter (1980) regard this taxa as being restricted to a Middle Oligocene age.

Although *Echinosporis echinatus* has its top occurrence in Association C in this section, it was regarded as being of stratigraphical importance in the marine sections picking out Upper Rupelian aged sediments. While Krutzsch (1967c) regards the top occurrence of this taxa to indicate a Lower Miocene age in Germany, and Association B in 88/12 which is Rupelian also shows the top occurrence of this taxa.

Interestingly the top occurrence of both *Cupuliferoipollenites cingulum* subsp. *pusillus* and *Cupuliferoipollenites cingulum* subsp. *oviformis* in this association are seen to have their top occurrence recorded together in Association C of 77/7 and Association F of 80/14 which are of a Chattian age. The top occurrence of *Stereisporites (Stereisporites) stereoides* recorded from this association can be correlated to Association D of 77/7 and Association F of 88/12 and is thought to indicate a Chattian age. The base occurrences of taxa within this association suggest a different age here. *Trilites multivallatus* has its base occurrence in this association, this can be compared to Association C in 80/14 which is Rupelian. The base of *Cupuliferoipollenites cingulum* subsp. *fusus* can be compared to Association B of 16/16 which is also Rupelian. Significantly *Tricolporopollenites* sp. 1 shows some stratigraphical importance as the base of this taxa compares to Association B of 77/7, Association B of 21/28 and Association B of 16/16. The base of Algae sp. 1 seen here can be compared to Association C of 80/14 and Association D of 21/28 which are thought to be Rupelian in age.

The top occurrence in Association D of *Cleistosphaeridium* sp. 1 of Manum *et al.* (1989) was suggested to represent a Lower Miocene age (Manum *et al.* , 1989) but it has been recorded from older aged sediments here Association A of 16/16 which is Rupelian and Association D of 88/12 which is Chattian.

Trilites multivallatus is regarded by Wilkinson & Boulter (1980) to commonly occur in Middle Oligocene aged sediments and younger, the top occurrence of this taxa here corresponds to this, and can also be compared to Association D of 77/7 which is regarded as Chattian in age. The top occurrence of *Torosporis* spp. which is seen in this association is suggested to indicate an Oligocene age by Wilkinson & Boulter (1980) and Lower/Middle Oligocene age by (Chateauneuf, 1980). The top of this taxa can also be correlated to Association E in 16/16 which is Chattian in age. The top occurrence of *Trilites* spp. is recorded in this association and can be compared to Association F of 80/14 and Association F of 16/16 which are both Chattian in age.

A number of significant top occurrences are noted to occur within Association F. The top occurrence of *Nyssapollenites kruschi* subsp. *accessorius* from this association can be compared to Association E of 16/16 which is Chattian and the top of *Nyssapollenites satzveyensis* here can be correlated to Association D in 77/7 and Association E in 88/12 which are also Chattian. Gruas-Cavagnetto (1978) regards the top occurrence of *Tricolporopollenites viburnoides* in the Eocene although its top occurrence in this section compares well to the top occurrence in Association E of 77/7 and Association G of 21/28 which are of a Chattian age. Importantly the top occurrence of *Cyrillaceaepollenites megaexactus* is regarded as pre Upper Oligocene in age by (Vinken *et al.*, 1988) and top Oligocene by Chateauneuf (1980) and can be compared to Association D of 16/16 which is Chattian. The top occurrence of *Quercoidites microhenrici* can also be correlated to Association D of 16/16 which is Chattian along with Association C of 77/7, Association G of 80/14 and Association F of 21/28. This compares well to Chateauneuf (1980) who sees the top occurrence of this taxa as Upper Oligocene while Vinken *et al.* (1988) see this species ranging up into the Upper Miocene. Krutzsch (1970) regards the top occurrence of *Monocolpopollenites tranquillus* to be into the Miocene but a top here and in Association G of 21/28 indicates a Chattian local top. A top occurrence of the Cretaceous species *Tetracolpites reticulatus* of Srivastava (1966) is seen in this association along with isolated specimens form Association A of 16/16, Association C of 77/7 and Association F of 21/28 which is upto a Chattian age. The only occurrence of *Graminidites annulatus* seen in this association has some significance as Krutzsch (1966) records this species as being rare in the Oligocene and becoming more abundant into the Miocene-Pliocene. Also the only occurrence of *Verrucatosporites megabalticus* in this association can be correlated to Wilkinson & Boulter (1980) who regard this species as topping out in the Late Oligocene while Krutzsch (1966) sees this species into the Lower Miocene. This species is also known from Association E of 16/16 and Association G of 80/14 which is Chattian in age.

Limited data is available from Association G as this is the topmost sample of the section. Here the only occurrence of *Nyssapollenites kruschi* subsp. *pseudolaesus* can be compared to Association D of 77/7 which is Chattian. The only occurrence of *Verrucatosporites histiopteroides* seen here is also recorded from Association F in 21/28 which is Chattian, also a number of base occurrences of this taxa are recorded from Association C in 77/7 which is Chattian and Association B of 80/14 and 16/16.

These records compare well to those from the published literature. Where Krutzsch (1966) sees the base of this species in the Middle Oligocene with increasing abundances into the Upper Oligocene.

In conclusion the lower part of the section, including Association A to B represents a Rupelian age. The upper part of this section, Association C to G represents a Chattian age.

SECTION 77/7

ASSOCIATION A

This association is defined from two samples from the upper part of the kaolinitic unit from the interval between 125m to 120.13m.

Characteristic palynological features

Inaperturopollenites hiatus and *Laevigatosporites haardti* occur in abundant numbers. *Nyssapollenites kruschi* subsp. *analepticus* occurs in common numbers in this association. The taxa *Triporopollenites robustus* and *Retitricolpites retiformis* also occur in common numbers, the latter of which reduces in number upsection from the base of this association to rare at the top. *Alnipollenites verus* is present and *Tricolpopollenites* cf. *hians* is present upsection from the base of this association. Bisaccate pollen is also seen to occur in present numbers in Association B. A number of taxa occur in rare numbers these include *Intratriporopollenites microreticulatus, Triporopollenites coryloides, Gothanipollis gothanii, Tricolporopollenites viburnoides, Baculatisporites primarius* and *Verrucatosporites alienus.* Also a slight peak to rare in the numbers of *Tricolporopollenites edmundi* is seen.

Comments

Low numbers of grains per gram are seen, giving the lowest values recorded in the section. Low diversity values of just over 30 are also seen. The pollen sum for this sample is just over 100 giving results which are statistically viable.

Tops and Bases

Two taxa are recorded as having their only occurrence in this section, from this association:

125m	only occurrence of *Scolecosporites* spp.
120.13m	only occurrence of *Stereisporites (Stereisporites)* sp. 1

The first uphole occurrence of a number of taxa are recorded from this association:

125m	base *Intratriporopollenites ceciliensis*
	base *Cyrillaceaepollenites megaexactus*
	base *Polypodaceoisporites* spp.
	base *Ovoidites* spp.
120.13m	base *Inaperturopollenites dubius*
	base *Caryapollenites* spp.
	base *Momipites tenuipolus*
	base *Polyatriopollenites stellatus*
	base *Quercoidites microhenrici*
	base *Triatriopollenites rurensis*
	base *Tricolporopollenites edmundi*
	base *Tricolporopollenites pseudocingulum*

ASSOCIATION B

This association is defined from two samples from the lower part of the Carbonaceous Unit and covers the interval from 119.38m to 115.7m. Although at the base of this association a low pollen sum of less than 50 is recorded and is probably the cause of the apparent peak in the numbers of taxa such as *Triporopollenites robustus*, bearing this in mind, the overall characteristics of this assemblage are different therefore a new association is defined here.

Characteristic palynological features

The numbers of *Nyssapollenites kruschi* subsp. *analepticus* increase from common at the base of this association to abundant upsection. While the peak in the numbers of *Triporopollenites robustus* from rare to abundant at the base of this association then the decline to rare upsection from here is a statistical feature of the data due to the normalisation of the low pollen sums recorded. Upsection from the base of this association sees a marked increase in the numbers of bisaccate pollen from rare below to abundant upsection into this association. A characteristic reduction in the numbers of *Inaperturopollenites hiatus* from abundant to common upsection into the base of this association is seen. This is followed with the reduction in numbers of *Laevigatosporites haardti* which decline from abundant below to rare upsection into this association. The numbers of *Tricolpopollenites hians* show a significant increase within this association. Present to common numbers of *Tricolpopollenites* cf. *hians* are recorded within this association and the peak of *Trivestibulopollenites betuloides* at the base of this association is seen. Also a peak to present numbers of *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis* in the middle of the association is seen. A large number of rare taxa occur within this association. *Alnipollenites* *verus* shows a marked decline in numbers to absent/rare within this association. While the numbers of *Retitricolpites retiformis* are rare, showing a slight increase upsection through the association. A peak to rare occurrences of *Erecipites* spp. is seen at the base of this association and a peak of *Quercoidites microhenrici* is also seen at the base. Rare numbers of *Verrucatosporites favus* are noted and the only microplankton recorded in this association is *Tasmanites* spp., as single specimens. *Trilites multivallatus* and *Baculatisporites primarius* records are absent from this association.

Comments

The diversity is seen to increase upsection from less than 20 at the base of the association and increases to 40 upsection. The numbers of grains per gram are very low at the base of this association being less than 500 000, this number is seen to increase four fold upsection to over 2 000 000.

Tops and Bases

The only occurrence of two taxa are recorded from this association:

115.7m	only occurrence of *Polypodaceoisporites* sp. 1
	only occurrence of *Cupuliferoidaepollenites liblarensis* subsp. *fallax*

A number of taxa have been recorded for the first time upsection within this association:

115.7m	base *Nyssapollenites satzveyensis*
119.38m	base *Favitricolporites microreticulatus*
	base *Tricolporopollenites* sp. 1
	base *Momipites* spp.

ASSOCIATION C

This association is defined from four samples and covers the interval from 112m to 111.01m. This association is characterised by very high diversity figures of between 79 to 90 and a close similarity between the samples is shown by the cluster analysis dendrogram (enclosure 8).

Characteristic Palynological features

Laevigatosporites haardti and bisaccate pollen occur in abundant numbers in this association, as does *Inaperturopollenites hiatus* which is seen to increase in number into the middle of this association. Common taxa include *Nyssapollenites kruschi* subsp. *analepticus* and *Baculatisporites primarius*, the numbers of both decline upsection and the latter reduces in number from common to present. *Retitricolpites retiformis* occurs in common numbers in this association but is seen to increase significantly to abundant into the next association upsection. Other taxa occurring in present numbers include *Alnipollenites verus*. *Tricolpopollenites* cf. *hians* is present in this association and is seen to increase slightly in number into the next association upsection. *Triporopollenites robustus* and *Deltoidospora wolffi* occur in present numbers which decline slightly upsection through the association. The very high diversities recorded within this association are as a result of the large number of rare taxa present in this association. The last occurrence of the majority of *Cupuliferoidaepollenites* and *Cupuliferoipollenites* species are recorded from within this association. Rare occurrences of *Graminidites annulatus, Dicolpopollis kockeli, Pompeckjoidaepollenites subhercynicus, Micrhystridium fragile* and *M.* spp are seen. Overall the numbers of and diversity of fungi and microplankton in this association is greater than in any other association in the section.

Comments

As already noted very high diversity's between 79 and 90 are characteristic of this association and represent a peak compared to numbers of 40 to 42 recorded both uphole and downhole from here. The numbers of grains per gram reduce to less than 500 000 into the base of this association then increase to over 1 000 000 then decline steadily upsection.

Tops and Bases

A very large number of taxa are seen to occur for the last time uphole or as only recorded occurrences within the section from this association:

111.01m	top *Polyatriopollenites carpinoides*
	top *Cupuliferoipollenites cingulum* subsp. *oviformis*
	top *Cupuliferoipollenites cingulum* subsp. *pusillus*
	top *Dicolpopollis kockeli*
	top *Microthallites* spp.
	top Algae sp. 1
	top *Ovoidites* spp.
	top *Stereisporites* sp. 1
	top *Verrucingulatisporites treplinensis*
	top *Tricolporopollenites spinus*
	top *Cicatricosisporites dorogensis*
	top *Polypodaceoisporites* spp.
	top *Trilites corruvallatus*
	top *Trilites* sp. 1

	top *Plicatopollis* spp.
	only occurrence of *Juglanspollenites* spp.
	only occurrence of *Abiespollenites* spp.
	only occurrence of *Mediocolpopollis* spp.
111.03m	top *Graminidites annulatus*
	top *Caryapollenites* spp.
	top *Cupuliferoipollenites cingulum* subsp. *fusus*
	top *Microfoveolatisporis* spp.
	top *Quercoidites microhenrici*
	top *Tricolporopollenites pseudocingulum*
	only occurrence of *Liquidambarpollenites stigmosus*
	only occurrence of *Ulmipollenites undulosus*
	only occurrence of *Verrucatosporites megabalticus*
	only occurrence of *Tetracolpites reticulatus*
111.8m	top *Diporicellaesporites* spp.
	only occurrence of *Sequoiapollenites polyformosus*
	only occurrence of *Pesavis tagluensis*
	only occurrence of *Paralecaniella indentata*
	only occurrence of *Schizosporis* spp.
	only occurrence of *Kekryphalospora* spp.
	only occurrence of *Undulatisporites sculpturis*
112m	top *Momipites anellus*
	top *Microfoveolatosporis pseudodentatus*
	top Hyphae spp.
	top *Cicatricosisporites chattensis*
	only occurrence of *Micrhystridium lymense*
	only occurrence of *Micrhystridium stellatum*
	only occurrence of *Pediastrum* spp.
	only occurrence of *Veryhacium* spp.
	only occurrence of *Triatriopollenites aroboratus*
	only occurrence of *Triatriopollenites roboratus*

A number of taxa are recorded to occur for the first time uphole in this association:

111.03m	base *Verrucatosporites histiopteroides*
111.8m	base *Retitricolpites anguloluminosus*
	base *Triatriopollenites rurensis*
	base *Deltoidospora maxoides*
112m	base *Microthallites* spp.
	base *Microfoveolatisporites* spp.

base *Trilites* sp. 1

ASSOCIATION D

This association is defined from one sample at a depth of 110.6m.

Characteristic Palynological Features

The abundant taxa characterising this association are *Inaperturopollenites hiatus* which is seen to decrease in numbers into the base of this association and *Retitricolpites retiformis* which shows a significant increase in numbers from present to abundant at the base of this association. Taxa occurring in common numbers include *Nyssapollenites kruschi* subsp. *analepticus, Laevigatosporites haardti* and bisaccate pollen. While *Tricolpopollenites* cf. *hians* shows a significant increase in numbers at the base of this association from rare to common, then shows a decline upsection to rare into the next association upsection. *Alnipollenites verus* occurs in present numbers and *Tricolpopollenites hians* increases in number upsection slightly from rare to present. Rare taxa to be noted include *Triporopollenites robustus* and *Baculatisporites primarius* the latter of which reduces in number upsection.

Comments

A continuation of the high diversity's is seen here with a value of over 80 being recorded. Moderate figures of grains per gram of over 500 000 are seen.

Tops and Bases

A very large number of taxa are recorded for the last time upsection in this association:

110.6m top *Caryapollenites veripites*
top *Momipites coryloides*
top *Momipites tenuipolus*
top *Nyssapollenites satzveyensis*
top *Polyatriopollenites stellatus*
top *Intratriporopollenites ceciliensis*
top *Intratriporopollenites microreticulatus*
top *Pompeckjoidaepollenites subhercynicus*
top *Cupaneidites* spp.
top *Gothanipollis gothanii*
top *Favitricolporites microreticulatus*
top *Ilexpollenites iliacus*
top *Porocolpopollenites vestibulum*

top *Retitricolpites anguloluminosus*
top *Triatriopollenites rurensis*
top *Tricolporopollenites baculoferus*
top *Tricolporopollenites edmundi*
top *Tricolporopollenites viburnoides*
top *Camerozonosporites heskemensis*
top *Deltoidospora maxoides*
top *Deltoidospora wolffi*
top *Polypodiaceoisporites marxheimensis*
top *Trilites multivallatus*
top *Triplanosporites* spp.
top *Baculatisporites nanus*
top *Baculatisporites primarius*
top *Corrusporis tuberculatus*
top *Stereisporites (Stereisporites) stereoides*
top *Laevigatosporites discordatus*
top *Pluricellaesporites* spp.
top *Micrhystridium fragile*
top *Tasmanites* spp.
only occurrence of *Sparganiaceaepollenites* spp.
only occurrence of *Nyssapollenites kruschi* subsp. *pseudoleasus*
only occurrence of *Arecipites* spp.
only occurrence of *Triatriopollenites subtriangulus*
only occurrence of *Cicatricosisporites paradorogensis*
only occurrence of *Corrusporis granotuberculatus*
only occurrence of *Areoligera semicirculata*

ASSOCIATION E

This association is defined from one sample at a depth of 104m. This is the top most sample of the section occurring in the Glauconitic unit. This unit has been suggested to be of a lower to middle Miocene age from the work of Evans *et al.*, (in press).

Characteristic Palynological Features

The numbers of *Tricolpopollenites hians* increases markedly from present to abundant at the base of this association and the numbers of bisaccate pollen increase upsection into the base of this association from common to abundant while abundant numbers of *Inaperturopollenites* are also noted. *Laevigatosporites haardti* is the only taxa occurring in this association in common numbers. A number of taxa such as *Alnipollenites verus, Triporopollenites robustus* and *Spiniferites ramosus* subsp. *ramosus* occur in present numbers. While the numbers of *Nyssapollenites kruschi* subsp. *analepticus* decrease upsection from common to present into this association. An increase in the number of *Verrucatosporites balticus* upsection to present in this association is seen while a peak in the numbers of *Tricolporopollenites* sp. 1 to present also occurs in this association. A number of rare taxa occur in this association, these include *Tricolpopollenites* cf. *hians, Cupuliferoidaepollenites liblarensis* subsp. *liblarensis, Verrucatosporites histiopteroides, Echinosporis* sp. 1, *Verrucatosporites alienus, Verrucatosporites favus, Achomosphaera ramulifera, Systematophora placacantha* and *Micrhystridium* spp. This association sees the only absence in the taxa *Retitricolpites retiformis* from this section.

Comments

A pollen sum of over 100 in this association makes the data here statistically viable. The grains per gram values are low being at their lowest in the section. Also the diversity figure is seen to decline by over half to a value of just over 40.

The occurrence of marine palynomorphs along with a change in association characteristics and sedimentology to glauconitic sands with bivalves is indicative of a major break in the section between Association D and Association E.

Tops and Bases

A number of taxa are recorded for the only time in this association from this section:

104m only occurrence of *Achomosphaera ramulifera*
only occurrence of *Spiniferites ramosus* subsp. *ramosus*
only occurrence of *Systematophora placacantha*

BRIEF AGE COMPARISON OF 77/7 TO THE DATA IN THE PUBLISHED LITERATURE

The associations in this section are dominated by *Inaperturopollenites hiatus, Nyssapollenites kruschi* subsp. *analepticus, Laevigatosporites haardti* and bisaccate pollen with subordinate numbers of *Retitricolpites retiformis, Triporopollenites robustus, Tricolpopollenites hians, Monocolpopollenites tranquillus* and *Porocolpopollenites vestibulum.* The presence of stratigraphically significant taxa such as *Cicatricosisporites chattensis, Polyatriopollenites carpinoides, Corrusporis tuberculatus, Corrusporis granotuberculatus* and *Verrucatosporites* species along with abundance of the taxa above indicate these sediments to be of Oligocene age (Wilkinson & Boulter, 1980; Krutzsch, 1966). Precise dating of the association described in this section is limited by poor quality and content of the published zonation schemes although some stratigraphical significant tops and bases have been noted in this section and can be correlated to other sections.

A number of taxa from Association A such as the base occurrence of *Tricolporopollenites pseudocingulum* can be correlated to the Middle Oligocene of Vinken *et al.* (1988) and Wilkinson & Boulter (1980) and to Association D of 21/28 and Association B of 88/12 which are Rupelian in age. The base of *Triatriopollenites rurensis* correlates to the Lower Oligocene of Chateauneuf (1980) and to Association C of 80/14 which is Rupelian.

Association B sees the base occurrence of *Favitricolporites microreticulatus* this can be compared to a pre Upper Oligocene age by Chateauneuf (1980) and to the Rupelian aged sediments of Association C of 80/14, Association A of 88/12 and Association C of 21/28. The base of *Tricolporopollenites* sp. 1 can be compared to a Rupelian age of Association B in 21/28 and Association B in 80/14. Also the base of *Nyssapollenites satzveyensis* can be compared to Association C of 21/28 which is also thought to be Rupelian.

A very large number of top occurrences are recorded from Association C. The top occurrence of *Polyatriopollenites carpinoides* and *Graminidites annulatus* in this association suggests an age younger than Lower/Middle Oligocene which Krutzsch (1966) regards as the base occurrence of these taxa. The top occurrence of the former can also be correlated to the Chattian of 88/12 Association F. Vinken *et al.* (1988) records the topmost occurrence of *Dicolpopollis kockeli* in an Upper Chattian to Lower Miocene range, this compares well to the top occurrences of this taxa in Association G of 21/28 and Association G of 80/14. The top occurrence of *Verrucingulatisporites treplinensis* is of stratigraphical importance here, being regarded as Upper Oligocene in age (Wilkinson & Boulter, 1980) and can be compared to a Chattian age from Association D of 21/28 and Association G of 88/12. Importantly the top occurrence of *Tricolporopollenites spinus* noted in this association is suggested to represent a Middle Oligocene age (Wilkinson & Boulter, 1980) although the top occurrence of this taxa is recorded from Association C in 21/28 which is Rupelian. The top occurrence of *Cicatricosisporites chattensis* correlates to a Middle and especially Upper Oligocene age (Krutzsch, 1966; Wilkinson & Boulter, 1980). Chateauneuf (1980) regards the top occurrence of *Quercoidites microhenrici* to be Upper Oligocene. This compares well to the top occurrences in the Chattian recorded from Association D in 16/16, Association F in 21/28 and Association G in 80/14. *Liquidambarpollenites stigmosus* sees its only occurrence in Association D here, this correlates to Middle Oligocene of Wilkinson &

Boulter (1980) and to the Chattian of 80/14, Association D and 88/12, Association G. The only occurrence of *Verrucatosporites megabalticus* in this association can be compared to a Late Oligocene age as Wilkinson & Boulter (1980) regard the top most occurrence of this species at this age, although Krutzsch (1966) suggests a Middle Oligocene to Lower Miocene age. This species is also recorded from the Chattian of 16/16 Association E and 80/14 Association G. The top occurrence of *Momipites anellus* recorded in this association can be correlated to the Chattian of 21/28 Association D and of 16/16 Association E. Also a number of base occurrences have been recorded from Association C in this section. The base occurrence of *Verrucatosporites histiopteroides* is regarded as indicative of a Middle Oligocene age (Krutzsch, 1966) although it is also recorded in Association B of 16/16 and Association B of 80/14 which are Rupelian in age. The base occurrence of *Triatriopollenites rurensis* is regarded as Lower Oligocene in age by Chateauneuf (1980) and is recorded from Association C in 80/14. Although the base of *Trilites* sp. 1 in this association can be correlated to Association G in 80/14 which is Chattian in age.

A large number of top occurrences are recorded from Association D in this section. The top occurrence of *Intratriporopollenites microreticulatus* can be correlated to an Oligocene age (Wilkinson & Boulter, 1980) and to the Chattian of Association F in 21/28 and Association F of 88/12. The top occurrence of *Intratriporopollenites ceciliensis* correlates to Association F of 16/16 and Association H of 80/14 which are of a Chattian age. The top of the stratigraphically important taxa *Gothanipollis gothanii* seen in this association is suggested to correlate to an Upper Chattian to Miocene age (Vinken *et al.,* 1988). A Oligocene/Miocene boundary age is also suggested by Wilkinson & Boulter (1980) and Chateauneuf (1980) for the top occurrence of *Favitricolporites microreticulatus*. This species is also recorded from Association F of 16/16 and Association G of 80/14 which are topmost Chattian. A similar age of Upper Oligocene/Lower Miocene is suggested for the top occurrence of *Ilexpollenites iliacus* (Wilkinson & Boulter, 1980). The top occurrence of *Retitricolpites anguloluminosus* in this association can be compared to Association G of 21/28, Association G of 80/14 and Association E of 88/12 which are Chattian. A top occurrence of *Tricolporopollenites viburnoides* can be correlated to the Upper Oligocene of 21/28 (Association G) and 80/14 (Association F). Wilkinson & Boulter (1980) and Krutzsch (1966) both regard the top occurrence of *Corrusporis tuberculatus* as representing an Upper Oligocene age. This is confirmed with top occurrences of this taxa in Association E of 16/16 and Association D of 88/12 which are Chattian. *Cicatricosisporites paradorogensis* has its only occurrence in this association, and can be correlated to Association F of 16/16 and Association D of 21/28 which are Upper Oligocene, Chattian in age. The only occurrence of

Triatriopollenites subtriangulus can be compared to an only occurrence of this taxa in Association F of 88/12. Importantly, this association sees the only occurrence of the marine microplankton species *Areoligera semicirculata* which suggests an Upper Oligocene age. This species is restricted in its occurrence to the Oligocene (Powell, 1992) and shows a peak in its numbers in the Middle/Upper Oligocene aged sediments.

Association E in this section sees the only occurrence of a number of marine microplankton. *Systematophora placacantha* and *Spiniferites ramosus* subsp. *ramosus* indicate an age younger than the Middle Miocene (Aal biozone of Powell, 1992; Figure 6.1) and the presence of *Paralecaniella indentata* also suggests an age no younger than Lower to Middle Miocene (Figure 6.3).

In conclusion the basal part of the section, Association A is thought to represents a Rupelian age, Association B to D thought to represent a Chattian age and Association E represents the Miocene at the top of the section.

SECTION 73/36

ASSOCIATION A

This is the basal association in this section and occurs from the interval between 33.10m and 26.79m and is defined from 4 samples.

Characteristic Palynological features

The most striking feature of this association is the highly abundant numbers of *Inaperturopollenites hiatus* which increase upsection through the association from over 40% to over 70%. *Nyssapollenites kruschi* subsp. *analepticus* occurs in abundant numbers and declines to common upsection. Bisaccate pollen are also abundant in number in this association. Importantly the common taxa occurring within this association are *Retitricolpites retiformis* which increases in number from rare at the base to common upsection through the association and *Tricolpopollenites hians* which occurs in common numbers at the base of this association and declines upsection to present at the top of the association. While *T.* cf. *hians* occurs in rare numbers in this association. A large number of other taxa occur in rare numbers, this is a result of the high diversity recorded within this association. The more important rare taxa include *Alnipollenites verus, Boehlensipollis hohli, Gothanipollis gothanii, Monocolpopollenites tranquillus* and *Laevigatosporites haardti*. Other rare taxa such as *Inaperturopollenites dubious, Graminidites annulatus, Retitricolpites anguloluminosus, Baculatisporites primarius* and a slight peak to rare at the base, of *Tricolporopollenites edmundi* are recorded.

Comments

The diversity seen within this association is the highest for the section. It increases upsection through the association from just under 30 to a value of over 60 at the top. The numbers of grains per gram vary through this association with a high point in the middle of the association.

Tops and bases

A large number of taxa occur for the only time within this association from this section:

30.20m	only occurrence of *Intratriporopollenites instructus* only occurrence of *Compositoipollenites rhizophorous* subsp. *burghasungensis* only occurrence of *Dicolpopollis kockeli* only occurrence of *Reevesiapollis triangulus*

27.78m	only occurrence of *Compositoipollenites rhizophorous* subsp. *rhizophorous*
	only occurrence of *Echinosporis echinatus*
	only occurrence of *Ovoidites* spp.
	only occurrence of *Piceapollis* spp.
26.79m	only occurrence of *Cicatricosisporites chattensis*
	only occurrence of *Phthanoperidinium* spp.
	only occurrence of *Selenopemphix nephroides*
	only occurrence of *Svalbardella cooksoniae*
	only occurrence of *Thalassiphora pelagica*
	only occurrence of *Cyclopsiella* sp. B
	only occurrence of *Paralecaniella indentata*
	only occurrence of *Veryhacium* spp.

The first uphole occurrence of a large number of taxa are recorded within this association:

33.10m	base *Echitricolporites spinosus*
	base *Tricolporopollenites viburnoides*
	base *Pediastrum* spp.
30.20m	base *Liquidambarpollenites stigmosus*
	base *Momipites coryloides*
	base *Nyssapollenites kruschi* subsp. *accessorious*
	base *Pterocarya* type
	base *Graminidites annulatus*
	base *Boehlensipollis hohli*
	base *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis*
	base *Ilexpollenites iliacus*
	base *Ilexpollenites margaritatus*
	base *Monocolpopollenites tranquillus*
	base *Quercoidites microhenrici*
	base *Retitricolpites anguloluminosus*
	only occurrence of *Tricolporopollenites pseudocingulum*
	base *Lycododiumsporites* spp.
	base *Verrucatosporites favus*
	base *Verrucatosporites balticus*
	base *Schizosporis reticulatus*
27.78m	base *Sparganiaceaepollenites polygonalis*
	base *Corsinipollenites oculusnoctis*
	base *Intratriporopollenites ceciliensis*

base *Ulmipollenites undulosus*
base *Trivestibulopollenites betuloides*
base *Tricolporopollenites baculoferus*
base *Tricolporopollenites edmundi*
base *Cicatricosisporites dorogensis*
base *Stereisporites (Structisporis) infrareticulatus*
base *Verrucatosporites alienus*
base *Deltoidospora maxoides*
base *Polypodiaceoisporites marxheimensis*
base *Diporicellaesporites* spp.
base *Hyphae* spp.
base *Pluricellaesporites* spp.
base *Piceapollis* spp.
base *Sciadopityspollenites* spp.
base *Micrhystridium* spp.
26.79m base *Intratriporopollenites microreticulatus*
base *Arecipites* spp.
base *Trilites multivallatus*
base *Triplanosporites* spp.
base *Verrucatosporites histiopteroides*
base *Corrusporis tuberculatus*
base *Fusiformisporites* spp.
base *Microthallites* spp.
base *Pesavis tagluensis*
base *Tasmanites* spp.
base *Botryococcus* spp.
base Dinoflagellate fragment
base *Micrhystridium fragile*

ASSOCIATION B

This association has been defined from one sample. It occurs at a depth of 24.42m.

Characteristic Palynological Features

This association is dominated by the highly abundant numbers of *Inaperturopollenites hiatus* at over 70%. Numbers of *Retitricolpites retiformis* are common and the numbers of *Nyssapollenites kruschi* subsp. *analepticus* are seen to decline upsection into the base of this association to common numbers. The taxa *Tricolpopollenites hians* and *Deltoidospora wolffi* occur in present numbers. Characteristically *Alnipollenites verus* and *Laevigatosporites haardti* occur in rare numbers and bisaccate pollen show a dramatic upsection decline in numbers from abundant to rare into the base of this association. Other rare taxa include *Retitricolpites anguloluminosus, Tricolporopollenites* sp. 1 and *Baculatisporites primarius.* A number of taxa are noted by their absence from this association these are *Trivestibulopollenites betuloides, Polyatriopollenites carpinoides, Stereisporites (Stereisporites) stereoides, Intratriporopollenites* species and *Verrucatosporites* species. *Pluricellaesporites* spp. is the only species of fungi recorded and *Tasmanites* spp. is the only algae represented in this association.

Comments

This association is characterised by a low diversity. The diversity figure declines from over 60 below upsection to 25 into this association.

Tops and Bases

No base occurrences of taxa are recorded from within this association and only one taxa is recorded for the last time upsection in this association:

24.42m	top *Tasmanites* spp.

ASSOCIATION C

This association is defined from one sample at a depth of 22.15m.

Characteristic Palynological Features

This association sees the reduction in numbers of *Inaperturopollenites hiatus* to abundant from highly abundant below. Also significant uphole increases in the number of *Alnipollenites verus* from rare to abundant are recorded in this association. Both *Nyssapollenites kruschi* subsp. *analepticus* and *Retitricolpites retiformis* are seen to decline in number from common to rare while a peak in *Baculatisporites primarius* and *Triporopollenites coryloides* numbers from rare to common in this association is noted. *Tricolpopollenites hians* occurs in present numbers with *Laevigatosporites haardti* and bisaccate pollen increasing slightly in number upsection from rare to present. Rare taxa recorded from this association such as *Echitriporites* sp. 1, *Verrucatosporites balticus* and *V. megabalticus* are seen. A distinct absence of the occurrence of fungal, algal and microplankton species within this association is noted.

Comments

The diversity figures show a slight upsection increase in number into this association.

Tops and Bases

The last uphole occurrence of one taxa is recorded from this association:

22.15m top *Verrucatosporites histiopteroides*

The first uphole occurrence of two taxa are recorded from this association:

22.15m base *Camerozonosporites heskemsis*
base *Baculatisporites nanus*

ASSOCIATION D

This association is defined from three samples and occurs from 21.38 to 20.09m in depth.

Characteristic Palynological Features

Significant increases in the numbers of *Inaperturopollenites hiatus* from abundant to highly abundant and the numbers of *Nyssapollenites kruschi* subsp. *analepticus* from rare to abundant into this association are seen. The numbers of *Tricolpopollenites hians* show increases upsection to common at the base of this association then decline to present numbers at the top of this association. A significant decline in the numbers of *Alnipollenites verus* from abundant below to present at the base of this association then to rare up through the association is seen. With *Retitricolpites retiformis* increasing slightly from rare to present into this association and bisaccate pollen remaining in present numbers but increasing slightly upsection. A dramatic decline in the numbers of *Triporopollenites coryloides* and *Baculatisporites primarius* from common below to rare in this association is noted. *Deltoidospora wolffi* numbers increase from rare at the base to present at the top of this association. Other important rare taxa are listed here, *Boehlensipollis hohli, Cyrillaceaepollenites megaexactus, Tricolporopollenites baculoferus, Cicatricosisporites dorogensis* and *Laevigatosporites discordatus*. A single specimen of *Pterocarya* type is recorded in this association and the first constant but rare occurrence of *Tricolporopollenites* sp. 1 is noted. Also *Gleicheniidites senonicus, Lycopodium* spp., *Verrucatosporites balticus, V. favus, Hyphae* spp., *Micrhystridium fragile* and *Pediastrum* spp. occur in rare numbers.

Comments

Diversity decreases upsection into the base of this association then is seen to increase in number up through this association. This increase coincides with an increase in the number of grains per gram in the middle of this association giving the maximum number recorded for this section at over 20 000 000.

Tops and Bases

A number of taxa have their only occurrence within this section recorded from this association:

21.38m	only occurrence of *Momipites anellus*
20.90m	only occurrence of *Triatriopollenites confusus*
20.09m	only occurrence of incertae sedis A

A number of first uphole occurrences of taxa are recorded from within this association:

20.09m	base *Cyrillaceaepollenites megaexactus*
20.90m	base Algae sp. 1

ASSOCIATION E

This association is defined from four samples and occurs in the interval between 19.80 and 18.03m.

Characteristic Palynological Features

The numbers of *Laevigatosporites haardti* increase significantly from rare at the base of the association to abundant at the top. Bisaccate pollen also show upsection increases in numbers from present below to abundant into the base of the association, while numbers of *Inaperturopollenites hiatus* decline upsection from highly abundant to abundant through this association. *Nyssapollenites kruschi* subsp. *analepticus* occurs in common numbers through this association. While *Retitricolpites retiformis* peaks to common near the middle of the association. The numbers of *Alnipollenites verus* increase upsection from rare to present into this association then decline up through the association to rare again. The numbers of *Deltoidospora wolffi* increase upsection from rare to present into this association and a slight peak to present of *Stereisporites (Structisporis) intrareticulatus* in this association is seen. *Triporopollenites coryloides* increases from rare to present upsection from the base of this association. The first rare but constant *Intratriporopollenites microreticulatus* are recorded in this association and single specimens of *Corsinipollenites oculusnoctis* are noted to occur here. A large number of rare taxa occur within this association. These include *Graminidites annulatus, Boehlensipollis hohli, Cupanieidites* spp.. *Gothanipollis gothanii, Tricolporopollenites spinus, Baculatisporites primarius,* Algae sp. 1, *Pediastrum* spp., *Schizosporis reticulatus, Trilites multivallatus, Microthallites* spp. and *Microfoveolatosporites pseudodentatus.*

Comments

In this association diversity is high and constant at a level of over 50.

Tops and Bases

A number of last occurrences and only occurrences of taxa are recorded from this association:

19.80m	only occurrence of *Triatriopollenites subtriangulus*
19.31m	top *Verrucatosporites balticus*
	only occurrence of *Cicatricosisporites* spp.
18.75m	only occurrence of *Platycaryapollenites* spp.
	only occurrence of *Areoligera semicirculata*
	top *Lycopodiumsporites* spp.
18.03m	top *Micrhystridium fragile*
	top *Micrhystridium* spp.
	top *Cyrillaceaepollenites megaexactus*
	top *Corrusporis tuberculatus*
	only occurrence of *Corsinipollenites oculusnoctis minor*
	only occurrence of *Micrhystridium* cluster

A number of first uphole occurrences of taxa are recorded from this association:

19.80m	base *Sequoiapollenites polyformosus*
	base *Tricolporopollenites spinus*
19.31m	base *Nyssapollenites satzveyensis*
	base *Corrusporis granotuberculatus*
18.75m	base *Cicatricosisporites paradorogensis*
	base *Microfoveolatosporites pseudodentatus*

ASSOCIATION F

This association occurs in the interval between 17.22m and 15.18m and is defined from two samples.

Characteristic Palynological Features

A significant upsection increase is seen in the numbers of *Laevigatosporites haardti* from abundant below to highly abundant into the base of the association. This is followed by a significant decline uphole in the numbers of this species to common at the top of the association. *Inaperturopollenites hiatus* is seen to occur in abundant numbers and bisaccate pollen numbers show a reduction upsection from abundant below to common into this association. The numbers of *Nyssapollenites kruschi* subsp. *analepticus* increase from common to abundant up through this association and *Alnipollenites verus* numbers increase from rare below to common into this association. *Tricolpopollenites hians* declines in number from present to rare upsection into the base of this association. This is mirrored by the upsection decline in numbers of *Retitricolpites retiformis* from present to rare into the base of this association. A peak in the numbers of *Graminidites annulatus* to present is recorded in this association. The numbers of *Triporopollenites coryloides* and *Triporopollenites robustus* are present and rare respectively. A significant increase in the numbers of *Baculatisporites primarius* upsection from present to common in this association is seen. A number of rare taxa are recorded from this association, these include *Boehlensipollis hohli, Quercoidites microhenrici, Cicatricosisporites dorogensis, Verrucatosporites alienus* and *Sciadopityspollenites* spp. A peak in single specimens of *Corsinipollenites oculusnoctis* occurs at the base of this association and the first constant but rare occurrence of *Arecipites* spp. is noted here. No fungi have been recorded and only one species of algae, namely *Botryococcus* spp. is seen here.

Comments

Diversity is seen to reduce from over 50 to 30-35 uphole into the base of this association. The top of this association sees slightly higher numbers of grains per gram.

Tops and Bases

One taxa is recorded for the last time uphole within this association:

17.22m	top *Botryococcus* spp.

ASSOCIATION G

This association occurs at a depth of 14.15m and is defined from one sample.

Characteristic Palynological Features

The numbers of *Inaperturopollenites hiatus* show a slight peak in this association but remain abundant in number, while a peak in the number of *Alnipollenites verus* to abundant in this association from present below is noted. *Nyssapollenites kruschi* subsp. *analepticus* decreases in number upsection from abundant to common into this association. *Laevigatosporites haardti* decreases slightly in number upsection into this association but remains common. *Baculatisporites primarius* reduces in number upsection from common to present into the base of this association, with bisaccate pollen falling significantly in number from present to rare upsection into the base of this association. *Retitricolpites retiformis* is rare occurring as single specimens and *Graminidites annulus* is rare in number reducing from the peak noted downsection to common into this association. Both *Triporopollenites coryloides* and *Triporopollenites robustus* decline in number upsection to the base of this association from present to rare. *Pesavis tagluensis* is also rare in occurrence and no *Polyatriopollenites carpinoides, Tricolpopollenites hians* and *T.* cf. *hians* are recorded as occurring in this association.

Comments

Diversity is seen to decline upsection from just over 30 to just over 20 at the base of this association. The number of grains per gram also declines upsection in this association.

Tops and Bases

No top or base occurrences of taxa are recorded from within this association.

ASSOCIATION H

This association has been defined from four samples and occurs between the interval at 12.65m and 10.86m.

Characteristic Palynological Features

Significant reductions in the numbers of *Alnipollenites verus* from abundant to rare at the base of this association is noted along with the peak in numbers of *Baculatisporites primarius* from rare at the base of this association upsection to abundant in the middle. The base of this association sees a peak in the numbers of *Nyssapollenites kruschi* subsp. *analepticus* from rare below to abundant and *Inaperturopollenites hiatus* declines upsection from abundant to common into the base of the association. The numbers of *Laevigatosporites haardti* are common and seen to decline slightly upsection through the association. A peak in numbers from rare to present in this association is seen from the taxa *Intratriporopollenites microreticulatus* and *Momipites coryloides.* *Triporopollenites coryloides* and *Triporopollenites robustus* are similar, increasing in number from rare to present at the base of the association then declining to rare in the middle of the association then peaking to abundant and common respectively at the top of the association. The numbers of *Deltoidospora wolffi* increase from rare to present up into the base of this association and *Stereisporites (Stereisporites) stereioides* peaks from rare to present in the middle of the association. Bisaccate pollen increases in number from rare below to present/common upsection into this association. A number of rare taxa occur in this association. *Retitricolpites retiformis, Boehlensipollis hohli, Quercoidites microhenrici, Corrusporis granotuberculatus* and *Laevigatosporites discordatus* occur in rare numbers. *Baculatisporites nanus* increases in number upsection from absent to rare into the base of this association. An absence of fungal taxa is noted here.

Comments

Diversity increases upsection from a value of 20 below to 40 at the base of the association and then shows a general decline to less than 30 up through the association.

Tops and Bases

A large number of last uphole occurrences of taxa are seen to occur within this association:

12.65m	top *Momipites tenuipolus*
	top *Camerozonosporites heskemsis*
	top *Polypodiaceoisporites marxheimensis*
	top *Trilites multivallatus*
	only occurrence of *Caryapollenites triangulus*
	only occurrence of *Caryapollenites simplex*
	only occurrence of *Milfordia incerta*
	only occurrence of *Baculatisporites* spp.
	only occurrence of *Microfoveolatisporites tuemmlitzensis*
12.22m	top *Ulmipollenites undulosus*
	top *Gothanipollis gothanii*
11.17m	top *Liquidambarpollenites stigmosus*
	top *Corsinipollenites oculusnoctis*
	top *Graminidites annulatus*
	top *Tricolporopollenites viburnoides*
	top *Triplanosporites* spp.
	top *Stereisporites (Structisporis) intrareticulatus*
10.86m	top *Trivestibulopollenites betuloides*
	top *Verrucatosporites favus*
	top *Sciadopityspollenites* spp.

ASSOCIATION I

This association is defined from one sample at a depth of 10.35m.

Characteristic Palynological Features

The increase in number upsection of *Alnipollenites verus* from rare to abundant into the base of this association is characteristic. Also a significant reduction in the numbers of *Triporopollenites coryloides* and *Triporopollenites robustus* from common/abundant below to rare upsection at the base of this association is seen. *Inaperturopollenites hiatus* increases in number upsection to abundant into this association from common below. *Baculatisporites primarius* occurs in common numbers and *Nyssapollenites kruschi* subsp. *analepticus* reduces in number upsection to common in this association from abundant below. *Laevigatosporites haardti* also declines in number upsection slightly although remains common. Bisaccate pollen in this association occurs in present/common numbers. A slight increase is noted in the numbers of *Monocolpopollenites tranquillus* from rare to present upsection into this association. A number of rare taxa are recorded within this association these include *Tricolpopollenites hians,* Algae sp. 1, *Tricolporopollenites* sp. 1, *Ilexpollenites iliacus* and *Tricolpopollenites* cf. *hians.*

Comments

An increase in diversity upsection from under 30 to over 45 into the base of this association is recorded. And a slight increase in the numbers of grains per gram upsection into this association is also noted.

Tops and Bases

A large number of last uphole occurrences of taxa are seen to occur within this association:

10.35m	top *Sparganiaceaepollenites polygonalis*
	top *Momipites coryloides*
	top *Nyssapollenites satzveyensis*
	top *Intratriporopollenites cecilensis*
	top *Boehlensipollis hohli*
	top *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis*
	top *Cupuliferoidaepollenites liblarensis* subsp. *fallax*
	top *Cupuliferoipollenites cingulum* subsp, *pusillus*
	top *Cupuliferoipollenites cingulum* subsp. *oviformis*
	top *Ericipites* spp.
	top *Quercoidites microhenrici*
	top *Cicatricosisporites dorogensis*

top *Cicatricosisporites paradorogensis*
top *Corrusporis granotuberculatus*
top *Stereisporites (Stereisporites) stereioides*
top *Verrucatosporites alienus*
top *Schizosporis reticulatus*
top *Triporopollenites coryloides*
top *Triporopollenites robustus*
top Algae sp. 1
only occurrence of *Mediocolpopollis* spp.

ASSOCIATION J

This association is defined from the topmost sample of this section which is at a depth of 8m.

Characteristic palynological Features

The most striking feature of this association is the upsection increase in numbers of *Monocolpopollenites tranquillus* form present below to abundant into this association. The numbers of *Alnipollenites verus* remain abundant into this association. Commonly occurring taxa include *Inaperturopollenites hiatus* which is seen to decline in numbers upsection to common in this association from abundant below and a reduction in the numbers of *Baculatisporites primarius* from common to rare into this association are seen. Hyphae spp. increase in number from absent below to present into this association and the number of *Tricolpopollenites hians* increases slightly upsection to present into this association from rare below. *Laevigatosporites haardti* declines slightly in number uphole from common to present and bisaccate pollen numbers decline significantly from common to rare uphole into this association. A number of taxa occur in rare numbers these include *Retitricolpites retiformis, Sequoiapollenites polyformosus, Cupanieidites* spp., *Cupuliferoipollenites cingulum* subsp. *fusus, Tricolporopollenites edmundi, Tricolporopollenites spinus* and *Pediastrum* spp. The numbers of fungal species occur from absent below to rare upsection into this association is seen.

Comments

Diversity reduces upsection slightly from under 45 to 40 in this association. Also a significant increase in the number of grains per gram, 10 fold, upsection is seen into this association.

Tops and Bases

One taxon is recorded as occurring for the last time upsection within this association:

8m top *Pediastrum* spp.

BRIEF AGE COMPARISON OF THE SECTION 73/36 DATA TO THE PUBLISHED LITERATURE AND OTHER SECTIONS.

Association A sees the only occurrence of a large number of taxa. *Dicolpopollis kockeli* has its only occurrence in this association, this can be correlated to a Middle Eocene to Middle Oligocene age range suggested for this species by Krutzsch (1967c) and Wilkinson & Boulter (1980). *Intratriporopollenites instructus* is thought to range from Early Oligocene to Miocene, although Mai (1961) and Krutzsch (1967c) suggest this species is rare in the Middle/Upper Oligocene, becoming more common into the Miocene. The only occurrence of *Reevesiapollis triangulus* can be compared to an only occurrence of this species in Association D of 78/1. The important taxa *Echinosporis echinatus* which is thought to top in the Miocene (Krutzsch, 1967c) is recorded in the topmost Chattian, Association F of 16/16 and Association E of 21/28, although the terrestrial section 88/12 has a top occurrence of this taxa in Association B. The taxon *Cicatricosisporites chattensis* is restricted to the Middle Oligocene (Krutzsch, 1966; Wilkinson & Boulter, 1980) and is seen to have its only occurrence in this association and Association A of 78/1. The dinoflagellate cysts occurring in this section such as *Phthanoperidinium* spp. are thought to be no younger than zone Lxa (Powell, 1992) which is Chattian and zone D14 (Costa & Manum, 1988) which is also Chattian. *Svalbardella cooksoniae* has been shown to range from the Eocene/Oligocene boundary (Manum *et al*, 1989), the Middle Rupelian Wgo/Pcr zone of Powell (1992), the Lower Chattian of Costa & Manum (1988) and older than tops recorded in Association C of 16/16 which is Rupelian. The only occurrence of *Thalassiphora pelagica* here is thought to represent an age older than top occurrences of this taxa in the Tva zone of Powell (1992) which is Late Oligocene/Lower Miocene and the Oligocene/Miocene boundary (Costa & Manum, 1988). The presence of this species also correlates to top occurrences in Association C of 21/28 and Association F in 16/16. The top occurrence of *Paralecaniella indentata* is thought to be in the Lower Miocene (Fig. 6.3), therefore the only occurrence of this taxa in this section must be older than Miocene and older than the top occurrence recorded in Association G of 16/16. Also Association A has a large number of base occurrences the more important stratigraphically can give an idea of age here. The base of *Boehlensipollis hohli* is important, as this taxa is reported to be restricted to Middle Oligocene (Krutzsch, 1966; Vinken *et al.*, 1988; Chateauneuf, 1980; Wilkinson & Boulter, 1980 and Gorin, 1975) and can be correlated to Association C of 80/14 which is Rupelian. The base occurrence of a *Graminidites* species is important as this genera is published to just appear in the record in the Lower/Middle Oligocene (Krutzsch, 1967c). The taxon *Tricolporopollenites pseudocingulum* has its base in this association although Thomson & Pflug (1953) record the base of this taxon in the Palaeocene. While Vinken *et al.* (1988) and Wilkinson & Boulter (1980) regard the base occurrence of this taxon as suggesting a Middle Oligocene age. This can also be correlated to bases seen in Association B of 88/12 which is Rupelian, Association D of 21/28 which is Rupelian and Association A of 77/7 which is also Rupelian. The base of *Trivestibulopollenites betuloides* here is recorded as being Lower Oligocene in age (Ollivier-Pierre, 1980) and can be correlated to bases seen in Rupelian aged sediments from Association A of 16/16 and Association C of 21/28. The presence of *Tricolporopollenites baculoferus* also indicates an Oligocene age (Wilkinson & Boulter, 1980). The base of *Trilites multivallatus* can be correlated to Association C of 78/1 and Association C of 80/14 and to the Middle Oligocene of Krutzsch (1967c), Thomson & Pflug (1953) and Wilkinson & Boulter (1980). The oldest age of *Corrusporis tuberculatus* is regarded by Krutzsch (1962) and Wilkinson & Boulter (1980) as being Middle Oligocene which is comparable to the Rupelian floras of Association C of 80/14 and Association B of 78/1. The base occurrence of a number of *Verrucatosporites* species is seen at this level. The first uphole appearance of *Verrucatosporites histiopteroides* is well documented, and regarded by Krutzsch (1966) and Wilkinson & Boulter (1980) as occurring in the Middle Oligocene. This occurrence can be correlated with the Rupelian of Association B in 16/16 and Association B of 80/14 and the Chattian of Association C of 77/7. The base of *Verrucatosporites balticus* suggests an Oligocene age (Wilkinson, 1979; Wilkinson & Boulter, 1980; Krutzsch, 1966; Evans *et al.*, 1991), but corresponds to Association C of 80/14 which is Rupelian and Association F of 21/28 which is Chattian. A Middle Oligocene age has been suggested for the base occurrence of *Verrucatosporites favus* (Krutzsch, 1967c; Wilkinson & Boulter, 1980; Evans *et al.*, 1991) and can be compared to the Rupelian of Association B in 88/12. The base occurrence of *Verrucatosporites alienus* can be correlated to the Lower Oligocene (Krutzsch, 1967c) which can also be compared to the Rupelian of Association B in 80/14. A Lower Eocene to Upper Miocene range is published by Wilkinson & Boulter (1980) for the taxa *Corsinipollenites oculusnoctis* whos base occurrence is recorded in Association A here. The base of the fungi *Pluricellaesporites* spp. can be compared to occurrences recorded from the Rupelian aged Association B of 16/16 and Association C of 21/28 and a single occurrence in Association D of 88/12. A Middle Oligocene age is suggested as the base occurrence of *Liquidambarpollenites stigmosus* by Thomson & Pflug (1953) and Wilkinson &

Boulter (1980). This can be compared to Rupelian bases recorded in Association C of 80/14 for this taxa.

Association C sees the base occurrence of *Camerozonosporites heskemensis*. The range of this taxa is published as Upper Eocene to Middle Oligocene (Wilkinson & Boulter, 1980) although Krutzsch (1963a) regards this taxa as being characteristic of Lower/Middle Oligocene sediments. While the top occurrence of *Verrucatosporites histiopteroides* for the section here is compared to an Upper Oligocene age (Krutzsch, 1966) and a Chattian age when compared to the other sections in this study, Association G in 78/1, Association F in 21/28 and Association C in 77/7.

From Association D the only stratigraphically important taxa is the base occurrence of *Cyrillaceaepollenites megaexactus*. This is regarded as pre Upper Oligocene in age and can be correlated to the Chattian of Association E in 80/14 and Association D of 21/28 for the base of this taxa.

In the literature *Tricolporopollenites spinus* is restricted to a Middle Oligocene age (Krutzsch, 1962; Wilkinson & Boulter, 1980; Ollivier-Pierre, 1980) and is seen to have its base occurrence in Association E in this section. The base occurrence of *Corrusporis granotuberculatus* is suggested to be restricted to Upper Oligocene (Krutzsch, 1966; Wilkinson & Boulter, 1980) although an occurrence in the Rupelian of Association B of 80/14 conflicts with this. An age range from Rupelian to Miocene is suggested by Krutzsch (1967c) and Wilkinson & Boulter (1980) for *Microfoveolatosporites pseudodentatus* whos base occurrence occurs in Association E of this section. The only occurrence of *Triatriopollenites subtriangulus* here can be correlated to only occurrences reported from Association D of 77/7 and Association F of 88/12 which are both Chattian. An Upper Oligocene age is suggested for the top of the taxa *Verrucatosporites balticus* (Krutzsch, 1967c; Chateauneuf, 1980) this compares well to the Chattian age for this event seen in Association F of 21/28. The top occurrence of *Corrusporis tuberculatus* is published by Krutzsch (1967c) and Wilkinson & Boulter (1980) to represent an Upper Oligocene age. This correlates to the Association C of 80/14 which is Rupelian in age and Association E of 16/16, Association D of 77/7 and Association D of 88/12 which are Chattian. The only occurrence of the microplankton taxa *Areoligera semicirculata* in this association is important and can be correlated to a similar occurrence in Association D of 77/7 which is Chattian. The top of this taxa is reported in the literature as indicating an Upper Oligocene age by Powell (1992) although a peak in abundance of the taxa in middle Upper Oligocene is the more probable age of this event recorded here.

Association H sees a number of top occurrences of taxa. Krutzsch (1963a) and Wilkinson & Boulter (1980) record *Camerozonosporites heskemensis* as a taxa stratigraphically restricted to an Upper Eocene to Middle Oligocene age. The top occurrence of this taxa in this association can be interpreted as indicating a Middle

Oligocene age. The top of *Trilites multivallatus* is regarded as indicating a Middle Oligocene age (Wilkinson & Boulter, 1980) and can be correlated to the Chattian of Association D in 77/7. *Caryapollenites triangulus* ranges from the Lower Eocene of Krutzsch (1966) to the Eocene/Oligocene boundary (Vinken *et al.*, 1988) and has its only occurrence in this association extending the published range of this species into the Upper Oligocene. *Milfordia incerta* has a range from the Lower Eocene to the top Rupelian (Vinken *et al.*, 1988) and has its only occurrence from Association H in this section. The top occurrence of *Liquidambarpollenites stigmosus* seen in this association has a published last appearance of Upper Oligocene (Wilkinson & Boulter, 1980; Thomson & Pflug, 1953). While the top occurrence of *Trivestibulopollenites betuloides* in this association can be correlated to the Chattian in Association H of 80/14 and Association D of 88/12. Vinken *et al.* (1988) suggests this taxa as having a top occurrence ranging above the Oligocene/Miocene boundary. *Corsinipollenites oculusnoctis* has its top occurrence in this association. This event occurs in the Upper Oligocene (Wilkinson & Boulter, 1980; Chateauneuf, 1980) and at the Oligocene/Miocene boundary (Pacltova, 1960). It can be correlated to Association E of 16/16 which is Chattian. Similarly the top occurrence of *Gothanipollis gothanii* is thought to represent a topmost Oligocene age (Vinken *et al.*, 1988) and can be correlated to the Chattian of Association D in 77/7. The top of *Tricolporopollenites viburnoides* can be correlated to the Chattian of Association G of 21/28, Association F of 80/14, Association D of 77/7 and Association F of 78/1. The taxa *Boehlensipollis hohli* has a restricted stratigraphic range in the Middle Oligocene (Wilkinson & Boulter, 1980; Krutzsch, 1966; Chateauneuf, 1980; Gorin, 1975) although Sittler & Schuler (1975) report the top occurrence of this species into the Upper Oligocene as is seen here in this association. The taxa *Cupuliferoipollenites cingulum* subsp. *pusillus* and *Cupuliferoipollenites cingulum* subsp. *oviformis* both top out in this association together and this can be compared to Association C of 78/1 which is Rupelian, Association C of 77/7 which is Chattian and Association F of 80/14 which is Chattian, where these taxa also top out together. The former can also be correlated to tops in Association E of 16/16, Association D of 88/12 and Association F of 80/14 which are Chattian in age. *Quercoidites microhenrici* has its top occurrence in this association this can be compared to tops seen in the Chattian of Association G in 80/14, Association F in 78/1, Association D in 16/16, Association F in 21/28 and Association C in 77/7. Chateauneuf (1980) also places this event in the Upper Oligocene but Vinken *et al.* (1988) sees this taxa extending up into the Miocene. *Cicatricosisporites paradorogensis* occurs for the last time uphole in this association, it is regarded as being representative of an Oligocene age (Wilkinson & Boulter, 1980) and can be correlated to the Chattian in Association D of 77/7 and Association F of 16/16 and the Rupelian of Association D in 21/28. An Upper

Oligocene age (Krutzsch, 1967c) to a Oligocene/Miocene age (Krutzsch, 1963a) is suggested for the top occurrence of *Corrusporis granotuberculatus* which is recorded from this association. The top occurrence of *Verrucatosporites alienus* recorded from this association is thought to suggest an Oligocene age (Wilkinson & Boulter, 1980) up to a Lower Miocene age (Krutzsch, 1967c). While the top occurrence of *Stereisporites (Stereisporites) stereoides* can be compared to Chattian aged parts of other sections (Association D in 77/7 and Association F in 88/12). The top occurrence of *Nyssapollenites satzveyensis* can also be correlated to Chattian aged parts of the other sections (Association F of 78/1, Association D of 77/7 and Association E of 88/12). Ollivier-Pierre (1980) places the top occurrence of *Sparganiaceaepollenites polygonalis* at an Upper Oligocene age, this compares well to the top occurrence of this taxa in this association. And finally the top occurrence of *Intratriporopollenites ceciliensis* can be correlated to a Chattian age interpreted from the other sections studied (Association H of 80/14, Association F of 16/16 and Association D of 77/7).

In conclusion the lower part of the section, Association A to D represents a Rupelian age whiles the upper part of the section Association E to J represents a Chattian age.

LOUGH NEAGH SECTION

ASSOCIATION A

This association has been defined from three samples.

Characteristic Palynological Features

This association is dominated by abundant numbers of *Nyssapollenites kruschi* subsp. *analepticus* which are seen to increase slightly upsection and *Alnipollenites verus* which varies in number from abundant to highly abundant in the middle of the association. While *Laevigatosporites haardti* increases from common to abundant into the middle of this association then declines upsection to rare at the top of the association. *Tricolpopollenites hians* is seen to increase from present to common upsection from the base of this association while *Inaperturopollenites hiatus* declines in number from common to present upsection through this association. The taxa *Quercoidites microhenrici* occurs in present numbers and *Triporopollenites robustus* and *Tricolporopollenites* sp. 1 vary from rare to present numbers within this association. A large number of rare taxa occur within this association and these include *Momipites tenuipolus, Nyssapollenites kruschi* subsp. *accessorious, Retitricolpites retiformis, Tricolpopollenites* cf. *hians, Plicatopollis* spp., *Favitricolporites microreticulatus, Tricolporopollenites spinus* and bisaccate pollen.

Tops and Bases

A number of last uphole occurrences or only occurrences of taxa are recorded within this association:

12-2	only occurrence of *Corsinipollenites oculusnoctis*
11-2	only occurrence of *Inaperturopollenites distichiforme*
10-3	only occurrence of *Caryapollenites simplex*
	top *Platycaryapollenites* spp.

A number of taxa are seen to occur for the first time uphole within this association:

11-2	base *Platycaryapollenites* spp.
	base *Nyssapollenites kruschi* subsp. *pseudolaesus*
	base *Nyssapollenites satzveyensis*
	base *Triporopollenites coryloides*
	base *Baculatisporites primarius*
	base *Laevigatosporites discordatus*
10-3	base *Intratriporopollenites ceciliensis*
	base *Intratriporopollenites microreticulatus*
	base *Tricolporopollenites baculoferus*
	base *Stereisporites (Stereisporites) stereoides*
	base *Camerozonosporites heskemensis*
	base *Trilites multivallatus*
	base *Baculatisporites nanus*

ASSOCIATION B

This association has been defined from three samples.

Characteristic Palynological Features

This association is characterised by a dominance of *Inaperturopollenites hiatus* which increases in number from present at the base to abundant at the top of the association. While the numbers of *Alnipollenites verus* decline from highly abundant to abundant upsection to the top of the association and *Nyssapollenites kruschi* subsp. *analepticus* which declines in number from abundant at the base of the association to present/common upsection. Common taxa include *Laevigatosporites haardti* which increases upsection from rare at the base of the association. *Retitricolpites retiformis, Tricolpopollenites* cf. *hians, Nyssapollenites satzveyensis* and *Triporopollenites coryloides* occur in rare numbers. The numbers of *Tricolpopollenites hians* decline upsection to rare from common below and the numbers of *Triporopollenites robustus* reduce to rare and *Quercoidites microhenrici* reduces from present to rare upsection. Other rare taxa include *Tricolporopollenites spinus*, *Verrucatosporites favus*, *Monocolpopollenites tranquillus*, *Diporicellaesporites* spp., *Tricolporopollenites baculoferus* and *Tricolporopollenites viburnoides*.

Tops and Bases

One taxa is recorded to occur for the last time uphole in this association:

8-3 top *Polyatriopollenites carpinoides*

A number of taxa are recorded to occur for the first time uphole in this association:

8-3 base *Inaperturopollenites dubious*
base *Gothanipollis gothanii*
base *Baculatisporites* spp.
6-1 base *Momipites tenuipolus*
base *Retitricolpites anguloluminosus*
base *Triplanosporites* spp.
base *Diporicellaesporites* spp.
base *Pluricellaesporites* spp.

ASSOCIATION C

This association is defined from five sample.

Characteristic Palynological Features

The numbers of *Laevigatosporites haardti* remain abundant while *Nyssapollenites kruschi* subsp. *analepticus* becomes dominant increasing in number from common in the association below to abundant upsection into this association. The dominance of *Alnipollenites verus* decreases from abundant below to rare into this association and *Inaperturopollenites hiatus* decreases in number from rare into the base of this association then increases in number upsection. *Retitricolpites retiformis* shows an important increase in numbers from rare below to common uphole in this association. Also *Quercoidites microhenrici* increases from rare below to common upsection into the middle of this association. The numbers of *Tricolpopollenites* cf. *hians* increase upsection and the numbers of *Tricolporopollenites pseudocingulum* increase to present at the top of the association from rare at the base. The taxa *Triporopollenites robustus* increases in number from rare to present into the base of this association. *Dicolpopollis kockeli* peaks in numbers from absent to present at the base of this association. The numbers of *Verrucatosporites favus* increase from rare below and in the base of this association to present upsection. *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis* peaks to common at the base of this association from rare. Numbers of *Arecipites* spp. increase from rare at the base to common in the middle of this association then decline to the top of this association. *Monocolpopollenites tranquillus* increases in number into this association but remains rare. Other rare taxa include *Gothanipollis gothanii, Cyrillaceaepollenites megaexactus, Favitricolporites microreticulatus*, *Triporopollenites aroboratus, Pediastrum* spp. and bisaccate pollen.

Tops and Bases

A large number of last uphole occurrences of taxa are recorded from this association:

5-28	only occurrence of *Ericipites* spp.
	only occurrence of *Triatriopollenites roboratus*
	only occurrence of *Triatriopollenites subtriangulus*
	only occurrence of fungal fruiting body
5-5	only occurrence of *Sequoiapollenites polyformosus*
	only occurrence of *Cupanieidites* spp.
5-1	top *Triatriopollenites rurensis*
	top *Polyatriopollenites carpinoides*
	top *Tricolporopollenites baculoferus*
	top *Cupuliferoidaepollenites liblarensis* subsp. *fallax*
	top *Cupuliferoipollenites cingulum* subsp. *fusus*
	top *Camerozonosporites heskemensis*
	only occurrence of *Corrusporis granotuberculatus*
	top *Polypodiaceoisporites marxheimensis*
	top *Baculatisporites primarius*
4-1	top Algae sp. 1
	top *Diporicellaesporites* spp.
	top Hyphae spp.
	only occurrence of *Pediastrum* spp.
3-1	top *Intratriporopollenites ceciliensis*
	top *Intratriporopollenites microreticulatus*
	top *Ilexpollenites margaritatus*
	top *Pluricellaesporites* spp.
	only occurrence of *Deltoidospora maxoides*
	top *Gleicheniidites senonicus*
	top *Trilites multivallatus*
	top *Triplanosporites* spp.
	top *Baculatisporites nanus*

A large number of first uphole occurrence of taxa are seen to occur within this association:

5-28	base *Verrucatosporites balticus*
	base *Momipites coryloides*
	base *Dicolpopollis kockeli*
	base Hyphae spp.
	base *Sciadopitysporites* spp.
5-5	base *Gleicheniidites senonicus*
	base *Ilexpollenites margaritatus*
	base *Mediocolpopollis* spp.
	base Algae sp. 1
5-1	base *Trivestibulopollenites betuloides*
3-1	base *Momipites anellus*

ASSOCIATION D

This association has been defined from two samples.

Characteristic Palynological Features

The dominant taxa in this association are *Nyssapollenites kruschi* subsp. *analepticus* which occurs in abundant numbers and *Inaperturopollenites hiatus* which increases in number upsection from present below to common/abundant in this association. The numbers of *Retitricolpites retiformis* remain at present/common numbers. Bisaccate pollen is seen to peak in number from rare to present at the base of this association and *Mediocolpopollis* spp. peaks to present at the top of the association. The numbers of *Monocolpopollenites tranquillus* increase from rare below to present upsection into this association. While the numbers of *Triporopollenites robustus* decline from present below to rare into this association and *Verrucatosporites favus* reduces slightly from present below to rare into the base of this association. This is mirrored by the reduction in numbers of *Laevigatosporites haardti* from common to present here. The numbers of *Arecipites* spp. reduce upsection from present below to rare at the base of this association then increase to the top of the section. The numbers of *Cupuliferoidaepollenites liblarensis* subsp. *liblarensis* are seen to decline to rare into this association. Other rare taxa recorded include *Alnipollenites verus, Tricolporopollenites spinus, Porocolpopollenites vestibulum, Pesavis tagluensis* and *Tasmanites* spp.

Tops and Bases

A number of last uphole occurrences and only recorded occurrences of taxa occur within this association:

2-8	top *Cyrillaceaepollenites megaexactus*
	top *Dicolpopollis kockeli*
	top *Stereisporites (Stereisporites) stereoides*
	top *Microfoveolatosporites* spp.
	top *Verrucatosporites alienus*
	top *Verrucatosporites balticus*
1-20	top *Favitricolporites microreticulatus*
	only occurrence of *Ovoidites* spp.
	only occurrence of *Pesavis tagluensis*
	only occurrence of *Scoleosporites* spp.
	only occurrence of *Tasmanites* spp.

The associations in this section are dominated by *Laevigatosporites haardti, Inaperturopollenites hiatus, Alnipollenites verus, Retitricolpites retiformis* and *Polyatriopollenites carpinoides* with subordinate numbers of *Nyssapollenites kruschi* subsp. *analepticus, Monocolpopollenites tranquillus, Porocolpopollenites vestibulum, Tricolpopollenites hians* , *T.* cf. *hians, Verrucatosporites* species and bisaccate pollen. The presence of stratigraphically significant taxa indicate these sediments to be of Oligocene age (Wilkinson & Boulter, 1980).

CORRELATIVE EVENTS IN THE TERRESTRIAL SEQUENCES

LOCAL BASIN CORRELATION

SEA OF THE HEBRIDES

Three boreholes in this study are located within the Sea of the Hebrides Basin, 80/14 and 88/12 from the Little Minch Basin and 78/1 from the Canna Basin. The location of these sections within one basin and there geographical proximity (figure 3.2) make these sections an ideal starting point for correlating the terrestrial sequences of this study. As already discovered from the marine pollen and spore data, correlation and boundary lines can be picked out by multiple events. It is the major changes in patterns and abundances of taxa rather than the top and base ranges of taxa that is concentrated on with the microplankton correlations.

A number of Units P1 to P4 have been identified in the terrestrial sequences of this study. P1 represents the Rupelian aged part of the sequence, P2 represents the Lower Chattian, P3 represents the Upper Chattian and P4 represents Miocene aged parts of the sequence (see figure 7.1).

In the following section a number of correlative events are picked out from the data and the characteristics of the events described. Attention must be drawn to the fact that although, for example the P1/P2 boundary here represents the Rupelian/Chattian boundary, P2/P3 the Lower Chattian/Upper Chattian boundary and P3/P4 the Oligocene/Miocene boundary, that this applies to the sections studied in this project only. Therefore without detailed and comparative work on the Stratotype material one cannot be definite that these events represent the 'true' boundaries but are rather those of the localised boundaries for the British Isles material studied here.

P1/P2 Boundary

A major correlative boundary can be seen to run through all of the sections from the Sea of the Hebrides Basin (Enclosures 5, 6 and 7). The level of this event is seen at the base of Association D in 80/14, the base of Association D in 88/12 and the base of Association C in 78/1 (figure 7.1). This boundary is characterised by:

i) an increase in the numbers of reworked taxas

ii) a decline in the numbers of *Verrucatosporites* especially in 80/14

iii) increasing numbers of *Laevigatosporites haardti*

iv) increasing numbers of bisaccate pollen especially in 80/14 and 78/1 compared with the numbers below

v) a reduction in the numbers of *Cupuliferoidaepollenites, Cupuliferoipollenites* and *Cyrillaceaepollenites* in all the sections here, compared with higher numbers below.

vi) a reduction in the numbers of *Porocolpopollenites vestibulum, Tricolporopollenites edmundi* and *Tricolporopollenites pseudocingulum* in all the sections compared with much higher numbers below

vii) an increase in the numbers of *Polyatriopollenites carpinoides* in 80/14 and 88/12 compared with much lower numbers below. This is comparable to the increase of *Arecipites* sp. in 88/12.

viii) increases in the numbers of taxa such as *Triporopollenites coryloides, Triporopollenites robustus* and *Trivestibulopollenites betuloides* especially in 80/14 and 78/1

ix) declining numbers of *Retitricolpites retiformis* in 80/14

x) increasing diversity in 80/14 and 88/12

A note must be made of *Deltoidospora wolffi* which shows an influx in 80/14, 78/1 and 88/12 at this boundary.

The gamma ray signature at this level, the Rupelian/Chattian boundary, shows a characteristic 'hot' spike. This is especially apparent in the 80/14 and 78/1 section where gamma ray data was available (figures 4.1 and 4.3) and occurs at a depth of 74.10m and 134.5m respectively. Although no gamma ray data for 88/12 is available the occurrence of plant fragments, lignites and finer grained sediments at a level of 41.40m to 41.65m, could possibly indicate a 'hotter' area marking the boundary in this section. Sedimentologically this boundary is also marked by a coarse grained sand layer in 80/14 at a depth of 74.10m to 74.14m (figure 4.1).

P2/P3 Boundary

A second more discrete correlative event (P2/P3 boundary) can be seen across the basin, and is thought to represent the Lower Chattian/Upper Chattian Boundary in this area. The level of this boundary occurs at the base of Association H in 80/14, the base of Association F in 78/1 and the base of Association G in 88/12 (figure 7.1). The changes characterising this event upsection are:

i) a further increase in the numbers of bisaccate pollen which is seen from all the sections

ii) the two sections from the Little Minch Basin show an increase in *Inaperturopollenites* and *Laevigatosporites* at this level while a reduction in the numbers of *Alnipollenites* is noted. A further reduction in the numbers of *Retitricolpites retiformis* also occurs.

iii) in general the sections 78/1 and 88/12 both show an increase in the numbers of spores above this boundary.

iv) increasing numbers of *Nyssapollenites kruschi* subsp. *analepticus* seen in 78/1

v) increasing numbers of or the top of the *Deltoidospora wolffi* influx seen in 78/1 and 88/12

The P2/P3 boundary in the 88/12 section is regarded as representing a more significant break in time. Little to no variation in the data is seen between P2 and P3 in this section compared to 80/14 and 78/1 therefore it is assumed that the part of the section represented by Association F and G in 80/14 is not present in 88/12. This absence of sediments is based on the lack of the *Alnipollenites* increase that is seen in 80/14 (Association F and G) and in 78/1 (Association G) and the decline in *Laevigatosporites* that is seen in 80/14 (Association F and G) and in 78/1 (Association G) which is also not picked up in the 88/12 section.

SOLAN BANK HIGH

The next terrestrial sequence to be correlated is the sequence from the 77/7 borehole which is from the Solan Bank High area north of the Scottish mainland. Using the same criteria as for the Sea of the Hebrides area a number of correlative events were identified.

P1/P2 Boundary

Again this correlative event can be seen through this sequence as well as in the Sea of the Hebrides Basin sequences. In this section the event is seen to occur at the base of Association B (figure 7.1). This boundary is characterised upsection by:
i) the base level of the influx of *Deltoidospora wolffi* (also seen in the Sea of the Hebrides sequences)
ii) increases in the number of reworked taxas (also seen in the Sea of the Hebrides sequences)
iii) a decline in the number of *Verrucatosporites* species (also seen in 80/14)
iv) increasing numbers of bisaccate pollen (also seen in 80/14 and 78/1)
v) increasing numbers of *Triporopollenites robustus* and *Trivestibulopollenites betuloides* (also seen in 80/14 and 78/1)
vi) increases in the numbers of *Tricolpopollenites hians*
vii) increases in the numbers of *Tricolporopollenites pseudocingulum* and *T.* sp.1
viii) increasing numbers of diversity and grains per gram (the former is also seen in 80/14 and 88/12)

The poor gamma ray data for this section does not enable a gamma 'spike' to be identified at the boundary level here as was possible for the Sea of the Hebrides sections. This boundary is seen to occur at a level which falls within the 'Carbonaceous Unit' of Evans *et al.* (in press). The boundary is suggested to occur at the top of a fine sand unit below a lignite band (c. 119.4m). This boundary can also picked up at this level from the dendrogram produced from the cluster analysis performed on this data (enclosure 8)

P2/P3 Boundary

This boundary was clearly recognised in the Sea of the Hebrides Basins but is not represented in this sequence.

P3/P4 Boundary

A major boundary event, the Oligocene/Miocene boundary, occurring in this section is seen below the base of Association E. This is the topmost association of the section (figure 7.1). This event is characterised by upsection:
i) increases in the numbers of bisaccate pollen
ii) increases in the number of *Tricolpopollenites hians*
iii) increases in the number of *Verrucatosporites* species
iv) the presence of taxa ranging up into the Miocene such as *Achomosphaera ramulifera, Spiniferites ramosus* subsp. *ramosus* and *Systematophora placacantha*
v) increases in the number of *Micrhystridium* spp.
vi) increases in the numbers of *Triporopollenites coryloides*

vii) declining numbers of *Deltoidospora wolffi*

This event occurs at the base of Association E, this corresponds to the boundary between the 'Mudstone unit' and 'Glauconitic unit' of Evans *et al.* (in press). This suggests the boundary here to be at a depth of about 110.2m.

SOUTHERN WESTERN BRITISH ISLES

Two sections namely well 28 from Northern Ireland and borehole 73/36 from the Stanley Bank Basin occur in the southern part of the Western British Isles and are considered separately for correlation from the northern Western British Isles sections. Again a number of correlative events can be seen throughout these sequences.

P1/P2 Boundary

This event occurs at the base of Association E in 73/36 and is not recorded from the well 28 section (figure 7.1). This boundary is characterised by:

i) the base level of the influx of *Deltoidospora wolffi* (also seen in the Sea of the Hebrides sections and 77/7)
ii) increasing numbers of reworking (also seen in the Sea of the Hebrides sections and 77/7)
iii) increases in the numbers of bisaccate pollen (also seen in 80/14, 78/1 and 77/7)
iv) increases in the numbers of *Triporopollenites robustus, T. coryloides* and *Trivestibulopollenites betuloides* (also seen in 80/14, 78/1 and 77/7)
v) increasing numbers of *Laevigatosporites haardti* (also seen in the Sea of the Hebrides sections)
vi) increasing numbers of *Tricolporopollenites* sp. 1 (also seen in 77/7) and *Porocolpopollenites vestibulum* (also seen in the Sea of the Hebrides sections)
vii) increases in the number of *Polyatriopollenites carpinoides* (also seen in 80/14 and 88/12)
viii) increasing numbers of *Boehlensipollis hohli*
ix) decreasing numbers of *Inaperturopollenites hiatus* (also seen in 77/7 and 78/1)
x) declining numbers of *Retitricolpites retiformis* (also seen in 80/14)

It is important to note here that the low numbers of *Inaperturopollenites hiatus* recorded at the base of the well 28 section are regarded as representing a P2, Lower Chattian, age equivalent. The change from abundant/highly abundant numbers of this species in the Rupelian to common/abundant in the Chattian is marked in this section, a similar decline in the numbers of this species at this boundary is also noted in 88/12.

The P1/P2 boundary can be picked out in the 73/36 data from the cluster analysis results, although clustering into the Rupelian and Chattian aged sections here is at a lower level than seen between the P2/P3 Boundary (enclosure 9). The laminated claystone sediments here above a red coloured siltstone layer also pick out this boundary at a level of 20.03 to 19.80m.

P2/P3 Boundary

This event occurs at the base of Association J in 73/36 and again is seen not to occur in the well 28 section (figure 7.1). This boundary is characterised by:

i) decreasing numbers of *Retitricolpites retiformis* (also seen in the Sea of the Hebrides sections)
ii) increasing numbers of *Monocolpopollenites tranquillus* and *Arecipites* species
iii) increasing numbers of *Alnipollenites verus*
iv) increasing numbers of Hyphae spp.

As mentioned earlier the cluster analysis for the data from this section picks out or distinguishes between the Lower Chattian and Upper Chattian sediments at a higher level than it distinguishes the Rupelian from the Chattian (enclosure 9).

The sections 73/36 and well 28 show clear local correlations. Well 28 is a much smaller section than 73/36. These two sections can be directly correlated to each other with well 28 being thought to represent and age within the P2 age of the 73/36 section. The Association B/C boundary in well 28 correlates directly to the Association G/H boundary of 73/36 (figure 7.1). This is based on the distinct changes in *Alnipollenites verus, Triporopollenites robustus* and *Arecipites* spp. Also Association D of well 28 correlates to Association I of 73/36, this is based on *Monocolpopollenites tranquillus*.

P2 subdivision

Within the P2 unit two further events are seen to occur. These can be correlated between the sections in this study and are, the *Laevigatosporites* event and the *Baculatisporites* event.

Laevigatosporites event (P2a)

This event generally occurs below the *Baculatisporites* event (P2b) although is seen to be absent from the 88/12 section and occurs at a coincident level with the *Baculatisporites* event in the 77/7 sequence. The *Laevigatosporites* event occurs at the base of Association F in 80/14, the base of Association E in 78/1, the base of

Association F in 73/36, within Association C in well 28 and in Association C of 77/7 (figure 7.1). This event is characterised by:

i) increases in the numbers of *Laevigatosporites haardti* (seen in all the sections)
ii) declining numbers of *Tricolpopollenites hians* and *T.* cf. *hians* (seen in 80/14, 78/1 and 73/36)
iii) declining numbers of *Retitricolpites retiformis* (seen in 80/14, 78/1 and 73/36)
iv) decreasing numbers of bisaccate pollen (seen in 80/14 and 78/1)
v) decreasing numbers of *Inaperturopollenites hiatus* (seen in 78/1, 73/36 and well 28)
vi) increasing numbers of *Deltoidospora wolffi* (seen in 78/1 and well 28)
vii) increases in the numbers of *Verrucatosporites* species (seen in well 28, and 80/14)
viii) low numbers of grains per gram (seen in 80/14, 78/1, 77/7 and 73/36)
ix) increases in variance values (seen in 80/14 and 78/1)

Baculatisporites event (P2b)

This event generally occurs stratigraphically above the *Laevigatosporites* event (P2a) but within the P2 unit. The level of this event occurs at the base of Association G in 80/14, the base of Association F in 78/1, the base of Association F in 88/12, within Association C in 77/7, within Association H in 73/36 and the base of Association D in well 28 (figure 7.1). This event is characterised by:

i) increasing numbers of *Baculatisporites* spp. (seen in 80/14, 78/1, 88/12, 77/7 and well 28) and significant increases in *Baculatisporites primarius* (seen in 88/12 and 73/36)
ii) increases in the number of bisaccate pollen (seen in 80/14, 78/1, 73/36 and well 28)
iii) increases in the numbers of *Polyatriopollenites carpinoides* (seen in 80/14 and 77/7) and *Arecipites* spp. (seen in 88/12)
iv) increases in the numbers of *Monocolpopollenites tranquillus* (seen in 80/14, 88/12, 77/7 and well 28)
v) increasing numbers of *Tricolpopollenites* cf. *hians* (seen in 78/1 and well 28)
vi) increases in the number of *Stereisporites (Stereisporites) stereioides* (seen in 73/36 and 88/12)
vii) declining numbers of *Verrucatosporites* species (seen in well 28 and 80/14)
viii) the top level of the *Deltoidospora wolffi* influx (seen in 78/1 and 73/36)
ix) high diversities of taxas (seen in 77/7 and 78/1)

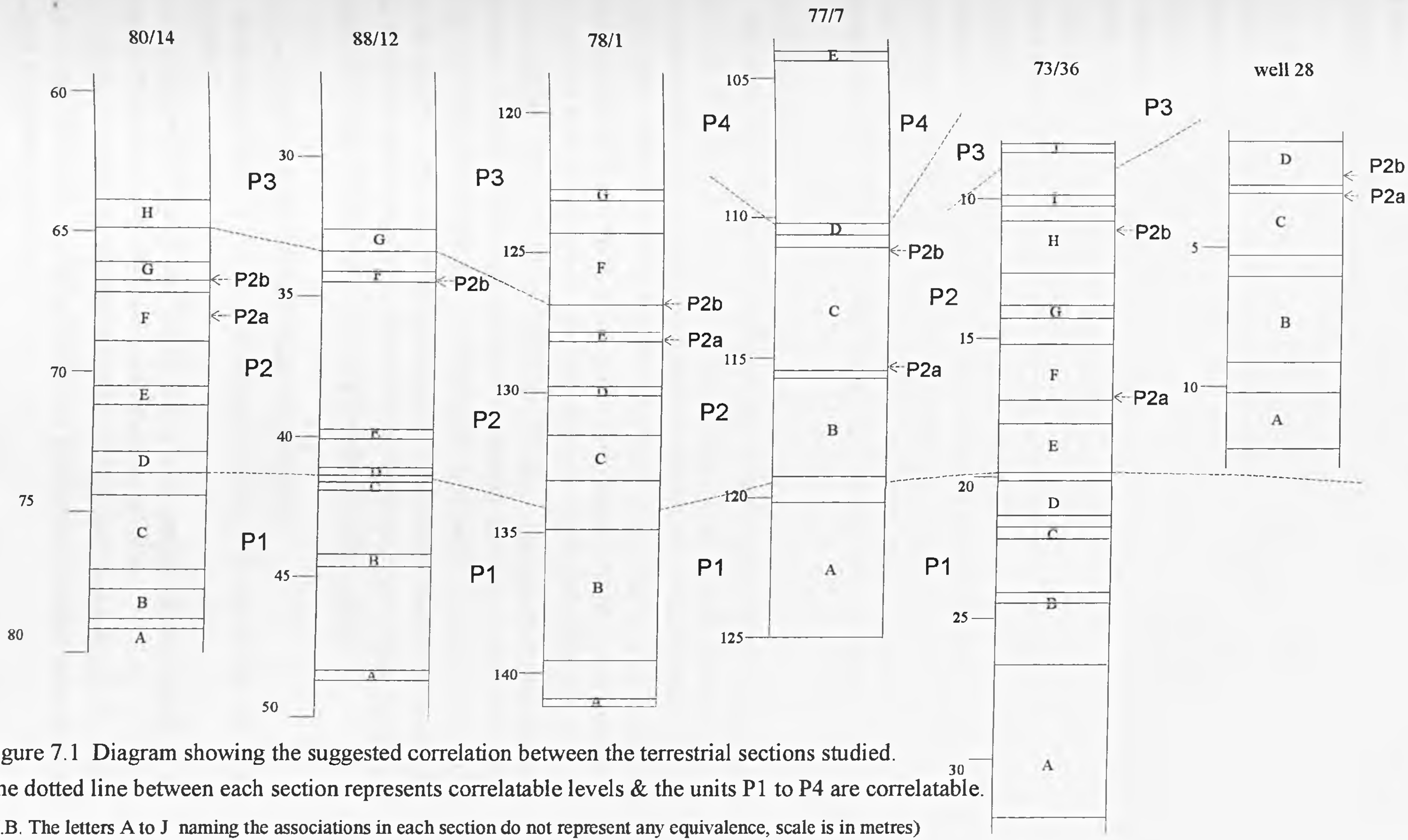


Figure 7.1 Diagram showing the suggested correlation between the terrestrial sections studied.
The dotted line between each section represents correlatable levels & the units P1 to P4 are correlatable.
(N.B. The letters A to J naming the associations in each section do not represent any equivalence, scale is in metres)

ABSOLUTE AGES INFERRED FROM THE CORRELATION OF THE TERRESTRIAL AND MARINE POLLEN EVENTS

A number of pollen and spore events have been defined and described in the previous section and it has been shown that these events enable correlation between the terrestrial sections. This correlation has been shown to be possible on both a local scale i.e. within individual basins such as the Sea of the Hebrides Basin, but also on a larger scale over a wider geographical extent in this case encompassing the Western British Isles area.

One of the major aims of this study is to use the correlative events defined from the pollen and spore profiles of the terrestrial sequences and then to compare them to the chronologically and biostratigraphically constrained North Sea pollen profiles (Chapter 6). From this chronologically constrained section absolute ages can be placed upon these events from which the correlation between the terrestrial sequences have been based. Therefore absolute ages can be interpolated for the P1 to P4 correlative events here by comparison to the North Sea marine data (figure 7.2).

P1/P2 Boundary

This boundary which has been described fully in the previous section is regarded as the most distinctive correlative boundary recognised through all of the terrestrial sequences (where present) and represents the Rupelian/Chattian Boundary in this study area. The Unit P1/P2 boundary is clearly evident in both of the marine sequences and is seen to occur at the base of Association D in 16/16 and the base of Association E in 21/28 (figure 7.2). This event has been dated precisely using the microplankton present in the associations and their comparisons to the published literature, zonation schemes and magnetostratigraphy (Haq *et al.* (1987) to give a Rupelian/Chattian boundary age of 30Ma which corresponds to an age of 28.283Ma on the updated Cande & Kent (1995) timescale. The pollen profiles for this interval in the North Sea when compared to those of the terrestrial sequences show a number of similarities to the characteristics previously described for this boundary :

Section 16/16 and 21/28: P1/P2 boundary characteristics

i) declining numbers of *Tricolporopollenites edmundi* (also seen in the Sea of the Hebrides)

ii) increasing numbers of *Polyatriopollenites carpinoides* (also seen in 80/14, 88/12, well 28, 73/36) and increasing numbers of Arecipites (21/28)

iii) increasing numbers of *Triporopollenites coryloides* (also seen in 80/14, 78/1, 77/7, well 28 and 73/36) and increasing numbers of *Trivestibulopollenites betuloides* (also seen in 77/7, 80/14 and 78/1)

iv) base of the influx of *Deltoidospora wolffi* (also seen in the Sea of the Hebrides, 77/, 73/36 and well 28)
v) declining numbers of *Retitricolpites retiformis* (also seen in 80/14 and 73/36)

Section 16/16: P1/P2 Boundary characteristics:
i) declining numbers of *Cupuliferoidaepollenites, Cupuliferoipollenites* and *Cyrillaceaepollenites* species (also seen in Sea of the Hebrides)
ii) increase in the numbers of *Tricolpopollenites hians* (also seen in 77/7)

Section 21/28: P1/P2 Boundary characteristics:
i) increasing numbers of *Triporopollenites robustus* (also seen in 80/14, 78/1, 77/7, well 28 and 73/36)
ii) increasing numbers of *Laevigatosporites haardti* (also seen in Sea of the Hebrides, well 28 and 73/36)

The Rupelian/Chattian boundary of the section 16/16 is seen to occur at a depth of 3875 ft, this level is marked by the characteristic gamma ray spike (figure 4.6) and a change in lithology from siltstone below to claystones above. This boundary is also picked out clearly from the cluster analysis data (figure 6.2a) this shows the break in section between Association C and D indicated by the phenon line P2 which picks out two clusters representing Rupelian and Chattian aged sediments.

The Rupelian/Chattian Boundary in the 21/28 section is clearly denoted at a depth of 3030 ft, this is marked by a significant unconformity (figure 4.7). This boundary is also picked up by a peak in the gamma ray response curve (figure 4.7) and the cluster analysis results (figure 6.2b).

P2/P3 Boundary

A second more subtle boundary, which is described fully in the previous section, has been recorded from a number of the terrestrial sequences in this study. It is only the larger and more complete marine sequence that is seen to encounter the P2/P3 boundary here and it occurs at the top of Association E in 16/16 and corresponds to a slight peak in the gamma ray curve here.

A number of pollen events noted from the terrestrial sequence that characterise this boundary and have been described. Further to this a number of similar pollen events from the marine sequence enable these data to be correlated together. The characteristic pollen events seen in the marine section are detailed below here along with correlation to the terrestrial sequences.

16/16: P2/P3 Boundary characteristics:

i) increases in the numbers of bisaccate pollen (also seen in 88/12 and 78/1)
ii) increases in the number of *Inaperturopollenites hiatus* (also seen in 80/14, 88/12 and 78/1)
iii) declining numbers of *Tricolpopollenites* cf. *hians* (also seen in 88/12)
iv) a slight increase in numbers or the top of the *Deltoidospora wolffi* influx (also seen in 80/14, 88/12 and 78/1)
v) increasing numbers of *Sequoiapollenites polyformosus* (also seen in 80/14, 78/1 and 73/36)
vi) increases in the numbers of *Triporopollenites coryloides* (also seen in 80/14)
vii) increases in the numbers of *Nyssapollenites kruschi* subsp. *analepticus* (also seen in 80/14 and 78/1)
viii) increases in the numbers of *Momipites coryloides*

Subsequent to the correlation of the pollen events between the terrestrial and marine sequences, it is possible to determine absolute dates for these events. The absolute dating is achieved from the precise dating of the pollen events described for both the terrestrial and marine. Then comparing the marine pollen events to the marine microplankton data which has previously been dated using biostratigraphy and Haq *et al.* (1987) (figures 6.5 and 6.6). Here an absolute age of 25.496Ma is indicated (figure 7.2) for this event.

P3/P4 Boundary

The borehole 77/7 from the Solan Bank High area is suggested to be the only terrestrial section in this study that penetrates into Miocene aged sediments. This major boundary, P3/P4, is equivalent to the Oligocene/Miocene boundary and this event is seen at the base of Association E in 77/7. The pollen events characterising this boundary have been described earlier. The larger of the two marine sequences, namely 16/16, also spans across the Oligocene/Miocene boundary, this occurs between Association F and Association G in 16/16. The pollen events characterising this boundary in the marine sequences show a number of similarities to the pollen events at this level in the terrestrial sequence and are characterised by:
i) increasing numbers of bisaccate pollen and *Sciadopityspollenites* (also seen in 77/7)
ii) increases in the numbers of *Triporopollenites coryloides* (also seen in 77/7)
iii) increases in the numbers of *Tricolpopollenites hians* (also seen in 77/7)
iv) increasing numbers of *Michrystridium* spp. (also seen in 77/7)
v) declining numbers of *Deltoidospora wolffi* (also seen in 77/7)

This event is characterised by a change in lithology (figure 4.6) from claystones below to a glauconitic sand layer above. This sand layer above marks the onset of

Miocene sedimentation in this area and occurs at a depth of 3578 ft. Also a shift to the right in the gamma ray curve marks this boundary event.

From the correlation of the terrestrial pollen events to the marine pollen event absolute ages for this boundary can be inferred. This boundary is seen to occur at an age of 24.230Ma (figures 6.6 and 7.2).

P2 sub events

Two subevents within unit P2 can be seen. They have been fully described from the terrestrial sequences in the previous section. The pollen and spores characterising these sub events can again be compared directly to the pollen and spore data from the marine sections, here one of these events can be picked up, namely P2a. A number of marked similarities characterising the terrestrial pollen and spore events are noted below and this enables more detail for the correlation of the terrestrial and marine sections here and possibly a more refined absolute dating.

P2a event:

The lower stratigraphical event P2a occurs at a depth of 3640 ft in Association E of 16/16 and at 2910 ft in Association G of 21/28 (figure 7.2). The characteristics and their similarities to the same events from the terrestrial sequences are briefly noted below:

i) increasing numbers of *Laevigatosporites haardti* (seen in all the sections)
ii) declining numbers of *Tricolpopollenites* cf. *hians* (also seen in 80/14, 78/1, 73/36 and 16/16)
iii) declining numbers of *Retitricolpites retiformis* (also seen in 80/14, 78/1, 73/36, 16/16 and 21/28)
iv) increases in the numbers of *Deltoidospora wolffi* (also seen in 78/1, well 28 and 16/16)
v) declining numbers of *Inaperturopollenites hiatus* (also seen in 78/1, 73/36, well 28 and 21/28)
vi) significant increases in the variance value (also seen in 80/14, 78/1, 16/16 and 21/28)
vii) final peak in the numbers of *Echinosporis echinatus* (only from 16/16 and 21/28)
viii) increasing numbers of *Tricolpopollenites hians* (only from 16/16 and 21/28)

An absolute age of 25.823Ma for this event is suggested by the comparison of the pollen events to the marine microplankton data (figures 6.6 and 7.2).

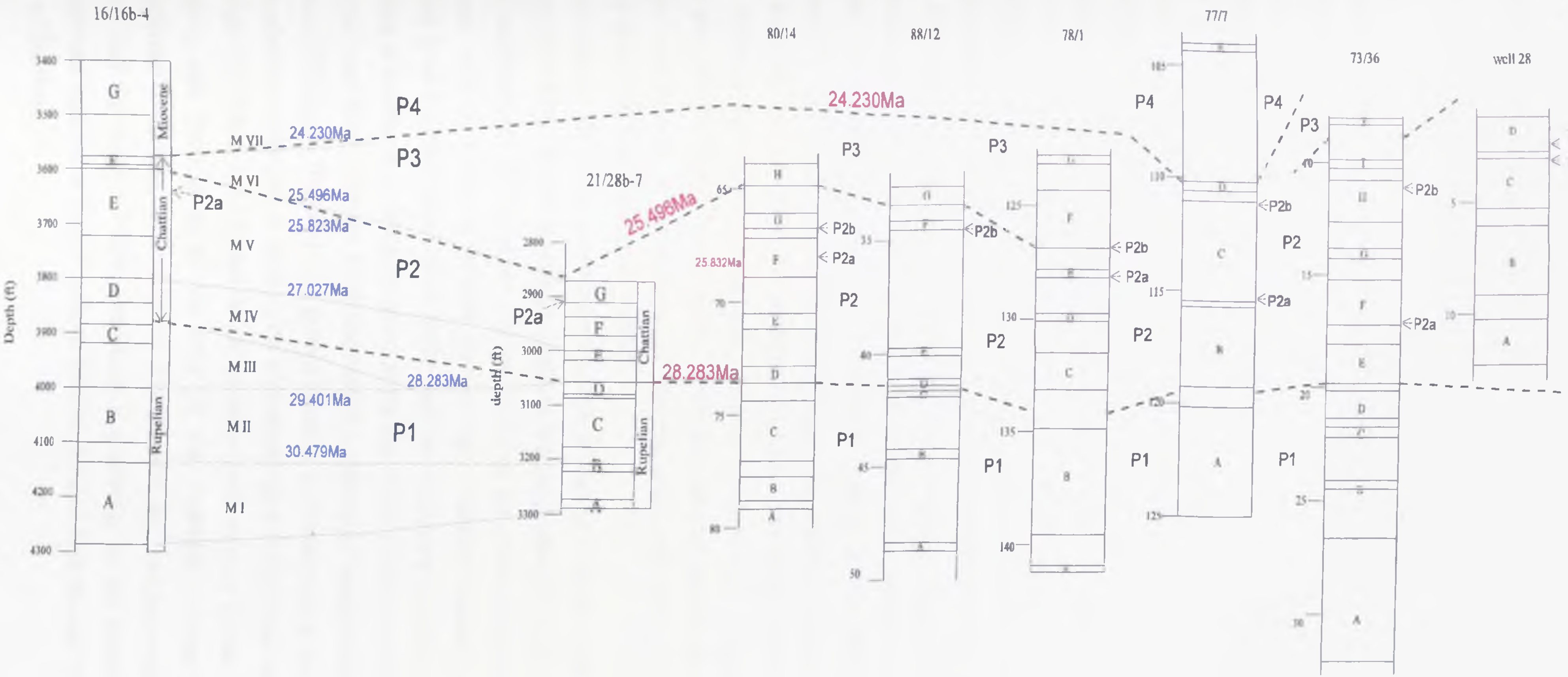


Figure 7.2 Diagram showing the suggested correlation between the marine and terrestrial sections.
MI to MVII units are shown with absolute ages denoted in blue, P1 to P4 units are shown with their absolute ages denoted in red
(NB. the scale for the terrestrial sections is in metres)

CHAPTER 8

REWORKING

Reworking was evident from the palynological data collected from all of the sections studied. For each section the details of the reworked taxa encountered are give on the Tilia charts (enclosures 1 to 10) and are listed at the end of each systematic palynology section (Chapter 12).

The two sections from the Little Minch Basin recorded significant numbers of reworked palynomorphs. These included predominantly Jurassic taxa such as *Caliallasporites dampierii, C. turbatus, Cerebropollenites mesozoicus, Chasmatosporites* spp., *Classopollis* spp., *Perinopollenites elatoides, Cycadopites* spp. and *Densoisporites velatus*. These taxa were seen along with some Carboniferous spores. Evans *et al.,* (1991) also reported Jurassic reworking in this area from their work on Borehole 80/14. This was concluded from reworked Jurassic pollen and spores encountered (as above) and the presence of glaucony grains in the sandstones of the sequence. In this study the number of reworked taxa are seen to increase in abundance upsection. A marked change at the Rupelian/Chattian boundary (73.77m in 80/14) from under 15% below, increasing in places to over 40% above is noted. The origins of this dominantly Jurassic reworking, is derived from the basins drainage areas to the south east. Jurassic sediments are documented in the Minch area and on Skye (Evans *et al.,* 1991) and also westwards from the Outer Hebrides and beyond, where pockets of Jurassic sediments have also been noted (Stoker *et al.,* 1993 and Fyfe *et al.,* 1993).

In the case of 88/12 the dominantly Jurassic reworked taxa are seen to occur in numbers upto 40%. It was these high numbers that originally led to the initial studies on the sediments of this borehole (by the BGS) to conclude that these Oligocene sediments were of a Late to Middle Jurassic age. Similar Jurassic taxa to those described from the 80/14 section are noted here (see enclosure 6). The source of this reworking is envisaged as being the same as for the 80/14 section, as they are located within the same basin. Further work undertaken on the large basalt clasts within these sediments (Hitchen & Richie, 1993) proved them to be Palaeocene in age. The origin of these clasts is envisaged to be from the Palaeocene lava fields in the area, especially the North Skye Main Lava Series which extends south west to Canna (Canna Lava Formation) and from areas to the west of the Hebrides. Some evidence of Carboniferous reworking, in the form of *Triquitrilites* spp. has been recorded in this section. But the origin of such reworking is uncertain, as the nearest reports of Carboniferous material is from Northern Ireland, west of Kintyre and in the Midland Valley of Scotland.

A similar situation is seen to occur from the data from the 78/1 section, where the numbers of reworked taxa is seen to increase upsection above the Rupelian/Chattian boundary (133.1m). Here levels of reworking upto 15% are recorded in the Chattian compared to numbers of less than 5% below this. The reworking in this section is again dominated by Jurassic aged taxa with the possibility of some Cretaceous material, these are similar to those seen and listed for the 80/14 and 88/12 sections (see enclosure 7, for details). The origins of these reworked taxa are again similar to those envisaged for the Little Minch Basin sediments. Jurassic sediments are documented to occur from the north west of Canna in the Sea of the Hebrides to the south west in the Inner Hebrides trough (running from South Skye to the Malin Basin) with Permo-Triassic rock underling the whole area.

To the North of Scotland in the Solan Bank High area (77/7) reworking again is seen to increase from less than 10% in the Rupelian to over 20% upsection into the Chattian aged parts of the section (112-115.7m) and is then seen to decline in number again to less than 10% in the Miocene aged sediments. Here the reworking is composed of a jumble of taxa from an Early to Late Jurassic sediments (Sinemurian to Kimmeridgian). Enclosure 8 gives the details of the reworked taxa encountered here. The palynological evidence of Jurassic reworking from this borehole is documented by Evans *et al.* (in press), although no speculation as to the origin of such sediments is postulated. In this area Jurassic sediments occur to the north and west of this borehole (Stoker *et al.*, 1993) in the northern parts of the North Rona Basin, Faeroe-Shetland Basin, West Shetland Basin and beyond and also to the southwest in the Sea of the Hebrides Basin, Skye and North Minch Basin.

In south western Britain, the palynological results from the Stanley Bank Basin material also include some reworking. Low numbers of reworking, less than 5% are recorded in the Rupelian part of the section, increasing upsection to over 20% in the basal Chattian aged sediments. Reworking (detailed in enclosure 9) is composed again of a jumble of Triassic to Jurassic taxa, dominated by Early to Late Jurassic material with the occurrence of Carboniferous taxa (*Lycospora pusilla*) and some Cretaceous to Palaeocene taxa (*Triporoletes reticulatus*). The nature of the reworked taxa in this basin has also been noted by Boulter & Craig (1979) who recorded Jurassic reworking throughout this basin, in the form of *Classopollis*, *Cerebropollenites* and Carboniferous taxa in the form of *Lycospora*. The origin of the predominantly Jurassic reworking can be suggested to be derived from the Jurassic strata on the western side of the SLF scarp and to the east in the Bristol Channel Basin area, (Tappin *et al.*, 1994).

The small section from Northern Ireland, well 28, is limited in the nature of the sediments processed for palynological investigation. The sediments were dominantly lignitic or lignitic claystones, therefore represent more *in situ* sediments which by their nature, will contain less reworked taxa. In this section little reworking is recorded, never occurring in abundances greater than 10%. This reworking is very restricted in nature with only two taxa, *Classopollis* spp. and *Cycadopites* spp., being listed (enclosure 10). These suggest a Jurassic to Cretaceous age but the limited data is not enough to draw any conclusions. Although drainage must have been much lower in this area compared to the other sections possibly due to the underlying basalts. Jurassic sediments do occur in northern Northern Ireland, north of the Tow Valley Fault and in the Malin Basin area to the northwest.

Conclusions

A significant factor which can be drawn from the detailed examination of this data from the terrestrial sections is the characteristic increase in reworking numbers upsection from the Rupelian/Chattian boundary. This feature fits well with the overall environmental conclusions drawn from the marine data. Haq *et al.* (1987) figures 6.5 and 6.6 show a marked fall in sea level at the Rupelian/Chattian boundary. This fall in sea level and associated fall in base level causes the incision of rivers and streams in the land areas. The incision of the rivers cut into bedrock (in this case dominantly Jurassic sediments) remobilising the palynomorphs contained in them. This is backed up by the coincidence of the peak reworking with a peak in bisaccte or montane floras (seen in 80/14, 88/12, 77/7, 73/36 and well 28) indicating a greater influence and quantity of material transported from the source areas and tributary rivers and streams in the catchment areas.

CHAPTER 9

PALAEOFLORAL COMMUNITIES AND PALYNOFLORAL INTERPRETATIONS

INTRODUCTION

The use of the quantitative terrestrial palynomorphs namely pollen and spore data which has been recovered from the sections studied is twofold.

i) Upto now it is the stratigraphical use of these palynomorphs has been concentrated on. This involves looking at first and last occurrences, overall ranges of the individual taxa in each of the sections and pollen and spore associations. This has proved to be a useful tool (see Chapter 7) as some taxa show restricted ranges within the ages of the material studied here. The limitations of using pollen and spores include the relationship of the taxa to local or global climatic factors and the limited geographical extent of the taxa mirroring the geological and ecological niches and habitats available. Despite these factors and views of many authors that pollen and spores cannot be used as a stratigraphical tool, they have been found suitable in this work when used as part of a detailed quantitative study.

ii) The second way of utilising the pollen and spore data from this study is to look at the palaeofloral communities that are indicated from the palynological data. It is this aspect that will be concentrated on in the following section.

PARENT PLANT COMMUNITIES

Defining palaeofloral communities can be subjective as the botanical affinity of pollen and spore grains to their modern plant families is dependant on i) the ease of recognition and distinctiveness of each individual taxa ii) the abundance of each taxa with the fossil recorded iii) the preservation of the grains, especially in the form and ornament which is important as this is often the basis for determining the species and affinities of taxa.

Where possible the palaeobotanical affinities of the pollen and spore taxa recorded in this study are given following the description of each of the genera and species in the terrestrial systematic chapter (Chapter 12). The botanical affinities given are sourced from many authors, often whom have worked on well preserved material or *in situ* assemblages recorded from samples containing fossil plant leaves or other plant tissues. In some cases a direct link to the identity of the parent plant has been reported (Boulter & Kvacek, 1989; Boulter & Hubbard, 1982; Collinson, 1983).

In this work a number of palaeofloral communities i.e. parent plant communities have been defined. These are based on the botanical affinity of the taxa from the data collected as part of this study. A number of plant community structures for the Palaeogene of NW Europe have been proposed (Boulter & Hubbard, 1982; Jolley &

Spinner, 1991). Differences between the Palaeocene/Eocene taxa from the authors' above to the Oligocene taxa recorded in this study has led to the plant communities here differing slightly from those published, for example Jolley (in press) has separate communities listed for broadleaved deciduous and broadleaved evergreen taxa to differentiate between palaeotemperate and palaeotropoical forests, whereas here the overall picture envisaged is that of a mixed mesophytic forest (Mixed broadleaved, evergreen and deciduous forest) therefore all the tree taxa are grouped together as are not as diverse or do not occur in such large abundances as seen in Jolley (in press).

The plant communities used in this work are listed and described below. This is followed by a summary table of the taxa encountered in this study with an indication of which palaeofloral community each belongs to. The plant communities defined here will be important in the comparison and interpretation of the data obtained from the sections in this study. The interpretation of the palaeoflora and environment, from the data here is discussed later in this chapter.

a) montane community

This community is comparable to the montane conifer forest community of Jolley (in press) and Wolfe (1978) and includes taxa such as *Abiespollenites, Piceapollis, Pityosporites* and *Sciadopityspollenites*.

b) primary forest community

The taxa from this community are envisaged as the primary colonising arborescent vegetation. This is thought to include Palmae taxa such as *Arecipites* spp. and Betulaceae such as *Polyatriopollenites carpinoides* which is seen as a coloniser of wet (not saturated) base rich soils. Also included here are the more complex wall structured Normapolls group and protojuglandaceae such as *Platycaryapollenites, Pompeckjoidaepollenites* and *Plicatopollis*.

c) climax forest community

This community is envisaged as containing those taxa which form the majority of the forest canopy vegetation. This includes the pollen of *Ginkgo* (as *Monocolpopollenites tranquillus*) Ulmaceous pollen such as *Ulmipollenites undulosus* and *Triporopollenites* cf. *plectosus*, Tiliaceous (*Tilia*) pollen such as *Intratriporopollenites*. Also included are tropical tree taxa such as *Cupuliferoidaepollenites, Cupuliferoipollenites,* Fagaceae *Quercoidites, Cyrillaceaepollenites* and *Retitricolpites anguloluminosus*.

d) climax understorey shrubs and lianas

This group of taxa was included within the climax forest community (Jolley, in press). But the large numbers and general diversity of such understorey shrubs, lianas and parasite taxa in the material from this study warrants a separate community group to be erected for them. This community includes shrub taxa such as *Ilexpollenites, Tricolporopollenites, Porocolpopollenites vestibulum, Reevesiapollis, Favitricolporites microreticulatus, Ericipites* and Myricaceae shrubs *Triatriopollenites* which represent drier understorey communities. Liana taxa such as *Dicolpopollis kockeli* which represents dense riverside palms (*Calamus*) vegetation and Icacinaceae *Compositoipollenites.* Parasite taxa such as *Cupanieidites, Boehlensipollis* and *Gothanipollis* are also included in this community.

e) secondary dryland community

The Oligocene age sees an increase in the importance of secondary dryland vegetation taxa, not seen previously from Palaeocene/Eocene sediments, but before the appearance of the '*Sequoia* moorland' communities that characterise the Miocene. This community includes the myricaceous secondary vegetation described by Jolley (in press) but is expanded to include the newly evolved betulaceous and *Sequoia* vegetation. This community accounts for dryland vegetation, post forest fire vegetation and vegetation from small clearings that are envisaged to develop during this time. The taxa occurring in this expanding ecological niche include *Sequoiapollenites polyformosus, Graminidites annulatus, Corsinipollenites oculusnoctis, Trivestibulopollenites betuloides, Triporopollenites robustus, Triporopollenites coryloides, Echitriporites* and *Umbellifera* types.

f) streamside community

This community incorporates all lowland streamside taxa, the principle of which are *Alnipollenites verus* and *Liquidambarpollenites stigmosus*.

g) arborescent floodplain community

This community is defined as in Jolley (in press) and includes such taxa as *Retitricolpites retiformis, Tricolpopollenites hians, Tricolpopollenites* cf. *hians* and *Tetracolpites reticulatus*. These are seen to have affinities to the Platanaceae (Manchester, 1986) and are often seen to dominate the palaeofloras in unstable floodplain environments.

h) taxodium swamp community

The dominant taxa of this community is *Inaperturopollenites hiatus* with lesser numbers of *I. dischiforme. I. dubius* and *I magnus* being recorded. This can be compared directly to the littoral swamp community of Jolley (in press).

i) juglandaceous swamp community

As the name implies this community is dominated by juglandaceous pollen and is directly comparable to the juglandaceous swamp community of Jolley (in press). Here this community includes the numerically important taxa in this study, *Nyssapollenites* along with *Caryapollenites, Momipites, Juglanspollenites* and *Pterocarya.*

j) aquatic community

This community is described as in Jolley (in press) but has been expanded here to include aquatic taxa of spores as well as those of pollen taxa. The aquatic pteridophyte ferns taxa such as *Echinatisporis* and *Microfoveolatisporis tuemmlitzensis* are included along with the aquatic monocotyledonous pollen taxa such as *Milfordia* and *Sparganiaceaepollenites.*

k) floodplain fern community

This community is as defined by Jolley (in press) and the taxa included are pteridacean (standing water) *Camerozonosporites;* schizacean (low watertable) *Cicatricosisporites,* some *Deltoidospora, Polypodiaceoisporites* and *Trilites;* cyathacean (high watertable) some *Deltoidospora* and *Gleicheniidites, Torosporis, Triplanosporis* and *Verrucatosporites histiopteroides.* These are dominant in wet floodplains which are too unstable to support colonisation by Platanaceous trees.

l) cosmopolitan fern community

This community is described and applied as in Jolley (in press) and includes Dryopteris plants such as *Laevigatosporites.*

m) small ferns and moss community

This community is comparable to the understorey cosmopolitan ferns and mosses of Jolley (in press). It is seen to include taxa such as *Corrusporis, Baculatisporites, Lycopodiumsporites, Stereisporites (Stereisporites) stereoides, Undulatisporites, Verrucingulatisporites* and *Kekryphalospora.*

n) epiphytic fern community

This community is directly comparable to the understorey epiphytic fern community of Jolley (in press) and includes *Echinosporis, Microfoveolatosporis pseudodentatus* and *Verrucatosporites* (except *V. histiopteroides*).

o) fungal spores

This group of palynomorphs is applied as Jolley (in press) and are thought to be derived from lowland swamps and forest floor litter fungi.

The table below summarises the pollen and spore taxa encountered in this study. It gives an idea to which palaeofloral community each is assigned to for the purpose of this study. The community groups will be used on the tilia charts (enclosure 3 to 10) and also to simplify the palynofloral description and interpretations later in this chapter.

Taxa	Community type
Genus ***Corrusporis***	M
Corrusporis granotuberculatus	M
Corrusporis tuberculatus	M
Genus ***Echinosporis***	N
Echinosporis echinatus	N
Echinosporis sp. 1	N
Genus ***Laevigatosporites***	L
Laevigatosporites haardti	L
Laevigatosporites discordatus	L
Genus ***Microfoveolatosporis***	N
Microfoveolatosporis pseudodentatus	N
Genus ***Verrucatosporites***	N
Verrucatosporites alienus	N
Verrucatosporites balticus	N
Verrucatosporites favus	N
Verrucatosporites histiopteroides	K
Verrucatosporites megabalticus	N
Genus ***Baculatisporites***	M
Baculatisporites nanus	M
Baculatisporites primarius	M
Genus ***Camerozonosporites***	K

Camerozonosporites heskemsis	K
Genus ***Cicatricosisporites***	K
Cicatricosisporites chattensis	K
Cicatricosisporites dorogensis	K
Cicatricosisporites paradorogensis	K
Genus ***Deltoidospora***	K
Deltoidospora apheles	K
Deltoidospora maxoides	K
Deltoidospora wolffi	K
Genus ***Echinatisporis***	J
Echinatisporis echinoides	J
Echinatisporis miocenicus	J
Genus ***Gleicheniidites***	K
Gleicheniidites senonicus	K
Genus ***Kekryphalospora***	M
Genus ***Lycopodiumsporites***	M
Genus ***Microfoveolatisporis***	J
Microfoveolatisporis tuemmlitzensis	J
Genus ***Polypodiaceoisporites***	K
Polypodiaceoisporites gracillimus	K
Polypodiaceoisporites marxheimensis	K
Polypodaceoisporites sp 1	K
Genus ***Stereisporites***	M
Subgenus ***Stereisporites (Cingulitriletes)***	M
Stereisporites (Cingulitriletes) spp.	M
Subgenus ***Stereisporites (Stereisporites)***	M
Stereisporites (Stereisporites) stereoides	M
Subgenus ***Stereisporites (Structisporis)***	M

Stereisporites (Structisporis) intrareticulatus	M
Subgenus ***Stereisporites (Distgranisporis)***	M
Stereisporites (Distgranisporis) spp.	M
Stereisporites sp. 1	M
Genus ***Toroisporis***	K
Genus ***Trilites***	K
Trilites corruvallatus	K
Trilites multivallatus	K
***Trilites* sp. 1**	K
Genus ***Triplanosporites***	K
Genus ***Undulatisporites***	M
Undulatisporites sculpturis	M
Genus ***Verrucingulatisporites***	M
Verrucingulatisporites treplinensis	M
Spore sp. 88	M
Genus ***Diporicellaesporites***	O
Genus ***Fusiformisporites***	O
Hyphae spp.	O
Genus ***Microthallites***	O
Genus ***Pesavis***	O
Pesavis tagluensis	O
Genus ***Pluricellaesporites***	O
Genus ***Scolecosporites***	O
Genus ***Abiespollenites***	A
Genus ***Piceapollis***	A
Genus ***Pityosporites***	A
Genus ***Podocarpidites***	A
Genus ***Arecipites***	B

Arecipites spp.	B
Genus ***Monocolpopollenites***	C
Monocolpopollenites tranquillus	C
Genus ***Dicolpopollis***	D
Dicolpopollis kockeli	D
Genus ***Graminidites***	E
Graminidites annulatus	E
Genus ***Milfordia***	J
Milfordia incerta	J
Genus ***Sparganiaceaepollenites***	J
Sparganiaceaepollenites polygonalis	J
Genus ***Inaperturopollenites***	H
Inaperturopollenites distichiforme	H
Inaperturopollenites dubius	H
Inaperturopollenites hiatus	H
Inaperturopollenites magnus	H
Genus ***Sequoiapollenites***	E
Sequoiapollenites polyformosus	E
Genus ***Sciadopityspollenites***	A
Sciadopityspollenites serratus	A
Genus ***Caryapollenites***	I
Caryapollenites circulus	I
Caryapollenites imparalis	I
Caryapollenites simplex	I
Caryapollenites triangulus	I
Caryapollenites veripites	I
Genus ***Momipites***	I
Momipites anellus	I

Momipites coryloides	I
Momipites tenuipolus	I
Momipites triradiatus	I
Genus ***Platycaryapollenites***	B
Genus ***Triatriopollenites***	D
Triatriopollenites aroboratus	D
Triatriopollenites confusus	D
Triatriopollenites bituitus	D
Triatriopollenites roboratus	D
Triatriopollenites rurensis	D
Triatriopollenites subtriangulus	D
Genus ***Juglanspollenites***	I
Genus ***Polyatriopollenites***	B
Polyatriopollenites carpinoides	B
Polyatriopollenites stellatus	B
Genus ***Pterocarya***	I
Genus ***Plicatopollis***	B
Genus ***Pompeckjoidaepollenites***	B
Pompeckjoidaepollenites subhercynicus	B
Genus ***Alnipollenites***	F
Alnipollenites verus	F
Genus ***Corsinipollenites***	E
Corsinipollenites oculusnoctis	E
Genus ***Trivestibulopollenites***	E
Trivestibulopollenites betuloiodes	E
Genus ***Compositoipollenites***	D
Compositoipollenites rhizophorous subsp. ***burghasungensis***	D

Compositoipollenites rhizophorous subsp. ***rhizophorous***	D
Genus ***Echitriporites***	E
Echitriporites sp. 1	E
Genus ***Liquidambarpollenites***	F
Liquidambarpollenites stigmosus	F
Genus ***Triporopollenites***	E
Triporopollenites coryloides	E
Triporopollenites cf. ***plectosus***	C
Triporopollenites robustus	E
Genus ***Ulmipollenites***	C
Ulmipollenites undulosus	C
Genus ***Intratriporopollenites***	C
Intratriporopollenites ceciliensis	C
Intratriporopollenites instructus	C
Intratriporopollenites microreticulatus	C
Intratriporopollenites pseudoinstructus	C
Genus ***Porocolpopollenites***	D
Porocolpopollenites vestibulum	D
Genus ***Reevesiapollis***	D
Reevesiapollis triangulus	D
Genus ***Boehlensipollis***	D
Boehlensipollis hohli	D
Genus ***Cupanieidites***	D
Cupanieidites eucalyptoides	D
Genus ***Gothanipollis***	D
Gothanipollis gothanii	D
Genus ***Cupuliferoidaepollenites***	C
Cupuliferoidaepollenites liblarensis	C

Cupuliferoidaepollenites liblarensis subsp. ***liblarensis***	C
Cupuliferoidaepollenites liblarensis subsp. ***fallax***	C
Genus ***Quercoidites***	C
Quercoidites microhenrici	C
Genus ***Retitricolpites***	
Retitricolpites anguloluminosus	C
Retitricolpites retiformis	G
Genus ***Tricolpopollenites***	G
Tricolpopollenites hians	G
Tricolpopollenites cf. ***hians***	G
Genus ***Tetracolpites***	G
Tetracolpites reticulatus	G
Genus ***Cupuliferoipollenites***	C
Cupuliferoipollenites cingulum	C
Cupuliferoipollenites cingulum subsp. ***fusus***	C
Cupuliferoipollenites cingulum subsp. ***oviformis***	C
Cupuliferoipollenites cingulum subsp. ***pusillus***	C
Genus ***Cyrillaceaepollenites***	C
Cyrillaceaepollenites megaexactus	C
Genus ***Echitricolporites***	D
Echitricolporites spinosus	D
Genus ***Favitricolporites***	D
Favitricolporites microreticulatus	D
Genus ***Ilexpollenites***	D
Ilexpollenites iliacus	D
Ilexpollenites margaritatus	D

Ilexpollenites microiliacus	D
Genus ***Mediocolpopollis***	D
Genus ***Nyssapollenites***	I
Nyssapollenites kruschi	I
Nyssapollenites kruschi subsp. ***analepticus***	I
Nyssapollenites kruschi subsp. ***accessorius***	I
Nyssapollenites satzveyensis	I
Genus ***Tricolporopollenites***	D
Tricolporopollenites baculoferus	D
Tricolporopollenites discus	D
Tricolporopollenites edmundi	D
Tricolporopollenites pseudocingulum	D
Tricolporopollenites spinus	D
Tricolporopollenites viburnoides	D
***Tricolporopollenites* sp. 1**	D
Genus ***Ericipites***	D

PALYNOFLORAL INTERPRETATIONS

The parent plant communities defined are used to give a detailed discussion of the palynofloral characteristics of the sections examined in this study. The plant communities are described from the P1 to P4 Units from the Sea of the Hebrides Basin, Solan Bank High, Southern England and the North Sea areas in turn.

Numerous and generalised suggestions of Taxodium swamp and floodplain environments (Wilkinson & Boulter, 1980; Boulter & Hubbard, 1982; Wilkinson *et al.*, 1980) have been suggested for the various isolated Oligocene Basins of the western British Isles. Importantly in this current study a very clear correlation between the basins has been defined. Therefore the palaeoenvironmental conclusions drawn from the data can be placed upon a more detailed stratigraphical framework here, than has been possible in the past, enabling more subtle and precise palaeoenvironmental changes to be recognised from the data than has been thought possible previously. Moreover it is possible to relate the changes in parent plant communities to both environmental and climatological factors and to tie these interpretations into the environmental suggestions of the marine and terrestrial data discussed in the previous chapters.

TERRESTRIAL DATA

SEA OF THE HEBRIDES

UNIT P1 (?-28.28Ma, Rupelian equivalent)

80/14

The pollen and spore data indicate palynofloral communities dominated by a climax forest vegetation, this is suggested by the numbers and diversity of climax forest taxa (*Cupuliferoipollenites, Cupuliferoidaepollenites, Cyrillaceaepollenites*). The high diversity of *Tricolporopollenites, Porocolpopollenites, Reevesiapollis* and *Favitricolporites* evident here indicate a well established understorey of subtropical trees/shrubs associated with the climax forest.

The climax forest forms the surrounding vegetation to an area of floodplain and floodplain swamp communities (although the taxa representing the environments are probably over represented due to over production and a proximity to the rivers depositing the sediments). The floodplain floras are dominated by true floodplain trees, platanaceous trees (*Retitricolpites retiformis, Tricolpopollenites, Tertracolpites reticulatus*). With areas of standing water dominated by *Inaperturopollenites /Alnipollenites* swamps (Taxodium/Betulaceae swamps of Collinson, 1992). Some free standing floodplain ferns occur (*Verrucatosporites histiopteroides, Gleicheniidites, Torosporis*) and some transported taxa from adjacent upland areas (bisaccate pollen and *Sciadopityspollenites*) are represented. Few primary forest or juglandaceous swamp trees are noted to occur here.

An overall picture of a climax forest and its highly diverse understorey surrounding floodplain and floodplain swamp environments is envisaged here. A lack of tropical taxa (except *Cupanieidites* and *Dicolpopollis*) and relatively sparse secondary dryland taxa which here probably represent areas of forest disturbance e.g. forest fires, along with the large number of cosmopolitan ferns (*Laevigatosporites haardti*) and epiphytic ferns (*Verrucatosporites*) indicate a damp humid environment. With an overall forest structure of mixed broadleaved evergreen and deciduous forest or mixed mesophytic forest (Wolfe 1979) is indicated.

88/12

From the close proximity of borehole 80/14 and 88/12 (less than 10 km) it would follow that the palynofloral communities indicated by the taxa present in 88/12 should be very similar to those seen to be present in 80/14. The pollen and spore data from 88/12 shows a palynofloral community dominated by climax forest trees (*Cupuliferoipollenites, Cyrillaceaepollenites, Monocolpopollenites, Quercoidites*). This is seen in 80/14 although a less diverse understorey vegetation is seen in the data from 88/12. Significantly fewer arborescent floodplain trees are apparent and fewer cosmopolitan fern taxa and epiphytic taxa occur in 88/12 indicating a slightly less humid environment here. *Inaperturopollenites* or *Taxodium* swamp communities are apparent from the data but in general 88/12 shows a lesser development of floodplain areas than is envisaged for the 80/14 section. Although a Mixed broadleaved evergreen and deciduous forest fits with the range of taxa and communities described along with the lack of tropical and secondary dryland vegetation here.

Interestingly larger numbers of the transported element, bisaccate pollen and *Sciadopityspollenites*, are represented here compared with 80/14. The apparent dominance of an upland forest community through this section is not as a result of vegetational changes but more as a result of the sedimentological and depositional regime resulting in these deposits. The predominance of poorly sorted conglomerates in this section implies an upper alluvial fan/proximal setting adjacent to the tectonically active Minch Fault during deposition. Therefore accounting for the large amounts of transported taxa present here feeding from the upland areas to the NW of the Minch Fault. This is very different to the floodplain environment of deposition envisaged for 80/14 which results in a predominance of claystone sediments there.

78/1

This section is located to the south of 80/14 and 88/12 but within the same Sea of the Hebrides Basin. Here closely similar palynofloral communities to 80/14 are seen in this section. Palynofloral communities dominated by a highly diverse climax forest vegetation is indicated from the pollen and spore data, with a high diversity of understorey taxa being seen as in 80/14 although with lower numbers here. As in 80/14 significant numbers of arborescent floodplain taxa are seen with some free standing floodplain ferns (*Deltoidospora, Triplanosporites*). An *Inaperturopollenites/Alnipollenites* swamp community surrounded by the climax forest is evidenced from the pollen and spore data, a similar community has also been described from 80/14. Few primary forest and juglandaceous swamp trees are recorded, as in 80/14 and similar low numbers of transported taxa from upland forest communities are represented. Fewer *Laevigatosporites* and *Verrucatosporites* taxa in this section indicate a slightly less damp humid environment than is envisaged for 80/14.

UNIT P2 (28.28Ma - 25.29Ma, Lower Chattian equivalent)

80/14

From the dinoflagellate data presented earlier, a significant fall in sea level causing a fall in base level at the boundary between unit P1 and unit P2 has been proposed. The fall in base level can be seen clearly from the pollen and spore data as it results in the marked increase in reworking and/or transported taxa recorded from the base of unit P2 and upsection. Further to this base level shift, a general instability in the environment can be seen from the pollen and spore data here.

A cut back in the climax forest component and the diversity of understorey taxa previously seen to be dominant in Unit P1 is overtaken by increases in scrub understorey taxa and the drier understorey element (*Triatriopollenites*) with more Myricaceae (*Triporopollenites robustus, T. coryloides, Trivestibulopollenites betuloides*) and secondary forest communities (*Graminidites, Sequoiapollenites*). These indicate the onset of a drier climate or sandy soil development giving the grass, *Sequoia* and shrub moors (a precursor to the *Sequoia* moors characteristic of a Miocene age). Other taxa such as *Umbellifera* and Compositae start to appear in this unit indicating the opening up of new ecological niches here. The cut back on climax forest components and the increase in secondary dryland vegetation is accompanied by increases in the primary forest element such as wetland colonisers (*Polyatriopollenites carpinoides*) and palms (*Arecipites*).

Floodplain swamp communities are still present, although the newly developed instability in the environment leads to fluctuations between *Inaperturopollenites* and *Alnipollenites* as the dominant swamp taxa through time. With more stable times producing the lignites characteristic of this unit in all the sections. *Laevigatosporites haardti* is prominent in the swamp community indicating a humid environment, also increases in forest floor taxa such as *Baculatisporites* occur at this level.

88/12

The proximal setting of this section has already been seen to show high numbers of reworked and transported taxa in Unit P1. This somewhat obscures the characteristic increase of the reworked and transported element at this level that is so clearly seen in 80/14. Although other communities from the pollen and spore data show many similarities. The reduction in the climax forest floras and declining diversity of understorey floras is seen, while the numbers of scrub understorey (*Porocolpopollenites vestibulum*) and drier understorey elements such as *Triatriopollenites* and myricaceous floras (*Triporopollenites coryloides*) increase to give a characteristic dominance of secondary dryland taxa over climax floras. Also primary forest floras increase to significant numbers. The arborescent floodplain trees (*Retitricolpites retiformis*) increase in number in this unit which is the opposite to what is observed for 80/14. An unstable environment is also indicated in this unit, as in 80/14 by the fluctuation of the taxa dominating the floodplain swamp communities with *Laevigatosporites* and

Inaperturopollenites dominating over *Alnipollenites* here. Forest floor litter and vegetation is also seen to increase here.

78/1

Virtually identical palynofloras to those shown from 80/14 are indicated from the data in this section at this level. Clearly evident is the characteristic marked increase in reworked and transported taxa associated with the fall in base level. The decline in diversity of climax forest and understorey flora seen here is accompanied by the increased diversity of the secondary dryland communities and significance of primary floras such as *Polyatriopollenites carpinoides*.

The floodplain swamp communities show the characteristic fluctuation between *Inaperturopollenites/Alnipollenites* and *Alnipollenites/Inaperturopollenites* swamps resulting from the environmental instability at this time also seen in 80/14 and 88/12. *Laevigatosporites haardti* also occurs in the swamp environment indicating humidity. The arborescent floodplain component which was seen to increase in 88/12, is seen to decline here in 78/1 as well as in 80/14.

This instability induced fluctuation between *Inaperturopollenites/Alnipollenites*, *Alnipollenites/Inaperturopollenites* and *Laevigatosporites* swamp components can be used to finely correlate between the associations within this unit in the Sea of the Hebrides Basin. This is shown in the table below.

Unit	Swamp Taxa	80/14	88/12	78/1
Unit P3				
Unit P2	*Alnipollenites/Inaperturopollenites*	G	-	-
Unit P2	*Laevigatosporites /Inaperturopollenites/Alnipollenites*	E	D/E	D/E
Unit P2	*Alnipollenites/Inaperturopollenites*	-	-	C
Unit P1				

UNIT P3 (25.49Ma - 24.23Ma, Upper Chattian equivalent)

Fewer samples have been studied from this unit, much less data is available therefore less detail can be interpreted for the palynofloral communities present at this level.

80/14

In Unit P3 increased numbers of taxa such as bisaccate pollen suggest high levels of transported material are still present and characteristic of this unit. No significant change in the climax forest component occurs here but the primary forest element is seen to fall back again, declining in numbers. This is accompanied by a more prominent position taken by the secondary dryland community here along with increases in the drier understorey elements and increases in epiphytic fern taxa.

Few representatives of the arborescent floodplain tree communities occur indicating fewer rivers and streams running over the floodplain although humid conditions do occur indicated by increases in the number of *Laevigatosporites*. Swamp communities are less dominant with only *Taxodium* swamp floras being present. The floodplain fern community declines in importance. Some small ferns and mosses such as *Baculatisporites* representing a forest floor community are present.

88/12

A very similar palynoflora to 80/14 is interpreted from the data for this section. Numbers of the transported element of the community are seen to remain significant in this unit. Also the fall back of the primary forest component and increase in the drier understorey taxa, myricaceae and secondary dryland communities can be seen here along with increasing epiphytic ferns. These changes reflect the hotter humid conditions at this time, as in 80/14. The presence of more tropical taxa (*Dicolpopollis kockeli*) also reflects this. The floodplain areas surrounded by these forest communities show less or restricted drainage by rivers and streams indicated by the declining importance of the arborescent floodplain trees such as *Retitricolpites retiformis* and *Tricolpopollenites hians*. Although the floodplain ferns and cosmopolitan ferns do increase here as in 80/14. The swamp communities are also smaller, more restricted in size probably due to the reduced river input and are a less dominant component of the flora with only taxodium swamps present and juglandaceous swamp communities absent.

78/1

The further increase in transported upland forest taxa is characteristic and similar to what is seen in 80/14 and 88/12. The decline in the primary forest element and sparsity of climax forest and understorey taxa also has similarities to 80/14. While the secondary dryland community of Gramionid, Sequoia and Myricaceae vegetation increase further to prominence along with the epiphytic fern community suggesting more hot humid conditions than seen below. The Taxadiaceae dominates the swamp community as seen in 80/14 and 88/12 after the decline in Betulaceae pollen. Although *Laevigatosporites* is seen to increase. Here forest floor taxa are still present.

SOLAN BANK HIGH

Despite the location of this borehole to the north of the Sea of the Hebrides Basin, many distinct similarities between the palynoflora of these two areas can be seen.

UNIT P1 (??- 28.28Ma, Rupelian equivalent)

A mature climax forest community is evident from the presence of forest trees indicated by taxa such as *Cupuliferoipollenites* and *Cyrillaceaepollenites.* A note should be made here of the apparent lower numbers and diversity of these taxa compared to the Sea of the Hebrides area. The understorey community associated with the forest is represented by *Monocolpopollenites tranquillus* and *Porocolpopollenites vestibulum* the latter being more tropical than is seen from the Sea of the Hebrides data.

The forested slopes described here surround a floodplain area. The presence of a Nyssaceae/Taxodiaceae/Betulaceae taxa along with *Laevigatosporites* represent a complex floodplain swamp community. Streams running through the swamp area occur, this is suggested by the presence of arborescent floodplain trees (*Retitricolpites retiformis* and *Tricolpopollenites hians*). With some free standing floodplain ferns such as (*Verrucatosporites histiopteroides* and *Deltoidospora*) occurring. Few floodplain ferns or small ferns and mosses are present in this unit although the epiphytic fern community is relatively diverse. Low numbers of transported taxa from adjacent upland areas occur in this unit this is similar to what is seen in the Sea of the Hebrides.

UNIT P2 (28.28Ma - 25.49Ma, Lower Chattian equivalent)

The marked increase in transported taxa at the base of this unit is a result of the falling base level described earlier and is also characteristic of this unit in the Sea of the Hebrides Basin. In general drier palynofloral communities are seen compared to Unit P1. The number and diversity of climax trees is cut back and an increase in the drier tropical element of the understorey community is seen to develop, such as *Triatriopollenites.* The predominance of this secondary forest over the climax forest is indicated by increases in the drier myricaceae taxa (*Triporopollenites robustus, Trivestibulopollenites betuloides*) and scrub understorey. This was accompanied by an increasing primary forest element starting to appear and is very similar to that described from the Sea of the Hebrides. A significant amount of floodplain trees (*Retitricolpites retiformis, Tricolpopollenites hians*) suggests well developed drainage through the swamp and floodplain area this is not consistent with that seen in 80/14 and 78/1. The swamp areas are dominated by *Nyssa* swamps with a lesser Taxodiaceae component being present.

The central part of this unit in this section shows a quite different flora. These occur in *in situ* dark mudstones and carbonaceous rich sediments (no lignites). Here good forest assemblages are seen from the data. Less secondary dryland forests occur with climax forest trees and understorey surrounding large unstable and fluctuating swamp areas. Fluctuating *Inaperturopollenites/Nyssapollenites/Alnipollenites* swamp communities are indicated with humid conditions suggested by the presence of *Laevigatosporites.* In the unstable floodplain environments numerous floodplain ferns grow (*Deltoidospora, Gleicheniidites, Cicatricosisporites, Trilites*) in and around the swamp and on the forest floor with the small ferns and mosses such as *Baculatisporites* being significant here. The transported component of the palynoflora remains high indicating an outside influx of material. Occurrences of the microplankton taxa, *Pediastrum* and *Micrhystridium* indicate a freshwater influx into the area.

A marine influence at the top of this unit, Association E, effects the palynofloral communities. Overall a similarity to the lower part of this unit is seen here but with a greater floodplain element being present (reflecting the increased drainage associated with the local transgression and rise in sea level). The numbers of true floodplain trees (*Retitricolpites retiformis, Tricolpopollenites* cf. *hians*) increase. The fluctuating swamp community is dominated by Taxodiaceae/Nyssaceae. The high numbers of transported taxa are significant but have been exacerbated by the marine influence here.

UNIT P3 (25.49Ma - 24.23Ma, Upper Chattian equivalent)

No samples from this unit were studied from this section.

UNIT P4 (24.28Ma - ?? Miocene equivalent)

The Miocene palynofloral community is dominated by the transported upland community flora and is marked by a significant increase in the numbers of bisaccate taxa here. This is due to the marine nature of the deposits which concentrate the taxa, such as bisaccate pollen which float well and survive over greater transportation distances. Also the dominance of floodplain communities associated with the marine conditions can be seen here as these taxa grow in the areas adjacent to the rivers transporting the material to the site of deposition. A faint trace of climax forest and secondary dryland forest components is indicated from the data. Swamp development is more stable in the higher sea levels of the Miocene and is dominated by *Inaperturopollenites/Alnipollenites* swamps.

SOUTHERN ENGLAND AND NORTHERN IRELAND

The sections from southern England (73/36) and from Northern Ireland (well 28) show some similarities in the plant communities interpreted from the pollen and spore data to the Scottish boreholes in this study although they are located at opposite ends of the country.

UNIT P1 (??-28.28Ma, Rupelian equivalent)

73/36

At this period in time a dominant Taxodiaceae/Nyssaceae swamp is seen with *Alnipollenites* increasing in importance up through the unit. Extensive floodplain communities are developed around these swamp areas. Numerous drainage channels are envisaged to run through the floodplain environment indicated by large numbers of

Retitricolpites retiformis and *Tricolpopollenites hians* here. This situation has similarities to the Sea of the Hebrides and Solan Bank High data. A significantly large diversity of taxa such as *Cupuliferoipollenites* and *Cupuliferoidaepollenites* are recorded here suggesting the presence of a mature climax forest with associated understorey vegetation developed on the surrounding catchment slopes. Few floodplain ferns and small ferns and mosses are recorded. Low numbers of *Laevigatosporites* suggests a lack of damp conditions here, larger numbers of this taxa were recorded from the Sea of the Hebrides and Solan Bank High are as indicating somewhat wetter conditions further north.

Some drier communities are indicated by the presence of Graminoidea and Compositae the former is only recorded at this level in 80/14 and 77/7 while the latter is seen from none of the other terrestrial sections at this level. The presence of these taxa are probably due to forest disturbances such as forest fires. The lack of other dryland vegetation indicates that it is not a hotter drier climate causing the differences here. A dominant montane conifer forest community is present at this time but probably represents a transported element from adjacent upland mountainous habitats.

A possible marine influence at 26.79m is indicated from a number of fresh water taxa (*Botryococcus*) and brackish taxa (*Cyclopsiella, Paralecaniella indentata* and *Selenophemphix nephroides*). This is indicative of a tip of a marine transgressive event influencing the basin most probably via a channel with esturine influences.

WELL 28

No material of Unit P1 age was sampled from this section in this study.

UNIT P2 (28.28Ma to 25.49Ma, Lower Chattian)

73/36

The floodplain instability introduced at the base of this unit caused by the fall in sea level and fall in base level noted in all the sections examined is also seen here. This instability leads to the dominant *Inaperturopollenites/Nyssapollenites* swamp being replaced by a fluctuating and less dominant *Alnipollenites/Inaperturopollenites/Nyssapollenites* swamp. The influx of *Alnipollenites* at this time suggests a wetter climate as does the appearance of *Laevigatosporites* at this level. After time the *Inaperturopollenites* swamp element is almost lost due to the instability, while the remaining Nyssaceae element implies a drier swamp environment.

The arborescent floodplain taxa *Retitricolpites retiformis* and *Tricolpopollenites hians* decline up through this unit. This is probably associated with the declining dominance of the swamp communities and declining drainage feeding these environments, this declining drainage is most likely a result of the fall in base level leading to the rise of the drier plant communities. Taxa from the mature climax forest still occur but are less evident although a more diverse understorey is seen here compared to Unit P1, with the subtropical element such as *Porocolpopollenites vestibulum* and *Monocolpopollenites tranquillus* being more significant. This is similar to what is seen in the data from the Scottish boreholes.

The secondary dryland community becomes increasingly important at the expense of a dominant swamp community. This is seen by an increase in myricaceous taxa such as *Triporopollenites* which is indicative of a drier climate along with increases in *Trivestibulopollenites betuloides, Sequoiapollenites polyformosus, Intratriporopollenites microreticulatus, Graminidites annulatus* and *Corsinipollenites oculusnoctis*. Along with this increasing dryland vegetation an appearance of primary forest taxa, *Polyatriopollenites carpinoides* and *Arecipites,* is noted. The increasing dryland taxa and primary forest taxa is very similar to that seen in the Scottish boreholes at this time.

Also increasingly important are epiphytic ferns such as *Microfoveolatisporites pseudodentatus* and *Verrucatosporites*. Many more floodplain fern taxa are recorded on this unstable floodplain such as *Deltoidospora, Camerozonosporites, Cicatricosisporites* and *Gleicheniidites* in and around the swamp with the small ferns and moss component becoming more important here, seen by the increasing numbers of *Baculatisporites*. This along with the presence of *Stereisporites (Stereisporites) stereioides* indicates a secondary vegetation on a sandy floodplain as a forest floor community. This feature is also clearly seen to occur in 80/14, 88/12 and 77/7.

The fall in base level at this stratigraphical level and the ensuing rejuvenation of source areas and incision of streams is seen in the Sea of the Hebrides and 77/7 sections by increases in the transported elements namely saccate pollen and reworked taxa. This is also very characteristic of this unit in 73/36.

In this section the arborescent floodplain taxa, *Retitricolpites retiformis* and *Tricolpopollenites hians* show a delayed fall of numbers compared to the characteristic decline seen at the Unit P1/P2 boundary in the Sea of the Hebrides, 77/7, and the North Sea sections. But here these taxa continue in significant numbers well into the base of Unit P2. The lower part of Unit P2 is seen as a wet saturated event indicated by a large number of freshwater taxa such as *Pediastrum, Algae* sp. 1 and *Schizosporis reticulatus* (with *Areoligera semicirculata* not regarded as being *in situ*) or as the tip of a further transgressive event (if *A. semicirculata* is regarded as being *in situ*). It is therefore the increased drainage associated with the saturated event (increasing water table or marine transgression) that probably caused the arborescent floodplain taxa to develop along the channels delaying their fall off in number until after the effects of this saturation event. This increase in water table associated with this saturated event is also reflected by the peak in *Laevigatosporites* at this level.

The top part of Unit P2 sees a decline in the wetter loving taxa such as *Alnipollenites* and increasing dryland taxa such as *Triporopollenites coryloides* and *Triporopollenites robustus* with peaks in the numbers of *Baculatisporites* which indicate base rich forest floor communities. The number of floodplain ferns here rather than trees still indicate the instabilities influencing the environment.

WELL 28

The whole of the Well 28 section falls within this unit. The lower part of this section has numerous palynofloral differences to the upper part so are described separately.
The lower part of this unit is much wetter indicated by the dominant Betulaceae/Nyssaceae/Taxodiaceae swamp and *Laevigatosporites* which indicate damp humid conditions here. The dominant taxa of these lowland swamps change due to the instability of the floodplain environment envisaged here as in the other sections studied.

The floodplain taxa are very sparse compared with the nearby 73/36 section. Some secondary forest taxa are present but these drier areas are less extensive than seen in 73/36. Few other forest taxa such as climax forest trees are seen. Although the tropical oak (*Quercoidites microhenrici*) is important with understorey taxa such as *Tricolporopollenites pseudocingulum, T.* sp. 1 and *Ilexpollenites iliacus* occurring.

The dominant wetness of this lower part indicated by *Alnipollenites* is seen to decline into the upper part. Here the swamp community is dominated by a Nyssaceae/Taxodiceae element with *Alnipollenites* declining to almost absent suggesting a much drier swamp. More floodplain taxa in the areas adjacent to the swamp are indicated by *Deltoidospora*. This is also seen in the Sea of the Hebrides sections, 77/7 and the 73/36 section. The arborscent floodplain trees become more important and suggest better drainage over the floodplain and swamp areas in the upper part of the section. The climax forest and understorey components are evident along with epiphytic fern communities. Similar occurrences are also seen in the Sea of the Hebrides and 73/36.

Significant increases in the secondary dryland taxa characteristic of this unit in all the other sections is also seen, such as *Triporopollenites robustus* and primary tropical palms (*Arecipites*) and ginkgos (*Monocolpopollenites tranquillus*) are similar along with the tropical oaks and associated understorey elements. The palynoflora from this part of the Lough Neagh Basin is regarded as being similar to those described from the Sea of the Hebrides, 77/7 and 73/36. Although local factors such as greater distances from the sea, the impermeable basin floor as well as climatic changes have an effect on the palynofloral results.

UNIT P3 (25.49Ma to 24.23Ma, Upper Chattian equivalent)

73/36

Only limited palynofloral conclusions can be drawn here as only one sample from this unit has been studied. A less dominant swamp community is indicated from the *Alnipollenites/Inaperturopollenites/Nyssapollenites* numbers, *Laevigatosporites* is associated with this and indicates damp conditions as seen in the Sea of the Hebrides. Although the restricted swamp and reduced drainage suggested in the Sea of the Hebrides, is not indicated here. Primary forest taxa such as *Polyatriopollenites carpinoides, Arecipites* and *Sequoiapollenites polyformosus* show some increase (different to the declining primary and climax elements of 80/14, 88/12). While the drier myricaceous trees *Triporopollenites robustus* and *T. coryloides* show a distinct decline along with other dryland vegetation (again different to 80/14). Climax forest taxa are almost absent although subtropical palms, ginkgos and symplicos (*Porocolpollenites vestibulum*) are significant. This more tropical element is also seen by the presence of *Dicolpopollis kockeli* in 88/12 and drier vegetation of 78/1 which is similar. Here *Corrusporis, Lycopodiumsporites*, *Stereisporites* and Hyphae spp. represent a forest floor element. A peak in *Baculatisporites,* a forest floor taxa, is also seen from 80/14 at this level. A peak in floodplain fern taxa such as *Deltoidospora* is noted.

UNIT P4 (24.28Ma to ??, Miocene equivalent)

No samples from the sections studied have been taken from this unit.

MARINE DATA

The palynofloral communities indicated from the pollen and spore data from the two marine sections is different to those seen for the terrestrial sections. Firstly the pollen and spores obtained from the marine sections are more mixed and effected by taphonomic processes. Secondly the distance from the source material i.e. the distance offshore, affects which taxa are represented in the data as this is usually the most easily transported.

Therefore the whole of the marine sections are dominated by this transported element such as bisaccate pollen from upland conifer communities. Such saccate taxa are more easily transported offshore over the long distances from the land source areas and are more abundant in the marine assemblages compared to the other pollen and spore taxa which are less easily transported and therefore underrepresented in these assemblages.

UNIT P1

16/16

After the dominance of saccate pollen which represent the easily transported upland conifer forest element, the next most dominant taxa are from a Taxodiaceae/Nyssaceae swamp community, possibly representing a coastal Taxodium/Nyssaceae swamp (littoral). A strong representation from a floodplain community is seen in the data, numerous floodplain trees such as *Retitricolpites retiformis* and *Tricolpopollenites hians* along with floodplain ferns such as *Deltoidospora* are seen. Significant numbers of *Stereisporites (Stereisporites) stereioides* occur, these are not seen in such numbers in this Unit in the terrestrial sections. Behind these dominating and perhaps over represented elements, a large diversity Mixed Mesophytic Forest is seen with mature climax trees indicated by *Cupuliferoipollenites* and *Cupuliferoidaepollenites* taxa and associated understorey taxa such as *Tricolporopollenites edmundi, T. pseudocingulum* and *T. spinus.* The communities indicated here have some similarities to the terrestrial sections in the western British Isles. The climax and understorey communities along with the floodplain element are similar although the Taxodiaceae/Nyssaceae coastal swamp differs from the more inland terrestrial *Inaperturopollenites* and *Inaperturopollenites/Alnipollenites* swamps of the Western British Isles. The strong representation from the transported element in the marine sections is characteristic, such abundances of this transported element decline and are at their lowest number in the sections and assemblages that are closest to the source area such as 88/12 or in *in situ* samples.

21/28

A similarity to the previous marine section in the numbers of transported taxa such as saccates from an upland conifer forest community is seen along with the dominance of *Inaperturopollenites/Nyssapollenites* swamp taxa which are also strongly represented throughout the section here. After the dominance of the transported element and coastal swamp communities, a floodplain community is seen to be abundant. This is characterised by true floodplain trees such as *Retitricolpites retiformis* and *Tricolpopollenites hians* along with the associated floodplain ferns such as *Deltoidospora.* Significant numbers of *Stereisporites (Stereisporites) stereioides* are recorded here and is very similar to that seen in 16/16. As this section is a similar distance from the source to 16/16 it has a similar number of grains per gram to those seen from this unit in 16/16. The components of the background flora or underrepresented flora suggest a Mixed Mesophytic Forest, this is indicated by the presence of diverse climax forest and understorey taxa with a few dryland taxa also occurring.

UNIT P2

16/16

Again a dominance of saccates and the Taxodiaceae/Nyssaceae coastal swamp element is seen here. These coastal swamps do not indicate fluctuations resulting from the unstable floodplain that is seen clearly in the terrestrial sections. In this unit environmental instability is indicated by the appearance of Juglandaceous taxa here. This instability is characteristic of Unit P2 in this study and is as a result of the falling sea levels. Here *Alnipollenites* never reaches the significant numbers seen in the terrestrial data. Behind the dominance of these lowland swamp communities a streamside component is present although changed as the *Retitricolpites retiformis* element is lost and the *Tricolpopollenites hians* and *T.* cf. *hians* elements increase. This decline in *Retitricolpites retiformis* at the Unit P1/P2 boundary is very characteristic of this period and is seen in the majority of the sections in the Western British Isles.

The diversity and abundance of mature climax forest vegetation and understorey taxa are seen to decline in this unit. Again this is also seen in the terrestrial sections along with an increasing secondary dryland community such as *Triporopollenites coryloides, Trivestibulopollenites betuloides, Graminidites annulatus, Sequoiapollenites polyformosus* and *Corsinipollenites oculusnoctis*. With primary forest taxa such as *Polyatriopollenites carpinoides* also increasing. A significant difference to the terrestrial sections here is noted. An increasing floodplain fern element seen by the epiphytic fern taxa *Echinosporis echinatus* and *Verrucatosporites* is noted in this unit. Importantly an increase in the opportunistic juglandaceous swamp taxa indicated by *Momipites* is seen here. This appearance of the juglandaceous element to the swamp is indicative of primary unstable wet lowland environments and also possibly indicates that the eastern side of the country is wetter than those areas to the west where the juglandaceous element is not seen. This juglandaceous element occurs on the extensive wetter coastal plains in the east. Although *Alnipollenites* also favours wetter conditions their numbers are low here, but *Alnipollenites* is perhaps not as opportunistic as the juglandaceous taxa. Also the presence of *Laevigatosporites* here indicates damp humid conditions.

21/28

The *Inaperturopollenites/Nyssapollenites* swamp in this unit is joined by more *Alnipollenites* and *Laevigatosporites* indicating slightly wetter or humid conditions. This increase in the numbers of *Alnipollenites* was not seen in 16/16. However as seen in the 16/16 section the juglandaceous swamp taxa is again more evident , this opportunistic taxa indicates a primary unstable wet lowland environment and reflects the widespread instability seen in the fluctuating swamps of the Chattian in the western British Isles terrestrial sections studied here. The floodplain taxa changes from a dominance of *Retitricolpites retiformis* to a dominance of *Tricolpopollenites* cf. *hians* and *T. hians*, with *Deltoidospora* still representing the dominant floodplain fern. The influx of the epiphytic fern taxa *Echinosporis echinatus* and *Verrucatosporites* in this unit is similar to that noted in 16/16 but is not so pronounced. Associated with the increase in *Laevigatosporites* and the wetter humid environment, is the change to a scrubby drier vegetation indicated by taxa such as *Triporopollenites robustus, Triporopollenites* *coryloides, Graminidites* and *Plicatapollis* along with primary forest taxa such as *Polyatriopollenites carpinoides* and *Arecipites*, and also the drier subtropical understorey element such as *Monocolpopollenites tranquillus* are noted here. The presence of a Mixed Mesophytic Forest element composed of *Cupuliferoipollenites, Cupuliferoidaepollenites* and *Cyrillaceaepollenites* and the associated understorey vegetation are still seen to occur although in declining numbers in this unit.

UNIT P3

16/16

The community indicated from the limited data in this unit is very similar to that seen in Unit P2. The juglandaceous swamp element again increases in number into this unit along with an increasing littoral *Taxodium*/Nyssaceae swamp component, possibly suggesting extensive wetter coastal conditions. The increasing secondary vegetation, epiphytic ferns and small ferns and mosses seen in the terrestrial sections in the western British Isles and declining floodplain ferns and less dominant swamp conditions is not reflected in the data here as the swamp component remains high and a peak in *Deltoidospora* is noted with declining secondary vegetation and epiphytic fern taxa. Also the marine sections do not see the more tropical taxa seen from the data in 88/12 and 73/36.

21/28

No samples from this section have been taken from this unit for this study.

UNIT P4

16/16

The *Inaperturopollenites/Nyssapollenites* swamp taxa here is dominated less by *Inaperturopollenites* through this unit, possibly indicating a drier Nyssaceae swamp with some juglandaceous element overtaking it. This is very different to the stable *Inaperturopollenites/Alnipollenites* swamps of 77/7. Behind this swamp community streamside taxa become important such as *Alnipollenites, Liquidambarpollenites* and *Tricolpopollenites hians* possibly reflecting the higher Miocene sea levels and resultant increased channel drainage available for such taxa to develop alongside. *Cupuliferoipollenites* forms the dominant tree in the climax forest representing a tropical chestnut forest with a diverse understorey of *Tricolporopollenites pseudocingulum, T. edmundi, Porocolpopollenites vestibulum* and *Ilexpollenites iliacus*. This is coincident with the decline in diversity and loss of the Mixed Mesophytic Forest so characteristic of the Oligocene. Some secondary communities indicated by *Sequoiapollenites* and *Triporopollenites coryloides* are seen, this fits with the development of the *Sequoia* moors that have been described for the Miocene. The increase in certain climax forest taxa are as expected for Miocene vegetation. Although 77/7 sees traces of climax and secondary vegetation with increasing floodplain communities. The floodplain element here remains very similar to Unit P3.

21/28

No samples from this section have been taken from this unit for this study.

CHAPTER 10

CONCLUSIONS AND SUMMARY

COMMENTS ON OLIGOCENE PALYNOLOGY AND PALAEOENVIRONMENTS WITH REFERENCE TO THE PUBLISHED LITERATURE

Following from the detailed palynological interpretations (Chapter 7) and palaeoenvironmental interpretations (Chapter 9) it has been possible to compare the findings and results of this study to those in the published literature. Direct comparisons are made to data from both sections studied in this thesis, such as the Little Minch, Canna Basin, Stanley Bank, Northern Ireland and the North Sea, along with other comprehensively studied locations in the published literature that due to time constraints were not possible to sample and study in detail as part of this project such a Cardigan Bay, Bovey Basin and the Isle of Wight. For completeness a brief look at the Oligocene published material from NW Europe was also made.

THE LITTLE MINCH BASIN

The first published data from the Little Minch Basin was given by Evans *et al.* (1991), who studied borehole 80/14. Detailed palynological data from this work was presented and its quantitative approach enable detailed comparisons to be made with the results of the current study. The published palynological data showed dominant *Laevigatosporites haardti, Alnipollenites verus,* bisaccate pollen, *Inaperturopollenites hiatus* and *Verrucatosporites* with lesser *Retitricolpites, Polyatriopollenites carpinoides, Arecipites, Porocolpopollenites vestibulum, Triporopollenites coryloides* with a *Verus-vestibulum* Association being proposed. The former four taxa are noted to be similar to those published in Evans *et al.* (1979) for 78/1 and from other western British Isles sections studied (Wilkinson & Boulter, 1980). All the taxa above published are very similar to the results of this current work.

The similarities of the taxa led to similar palaeoenvironmental conclusions being drawn by Evans *et al.* (1991) who envisaged a freshwater fen indicated by *Alnipollenites verus* and *Verrucatosporites histiopteroides* with a Nyssa/Taxodium swamp and a transported montane conifer community. This has many similarities to the findings and conclusions of this current research work. Both the published data and the data presented in this thesis show evidence of Jurassic reworking, probably from rivers eroding into a Mesozoic bedrock.

Evans *et al.* (1991) dated the sediments by the presence of *Cicatricosisporites chattensis* a Middle and Upper Oligocene taxa (Krutzsch, 1967c), and the lack of *Boelhensipollis hohli, Agloredia* and *Milfordia* (Lower Oligocene of Meyer, 1988). In addition, a general comparison to other Oligocene sediments west of the British Isles to support a Late Oligocene (Chattian) age.

The full strength of the work presented in this thesis can be shown when compared to other published quantitative data which uses genera and species rather than form taxa names. A number of the characteristic features of the Rupelian/Chattian (Unit P1/P2) boundary described from this thesis (Chapter 7) can also be seen in the published quantitative data of Evans *et al.* (1991). These characteristics can be seen here at a depth of between 72m and 74m, and include the uphole increase of *Polyatriopollenites carpinoides* (also seen in 80/14, 88/12, well 28, 73/36, 21/28b-7), the decline of *Retitricolpites* (also seen in (80/14, 73/36, 16/16b-4, 21/28b-7), the increase in bisaccate pollen, increase in *Laevigatosporites haardti* and the decline in *Verrucatosporites* species.

The results from the same section in the current work indicate the Rupelian/Chattian boundary to occur between 74.47m and 73.77m. Accounting for sampling errors this boundary can be seen to occur at the same level in the published literature. Therefore the section dated by Evans *et al.* (1991) as Chattian (Late Oligocene) is more accurately Rupelian in age in the lower part 78.93m to 74.47m and Chattian in age in the upper part from 73.77m to 63.97m.

No published palynological data from the adjacent borehole 88/12 is available for comparison. The distinctive conglomerates with sandstones, mudstones and lignites of this borehole have been studied by the BGS. The results published (Hitchen & Richie, 1993) suggest a Palaeocene age (from K-Ar whole rock analysis) for the basalt clasts within the conglomerate, sourced from the Skye lavas or more probably the footwall of the Minch Fault, therefore a Palaeocene age is assumed for the deposits and is backed up by unpublished biostratigraphy of BGS. Although only long ranging taxa which are common throughout the Tertiary were encountered in their work.

The results of this current study show a dominance of taxa similar to those of the western British Isles sediments (Wilkinson & Boulter, 1980 and this thesis) such as *Laevigatosporites, Inaperturopollenites,* bisaccate pollen, *Retitricolpites* with lesser *Polyatriopollenites carpinoides, Arecipites, Porocolpopollenites vestibulum, Alnipollenites* and other characteristic Oligocene taxa such as *Cicatricosisporites chattensis* and *Monocolpopollenites tranquillus*. From the work of the author this section has been dated as Rupelian in the lower part 48.50m to 41.70m and Chattian in upper part 41.35m to 32.78m, giving an Oligocene age based on comparative western British Isles and North Sea data. The Palaeocene age published was an indication of reworking present along with the Jurassic taxa encountered (Hitchen & Ritchie, 1993, BGS unpublished report and this thesis).

Other Oligocene sediments have been recorded in the Hebridean area to the East of the Hebrides in the Hebridean slope, Geike escarpment area by Evans *et al.* (1989) and Stoker *et al.* (1993). The former described an Eocene to Pliocene succession with Oligocene sediments being represented by chalk and the latter from borehole 88/7 describes an Oligocene to Pliocene succession. The Oligocene deposits of the Hebridean slope seen in 88/7 from 103m to 92.1m are marine grey green carbonates with rich muds and sands dated on foraminifera and nannofossil evidence. These Upper Oligocene sediments overlie the Geike escarpment erosive surface and indicate a Middle Oligocene age for its formation (Evans *et al.*, 1989) which corresponds to the fall in eustatic sea level (Haq *et al.*, 1987) which is thought to give this erosion. The Upper Oligocene sediments instead of suggesting increasing sea levels (Haq *et al.*, 1987), are of lowstand origin as this is in an area of regional tectonic uplift. This is also indicated by the terrestrial deposits of the same age on the adjacent shelf (Fyfe *et al.*, 1993).

THE CANNA BASIN

The original findings of borehole 78/1, a borehole studied in this project, were published by Evans *et al.* (1979). They describe the 19m of terrestrial Tertiary sediments as being the northern most terrestrial Oligocene deposits in the western British Isles, although since then 80/14 and 88/12 penetrating such sediments have been drilled and 77/7 has been re-examined (this study and Evans *et al.*, in press) the latter is now thought as the most northerly terrestrial Oligocene deposit.

The published pollen assemblages were dominated by the form genera *Polyatriopollenites, Laevigatosporites, Inaperturopollenites* and bisaccate pollen (Evans *et al.*, 1979). These compare well to the dominant pollen which were recovered in this present study *Polyatriopollenites carpinoides, Laevigatosporites haardti, Inaperturopollenites hiatus* and bisaccate pollen. Smythe & Kenolty (1975) suggest the lithologies and densities of these sediments to be similar to the Oligocene Lough Neagh Group sediments and Evans *et al.* (1979) compared the latter three pollen types to the Lough Neagh Group palynology and saw similarities despite these taxa being very long ranging and common species through the Palaeogene.

Evans *et al.*, (1979) suggested *Alnipollenites verus* and *Polyatriopollenites carpinoides* occurred together as being of similar morphology. With *A. verus* dominating in Lough Neagh and *P. carpinoides* dominating in the Canna Basin. The close links between these taxa described by Evans *et al.*, (1979) were based on morphological similarities, and are regarded here as dubious, as these pollen are derived from different plant families.

The data from this current study (enclosures 7 and 10) show *A. verus* to occur in only slightly lower numbers in 78/1 and in Lough Neagh (well 28) *P. carpinoides* is nearly absent with *A. verus* being dominant in lower parts but declining to absent upsection.

No detailed palynological data was presented by Evans *et al.* (1979) therefore comparisons to the current study are difficult. Depositional interpretations of Evans *et al.* (1979) suggested a lake basin with rivers cutting through Mesozoic and igneous Tertiary basin floor. A similar isolated lake basin is interpreted in this current study with a large floodplain dominated by swamp, floodplain, streamside and forest plant communities developed on surrounding slopes with rivers cutting into Mesozoic (Jurassic) bedrocks. The similar palaeoenvironments pictured suggest similar taxa were recorded from both the published study and this work.

P. carpinoides is regarded as being derived from a very local flora in this section therefore cannot be rigorously tied to any zonation schemes as its localised dominance is a result of local climate and geographical conditions. Evans *et al.* (1979) used this taxa to suggest a Middle/Late Oligocene age for the sediments based on Krutzsch (1967c) and from his work on German sediments. Other taxa though to be of stratigraphical significance from Krutzsch (1967c) include *Corrusporis* implying a Middle Oligocene to Lower Miocene age, *Verrucatosporites* which becomes significant in the Oligocene and *Cicatricosisporites chattensis* implying a Middle and especially Upper Oligocene age. Overall Evans *et al.* (1979) conclude these sediments to be of an Upper Oligocene age.

The limitations of using zonation schemes such as Krutzsch (1967c) based on German data is especially marked when dealing with pollen and spores, as these are very sensitive to climate and environment making long ranging zones over time and space difficult to be accurate. It has been shown in the current study the only possible way to accurately date these terrestrial sections was by comparing the pollen and spore events in the North Sea (an area in close proximity to the terrestrial sections which has a good marine biostratigraphical control on the pollen and spore events) to the terrestrial sections. Clear and more precise results than Evans *et al.* (1979) were obtained here indicating that for the borehole 78/1 the lower part of the section 141.2m to 134.92m is Rupelian in age and the upper part from 133.1m to 123.04m is Chattian in age. For a more detailed correlation see figure 7.1 and Chapter 7.

THE CARDIGAN BAY BASIN

Two well studied boreholes, the Mochras and the Tonfanau boreholes (figure 3.7) have been drilled into the east side of the Tremadoc Bay Basin (Dobson & Whittington, 1987, O'Sullivan, 1979 and Herbert-Smith, 1972, 1979). From the Tertiary sequence overlying the Palaeozoic and Mesozoic rocks, three lithological units have been described by O'Sullivan (1979). The Basal Red Unit is of a coarse grained conglomerate, red in colour with fining up sequences of sands, silts and clays (from subariel mass flow). The Transitional Unit is of fining up grey silty clays with lignites (representing a floodplain) and The Lignite and Clay Unit with green laminated clays and abundant lignites with rootlets (from a swamp or well drained wet environment). Later Dobson & Whittington (1987) described four facies in the Tertiary sequence three fine grained and one coarse grained, representing similar environments to those above, of perennial swamps, floodplains, fluvial environments and mass flows.

These sediments are similar to those seen in the western British Isles from this study. The current work has shown lignites being more common but not exclusive above the Rupelian/Chattian boundary (in Unit P2 and P3) a similar situation is seen in Mochras borehole with The Upper Lignite and Clay Unit at the top of the section containing the more abundant lignites. Other sedimentological similarities are the geochemistry on the Mochras borehole (O'Sullivan, 79) this shows the sediments to be derived from tropically weathered acid rocks which have been leached to give abundant kaolinite - Illite and gibsite. This is similar to the abundant kaolinite and smectite in 80/14 with gibsite identified there indicating intensively weathered source areas (Evans *et al.*, 1991). Although the provenance of the sediments is likely to be slightly different the climatic conditions giving the intensively leached mineral assemblages of the sediments is similar.

Palynological data for the Tertiary part of the Mochras section 77.5m to 601m (Woodland, 1971; Herbert-Smith, 1972) show assemblages dominated by *Alnipollenites verus, Porocolpopollenites vestibulum, Intratriporopollenites, Ilexpollenites, Liquidambarpollenites, Nyssapollenites kruschi,* bisaccate pollen, *Inaperturopollenites* and *Verrucatosporites*. Such taxa are very similar to those described from the western British Isles Oligocene sediments (Wilkinson & Boulter, 1980 and this thesis) with the *Alnus-vestibulum* association of Evans *et al*., (1991) being present here. The data is semi quantitative so limited comparison to the data compiled from this thesis can be made. It was due to time constraints that no material from this basin was studied in this current work. Comparisons are made to all the other sections on western British Isles and in North Sea concentrating on 73/36 which is the closest section to the Cardigan Bay Basin.

As in Evans *et al.,* (1991) on 80/14, certain characteristic features can be picked out from the Mochras data published (Herbert-Smith, 1972). At about 200m to 228m an increase upsection of *Alnipollenites verus,* bisaccate pollen, *Ilexpollenites, Intratriporopollenites* are noted and declining numbers of *Tricolporopollenites* (some of which probably represent what the author in this current study has called *Retitricolpites retiformis*). These compare well to the characteristics of the data recovered from 73/36 at the Rupelian/Chattian (Unit P1/P2) boundary. This again shows the strength of this current work and its application to previously published suitable quantitative data. The presence of *Polyporopollenites* probably represents what the author called *Polyatriopollenites carpinoides* in this current work and is present in 100m to 210m at Mochras. This correlates to an increase of this taxa seen in the Chattian aged parts of all the sections studied in this thesis. Therefore the Transitional Unit/Lignite and Clay Unit boundary occurring at about 240m in Mochras can be correlated to the Rupelian/Chattian boundary of this study.

The abundance of lignite in the Lignite and Clay Unit also correlates well to the abundances noted in the Unit P2 sediments of the sections studied in this thesis, along with higher numbers of bisaccate pollen and the presence of *Cicatricosisporites chattensis* and *Graminidites* in both the Unit P2 of this work and the Lignite and Clay Unit of Herbert-Smith (1972). The influx of *Deltoidospora* is very characteristic of Unit P2 in this study (Lower Chattian equivalent) and can be seen between 100m and 201m in the data of Herbert-Smith (1972).

The published palynological data of Herbert-Smith (1979) gives a middle Oligocene to Early Miocene age for the Mochras sediments based on presence-absence data of general long ranging species as more age specific taxa such as *Boehlensipollis hohli* were not recorded. The results of this thesis on western British Isles and North Sea material has enabled the published data here to be re-appraised and to suggest that both Lower and Upper Oligocene aged sediments are represented in Mochras between 77m and 601m. Wilkinson & Boulter (1980) proposed that the base of the Mochras section at a level lower than 602m represents an Eocene/Early Oligocene age by their comparisons with the Bovey section. This Eocene age for the sediments below 602m is very possible and is overlain by both Lower Oligocene and Upper Oligocene aged sediments determined from the re-appraisal of Herbert- Smiths' (1972) data, using the pollen characteristics and detailed comparative work collated in this current study. Wilkinson & Boulter (1980) see Early Oligocene sediments between 602m and 408m and Middle Oligocene sediments from 408m to 80m by a comparison to the Lough Neagh Group sediments. This is different to the Early and Late Oligocene ages re-interpreted for the sediments between 601m and 77m by the author here, with the Rupelian/Chattian boundary suggested to occur at a depth of 240m.

Both sedimentary and palynological interpretations indicate similar palaeoenvironments to those discussed from the Oligocene by the author. O'Sullivan (1979) saw sub aerial mass flow, floodplain and restricted lake environments. Dobson & Whittington (1987) described perennial swamps with fluvial and floodplain lithologies. Palaeofloras of Herbert-Smith (1972) saw declining subtropical forms and increasing temperate tree pollen and conifer pollen indicating a cooling event.

The increase in conifer pollen seen by the author in this current study is thought to be characteristic of the Chattian aged parts of the majority of the sections studied. However this is not regarded as a cooling indicator but rather caused by a shift in the base level and increase in transported taxa from the mountainous slopes of the source areas of the drainage catchment. Wilkinson & Boulter (1980) suggest the Tremadoc Bay boreholes to be similar to Bovey Basin sediments as both have a large numbers of *Tricolpopollenites* and *Tricolporopollenites* taxa with the Tremadoc Bay Basin environment being slightly drier (despite the palynology being dominated by *Inaperturopollenites* swamp taxa). A sporadic floodplain was envisaged not allowing the development of rich floodplain floras here.

The Tonfanau Basin in the Tremadoc Bay Basin contains 71m of Oligocene conglomerates, sands, silts, clays and lignites very similar to the Mochras lithologies (Wilkinson *et al*, 1980). No palynological data from this section has been published so comparisons cannot be made.

A small basin, the Teiffe Basin, to the south of the Cardigan Bay Basin (figure 3.7) has been penetrated by BGS boreholes, 74/21 and 72/66 or 70/08. Tappin *et al.*, (1994) describes lithologies upto 10m thick including clays with plant fragments, he suggested a possible Middle Eocene to Middle Oligocene age. Glauconitic bands within this section indicate marine influences and would represent the northern most marine influence in the terrestrial Oligocene along the western British Isles (not including 77/7, North of Scotland) if this was to be proven. Upto now it is the Stanley Bank Basin which represents the northern most extent of the marine influence on terrestrial Oligocene sediments (Boulter & Craig, 1979 and this thesis). It is probable that a palynological investigation into the Teife Basin sediments would indicate such marine influences to be present.

Again not studied here and with no palynological data available other Oligocene deposits in St Georges Channel Basin are known (Tappin *et al.*, 1994). BGS boreholes 107/21, 106/24-1 and 106/28-1 (figure 3.7) penetrate sands, silts, clays and lignites. The fluvial sediments, lignites and clays of 107/21 indicate terrestrial swamp environments. The sediments of 106/24-1 are similar to those from Mochras with a fluvial influence and 106/28-1 are fluvial floodplain deposits. The lithologies are similar to the Eocene/Oligocene deposits of the other basins in the western British Isles examined in this study. These non marine Oligocene deposits grade to the southeast into marginal marine deposits preserved in the South Celtic Sea area. The BGS borehole 89/10 penetrates such marginal marine Oligocene sediments which show a proximity to a vegetated land mass.

STANLEY BANK BASIN

Six shallow boreholes have been drilled by BGS in the sediments (upto 335m) in the Stanley Bank Basin (Boulter & Craig, 1979; Davies, 1987; Tappin *et al.*, 1994) see figure 3.9. The three most northwesterly boreholes 73/36, 73/58 and 74/43 are the deepest recovering between 10m and 30m of Tertiary sediments. Three shallower boreholes to the southeast margin of the basin penetrate between 5m and 6m of Tertiary sediments (72/45, 73/35 and 72/44).

About 30m of sediments from 73/36 have been examined in this current study and saw dominantly claystone lithologies with siltstones, sandstone and lignite layers with carbonaceous fragments occurring and rootlets being present but restricted to the lower part of the section 19m to 34m. While the upper part 14m to 19m is dominated by more lignites and clays. Lignite layers over 1m thick have been noted, this compares well to the records of Fletcher (1975) who recorded lignites up to 5m thick from the Stanley Bank Basin. The sediments studied from 73/36 can be compared closely to those described by Davies (1987) for the whole basin who noted dominantly clays towards the base with clays and lignites upsection with some silty sandy layers and rootlets. The increasing dominance of lignites into the upper part of the section fits with the general findings of this thesis where the dominantly lignitic sediments occur in the upper parts of the sections, which are Chattian in age.

Davies (1987) recognised three seismic units in the Stanley Bank Basin. An unsampled (Facies B) restricted to the south and east margins of the basin, interpreted as a braided channel system. Overlain by (Facies A) laminated clays and lignites dipping towards the south west basin bounding fault, representing distal floodplain deposits in back swamp /shallow lagoon environments (Boulter & Craig, 1979).

Semiquantitative palynological data presented in Boulter & Craig (1979) on three boreholes from the Stanley Bank Basin, one of which, 73/36 is the same section as worked on in this thesis, enables a direct correlation to the results of this current research to be made. The dominant form taxa recorded in the published data occurring in numbers over 5% include *Verrucatosporites, Laevigatosporites, Baculatisporites,* bisaccate pollen, *Inaperturopollenites, Arecipites, Nyssapollenites, Alnipollenites, Tricolporopollenites* and *Classopollis.* These are similar to the dominant taxa seen to be present in this research (see enclosure 9) except *Verrucatosporites* and *Arecipites* which are seen to occur in lesser numbers compared to the published data. Although the many similarities give a good indication of the consistency and ease of comparison to other data that is possible from the data collected in this project. Other rare taxa noted by Boulter & Craig (1979) such as *Echinosporis, Sparganiaceaepollenites, Graminidites, Dicolpopollis, Tetracolporites, Reevesiapollis, Gothanipollis, Boelhensipollis, Porocolpopollenites* and *Corsinipollenites* are also recorded in the current study along with *Cupanieidites* and *Milfordia* species which Boulter & Craig did not record.

As the published data is semi quantitative further comparisons can be made to the pollen characteristics defined in this current work. Both studies show similar low numbers of *Laevigatosporites* at the base of the section with higher numbers upto 30% upsection. A similar decline in the numbers of *Inaperturopollenites* upsection is seen, Boulter & Craig (1979) see a reduction from over 30% at the base to 5-15% at the top while in this thesis the data shows higher numbers upto 60% at the base declining upsection to 20%. Importantly *Tricolpopollenites* shows a decline in numbers upsection from both the data sets with Boulter & Craig (1979) showing a decline from 1-5% to absent and this study showing a decline from 10-15% near the base to less than 5% at the top. Both studies show significant numbers of bisaccate pollen at the base which reduce upsection to 1-15%. The peak in reworked taxa at 18.75m is seen in both studies and similar low numbers of *Porocolpopollenites vestibulum* and *Polyatriopollenites carpinoides* are also seen. A characteristic taxa of this section is *Baculatisporites*, this is seen to peak at over 30% by Boulter & Craig, (1979) and upto 40% in this study. The abundances of *Baculatisporites* are not seen in the palynological data from the other two sections (73/58 and 73/35 in Boulter and Craig, 1979) or from the other eight sections studied by the author here. *Monocolpopollenites tranquillus* is recorded in similar numbers from both studies but a peak of upto 30% is recorded at an 8m level in this thesis (enclosure 9) that is not picked up by Boulter & Craig (1979). Both data sets for the 73/36 section indicate *Reevesiapollis* occurring near the base of the section and *Arecipites* being more abundant towards the upper part. Similar numbers of *Intratriporopollenites* are noted with increases in the upper part of the section between 12-14m to 5-15%.

The palynological data presented by Boulter & Craig (1979) from the boreholes 73/35 and 73/58 are similar to the results from 73/36 although lacking in the predominance of *Baculatisporites* and the reworking influx. Boulter & Craig (1979) dated these sections as Middle Oligocene on the presence of *Boehlensipollis hohli* a good biostratigraphical marker fossil for the Middle Oligocene of Germany (Krutzsch, 1967c), along with *Gothanipollis, Dicolpopollis, Monocolpopollenites, Arecipites* and by comparison to other Oligocene sections in the British Isles. The conclusions drawn from the pollen characteristics identified from the current work give a slightly different picture. The lower part of the 73/36 section from 33.1m to 24.42m is Rupelian and the upper part from 22.15m to 8m is Chattian. (see Chapter 7 for details). The Rupelian part of the section is characterised by floodplain communities and swamp taxa (Nyssaceae/Taxodiaceae) surrounded by a mixed mesophytic forest and some secondary vegetation with a transported element represented by an upland conifer community. The Chattian part of the section sees a change to a more unstable floodplain community with less arborescent floodplain taxa and a reduced and fluctuating (Nyssaceae/Taxodiaceae/Betulaceae) swamp. The mature climax forest is still present but gives way to an increasing primary forest community (*Polyatriopollenites carpinoides* and palms) with increasing secondary vegetation and associated scrub and grass moors.

Boulter & Craig (1979) suggested a marine influx at about 18.72m. In this more detailed work by the author, two possible marine influences have been noted. At 26.79m (Rupelian) a marine influence is indicated here possibly indicating the tip of a marine transgression via esturine influenced channels and latter in the (Chattian) at about 18.72m (picked up by Boulter and Craig, 1979) which could represent the nearshore effects of a transgression or a wet saturated event associated with a local increase in sea level (transgression) on top of the increase in eustatic sea level of (Haq. *et al.*, 1987). See Chapter 7 for discussion.

NORTHERN IRELAND

The sediments of the Lough Neagh Group, Northern Ireland, consist of mudstones, conglomerates, lignites and siltstones and are similar to the other Oligocene sediments of the western British Isles. The geochemistry of the Lough Neagh Group (LNG) sediments (Parnell *et al.*, 1989) show the Lough Neagh Clays to be derived from tropically weathered rocks with abundant kaolinite and gibsite being present. These clay minerals are also characteristic of the sediments seen in the Cardigan Bay Basin, O'Sullivan (1979) and the Sea of the Hebrides Basin, Evans *et al.* (1991).

No sedimentary log for the Well 28 samples studied in this project was available, although the material processed was similar being claystones, lignitic claystones and lignites from the Lough Neagh Group deposits on the western side of Lough Neagh. Wilkinson *et al.* (1980) suggested the LNG contained the youngest Oligocene sediments in the western British Isles. The Upper Oligocene age for these sediments (Boulter, 1980; Wilkinson *et al.*, 1980) was based on the presence of *B. hohli* (although some confusion occurs here as Boulter & Craig (1979) used this taxa to indicate a Middle Oligocene age) and its comparison with the palynology from other European Oligocene deposits. Also the presence of *Monocolpopollenites, Arecipites* and *Dicolpopollis* which indicate a warming climate therefore a Late Oligocene in age was suggested (again confusion occurs here as this combination of taxa led to a Middle Oligocene age being interpreted for the Stanley Bank material, Boulter & Craig (1979) Also other taxa *Verrucingulatisporites treplinensis, Cicatricosisporites chattensis, Corrusporis granotuberculatus, Mediocolpopollis, Verrucatosporites alienus* and *Intratriporopollenites instructus* also occur with an absence of 'Eocene' or 'Miocene' taxa, but the author of this thesis suggests that this is not enough to settle on an Upper Oligocene age here.

Palynological data obtained from the small section, Well 28 and the nearly by 73/36 from the Stanley Bank Basin were compared to the published findings of (Wilkinson *et al.*, 1980; Boulter, 1980). The presence of *B. hohli* in both Well 28 and 73/36 was recorded along with *Monocolpopollenites, Arecipites, Dicolpopollis, Corrusporis granotuberculatus, Mediocolpopollis, Verrucatosporites alienus* with records of *Cicatricosisporites chattensis* and *Intratriporopollenites instructus* occurring in 73/36. These data clearly indicate very similar taxa being present to the published work. The limited data set of thirteen samples from Well 28 was shown to be upper Oligocene in age based on a very detailed palynological comparison to the other sections in this study. The numbers of *Alnipollenites* were almost identical to the Chattian part of 73/36. Other characteristic pollen events such as the *Deltoidospora* influx and *Baculatisporites* event characterising a Lower Chattian age can be seen here in Well 28. Only general comparisons to the published data can be made here due to the limited data presented in Wilkinson *et al.* (1980). Wilkinson & Boulter (1980) saw a Middle/Late Oligocene boundary at 273m and 213m in the Washing Bay borehole and the Mire House borehole respectively. They based this division on the higher numbers of *Arecipites* and *Monocolpopollenites* in the upper part being indicative of their envisaged Upper Oligocene warming climate. Although a similar increase in *Arecipites* and *Monocolpopollenites* is seen in Well 28 (Chattian) and the Chattian parts of 73/36, their assumption of a Late Oligocene age is proved to be accurate.

Similar high number of *Alnipollenites* in the Washing Bay and Mire House boreholes compare well to the high numbers upto 60% in the base of Well 28 which is Chattian and upto 30% in the Chattian parts of 73/36. The high numbers of *Inaperturopollenites* (Wilkinson *et al.*, 1980) in Washing Bay and Mire House are similar to the high numbers seen in the Chattian of Well 28 (20%) and upto 70% in the Rupelian part of 73/36. With the low numbers in Bellbrook and Ballymoney suggesting a Chattian age here.

Numerous palaeofloral interpretations have been published, Boulter (1980) envisaged taxodium swamps with abundant ferns and palms surrounded by Mixed woodland communities. Wilkinson *et al.* (1980) saw warm humid swamps in a frost free environment characterising the Upper Oligocene. Parnell *et al.* (1989) and Boulter (1989) suggest lowland swamp cypress trees with shrubs and a mixed fern prairie under a conifer woodland in a warm temperate climate. All occupying shallow lakes with fluvial input and lagoons on a floodplain similar to the floodplain and lake environment envisaged for the depositional environment of the other Oligocene sediments of the western British Isles. These interpretations are similar to the conclusions drawn from the data in this study with lowland swamps, although a much more significant floodplain element is indicated along with the mature climax forest and secondary dryland vegetation on the adjacent slopes. In this study the upland conifer forest community is taken to represent a transported community as in

Mochras rather than a cooling indicator which would contradict the temperatures indicated from the more tropical palm taxa.

Wilkinson *et al.* (1980) saw 'Little vegetational change' throughout the Oligocene. The resulting vegetational characteristics of the palynofloras evident from this thesis would indicate 'subtle' changes rather than 'little' change is a more appropriate term.

BOVEY AND ASSOCIATED BASINS

Sediments over 1100m thick are reported to occur within the Bovey Basin. These include sandy clays representing floodplain environments, lignitic clays and rootlets representing back swamps and laminated clays representing lacustrine environments with sands representing levee and crevasse splay deposits (Edwards, 1976). These sediments are comparable and similar in character to those found in other basin along the western British Isles. Similar sediments described by Edwards & Freshney (1982) in the adjacent Petrockstow Basin and by Freshney *et al.* (1982) in the Dunston Basin are noted.

The Dunston Basin was dated with palynology to be Eocene in age by the presence of 'Eocene' taxa such as the Normapolls. While the Bovey and Petrockstow sequences contain Middle Eocene to Upper Oligocene aged sediments. Wilkinson & Boulter in Edwards & Freshney (1982) recorded Eocene taxa such as Normapolls, *Anacolosidites* and *Pompeckjoidaepollenites* at a depth of 290m with Oligocene sediments above this. A great deal of palaeobotanical interest in the Bovey floras enables comparisons to the taxa and palynofloras suggested in this thesis, for the western British Isles deposits of the same Oligocene age to those in the published literature. Chandler (1957) described the palynofloras of the Middle Oligocene Bovey sediments as being dominated by *Sequoia (Sequoiapollenites), Osmunda (Baculatisporites)* and *Calamus (Dicolpopollis)*. The *Sequoia* (Taxodiaeae) upland forest with marsh vegetation (*Cypress*, Myricaceae) envisaged by Chandler occurs along with aquatics, climbers, climax forest trees (*Nyssa*, *Symplocus*, *Carpinus*, *Magnolia*, *Ilex*, *Quercus*, *Tilia*, Ericaceae, Ulmaceae, Anacardiaceae, *Engelhardtia*, *Corylus*, *Fagus*) and coniferous upland trees (*Picea, Pinus* and *Podocarpus*). Collinson *et al.* (1981) described similar palaeofloras with swamp vegetation, palms, ferns and heathers occurring.

Work on the Middle and Upper Bovey formation (Wilkinson & Boulter, 1980) did not record any *Sequoia*, therefore they disputed the upland *Sequoia* forests envisaged by Chandler (1957; 1964). From this current work, especially the 73/36 Stanley Bank Basin borehole which is the closest in proximity to the Bovey Basin, low numbers of *Sequoia* pollen were present supporting the earlier views of Chandler. Wilkinson & Boulter (1980) regarded an upland conifer vegetation as being dominant, suggested by the presence of bisaccate pollen taxa with dominant lowland autochthonous taxodium swamp communities indicated by the numbers of *Inaperturopollenites*. Similar communities were shown from the nearby 73/36 section of this study with over 60% *Inaperturopollenites* being recorded in places. Also the high numbers of *Laevigatosporites* seen by Wilkinson & Boulter (1980) compare well to the numbers recorded from the nearby 73/36 section especially above the Rupelian/Chattian (Unit P1/P2) boundary level. Other pollen from trees and shrubs (*Tricolpopollenites* and *Tricolporopollenites*) along with *Nyssa/Salix* represent floodplain swamp communities. It must be noted that *Salix* pollen seen by Wilkinson & Boulter (1980) were never recorded in any of the material studied in this project.

The Eocene/Oligocene boundary is represented in the work of Wilkinson & Boulter (1980) by the increase of *Inaperturopollenites* at the Stover Member/Twineo Member boundary. With *Inaperturopollenites* thought to represent warm swamp floras associated with the Oligocene here (Kissling, 1974). The increase in *Inaperturopollenites* is picked up subtly from the North Sea marine sections looked at in this study. Wilkinson & Boulter (1980) recorded *Mediocolpopollis, Salixipollenites, Arecipites* and *Dicolpopollis* with rare *Inaperturopollenites, Ilexpollenites* and *Intratriporopollenites* from the middle and lower Upper Bovey Formation (Southacre and Twinyeo Members). From the Upper Bovey Formation, Oligocene (Stover, Brimley and Heathfield Members) they recorded *Alnipollenites, Polyatropollenites carpinoides*, *Corrusporis, Inaperturopollenites, Ilexpollenites* and *Intratriporopollenites* with rare *Salixipollenites*, *Dicolpopollis* and *Arecipites*. These latter taxa compare very well to the taxa described from other published Oligocene British Isles sediments and those also worked on in this thesis. They also suggest Bovey sediments to contain richer spore assemblages and poorer bisaccate and *Inaperturopollenites* assemblages compared to the other sections from the western British Isles (Wilkinson & Boulter, 1980) possibly suggesting more fern communities associated with the floodplain and forest ecosystems.

From their work on the Bovey sediments and the Mochras sediments (Wilkinson & Boulter, 1980) suggested a correlation between the two. With 140m to 300m in Bovey correlating to the Early Oligocene basal beds of Mochras and 140m to 0m in Bovey correlating to the Transitional unit of Mochras.

ISLE OF WIGHT

The Isle of Wight is a well worked 'classic' area for geological study. Liengjaren *et al.* (1980) worked on the dinoflagellate cysts of the Lower Oligocene of the Isle of Wight. Repeated transgressions and regressions in the Tertiary sequences were described. This cyclicity led to the deposition of the non marine Bembridge Oyster beds, marine Bembridge limestones and other clear transgressions within the dominantly terrestrial Bembridge Marls and Hamstead Beds.

Pollen and spore assemblages described from the Lower Oligocene of the Isle of Wight (Gruas-Cavagnetto, 1976) were comparable to those seen throughout the UK Oligocene. A lack of quantitative data and limited taxa published by Gruas-Cavagnetto (1976) make any comparisons other than general, difficult. The recorded presence of *Boehlensipollis hohli* in the Hamstead Beds indicates an Oligocene age comparable to the sections studied in this current work. Other taxa recorded by Gruas-Cavagnetto (1976) in common with the sections studied for this thesis include *Inaperturopollenites-Sequoiapollenites*, bisaccate pollen, *Alnipollenites, Quercoidites, Porocolpopollenites, Intratriporopollenites, Momipites, Milfordia, Sparganiaceaepollenites, Polyatriopollenites carpinoides* (Upper Hamstead) and *Porocolpopollenites undulatus.* She regarded the taxa as suggesting a temperate climate. This has similarities to the conclusions drawn in this current study although she made no distinction between communities within this environment such as the swamp, floodplain and forest communities distinguishable from this current research. Furthermore such communities cannot be interpreted from the published data which is in the form of presence and absence data rather than in a quantitative format.

More recent palaeobotanical work on the Lower Oligocene of the Isle of Wight by Collinson (1983) and Hooker *et al.* (1995) on the Bembridge Marls has been published. The sediments are composed of olive brown to black silty clays and clays. Note the significant difference to the Oligocene sediments of the western British Isles which contain characteristic lignites. Again no quantitative data is published in Collinson (1983) so only limited comparisons can be made. Her emphasis on the taxa *Sparganiaceaepollenites* would suggest significant numbers were recorded from the Isle of Wight sediments. This is very different to the western British Isles sediments where this taxa was only noted from two sections (16/16b-4 and 73/36) all at numbers under 5% and never forming an important part of the assemblage. Gruas-Cavagnetto (1976) also recorded this taxa but in what abundances is unknown.

The palynological data (Collinson, 1983) shows *Inaperturopollenites hiatus* occurring through the section with *Monocolpopollenites* and *Arecipites* occurring in greater numbers at the base than the top. This is the opposite to the palynological assemblages recorded in this current work which show *Monocolpopollenites tranquillus* (Ginkgo), *Arecipites* and *Dicolpopollis* being of less significance in the Lower Oligocene and increasing upsection. The bisaccate numbers are low compared to the findings of this study but do increase upsection which is comparable. Also taxa such as *Tricolpopollenites, Triatriopollenites* and *Intratriporopollenites* are comparable by their appearance in this research.

Sedimentary evidence led Dailey (1973a, 1973b) to suggest a range from esturine (Oyster Beds) to brackish lagoonal, coastal and floodplain lake environments. Collinson (1983) saw similar environments of reed marshes and scattered trees in the marginal aquatic areas, with the terrestrial areas adjacent to the lake fluctuating between open and closed woodlands. Extensive wetland environments were also described by Collinson (1983, 1990) and Collinson & Hooker (1987). Such environments have some similarity to those described for the Oligocene basins along the western British Isles. Although the Isle of Wight Oligocene is greatly influenced by transgressive-regressive cycles giving intermittent marine and esturine conditions which lead to the slight differences such as the reed marshes in the Isle of Wight compared to the lignite forming *Nyssa/Taxodium*/Betulaceae swamps and diverse floodplain and forest vegetation interpreted in this study. Transgressive effects such as those on the Isle of Wight are only seen in the southern most Oligocene material studied in this work, from 73/36. This fits with the overall idea of the marine influences declining to the north and west of the London-Hampshire and Paris Basins.

NORTH SEA

The pollen and spore data from the North Sea marine sediments is perceived to be very limited by many authors such as Manum *et al.* (1989), who stated that 'pollen and spores are less useful for zonation'. Boulter (1986), concentrating on pollen and spore data from the Central North Sea (16/1-1) and the Norwegian Sea, published his data in a semi-quantitative format, from which numerous pollen and spore characteristics can be compared to the data of this study.

Inaperturopollenites abundances are greater in number in the base of 16/1-1 compared with the top, this is comparable to the characteristics of this thesis where higher numbers of this taxa are seen in the Rupelian declining into the Chattian. Also the Middle Oligocene Norwegian Sea section has lower *Inaperturopollenites* therefore is indicative of being higher up in the section. This is comparable to the data collected in this current study especially 73/36. Other common taxa noted by Boulter (1986) from 16/1-1 are also found in this study such as bisaccate pollen, *Laevigatosporites, Tricolpopollenites, Tricolporopollenites, Alnipollenites, Monocolpopollenites, Deltoidospora* and *Baculatisporites* along with lesser *Graminidites, Sequoiapollenites, Nyssapollenites, Verrucatosporites, Stereisporites* and *Cicatricosisporites*. Although important Oligocene taxa such as *Polyatriopollenites carpinoides, Dicolpopollis kockeli, Trivestibulopollenites betuloides, Corsinipollenites, Echinosporis* and *Arecipites* were not recorded in Boulter's (1986) data.

The Norwegian Sea data again shows common *Inaperturopollenites*, bisaccate pollen, *Laevigatosporites, Intratriporopollenites, Sequoiapollenites, Verrucatosporites, Cicatricosisporites* and *Stereisporites* with less common *Deltoidospora, Nyssapollenites, Monocolpopollenites, Trivestibulopollenites, Tricolpopollenites, Tricolporopollenites, Alnipollenites* and *Polyatriopollenites.*

These latter less common taxa were found to be much more dominant and in some cases were the important taxa in this current work.

From Boulter's work he was unable to detect any fall in sea level at the Lower/Upper Oligocene boundary from the pollen and spore record, suggesting the land vegetation didn't change greatly over this period. Importantly the interpretations of the authors work in this thesis indicates a significant reduction in sea level (the largest in the Cainozoic period, Haq *et al.* (1987)) to be clearly shown and dated from the dinoflagellate data. This fall in sea level can be correlated to subtle but significant changes in the pollen and spore data from the same sections over the same time intervals. The subtle changes in the pollen and spore events can also be identified in the terrestrial realm due to the associated base level fall with the falling sea level on the western British Isles material.

More recent work on the East Shetland Platform (Condon *et al.* 1992) describes Rupelian sands and clays. The presence of *Gerdiocysta canopia* in their sand unit from 80/03 suggest this marine section to be of a Lowest Rupelian age (Powell, 1992, Vinken *et al.,* 1988). This is lower stratigraphically than any of the marine or terrestrial sections studied in this work. Overlying this a transgressive claystone unit (80/03 and 81/16) of latter Rupelian sediments contained similar taxa to those seen in the Rupelian of the marine sections (16/16 and 21/28). Jurassic reworking was noted by Condon *et al.* (1992) and is interesting as all sections from this current study show evidence of Jurassic reworking although the provenance here is thought to be from the Unast Basin to the NW. The selective quantitative pollen and spore data published from these Rupelian sediments show high numbers of bisaccate pollen (Over 40%) with less than 2.5% of *Ilexpollenites, Retitricolpites, Inaperturopollenites, Laevigatosporites, Triporopollenites coryloides* and *Polyatriopollenites carpinoides*. These abundances are very different to the dominant *Inaperturopollenites, Laevigatosporites, Tricolpopollenites* and *Tricolporopollenites* taxa seen in the results of this thesis and in Boulter (1986).

The Geike escarpment on the Hebridean slope was cut during the Middle Oligocene falling sea level, erosive event. Early Oligocene shelf carbonate chalks occur with an erosive top, these are followed by Late Oligocene carbonate rich muds and sands (Jones *et al.*, 1988; Evans *et al.,* 1989) in warm water marine conditions. Although no pollen and spore data is available here the fall in sea level seen in the Middle Oligocene and local transgression in the Late Oligocene seen in 77/7, 16/16 and 21/28 bringing in the basinal muds here, this fit well with the interpretations of this study.

BRIEF COMMENTS ON THE EUROPEAN OLIGOCENE

Oligocene sediments are well known from the European sequences. Widespread sands, silts, clays and lignites occur over the continent and represent a variety of marine to continental deposits, which have a good defined stratigraphy. This is very different to the Oligocene sediments from the isolated basins along the western British Isles. It is only the Bovey Formation and Isle of Wight Bouldnor Formation (Bembridge and Hamstead Members) that have a clearly described stratigraphy here.

Numerous transgressive and regressive events in the European Oligocene would suggest differences in any comparisons drawn with the British wholly terrestrial sequences studied here, in which only slight influences from transgressive sea level activity appearing in 73/36 (Stanley Bank Basin) and 77/7 (north Scotland) are seen.

Over the NW European Basin an early Oligocene transgressive event resulting in transgressive sands in the Netherlands, NE. Belgium, Lower Rhine and north and central Germany are seen to occur, such as the Grimmerton Sands of Belgium (Cavalier, 1979). This transgression did not reach the Paris Basin and only some marine influence was seen in the Hampshire Basin, Isle of Wight (as near shore lakes). A regressive phase gave terrestrial deposits in NE. Belgium and the Paris-Hampshire Basin (non marine Osborne Beds, Upper Bembridge and Lower Hamstead Beds). The only continuous sedimentation was in the Central North Sea and Early Oligocene subsiding areas such as the Viking Graben, Moray Firth Basin, Central North Sea and Central Graben.

Middle Oligocene and early Late Oligocene times (Vinken *et al.,* 1988) gave marine deposits in the majority of the Hampshire, Paris, Belgium and German areas. This gave the marine Upper Hamstead Beds while the lacustrine limestones in the Paris Basin and Netherlands was indicative of a following regressive phase.

A Late Oligocene transgressive event gave marine conditions in Poland with shallower marine clays in Belgium and Germany. This transgressive event was not recorded in the Hampshire-Paris Basin areas. The nature of these Oligocene sequences make comparisons to the more stable sedimentary sequences on the western side of the British Isles limited.

Much work on the Paris Basin Oligocene sediments and palynology has been published (Chateauneuf, 1980; Sittler & Ollivier-Pierre, 1994; Ollivier-Pierre, 1980). Taxa in common to those from this study were reported in the published literature and include important Oligocene taxa such as *Trivestibulopollenites betuloides, Boehlensipollis hohli, Porocolpopollenites vestibulum, Cupuliferoipollenites cingulum* subsp. *fusus, Polyatriopollenites carpinoides, Inaperturopollenites,* bisaccate pollen, *Nyssapollenites, Alnipollenites* and *Laevigatosporites*. The quantitative data published by Chateauneuf (1980) on the Lower/Middle Oligocene showed some similarities to the findings of this study on British Isles material. The numbers of *Inaperturopollenites* at the base are greater than those up section and the numbers of *Tricolpopollenites* are higher at the base and decline upsection. Both are characteristic of the pollen events suggested in this current study. Although higher numbers of bisaccate pollen especially in Lower Oligocene are seen by Chateauneuf (1980) than in the western British Isles material. The larger numbers of *Laevigatosporites, Nyssapollenites* and *Alnipollenites* from the British Isles material compared to the Paris material suggest environmental differences with isolated floodplain and swamp communities prevailing in terrestrial British Isles differing from the cyclic marine to terrestrial deposits in Paris.

Increasing bisaccate pollen upsection in the Paris Basin (Sittler & Ollivier-Pierre, 1994) correspond to the increase in sea level associated with the Rupelian transgression. This is very different to the UK terrestrial material where the increased bisaccate pollen are characteristic of the Chattian, although the marine sections studied show high bisaccate recovery throughout the whole section.

Gorin (1975) studied Oligocene sections from the Massif central and saw increasing *Pinus* upsection into the Chattian (similar to the western British Isles) along with increasing cypress/Nyssaceae/Betulaceae swamp taxa, arborescent floodplain taxa and *Graminidites*. He envisaged a hotter humid Rupelian with dominant spores, *Sparganiaceaepollenites,* Betulaceae, *Alnipollenites* and *Boehlensipollis hohli.* Ollivier-Pierre (1980) described subtropical to temperate Oligocene taxa with similar species to those seen in this current study.

Rupelian equivalent sediments in Belgium (Stover & Hardenbol, 1993) show two sequence events but no pollen and spore data. While the work of Roche & Schuler (1976) on Belgium sediments saw Oligocene taxa *Boehlensipollis hohli* in the Rupelian along with *Agloridia* (a genera not recorded in the western British Isles Oligocene in this study) and with conifer taxa becoming more important into the Chattian. This is also shown by this current work and the development of a subtropical community including taxa such as *Porocolpopollenites, Sequoiapollenites* and *Pterocarya.*

German data presented by authors such as Krutzsch and Thomson & Pflug (1953), provided detailed work on pollen and spores in the German Tertiary. They defined and found many similar taxa to those seen in this study, but their lack of quantitative data limits any further comparisons.

Collinson (1992) who worked on macrofossils from Czechoslovakia, Germany, France and Belgium over the Eocene/Oligocene boundary, reported changes from evergreen subtropical to mixed evergreen deciduous communities with warm but seasonal temperatures into the Oligocene. Evidence of this seasonality is also seen in wood fragments (plate 70) from the Stanley Bank Basin.

From his work on east Russian material, Leopold *et al.* (1992) calculated vegetational biomass figures which were high in the Lower Oligocene and lower in Upper Oligocene indicating changing vegetation from forest to more open habitats providing the ecosystem between the tropical forests of the Eocene and the Steppes/Prairies of the Miocene.

Polish Oligocene studies (Grabowska, 1965; Ziembinska-Tworzydlo, 1974, Vinken *et al.,* 1988) have also showed similarities to this study with rare Normapolles (only *Pompeckjoideapollenites* is seen in the UK material in this study) and other similar taxa *Boehlensipollis hohli, Cupanieidites eucalyptoides, Quercoidites* and *Tricolporopollenites.*

Overall similar taxa are noted in the Oligocene of NW Europe to the findings of this current study. The cyclic depositional conditions in mainland Europe of repeated transgression-regression contrast to the mainly terrestrial lake basins characterising the Oligocene deposits of the western British Isles which have only limited marine influences. Also climatic differences are seen such as the hotter humid Paris Basin (Gorin, 1975) with the presence of calcareous and evaporitic deposits (Marnes de supergypsee) during this period, hence the palynofloras indicated by pollen and spore data are different. The swamp dominated floodplain communities of the British Isles with fluviatile influences and surrounding climax forest, primary forest and some secondary dryland vegetation is seen along with the overprint of transported bisaccate taxa is different to those environments envisaged for mainland Europe.

In the Late Oligocene, coals of the Koln Member in the Lower Rhine area are seen to occur. These German coals and lignites are important and have some similarities to the lignites dominant in the Upper Oligocene of the western British Isles.

Although overall similarities (Leopold *et al.,* 1992; Hooker, 1992) from forests to increasingly open environments and the mixed evergreen deciduous woodlands of Collinson (1992) can be seen. The changing environments limit the use of pollen and spores on an interregional correlation, although IGCP 124 (Meyer, 1988) have a limited zonation scheme which picks out:

Upper Oligocene:	Sp 6	top *Caryapollenites simplex, Tiliapollenites instructus*
Middle Oligocene:	Sp 7	*Boehlensipollis hohli* marker

A much finer scale division of the Oligocene in the UK region using pollen and spore events has been defined in this study (see Chapter 7 for details). Such characteristic pollen and spore events have proved the only method to accurately date (both relative and absolutely) the terrestrial Oligocene deposits from the western British Isles and to correlate between the terrestrial and marine environments of the area. Furthermore it has been shown above that accurate correlations can be made, using the pollen and spore events defined in this study, to the published data and can give precise dates to this previous work which has previously only defined very loose or inaccurate ages.

SUMMARY AND CONCLUSIONS

Prior to this study, it had proved to be impossible to correlate the terrestrial western British Isles sections with the European Oligocene stages (Wilkinson & Boulter, 1980; Evans *et al.,* 1979 and Boulter & Craig, 1979). The methodology adapted here; comparing pollen profiles from these sections with those of the marine North Sea record, and calibration of this to the dinoflagellate cyst record, has allowed this correlation to be established. Using this high resolution stratigraphy for the Rupelian and Chattian it has been possible to analyse the ecological and climatological information contained within the quantitative palynological data. Because of the robust nature of the correlation, the recognition of the effects of relative sea level change, evolution and climatic variation on the palynofloras and parent vegetation can be highlighted, features which invalidate previous ecological interpretation (e.g. Boulter & Hubbard, 1982). It is reassuring to see that the interpretations and conclusions that have been drawn are indicated from not one interpretative method but from numerous different methodologies.

The dominant feature of the terrestrial and marine palynological data has been the identification of the significant fall in relative sea level at the Rupelian/Chattian boundary. This is apparent primarily from the environmental preferences of the dinoflagellate taxa involved (see Chapter 6). The Rupelian interval of the North Sea sections 16/16b-4 and 21/28b-7 are characterised by *Cordosphaeridium cantharellum, Homotryblium tenuispinosum, Spiniferites ramosus* subsp. *ramosus, Spiniferites pseudofurcatus* which occur in open marine environments (Liengjaren *et al*, 1980; Islam, 1983; Brinkhuis, 1994). Conversely the marine sections of Chattian age show taxa with preferences for restricted, or shallower water shelf slope conditions.

This Chattian shallowing, is confirmed from diversity figures calculated from the marine sequences. The diversity values are seen to be greater in Rupelian aged parts of the section and lower in the Chattian parts of the section. This is interpreted as a reflection of the falling sea level here (Chapter 6). The grains per gram figures in the marine sections are seen to increase into the Chattian, also suggesting shallowing. It is these general conclusions that showed clear similarities to the Haq *et al.* (1987) onlap and sea level curve (figure 6.5) which places the largest fall in Cainozoic sea level at the Rupelian/Chattian boundary.

Significantly from the comparison of the Haq curve, direct inferences to an absolute time scale can be made firstly placing an absolute age on the most distinctive and notable feature throughout the sections i.e. the Rupelian/Chattian boundary which occurs at 28.28Ma. The falling sea level at time is recognised as a global event. A major 'mid' Oligocene unconformity in many of the marine shelf sequences in the world have been described from N. America (Prothero & Berggren, 1992 and Prothero, 1994) to the North Sea and on the Hebridean slope, these are regarded as being the result of the great erosive force occurring after a significant fall in sea level.

Superimposed upon this overall shallowing upsection, local sea level conditions have been interpreted. Variance calculations on the data (Chapter 5 & 6) have been shown to be a useful indication of sea level, indicating proximal to distal environments and the presence of transgressive events.

From these marine data, three transgressive events have been identified. T1a occurs in the Rupelian part of the sequence (below 29.40Ma), T1 occurs close to the top of the Rupelian part of the sequence (below 28.283Ma) and is recognised from a variance spike resulting from peak *Areoligera semicirculata* and occurs at the top of a coarsening upwards unit. T2 is a transgressive event (about 25.823Ma) again recognised by the peak variance associated with a peak in abundance of *Homotryblium floripes* and occurs near the top of the Chattian part of the sequence.

Both T1 and T2 events are also recognised from the marine pollen and spore statistics which show a peak variance at these levels, representing a dominance of the taxa in this case transported bisaccate taxa, a characteristic of more open marine environments.

Above the T1 and T2 transgressive events a shallowing is indicated by the variance figures and also the presence of more Peridinioid cysts which indicate stressed shallower conditions. This shallowing is characteristic of the top of the sequence boundaries and ties in very well to the top Rupelian and top Chattian levels picked out by described associations and cluster analysis.

Evidence of local sea level fluctuations in the Oligocene is well documented for the Isle of Wight (Liengjaren *et al*, 1980) and for the North Sea (Mudge & Bujak, 1994) and over NW Europe as a whole IGCP 124 (Vinken *et al*., 1988). A very clear picture of what is occurring above the Early Oligocene and Late Oligocene in the western British Isles, is shown in this study.

Speculation as to the causal effects of such global sea level events, as this major fall in sea level at the Rupelian/Chattian boundary is important. Both Prothero & Berggren 1992 and Prothero, 1994 summarise temperature and climate conditions in the Eocene and Oligocene. They envisage a Late Eocene Antarctic cooling, as Australia and S. America separate from Antarctica resulting in new oceanic circulation patterns. The continued separation of Antarctica and Australia in the Middle Oligocene led to the expansion of the ice and to the development of a new phase of circum-polar oceanic circulation that started at the end of the early Oligocene which further lowered temperatures. It is at this time that the first major Antarctic ice development occurred. The size and duration of ice sheets is controversial (Kennet & Barker, 1990), but short term glaciations have occurred since the Eocene and significant ice sheets have occurred since about 30Ma with evidence of early Oligocene Antarctic ice confirmed by ODP (Barron *et al.,* 1989). The importance of such major ice development here has implications for sea level as major ice sheets in the Antarctic cause significant reductions in sea level (as seen in Pleistocene to Recent times).

Parent plant communities can be inferred from the various taxa recorded in this study. The underlying effects of sea level on such plant communities was indicated in the data in this study, despite the fact that Wilkinson *et al.* (1980) working on similar data saw little vegetational change throughout the Oligocene. Throughout the six terrestrial and two marine sequences a number of changes in vegetation can be picked up at certain levels.

The P1 unit, Rupelian equivalent, sequence shows a distinct mixed mesophytic forest structure with climax forest and understorey communities occurring with floodplain and floodplain swamp communities. True floodplain trees are characteristic with swamp communities dominated by *Inaperturopollenites/Alnipollenites*, many free standing floodplain ferns and some transported taxa from surrounding upland conifer vegetation can be seen. With fewer primary forest, juglandaceous swamp and lack of tropical taxa and secondary dryland communities.

The P2 unit, Chattian equivalent, sequences of this study show marked changes in the parent plant communities to those described above. The underlying cause of these changes are again due to the influence of sea level. The fall in sea level and corresponding fall in base level on land causes the incision and rejuvenation of many streams and rivers, leading to significant increases in reworked taxa or transported taxa at this level. Moreover, the base level shift leads to a general instability and fluctuation of communities. The climax forest element is seen to decline while the primary forest element, drier understorey element and secondary dryland forest elements are seen to increase in number within this unit. The latter possibly suggesting sandy soil or drier climate. The newly developed instability in the environment is very distinctive with the floodplain swamp communities fluctuating between *Alnipollenites* and *Inaperturopollenites*. Within the P2 unit a transgressive event (T2 defined from the marine sections) can be recognised from the pollen and spore events. In 77/7 the marine influence leads to an increase in the floodplain element and transported taxa reflecting the increase in base level and drainage and 73/36 sees the increase drainage and base level causing the delayed fall off of arborescent floodplain taxa.

The P3 unit, Upper Chattian equivalent again shows distinct changes in plant communities developed. The transported element is seen to increase along with increasing secondary dryland and drier understorey elements while the primary forest communities decline and the swamp communities are less dominant and composed of *Taxodium* only.

The P4 Unit, Miocene equivalent, is characterised by an abundance of the transported element due to the marine influence of the higher sea levels typical of the Miocene period, associated with this the floodplain community element is also seen to increase and a more stable *Inaperturopollenites/Alnipollenites* swamp environment is seen with only traces of climax and secondary communities.

The plant communities indicted in the North Sea marine sections are derived from the eastern coastal plains of the country. These transported assemblages are dominated by bisaccate pollen along with coastal swamp elements. The Rupelian parent plant communities here after the dominance of the saccates is the Taxodaceae/Nyssaceae coastal littoral swamps, with strong floodplain tree and fern communities and a large diversity of climax forest and understorey taxa. The distinctive change in plant communities indicated by the terrestrial data is mirrored in these data into the Chattian aged part of the section. While the instability in the environment does not lead to a fluctuating swamp composition, it is the appearance of juglandaceous swamps in response to the fall in sea level that is seen. This develops here on the wetter coastal plains on the eastern side of the country, compared to the drier communities seen in the western British Isles. Along with this, the diversity and abundance of climax forest and understorey communities, probably from the central England landmass, decreases, while primary forest and secondary dryland forest elements increase.

This interpretation of these data shows clear evidence of the effects of the sea level changes on palynofloral communities. The terrestrial communities described from the western British Isles are very localised, they compare well to those described by Wilkinson & Boulter (1980), of swamp and floodplain environments. They are similar to the environments envisaged for the Cardigan Bay sediments (Dobson & Whittington, 1987) and Bovey Basin (Wilkinson & Boulter, 1980) not studied in this research, where periodic lake and swamp development on a well drained floodplain is envisaged. These define general palaeoenvironments, but changes of communities through the Oligocene especially at the Rupelian/Chattian boundary has been neglected. The work of Collinson *et al.* (1981) and Collinson (1992) for the Isle of Wight area, described similar mixed deciduous and evergreen forest communities, comparable to the mixed mesophytic forests here. She envisaged warm temperate seasonal climates derived from a more tropical and subtropical community seen in the Eocene. Collinson (1992) placed an emphasis on early Oligocene reed marshes with Betulaceae and juglandaceous taxa also being present. These are distinctly different to the communities described in this project. These differences can be accounted for by the location of the Isle of Wight sections studied by Collinson (1992) and Collinson *et al.* (1981), which are subjected to a greater marine influence and the repeated transgressive and regressive events reported by Liengjaren *et al.* (1980).

Accompanying the changes in vegetation during the Oligocene such as drier more open forest environment becoming increasingly important over the climax forest and understorey mixed mesophytic forests prominent in the early Oligocene. Hooker (1992), studied the mammals of this period, his results compliment these seen here. He saw a change from large mammals with an even distribution of body sizes, in the Middle/Late Eocene humid tropical forests to a dominance by small mammals with large sized animals becoming rare and an absence of medium sized taxa in the Oligocene. He coined this change 'the Grande Coupure' which is characterised by a selective extinction of the mammal faunas after which a dominance of small mammals such as rabbits and rodents occur. This reflects the change in climate and vegetation to a cooler, more arid environment such as closed to moderate savannas (not to the extent of *Sequoia* scrub moors of the Miocene). Retallack (1983), working in USA, also saw similar vegetational changes from dense moorlands in the Late Eocene to open scrub and grassland with streamside woodlands in the Late Oligocene, again as a result of changing climate. Leopold *et al.* (1992) working on biomass calculations from mid-continental USSR, China and America, also noted a significant change into the Oligocene. They recorded changes in vegetation from Eocene forests to Oligocene open woodland and savanna types with more seasonal precipitation in the latter. He also accompanied this with a declining mean annual temperature figure from about 18°C in the Late Eocene to 13°C in the Oligocene.

Numerous palaeotemperature have been estimated for the Oligocene climate from palaeobotanical evidence. Wolfe (1978) using leaf margin analysis, devised a plot of mean annual temperatures verses mean annual range of temperatures for different climatic and vegetational types. With Oligocene vegetation being characterised by mixed mesophytic forests types (similar to those described from the parent plant communities in this project) giving a mean annual temperature of about 13°C.

Krutzsch (1967c) also defined a pollen based temperature curve in their central European model and they recognised a significant relative fall in temperature in the Middle Oligocene. Boulter (1984) also used fossil plant groups to calculate palaeotemperatures, he defined three groups, group III paratropical rainforests (22.5°C), group II fern and conifer forests (14°C) and group I deciduous forests (10°C). This was explained by the work of Boulter & Hubbard (1982) who noted a change from group III forests in the Middle Eocene to group I and II in the Late Eocene and to group I forests in the Lower Oligocene where they suggested mean annual temperatures of 10°C and mean annual range of temperatures of 30°C. Such ranges in temperature differ from the much milder winters they envisaged for the

Eocene. Although the methods used by Boulter & Hubbard (1982) and Boulter (1984) of going from palynomorphs to plant communities and temperatures is unclear, which must call into question their results.

Prothero (1994) summarises geochemical Palaeogene temperature calculations. Early calculations such as Shackleton & Kennet (1975) were based on an ice free assumption, since then palaeotemperatures have been calculated with Antarctic ice taken into account such as Matthews & Poore (1980), Keigwin & Keller (1984) and Shackleton (1986). In almost all of the oxygen isotope results, the most dramatic change occurred in the early Oligocene Shackleton & Kennet (1975), Miller *et al.* (1987) and Miller (1992). Both benthonic and planktonic foramanifera show a brief positive excursion of about 1.3‰. Miller (1992) calculated that 0.3-0.4‰ of this change is due to ice volume increases leading to falling global sea levels by about 30 m (Haq *et al.*, 1987) the remaining 0.9-1.0‰ is explained by declining global temperatures by 5°C. Shackleton (1986) from his $\delta^{18}O$ results from benthonic foraminifera data shows a significant temperature fall and the cooling of deep waters associated with Antarctic glaciations. Shackleton also picked out two further events one in the middle Oligocene and a further near to the top of the Oligocene where other $\delta^{18}O$ excursions could possibly represent periods of Antarctic ice build up and glaciation. It is important to note that although no actual temperature figures have been estimated in this work. The general findings of the palaeobotanical and geochemical data suggest a significant fall in water temperature associated with Antarctic ice development. It is the influence of such developments (i.e. Antarctic ice) that is reflected in the palaeoenvironmental data here, along with the botanical evidence for the development of more open woodlands and the increasing importance of secondary dryland communities which reflect the increasing savanna environments envisaged in the published literature. This global cooling can be concluded from the palaeobotanical interpretations of this study, while together with the falling relative sea level it is associated with the first development of Antarctic ice.

ENCLOSURE

1


16/16b-4, NORMALISED MICROPLANKTON DATA
Depth
4320
4300
4260
4220
4180
4140
4100
4020
4000
3960
3920
3880
3840
3800
3720
3640
3600
3580
3500
3460
3440
ACRITARCHS
Cymatiosphaera spp.
Cyclopsiella sp. A
Cyclopsiella sp. B
Cyclopsiella vieta
Paralecaniella indentata
CHORATES
Achilliodinium biformoides
Adnatosphaeridium vittatum
Aoria spp.
Areoligera cf. semicirculata
Areoligera semicirculata
Areosphaeridium arcuatum
Areosphaeridium? actinocoronatum
Callaiosphaeridium spp.
Cannosphaeropsis utinensis
Chiropteridium lobospinosum
Chiropteridium mespilanum
Chiropteridium partispinatum
Cleistosphaeridium sp. 1 of Manum 1989
Cordosphaeridium cantharellum
Cordosphaeridium funiculatum
Cordosphaeridium minimum
Dapsilidinium pastielsii
Dapsilidinium simplex
Dinocyst sp. 4 of Manum
Diphyes colligerum
Distatodinium craterum
Distatodinium ellipticum
Distatodinium paradoxum
Homotryblium floripes
Homotryblium oceanicum
Homotryblium tenuispinosum
Homotryblium vallum
Hystrichokolpoma cinctum
Hystrichokolpoma rigaudiae
Hystrichosphaeridium latirictum
Hystrichosphaeridium patulum
Hystrichosphaeridium spp.
Hystrichostrogylon membraniphorum
Hystrichostrogylon sp. 1 of Manum 1989
Lingulodinium machaerophorum
Melitasphaeridium asterium
Melitasphaeridium pseudorecurvatum
Melitisphaeridium choanophurum
Membranophoridium aspinatum
Paucisphaeridium cf. invesibuccinum
Polysphaeridium cf subtile
Polysphaeridium subtile
Systematophora ancerea
Systematophora placacantha
Tanyosphaeridium sp. 1 Manum 1989
PROXIMOCHORATES
Dinopterygium fehmarnense
Impagidinium sp
Impletosphaeidium implicatum
Impletosphaeridium insolitum
Impletosphaeridium ligospinosum
Kallosphaeridium spp.
Operculodinium bellulum
Operculodinium centrocarpum
Operculodinium microtriainum
Operculodinium sp. 1
Operculodinium sp. 2
Operculodinium sp. 3
Operculodinium sp. of Piasecki 1980
Operculodinium spp.
Achomosphaera alcicornu
Achomosphaera crassipellis
Achomosphaera ramulifera
Nematosphaeropsis labyrinthea
Nematosphaeropsis lemniscata
Nematosphaeropsis sp.
Spiniferites multibrevis
Spiniferites pseudofurcatus
Spiniferites ramosus granomembranaceous
Spiniferites ramosus granosus
Spiniferites ramosus subsp. ramosus
Spiniferites sp. 1 Manum 1989
PROXIMATES
Amiculosphaera umbracula
Apteodinium spiridoides
Apteodinium trinovanteum
Corodinium incompositum
Cribroperidinium giuseppei
Fromea fragilis
Microdinium sp. 1 of Chateauneuf 1980
Microdinium sp. 2
Microdinium spp.
Pentadinium laticinctum
Tectatodinium sp
Thalassiphora fenestrata
Thalassiphora pelagica
Tuberculodinium vancampoae
PERIDINIOIDS
Deflandrea heterophlycta
Deflandrea phosphoritica
Deflandrea sp.
Lejeunecysta hyalina
Lejeunecysta spp.
Lentinia wetzelii
Palaeocystodinium golzowense
Palaeocystodinium sp. A of C&D 1979
Phthanoperidinium alectelophum
Phthanoperidinium amoenum
Phthanoperidinium comatum
Phthanoperidinium geminatum
Phthanoperidinium laevimurum
Phthanoperidinium sp.
Selenopemphix nephroides
Svalbardella cooksoniae
Svalbardella sp. 1
Wetzeliella gochtii
Wetzeliella sp.
Wetzeliella symmetrica
M4N
Scolecodont fragment
~~Batiacasphaera (rwd)~~
REWORKING
Cleistosphaeridium (reworked)
Cleistosphaeridiun disjunctum (reworked)
Cribroperidinium granulatum (Reworked)
Ctenidodinium sellwoodii (reworked)
Kallosphaeridium cf 'brevibabatum'(rwd)
Muderongia tetracantha (rwd)
Oligosphaeridium complex (reworked)
OTHER ALGAE
ACRITARCHS
CHORATES
PROXIMOCHORATES
PROXIMATES
PERIDINIOIDS
REWORKING
MICROFAUNA
MICROPLANKTON SUM
DIVERSITY
VARIANCE
STANDARD DEVIATION
GRAINS PER GRAMME
20
40
60
100
200
300
20000
40000
60000
80000
100000
A
B
C
D
E
F
G
ASSOC.

ENCLOSURE

2


NORMALISED MICROPLANKTON PLOT
21/286-7
Depth
3270
3210
3180
3150
3090
3060
3000
2970
2940
2910
2880
Ascostomocystis granulatus
Cyclopsiella sp. A
Cyclopsiella sp. B
Cyclopsiella vieta
Cymatiosphaera spp.
Paralecaniella indentata
ACRITARCHS
Areoligera cf. semicirculata
Areoligera medussetiformis
Areoligera semicirculata
Areosphaeridium arcuatum
Areosphaeridium? actinocoronatum
Chiropteridium lobospinosum
Chiropteridium mespilanum
Chiropteridium partispinatum
Cordosphaeridium cantharellum
Cordosphaeridium fibrospinosum
Cordosphaeridium funiculatum
Cordosphaeridium minimum
Dapsilidinium pastielsii
Dapsilidinium simplex
Dinocyst sp. 4 Manum 1976
Diphyes colligerum
Distatodinium craterum
Distatodinium paradoxum
Homotryblium floripes
Homotryblium oceanicum
Homotryblium tenuispinosum
Homotryblium vallum
Hystrichokolpoma cinctum
Hystrichokolpoma rigaudiae
Hystrichosphaeridium latirictum
Hystrichosphaeridium patulum
Hystrichostrogylon membraniphorum
Kallosphaeridium spp.
Lingulodinium machaerophorum
Melitasphaeridium asterium
Melitasphaeridium pseudorecurvatum
Membranophoridium aspinatum
Paucisphaeridium cf. invesibuccinum
Systematophora placacantha
CHORATES
Dinopterygium fehmarnense
Impagidinium patulum
Impagidinium sp.
Impletosphaeridium insolitum
Impletosphaeridium ligospinosum
Impletosphaeridium spp.
Operculodinium bellulum
Operculodinium centrocarpum
Operculodinium microtriainum
Operculodinium severinii
Operculodinium sp. 2
Operculodinium sp. Piaskei 1980
Operculodinium sp.1
Operculodinium sp.3
Operculodinium spp.
Pentadinium laticinctum
Achomosphaera alcicornu
Achomosphaera crassipellis
Achomosphaera ramulifera
Nematosphaeropsis labyrinthea
Nematosphaeropsis lemniscata
Nematosphaeropsis spp.
Spiniferites multibrevis
Spiniferites pseudofurcatus
Spiniferites ramosus granosus
Spiniferites ramosus subsp. ramosus
Spiniferites sp. A
Spiniferites sp. Manum 1989
PROXIMOCHORATES
Amiculosphaera umbracula
Apteodinium spiridoides
Apteodinium trinovanteum
Cribroperidinium giuseppei
Fromea fragilis
Microdinium sp.
Microdinium sp. 1 of Chateauneuf 1980
Microdinium spp.
Tectatodinium spp.
Thalassiphora fenestrata
Thalassiphora pelagica
PROXIMATES
Deflandrea heterophlycta
Deflandrea phosphoritica
Deflandrea sp.
Lentinia wetzelii
Palaeocystodinium golzowense
Palaeocystodinium sp. A of C&D 1979
Phthanoperidinium amoenum
Phthanoperidinium comatum
Phthanoperidinium filigranum
Phthanoperidinium geminatum
Phthanoperidinium laevimurum
Rhombodinium draco
Selenopemphix nephroides
Svalbardella cooksoniae
Svalbardella sp. 1
Svalbardella sp. 2
Wetzeliella gochtii
Wetzeliella sp.
Wetzeliella symmetrica
PERIDINIOIDS
Cleistosphaeridium spp. (reworked)
Cribroperidinium granuligerum (reworked)
Ctenidodinium sellwoodii (reworked)
Kallosphaeridium cf.'brevibarbatum' (Rd)
Sentusidinium sp. (reworked)
REWORKING
OTHER ALGAE
ACRITACHS
CHORATES
20
40
PROXIMOCHORATES
20
40
PROXIMATES
PERIDINIOIDS
REWORKING
MICROPLANKTON SUM
100
200
300
DIVERSITY
20
40
60
STANDARD DEVIATION
2
4
VARIANCE
2
4
6
8
10
GRAINS PER GRAMME

ENCLOSURE

3


16/16b-4 NORMALISED MICROPLANKTON DATA
Depth
4320
4300
4260
4220
4180
4140
4100
4020
4000
3960
3920
3880
3840
3800
3720
3640
3600
3580
3500
3460
3440
20
40
60
80
Abiespollenites spp.
Bisaccate pollen undif.
Piceapollis spp.
Sciadopityspollenites serratus
MONTANE
Arecipites spp.
Polyatriopollenites carpinoides
Pompeckjoidaepollenites subhercynicus
PRIMARY FOREST
Cupuliferoidaepollenites lib liblarensis
Cupuliferoidaepollenites lib. fallax
Cupuliferoipollenites cingulum fusus
Cupuliferoipollenites cingulum oviformis
Cupuliferoipollenites cingulum pusillus
Cyrillaceaepollenites megaexactus
Intratriporopollenites ceciliensis
Intratriporopollenites microreticulatus
Monocolpopollenites tranquilis
Quercoidites microhenrici
Retitricolpites anguloluminosus
CLIMAX FOREST
Cupaniidites spp.
Dicolpopollis kockeli
Erecipites spp.
Favitricolporites microreticulatus
Ilexpollenites iliacus
Ilexpollenites margaritatus
Porocolpopollenites vestibulum
Triatriopollenites rurensis
Tricolporopollenites baculoferus
Tricolpopollenites cf. discus
Tricolporopollenites edmundi
Tricolporopollenites pseudocingulum
Tricolporopollenites sp. 1
Tricolporopollenites spinus
Tricolporopollenites viburnoides
LIANES AND UNDERSTOREY
Corsinipollenites oculusnoctis
Fenestrites spinosus (Caved)
Graminidites anulatus
Sequoiapollenites polyformosus
Triporopollenites coryloides
Triporopollenites robustus
Trivestibulopollenites betuloides
SECONDARY DRYLAND
Alnipollenites verus
STREAMSIDE
Liquidambarpollenites stigmosus
Retitricolpites retiformis
Tetracolpites reticulatus
Tricolpopollenites cf. hians
Tricolpopollenites hians
ARBORESCENT FLOODPLAIN
Inaperturopollenites distichiforme
Inaperturopollenites dubius
Inaperturopollenites hiatus
TAXODIUM SWAMP
Caryapollenites simplex
Caryapollenites imparalis
Caryapollenites spp.
Caryapollenites triangulus
Caryapollenites veripites
Momipites anellus
Momipites coryloides
Momipites tenuipolus
Momipites triradiatus
Nyssapollenites kruschi accesorious
Nyssapollenites kruschi analepticus
Nyssapollenites satzveyensis
Pterocarya type
JUGLANDACEOUS SWAMP
Microfoveolatisporites tuemmlitzensis
Sparganiaceaepollenites polygonalis
AQUATICS
Camerozonosporites haskemensis
Cicatricosisporites chattensis
Cicatricosisporites dorogensis
Cicatricosisporites paradadorogensis
Cicatricosisporites spp.
Deltoidospora apheles
Deltoidospora maxoides
Deltoidospora wolffi
Gleicheniidites senonicus
Polypodiaceoisporites marxheimensis
Polypodiaceoisporites spp.
Torisporis spp.
Triletes corruvallatus
Triletes multivallatus
Triletes sp. 1
Triletes spp.
FLOODPLAIN FERNS
Triplanosporites spp.
Verrucatosporites histiopteroides
COSMOPOLITAN FERNS
Laevigatosporites discordatus
Laevigatosporites haardti
Baculatisporites nanus
Baculatisporites primarius
Baculatisporites spp.
Corrusporis turberculatus
Lycopodiumsporites spp.
Stereisporites (Distgranus) spp.
Stereisporites (Stereisporites)steroides
Verrucingulatisporities treplinensis
SMALL FERNS & MOSSES
Echinosporis echinatus
Echinosporis sp.1
Microfoveolatosporites pseudodentatus
Verrucatosporites alienus
Verrucatosporites balticus
Verrucatosporites favus
Verrucatosporites megabalticus
Verrucatosporites spp.
EPIPHYTIC FERNS
Hyphae
Microthallites spp.
Pluricellaesporites spp.
FUNGI
Alga sp. 1
Botryococcus
Michrystridium spp.
Micrhystridium fragile
Pediastrum spp.
Tasmanites spp.
Veryhacium spp.
ALGAE
Anapiculatisporites spp. (reworked)
Calialiasporites dampierii (reworked)
Calialiasporites turbatus (reworked)
Cerebropollenites mesozoicus (reworked)
Chasmatosporites spp. (reworked)
Cibotiumspora jurinense (reworked)
Classopollis spp. (reworked)
Concavisimisporites spp. (Reworked)
Cycadopites spp. (Reworked)
Densoisporites spp. (reworked)
Densosporites anulatus (Reworked)
Dictyophylidites spp. (reworked)
Exesispollenites spp. (reworked)
Klukisporites spp. (reworked)
Krauselisporites reisingeri (reworked)
Parvisaccites enigmatus (reworked)
Perinopollenites elatoides (reworked)
Podocarpidites spp. (reworked?)
REWORKING
MONTANE
PRIMARY FOREST
CLIMAX FOREST
CLIMAX UNDERSTOREY SHRUBS & LIANES
SECONDARY DRYLAND
STREAMSIDE
ARBORESCENT FLOODPLAIN
TAXODIUM SWAMP
JUGLANDACEOUS SWAMP
AQUATIC
FLOODPLAIN FERNS
COSMOPOLLITAN FERNS
SMALL FERNS & MOSSES
EPIPHYTIC FERNS
FUNGI
OTHER ALGAE
REWORKING
100
200
300
POLLEN SUM
50
100
150
200
POLLEN SUM EX MONTANE
STANDARD DEVIATION
VARIANCE
20000
40000
60000
80000
100000
GRAINS PER GRAMME
A
B
C
D
E
F
G
ASSOC.
Total sum of squares
2
4
6
8
10 x10⁵
CONISS

ENCLOSURE

4


21/28b-7 NORMALISED POLLEN AND SPORE DATA

ENCLOSURE

5


80/14 NORMALISED PALYNOLOGY DATA
Depth
78.93
77.96
76.73
77.0
75.20
74.47
73.77
72.95
71.28
70.75
68.96
67.75
67.21
66.88
66.19
64.95
64.26
63.97
Abiespollenites spp.
Bisacate pollen unaif.
Piceapollis spp.
Sciadopityspollenites spp.
MONTANE
Arecipites spp.
Arecipites spp.
Platycaryapollenites spp.
Plicatapollis spp.
Polyatriopollenites carpinoides
PRIMARY
Cupuliferoidaepollenites lib liblarensis
Cupuliferoidaepollenites lib. fallax
Cupuliferoipollenites cingulum fusus
Cupuliferoipollenites cingulum oviformis
Cupuliferoipollenites cingulum pusillus
Cyrillaceaepollenites megaexactus
Intratriporopollenites ceciliensis
Intratriporopollenites microreticulatus
Monocolpopollenites tranquilis
Quercoidites microhenrici
Retitricolpites anguloluminosus
Tricolpopollenites discus
Triporopollenites cf. plektosus
Ulmipollenites undulosus
CLIMAX FOREST
Boehlensipollis hohli
Cupanidites euycaliptoides
Dicolpopollis kockeli
Favitricolporites microreticulatus
Gothanipollis gothanii
Ilexpollenites iliacus
Ilexpollenites margaritatus
Ilexpollenites microiliacus
Porocolpopollenites vestibulum
Triatriopollenites rurensis
Triatriopollenites aroboratus
Tricolporopollenites baculoferus
Tricolporopollenites edmundi
Tricolporopollenites pseudocingulum
Tricolporopollenites sp. 1
Tricolporopollenites spinus
Tricolporopollenites viburnoides
CLIMAX UNDERSTORY
Graminidites annulatus
Sequoiapollenites polyformosus
Triporopollenites coryloides
Triporopollenites robustus
Trivestibulopollenites betuloides
DRYLAND
Alnipollenites verus
Liquidambarpollenites stigmosus
SS
Retitricolpites retiformis
Tricolpopollenites cf. hians
Tricolpopollenites hians
AFP
Inaperturopollenites distichiforme
Inaperturopollenites dubius
Inaperturopollenites hiatus
TAXOD. SWAMP
Caryapollenites imparalis
Momipites coryloides
Nyssapollenites kruschi analepticus
Nyssapollenites kruschi instructus
Nyssapollenites satzveyensis
JUGL. SWAMP
Microfoveolatisporites tuemmlitzensis
AQ
Cicatricosisporites chattensis
Deltoidospora apheles
Deltoidospora maxoides
Deltoidospora wolffi
Gleicheniidites senonicus
Polypodiaceoisporites marxheimensis
Polypodiaceoisporites spp.
Toroisporis spp.
Triletes corruvallatus
Triletes multivallatus
Trilites sp. 1
Trilites spp.
Triplanosporites spp.
Verrucatosporites histiopteroides
FLOODPLAIN FERNS
Laevigatosporites discordatus
Laevigatosporites haardti
COSMO. FERNS
Baculatisporites nanus
Baculatisporites primarius
Baculatisporites spp.
Corrusporis granoturberculatus
Corrusporis turberculatus
Lycopodiumsporites spp.
Stereisporites (Stereisporites)steroides
SMALL FERNS
Echinosporis echinatus
Echinosporis sp. 1
Microfoveolatosporites pseudodentatus
Verrucatosporites alienus
Verrucatosporites balticus
Verrucatosporites favus
Verrucatosporites megabalticus
Verrucatosporites spp.
EPIPHYTIC FERNS
Hyphea
Diporicellisporonites spp.
Fusiformisporites spp.
Microthallites spp.
Pesavis tagluensis
FUNGI
Algae sp.1
Michrystridium spp.
Micrhystridium stellatum
Ovoidites spp.
Pediastrum spp.
Schizosporis spp.
Tasmanites spp.
Veryhacium spp.
MICROPLANKTON
Caliallasporites dampierii (reworked)
Caliallasporites turbatus (reworked)
Carboniferous monosaccate (reworked)
Cerebropollenites mesozoicus (reworked)
Chasmatosporites spp. (reworked)
Classopollis spp. (reworked)
Cycadopites spp. (Reworked)
Densoispororites velatus (reworked)
Klukisporites spp. (reworked)
Muraspora spp. (Reworked)
Perinopollenites elatoides (reworked)
Podocarpidites spp. (reworked?)
REWORKING
20
40
DIVERSITY
20
40
60
PALYNOMORPHS PER GRAM
100
200
300
400
×10⁴
STANDARD DEVIATION
VARIANCE
20
MONTANE
PRIMARY FOREST
CLIMAX FOREST
CLIMAX UNDERSTOREY SHRUBS & LIANAS
SECONDARY DRYLAND VEGETATION
STREAMSIDE
ARBORESCENT FLOODPLAIN
TAXODIUM SWAMP
JUGLANDACEOUS SWAMP
AQUATICS
FLOODPLAIN FERNS
COSMOPOLLITAN FERNS
SMALL FERNS & MOSSES
EPIPHYTIC FERNS
FUNGI
MICROPLANKTON
REWORKING
POLLEN SUM EX MONTANE
POLLEN SUM
100
200
300
A
B
C
D
E
F
G
H
ASSOC.
CONISS
Total sum of squares ×10⁴
2
4
6
8
10
12

ENCLOSURE

6


88/12, NORMALISED PALYNOLOGY DATA

ENCLOSURE

7


78/1 NORMALISED POLLEN AND SPORE DATA
30 Ma -
Depth
141.2
139.57
136.6
134.92
133.1
131.5
130.1
128.2
126.9
124.37
123.04
Bissacate pollen undif.
Piceapollis spp.
Pityosporites diplox
Pityosporites haplox
Sciadopityspollenites serratus
MONT
Arecipites spp.
Plicatapollis spp.
Polyatriopollenites carpinoides
PRIM
Cupuliferoidaepollenites lib liblarensis
Cupuliferoidaepollenites lib. fallax
Cupuliferoipollenites cingulum fusus
Cupuliferoipollenites cingulum oviformis
Cupuliferoipollenites cingulum pusillus
Cyrillaceaepollenites megaexactus
Intratriporopollenites ceciliensis
Intratriporopollenites instructus
Intratriporopollenites microreticulatus
Intratriporopollenites pseudoinstructus
Monocolpopollenites tranquilis
Quercoidites microhenrici
Retitricolpites anguloluminosus
Ulmipollenites spp.
CLIMAX
Ilexpollenites iliacus
Ilexpollenites margaritatus
Porocolpopollenites vestibulum
Reevesiapollis triangulus
Triatiopollenites rurensis
Triatriopollenites bituitus
Tricolporopollenites cf. edmundi
Tricolporopollenites edmundi
Favitricolporites microreticulatus
Tricolporopollenites pseudocingulum
Tricolporopollenites sp. 1
Tricolporopollenites viburnoides
UNDERSTOREY SHRUBS & LIANAS
Graminidites annulatus
Sequoiapollenites polyformosus
Triporopollenites coryloides
Triporopollenites robustus
Trivestibulopollenites betuloides
S.C. DRYLAND
Alnipollenites verus
Liquidambarpollenites stigmosus
SS
Retitricolpites retiformis
Tetracolpites reticulatus
Tricolpopollenites cf. hians
Tricolpopollenites hians
ARB. FLOODPLAIN
Inaperturopollenites distichiforme
Inaperturopollenites dubius
Inaperturopollenites hiatus
TAXODIUM SWAMP
Nyssapollenites kruschi accesorious
Nyssapollenites kruschi analepticus
Nyssapollenites kruschi pseudoleasus
Nyssapollenites satzveyensis
'JUGLAND' SWAMP
Echinatisporis miocenicus
Microfoveolatisporites tuemmlitzensis
AF
Cicatricosisporites chattensis
Deltoidospora maxoides
Deltoidospora wolffi
Polypodiaceoisporites marxheimensis
Toroisporis spp.
Trilites multivallatus
Trilites sp. 1
Trilites spp.
Triplanosporites spp.
Verrucatosporites histiopteroides
FLOODPLAIN FERNS
Laevigatosporites discordatus
Laevigatosporites haardti
CF
Baculatisporites nanus
Baculatisporites primarius
Corrusporis granoturberculatus
Corrusporis turberculatus
Lycopodiumsporites spp.
Stereisporites (Cingulitriletes) spp.
Stereisporites (Stereisporits) steroides
Stereisporites sp. 1
SMALL FERNS & MOSSES
Echinosporis echinatus
Echinosporis sp. 1
Microfoveolatosporites pseudodentatus
Verrucatosporites alienus
Verrucatosporites balticus
Verrucatosporites favus
Verrucatosporites megabalticus
EPIPHYTIC FERNS
Hyphea
Algae sp.1
Diporicellaesporites spp.
Fusiformisporites
Microthallites spp.
Pesavis tagluensis
Pluricellaesporites spp.
Scolecosporites spp.
FUNGI
Cleistosphaeridium sp. 1 Manum et al '89
Leiosphere
Mychristridium fragile
Mychristridium spp.
Sphaeromorph acritarch
Tasmanites spp.
ALGAE
Anapiculatisporites spp. (reworked)
Caliallasporites dampierii (reworked)
Caliallasporites turbatus (reworked)
Cerebropollenites mesozoicus (reworked)
Chasmatosporites spp. (reworked)
Cibotiumspora jurinense (reworked)
Circulocinium hystrix
Classopollis spp. (reworked)
Cycadopites spp.(reworked)
Densoisporites velatus (reworked)
Dichtyophylidites spp. (reworked)
Exesipollenites spp.(reworked)
Klukisporites variegatus (reworked)
Krauselisporites reisingeri (reworked)
Parvisaccites enigmatus (reworked)
Perinopollenites elatoides (reworked)
Podocarpidites spp. (reworked?)
REWORKING
MONTANE
PRIMARY FOREST
CLIMAX FOREST
CLIMAX UNDERSTOREY SHRUBS & LIANAS
SECONDARY DRYLAND
STREAMSIDE
ARBORESCENT FLOODPLAIN
TAXODIUM SWAMP
JUGLANDACEOUS SWAMP
AQUATICS
FLOODPLAIN FERNS
COSMOPOLLITAN FERNS
SMALL FERNS & MOSSES
EPIPHYTIC FERNS
FUNGI
MICROPLANKTON
REWORKING
20
40
60
211 224 200 199 203 215 192 227 197 189 203
POLLEN SUM EX MONTANE
247 255 240 232 237 242 226 233 243 254 240
POLLEN SUM
20000
40000
60000
80000
100000
GRAINS PER GRAM
50
100
150
200
DIVERSITY
VARIANCE
A
B
C
D
E
F
G
ASSOC.
2
4
6
8
CONISS
SJW 4TH SEPTEMBER 1995
Total sum of squares x10⁷

ENCLOSURE

8


77-7 NORMALISED PALYNOLOGY DATA
Depth
125
120.13
119.38
115.7
104
Abiespollenites spp.
Bissacate pollen undif.
Piceapollis spp.
Pityosporites diplox
Pityosporites haplox
Sciadopityspollenites serratus
MONTANE
Arecipites spp.
Plicatapollis spp.
Polyatriopollenites carpinoides
Pompeckjoidaepollenites subhercynicus
PRIMARY
Cupuliferoidaepollenites lib liblarensis
Cupuliferoidaepollenites lib. fallax
Cupuliferoipollenites cingulum fusus
Cupuliferoipollenites cingulum oviformis
Cupuliferoipollenites cingulum pusillus
Cycadopites spp.
Cyrillaceaepollenites megaexactus
Intratriporopollenites ceciliensis
Intratriporopollenites microreticulatus
Monocolpopollenites tranquilis
Quercoidites microhenrici
Ulmipollenites undulosus
CLIMAX
Cupaneidites spp.
Dicolpopollis kockeli
Ericipites spp.
Favitricolporites microreticulatus
Gothanipollis gothanii
Ilexpollenites iliacus
Ilexpollenites margaritatus
Mediocolpopollis spp.
Porocolpopollenites vestibulum
Retitricolpites anguloluminosus
Tetracolpites reticulatus
Triatriopollenites rurensis
Triatriopollenites aroboratus
Triatriopollenites roboratus
Triatriopollenites subtriangulus
Tricolporopollenites baculoferus
Tricolporopollenites edmundi
Tricolporopollenites pseudocingulum
Tricolporopollenites sp. 1
Tricolporopollenites spinus
Tricolporopollenites viburnoides
UNDERSTOREY
Graminidites annulatus
Sequoiapollenites polyformosus
Triporopollenites coryloides
Triporopollenites robustus
Trivestibulopollenites betuloides
DRYLAND
Alnipollenites verus
Liquidambarpollenites stigmosus
SS
Retitricolpites retiformis
Tricolpopollenites cf. hians
Tricolpopollenites hians
AFP
Inaperturopollenites distichiforme
Inaperturopollenites dubius
Inaperturopollenites hiatus
TAXOD. SWAMP
Caryapollenites spp.
Caryapollenites veripites
Juglanspollenites spp.
Momipites anellus
Momipites coryloides
Momipites spp.
Momipites tenuipolus
Momipites triradiatus
Nyssapollenites kruschi accesorious
Nyssapollenites kruschi analepticus
Nyssapollenites kruschi pseudoleasus
Nyssapollenites satzveyensis
Polyatriopollenites stellatus
JUGLAND. SWAMP
Sparganiaceaepollenites spp.
AQ
Camerozonosporites heskemensis
Cicatricosisporites chattensis
Cicatricosisporites dorogensis
Cicatricosisporites paradorogensis
Cicatricosisporites spp.
Deltoidospora maxoides
Deltoidospora wolfii
Gleicheniidites senonicus
Polypodiaceoisporites marxheimensis
Polypodiaceoisporites sp 1
Polypodiaceoisporites spp.
Toroisporis spp.
Trilites corruvallatus
Trilites multivallatus
Trilites sp. 1
Triplanosporites spp.
Verrucatosporites histiopteroides
FLOODPLAIN FERNS
Laevigatosporites discordatus
Laevigatosporites haardti
COSMO. FERNS
Baculatisporites nanus
Baculatisporites primarius
Corrusporis granoturberculatus
Corrusporis turberculatus
Kekryphalospora spp.
Lycopodiumsporites spp.
Microfoveolatisporites spp.
Stereisporites (Stereisporits) steroides
Stereisporites sp.1
Undulatisporites sculpturis
Verrucingulatisporities treplinensis
SMALL FERNS
Echinosporis sp.1
Microfoveolatosporites pseudodentatus
Verrucatosporites alienus
Verrucatosporites balticus
Verrucatosporites favus
Verrucatosporites megabalticus
EPIPHYTIC FERNS
Diporicellaesporites spp.
Hyphae
Microthallites spp.
Pesavis tagluensis
Pluricellaesporites spp.
FUNGI
Achomospherea ramulifera
Algae sp.1
Areoligera semicirculata
Michrystridium lymnense
Micrhystridium stellatum
Micrhystridium fragile
Micrhystridium spp.
Ovoidites spp.
Paralecanella indentata
Pediastrum spp.
Schizosporis spp.
Scolecosporites spp.
Spiniferites ramosus subsp. ramosus
Systematophora placacantha
Tasmanites spp.
Veryhacium spp.
MICROPLANKTON
Anapiculalisporites spp. (reworked)
Auritulinasporites spp. (reworked)
Caliallasporites dampierii (reworked)
Caliallasporites turbatus (reworked)
Caliallisporites trilobatus (reworked)
Cerebropollenites mesozoicus (reworked)
Chasmatosporites spp. (reworked)
Cibotiumspora jurinense (reworked)
Circulodinium spp. (reworked)
Classopollis 'norissii' (reworked)
Classopollis spp. (reworked)
Cleistospheridium spp. (reworked)
Ctenidodinium sellwoodii (reworked)
Densoisporites velatus (reworked)
Dichtyophylidites spp. (reworked)
Gonyaulacysta jurassica (reworked)
Krauselisporites reisingeri (reworked)
Liassidinium variablie (reworked)
Muraspora spp.(Reworked)
Nannoceratopsis pellucida (reworked)
Nannoceratopsis senex (reworked)
Perinopollenites elatoides (reworked)
Podocarpidites spp. (reworked?)
Sentusidinium sp. hyaline spines (rew.)
Stephanyltron redcliffensis (reworked)
Sublitisphera spp. (reworked)
Systematophora fasiculigera (reworked)
Tetrad of Classopollis (reworked)
REWORKING
MONTANE
PRIMARY
CLIMAX FOREST
CLIMAX UNDERSTOREY SHRUBS & LIANES
SECONDARY DRYLAND
STREAMSIDE
ARBORESCENT FLOODPLAIN
TAXODIUM SWAMP
JUGLANDACEOUS SWAMP
AQUATICS
FLOODPLAIN FERNS
COSMOPOLLITAN FERNS
SMALL FERNS & MOSSES
EPIPHYTIC FERNS
FUNGI
MICROPLANKTON
REWORKING
POLLEN SUM EX MONTANE
50
100
150
200
POLLEN SUM
100
200
300
Grains per gramme
100
200
300
x10⁴
Diversity
20
40
60
80
Varience
20
ASSOC.
A
B
C
D
E
CONISS
20000000 40000000 60000000
Total sum of squares

ENCLOSURE

9


73/36 SPP NORMALISED PLOT
Depth
33.10
30.20
27.78
26.79
24.42
22.15
21.38?
20.90
20.03
19.80
19.31
18.75
18.03
17.22
15.18
14.15
12.65
12.22
11.17
10.86
0.35
8
Bissacate pollen undif.
Piceapollis spp.
Sciadopitysppollenites spp
MONT
Arecipites spp.
Platycaryapollenites spp.
Polyatriopollenites carpinoides
PRIM FOREST
Cupuliferoidaepollenites lib liblarensis
Cupuliferoidaepollenites lib. fallax
Cupuliferoipollenites cingulum fusus
Cupuliferoipollenites cingulum oviformis
Cupuliferoipollenites cingulum pusillus
Cyrillaceaepollenites megaexactus
Intratriporopollenites ceciliensis
Intratriporopollenites instructus
Intratriporopollenites microreticulatus
Monocolpopollenites tranquilis
Quercoidites microhenrici
Retitricolpites anguloluminosus
Ulmipollenites undulosus
CLIMAX FOREST
Boehlensipollis hohli
Compositoipollenites rhizophorous burg.
Compositoipollenites rhizophorous rhiz.
Cupanieidites spp.
Dicolpopollis kockeli
Ericipites spp.
Favitricolporites microreticulatus
Gothanipollis gothanii
Ilexpollenites iliacus
Ilexpollenites margaritatus
Mediocolpopollis spp.
Porocolpopollenites vestibulum
Reevesiapollis triangulus
Triatiopollenites subtriangulus
Triatriopollenites confusus
Tricolporopollenites baculoferus
Tricolporopollenites edmundi
Tricolporopollenites pseudocingulum
Tricolporopollenites sp. 1
Tricolporopollenites spinus
Tricolporopollenites viburnoides
CLIMAX UNDERSTOREY
Corsinipollenites oculusnoctis
Corsinipollenites oculusnoctis minor
Echitriporites sp. 1
Graminidites annulatus
Sequoiapollenites polyformosus
Triporopollenites coryloides
Triporopollenites robustus
Trivestibulopollenites betuloides
SECONDARY DRYLAND
Alnipollenites verus
Liquidambarpollenites stigmosus
SS
Retitricolpites retiformis
Tricolpopollenites cf. hians
Tricolpopollenites hians
ARB FP
Inaperturopollenites distichiforme
Inaperturopollenites dubius
Inaperturopollenites hiatus
TAXOD
~~Caryapollenites simplex~~
Caryapollenites triangulus
Momipites anellus
Momipites coryloides
Momipites tenuipolus
Nyssapollenites kruschi accesorious
Nyssapollenites kruschi analepticus
Nyssapollenites satzveyensis
Pterocarya type
JUGL SWAMP
Microfoveolatisporites tummlitzensis
Milfordia incerta
Sparganiaceaepollenites polygonalis
AQUATICS
Camerozonosporites haskemensis
Cicatricosisporites chattensis
Cicatricosisporites dorogensis
Cicatricosisporites paradorogensis
Cicatricosisporites spp.
Deltoidospora apheles
Deltoidospora maxoides
Deltoidospora wolffi
Gleicheniidites senonicus
Polypodiaceoisporites marxheimensis
Trilites multivallatus
Triplanosporites spp.
Verrucatosporites histiopteroides
FPF
Laevigatosporites haardti
Leavigatosporites discordatus
COSMO FERNS
Baculatisporites nanus
Baculatisporites primarius
Baculatisporites spp.
Corrusporis granoturberculatus
Corrusporis turberculatus
Lycopodiumsporites spp.
Stereisporites (S) stereiodes
Stereisporites (Structisporis)intraretic
~~Echinosporis echinatus~~
SMALL FERNS ETC
Microfoveolatosporites pseudodentatus
Verrucatosporites alienus
Verrucatosporites balticus
Verrucatosporites favus
Verrucatosporites megabalticus
Verrucatosporites spp.
EPIPHYT FERNS
Diporicellaesporites spp.
Fusiformisporites spp.
Hyphea
Incertae sedis A
Microthallites spp.
Multicellaesporites spp.
Ovoidites spp.
Pesavis tagluensis
Pluricellaesporites spp.
Scolecosporites spp.
FUNGI
Algae sp.1
Areoligera semicirculata
Botryococcus spp.
Cyclopsiella sp. B
Dinoflagellate fragment
Micrhystridium spp. cluster
Micrhystridium fragile
Micrhystridium spp.
Paralecaniella indentata
Pediastrum spp.
Phthanoperidinium spp.
Pterospermella spp.
Schizosporis reticulatus
Selenopemphix nephroides
Svalbardella cooksoniae
Tasmanites spp.
Thalassophora pelagica
Veryhacium spp.
MICROPLANKTON
~~Aptea anaphrissa (reworked)~~
Areoligera medusettiformis (reworked)
Caliallasporites dampierii (reworked)
Caliallasporites turbatus (reworked)
Canningia (reworked)
Cerebropollenites mesozoicus (reworked)
Chasmatosporites spp. (reworked)
Cibotiumspora jurinense (reworked)
Circulodinium hystrix (reworked)
Circulodinium spp. (reworked)
Classopollis 'norissii' (reworked)
Classopollis spp. (reworked)
Cribroperidinium spp. (reworked)
Ctenidodinium sellwoodii (reworked)
Cycadopites spp. (reworked)
Densoisporites velatus (reworked)
Devonian spore? (reworked)
Exesipollenites (reworked)
Gonyaulacysta jurassica (reworked)
Klukisporo spp. (reworked)
Krauselisporites reisingeri (reworked)
Lycospora pusilla (reworked)
Mendicodinium groenlandicum (reworked)
Muraspora spp. (reworked)
Oligosphaeridium pulcherum (reworked)
Parvisaccites enigmatus (reworked)
Perinopollenites elatoides (reworked)
Pilosisporites (reworked)
Rhynchodiniopsis cladophora (reworked)
Sentusidinium spp. (reworked)
Stephanelytron redcliffensis (reworked)
Systematophora fasiculigera (reworked)
Systematophora spp. (reworked)
Tetrad of Classopollis (reworked)
Triporoletes reticulatus (reworked)
REWORKED
MONTANE
PRIMARY FOREST
CLIMAX FOREST
CLIMAX UNDERSTOREY
SECONDARY DRYLAND
STREAMSIDE
ARBORESCENT FLOODPLAIN
TAXODIUM SWAMP
JUGLANDACEOUS SWAMP
AQUATICS
FLOODPLAIN FERNS
COSMOPOLLITAN FERNS
SMALL FERNS & MOSSES
EPIPHYTIC FERNS
FUNGI
MICROPLANKTON
REWORKING
SJW 15TH SEPT 1995
182
235
169
149
247
266
234
242
253
227
204
207
198
223
252
248
244
289
228
231
243
275
POLLEN SUM EX MONTANE
251
272
223
205
253
274
249
256
275
277
249
246
238
251
272
255
265
304
258
251
265
277
POLLEN SUM
100
200
300
x10⁵
GRAINS PER GRAM
20
40
60
VARIANCE
DIVERSITY
A
B
C
D
E
F
G
H
I
J
ASSOC.
2
6
10
14
18
20
Total sum of squares x10¹
CONISS

ENCLOSURE

10


WELL 28 NORMALISED POLLEN DATA
SAMPLE
12-2
11-2
10-3
9-2
8-3
6-1
5-28
5-5
5-1
4-1
3-1
2-8
1-20
~~Abiespollenites spp.~~
Bisaccate undiff.
Piceapollis spp.
Pityspories diplox
Pityspories haplox
Sciadopitysporites spp.
MONTANE
Arecipites spp.
Platycaryapollenites spp.
Plicatopollis spp.
Polyatriopollenites carpinoides
PRIMARY
Cupuliferoidaepollenites lib. fallax
Cupuliferoidaepollenites lib.liblarensis
Cupuliferoipollenites cingulum fusus
Cupuliferoipollenites cingulum oviformis
Cupuliferoipollenites cingulum pusillus
Cyrillaceaepollenites megaexactus
Monocolpopollenites tranquillus
Retitricolpites anguloluminosus
Tricolporopollenites microhenrici
CLIMAX
~~Cupanieidites spp.~~
Dicolpopollis kockeli
Ericipites spp.
Favitricolporites microreticulatus
Gothanopollis gothanii
Ilexpollenites iliacus
Ilexpollenites margaritatus
Mediocolpopollis spp.
Porocolpopollenites vestibulum
Triatriopollenites aroboratus
Triatriopollenites roboratus
Triatriopollenites rurensis
Triatriopollenites subtriangulus
Tricolporopollenites baculoferous
Tricolporopollenites edmundi
Tricolporopollenites pseudocingulum
Tricolporopollenites sp. 1
Tricolporopollenites spinus
Tricolporopollenites viburnoides
CLIMAX UNDERSTOREY
~~Corsinipollenites oculusnoctis~~
Intratriporopollenites ceciliensis
Intratriporopollenites microreticulatus
Sequoiapollenites polyformosus
Triporopollenites coryloides
Triporopollenites robustus
Trivestibulopollenites betuloides
DRYLAND
Alnipollenites verus
SS
Retitricolpiites retiformis
Tricolpopollenites cf. hians
Tricolpopollenites hians
AFP
~~Inaperturopollenites distichiforme~~
Inaperturopollenites dubius
Inaperturopollenites hiatus
TAXO. SWAMP
~~Caryapollenites simplex~~
Momipites anellus
Momipites coryloides
Momipites tenuipolus
Nyssapollenites kruschi accesorious
Nyssapollenites kruschi analepticus
Nyssapollenites kruschi pseudoleasus
Nyssapollenites satzveyensis
JUGLAND. SWAMP
Camerozonosporites heskemensis
Deltoidospora maxoides
Deltoidospora wolffi
Gleicheniidites senonicus
Polypodiaceoisporites marxhemensis
Toroisporis spp.
Trilites multivallatus
Triplanosporites spp.
FLOODPLAIN FERNS
Laevigatosporites discordatus
Laevigatosporites haardti
CF
Baculatisporites nanus
Baculatisporites primarius
Baculatisporites spp.
Corrusporis granoturburculatus
Stereisporites(Stereisporites)stereoides
SMALL FERN S
Microfoveolatosporites spp.
Verrucatosporites alienus
Verrucatosporites balticus
Verrucatosporites favus
EPIPHYTIC FERNS
Diporicellaesporites spp.
Hyphea
Microthallites spp.
Pesavis tagluensis
Pluricellaesporites spp.
Scolecosporites spp.
fungal fruiting body
FUNGI
Algae sp.1
Ovoidites spp.
Pediastrum spp.
Tasmanites spp.
MICROPLK.
Classopollis spp. (reworked)
Cycad (reworked)
MONTANE
PRIMARY FOREST
CLIMAX FOREST
CLIMAX UNDERSTOREY SHRUBS & LIANES
SECONDARY DRYLAND
STREAMSIDE
ARBORESCENT FLOODPLAIN
TAXODIUM SWAMP
JUGLANDACEOUS SWAMP
COSMOPOLLITAN FERNS
FLOODPLAIN FERNS
SMALL FERNS & MOSSES
EPIPHYTIC FERNS
FUNGAL SPORES
MICROPLANKTON
REWORKING
POLLEN SUM EX MONTANE
POLLEN SUM
20
40
60
100
200
300
ASSOC.
A
B
C
D
CONISS
Total sum of squares
2
4
6