AN INVESTIGATION OF THE PALYNOLOGY, STRATIGRAPHY AND PALAEOGEOGRAPHY OF CARBONIFEROUS ROCKS IN WESTERN IRISH OFFSHORE BASINS

by

Alastair Haddow

A thesis submitted in accordance with the requirements for the degree of Doctor of Philosophy

Department of Geology, University of Dublin, Trinity College
2012

DECLARATION

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university and it is entirely my own work.

I agree to deposit this thesis in the University's open access institutional repository or allow the library to do so on my behalf, subject to Irish Copyright Legislation and Trinity College Library conditions of use and acknowledgement.

Alastair Haddow

SUMMARY

An investigation into the palynostratigraphy and palaeogeography of Carboniferous rocks in offshore western Irish basins was undertaken. Intervals from 19 hydrocarbon wells, located in the Porcupine, Slyne, Erris, Donegal and Rockall Basins were examined. Samples (predominantly well-bore cuttings) were processed for palynostratigraphic and palynofacies analysis using standard techniques. Palynological slides and microfossil occurrence data from previous studies were also analysed.

Carboniferous strata, ranging from Courceyan to lower Autunian in age, have been confirmed in 17 of the 19 well sections. A stratigraphic break is observed from the uppermost Arnsbergian to the middle Langsettian. 15 biozones and 10 sub-biozones from the Western European Carboniferous miospore zonal scheme of Clayton *et al.* (2003) have been recorded, although with varying levels of confidence. This is an increase from the 11 biozones recognised using the original zonal scheme of Clayton *et al.* (1977) for the same stratigraphic interval. As the biozones of Clayton *et al.* (2003) are generally defined based on the first stratigraphic occurrence of a single index taxon, the range tops and bases of alternative taxa are used to define biozone limits if occurrences of the index taxa are infrequent, considered caved or absent in a given well section. Range data from the North Sea, onshore Great Britain and continental Western Europe are used.

As the zonal scheme of Clayton *et al.* (2003) does not include biozones younger than Cantabrian in age, offshore western Irish strata considered to be upper Stephanian in age is assigned to the *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone of Clayton *et al.* (1977). Strata considered to be lower Autunian in age is tentatively assigned to the *Vittatina costabilis* (VC) Biozone of Clayton *et al.* (1977).

An alternative miospore biozonation for offshore western Ireland is proposed to account for the rarity of a number of index taxa used in the Clayton *et al.* (2003) zonal scheme.

The Mississippian and Pennsylvanian of offshore western Ireland and Eastern Canada have been correlated based on eight palynological events; typically the first stratigraphic appearance of a genus or species.

Incorporating existing lithological and microfaunal data into the revised offshore western Irish palynostratigraphic framework enabled high-resolution reconstructions of the regional depositional environment throughout the Carboniferous. Correlation with coeval deposits in Eastern Canada and Western Europe resulted in the creation of 7 palaeogeographic time-slices for the North Atlantic region. Time-slices range from Arundian-Holkerian to Asturian-Cantabrian in age.

During investigation of possible upper Bolsovian to Stephanian age marine deposition in the offshore western Irish region (as indicated by the identification of marine microfossils in previous studies), palynofacies analysis of cuttings samples identified rare marine palynomorphs, although often in association with freshwater to brackish palynomorphs. The majority of amorphous organic matter recorded was considered terrestrial (woody) in origin. Mixed marine and non-marine characteristics may represent the incorporation of rock fragments from both marine and non-marine horizons into the same cuttings sample.

Alternatively, these characteristics may reflect marginal marine lagoonal or brackish bay depositional environments, with marine palynomorphs/microfauna being occasionally washed in. $\delta^{13}C$ and $\delta^{18}O$ values for most limestones analysed from the intervals plot outside the ranges for marine carbonates. A small number of samples, which plot in proximity to the range for marine carbonates, may reflect a marginal marine environment. The presence of both non-marine and marine carbonate (shelly) fragments in one sample may reflect the lagoonal/brackish bay depositional model outlined above. These environments may be similar to coeval brackish bays/restricted marine environments recorded in the Maritimes Basin of Eastern Canada.

Acknowledgements

Thank you to Professor Geoff Clayton for suggesting this project and for the support, patience and encouragement throughout the Ph.D.

Thanks also to the acadamic staff in the Geology Department, especially Dr. John Graham, Dr. Robbie Goodhue, Professor George Sevastopulo and Dr. Ian Sanders.

This work uses data and survey results acquired during a project funded by PIPCo RSG Ltd on behalf of the Irish Shelf Petroleum Studies Group (ISPSG). The ISPSG comprises: Chevron Upstream Europe, ENI Ireland BV, ExxonMobil Exploration and Production Ireland (Offshore) Ltd, Hess Exploration Ireland Ltd, Husky Energy, Providence Resources Plc, Repsol, San Leon Energy Plc, Serica Energy Plc, Shell E&P Ireland Ltd, Sosina Exploration Ltd, Statoil Exploration (Ireland) Ltd and the Petroleum Affairs Division of the Department of Communications, Energy and Natural Resources.

To Francis Hendron for showing me how to process palynological samples and for the witty banter and chats.

To Dr. Robbie Goodhue for the assistance with the mass spectrometry work and for the discussions regarding the subsequent isotope analysis write up.

To Mags for helping out with all sorts of administrative issues.

To the department technical staff; Neil, Moira, Declan and Noel for solving my computer problems and other technical issues.

To my office mates past and present – Niall, Sarah, Nina, Allyson, Abi and Luca – thanks for putting up with me! Thanks also to the other post-grads for their friendship.

Thanks to Professor Reed Wicander for the acritarch identifications, Dr. Duncan McLean for helping me out with various palynological queries, Professor Martin Gibling, Dr. John Utting, Dr. Peter Giles and Professor Elliott Burden for assistance with the Canadian aspect of my project, Dr. Giles Miller at the Natural History Museum, Dr. Carys Bennett for information on ostracods and Professor Paul Selden for assistance with arthropod cuticle identification.

To Elliott Burden for his hospitality during my visit to Newfoundland.

Many thanks to Mum and Dad for their support and encouragement and last but not least to Jenn, my long suffering wife, who has been fantastic throughout.

TABLE OF CONTENTS

APPENDICES

TABLE OF FIGURES

See enclosed CD for figures

CHAPTER 1 – INTRODUCTION

CHAPTER 2 – CARBONIFEROUS MIOSPORES OF WESTERN EUROPE AND EASTERN CANADA

CHAPTER 4 – TERMINOLOGY

CHAPTER 5 – SYSTEMATIC PALYNOLOGY

CHAPTER 6 – REVISED PALYNOSTRATIGRAPHY OF OFFSHORE WESTERN IRELAND AND COMPARISON WITH OTHER LOCALITIES

CHAPTER 7 – LITHOLOGIES AND DEPOSITIONAL ENVIRONMENTS OF THE OFFSHORE WESTERN IRISH CARBONIFEROUS

CHAPTER 8 – PALYNOFACIES

CHAPTER 9 – ISOTOPE ANALYSIS OF CARBONATES

CHAPTER 10 – PALAEOGEOGRAPHIC RECONSTRUCTIONS OF THE NORTH ATLANTIC REGION

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

Carboniferous strata have been encountered in hydrocarbon exploration wells drilled into the Porcupine, Slyne, Erris, Donegal and Rockall sedimentary basins of offshore western Ireland. The Carboniferous is considered a key regional source rock with coal-rich Pennsylvanian age strata assumed to be the source of gas encountered in the 1996 Slyne Basin Corrib Gasfield discovery (Naylor and Shannon 2011).

The Carboniferous of offshore western Ireland has been almost exclusively dated using plant miospores (palynostratigraphy). A number of previous palynostratigraphic interpretations (e.g. Robeson 1988) were based on the Carboniferous Western European miospore zonal scheme of Clayton *et al*. (1977). Major advances have been made in Western European palynostratigraphy since 1977 (e.g. Owens *et al.* 2004; McLean *et al.* 2005). As a result, Clayton *et al.* (2003) proposed a revised Western European miospore zonal scheme, increasing the number of biozones and sub-biozones that can be recognised. The main objective of the present study was to apply, where possible, the updated zonal scheme to the Carboniferous of offshore western Ireland, in order to produce revised, high-resolution palynostratigraphic interpretations and regional palaeogeographic reconstructions.

Previous biostratigraphic investigations of the offshore western Irish Carboniferous identified microfaunal and microfloral evidence for late Westphalian (upper Bolsovian and Asturian) and Stephanian age marine influences (e.g. Ducazeaux *et al.* 1981; King *et al.* 1979). Possible marine intercalations of this age are unlike anything known from onshore Ireland or the UK. The nearest comparable marine rocks of equivalent age are located in the Oslo Graben of Norway and the Cantabrian Mountains of Spain. A second objective of the present study was to undertake palynofacies analysis of samples from the intervals of interest in order to identify any further evidence for marine influences and provide information on their depositional environment.

Carboniferous sequences encountered in the Maritimes Basin of Eastern Canada show similarities with the Carboniferous succession of offshore western Ireland. This reflects the proximity of offshore western Ireland and Eastern Canada prior to North Atlantic rifting (Robeson 1988). Recent revisions to the Carboniferous palynostratigraphy of Eastern Canada (e.g. Utting 1987; Utting *et al.* 1989; Utting *et al.* 2010; Utting and Giles 2004 and 2008) provide an opportunity to compare and correlate the Carboniferous palynostratigraphy of the Maritimes Basin with that of offshore western Ireland and revise the palaeogeography of the North Atlantic region during Carboniferous times.

1.2 CARBONIFEROUS CHRONOSTRATIGRAPHIC NOMENCLATURE

The present study follows the global chronostratigraphic subdivision of the Carboniferous System recently proposed by the Subcommission on Carboniferous Stratigraphy (SCCS) and ratified by the International Union of Geological Sciences (IUGS) (see Heckel and Clayton 2006). The global chronostratigraphic subdivision recognises the Mississippian and Pennsylvanian as global subsystems. The global subsystems are further subdivided into global series and stages (figure 1.1). Heckel and Clayton indicate that regional geographic names for series and stages can still be used in those regions in which they developed. The Western European series and stages outlined in figure 1.1 are therefore used for offshore western Irish chronostratigraphy. For Eastern Canadian chronostratigraphy, the present study follows recently published literature (e.g. Utting *et al.* 2010), which still employs Western European substages as chronostratigraphic units.

1.3 GLOBAL CARBONIFEROUS PALAEOGEOGRAPHY

During Tournaisian and Viséan times, Ireland lay in tropical latitudes on the southern margin of the Laurussian (Euramerican) supercontinent, separated from the Gondwanan supercontinent to the south by the Rheic Ocean (figure 1.2a). Through the Late Palaeozoic, ribbon like terraces that had rifted off the northern margin of Gondwana docked with Laurussia, closing the Rheic Ocean and opening the Tethys Ocean (Sevastopulo and Wyse Jackson 2009). Closure of the Rheic Ocean as the margins of Gondwana and Laurussia moved increasingly closer, resulted in the

Variscan orogeny and the formation of the Pangaean supercontinent by the Early Permian (figure 1.2b).

Calder (1998) suggests that palaeoflow and faunal trends point to the existence of a mid-Laurussian (mid-Euramerican) Sea between the Maritimes Basin and Western Europe that persisted throughout the Carboniferous (figure 1.3).

1.4 OFFSHORE IRISH SEDIMENTARY BASINS

Ireland is virtually encircled by sedimentary basins that developed from Permo-Triassic to Cenozoic times in response to episodes of rifting and thermal subsidence (Shannon *et al.* 2001; Naylor and Shannon 2011) (figure 1.4). Irish Sea basins are the oldest and predominantly filled by Permo-Triassic sediments. Basins located in the Celtic Sea are typically younger than the Irish Sea basins, with the main phase of basin development occurring in the Jurassic to Early Cretaceous. Basins in Atlantic waters to the west of Ireland are larger and generally the youngest. The Slyne, Erris and Donegal basins lie to the east of larger basins that include the Porcupine, Rockall and Hatton basins. Most of the Atlantic basins follow a NNE-SSW trend, with an exception being the north-south orientated Porcupine Basin. The larger basins also underlie bathymetric depressions, reflecting subsidence and under-sedimentation in the mid-Cenozoic (Naylor and Shannon 2009).

1.4.1 History of exploration

The discovery of large hydrocarbon accumulations in the North Sea during the 1960s and early 1970s resulted in oil companies assessing the potential of offshore Irish waters. The first offshore Irish well (48/25-1) was drilled into the North Celtic Sea Basin in 1970. A year later, within the same block, the Kinsale Head Gasfield was discovered in Lower Cretaceous strata. The field was brought on-stream in 1978. In 1974, the Seven Heads Oil and Gasfield was discovered in the North Celtic Sea Basin with hydrocarbons flowing from Lower Cretaceous sandstones. Although the field was considered uneconomic for a number of years, it was brought on-stream in 2003. The first Porcupine Basin well was drilled in 1977. Wells drilled into the basin have encountered many oil shows with several wells flowing oil. However, the discoveries were considered either too small or complex to be developed. They include the 1979 Connemara oil accumulation of Block 26/28 and the 1981 Philips Petroleum Spanish Point gas condensate discovery of Block 35/8; both of which are in Jurassic sandstones. In 1989, well 48/20-2 discovered the Ballycotton Gasfield in the North Celtic Sea Basin. The prospect was developed as a linked satellite field to the Kinsale Head Gasfield. In 1996, the Corrib Gasfield was discovered in Block 18/20 of the Slyne Basin. This Triassic age field is under development at the time of writing. In 2001, the first exploration well in the Irish sector of the Rockall Basin was drilled. The following year, the Dooish gas condensate discovery was made by well 12/2-1 in Permian/Triassic strata on the eastern flank of the basin. At the time of writing, the only producing fields in offshore Irish waters are the Kinsale Head, Ballycotton and Seven Heads Gasfields (Shannon *et al.* 2001; Naylor and Shannon 2009 and 2011).

To date, 156 wells have been drilled offshore Ireland with 50 wells located within or on the margins of the Porcupine, Slyne, Erris, Donegal and Rockall Basins (Naylor and Shannon 2011). Previous studies have identified Carboniferous strata in 18 offshore western Irish wells and in each of the above basins (figures 1.5 and 1.6).

1.4.2 Geological framework

Offshore western Ireland, ‘basement’ most likely consists of granites in addition to Lower Palaeozoic and older metamorphic rocks (Shannon and Naylor 1998). Upper Palaeozoic rocks have a widespread occurrence and are relatively undeformed (Naylor and Shannon 2011).

The north-south oriented Porcupine Basin (figure 1.5) contains up to 10km of Upper Palaeozoic to Cenozoic sediments (Naylor and Shannon 2009). Pre-Carboniferous rocks have been encountered in two wells. In 26/26-1, fractured metasediments overlain by Carboniferous strata are considered Precambrian to Cambrian in age (26/26-1 Final Well Report 1981). In 26/30-1 a biotite granodiorite unconformably overlain by Pennsylvanian strata is recorded as pre-Carboniferous (Robeson *et al.* 1988). Of the 14 wells deemed to have encountered Carboniferous strata within or on the margins of the basin, Mississippian age rocks have been confirmed in one well and tentatively identified in two wells. Within the basin, the Carboniferous is locally overlain by Permo-Triassic shallow marine sandstones and evaporitic mudstones and regionally overlain by extensive Middle and Upper Jurassic fluvial to shallow marine sediments. The Jurassic succession is unconformably overlain by Cretaceous mudstones, marine and deltaic sandstones, which are in turn succeeded by a thick chalk succession. Up to 2km of Cenozoic sediments have also been drilled (Naylor and Shannon 2009). On the basin margins, the Carboniferous is unconformably overlain by Cretaceous or Cenozoic strata. The Carboniferous of the Porcupine Basin shows moderate reservoir potential. On the eastern side of the basin, porosities of sandstones are in the range 5-15% but can reach 20%. Pennsylvanian age successions commonly contain thin coal beds which show good gas and condensate generating potential. Jurassic age Kimmeridgian marine shales show excellent oil and gas source potential (Naylor and Shannon 2011).

The Slyne, Erris and Donegal Basins comprise a series of interconnected, narrow, half-graben basins (figure 1.6). In the NE-SW trending Erris Basin, well 19/5-1 encountered over 1500m of Carboniferous (Mississippian and Pennsylvanian) strata, unconformably overlain by Upper Permian deposits. Pennsylvanian strata have also been encountered in the NNE-SSW oriented Slyne Basin and ENE trending Donegal Basin. In the Slyne Basin, well 27/5-1 encountered Pennsylvanian strata unconformably overlain by Permian halite. In the Donegal Basin, well 13/3-1 encountered a Pennsylvanian succession unconformably overlain by Miocene sediments. In the Erris Basin, well 12/13-1a encountered 25m of low-grade metasediments of possible Devonian age overlain by Permo-Triassic strata. Triassic sediments are also recorded in the Slyne Basin. The Permo-Triassic successions are interpreted as early rift deposits. Lower Jurassic strata have been encountered in the Slyne and Erris Basins with Middle Jurassic deposits also present in the Slyne Basin. The Upper Jurassic and Cretaceous are generally thin to absent in the Slyne-Erris-Donegal region, although a ~600m interval of Lower Cretaceous strata is recorded in well 12/13-1a. The Cenozoic succession in the region rests unconformably on the Mesozoic and reaches a thickness of 1km (Naylor and Shannon 2011).

Namurian age sandstones encountered in well 19/5-1 show average porosities of 22% and are considered potential reservoir rocks. The major source rocks in the Slyne, Erris and Donegal basins are Pennsylvanian age coals and deltaic mudstones in addition to Lower Jurassic marine mudstones. Pennsylvanian age coals are assumed to be the source rock of gas encountered in the Corrib Gasfield. Lower Jurassic source rocks are oil-prone (Naylor and Shannon 2011).

The Rockall Basin contains up to 7km of Upper Palaeozoic to Holocene rocks (Naylor and Shannon 2009) (figure 1.6). Drilled into the eastern margin of the basin, well 12/2-1z encountered a succession of Carboniferous, Permian, Permo-Triassic, possible Middle Jurassic and Cretaceous strata. The Dooish gas condensate discovery (section 1.4.1) demonstrates the presence of a working petroleum system. Similar source rocks to those encountered in the Porcupine, Slyne and Erris basins are anticipated (Naylor and Shannon 2011).

1.4.3 Upper Palaeozoic geological history of the Irish region

Following the Caledonian orogeny, Ireland lay on the southern margin of the Laurussian (Euramerican) supercontinent (Graham 2009). Terrestrial desert conditions prevailed across Ireland and most likely in offshore regions during the Devonian. Basins developed as a response to periods of extension and transtension, with sedimentation taking place in localised alluvial fans, alluvial plains and playa lakes. By the Early Carboniferous, Ireland lay in tropical latitudes, south of the Equator. Through the Tournaisian and Viséan, a marine transgression progressed northward across Ireland. By Viséan times, shallow water carbonate shelf conditions had developed across much of Ireland with localised deeper water basins. Episodes of late Viséan carbonate shelf deposition are recorded in the Porcupine and Erris Basins. In the north of Ireland, mixed terrigeneous and carbonate sediments were deposited along the margins of the shrunken continent (Sevastopulo and Wyse Jackson 2009).

As the margins of Gondwana and Laurussia moved increasingly closer, the late Viséan saw the onset of Variscan deformation (Naylor and Shannon 2011). Around the beginning of the Serpukhovian (lower Namurian), a switch from carbonate sedimentation to terrigeneous mud and sand deposition occurred. This is most likely associated with tectonic uplift of source areas to the south and north (Sevastopulo 2009). Lower Namurian age deltas prograded southeastwards from Caledonian uplands, depositing sandstones over substantial parts of Ireland. Coal bearing sandstones and shales recorded in the Erris Basin reflect coal swamp and fluvio/deltaic deposition. Erosion of Carboniferous strata occurred during the Variscan tectonic phase, resulting in intra-Carboniferous unconformities (Naylor and Shannon 2011). Upper Namurian strata are not recorded offshore western Ireland, potentially indicating a widespread erosional event.

Although widely reported offshore western Ireland, Pennsylvanian deposits are limited in presence onshore Ireland. Westphalian age strata typically comprise Coal Measures deposits with evidence for marine influences. By Stephanian times, the Variscan orogeny had produced fold mountains extending from southwest Ireland to Britain and Central Europe. Although Stephanian rocks are not preserved onshore Ireland, offshore western Irish deposits are typically continental with sporadic evidence for marine influences (Naylor and Shannon 2011). Ziegler (1982) suggested that the Late Carboniferous marine influences resulted from marine incursions from the Bay of Biscay rift system into the Porcupine region. As indicated in section 1.3, Calder (1998) suggested that a mid-Laurussian (mid-Euramerican) Sea between the Maritimes Basin and Western Europe persisted throughout the Carboniferous (figure 1.3). Continental rocks of possible Autunian age are also encountered offshore western Ireland.

By the Early Permian, the suturing of Laurussia and Gondwanaland was complete and Ireland was incorporated into the Pangaean supercontinent. Small rift basins developed along reactivated NE-SW Caledonian features in response to extensional stresses within the supercontinent. Erosion of the Variscan uplands provided the source for fluvial and dune redbeds deposited under arid and desert conditions. Rifting progressed in the Late Permian and marine conditions extended from the Norway Greenland rift into the Rockall region and Irish Sea. Restricted marine Zechstein dolomites and evaporites are recorded in wells drilled into the Erris basin (Shannon and Naylor 1998; Naylor and Shannon 2011).

1.4.4 Mesozoic to Cenozoic development of the offshore western Irish basins

The main phase of rifting in the offshore western Irish region was in the Middle to Late Jurassic. Rifting in the Middle Jurassic followed Caledonoid-orientated crustal fabrics and structures, as preserved in the Slyne and Erris Basins. North-south rifts in the Porcupine Basin developed in the Late Jurassic. Syn-rift faulting waned in the Late Jurassic and was followed by uplift, thermal subsidence, sea level rise and a rapid marine incursion across a partly peneplaned late Cimmerian surface. The resulting base Cretaceous unconformity is recorded in many offshore Irish basins. Chalk and marls were deposited throughout the region as a result of the sea level rise and thermal subsidence. The Early Cenozoic was marked by a marine regression and a transition from carbonate to clastic sedimentation. The Cenozoic was also marked by igneous activity and uplift on the Rockall Basin margins which resulted in the erosion of Late Mesozoic strata in the Slyne and Erris Basins (Naylor and Shannon 2009; Naylor and Shannon 2011).

1.5 WELLS STUDIED

Nineteen offshore western Irish well sections were analysed in the present study (figures 1.5 and 1.6, Appendix I). Previous studies identified Carboniferous strata in 18 of the wells. Appendix II summarises the Carboniferous stratigraphy encountered in each well in addition to the strata immediately overlying, as defined by previous biostratigraphic studies.

1.5.1 Well 12/2-1z

Enterprise Energy Ireland Ltd drilled well 12/2-1 into the eastern margin of the Rockall Basin to test the Dooish exploration prospect. The well encountered gas-condensate bearing Permo-Triassic sandstones, but well control problems resulted in the well being halted 400m short of the proposed total depth (TD). Well 12/2-1z was planned as a re-entry of 12/2-1 to re-drill the reservoir interval, determine the vertical extent of the hydrocarbon column and drill on beyond the hydrocarbon-water contact. The well penetrated Cretaceous, possible Middle Jurassic, Permo-Triassic, Early Permian and Carboniferous sediments. Gas-condensate bearing sandstones were encountered and a hydrocarbon-water contact positioned within the Early Permian interval. Carboniferous strata were penetrated at a shallower depth than the pre-drill prognosis. Sandstones encountered were water-wet. The well reached TD in the

Carboniferous section at a depth of 14668'/4471m. The well was plugged and abandoned as a condensate discovery (Mecklenburgh 2004).

Based on palynological content, Millennia Stratigraphic Consultants (2004) dated the Early Permian interval as Asselian in age and the Carboniferous succession as Bolsovian to Duckmantian in age. An interval separating the Permian and Carboniferous successions remained undated due to a lack of age diagnositic microfossils. An unconformity between the Early Permian and Bolsovian strata was eventually positioned at 14155'/4314.5m. Analysis of the Carboniferous section indicated a thermal maturity within the oil window with coals showing vitrinite reflectance values of ~0.72%Rr. Dark shales analysed from 13753'/4192m - 14668'/4471m were deemed to be dominantly gas prone (Mecklenburgh 2004).

1.5.2 Well 12/13-1a

Well 12/13-1a was a re-drill of well 12/3-1, initially drilled by Amoco Ireland into what was considered a tilted fault block on the eastern margin of the Rockall Basin. Naylor and Shannon (2011) now consider the well to be located within the Erris Basin. The primary objective of the well was Permo-Triassic sandstones with Jurassic sandstones and limestones as a secondary objective. Beneath Cenozoic sands and claystones, the well encountered a succession of Upper Cretaceous to Permo-Triassic strata. The well terminated in an interval (9331'/2844m - 9414'/2869m TD) of red-brown metasediments. Odell and Walker (1979) suggested a Devonian age for the metasediments based on lithological composition. Based on palynological content, Church *et al.* (1979) tentatively assigned a Triassic age to the interval 7310'/2228m - 9414'/2869m. The authors did not recover age diagnostic forms from sidewall core samples and suggested that the only *in situ* miospores from the interval were striate bisaccate pollen (including possible *Lunatisporites* sp.) and a single retusoid spore.

As the entire well section was water bearing, the well was plugged and abandoned (Odell and Walker 1979).

1.5.3 Well 13/3-1

Texaco Ireland Ltd drilled well 13/3-1 into Block 13/3 of the Donegal Basin to evaluate the hydrocarbon potential of a faulted northwest-southeast trending anticlinal structure. The primary objective was Permo-Triassic sandstones with Jurassic and Palaeozoic sandstones as secondary objectives. The well spudded in Quaternary sediments and penetrated 725'/221m of Cenozoic strata unconformably overlying 3114'/949m of Carboniferous sandstones, siltstones and mudstones. The top Carboniferous was picked at 1241'/378m based on palynological data from Love *et al.* (1978) in addition to wireline log and lithological data. The well also penetrated low-grade contact metamorphics at 4290'/1308m and a Tertiary igneous intrusion at 4355'/1327m. The well reached TD at 4483'/1366m and was plugged and abandoned as a dry hole (Stuart 1978). Based on palynological content, Love *et al.* (1978) dated the Carboniferous interval as Stephanian B to Duckmantian in age.

Robeson (1988) subsequently reassessed the palynostratigraphy and thermal maturity of the Carboniferous succession, reinterpreting the interval as Asturian strata faulted against a succession of Bolsovian and Duckmantian age strata. Vitrinite reflectance data positioned the fault between 1740'/530m and 1780'/543m with values ranging from 0.59%Rr - 1.00%Rr above the fault and 1.60%Rr - 9.26%Rr below the fault (the coal rank rapidly increasing towards the igneous intrusion). Kerogen analysis of the palynological samples indicated a predominance of humic, gas prone organic matter. Sediments above the fault are considered mature with regards to oil generation. Sediments below the fault reach peak maturation levels for gas generation before becoming post-mature (Robeson 1988).

1.5.4 Well 19/5-1

Amoco Ireland drilled well 19/5-1 into the Erris Basin to test a large faulted anticlinal structure expected to comprise Carboniferous to Cenozoic age sediments. The well penetrated approximately 2500'/762m of Quaternary to Upper Permian strata unconformably overlying Carboniferous strata. TD was reached within the Carboniferous at 8479'/2584m. No significant indications of hydrocarbons were encountered (Odell and Thomas 1978). Based on the palynological and microfaunal content of the Carboniferous succession, Palaeoservices (1978) identified an interval of Bolsovian to Langsettian age strata unconformably overlying a succession tentatively dated as Arnsbergian/Pendleian to pre-Asbian in age. Westphalian age deposits comprised coal bearing claystones and sandstones. Namurian and Viséan strata comprised sandstones, limestones, siltstones and shales with rare coals restricted to the Namurian. Palaeoservices (1978) positioned the Carboniferous/Upper Permian unconformity at 3030'/924m.

Robeson (1988) subsequently reassessed the palynostratigraphy and thermal maturity of the Carboniferous succession, identifying a Duckmantian to Langsettian interval unconformably overlying a succession of Arnsbergian to Holkerian age strata. Vitrinite reflectance values ranged from 0.55%Rr at the top of the interval to 0.92%Rr at the base, suggesting the Carboniferous interval lies wholly within the oil window. Kerogen analysis indicated that samples between 3240'/988m and 7320'/2231m are predominantly humic and gas prone, with the organic content of samples below 7320'/2231m being minimal (Robeson 1988).

1.5.5 Well 26/21-1

Gulf Oil (Ireland) Ltd drilled well 26/21-1 near the crest of tilted fault block in northern end of the Porcupine Basin. The primary objectives were Triassic sandstones; with Middle Jurassic sandstones and a possible pre-Triassic play as secondary objectives. The well encountered Cenozoic, Cretaceous, Jurassic and Permo-Triassic sediments unconformably overlying Carboniferous shales, siltstones and sandstones. In a palynological study, Gueinn and King (1979) recorded the first downhole occurrence of Carboniferous strata at 6975'/2126m. The well reached TD within the Carboniferous at 7139'/2176m. The only indication of hydrocarbons was high background gas from 4593'/1400m - 5741'/1750m and poor oil shows in the Lower Cretaceous (Bignell and Black 1980). Gueinn and King dated a sample from the Carboniferous succession as early Autunian/Stephanian in age based on palynological content. The ages of other samples from the Carboniferous interval could not be precisely dated due to the limited microflora present. Cornet *et al.* (1980) indicated that kerogen recovery from the interval 6690'/2039m - 7138'/2175.6m was poor and no vitrinite was recovered. A Thermal Alteration Index (TAI) value of 4 was estimated for the samples.

1.5.6 Well 26/26-1

Irish Shell Petroleum Development Company Teoranta drilled well 26/26-1 in the northern end of the Porcupine Basin. The objective of the well was to evaluate the hydrocarbon potential of Triassic and Early Cretaceous reservoirs. The well penetrated a succession of Cenozoic and Early Cretaceous strata unconformably overlying Carboniferous sandstones, siltstones, claystones and limestones. The Carboniferous in turn rested unconformably on Precambrian-Cambrian metasediments. The well reached TD at 4121'/1256m and was plugged and abandoned as a dry hole after encountering only minor shows of hydrocarbons (26/26-1 Final Well Report 1981). The 26/26-1 Final Well Report positioned the Cretaceous-Carboniferous unconformity at 2602'/793m based on microfossil and lithological data. Based on palynological content, Whitaker (1981) and the 26/26-1 Final Well Report (1981) dated samples from the Carboniferous interval as Duckmantian, lower Namurian, Viséan and possibly late Tournaisian in age. The base of the Carboniferous interval was positioned at 3704'/1129m based on a sharp transition to Precambrian-Cambrian metasediments. In the upper part of the Carboniferous interval, only one sample (2858'/871m) contained enough organic matter to qualify as a source rock. The sample was considered a marginal source rock for gas with a vitrinite reflectance of 0.66%Rr. Humic organic matter was recorded in the lower part of the Carboniferous interval (at 3369'/1027m and 3389'/1033m), with vitrinite reflectance values of ~1.00%Rr (26/26-1 Final Well Report 1981).

1.5.7 Well 26/27-1b

Chevron Oil Company of Ireland drilled well 26/27-1b in the northern end of the Porcupine Basin. The primary objective was a Jurassic play, with a secondary objective being Triassic sandstones. The well encountered 6375'/1943m of Cenozoic, Cretaceous and Upper Jurassic strata unconformably overlying a succession of Carboniferous siltstones, claystones, sandstones and coals (26/27-1b Final Well Report 1981). The 26/27-1b Final Well Report 1981 positioned the top Carboniferous at

7715'/2352m, based on palynological data from King *et al.* (1981), in addition to lithological and wireline log data. The well reached TD at 9223'/2811m, within the Carboniferous. No hydrocarbon shows were encountered in the well, although the Carboniferous section was shown to be gas prone (26/27-1b Final Well Report 1981). Based on palynological content, King *et al.* (1981) dated the Carboniferous interval as Asturian to Duckmantian in age. Vitrinite reflectance values for the Carboniferous interval ranged from ~0.6% to ~0.68%Rr (Robeson *et al.* 1988); within the zone for early oil generation.

1.5.8 Well 26/28-1

BP Petroleum Development (Ireland) Ltd. drilled well 26/28-1 in the northern end of the Porcupine Basin with the aim of evaluating potential Early to Late Jurassic reservoirs. The well encountered a succession of Cenozoic, Cretaceous and Jurassic strata unconformably overlying Carboniferous rocks. The Carboniferous succession comprised mudstones, siltstones, sandstones, thin coals and thin limestones. Oil was encountered in Late to Middle Jurassic sediments (the Connemara oil accumulation) with minor gas shows in the Carboniferous (Simpson 1979). The well produced 5589 barrels of oil per day on test from the Jurassic before being plugged and abandoned (Compton 1983). Duxbury *et al.* (1979) dated the Carboniferous succession as Stephanian A/B to Asturian in age based on palynological and microfaunal content. The top of the Carboniferous was picked at 8973.6'/2735.2m based on microfossil evidence and a downhole increase in resistivity and sonic travel time (Simpson 1979).

Robeson (1988) subsequently reassessed the palynostratigraphy and thermal maturity of the Carboniferous succession, identifying a Stephanian to upper Bolsovian succession juxtaposed against Duckmantian age strata. Vitrinite reflectance values suggested a faulted contact; averaging between 0.80% - 0.90%Rr above the fault and in the region of 1.30% - 1.40%Rr below the fault. Robeson concluded that Carboniferous strata above the fault are mature with regards to oil generation and strata below the fault are marginally mature for the generation of gas. Kerogen content of the Carboniferous samples were dominantly humic (gas prone).

1.5.9 Well 26/28-2

BP Petroleum Development (Ireland) Ltd drilled well 26/28-2 in the northern end of the Porcupine Basin to confirm the presence of Jurassic sandstones updip from 26/28-1 and to prove a common oil-water contact. Carboniferous and older sandstones were a secondary objective (Rainey 1980). The well penetrated Cenozoic, Cretaceous and Jurassic strata unconformably overlying Carboniferous rocks. Rainey positioned the Carboniferous/Jurassic unconformity at 7431 '/2265m based on palynological data from Paley and Athersuch (1980) in addition to lithological data. The Carboniferous interval comprised mudstones, sandstones, thin coals and limestones. The well reached TD within the Carboniferous at a depth of 8848'/2697m. Bathonian age sandstones were oil bearing. Although the oil-water-contact (OWC) was not seen, it was assumed to be at the same depth as in 26/28-1. Minor oil and gas shows were observed in both Cretaceous and Carboniferous sandstones (Rainey 1980). The well produced 1490 barrels of oil per day on test from the Jurassic zones before being plugged and abandoned (Compton 1983).

Based on palynological content, Paley and Athersuch (1980) dated the Carboniferous interval as Stephanian A to Bolsovian in age. Robeson (1988) subsequently reassessed the palynostratigraphy and thermal maturity of the Carboniferous succession, confirming a succession of Stephanian to Bolsovian age strata. Vitrinite reflectance values ranged from 0.85% - 1.00%Rr, indicating the Carboniferous is mature with regards to oil generation. Kerogen samples were predominantly humic and gas prone (Robeson 1988).

1.5.10 Well 26/28-3

BP Petroleum Development (Ireland) Ltd drilled well 26/28-3 in the northern end of the Porcupine Basin with the aim of evaluating the potential of Jurassic sandstones in a fault block 4km to the northeast of 26/28-1. The well encountered ~6562'/~2000m of Quaternary to Jurassic strata resting unconformably on Carboniferous mudstones and sandstones. The well reached TD within the Carboniferous at 8491'/2588m (Gidman 1981). Athersuch *et al.* (1981) dated the Carboniferous interval as ?Stephanian to Asturian/Bolsovian in age based on palynological content. Positioning of the

Jurassic/Carboniferous unconformity at ~7861'/2396m was based on microfossil and wireline log data (Gidman 1981). Robeson (1988) subsequently reassessed the palynostratigraphy and thermal maturity of the Carboniferous succession, dating the interval as Asturian to upper Bolsovian in age. The Carboniferous interval yielded very little reliable vitrinite reflectance data. Values ranged from 0.81% - 1.19%Rr, indicating the strata is mature with regards to oil generation. Carboniferous kerogen samples were considered gas prone. Minor oil shows were recorded in Cretaceous limestones, although no hydrocarbons were noted in the Carboniferous section (Gidman 1981).

1.5.11 Well 26/28-4a

BP Petroleum Development (Ireland) Ltd drilled well 26/28-4a in the northern end of the Porcupine Basin to investigate the continuity of Jurassic reservoir sandstones in a fault block to the east of wells 26/28-1, 2 and 3. The well penetrated a succession of Cenozoic, Cretaceous and Jurassic strata unconformably overlying Carboniferous mudstones, siltstones and occasional fine sands (Cottle and Evans 1982). The top Carboniferous was positioned at 7808'/2380m based on log correlation with 26/28-1 and palynological evidence (Crawley *et al.* 1981). TD was reached within the Carboniferous at 7933'/2418m. All sands penetrated by the well were devoid of hydrocarbon shows (Cottle and Evans 1982). The well was plugged and abandoned without testing (Crawley *et al.* 1981). Athersuch *et al.* (1982) dated the Carboniferous interval as Bolsovian to Asturian in age based on palynological content. Vitrinite reflectance values ranged from 0.68%Rr at the top of the Carboniferous interval to 0.74%Rr at the base (Crawley *et al.* 1981).

1.5.12 Well 26/29-1

BP Petroleum Development (Ireland) Ltd drilled 26/29-1 in the northern end of the Porcupine Basin to test a large, southerly tilted fault block structure updip and to the east of Block 26/28. Middle and Upper Jurassic sands were proposed targets. The well encountered a succession of Cenozoic, Cretaceous, Upper and Middle Jurassic strata unconformably overlying Carboniferous sediments. Although good quality Middle-Upper Jurassic and Cretaceous reservoir rocks were encountered, minor oil shows were restricted to the Cenozoic and Cretaceous intervals. TD was reached within the Carboniferous at 6043'/1842m (Richards 1982; Compton 1983). Athersuch *et al.* (1983) assigned a Bolsovian age to core samples from 6016'/1833.8m to 6027.8'/1837.3m based on palynological content. The top Carboniferous was positioned at 5873'/1790m based on the palynological data and wireline log data. The well was plugged and abandoned without testing (Richards 1982; Compton 1983). Vitrinite reflectance values from the Carboniferous interval range from ~0.6% - 0.68% Rr (Robeson *et al.* 1988).

1.5.13 Well 26/30-1

Enterprise Oil drilled well 26/30-1 into the north-eastern corner of the Porcupine Basin. The primary objective was Middle Jurassic sandstones. Secondary objective were Upper Jurassic and Triassic sandstones. The well penetrated a succession of Cenozoic, Cretaceous and Jurassic strata unconformably overlying Carboniferous sandstones and mudrocks with occasional coal seams. The Carboniferous in turn rested unconformably on granitic basement; the unconformity positioned at 5593'/1705m. TD was reached at 5648'/1722m, within the crystalline basement. All sands tested were water wet and the well was plugged and abandoned (26/30-1 Final Well Report 1982). King *et al.* (1982) dated the interval 5090'/1551m - 5260'/1603m as Bolsovian in age based on palynological content. The Jurassic-Carboniferous unconformity was positioned at 4935'/1504m based on a 'convenient break on the gamma and sonic logs which is between palynology picks in the Jurassic and Carboniferous' (26/30-1 Final Well Report 1982).

Vitrinite reflectance values for the Carboniferous succession ranged from 0.60% - 0.68%Rr, indicating the strata is mature for oil generation. Pyrolysis of Carboniferous samples showed they were gas prone with some potential to source additional liquid hydrocarbons (Paleochem Ltd Geochemical Consultants 1982).

1.5.14 Well 27/5-1

Enterprise Oil drilled well 27/5-1 into the Slyne Basin to evaluate the potential of Middle Jurassic and Lower Triassic reservoirs. The well encountered a sequence of

Cenozoic, Jurassic, Triassic and Late Permian (Zechstein) deposits lying unconformably on a succession of Carboniferous claystones, siltstones, sandstones and coals (Enterprise Oil 1996). Millennia Stratigraphic Consultants (1996) dated the Carboniferous interval as Bolsovian to Langsettian in age based on palynological content. The top of the Carboniferous succession was positioned at 5834'/1641m based on lithological, wireline log and palynological evidence (Enterprise Oil 1996). TD was reached within the Carboniferous at 6266'/1910m. Oil shows were encountered in Middle Jurassic sandstones, although geochemical analysis showed the oil to be highly biodegraded. Minor gas shows were recorded from thin coal seams in the Carboniferous. Economic accumulations of hydrocarbons were not encountered (Enterprise Oil 1996). Vitrinite reflectance values from the Carboniferous interval reach 7.20%Rr in the vicinity of a ?Cenozoic age dolerite sill at ~5535'/1687m. Vitrinite reflectance values deemed unaffected by contact heating range from 0.65% - 0.73%Rr (Gibson *et al.* 1996).

1.5.15 34/5-1

Elf Aquitaine (Ireland) Ltd drilled well 34/5-1 into the north-western rim of the Porcupine Basin to test an anticlinal structure expected to comprise Jurassic, Triassic and Carboniferous age strata. The well encountered 2411'/735m of Cenozoic strata unconformably overlying 2470'/753m of Carboniferous sandstones, siltstones, claystones and coals. TD was reached within the Carboniferous at 4882'/1488m. No hydrocarbon shows were recorded (Croisile 1981). Based on palynological data, with additional microfaunal evidence, Church *et al.* (1980) suggested the Carboniferous interval could potentially range from Stephanian B to Duckmantian in age. Ducazeaux *et al.* (1981) assigned a possible Stephanian to lower Duckmantian age to the interval based largely on palynological content. Croisilie (1981) positioned the Cenozoic/Carboniferous unconformity at 2411'/735m.

Robeson (1988) subsequently reassessed the palynostratigraphy and thermal maturity of the Carboniferous succession, dating the interval as ?Stephanian A-B to Duckmantian in age. Vitrinite reflectance values ranged from 0.69%Rr at 2707'/825m to 1.10%Rr at 4806'/1465m, indicating the Carboniferous section is mature with regards to oil generation. Kerogen samples from the Carboniferous were predominantly humic (gas prone), although algal (*Botryococcus*) rich samples were recorded between 3084'/940m and 3888'/1185m, representing a potential oil source (Robeson 1988).

1.5.16 Well 34/15-1

Deminex Ireland Ltd drilled well 34/15-1 into the Porcupine Basin with the primary aim of evaluating the hydrocarbon potential of Jurassic strata. The well encountered a succession of Cenozoic, Cretaceous, Jurassic, ?Permian (Autunian) and Carboniferous strata. Commercially insignificant quantities of liquid hydrocarbons were encountered in Palaeocene strata and Upper Jurassic sands. Hydrocarbon shows were recorded in Upper Cretaceous limestones. The well was subsequently plugged and abandoned (34/15-1 Completion Report, Volume 1, 1977).

Roveda *et al.* (1977) dated the interval 13222'/4030m - 14587.58'/4446.35m as Permian (Autunian) to Carboniferous (Stephanian) in age based on palynological content. The interval comprised shales, claystones, sandstones and limestones with coals towards the base. The top of the Permo-Carboniferous interval was tentatively positioned at 13104'/3994m based on lithological and palynological data (34/15-1 Completion Report, Volume 1, 1977).

Organic matter recovered from the Permo-Carboniferous interval was predominatly vitrinitic. Leythaeuser *et al.* (1977) recorded vitrinite reflectance values for the interval 13222'/4030m - 13484'/4110m ranging from 0.51 - 0.71%Rr. Values for the interval 14009'/4270m - 14567'/4440m ranged from 1.3% - 2.3%Rr. Based on the 'jump' in vitrinite reflectance values, Leythaeuser *et al.* suggested the possibility of a stratigraphic break between 13484'/4110m and 14403'/4390m.

1.5.17 Well 34/19-1

Irish Shell Petroleum Development Company Teoranta drilled well 34/19-1 into the Porcupine Basin to test the hydrocarbon potential of Cenozoic, Cretaceous and Late Jurassic deposits. The well encountered a succession of Cenozoic, Cretaceous and Jurassic strata unconformably overlying an interval of claystones, siltstones and thin sandstones with traces of coal and limestone assigned to the Upper Carboniferous and/or Permian. TD was reached at 10525'/3208m. Only small quantities of oil and traces of hydrocarbons were detected in Cenozoic and Mesozoic strata. The well was plugged and abandoned without testing.

A Late Carboniferous to Early Permian age was tentatively assigned to the interval 9701'/2957m - 10525'/3208m based on the palynological content of core cut from 10499'/3200 - 10525'/3208m. The top of the interval was positioned using wireline log data (34/19-1 Final Well Report, 1978).

1.5.18 Well 35/15-1

Phillips drilled well 35/15-1 into the Porcupine Basin with Lower Cretaceous/Upper Jurassic conglomerates and Paleocene/Upper Cretaceous chalk being primary objectives. The well encountered a succession of Eocene, Palaeocene and Cretaceous strata unconformably overlying an interval of sandstones, siltstones, claystones/shale limestones and tuffs tentatively assigned to the Carboniferous. TD was reached within the Carboniferous interval at 12100'/3688m. Although oil shows were recorded in Lower Palaeocene/Upper Cretaceous chalks, no oil was produced on testing due to the unit being water wet (35/15-1 Final Well Report 1980). Church *et al.* (1981) tentatively assigned an Early Carboniferous age to the interval 8750'/2667m - 9140'/2786m due poor miospore recovery. The interval 9140'/2786m - 12096'/3687m was tentatively assigned to the Early Carboniferous based on its limited miospore content. The top of the Carboniferous interval was cautiously positioned at 8260'/2518m based on lithological and maturity data. Cooper and Collins (1981) indicate that below 8260'/2518m, sediments are post-mature for oil generation and late or post-mature for dry gas generation. Vitrinite reflectance measurements ranged from 2.8%Rr(av) at 8750-800'/2667-82m to 6.1%Rr(av) at 11750-800'/3581-97m. Igneous activity was considered the reason for raised reflectivity values. Kerogen content of samples were dominated by inertinite.

1.5.19 Well 36/16-1

Chevron Oil Company of Ireland drilled well 36/16-1 on the eastern flank of the Porcupine Basin. The primary objective of the well was Jurassic and/or Permo-Triassic reservoirs. The well encountered 4300'/1311m of Cenozoic to Cretaceous sediments unconformably overlying 4711'/1436m of interbedded claystones, siltstones, sandstones, thin coals and infrequent thin limestones of Carboniferous age. King *et al.* (1979) dated the Carboniferous interval as Asturian to Duckmantian/late Namurian in age based on palynological content. The Cretaceous/Carboniferous unconformity was positioned at 4300'/1311m. TD was reached within the Carboniferous at 9011'/2747m. Hydrocarbon shows were recorded in basal Palaeocene sands and in a Palaeocene-Cretaceous limestone interval (36/16-1 Final Well Report 1979).

Robeson (1988) subsequently reassessed the palynostratigraphy and thermal maturity of the Carboniferous interval, dating the succession as Stephanian A-B to Langsettian-Duckmantian in age with a questionable Namurian age interval at the base. Vitrinite reflectance values ranged from 0.58%Rr at the top of the Carboniferous interval to 2.80%Rr close to TD (Robeson 1988). Robeson indicated that the curved, shallow vitrinite reflectance gradient reflected heating by an igneous intrusion at depth. Kerogen samples were dominantly humic (gas prone). Only locally were samples rich in sapropel. Robeson concluded that the interval shows good gas generating potential. It was also suggested that the fractured and brecciated nature of vitrinite samples may reflect the generation of gas.

1.6 MARITIMES BASIN OF EASTERN CANADA

The Maritimes Basin is a composite Upper Palaeozoic sedimentary basin, covering a large area of onshore and offshore Eastern Canada (figure 1.7). It extends from south-western New Brunswick to the continental margin on the eastern Grand Banks and from the southern Grand Banks to offshore Labrador. Upper Devonian to Early Permian age continental to shallow marine deposits are recorded in a series of component basins (Gibling *et al.* 2008, Lavoie *et al.* 2009). The depositional and structural history of the Maritimes Basin includes extensional and strike slip settings in the Late Devonian to Mississippian and a wrench-foreland basin setting in the Pennsylvanian to Early Permian.

Petroleum exploration in the basin dates back to the 1800s following the discovery of oil seeps in Carboniferous outcrops. Onshore drilling has resulted in a number of oil and gas discoveries (figure 1.7). Hydrocarbon accumulations are predominantly encountered in Carboniferous strata. Reservoir rocks include Tournaisian age lacustrine shoreface and deltaic/fluvial-deltaic sands, Viséan age marine carbonates and thick multistoried fluvial sandstones of Namurian to Permian age. Source rocks include Lower Carboniferous lacustrine black shales, Viséan marine carbonates and calcareous shales in addition to Upper Carboniferous coal measures. The Stoney Creek oil field, discovered in 1909, was the first producing oil field in Canada. The McCully Gasfield, discovered in 2000, currently produces from 23 wells. Other as yet undeveloped onshore gas discoveries include West Stoney and Downey in New Brunswick, Green Gables in Prince Edward Island and Western Adventure in Newfoundland. Most offshore exploration was undertaken in the 1970s and 1980s when 14 wells were drilled. Offshore drilling has resulted in one significant gas discovery, made by the East Point E-49 well in 1970.

CHAPTER 2
CARBONIFEROUS MIOSPORES OF WESTERN EUROPE AND EASTERN CANADA

2.1 KEY STUDIES IN WESTERN EUROPEAN CARBONIFEROUS PALYNOSTRATIGRAPHY

Since the early attempts of Raistrick (1934) to characterise the miospore assemblages of Westphalian coals seams in Great Britain based on the quantitative distribution of key miospores (Owens *et al.* 1996), palynological zonations have been proposed for localities throughout Western Europe, leading to the unified Western European miospore zonal schemes of Clayton *et al.* (1977; 2003). Several key developments in Western European palynostratigraphy are outlined below.

2.1.1 Neves (1958; 1961)

Neves (1958; 1961) recognised progressive compositional changes in Namurian miospore assemblages from the southern Pennines region of northern England, correlating the changes with the existing ammonoid chronostratigraphic framework (Owens *et al.* 2004).

2.1.2 Smith and Butterworth (1967)

Smith and Butterworth (1967) published the first unified miospore zonation scheme for coal-bearing Carboniferous strata in British coalfields. It was also the first formal scheme to include index taxa (Owens *et al.* 1996). The authors proposed 11 assemblage biozones spanning the middle Viséan (Holkerian) to the late Westphalian (Asturian) (figure 2.1). However, the absence of significant commercial coal seams in the Namurian resulted in major gaps in the proposed zonation (Owens *et al.* 2004).

2.1.3 Alpern *et al.* (1969; 1970), Grebe (1972), Chateauneuf (1973), Loboziak (1974), van Wijhe and Bless (1974)

During the 1970s, Westphalian and Stephanian palynological zonations were proposed for several regions in Western Europe, i.e. the upper Westphalian-Stephanian of the coal basins of central France (Alpern *et al.* 1969; 1970), the Westphalian of the Pas de Calais, France (Loboziak 1974), the Westphalian of the Ruhr Basin, Germany (Grebe 1972), the Westphalian-Stephanian of the Asturias Basin, Spain (Chateauneuf 1973) and the Westphalian of the Limburg Coalfield in the Netherlands (van Wijhe and Bless 1974) (Owens *et al.* 1996).

2.1.4 Neves *et al.* (1972; 1973), Owens *et al.* (1977)

Neves *et al.* (1972; 1973) developed a miospore zonation for the Dinantian (Mississippian) of northern England and central Scotland. Eight concurrent range zones were recognised spanning the latest Famennian to earliest Namurian (figure 2.1). In general, two species were selected as index taxa for each biozone. To bridge the gap between the Dinantian scheme of Neves *et al.* (1972; 1973) and the largely Westphalian scheme of Smith and Butterworth (1967), Owens *et al.* (1977) established a zonation for the Namurian of the British Isles. Owens *et al.* subdivided the Namurian into five biozones, calibrating the changes in miospore population with all available independent biostratigraphic data (figure 2.1).

2.1.5 Coquel *et al.* (1976)

Coquel *et al.* (1976) proposed eight biozones (numbered I-VIII) for the Westphalian, Stephanian and Autunian of Western Europe, using palynological data selected from previous studies (figure 2.1).

2.1.6 Clayton *et al.* (1977)

Clayton *et al.* (1977) synthesized all data that was available from the Carboniferous deposits of Western Europe into a unified miospore zonal scheme. The zonation became the Western European standard for palynologists. The scheme comprised 24 concurrent range biozones spanning the uppermost Devonian to the Autunian (figure 2.2). In general, two species were selected as index taxa for each biozone. Viséan age biozones were based largely on palynological data from the British Isles (e.g. Neves *et al.* 1972; 1973). Namurian biozones were based on the zonal scheme of Owens *et al.* (1977). Westphalian and Stephanian age biozones incorporated data from a range of localities in Western Europe. Ranges of key taxa as given in the zonal scheme are shown in figure 2.2.

2.1.7 Clayton *et al.* (1978), Clayton (1985)

Viséan age biozones of the British Isles were further refined by Clayton *et al.* (1978) and Clayton (1985). Revisions included the introduction of the *Murospora margodentata – Rotaspora ergonulii* (ME) and *Tripartites distinctus - Murospora parthenopia* (DP) Sub-biozones within the *Raistrickia nigra - Triquitrites marginatus* (NM) Zone. The *Knoxisporites triradiatus - Knoxisporites stephanephorus* (TS) Biozone was also introduced and the *Perotrilites tessellatus – Schulzospora campyloptera* (TC) Biozone, originally introduced by Neves *et al.* (1972), was redefined (figure 2.1).

2.1.8 Cleal (1984)

In Western Europe, the Westphalian stage is sub-divided into the Langsettian, Duckmantian, Bolsovian and Asturian Substages. The boundaries between the lower three substages are taken at discrete marine bands. As the highest recognised marine band is in the middle Bolsovian, other criteria have to be used to recognise the Bolsovian-Asturian boundary. Historically, the base of the Asturian has been linked with the biozone of the plant macrofossil *Neuropteris ovata* and has often been associated with the range base of *Thymospora* spp. (Cleal 1984).

Due to the inherent risk of linking the base of the stage to the range of only one fossil species (*Neuopteris ovata*), the Westphalian D (Asturian) Working Group of the Subcommission on Carboniferous Stratigraphy (SCCS) developed a series of eight palaeobotanical events for the purpose of locating the base of the Asturian (see Laveine 1977). The base of the acme of *Neuropteris ovata* was deemed an effective lower boundary for the base Asturian. Cleal (1984) assigned the system to the South Wales Coalfield and recorded the first stratigraphic occurrence of *Thymospora* spp. nearly a full formation (250m) below the base of the Asturian as indicated by the macroflora.

2.1.9 Smith (1987)

Smith (1987) subdivided the *Thymospora obscura* Assemblage Zone XI of Smith and Butterworth (1967) into three biozones (zones XI, XII and XIII) based on miospore assemblages in coals from Oxfordshire and southeast Warwickshire, Great Britain. The base of Zone XII was deemed to be approximately equivalent to the base of the Cantabrian Stage (figure 2.1).

2.1.10 Higgs *et al.* (1988)

The miospore zonation for the Fammennian and Tournaisian of onshore Ireland was revised by Higgs *et al.* (1988) (figure 2.1). The authors proposed two new zones within the middle Tournaisian; the *Kraeuselisporites hibernicus - Umbonatisporites distinctus* (HD) and *Spelaeotriletes balteatus – Rugospora polyptycha* (BP) Biozones. The *Retispora lepidophyta - Verrucosisporites nitidus* (LN) and *Vallatisporites verrucosus - Retusotriletes incohatus* (VI) Sub-biozones of the *V. nitidus – Vallatisporites verrucosus* (NV) Biozone were upgraded to full biozone status and the *R. lepidophyta - Knoxisporites literatus* (LL) and *R. lepidophyta - Hymenozonotriletes explanatus* (LE) Sub-biozones (originally introduced by Clayton *et al.* 1978) were also upgraded to full biozone status, replacing the *Vallatisporites pusillites-Spelaeotriletes lepidophytus* (PL) Biozone. The ranges of key taxa as recorded by Higgs *et al.* are shown in figure 2.3.

2.1.11 Clayton *et al.* (2003)

In 2003, Clayton *et al.* proposed a revised version of the 1977 Western European miospore zonal scheme. The revised scheme incorporates advances made in Western European palynostratigraphy since the original zonation was published (e.g. Clayton *et al.* 1978; Clayton 1985; Higgs *et al.* 1988; Owens *et al.* 2004 and McLean *et al.* 2005).

The revised scheme comprises 25 biozones from the base of the Carboniferous to the Cantabrian Substage (figure 2.1). Six of the biozones are divided into sub-biozones. In contrast to the original zonal scheme, biozones and sub-biozones are named after a single index taxon. The first stratigraphic appearance of the index taxon typically defines the lower limit of the biozone or sub-biozone. Key characteristics of the zonal scheme are outlined in section 2.2.

2.1.12 Owens *et al.* (2004)

In 2004, Owens *et al.* published a revised miospore zonal scheme for the Namurian of onshore Great Britain, updating the zonation of Owens *et al.* (1977) (figure 2.1). The revisions reflect ‘improvements in independent biostratigraphical calibration and species distribution data’ since the original zonation was published (Owens *et al.* 2004). Biozone boundaries have been accurately repositioned and new sub-biozones introduced. The ranges of key taxa as given in the zonal scheme are shown in figure 2.4.

2.1.13 McLean *et al.* (2005)

Based on the analysis of more than 300 hydrocarbon well sections, McLean *et al.* (2005) subdivided the late Tournaisian to Asturian of the North Sea into 18 miospore biozones and 40 sub-biozones (figure 2.1). As North Sea palynological samples are typically derived from borehole cuttings, biozones were defined where possible by last stratigraphic occurrences (i.e. the range top or first downhole appearance) of taxa. The majority of biozone bases were defined by the range top of a single ‘defining’ taxon, with the taxon occurring in the biozone below (figure 2.5). To avoid confusion, the biozones were numbered sequentially instead of being named after the defining taxa (McLean *et al*. 2005). McLean *et al.* also recognised that the defining taxa may not always be present in a given sample. As a result, the author listed associated taxa whose range tops and bases occur in proximity to that of the defining taxon (figure 2.5).

The North Sea zonal scheme comprises a greater number of Westphalian age biozones compared to the British coalfields zonal scheme of Smith and Butterworth (1967) and the Western European zonal scheme of Clayton *et al.* (1977). McLean *et al.* (2005) indicated that the Mississippian biozones of the North Sea are comparable with those developed for northern Britain and the Midland Valley of Scotland (Neves *et al.* 1972; 1973 and Clayton *et al.* 1977; 1978). Namurian age biozones are also comparable with those developed for onshore northern England (i.e. Owens *et al.* 1977; 2004), although the Mississippian age North Sea sub-biozones are only locally recognisable (McLean *et al.* 2005).

2.1.14 Pereira (1999), Pereira *et al.* (2007)

Analysing palynological samples from the South Portuguese Zone, Portugal, Pereira (1999) identified a number of biozones from the Western European miospore zonal scheme of Clayton *et al.* (1977) in Upper Devonian to lower Stephanian age strata (figure 2.6). Two new biozones; *Savitrisporites nux* (SN) and *Raistrickia nigra* - *Proprisporites laevigatus* (NL) Biozones were also introduced. In 2007, Periera *et al.* published an overview of recent palynostratigic advances made in the region with a revised list of index species (figure 2.6).

2.1.15 Cleal *et al.* (2003), Dimitrova *et al.* (2005), Dimitrova and Cleal (2008)

Integrating macrofloral and palynological data, Cleal *et al.* (2003), Dimitrova *et al.* (2005) and Dimitrova and Cleal (2008) attempted to identify the Asturian-Cantabrian boundary outside of its stratotype in the Guardo-Cevera Coalfield, Palencia, Spain. Dimitrova and Cleal (2008) indicated that the base of the Cantabrian Stage in the South Wales and Forest of Dean Coalfields of Great Britain in addition to the Sydney Coalfield of Eastern Canada could be approximated by increases in the abundance of *Thymospora pseudothiessenii*, *Schopfites dimorphus* and *Cadiospora magna* in addition to the first stratigraphic occurrences of *Lundbladispora gigantea* and *Angulisporites splendidus*.

2.2 WESTERN EUROPEAN MIOSPORE ZONAL SCHEME (Clayton *et al.* 2003)

The following section provides an overview of the Western European miospore zonal scheme of Clayton *et al.* (2003) (figure 2.7). See figure 2.1 for a comparison of the zonal scheme with other miospore zonations of Western Europe.

***Thymospora pseudothiessenii* Biozone**

The lower limit of the upper Bolsovian to Cantabrian age *Thymospora pseudothiessenii* Biozone is defined by the first stratigraphic occurrence of the index taxon (figure 2.7). The biozone is sub-divided into the upper Bolsovian age *Westphalensisporites irregularis* Sub-biozone, the Asturian age *Torispora verrucosa* Sub-biozone and the Cantabrian age *Angulisporites splendidus* Sub-biozone.

The biozone corresponds in part to the W7 North Sea Biozone of McLean *et al.* (2005), the *Thymospora obscura – Thymospora thiessenii* (OT) Biozone of Clayton *et al.* (1977) and Assemblage Biozones XI, XII and XIII of Smith and Butterworth (1967) and Smith (1987).

***Angulisporites splendidus* Sub-biozone**

The lower limit of the *Angulisporites splendidus* Sub-biozone is defined by the first stratigraphic occurrence of the index taxon and corresponds to the base of the Cantabrian Substage. There is uncertainty regarding the age of the upper limit as the revised zonal scheme of Clayton *et al.* (2003) does not include revised Barruelian to lower Autunian age biozones (figure 2.7). The *A. splendidus* Sub-biozone is considered to be at least Cantabrian in age.

***Torispora verrucosa* and *Westphalensisporites irregularis* Sub-biozones**

The upper Bolsovian age *Westphalensisporites irrelgularis* Sub-biozone is characterised by occurrences of the index taxon. The range top of *W. irregularis* is recorded in the succeeding Asturian age *Torispora verrucosa* Sub-biozone. The lower limit of the *T. verrucosa* Sub-biozone is marked by the first stratigraphic occurrence of the index taxon. The boundary between the two sub-biozones corresponds to the Bolsovian-Asturian Substage boundary. The sub-biozones correspond to the W7a, W7b and W7c North Sea Sub-biozones of McLean *et al.* (2005).

The *Torispora verrucosa* Sub-biozone was originally named the *Thymospora verrucata* Sub-biozone in the Western European zonal scheme of Clayton *et al.* (2003). Dr. Duncan McLean (pers comm. 29 November 2011) indicates the sub-biozone was incorrectly named in the 2003 zonal scheme and should instead be named the *Torispora verrucosa* Sub-biozone. Dr. McLean indicates that *T. verrucata* should not be used in the zonal scheme as the taxon is a synonym of *Thymospora thiessenii*.

Vestispora fenestrata Biozone

The lower limit of the Bolsovian age *Vestispora fenestrata* biozone is defined by the first stratigraphic occurrence of the index taxon. The biozone is sub-divided into the *Raistrickia aculeata* and *Torispora securis* Sub-biozones and corresponds to the W6 North Sea Biozone of McLean *et al.* (2005), the *T. securis – Torispora laevigata* (SL) Biozone of Clayton *et al.* (1977) and the *T. securis* Assemblage Biozone X of Smith and Butterworth (1967).

Raistrickia aculeata and *Torispora securis* Sub-biozones

The lower limits of the Bolsovian age *Raistrickia aculeata* and *Torispora securis* Sub-biozones are defined by the first stratigraphic occurrences of the respective index taxa. The sub-biozones correspond to the North Sea W6a and W6b Sub-biozones of McLean *et al.* (2005).

Triquitrites sculptilis Biozone

The base of the lower Bolsovian age *Triquitrites sculptilis* Biozone is marked by the first common stratigraphic occurrence of the index taxon. The biozone corresponds to the W5b North Sea Sub-biozone of McLean *et al.* (2005). The lower limit also corresponds to the Duckmantian-Bolsovian Substage boundary.

***Microreticulatisporites nobilis* Biozone**

The lower limit of the Duckmantian age *Microreticulatisporites nobilis* Biozone is defined by the first stratigraphic occurrence of the index taxon and the last stratigraphic occurrence of *Sinuspores sinuatus.* The biozone is subdivided into the *Vestispora magna* and *Lycospora noctuina noctuina* Sub-biozones and corresponds with the North Sea W4b, W4c and W5a Sub-biozones of McLean *et al.* (2005).

***Vestispora magna* and *Lycospora noctuina noctuina* Sub-biozones**

The lower limit of the *Vestispora magna* Sub-biozone is defined by the first stratigraphic occurrence of the index taxon. The sub-biozone corresponds to the W5a North Sea Sub-biozone of McLean *et al*. (2005). The *Lycospora noctuina noctuina* Sub-biozone is characterised by occurrences of the index taxon and corresponds to the W4b and W4c Sub-biozones of McLean *et al*. Based on range data in McLean *et al.,* the last stratigraphic occurrence of *L. noctuina noctuina* occurs in the upper part of the sub-biozone.

The boundary between the *Vestispora magna* and *Lycospora noctuina noctuina* Sub-biozones also corresponds with the boundary between the *Dictyotriletes bireticulatus* Assemblage Zone VIII and *V. magna* Assemblage Zone IX of Smith and Butterworth (1967).

***Sinuspores sinuatus* Biozone**

The lower limit of the lower Duckmantian age *Sinuspores sinuatus* Biozone is defined by the last stratigraphic occurrence of *Schulzospora rara*. Occurrences of *S. sinuatus* characterise the biozone. The lower limit corresponds to the Langsettian-Duckmantian Substage boundary. The biozone also corresponds to the North Sea W4a Sub-biozone of McLean *et al.* (2005).

Together, the *Sinuspores sinuatus, Microreticulatisporites nobilis* and *Triquitrites sculptilis* Biozones of Clayton *et al.* (2003) correspond to the *M. nobilis - Florinites junior* (NJ) Biozone of Clayton *et al.* (1977) in addition to the *Dictyotriletes* *bireticulatus* Assemblage Zone VIII and *Vestispora magna* Assemblage Zone IX of Smith and Butterworth (1967).

***Schulzospora rara* Biozone**

The lower limit of the *Schulzospora rara* Biozone is defined by the last stratigraphic occurrence of *Radiizonates aligerens*. Occurrences of *S. rara* characterise the biozone. The uppermost Langsettian age biozone corresponds to the North Sea W3 Biozone of McLean *et al.* (2005) and the *S. rara* Assemblage Zone VII of Smith and Butterworth (1967).

***Radiizonates aligerens* Biozone**

Based on range data from McLean *et al.* (2005), the first common stratigraphic occurrence of the index taxon occurs in proximity to the lower limit of the *Radiizonates aligerens* Biozone. Occurrences of the index taxon characterise the Langsettian age biozone. The biozone roughly corresponds to the North Sea W2b Sub-biozone of McLean *et al.* (2005).

***Vestispora cancellata* Biozone**

Based on range data from McLean *et al.* (2005), the first stratigraphic occurrence of *Vestispora cancellata* occurs just below the lower limit of the *V. cancellata* Biozone. The Langsettian age biozone roughly corresponds to the North Sea W2a Sub-biozone of McLean *et al.* (2005).

***Spelaeotriletes arenaceus* Biozone**

The *Spelaeotriletes arenaceus* Biozone roughly corresponds to the North Sea W1b Sub-biozone of McLean *et al.* (2005). McLean *et al.* recorded the range top of *Stenozonotriletes triangulus* at the lower limit of the W1b Sub-biozone (figure 2.5). The *S. arenaceus* Biozone is characterised by occurrences of the index taxon. The Langsettian age biozone also corresponds to the upper part of the *Triquitrites sinani – Cirratriradites saturni* (SS) Biozone of Owens *et al.* (1977) and Clayton *et al.* (1977).

Together, the *Schulzospora rara*, *Radiizonates aligerens* and *Vestispora cancellata* Biozones of Clayton *et al.* (2003) correspond to the *R. aligerens* (RA) Biozone of Clayton *et al.* (1977). The *R. aligerens* and *V. cancellata* Biozones also correspond to the *R. aligerens* Assemblage VI Biozone of Smith and Butterworth (1967).

Dictyotriletes probireticulatus Biozone

The lower limit of the *Dictyotriletes probireticulatus* biozone is defined by the first stratigraphic occurrence of the index taxon. The biozone spans the Yeadonian-Langsettian Substage boundary and corresponds to the upper part of the *Raistrickia fulva – Reticulatisporites reticulatus* (FR) Biozone of Owens *et al.* (2004) and the lower part of the *Triquitrites sinani – Cirratriradites saturni* (SS) Biozone of Owens *et al.* (1977). The biozone also corresponds to the North Sea N5c and W1a Sub-biozones of McLean *et al.* (2005).

Reticulatisporites reticulatus Biozone

The *Reticulatulatisporites reticulatus* Biozone spans the middle Marsdenian to the middle Yeadonian. The lower limit of the biozone is defined by the first stratigraphic occurrence of the index taxon. The biozone corresponds to part of the *Raistrickia fulva – R. reticulatus* (FR) Biozone of Owens *et al.* (2004) (figure 2.4) and the North Sea N5a and N5b Sub-biozones of McLean *et al.* (2005).

Crassispora kosankei Biozone

The *Crassispora kosankei* Biozone spans the middle Alportian to the middle Marsdenian. The lower limit of the biozone is marked by the first common stratigraphic occurrence of the index taxon. The biozone corresponds to the *C. kosankei – Grumosisporites varioreticulatus* (KV) Biozone of Owens *et al.* (2004) (figure 2.4). The biozone also corresponds to the North Sea N4 Biozone of McLean *et al.* (2005).

Lycospora subtriquetra Biozone

The *Lycospora subtriquetra* Biozone spans the upper Arnsbergian to the middle Alportian. The base of the biozone is marked by the first stratigraphic appearance of the index taxon. The biozone corresponds to the *L. subtriquetra - Kraeuselisporites ornatus* (SO) Biozone of Owens *et al.* (2004) (figure 2.4). The biozone also corresponds to the North Sea N3 Biozone of McLean *et al.* (2005). The biozone is subdivided into the *Apiculatisporis variocorneus* and *Cirratriradites rarus* Sub-biozones.

Apiculatisporis variocorneus Sub-biozone and *Cirratriradites rarus* Sub-biozone

The base of the upper Arnsbergian age *Apiculatisporis variocorneus* Sub-biozone is marked by the first stratigraphic occurrence of the index taxon. The base of the Chokerian to middle Alportian age *Cirratriradites rarus* Sub-biozone is marked by the first common stratigraphic occurrence of *C. rarus*. The boundary between the sub-biozones corresponds to the Arnsbergian - Chokerian Substage boundary. The sub-biozones correspond to the *Lycospora subtriquetra – A. variocorneus* (SV) and *L. subtriquetra – C. rarus* (SR) Sub-biozones of Owens *et al.* (2004) (figure 2.4).

The *Apiculatisporis variocorneus* Sub-biozone also corresponds to the North Sea N3a Sub-biozone of McLean *et al.* (2005). The *Cirratriradites rarus* Sub-biozone corresponds to the N3b and N3c Sub-biozones.

The present study follows Ravn (1986) who argued for the synonymy of the genera *Apiculatasporites* and *Apiculatisporis,* with the former having priority (see Appendix VI - Systematic Palynology). In the following chapters, the sub-biozone of Clayton *et al.* (2003) will continue to be referred to as the *Apiculatisporis variocorneus* Sub-biozone. Otherwise, the taxon will be referred to as *Apiculatasporites variocorneus*.

Mooreisporites trigallerus Biozone

The first stratigraphic occurrence of the index taxon defines the lower limit of the *Mooreisporites trigallerus* Biozone which corresponds to the base of the Arnsbergian

Stage. The Arnsbergian age biozone corresponds to the *M. trigallerus – Rotaspora knoxi* (TK) Biozone of Owens *et al.* (2004) (figure 2.4) and the North Sea N2 Biozone of McLean *et al.* (2005).

***Cingulizonates* cf. *capistratus* Biozone**

The base of the upper Brigantian to Pendlian age *Cingulizonates* cf. *capistratus* Biozone is marked by the first stratigraphic appearance of the index taxon. The biozone corresponds to the *C. capistratus* - *Bellispores nitidus* (CN) Biozone of Owens *et al.* (2004) (figure 2.4) and the North Sea N1 Biozone of McLean *et al.* (2005).

The *Cingulizonates* cf. *capistratus* Biozone is sub-divided into the *Bellispores nitidus* and *Verrucosisporites morulatus* Sub-biozones

***Bellispores nitidus* Sub-biozone and *Verrucosisporites morulatus* Sub-biozone**

The lower limits of the *Bellispores nitidus* and *Verrucosisporites morulatus* Sub-biozones are defined by the first stratigraphic occurrences of the respective index taxa. The sub-biozone boundary approximates to the Viséan - Namurian Stage and Brigantian - Pendleian Substage boundaries.

The upper Brigantian age *Bellispores nitidus* Sub-biozone and the Pendleian age *Verrucosisporites morulatus* Sub-biozone correspond to the *Cingulizonates* cf. *capistratus* and *V. morulatus* Sub-biozones of Owens *et al.* (2004) (figure 2.4) in addition to the North Sea N1a and N1b Sub-biozones of McLean *et al.* (2005).

***Tripartites vetustus* Biozone**

The base of the Brigantian age *Tripartites vetustus* Biozone is marked by the first stratigraphic occurrence of the index taxon. The biozone corresponds to the *T. vetustus – Rotaspora fracta* (VF) Biozone as defined by Clayton *et al.* (1978). The biozone lower limit coincides with the base of the Brigantian Stage. The biozone also corresponds to the North Sea V5 Biozone of McLean *et al.* (2005).

Triquitrites marginatus Biozone

The first stratigraphic occurrence of the index taxon defines the base of the Asbian age *Triquitrites marginatus* Biozone. The biozone corresponds to the *Raistrickia nigra – T. marginatus* (NM) Biozone as defined by Clayton *et al.* (1978).

Murospora margodentata and *Murospora parthenopia* Sub-biozones

The *Triquitrites marginatus* Biozone is sub-divided into the *Murospora margodentata* and *Murospora parthenopia* Sub-biozones. The sub-biozones correspond to the *M. margodentata – Rotaspora ergonuli* (ME) and *Tripartites distinctus - M. parthenopia* (DP) Sub-biozones of Clayton *et al.* (1978). The first stratigraphic occurrences of the index taxa mark the bases of the respective sub-biozones. The sub-biozones also correspond to the North Sea V4a and V4b Sub-biozones (McLean *et al.* 2005).

Schulzospora campyloptera Biozone

The upper Holkerian to lower Asbian age *Schulzospora campyloptera* Biozone corresponds to the *Perotrilites tessellatus – S. campyloptera* (TC) Biozone as defined by Clayton (1985). The biozone also corresponds to the North Sea V3 Biozone of McLean *et al.* (2005)

Knoxisporites stephanephorus Biozone

The base of the upper Arundian to lower Holkerian age *Knoxisporites stephanephorus* Biozone is marked by the first stratigraphic appearance of the index taxon. The biozone corresponds to the *K. triradiatus – K. stephanephorus* (TS) Biozone of Clayton (1985). The *K. stephanephorus* biozone also corresponds to the North Sea V2 Biozone of McLean *et al.* (2005).

Lycospora pusilla Biozone

The base of the Chadian to Arundian age *Lycospora pusilla* Biozone is defined by the first stratigraphic occurrence of the index taxon. The biozone corresponds to the Pu

Biozone as defined by Clayton (1985). The biozone is also equivalent to the V1 North Sea Biozone of Mclean *et al.* (2005).

Schopfites claviger **Biozone**

The upper Courceyan age *Schopfites claviger* Biozone corresponds to the *S. claviger – Auroraspora macra* (CM) Biozone as defined by Higgs *et al.* (1988). The lower limit of the biozone is defined by the first stratigraphic occurrence of the index taxon.

Spelaeotriletes pretiosus **Biozone**

The lower limit of the Courceyan age *Spelaeotriletes pretiosus* Biozone is defined by the first stratigraphic occurrence of the index taxon. The biozone corresponds to the *S. pretiosus – Raistrickia clavata* (PC) Biozone as defined by Higgs *et al.* (1988).

Spelaeotriletes balteatus **Biozone**

The lower limit of the Courceyan age *Spelaeotriletes balteatus* Biozone is marked by the first stratigraphic occurrence of the index taxon. The biozone corresponds to the *S. balteatus – Rugospora polyptycha* (BP) Biozone of Higgs *et al.* (1988).

Cristatisporites hibernicus **Biozone**

The lower limit of the Courceyan age *Cristatisporites hibernicus* Biozone is marked by the first stratigraphic occurrence of the index taxon. The biozone is equivalent to the *C. hibernicus – Umbonatisporites distinctus* (HD) Biozone of Higgs *et al.* (1988).

Cyrtospora cristifera **Biozone**

The first stratigraphic occurrence of the index taxon occurs just above the lower limit of the Courceyan age *Cyrtospora cristifera* Biozone. The biozone corresponds to the *Vallatisporites verrucosus – Retusotriletes incohatus* (VI) Biozone as defined by Higgs *et al.* (1988). The base of the biozone approximates to the base of the Carboniferous system.

2.3 STEPHANIAN AND AUTUNIAN BIOZONES OF WESTERN EUROPE (Clayton *et al*. 1977)

The Western European Miospore Zonal Scheme of Clayton *et al.* (2003) does not include Barruelian to Autunian age revisions. The original Western European zonal scheme of Clayton *et al.* (1977) included three biozones of Stephanian to lower Autunian age (ST, N.B.M and VC Biozones) and one upper Autunian (Permian) age biozone (DS Biozone) (figure 2.1).

Disaccites striatiti **(DS) Biozone**

The base of the upper Autunian age DS Biozone corresponds to the boundary between the lower and upper Autunian Substages (equivalent to the Carboniferous and Permian boundary). Clayton *et al.* (1977) indicated the biozone is characterised by a rarity of spores. The lower limit is marked by the last stratigraphic occurrence of *Lycospora* spp., in addition to a marked reduction in the frequency of *Laevigatosporites* spp., *Punctatosporites* spp., *Thymospora* spp., *Florinites* spp., *Lundbladispora gigantea*, *Latensina trilea* and *Cheiledonites* sp. Monosaccate pollen are exclusively represented by *Potonieisporites* spp., *Vittatina* spp. and *Disaccites striatiti*. *Potonieisporites* spp. predominates in the biozone with a strong representation of *Disaccites striatiti.*

Vittatina costabilis **(VC) Biozone**

The base of the lower Autunian age VC Biozone corresponds to the Stephanian and Autunian Substage boundary. The biozone is characterised by a predominance of monosaccate pollen (*Potonieisporites* spp. and *Florinites* spp.). Clayton *et al.* (1977) indicate the lower limit is marked by the maximum development of *Potonieisporites*, a continued presence of *Vittatin*a spp., a marked reduction in *Lycospora* spp, *Laevigatosporites* spp., *Punctatosporites* and *Spinosporites spinosus* and the disappearance of *Densosporites* spp., *Angulisporites splendidus* and *Savitrisporites camptotus*. The biozone is also characterised by occurrences of *Cheiledonites* spp., *Disaccites* non *striatiti*, *Lundbladispora gigantea* and *Latensina trileta*, rare occurrences of *Thymospora* spp, in addition to very rare occurrences of *Triquitrites* spp. and *Candidispora* spp. The middle of the biozone is marked by the range tops of *Polymorphisporites* spp. and *Candidispora* spp. Towards the top of the biozone, the range top of *Torispora* sp. is recorded.

Potonieisporites novicus-bharadwajii - Cheiledonites major **(NBM) Biozone**

The NBM Biozone is upper Stephanian B to Stephanian C in age. The base of the biozone is marked by an increase in the frequency of *Cheiledonites* spp., *Potonieisporites* spp. and *Spinosporites spinosus*, the range top of *Vestispora fenestrata* and the last stratigraphic occurrence of common *Densosporites* spp. and *Savitrisporites camptotus*. The middle of the biozone is marked by the range tops of *Westphalensisporites irregularis, Florinites junior* and *Crassispora kosankei*. The biozone is also characterised by an abundance of *Lycospora* spp., *Laevigatosporites* spp., *Punctatosporites* spp., *Thymospora* spp., *Spinosporites spinosus* and *Florinites* spp., in addition to occurrences of *Triquitrites* spp., *Lundbladispora gigantea*, *Latensina trileta*, *Angulisporites splendidus, Candidispora* spp., *Cheleidonites* spp., *Potonieiesporites* spp., *Disaccites* non *striatiti* (except in the lower part) and *Polymorphisporites* spp. (except in the upper part). The biozone is additionally characterised by the presence of several *Vittatina* spp., *Disaccites striatiti* and a decline in the frequency of *Densosporites* spp. and *Triquitrites* spp.

Angulisporites splendidus – Latensina trileta **(ST) Biozone**

Clayton *et al.* (1977) recorded the ST Biozone as being upper Barruelian to Stephanian B in age (figure 2.1). The lower limit of the biozone is defined by the range bases of *Angulisporites splendidus* and *Cheleidonites* spp. with a more consistent presence of *Latensina trileta*. *Disaccites* non *striatiti*, *Candidispora* spp., *Polymorphisporites* spp. and *Spinosporties spinosus* become more abundant in the biozone, although occurrences of *Vestispora fenestrata* becomes less frequent. The first examples of *Vittatina* spp. are recorded in the biozone. The biozone is also characterised by an abundance of *Lycospora* spp., *Densosporites* spp., *Laevigatosporites* spp., *Torispora* spp., *Thymospora* spp. and *Florinites* spp. Consistent occurrences of *Westphalensisporiets irregularis, Lundbladispora gigantea* and *Savitrisporites* *camptotus* also characterise the biozone. Rare examples of *Crassispora kosankei, Cirratriradites saturni* and *Florinites junior* additionally characterise the biozone.

2.4 CARBONIFEROUS MIOSPORE ZONAL SCHEMES OF EASTERN CANADA

The Carboniferous of the Atlantic Provinces in Eastern Canada has been subdivided into a number of biozones based on miospore content. Many of the early biozones (e.g. Barss *in* Belt 1965; Barss *in* Hacquebard 1972) (figure 2.8) have now been superseded by biozones proposed by Utting (1987), Utting *et al.* (1989; 2010) and Utting and Giles (2004; 2008) (figure 2.9). The biozones can be correlated with Western Europe at a number of levels (Appendix II, figure 2.10). The Bolsovian to Autunian biozones of Barss and Hacquebard (1967) (figures 2.8, 2.11) are yet to be revised.

2.5 PALYNOLOGICAL EVENTS

Clayton *et al.* (1990) and Owens (1996) outlined a series of major palynological events that are identifiable in localities throughout the Northern Hemisphere. The following six Mississippian events were outlined in Clayton *et al.*

1. The extinction of *Retispora lepidophyta* at approximately the Devonian/Carboniferous boundary. This event can be recognised worldwide (Clayton *et al.* 1990).

2. The first stratigraphic appearance of *Spelaeotriletes pretiosus.* In Western Europe, the taxon first appears in the middle Tournaisian (Clayton *et al.* 1978). The taxon appears at a similar level in North America, Poland and North Africa (Clayton *et al.* 1990) and in sections dated as middle or possibly upper Tournaisian age in Eastern Canada (Utting 1987; Utting *et al.* 1989).

3. The first stratigraphic appearance of *Lycospora pusilla* around the Tournaisian-Viséan boundary. This event is recorded at or close to the boundary in the British Isles, in the early Viséan of Denmark, Germany, northern Poland and the Donets

Basin, Ukraine, the lower Viséan of China (Clayton *et al.* 1990) and at a similar level in Eastern Canada (Utting and Giles 2004).

4. The first stratigraphic appearance of *Tripartites vetustus* in the upper Viséan. This event is recorded in Western Europe, midcontinental U.S.A., the Donets Basin, Ukraine and Gansu, China. Other taxa that typically appear with *T. vetustus* are *Rotaspora fracta*, *R. knoxi*, *Grandispora spinosa* and *Savitrisporites nux* (Clayton *et al.* 1990). However, in Eastern Canada, Utting (1987) and Utting and Giles (2004) only recorded *G. spinosa* in upper Viséan age strata.

5. The first stratigraphic appearance of monosaccate pollen. Monosaccate pollen such as *Florinites* and *Potonieisporites elegens* first appear in the Serpukhovian of Western Europe. *Florinites* spp. appears at a similar level in midcontinental U.S.A. and in the Donets Basin, Ukraine (Clayton *et al*. 1990). The first stratigraphic occurrences of *P. elegens* and *Florinites* spp. are also recorded in the Serpukhovian of Eastern Canada (Utting and Giles 2008).

6. The extinction of *Tripartites vetustus* and *Rotaspora*. In Western Europe, the last stratigraphic occurrences of both taxa are recorded in the Arnsbergian Substage. The taxa also disappear at a similar level in the U.S.A. (Clayton *et al.* 1990).

Owens (1996) summarised the principal Pennsylvanian age palynological events that can be identified in the Northern Hemisphere. No clearly defined events correspond with either the Namurian - Westphalian boundary in Europe or its coeval counterpart in North America. Instead, a progressive change in miospore population is recorded from the base of the Yeadonian Substage to the base of the Duckmantian Substage. Owens noted that the base of the Westphalian Stage is marked by a quantitative increase in representatives of the genus *Laevigatosporites*. *Cirratriradites saturni* also characterises the assemblages at this level. Owens also noted that the first stratigraphic appearances of *Schulzospora rara* and *Radiizonates aligerens* characterise middle Langsettian age assemblages in the Northern Hemisphere with representatives of the genus *Vestispora* starting to play an important role in Langsettian assemblages.

Owens (1996) indicated that *Torispora* generally appears at the base of the Bolsovian Substage in the Northern Hemisphere, with minor variations in the precise level occurring between regions. In Eastern Canada, *Torispora* is the diagnostic genus of the Bolsovian age *Torispora* Zone B of Barss and Hacquebard (1967). The range bases of *Torispora laevigata* and *T. securis* are recorded at the biozone lower limit (figure 2.11).

Owens (1996) also noted a diversification of monolete miospores near the base of the Asturian in the Northern Hemisphere. *Thymospora* and *Spinosporites* become quantitatively significant and representatives of *Laevigatosporites, Punctatosporites* and *Torispora* are commonly encountered. Taxa also become progressively extinct; e.g. *Dictyotriletes bireticulatus*, *Grumosisporites varioreticulatus*, or become rare e.g. *Cirratriradites saturni, Florinites junior* and *Microreticulatisporites nobilis*. Owens noted that this progressive change is recorded in Western Europe, with comparable changes in the Illinois Coal Basin, U.S.A, the Polish Coal Basins and the Donets Basin of Russia. The Asturian age *Thymospora* Zone C of Eastern Canada is also defined by the first appearance of species belonging to the genus *Thymospora* (Barss and Hacquebard 1967).

In assemblages from the Stephanian A and B of Western Europe, monosaccate pollen predominate (Owens 1996). In Eastern Canada, representatives of *Potonieisporites* define the Stephanian age *Potonieisporites* Zone of Barss and Hacquebard (1967). Also in Western Europe, the first stratigraphic occurrences of the non-saccate striate pollen *Vittatina* are recorded in the upper Barruelian to Stephanian B age *Angulisporites splendidus – Latensina trileta* (ST) Biozone of Clayton *et al.* (1977) (figure 2.2).

CHAPTER 3

SAMPLE COLLECTION, EXISTING DATASETS AND SAMPLE PREPARATION

In the present study, the majority of samples processed were in the form of cuttings with a small number from sidewall core or core. Samples were processed for palynological, palynofacies and stable isotope analysis. Palynological slides from previous studies (notably Robeson 1988) were also used for palynological and palynofacies analysis.

3.1 SAMPLE COLLECTION

Unwashed cuttings were sampled at the Petroleum Affairs Division (PAD) Sample Store, in Sandyford, Dublin. Carboniferous age sidewall core and core samples from the study wells were requested, but stocks were depleted. Lithologies sampled for palynological and palynofacies analysis mainly comprised shales, siltstones and mudstones. Coal horizons were also sampled for palynological analysis. Carbonate horizons were sampled for use in stable isotope analysis. Sidewall core and core from wells 26/28-1 and 26/28-2, held in the Former British Petroleum Microfossil Collection, were sampled at the Natural History Museum, London. Unfortunately the stocks of sidewall core and core from many of the depths of interest were depleted. Sidewall core from well 12/2-1z was sampled at SLR Consulting Ireland, in Dublin.

3.2 EXISTING SLIDES AND REPORTS

Palynological slides from previous studies were derived from three sources (see Appendix IV);

- The Geological Museum, Trinity College Dublin.
- PAD Sample Store, Dublin.
- Millennia Limited Stratigraphic Consultants.

Palynological and biostratigraphic reports were provided by PAD, BP, Chevron UK and Millennia Limited Stratigraphic Consultants. Composite logs, geological, engineering, thermal maturity and end of well reports were provided by PAD.

3.3 SAMPLE PREPARATION

3.3.1 Palynological analysis

3.3.1.1 Siliciclastic samples

Unwashed cuttings samples were initially washed in a 200µm brass sieve using warm water and detergent to remove any drilling mud present. Sidewall core or core samples were rinsed using warm water and detergent. Samples were dried overnight in an oven at 50°C. Rock fragments over 1cm in size were subsequently crushed into smaller fragments to increase the surface area for processing.

Approximately 50-100g of rock fragments from each sample were placed into sterile, labelled, 600ml polythene containers. Samples were rinsed with water to remove any fine dust from the containers as dust can cause vigorous reactions when the sample is mixed with acid. Approximately 75ml of cold 32% hydrochloric acid (HCl) was slowly added to each sample to dissolve any carbonate present. If a strong reaction occurred, the sample was diluted with water and left to settle. Samples were left for 24 hours to ensure that any carbonate present had fully broken down. Excess HCl was subsequently decanted, the sample topped with water and allowed to settle before being decanted again.

To remove all silicates present, approximately 75ml of 60% hydrofluoric acid (HF) was initially added to each sample. In the event of a vigorous reaction, water was added to the sample. The sample containers were placed into a 30°C water bath, inside a fume cupboard. After 24 hours, a further 200ml of HF was added to each sample. Samples were stirred between one and two times per day and all silicate minerals were deemed to have completely broken down when the sample was smooth during stirring. This usually took between 7 and 14 days.

Once the silicates in the samples had broken down, the spent HF was decanted off and the sample container filled with water. The sample was left for 24 hours to settle before a second decant. Samples were decanted and topped up with water at least six times until neutral. The organic residue was then sieved, using a 20µm nylon mesh to remove very fine mineral and organic matter. A small amount of the residue collected in the sieve was pipetted onto a glass slide and examined under a transmitted light microscope to confirm the presence of palynomorphs and to determine if oxidation was necessary.

The sieved residue was then placed into a pyrex beaker with approximately 75ml of HCl and brought to a simmer using a Bunsen burner in order to remove fluorite crystals that may have formed during processing. The sample was then diluted in a 1 litre beaker of water and sieved using a 20µm nylon mesh. The residue was placed into a glass vial with a few drops of 'Cellusize' dispersal agent then pipetted onto glass cover slips and left to dry for between 24 and 48 hours. The cover slips were subsequently mounted onto microscope slides using 'Elvacite' mounting medium and the unoxidised sample slides were labelled.

Oxidation was necessary for almost all samples in order to lighten dark palynomorphs for microscopy. Most samples were oxidised using 65% nitric acid (HNO_3). Sieved samples were placed into pyrex beakers with approximately 75ml of nitric acid. Oxidation times typically ranged from 15 minutes to 40 minutes depending on the maturity of the sample. After oxidation, samples were diluted in a 1 litre beaker of water, sieved using a 20µm nylon mesh, pipetted onto cover slips and mounted onto labelled microscope slides. A few samples that showed high levels of carbonisation were left in HNO_3 for up to 48 hours. If the spores were still too dark, the oxidation procedure was repeated using 75ml of fuming nitric acid. Oxidation times ranged from 20 to 40 minutes.

Any remaining unoxidised residue was saved as stock.

3.3.1.2 Coal samples

Coal fragments were picked from washed and dried cuttings samples using a binocular microscope. Coal fragments were crushed to approximately 1mm size fragments using a pestel and mortar. Approximately 1g of the crushed coal fragments were placed into a sintered glass Büchner funnel, firmly attached to a Büchner flask using a bung. Approximately 50ml of fuming nitric acid was added to the sample and the coals left to oxidise for between 45 minutes and 2 hours. The sample was subsequently vacuum filtered using a pump attached to the Büchner funnel with water added to the sample to neutralise it. The neutralised sample was subsequently sieved using a 20µm nylon mesh, pipetted onto cover slips and left to dry before being mounted onto labelled microscope slides.

3.3.2 Palynofacies analysis

Microscope slides of unoxidised organic residue that had been gently boiled in HCl and sieved using a 20µm mesh (section 3.3.1.1) were used for palynofacies analysis (chapter 8). Existing unoxidised organic residue slides from the Ph.D. thesis of Robeson (1988) were also analysed. It is noted that Robeson followed the same method of processing unoxidised samples as the present study. See section 8.6 for a detailed methodology regarding quantitative palynofacies analysis.

3.3.3 Stable isotope analysis

The $\delta^{13}C$ and $\delta^{18}O$ composition of carbonate fragments picked from a selection of cuttings samples were analysed using mass spectrometry. See section 9.5 for a detailed methodology regarding sample preparation and mass spectrometry.

3.4 TRANSMITTED LIGHT AND FLUORESCENCE MICROSCOPY

A Leitz 'Wetzlar Dialux' transmitted light microscope was used for the examination of organic residue slides for palynology and palynofacies. Photographs were taken for reference and for quantitative palynofacies analysis using a Nikon Coolpix digital camera attached to the microscope. Plate quality photographs were taken using a

Nikon DXM1200 digital camera attached to a Nikon Eclipse E600 microscope and Nikon Act-1 software.

A Leitz 'Wetzlar Dialux 20' transmitted light microscope with attached incident fluorescent light tube was used for fluorescence microscopy. Only unoxidised slides were analysed as oxidation can affect the fluorescence of organic matter.

3.5 CURATION OF SAMPLE MATERIAL

All slides that were prepared and used in the present study are curated in the Geological Museum, Department of Geology, Trinity College, Dublin. Slides are labelled with a TCD museum number for curatorial purposes (Appendix V).

3.6 PRESENTATION OF DATA

Cuttings from some wells sections are recorded as being sampled over depth intervals (e.g. 3m/10' intervals in well 36/16-1). In Chapter 6 and Appendix VII, which concern palynostratigraphic reinterpretations, the samples are referred to by the shallowest depth in the interval, unless specified otherwise (e.g. 3800' in the sample interval 3800-3810'). This is mainly for simplicity and follows the practice of previous researchers such as Robeson (1988). In later chapters concerning palynofacies analysis and isotope analysis of carbonates, the full depth intervals are used (chapters 8 and 9).

CHAPTER 4
TERMINOLOGY

4.1 MORPHOLOGICAL TERMINOLOGY FOR SPORES

Spores are described in terms of their shape, symmetry, haptotypic features (i.e. tetrad mark), ornamentation, wall layering and size. The morphological terminology for spores used in the present study is derived from Punt *et al.* (2007), Playford and Dettman (1996), Grebe (1971), Smith and Butterworth (1967) and Neves and Owens (1966).

4.1.1 Haptotypic features

Spores form in tetrads within the plant sporangium. A tetrad refers to a group of four united spore (or pollen) grains (Punt *et al.* 2007). In tetrahedral tetrads, each spore is in contact with three neighbours (Grebe 1971). As a result, the proximal face of each spore shows three contact areas delimited by a three-rayed tetrad mark. The spores are typically radiosymmetrical in polar view (figure 4.1a-c). Spores from tetragonal tetrads are only in contact with two other spores. As a result, they show two contact areas delimited by a single tetrad mark. The spores are typically ellipsoidal or bean-shaped (figure 4.1d-g). The tetrad marks are usually associated with dehiscence slits or apertures (laesurae), which serve as germinal openings (Playford and Dettman 1996). Monolete spores possess one laesurae and trilete spores bear three laesurae (figure 4.1b,e) (Punt *et al.* 2007). The character, length and any associated features such as curvaturae and labrae are key features of the tetrad mark. Spores may possess a hilum - a circular, indistinctly delimited, irregular aperture or thinning (Punt *et al.* 2007). Such spores are termed hilate (Playford and Dettman 1996). Spores that lack laesurae are termed alete (Punt *et al*. 2007).

4.1.2 Shape

The equatorial outline of a spore in polar view is referred to as the ‘amb’. In tetrahedral spores, the amb may be circular, subcircular, triangular, convexly subtriangular or concavely subtriangular. Triangular amb apices may be rounded or pointed. As indicated in section 4.1.1, tetragonal spores are typically ellipsoidal or bean shaped (figure 4.2) (Playford and Dettman 1996).

4.1.3 Structure

The exine is the resistant layer of the spore wall (sporoderm), which is usually preserved in fossilised spores (Traverse 1988). It may be stratified into two layers; the intexine and exoexine (Playford and Dettmann 1996). The term 'camerate' was originally defined by Neves and Owens (1966) to describe spores in which the intexine and exoexine are separated by a chamber (camera) (figure 4.3c-e). Some workers, e.g. Dettmann (1963), Smith and Butterworth (1967), used the term 'cavate' instead of camerate. However, Neves and Owens rejected the term cavate as the original definition (Faegri and Iversen 1950, p.160) was used to describe the separation of exine layers in pollen grains, i.e. the separation of the bladder like sac from the main pollen body. Residual columellae that remain attached to the underside of the outer exine layer give an infrareticulate structure to the pollen grain sacci. Camerate spores do not possess such structure (Neves and Owens 1966). In acamerate spores, the layers are in continuous contact (Playford and Dettman 1996) (figure 4.3a-b).

The exine (or exoexine in camerate spores) may be thickened or extended equatorially, proximally or distally. A continuous, equatorial, rounded thickening is known as a cingulum (figure 4.3b-c). A zona comprises a continuous, equatorial, usually membraneous extension of the exoexine that thins equatorially (figure 4.3d). Spores with an equatorial feature that shows an inner thickened part and an outer membraneous part are termed cingulizonate (figure 4.3e) (Playford and Dettman 1996).

In trilete spores, non-continuous equatorial modifications of the three radial regions include smooth, uniform thickenings called valvae and fluted thickenings called auriculae (figure 4.3f-g). A kyrtome is an arcuate fold or linear thickening in the angle formed by the laesurae (figure 4.3j). Interradial areas may be characterised by a series of fimbriate projections known as a corona or by a uniform thickening or extension of the exine or exoexine, known as an interradial crassitude (figure 4.3h-i). Spores with a patina show a thickening of the sporoderm in one hemisphere (figure 4.3l) (Playford and Dettmann 1996).

4.1.4 Ornamentation

The external surface of the sporoderm or its individual layers may be smooth (laevigate) or show ornamentation (sculpture). Unbranched, positive projections can be non-pointed (e.g. bacula, grana, pila, verrucae) or pointed (e.g. spinae and coni). Negative (indenting) ornamentation includes vermiculi and foveolae. Elevations of the general surface can form a reticulate pattern comprising muri (the elevations) and lumina (the depressions between muri). Elevations of the general surface that leave no regular reticulate pattern of lumina between them include rugulae, cristae and costae (Smith and Butterworth 1967) (figures 4.4, 4.5).

4.1.5 Size

The term ‘miospore’ was introduced by Guennel (1952) to embrace small spores and pollen less than 200µm in diameter. Spores greater than 200µm are classed as megaspores (Playford and Dettmann 1996).

4.2 MORPHOLOGICAL TERMINOLOGY FOR POLLEN

Key morphological features of gymnosperm pollen that aid identification include the presence or absence of sacci, striations and tetrad marks. In the present study, the pollen terminology of Traverse (1988) and Punt *et al.* (2007) is followed.

4.2.1 Structure

The exine of pollen usually comprises two layers. The present study follows the terminology of Punt *et al.* (2007) in describing the inner layer as the intexine and the outer layer as the exoexine.

4.2.2 Sacci

Saccate pollen grains possess at least one saccus; an expanded, bladdery projection of the exoexine extending beyond the main body of the pollen grain (Traverse 1988). A true saccus is characterised by a complex internal structure. Monosaccate pollen possess a single saccus (e.g. *Florinites* and *Potonieisporites*) (figure 4.6b). Bisaccate (disaccate) pollen possess two sacci (e.g. *Pityosporites*) (Traverse 1988) (figure 4.6c).

In pseudosaccate spores, such as *Alatisporites* and *Endosporites,* the apparent sacci resemble the true sacci of pollen grains, but lack the complex internal structure. They instead represent extensions of the camerate (cavate) condition in which “the space between the two layers of exine balloons out to produce vesicles” (Traverse 1988) (figure 4.6a).

4.2.3 Striations, colpi and tetrad marks

The central body of saccate pollen grains may show a distinctive striate or ‘streaked’ appearance that is produced by deep parallel grooves (striae) and/or parallel straps of exine (taeniae), e.g. *Protohaploxypinus* (figure 4.7). Non-saccate striate pollen include *Vittatina* (Traverse 1988).

Colpi are elongated apertures with a length/breadth ratio greater than two (Punt *et al.* 2007) and are associated with germination (Traverse 1988). Monocolpate pollen grains bear a single, normally distal colpus. As a distal aperture that does not cross the equator is technically a sulcus, the term monosulcate is often used (Traverse 1988) (figure 4.8).

Gymnosperm pollen may also show a trilete tetrad scar (e.g. *Latensina*) or a monolete tetrad scar (e.g. *Potonieisporites*). Pollen grains that possess the haptotypic characteristics of spores and germinated proximally are termed prepollen (Traverse 1988).

CHAPTER 5
SYSTEMATIC PALYNOLOGY

5.1 NOMENCLATURE AND CLASSIFICATION OF MIOSPORES

Since the botanical affinities of most Palaeozoic miospores are yet unknown, their classification in the present study is based purely on morphology. The naming of miospore taxa is subject to the rules of priority and typification laid down in the International Code of Botanical Nomenclature (ICBN) (McNeill *et al.* 2007). The ICBN recognises the use of form-genera and form-species to describe the dissociated parts of fossil plants (i.e. dispersed spores and pollen, roots, leaves, fructifications, etc) (Playford and Dettmann 1996).

At a suprageneric level, where the rules of the ICBN do not apply, the turmal system of Robert Potonié, as outlined in seven volumes of *Synopsis der Gattungen der Sporae dispersae* (1956-1975), has been widely adopted (Traverse 1988). The largest unit in the system is the anteturma. Potonié set up the anteturma Sporites for spores and the anteturma Pollenites for pollen (figures 5.1 and 5.2). A series of smaller units within the system (e.g. turma, subturma and infraturma) are based on morphological features (Traverse 1988). Various modifications to the classification scheme have been proposed by a number of authors (see below).

5.2 ANTETURMA SPORITES

Several modified versions of Potonié's classification scheme for the anteturma Sporites have been proposed (e.g. Dettmann 1963; Neves and Owens 1966; Smith and Butterworth 1967). The present study follows the suprageneric classification used by McLean (1993). The scheme follows Dettmann (1963) as modified by Neves and Owens (1966) and incorporates several more recent modifications or suggested modifications (see McLean 1993) (figure 5.1).

Based on Neves and Owens (1966), separation of turma Triletes into suprasubturma 'Acameratitriletes' and 'Cameratitriletes' is based on the presence or absence of exine layer separation. As outlined in section 4.1.3, Neves and Owens rejected the term ‘cavate’ used by Dettman (1963) in favour of ‘camerate’ to describe spores in which separation of exoexine and intexine occurs. Subdivision of suprasubturma Cameratitriletes into subturmas Solutitriletes and Membranatitriletes is based on the degree of cameration, reflecting the nature of attachment of the intexine and exoexine. The presence or absence of sculptural elements defines the infraturma of Solutitriletes. Infraturma of Membranatitriletes are based on the nature of exoxine equatorial extension. Further subdivision of suprasubturma Acameratitriletes into subturmas Azonotriletes and Zonotriletes is based on the presence or absence of equatorial features. Infraturma of the former reflect the sculptural elements present. The nature of the equatorial extension defines infraturma of the latter (Neves and Owens 1966).

Following the scheme of Neves and Owens (1966), monolete spores are assigned to the turma Monoletes, while hilate spores are assigned to the turma Hilates. McLean (1993) further subdivided the turmas based on suggested modifications from unpublished Ph.D. studies (see McLean 1993).

5.3 ANTETURMA POLLENITES

For the anteturma Pollenites, the suprageneric classification scheme outlined in Traverse (1988) is followed (figure 5.2). Traverse based the scheme on the system of Robert Potonié, as outlined in the volumes of *Synopsis der Gattungen der Sporae dispersae* (1956-1975). Pollen with one or more sacci are assigned to the turma Saccites. Pollen with one or more colpi or colpi-like structures are assigned to the turma Plicates. Subturmas are based on the number of sacci or colpi present. Infraturmas under Saccites are based on haptotypic features (Traverse 1988). Traverse also indicates that infraturmas under Plicates are rarely used.

For a systematic account of miospores from the present study, see Appendix VI. Plates are located in Appendix X.

CHAPTER 6

REVISED PALYNOSTRATIGRAPHY OF OFFSHORE WESTERN IRELAND AND COMPARISON WITH OTHER LOCALITIES

6.1 INTRODUCTION

This chapter outlines the applicability of the Western European miospore zonal scheme of Clayton *et al*. (2003) to the Carboniferous of offshore western Ireland. As the zonal scheme does not include biozones younger than Cantabrian in age, the applicability of Stephanian to lower Autunian age biozones of Clayton *et al.* (1977) is also indicated.

Detailed revised palynostratigraphic interpretations for the 19 well sections are provided in Appendix VII. Interpretations based on the zonal scheme of Clayton *et al.* (2003) in addition to the 1977 zonal scheme are given. Palynological occurrence charts for each well are shown in figures 6.1 to 6.19. A summary correlation chart of the revised palynostratigraphic interpretations is shown in figure 6.20.

6.2 REVISED PALYNOSTRATIGRAPHY OF OFFSHORE WESTERN IRELAND AND COMPARISON WITH OTHER LOCALITIES

6.2.1. *Vittatina costabilis* Biozone (lower Autunian) and *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone (upper Stephanian B to top Stephanian C) (Clayton *et al.* 1977)

The lower Autunian age *Vittatina costabilis* (VC) Biozone of Clayton *et al.* (1977) is tentatively recorded in wells 34/15-1 and 12/2-1z. In both wells, the biozone lower limit is marked by the transition from a mixed spore and monosaccate pollen assemblage to an assemblage dominated by monosaccate pollen, notably *Potonieisporites*. The lower limit is also marked by the last stratigraphic occurrence of *Endosporites globiformis*. Peppers (1985) indicated that the range top of the taxon does not extend past the Stephanian Stage in Western Europe. The first stratigraphic occurrence of *Cordaitina* additionally characterises the intervals assigned to the biozone. However, in contrast to the VC Biozone of Clayton *et al.*, *Vittatina* is absent from the intervals assigned to the biozone. Other taxa that should characterise the biozone, but are absent offshore western Ireland, include *Lycospora* spp., *Laevigatosporites* spp., *Punctatosporites* spp., *Thymospora* spp., *Spinosporites spinosus* and *Florinites* spp. As a result, the VC Biozone is only tentatively identified in wells 12/2-1z and 34/15-1.

The upper Stephanian B to top Stephanian C age *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone of Clayton *et al.* (1977) is tentatively assigned to the lowest 472'/144m of strata in 12/2-1z (see Appendix VII.I, interpretation 1) and the lowermost 349'/106m of strata in 34/15-1. There is significant uncertainty regarding the age of the interval in 12/2-1z (Appendix VII.I). The base of the biozone has not been recorded in the present study.

The interval assigned to the NBM Biozone in 12/2-1z is characterised by a mixed assemblage of spores, monosaccate and bisaccate pollen. The last stratigraphic occurrence of *Crassispora kosankei* is recorded in the interval assigned to the biozone, reflecting the range given in Clayton *et al.* (1977). The authors additionally recorded common occurrences of *Lycospora* spp. throughout the NBM Biozone, very rare occurrences in the VC Biozone and the range top at the VC Biozone upper limit (figure 2.2). In 12/2-1z, common occurrences of *L. pusilla* are recorded in the interval assigned to the NBM Biozone, but the last stratigraphic occurrence of the genus is recorded 148'/45m below the NBM/VC Biozone boundary. It is possible that the early disappearance of *Lycospora* spp. reflects proximity to the biozone boundary and the associated reduction in abundance of the genus. Alternatively, it is possible that the disappearance reflects the development of unsuitable environmental conditions for the parent plant.

The interval assigned to the NBM Biozone in 12/2-1z is also characterised by occurrences of *Potonieisporites* spp., *Disaccites* non *striatiti*, *Lundbladispora gigantea*, *Florinites* spp., *Laevigatosporites* spp. and *Triquitrites* spp., with rare occurrences of *Vittatina* spp. *Spinosporites spinosus*, *Thymospora* spp., *Disaccites striatiti* and *Latensina trileta*. The assemblage is typical of the NBM Biozone recorded by Clayton *et al.* (1977). The absence of *Vestispora fenestrata* also confirms a biozone no older than the NBM Biozone. However, the additional occurrence of spores that possess Bolsovian age range tops in Western Europe i.e. *Calamospora breviradiata* results in uncertainty regarding the age of the interval (see Appendix VII.I).

As in 12/2-1z, the interval tentatively assigned to the NBM Biozone in 34/15-1 is characterised by a mixed assemblage of monosaccate pollen and trilete spores (although with a considerably less diverse spore content). The assemblage predominantly comprises representatives of *Potonieisporites* spp., *Endosporites* sp. *globiformis, Nuskoisporites* spp*., Lycospora* spp., *Florinites* spp. and *Triquitrites* spp. Rare occurrences of *Calamospora* spp., *Cyclogranisporites* spp. and *Cadiospor*a spp. are also recorded. The absence of *Vestispora fenestrata* confirms a biozone no older than the NBM Biozone. An absence of *Crassispora kosankei* suggests that only the upper part of the NBM Biozone is encountered. As in 12/2-1z, the NBM/VC Biozone boundary is marked by the transition to a monosaccate pollen dominated assemblage and the last stratigraphic occurrence of *E.* sp. *globiformis.* Although common occurrences of *Lycospora* spp. are recorded in the interval assigned to the NBM Biozone, the genus is absent from the uppermost 115'/35m. As in 12/2-1z, this could reflect proximity to the NBM/VC Biozone boundary or a transition to unsuitable environmental conditions for the parent plant. A number of species that characterise the NBM Biozone in Clayton *et al.* (1977) are not recorded in the 34/15-1 well, notably *Laevigatosporites* spp., *Spinosporites spinosus, Thymospora* spp., *Cheleidonites* spp. and *Angulisporites splendidus*. In this respect, the interval in 34/15-1 shows similarities with the younger VC Biozone.

Comparison with other localities

Western Europe

Clayton *et al.* (1977) assigned miospore assemblages from the Schistes d'Igornay, Autun, France to the NBM Biozone. In shales from the locality, Bouroz and Doubinger (1977) recorded an assemblage dominated by monolete and trilete spores (87%), with *Vittatina* spp. accounting for just 1% of the content. In addition, Clayton *et al.* (1977) assigned assemblages from the Assise de Muse, Autun, France to the VC Biozone. In shales from the locality, Bouroz and Doubinger recorded an assemblage dominated by monosaccate pollen (up to 75%), with 8% monolete and trilete spores. Representatives of *Vittatina* comprised just 2% of the assemblage. The assemblage assigned to the NBM Biozone in 12/2-1z resembles that of the Schistes d'Igornay in terms of the mixed monosaccate pollen and spore content. The lower spore content of the interval assigned to the NBM Biozone in 34/15-1 suggests the composition lies in between that of the Schistes d'Igornay and the Assise de Muse.

The assemblages assigned to the VC Biozone in wells 12/2-1z and 34/15-1 and those from the Assise de Muse are similar with regards to the dominance of monosaccate pollen. However, the assemblages from offshore western Ireland differ with regards to the lack of *Vittatina* spp.

Based on palynological data from various Western European localities, Coquel *et al.* (1976) introduced the upper Stephanian age Zone VI and lower Autunian age Zone VII (figure 2.1). The lower limit of Zone VI is marked by the development of *Potonieisporites* spp., *Cheleidonites* spp. and the range top of *Vestispora fenestrata.* The range tops of *Crassispora kosankei* and *Westphalensisporites irregularis* mark the middle of the zone. Only very rare occurrences of *Vittatina* spp. are recorded in Zone VI. The range tops of *Raistrickia* spp., *Densosporites* spp., *Verrucosisporites pergranulus*, *Savitrisporites camptotus* and a decrease in abundance of *Thymospora* spp. mark the base of Zone VII. Within Zone VII, occurrences of *Vittatina* spp. become more frequent and the range tops of *Angulisporites splendidus*, *Polymorphisporites* spp., *Torispora* spp. and *Spinosporites spinosus* are recorded. *Lycospora* spp. declines in abundance in the upper part of Zone VI, becoming very rare in Zone VII. The range top is recorded at the upper limit of Zone VII. Both zones are characterised by the common occurrence of *Potonieisporites* spp. and *Florinites* spp. with the maximum development of *Potonieisporites* spp. in Zone VII.

The interval assigned to the NBM Biozone in well 12/2-1z shows a number of characteristics of Zone VI. The last stratigraphic occurrence of *Crassispora kosankei*, recorded within the interval, potentially represents the middle of Zone VI. The occurrences of *Potonieisporites* spp., *Florinites* spp. and rarity of *Vittatina* spp. are also characteristic of the zone. The presence of *Raistrickia* spp. throughout the interval suggests a biozone no younger than Zone VI. However, the last stratigraphic occurrence of *Lycospora* spp., which is also recorded in the interval, is a characteristic of Zone VII. In 34/15-1, the interval assigned to the upper NBM Biozone shows characteristics of the uppermost Zone VI, notably the presence of *Potonieisporites* spp., *Florinites* spp. and the absence of *Crassispora kosankei.* The absence of *Vittatina* is also characteristic of Zone VI, although the absence of *Spinosporites* spp., *Torispora* spp. and the dissappearance of *Lycospora* spp. is more characteristic of Zone VII.

The intervals tentatively assigned to the VC Biozone in 12/2-1z and 34/15-1 are similar to Zone VII in terms of the presence of *Potonieisporites* spp., but contrast with regards to the absence of *Vittatina* spp.

South-western Poland

Jerzykiewicz (1987) recorded a late Stephanian assemblage from the Intrasudetic Basin, south-western Poland comprising 42% monolete and 8% trilete spores with 46% monosaccate and 4% disaccate pollen grains. The assemblage was characterised by representatives of *Wilsonites, Florinites, Nuskiosporites, Guthoerlisporites, Cordaitina* and specimens of *Potonieisporites novicus, Endosporites globiformis Laevigatosporites perminutus, Spinosporites spinosus* and *Thymospora thiessenii*. Jerzykiewicz noted an absence of *Vittatina* and *Cheleidonites* although the presence or absence of *Lycospora* was not recorded. The Polish assemblage shows some similarities with the interval assigned to the NBM Biozone in the 12/2-1z well, notably the presence of *Spinosporites*, *Thymospora*, *E. globiformis*, *Potonieisporites, Florinites* and a rarity of *Vittatina*. The interval assigned to the upper NBM Biozone in 34/15-1 differs from the Polish assemblage with regards to its lack of monolete spores.

Jerzykiewicz (1987) also recorded an early Autunian assemblage from the Intrasudetic Basin. The assemblage was dominated by specimens of *Potonieisporites*, which represented up to 40% of the palynomorph content. Minor occurrences of *Cordaitina, Florinites, Candidispora, Wilsonites, Guthoerlisporites* and *Nuskoisporites* were noted. The first stratigraphic occurrences of *Vittatina, Pityosporties, Vesicaspora* and *Limitisporites* were also recorded, accounting for approximatley 10% of the assemblage. The assemblages tentatively assigned to the VC Biozone in wells 12/2-1z and 34/15-1 are similar to the early Autunian assemblage from the Intrasudetic Basin with regards to the presence of *Potonieisporites* spp. and *Cordaitina* spp. However, the absence of *Vittatina, Pityosporties, Vesicaspora* and *Limitisporites* in the offshore western Irish assemblages is a key difference. It is noted that the assemblages assigned to the NBM Biozone in well 34/15-1 also shows similarites with the lower Autunian assemblages from south-western Poland, notably the presence of *Potonieisporites, Florinites* and *Nuskoisporites*. However the 34/15-1 assemblage lacks *Vittatina, Pityosporties, Vesicaspora* and *Limitisporites.* Overall, the assemblage shows characteristics of both Stephanian and lower Autunian assemblages from south-western Poland.

Ukraine

In the Donets Basin, Ukraine, Inosova (1976) recorded an abrupt reduction in the abundance of *Lycospora* spp. from the lower Stephanian A with rare occurrences of *L. pusilla* (in isolation and up to 3%) recorded from the mid Stephanian A to the lower Autunian. A brief increase in frequency is recorded in the Autunian, before occurrences reduce again to ‘sporadically in isolation’. Rare occurrences or ‘sporadic occurrences in isolation’ of *Vittatina* spp. are also recorded from the base Stephanian into the lower Autunian, before increasing in frequency within the Autunian. *Endosporites* spp. are recorded ‘sporadically more than 10%’ from the base Stephanian to the mid Stephanian C. Occurrences reduce to ‘sporadically in isolation and up to 3%’ from the mid Stephanian C into the lowermost Autunian, and very rare occurrences are recorded until the range top within the Autunian. Overall the ranges of *Endosporites* spp. *Lycospora pusilla* and *Vittatina* spp. recorded in the Donets Basin contrast with the ranges recorded offshore western Ireland.

Eastern Canada

In Eastern Canada, Barss and Haquebard (1967) assigned the *Potonieisporites* Zone D to Stephanian age strata and the *Vittatina* Zone E to Lower Permian (?Autunian) age strata from the Pictou Group (figures 2.8, 2.9 and 2.11). The biozones were named after the most characteristic genus present (Barss and Hacquebard 1967). The

Vittatina Zone E corresponds to the VC Biozone and the *Potonieisporites* Zone corresponds in part to the NBM Biozone (figure 2.10).

Occurrences of *Potonieisporites* characterise assemblages assigned to the NBM Biozone in 12/2-1z and 34/15-1 in addition to the *Potonieisporites* Zone of Eastern Canada. Barss and Hacquebard (1967) recorded the range base of *P.* cf. *novicus* at the base of the *Potonieisporites* Zone (figure 2.11). In well 12/2-1z, occurrences of *P. novicus* are recorded in the interval assigned to the NBM Biozone. However, occurrences of *P.* cf. *novicus* are restricted to the VC Biozone. In 34/15-1, occurrences of *P. novicus* are restricted to the interval assigned to the VC Biozone. Offshore Eastern Canada, Barss *et al.* (1979) recorded the *Potonieisporites* Zone in wells Bradelle L-49, Tyrone no. 1, Green Gables no. 1, and East Point E-49 from the Gulf of St. Lawrence. The biozone was also recorded in the North Sydney P-05 well from the Sydney Basin, offshore Nova Scotia (figure 10.9). The miospore assemblage assigned to the NBM Biozone in 12/2-1z shows similarities with that assigned to the *Potonieisporites* Biozone in the North Sydney P-05 well. Taxa recorded in both wells include *Apiculatasporites latigranifer, Cadiospora magna, Calamospora breviradiata, C. pallida, C. pedata, C. microrugosa, Endosporites globiformis, E. zonalis, Florinites mediapudens, F. junior, F. pumicosus, F. similis, Leiotriletes sphaerotriangularis, Lycospora pusilla, Potonieisporites novicus, Punctatosporites minutus, Raistrickia aculeata, R. saetosa, Triquitrites bransonii, T. spinosus*, and *Verrucosisporites donarii.* Range data from Butterworth (1984) and Smith and Butterworth (1967) suggests the range tops of species such as *C. breviradiata, L. sphaeotriangularis* and *C. microrugosa* are restricted to the mid Bolsovian in Western Europe. The presence of the taxa in both 12/2-1z and P-05 wells either suggests the ranges extend into the late Stephanian of offshore western Ireland and offshore Eastern Canada or that the taxa are reworked in both localities.

The miospore assemblage recorded in the *Potonieisporites* Zone of offshore Eastern Canada is typically more diverse than the assemblage assigned to the NBM Biozone in 34/15-1. The taxa recorded in the 34/15-1 well are generally present in the Canadian well sections, but additional spores typically characterise the Canadian assemblages, as seen in the North Sydney P-05 well.

The assemblages tentatively assigned to the VC Biozone in 12/2-1z and 34/15-1, contrast with the equivalent age *Vittatina* Zone of Barss and Hacquebard (1967) with regards to the absence of *Vittatina*. However, it is noted that the first stratigraphic appearance of *Cordaitina,* recorded at the base of the intervals assigned to the VC Biozone in 12/2-1z and 34/15-1, also marks the base of the *Vittatina* Zone of Eastern Canada (figure 2.11).

6.2.2. *Thymospora pseudothiessenii* Biozone (upper Bolsovian to Cantabrian)

Offshore western Ireland, the *Thymospora pseudothiessenii* Biozone of Clayton *et al.* (2003) is encountered in wells 36/16-1, 34/5-1, 26/27-1b, 13/3-1, 26/28-1, 26/28-2, 26/28-3 and 26/28-4. The biozone lower limit is recorded in 36/16-1, 34/5-1, 26/28-1, 26/28-2, 26/28-4a and possibly in 26/27-1b. Intervals assigned to the biozone are characterised by occurrences of the index taxon. The range base of *T. pseudothiessenii* should define the biozone lower limit (figure 2.7). However, the first stratigraphic occurrences of the index taxon are commonly recorded in cuttings samples and are often caved. As sidewall core is scarce, additional taxa are required to assist the positioning of the biozone lower limit.

The range top of *Dictyotriletes bireticulatus* provides a rough approximation for the *Thymospora pseudothiessenii* Biozone lower limit. The range top of the taxon defines the lower limit of the equivalent North Sea W7 Biozone (McLean *et al.* 2005) and marks the lower part of the equivalent Western European *Thymospora obscura – Thymospora thiessenii* (OT) Biozone of Clayton *et al.* (1977) (figures 2.1, 2.2 and 2.5). However, at this stratigraphic level offshore western Ireland, occurrences are rare. In 36/16-1, the last stratigraphic occurrence is recorded in the same cuttings sample as the first stratigraphic occurrence of *T. pseudothiessenii*. In 26/28-4a, the sole occurrence of the taxon is recorded in the same sidewall core sample as the sole occurrence of *T.* sp. aff. *pseudothiessenii*. In 34/5-1, the last stratigraphic occurrence is recorded 281’/88.8m above the biozone lower limit, defined by the first stratigraphic occurrence in sidewall core of *Spinosporites* spp. (see below). In 26/28-2, the taxon is recorded in a single sample, 85’/26m below the lower limit of the biozone, constrained by the last stratigraphic occurrence of *Radiizonates faunus* (see below). The taxon is absent from wells 26/28-1 and 26/28-3.

The range tops of *Radiizonates tenuis*, *Radiizonates faunus* and possibly *Raistrickia fulva* may also roughly constrain the lower limit of the *Thymospora pseudothiessenii* Biozone offshore western Ireland. McLean *et al.* (2005) recorded the range tops of the taxa in the middle of the North Sea W6b Biozone, equivalent to the uppermost part of the *Vestispora fenestrata* Biozone of Clayton *et al.* (2003) (figure 2.5). Butterworth (1984) recorded the range tops of *R. faunus* and *R. tenuis* in the middle of the Bolsovian age *Torispora securis - Torispora laevigata* (SL) Biozone of Western Europe. Only rare occurrences are recorded offshore western Ireland at this stratigraphic level. In 26/28-4a, the last stratigraphic occurrences of *R. fulva* and *R. faunus* are recorded in the same core sample as the sole occurrences of *T.* sp. aff. *pseudothiessenii* and *Dictyotriletes bireticulatus*. *R.* cf. *tenuis* is recorded in a sample 11'/3.5m shallower. In 26/27-1b, the last stratigraphic occurrences of *R. tenuis, R. faunus* and *R. fulva* are recorded in the same sidewall core sample as the first stratigraphic occurrence of *T. pseudothiessenii*. In 26/28-2, the sole occurrence of *R. faunus* is recorded 85'/26m shallower than the sole occurrence of *D. bireticulatus,* tentatively constraining the biozone lower limit. In 26/28-3, the biozone lower limit is tentatively constrained by the sole occurrence of *R. tenuis* and the lower limit in 26/28-1 is constrained by the last stratigraphic occurrence of *R. fulva*. It is stressed that the taxa can only be used to tentatively constrain the base of the *T. pseudothiessenii* Biozone offshore western Ireland due to their rarity at this stratigraphic level. In addition, rare occurrences of *R. fulva* have been recorded in samples assigned to the Cantabrian in well 36/16-1 and the Asturian in 34/5-1, suggesting that occurrences are often reworked.

Evidence from offshore western Ireland suggests the range base of *Spinosporites* is restricted to the *Thymospora pseudothiessenii* Biozone. Clayton *et al.* (1977) recorded the range base of the genus at the lower limit of the equivalent OT Biozone in Western Europe. The genus is not included in the North Sea zonal scheme of McLean *et al.* (2005). Occurrences recorded in wells 13/3-1, 26/27-1b, 26/28-2, 26/28-1 and 36/16-1 are rare but restricted to the *T. pseudothiessenii* Biozone. In 26/27-1b, the first stratigraphic occurrence of the genus is recorded 192.8'/59m above the first stratigraphic occurrence of *T. pseudothiessenii* in sidewall core. In 34/5-1, due to a lack of *Thymospora* spp. in sidewall core, the first stratigraphic occurrence of

Spinosporites in sidewall core is used to constrain the lower limit of the biozone, recorded 291'/88.8m deeper than the last stratigraphic occurrence of *Dictyotriletes bireticulatus*. *Spinosporites* is absent from wells 26/28-3 and 26/28-4a.

There is uncertainty regarding the stratigraphic range of *Cadiospora magna* offshore western Ireland. Smith and Butterworth (1967) recorded the range base of the taxon within the *Thymospora obscura* (XI) Biozone of onshore Great Britain and Butterworth (1984) recorded the range base at the OT Biozone lower limit in north-western Europe. However, McLean *et al.* (2005) recorded sporadic occurrences of the taxon in the mid and early Bolsovian of the North Sea. In well 26/27-1b, the first stratigraphic occurrence is recorded 307.8'/94m above the lower limit of the *Thymospora pseudothiessenii* Biozone. Occurrences are also restricted to the biozone in wells 13/3-1, 34/5-1 and 26/28-4a, although the taxon is also recorded in cuttings samples deeper than the first stratigraphic occurrence of *T. pseudothiessenii* in wells 36/16-1 and 26/28-3. It is possible that the occurrences are caved. In 26/28-1, an occurrence in sidewall core is deeper than the last stratigraphic occurrence of *Raistrickia fulva*, which may constrain the lower limit of the *T. pseudothiessenii* Biozone. In 26/29-1, an occurrence of *C.* cf. *magna* in sidewall core is assigned to a possible *Vestispora fenestrata* Biozone, although the interpretation is based on very limited palynological data. Overall, it cannot be conclusively proven if the range base is restricted to the *T. pseudothiessenii* Biozone.

Results from offshore western Ireland indicate that *Cingulizonates loricatus* is consistently recorded in samples assigned to the lower and mid *Thymospora pseudothiessenii* Biozone and even in samples assigned to the Cantabrian age *Angulisporites splendidus* Sub-biozone. It is difficult to ascertain if the occurrences reflect the true stratigraphic range of the taxon or if specimens are reworked. McLean *et al.* (2005) recorded the range top of *C. loricatus* in proximity to the lower limit of the North Sea W7 Biozone and Clayton *et al.* (1977) recorded the range top in the lower part of the Western European OT Biozone (figures 2.2 and 2.5). Overall, data from this study suggests the last stratigraphic occurrence of the taxon is not suitable for defining the *T. pseudothiessenii* Biozone lower limit offshore western Ireland.

Occurrences of *Punctatosporites oculus* and *Mooreisporites* cf. *inusitatus* characterise samples assigned to the *Thymospora pseudothiessenii* Biozone offshore western Ireland. Butterworth (1984) indicated that the range bases of the taxa in north-western Europe are restricted to the OT Biozone of Clayton *et al.* (1977). The first stratigraphic occurrence of *P. oculus* in well 26/27-1b is recorded in the *T. pseudothiessenii* Biozone, 419.8'/128m above the lower limit. The taxon is recorded in cuttings samples assigned to the biozone in 13/3-1, 26/28-1, 26/28-2, 26/28-3 and 34/5-1. Occurrences are also recorded in cuttings samples assigned to older biozones, which may be caved. *M.* cf. *inusitatus* is recorded in the *T. pseudothiessenii* Biozone in 13/3-1, 26/28-1, 26/28-2, 26/28-4a, 34/5-1 and 36/16-1, although occurrences are often recorded in cuttings samples below the biozone lower limit. Due to the occurrences in cuttings samples assigned to older biozones, it cannot be conclusively proven that the range bases of both taxa are restricted to the *T. pseudothiessenii* Biozone.

Comparison with other localities

Western Europe, the North Sea, onshore Great Britain and Eastern Canada

The *Thymospora pseudothiessenii* Biozone of Clayton *et al.* (2003) corresponds to the *Thymospora obscura – Thymospora thiessenii* (OT) Biozone of Western Europe (Clayton *et al.* 1977), the W7 Biozone of the North Sea (McLean *et al.* 2005), the *T. obscura* Assemblage Zone XI of onshore Great Britain (Smith and Butterworth 1967) and Zone IV of Western Europe (Coquel *et al.* 1976) (figure 2.1). The biozone lower limits are all uppermost Bolsovian in age. In Eastern Canada, the *Thymospora* Zone C of Barss and Hacquebard (1967) is Asturian in age (figure 2.9).

In the North Sea, the first stratigraphic appearance of *T. pseudothiessenii* is recorded in proximity to the W7 Biozone lower limit (McLean *et al.* 2005), reflecting the range base recorded offshore western Ireland. The range base of *Thymospora* spp. defines the lower limit of the OT Biozone (Clayton *et al.* 1977), marking the uppermost Bolsovian in the Netherlands (Van Wijhe and Bless 1974), the Pas-de-Calais Basin of northern France (Loboziak 1974), the Saar-Lorraine Basin (Alpern *et al.* 1967) and onshore Great Britain (Smith and Butterworth 1967). The range base of *Thymospora* spp. also marks the lower limit of Zone IV of Coquel *et al.* (1976). In Great Britain, Smith and Butterworth (1967) recorded the range bases of *T. pseudothiessenii* and *T. obscura* at the lower limit of the *T. obscura* Assemblage Zone XI. Offshore western Ireland, the range base of *T. obscura* may occur at a higher stratigraphic level than the range base of *T. pseudothiessenii* (section 6.2.2.2). The range base of *T. obscura* also marks the lower limit of the *Thymospora* Zone in Eastern Canada (Barss and Hacquebard 1967) (figure 2.9).

Evidence from the present study suggests the range base of *Spinosporites* spp. offshore western Ireland occurs within the *Thymospora pseudothiessenii* Biozone. In Western Europe, Clayton *et al.* (1977) recorded the range base of the genus at the lower limit of the OT Biozone and Coquel *et al.* (1976) recorded the range base in the lower part of Zone IV. Data from the present study also suggests the last stratigraphic occurrence of rare *Dictyotriletes bireticulatus* occurs roughly in proximity to the lower limit of the *T. pseudothiessenii* Biozone offshore western Ireland. Clayton *et al.* (1977) recorded the range top of the taxon extending into the lower part of the OT Biozone. However, it is noted that the range top of *D. bireticulatus* has been recorded at a variety of stratigraphic levels in Western Europe including the lower Bolsovian of onshore Great Britain (Smith and Butterworth 1967), the mid Duckmantian of the Netherlands (Van Wijhe *et al.* 1974) and the Asturian of the Pas-de-Calais Basin, north-western France (Loboziak 1974). Grebe (1972) recorded sporadic occurrences extending to the Bolsovian-Asturian boundary in the Ruhr Basin and McLean *et al.* (2005) recorded the range top at the lower limit of the upper Bolsovian age North Sea W7 Biozone. Infrequent occurrences of *Radiizonates tenuis, R. faunus* and *Raistrickia fulva* are also deemed to occur in proximity to the *T. pseudothiessenii* Biozone lower limit offshore western Ireland. Range tops of the taxa are recorded in the middle of the North Sea W6b Biozone, corresponding to the uppermost *Vestispora fenestrata* Biozone of Clayton *et al.* (2003). However, it is noted that Clayton *et al.* (1977) recorded the range top of *R. fulva* at the lower limit of the Bolsovian age *Torispora securis – Torispora laevigata* (SL) Biozone.

Data from the present study suggests the range top of *Cingulizonates loricatus* may extend into the Asturian and possibly into the Cantabrian of offshore western Ireland. The range top of *C. loricatus* is recorded in proximity to the lower limit of the North

Sea W7 Biozone (McLean *et al.* 2005), in the lower part of the Western European OT Biozone (Clayton *et al.* 1977) and in the lower part of Zone IV of Western Europe (Coquel *et al.* 1976). Peppers (1985) indicated that the range top in Western Europe is generally recorded in the mid to upper Bolsovian although the range top in Belgium has been recorded in the Asturian (Somers 1971 reported on by Peppers 1985).

Clayton *et al.* (1977) also recorded the first stratigraphic occurrences of *Polymorphisporites* spp. and *Candidispora* spp. in the lower part of the OT Biozone. Offshore western Ireland, rare occurrences of *Polymorphisporites* spp. are only encountered in well 26/28-2 and *Candidispora* spp. is not recorded. In addition to occurrences of *Thymospora pseudothiessenii* and *Thymospora obscura*, Smith and Butterworth (1967) noted that the *T. obscura* Assemblage XI of onshore Great Britain is also characterised by infrequent occurrences of *Mooreisporites* cf. *inusitatus, Schopfites dimorphus*, *Cadiospora magna*, in additon to *Triquitrites* spp., *Florinites mediapudens, Crassispora kosankei* and *Densosporites sphaerotriangularis*. The intervals assigned to the *T. pseudothiessenii* Biozone offshore western Ireland are also typically characterised by the above taxa.

6.2.2.1 *Angulisporites splendidus* Sub-biozone (Cantabrian)

Offshore western Ireland, the *Angulisporites splendidus* Sub-biozone of Clayton *et al.* (2003) (figure 2.7) is identified in wells 26/27-1b, 26/28-1, 26/28-2, 34/5-1 and 36/16-1. With the exception of well 36/16-1, the lower limit of the biozone is defined by the range base of the index taxon and positioned at its first stratigraphic occurrence. As the first stratigraphic occurrences are typically recorded in cuttings samples, there is inherent uncertainty in the positioning of the biozone lower limit due to the risk of caving. Occurrences of the index taxon within the sub-biozone are also rare.

The lower limit of the *Angulisporites splendidus* – *Latensina trileta* (ST) Biozone of Clayton *et al*. (1977) was also recorded in wells 26/27-1b, 26/28-1, 26/28-2, 34/5-1 and 36/16-1 (Appendix VII). In the zonal scheme of Clayton *et al.*, the range bases of *A. splendidus* and *Cheleidonites* spp. define the lower limit of the upper Barruelian to Stephanian B age ST Biozone (figure 2.2). However, at the time of publication, the oldest Stephanian age palynological data included in the 1977 zonal scheme was from the upper Barruelian (Cleal *et al.* 2003). Dimitrova *et al.* (2005) subsequently recorded the range bases of *A. splendidus* and *Cheleidonites* spp. in proximity to the base of the Cantabrian Substage in the eastern South Wales Coalfield of Great Britain (see below). It is therefore likely that the lower limit of the ST Biozone should also mark the base of the Cantabrian Substage, coinciding with the lower limit of the *A. splendidus* Biozone.

Offshore western Ireland, the first stratigraphic occurrence of *Cheleidonites* spp. is used to define the lower limit of *A. splendidus* Biozone in the absence of the index taxon. *Cheleidonites* spp. defines the biozone lower limit in 36/16-1, although it is noted that the genus is not recorded in other wells that encounter the *A. splendidus* Biozone.

In 34/5-1, the first stratigraphic occurrence of rare *Vittatina* spp. is recorded in sidewall core, 115'/35m shallower than the first stratigraphic occurrence of *Angulisporites splendidus* and the *A. splendidus* Biozone lower limit. A very questionnable occurrence in 26/28-1 is recorded in sidewall core below the first stratigraphic occurrence of *A. splendidus*. Clayton *et al.* (1977) recorded the first stratigraphic occurrences of rare *Vittatina* in the ST Biozone of Western Europe (figure 2.2). In the Donets Basin, Ukraine, Inosova (1976) recorded 'sporadic occurrences in isolation' of *Vittatina* spp. from the base of the Stephanian Stage.

The Carboniferous interval in well 26/21-1 is possibly assigned to the ST Biozone of Clayton *et al.* (1977) based on the presence of *A. splendidus* and a relative rarity of *Potonieisporites.* Clayton *et al.* (1977) indicated that frequent occurrences of *Potonieisporites* spp. are recorded from the lower limit of the younger NBM Biozone in Western Europe (figure 2.2). However, the poor recovery of miospores in the 26/21-1 well is likely to be a factor influencing the abundance of *Potonieisporites* spp. An 'undefined' ST-NBM Biozone is therefore assigned to the interval.

Comparison with other localities

Western Europe, the North Sea, onshore Great Britain and Nova Scotia

As noted above, the oldest Stephanian age palynological data included in the 1977 zonal scheme of Clayton *et al.* was from the upper Barruelian (Cleal *et al.* 2003). Cleal *et al.* subsequently investigated the macrofloral and palynological criteria for recognising the Asturian-Stephanian boundary at a number of localities in Europe and North America. The authors identifed key macrofloral events recognised at the Asturian-Cantabrian stratotype section in the Guardo-Cevera Coalfield, Palencia, Spain and integrated the macrofloral data with palynological data. Four key macrofloral events (Biohorizons 1-4) have been defined at the stratotype section (e.g Wagner in Wagner *et al.* 1983, Wagner 1984).

In the Oxfordshire coalfield, Cleal *et al.* (2003) identified Biohorizon 3, which occurs in proximity to the Cantabrian-Asturian boundary and incorporated palynological data from Smith (1987). Smith had previously identified a significant palynological event characterised by the range bases of *Schopfites dimorphus* and *Vestispora burfordiensis* with the epibole of *Thymospora pseudothiessenii* recorded just above. Smith introduced Zone XII to Smith and Butterworth's (1967) miospore zonal scheme of Great Britain to represent the palynological event (figure 2.1). Integrating the palynological data with the biohorizon data, Cleal *et al.* noted the first stratigraphic appearance of *S. dimorphus* and the base of the epibole of *T. pseudothiessenii* occurring in proximity to Biohorizon 3. Cleal *et al.* suggested that base of Zone XII of Smith (1987) occurs in proximity to the biohorizon.

In the Illinois Basin, USA, Cleal *et al.* (2003) recorded an incoming of *S. dimorphus*, the epibole of *T. pseudothiessenii* and an increase in the abundance of *Cadiospora magna* at Biohorizon 3; the assemblage essentially corresponding to the CP Biozone of Peppers (1985). Cleal *et al.* concluded that Biohorizon 3 was essentially coincident with the base of the CP Biozone of Peppers (1984) and Zone XII of Smith (1987). In the Sydney Coalfield, Cape Breton Island, Nova Scotia, Cleal *et al.* (2003) identified Biohorizon 2, which occurs even closer to the Cantabrian-Asturian boundary at the stratotype section. The authors recorded the first stratigraphic occurrences of

Angulisporites splendidus and *Columnisporites* sp. in proximity to the biohorizon and the base of the Cantabrian Substage. The Cantabrian age strata was also characterised by abundant *Lycospora* with abundant monosaccate and bisaccate pollen (*Florinites, Potonieisporites, Wilsonites, Guthoerlisporites, Illinites*). In contrast to the Oxfordshire coalfield, infrequent occurrences of *S. dimorphus* were recorded in Asturian age strata.

Dimitrova *et al.* (2005) subsequently recognised an approximate Asturian-Cantabrian boundary in the eastern South Wales Coalfield of Great Britain based on an increase in abundance of *Thymospora pseudothiessenii, Schopfites dimorphus* and *Cadiospora magna,* reflecting Zone XII of Smith (1987) and the CP Zone of Peppers (1985). The authors also recorded the first stratigraphic appearance of *Cheleidonites* spp. in the same coal seam with the first stratigraphic occurrence of *Angulisporites* spp. recorded 295'/90m shallower in the next seam above. In 2008, Dimitrova and Cleal indicated that their latest research in the Sydney Coalfields of Canada, and the South Wales and Forest of Dean Coalfields of Great Britain suggested that the base of the Cantabrian Stage could be approximated by increases in the abundance of *T. pseudothiessenii*, *S. dimorphus* and *C. magna* in addition to the first stratigraphic occurrences of *Lundbladispora gigantea* and *Angulisporites splendidus*.

Offshore western Ireland, the range base of *Angulisporites splendidus* defines the lower limit of the *A. splendidus* Biozone of Clayton *et al.* (2003), with the range base of *Cheleidonites* spp. acting as a guide for the biozone lower limit. This reflects the ranges recorded by Dimitrova *et al.* (2005) and Dimitrova and Cleal (2008). It is therefore possible to correlate the base Cantabrian of offshore western Ireland with Eastern Canada using the first stratigraphic occurrence of *A. splendidus*. Occurrences of *Thymospora pseudothiessenii* and *Cadiospora magna* also characterise the intervals assigned to the *A. splendidus* Biozone offshore western Ireland. The range base of *S. dimorphus* extends into the Asturian of offshore western Ireland (section 6.2.2.2) reflecting the range recorded in the Sydney Coalfield, Nova Scotia by Cleal *et al.* (2003) and the North Sea by McLean *et al.* (2005). In contrast to the findings of Dimitrova and Cleal (2008), the range base of *Lundbladispora gigantea* offshore western Ireland is recorded in the lower part of the *Thymospora pseudothiessenii* Biozone (section 6.2.2.2).

Clayton *et al.* (1977) indicated that the ST Biozone of Western Europe is also characterised by occurrences of *Vestispora fenestrata, Crassispora kosankei, Cirratriradites saturni*, *Latensina trileta, Candidispora* spp., *Polymorphisporites* spp., *Disaccites* non *striatiti* and *Spinosporites spinosus*. Offshore western Ireland, *V. fenestrata, C. kosankei, Spinosporites* and *L. trileta* are recorded in all five well intervals assigned to the *A. splendidus* Biozone. *C. saturni* is recorded in the *A. splendidus* Biozone in three of the five wells. *Polymorphisporites* spp. and *D. non-striatiti* are only recorded in the *A. splendidus* Biozone of well 26/28-2. It is also noted that occurrences of *Torispora securis* and *Endosporites globiformis* are commonly recorded in the intervals assigned to the *A. splendidus* Biozone offshore western Ireland. A number of taxa that possess range tops in the Asturian of the North Sea (McLean *et al.* 2005) are also recorded in the *A. splendidus* Biozone offshore western Ireland. In well 36/16-1, *Endosporites zonalis*, *Triquitrites tribullatus*, *Vestispora laevigata*, and *Westphalensisporites irregularis* are recorded in shallower samples than the occurrence of *Cheleidonites* spp. in sidewall core.

6.2.2.2 *Torispora verrucosa* Sub-biozone (Asturian) and *Westphalensisporites irregularis* Sub-biozone (upper Bolsovian)

The Asturian age *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003) is tentatively recorded in wells 36/16-1, 34/5-1, 26/27-1b, 13/3-1 26/28-1, 26/28-2 and 26/28-3. The range base of the index taxon should define the biozone lower limit (figure 2.7). However, occurrences of *T. verrucosa* are very rare offshore western Ireland. The taxon is recorded in just one sample in 34/5-1 and two samples in 36/16-1, although at depths shallower than the *T. pseudothiessenii* Biozone lower limit. Due to the rarity of the index taxon, alternative taxa are used to define the sub-biozone. Based on range data from the North Sea (McLean *et al.* 2005) (figure 2.5), the range bases of *Schopfites dimorphus*, *Cirratriradites annulatus* and *Savitrisporites camptotus* are used to constrain the lower limit of the sub-biozone. The range base of *Thymospora obscura* may also occur in proximity to the sub-biozone lower limit, reflecting the range of the taxon recorded in the North Sea. The range tops of *Florinites junior*, *Lophotriletes microsaetosus* and *Vestispora costata* may additionally help constrain the sub-biozone lower limit.

In the North Sea, McLean *et al.* (2005) recorded the range bases of *Schopfites dimorphus* and *Cirratriradites annulatus* at the base of the lower Asturian age W7b Sub-biozone. Offshore western Ireland, *S. dimorphus* is recorded in three wells, although occurrences are rare. In 34/5-1, occurrences are recorded in two sidewall core samples that are deeper than the sole occurrence of *Torispora verrucosa* and shallower than the *Thymospora pseudothiessenii* Biozone lower limit. The occurrences suggest an age no older than the Asturian Substage and a biozone no older than the *T. verrucosa* Sub-biozone. In 26/28-2, the taxon is restricted to a single sample at the lower limit of the *Angulisporites splendidus* Sub-biozone. Occurrences of *C. annulatus* are equally rare offshore western Ireland. In 26/28-3, an occurrence in a sidewall core sample, shallower than the lower limit of the *T. pseudothiessenii* Biozone, indicates a biozone no older than the *T. verrucosa* Sub-biozone. In 26/28-2, an occurrence in a mid Bolsovian age cuttings sample is assumed caved.

McLean *et al.* (2005) recorded the range base of *Savitrisporites camptotus* in the upper Asturian of the North Sea. Offshore western Ireland, rare occurrences in three wells confirm a biozone no older than the *T. verrucosa* Sub-biozone. In 34/5-1, the taxon is recorded in two samples; the deepest occurrence at a shallower depth than the first stratigraphic occurrence of *Schopfites dimorphus*. In 26/27-1b, an occurrence in a single sidewall core sample, 584.8'/178m above the lower limit of the *T. pseudothiessenii* Biozone, marks the *T. verrucosa* Sub-biozone. An occurrence of *S.* cf. *camptotus* in 13/3-1 tentatively indicates an Asturian age.

Thymospora obscura is recorded infrequently in wells 36/16-1, 34/5-1, 26/27-1b, 13/3-1 26/28-1, 26/28-2 and 26/28-3. Even though the first stratigraphic occurrence is commonly recorded in cuttings samples, in a number of wells it is recorded at a shallower depth than the lower limit of the *Thymospora pseudothiessenii* Biozone. This may suggest that the range base marks the lower limit of the Asturian age *Torispora verrucosa* Sub-biozone, reflecting the range recorded in the North Sea by McLean *et al.* (2005) (figure 2.5). In 34/5-1, the first stratigraphic occurrence is recorded in a cuttings sample 193'/58.8m shallower than the *T. pseudothiessenii* Biozone lower limit, but 284'/86.5m deeper than the first stratigraphic occurrence of *Schopfites dimorphus* and 525'/160m deeper than the sole occurrence of *T. verrucosa.*

In 26/27-1b, the first stratigraphic occurrence of *T. obscura* is recorded in a cuttings sample 203.8'/62m shallower than the *T. pseudothiessenii* Biozone lower limit, although deeper than the first stratigraphic occurrence of *Savitrisporites camptotus*. In 26/28-2, the first stratigraphic occurrence is recorded in a cuttings sample 79'/24m shallower than the lower limit of the *T. pseudothiessenii* Biozone. In 26/28-1, occurrences are recorded 196'/60m shallower than the *T. pseudothiessenii* Biozone lower limit. The first stratigraphic occurrences of both *T. obscura* and *T. pseudothiessenii* are recorded in the same cuttings sample in 36/16-1. The sample depth is deeper than the occurrences of *T. verrucosa*. Only a single, caved occurrence of *T. obscura* is recorded in 26/28-3 and the taxon is absent from the thin interval assigned to the *T. pseudothiessenii* Biozone in 26/28-4a. Overall, it is possible that the range base of *T. obscura* defines the base of the Asturian offshore western Ireland.

The range tops of *Florinites junior* and *Lophotriletes microsaetosus* may help to roughly constrain the lower limit of the Asturian Substage and the *Torispora verrucosa* Sub-biozone offshore western Ireland. McLean *et al.* (2005) recorded the range top of *F. junior* extending into the lowermost Asturian of the North Sea (figure 2.5). Butterworth (1984) recorded the range top of *L. microsaetosus* at the upper limit of the Bolsovian Substage in north-western Europe. Offshore western Ireland, the range tops are typically recorded in samples shallower than the *T. pseudothissenii* Biozone lower limit. In 34/5-1 the last stratigraphic occurrence of *L. microsaetosus* is recorded 66'/20m shallower than the first stratigraphic occcurrence of *Thymorpoa obscura*, 459'/140m deeper than the sole occurrence of *T. verrucosa* and 218'/66.5m deeper than the first stratigraphic occurrence of *Schopfites dimorphus.* The last stratigraphic occurrence of *F. junior* is recorded 33'/10m shallower than that of *L. microsaetosus.* In 36/16-1, the last stratigraphic occurrence of *L. microsaetosus* is recorded 210'/64 below the deepest occurrence of *T. verrucosa* and 6'/2m shallower than the deepest occurrence of *T. obscura* in sidewall core. *F. junior* is not recorded in the well. In 26/28-1, the first stratigraphic occurrence of *T. obscura* (excluding caved occurrences in Duckmantian age samples) and the last stratigraphic occurrence of *L. microsaetosus* are recorded at the same depth. The last stratigraphic occurrence of *F. junior* is recorded 115'/35m shallower. In 26/28-3, the last stratigraphic occurrence of *L. microsaetosus* is recorded 98'/30m deeper than the sole occurrence of *C. annulatus* in sidewall core. In 13/3-1, strata above a faulted contact with lower Bolsovian age strata is assigned to the Asturian Substage based on the occurrence of *Savitrisporites* cf. *camptotus* in sidewall core. The first stratigraphic occurrence of *T. obscura* and the last stratigraphic occurrence of *F. junior* are both recorded just above the fault, although *L. microsaetosus* is not. In 26/27-1b, the last stratigraphic occurrence of *L. microsaetosus* is recorded just 11'/3m below the first stratigraphic occurrence of *T. obscura*. However, the last stratigraphic occurrence of *F. junior* is recorded at the lower limit of the Cantabrian age *A. splendidus* Sub-biozone. In 26/28-2, the last stratigraphic occurrence of *L. microsaetosus* is recorded in Cantabrian age strata. Overall, due to the inconsistancies recorded, there is some uncertainty regarding the age of the range tops of *F. junior* and *L. microsaetosus* offshore western Ireland and their use for approximating the base of the Asturian Substage.

The range top of *Vestispora costata* may also occur in proximity to the base of the Asturian Substage offshore western Ireland. Clayton *et al.* (1977) recorded the range top of *V. costata-cancellata* extending into the lowermost OT Biozone of Western Europe (figure 2.2). Butterworth (1984) recorded the range top of *V. costata* at the top of the Bolsovian Substage in north-western Europe. The last stratigraphic occurrence in 26/28-3 is deemed to occur in Asturian age strata, recorded 295'/90m above the occurrence of *Cirratriradites annulatus* in sidewall core. In 26/27-1b, the last stratigraphic occurrence is recorded 326'/99m above the first stratigraphic occurrence of *Thymospora obscura* and 55'/17m below the first stratigraphic occurrence of *Savitrisporites camptotus.* In 34/5-1, the last stratigraphic occurrence is recorded just 33'/10m above the last stratigraphic occurrence of *L. microsaetosus*, but deeper than the first stratigraphic occurrences of *Schopfites dimorphus* and *S. camptotus* in sidewall core. In 26/28-2 the last stratigraphic occurrence is recorded in a sample shallower than the occurrence of *T. obscura* in sidewall core. In 36/16-1, the last stratigraphic occurrence is recorded below the deepest occurrence of *Torispora verrucosa*, but at the same depth as an occurrence of *T. obscura* in sidewall core. The last stratigraphic occurrence is restricted to the mid *Vestispora fenestrata* Biozone in 26/28-1.

McLean *et al.* (2005) recorded a number of additional taxa with range tops in the Asturian of the North Sea (figure 2.5). Several of the taxa are recorded offshore western Ireland, although with occurences often extending into the Cantabrian age

Angulisporites splendidus Sub-biozone. *Westphalensisporites irregularis* is recorded in the *A. splendidus* Sub-biozone of well 36/16-1 and at the Asturian-Cantabrian boundary in 34/5-1. The taxon is recorded in the Asturian age *T. verrucosa* Sub-biozone in 26/28-1, 26/28-2, 26/28-3, 13/3-1 and 26/27-1b; in samples shallower than occurrences of *Schopfites dimorphus, Savitrisporites camptotus, Cirratriradites annulatus* and *Thymospora obscura* in sidewall core. The last stratigraphic occurrence of *Endosporites zonalis* is recorded in the *A. splendidus* Sub-biozone of wells 36/16-1 and 26/28-2 and in samples assigned to the *T. verrucosa* Sub-biozone in wells 13/3-1, 26/28-1, 26/28-3 and 34/5-1. The last stratigraphic occurrence of *Triquitrites tribullatus* is recorded in the *A. splendidus* Sub-biozone of wells 36/16-1, 26/28-1, 26/28-2 and in the *T. verrucosa* Sub-biozone of wells 13/3-1, 26/27-1b, 26/28-3 and 34/5-1. *Vestispora pseudoreticulata* has been recorded in the *A. splendidus* Sub-biozone of well 34/5-1*,* at the Asturian-Cantabrian boundary in 26/27-1b and in the *T. verrucosa* Sub-biozone of wells 36/16-1 and 26/28-1. However, the last stratigraphic occurrence in 26/28-2 is recorded below the *T. pseudothiessenii* Biozone lower limit. *Alatisporites hoffmeisterii* is recorded very infrequently offshore western Ireland. The last stratigraphic occurrences are recorded in the *T. verrucosa* Sub-biozone of wells 34/5-1, 13/3-1, 26/28-2; in samples shallower than occurrences of *S. dimorphus, S. camptotus* and *T. obscura* in sidewall core. The last stratigraphic occurrence in 26/27-1b is recorded shallower than the first stratigraphic occurrence in sidewall core of *T. obscura*, but deeper than the first stratigraphic occurrence of *S. camptotus*. A single occurrence in 26/28-1 is recorded at the possible *A. splendidus/T. verrucosa* Sub-biozone boundary and the last stratigraphic occurrence in 36/16-1 is recorded at the base of the *T. pseudothiessenii* Biozone. The last stratigraphic occurrence of *Vestispora laevigata* is recorded in the *A. splendidus* Sub-biozone of wells 36/16-1 and 26/28-1, in the *T. verrucosa* Sub-biozone of wells 13/3-1 and 26/28-3 and at the same depth as the last stratigraphic occurrence of *L. microsaetosus* in 34/5-1. *Cristatisporites solaris* occurs inconsistently offshore western Ireland. Although the last stratigraphic occurrence is recorded in the *T. verrucosa* Sub-biozone of wells 34/5-1 and 26/27-1b, the last stratigraphic occurrence is recorded in samples assigned to the *Vestispora fenestrata* Biozone in 36/16-1, 26/28-2 and 26/28-3 and Duckmantian age strata in 26/28-1.

McLean *et al.* (2005) also recorded the range base of *Lundbladispora gigantea* at the lower limit of the Asturian age North Sea W7b Sub-biozone (figure 2.5). However, in well 26/27-1b, offshore western Ireland, the first stratigraphic occurrence of the taxon is recorded at the lower limit of the *Thymospora pseudothiessenii* Biozone, in the same sidewall core sample as the first stratigraphic occurrence of the index taxon. The first stratigraphic occurrence in 26/28-1 is also recorded at the lower limit of the biozone, occuring in the same cuttings samples as the last stratigraphic occurrence of *R. fulva*. Rare occurrences in 36/16-1 and 26/28-2 are restricted to the *Angulisporites splendidus* Sub-biozone and an occurrence in 26/28-3 is recorded in the *T. verrucosa* Sub-biozone. Overall, evidence from offshore western Ireland suggests a range base extending to the lower limit of the *T. pseudothiessenii* Biozone. It is noted that Clayton *et al.* (1977) recorded an even older range base, extending to the middle of the SL Biozone in Western Europe (figure 2.2).

Butterworth (1984) recorded various taxa with range tops at the top Bolsovian in north-western Europe. Although a number of the taxa are present offshore western Ireland, e.g. *Granulatisporites micrograníer, Calamospora* cf. *breviradiata* and *Raistrickia* cf. *superba,* the last stratigraphic occurrences are often recorded at varying stratigraphic levels.

The lowermost part of the *Thymospora pseudothiessenii* Biozone not assigned to the *T. verrucosa* Sub-biozone in wells, 26/27-1b, 26/28-1, 26/28-2, 26/28-3, 34/5-1 and 36/16-1 is assigned to the upper Bolsovian age *Westphalensisporites irregularis* Sub-biozone of Clayton *et al.* (2003) (figure 2.7). The range of *W. irregularis* offshore western Ireland extends from the lower Duckmantian into the Cantabrian Substage. Occurrences of the index taxon characterise the intervals assigned to the sub-biozone.

Comparison with other localities

Western Europe, North Sea and onshore Great Britain

The *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003) recorded offshore western Ireland rougly corresponds to the North Sea W7b and W7c Sub-biozones of McLean *et al.* (2005) (figure 2.1). Clayton *et al*. (1977) and Smith and Butterworth

(1967) did not record an exclusively Asturian age biozone in Western Europe or onshore Great Britain, positioning the lower limits of the OT Biozone / *Thymospora obscura* Assemblage Zone X in the uppermost Bolsovian.

Offshore western Ireland, rare occurrences of *Torispora verrucosa* are restricted to samples no older than Asturian in age. The range base may mark the base of the Asturian Substage, as recorded in the North Sea by McLean *et al*. (2005). However, this is difficult to confirm due to the rarity of occurrence.

The range bases of *Schopfites dimorphus, Savitrisporites camptotus* and *Cirratriradites annulatus* are deemed to occur in the Asturian of offshore western Ireland, reflecting the ranges recorded in the North Sea by McLean *et al.* (2005). It is noted that Smith (1987) recorded the range base of *Schopfites dimorphus* at the base of the Cantabrian Substage in the Oxfordshire coalfields of Great Britain. However, Dimitrova *et al.* (2005) and Dimitrova and Cleal (2008) subsequently recorded an increase in abundance of *S. dimorphus* at the base of the Cantabrian Substage in the South Wales and Forest of Dean coalfields of Great Britain. Clayton *et al.* (1977) recorded the range base of *S. camptotus* in the lower part of the OT Biozone of Western Europe, which may correspond to the Asturian Substage.

Offshore western Ireland, there is some uncertainty regarding the range base of *Thymospora obscura*. As the first stratigraphic occurrence is often recorded above the lower limit of the *T. pseudothiessenii* Biozone, it is possible that range base reflects the Asturian age range base recorded in the North Sea by McLean *et al.* (2005). In contrast, Smith and Butterworth (1967) recorded the range base of *T. obscura* at the upper Bolsovian age lower limit of the *T. obscura* Assemblage Zone XI of onshore Great Britain. Alpern *et al.* (1967) also recorded the range base in the upper Bolsovian of the Saar-Lorraine Basin. Clayton *et al.* (1977) did not distinguish between the various species of *Thymospora* in the miospore zonation of Western Europe, indicating that the lower limit of the OT Biozone is defined by range base of *Thymospora* spp. However, Butterworth (1984) recorded the range base of *T. obscura* at the upper Bolsovian age OT Biozone lower limit in north-western Europe.

Occurrences of *Westphalensisporites irregularis* offshore western Ireland suggest the stratigraphic range of the taxon extends into the Cantabrian. This is in contrast to the lower Asturian range top recorded in the North Sea by McLean *et al.* (2005), although it is noted that Clayton *et al.* (1977) recorded infrequent occurrences of the taxon in the Stephanian age NBM Biozone of Western Europe. Coquel *et al.* (1976) also recorded occurrences of *W. irregularis* in Stephanian age strata from Carmaux, St-Perdoux, and Decazeville in France. Occurrences of *Endosporites zonalis* and *Triquitrites tribullatus* are also recorded in Asturian and Cantabrian age strata of offshore western Ireland, which is in contrast to the lower Asturian age range tops recorded in the North Sea by McLean *et al.* Offshore western Ireland, occurrences of *Vestispora pseudoreticulata* and *V. laevigata* are recorded in Asturian and Cantabrian age strata. This contrasts with the Asturian age range tops recorded in the North Sea by McLean *et al.* The range tops of *Florinites junior* and *Alatisporites hoffmeisterii* recorded offshore western Ireland appear to be restricted to the Asturian; reflecting the range tops recorded in the North Sea. The range top of *Lophotriletes microsaetosus* may occur in proximity to the base of the Asturian offshore western Ireland, reflecting the top Bolsovian range top recorded by Butterworth (1984). However, inconsistancies in a number of wells indicate there is uncertainty regarding the true range top.

Offshore western Ireland, the range base of *Lundbladispora gigantea* is inferred to extend to the base of the *T. pseudothiessenii* Biozone. This contrasts with the lower Asturian range base recorded in the North Sea by McLean *et al.* (2005), and the mid SL Biozone range base recorded by Clayton *et al.* (1977).

Eastern Canada

Barss and Haquebard (1967) recorded the range base of *Thymospora obscura* at the lower limit of the Asturian age *Thymospora* Zone C of Eastern Canada (figure 2.11). As the first stratigraphic occurrence of *T. obscura* is recorded at a similar level offshore western Ireland, it may be possible to roughly correlate the *Thymospora* Zone of Eastern Canada with offshore western Ireland using this event. In the Sydney Basin of Nova Scotia, Cleal *et al.* (2003) recorded infrequent occurrences of *Schopfites dimorphus* in Asturian age strata. The range resembles that recorded offshore western Ireland. Barss *et al.* (1979) also recorded *Endosporites zonalis* in Stephanian age samples from the North Sydney P-05 well, located in the Sydney Basin, offshore Nova Scotia (section 6.2.1). A similar stratigraphic range is recorded offshore western Ireland.

6.2.3 *Vestispora fenestrata* Biozone (Bolsovian)

The *Vestispora fenestrata* Biozone of Clayton *et al.* (2003) is recorded in wells 13/3-1, 26/28-1, 26/28-2, 26/28-3, 26/28-4, 26/29-1, 26/30-1, 34/5-1 and 36/16-1. The biozone lower limit is tentatively recorded in wells 13/3-1, 34/5-1 and possibly encountered in 36/16-1. Clayton *et al.* (2003) indicated that the range base of the index taxon should define the lower Bolsovian age biozone lower limit (figure 2.7). However, as first stratigraphic occurrences offshore western Ireland are predominantly recorded in cuttings samples, there is an inherent risk of caving. The biozone lower limit in 13/3-1 and 34/5-1 is tentatively positioned at the first stratigraphic occurrence of *V. fenestrata,* which is recorded at a shallower depth than the top Duckmantian in both wells. Caving is noted in well 36/16-1, with the first stratigraphic occurrence recorded in a middle Duckmantian age cuttings sample. Due to the risk of caving affecting the depth of first stratigraphic occurrences, additional taxa are required to constrain the biozone lower limit.

The range base of *Torispora* spp. is commonly recorded in the lowermost Bolsovian of Western Europe. The range base of *Torispora securis* is recorded in proximity to the lower limit of the equivalent North Sea W6 Biozone of McLean *et al.* (2005) and at the lower limit of the equivalent *T. securis* Assemblage Zone X of onshore Great Britain (Smith and Butterworth 1967) (figure 2.1). Clayton *et al.* (1977) indicated that the range base of *Torispora* spp. marks the lower limit of the equivalent *T. securis – Torispora laevigata* (SL) Biozone of Western Europe. In the Maritime Provinces of Eastern Canada, Barss and Hacquebard (1967) recorded the first stratigraphic occurrence of *T. securis* and *T. laevigata* at the mid Bolsovian age *Torispora* Biozone lower limit (figure 2.11). Offshore western Ireland, *T. securis* is recorded in most wells that encounter the *V. fenestrata* Biozone. However, as first stratigraphic occurrences are predominantly recorded in cuttings samples, there is a risk of caving. The first stratigraphic occurrence in 13/3-1 is recorded at a shallower depth than the first stratigraphic occurrence of *V. fenestrata.* In 36/16-1, an occurrence of *T. securis* in sidewall core helps to constrain the lower limit of the *V. fenestrata* Biozone. Deeper occurrences in cuttings samples assigned to the upper Duckmantian are potentially caved. In 34/5-1 the first stratigraphic occurrence of *T. securis* is recorded in a cuttings sample, 108'/33m deeper than the first stratigraphic occurrence of *V. fenestrata* and assigned to the top Duckmantian. Overall, the true range base of *T. securis* offshore western Ireland is difficult to confirm due to occurrences in Duckmantian age cuttings samples. As the range base commonly occurs in the lower Bolsovian of Western Europe and the mid Bolsovian of Eastern Canada the range base is tentatively assumed to occur at a similar stratigraphic level offshore western Ireland.

Ideally, the lower limit of the *Vestispora fenestrata* Biozone would be constrained by the range tops of taxa. However, taxa with range tops that define the lower limit of the equivalent SL Biozone of Western Europe (Clayton *et al.* 1977) or the W6 Biozone of the North Sea (McLean *et al.* 2005) occur too infrequently to be of use or possess unsuitable ranges offshore western Ireland. Clayton *et al.* and McLean *et al.* both recorded the range top of *Grumosisporites varioreticulatus* at the SL and W6 Biozone lower limits (figures 2.2 and 2.5). Offshore western Ireland, occurrences are rare. In 36/16-1, *G. varioreticulatus* is recorded in a sample 612ft/187m shallower than an occurrence of *Torispora securis* in sidewall core and in a second sample assigned to the lower Duckmantian. The last stratigraphic occurrence of *G. varioreticulatus* in 34/5-1 is recorded in a sample assigned to the top Duckmantian and the taxon is absent from well 13/3-1. Overall, the taxon is not particularly reliable for defining the base of the *V. fenestrata* Biozone. McLean *et al.* also recorded the last stratigraphic occurrence of *Grumosisporites papillosus* at the lower limit of the W6 Biozone. However, in 36/16-1, the taxon is only recorded in samples assigned to the uppermost *V. fenestrata* Biozone and the *Thymospora pseudothiessenii* Biozone. The taxon is not recorded in wells 34/5-1 and 13/3-1.

Clayton *et al.* (1977) recorded the range top of *Raistrickia fulva* at the lower limit of the SL Biozone. However, rare occurrences offshore western Ireland are recorded in proximity to the base of the *Thymospora pseudothiessenii* Biozone (section 6.2.2). Clayton *et al.* also recorded the range base of rare *Lundbladispora gigantea* in the SL Biozone. Offshore western Ireland, the taxon is not recorded below the lower limit of the *T. pseudothiessenii* Biozone (section 6.2.2). Clayton *et al.* additionally recorded the range base of *Punctatosporites granifer* in the lowermost SL Biozone, although it is noted that McLean *et al.* (2005) recorded the range base of the taxon in the upper Duckmantian of the North Sea. In offshore western Irish wells, the first stratigraphic occurrences of the taxon are recorded at varying stratigraphic levels. In 13/3-1 and 34/5-1, the first stratigraphic occurrences are assigned to the mid *V. fenestrata* Biozone. Occurrences in 36/16-1 are restricted to the *T. pseudothiessenii* Biozone and the taxon has been recorded in Duckmantian age cuttings samples from well 26/28-1 (although it is possible that the occurrences are caved). There is therefore some uncertainty regarding the range base of the taxon offshore western Ireland. Clayton *et al.* also recorded the range bases of *Latensina trileta* and rare specimens of *Disaccites striatiti* in the SL Biozone. Occurrences of *D. striatiti* offshore western Ireland are rare and not recorded below the lower limit of the *V. fenestrata* Biozone. The range base of *L. trileta* appears to be restricted to the *T. pseudothiessenii* Biozone, mainly occurring in samples assigned to the *Angulisporites splendidus* and *Torispora verrucosa* Sub-biozones, although a single occurrence in 26/28-4a is recorded in a sidewall core sample at the *V. fenestrata/ T. pseudothiessenii* Biozone boundary.

Overall, no taxa have been identified that possess range tops that can reliably define the lower limit of the *Vestispora fenestrata* Biozone offshore western Ireland. There is low confidence in defining the biozone lower limit based solely on the first stratigraphic occurrence of the index taxon due the risk of caving. The range base of *Torispora securis* may be of use in constraining the lower limit, although the exact age of the range base is difficult to confirm.

6.2.3.1 *Raistrickia aculeata* and *Torispora securis* Sub-biozones (Bolsovian)

The range base of *Raistrickia aculeata* should define the lower limit of the *R. aculeata* Sub-biozone of Clayton *et al.* (2003) (figure 2.7). Using the first stratigraphic occurrence of the index taxon, the sub-biozone can only be tentatively identified in one offshore western Irish well section. Rare occurrences in cuttings samples assigned to the *Vestispora fenestrata* Biozone very tentatively define the sub-biozone lower limit in well 26/28-1. Occurrences of *R. aculeata* in wells 13/3-1 26/28-2, 26/28-3 26/28-4a, 34/5-1 and 36/16-1 are restricted to samples assigned to the *Thymospora pseudothiessenii* Biozone. The range base of *R. aculeata* offshore western Ireland potentially resembles that recorded onshore Great Britain by Smith and Butterworth (1967), who recorded the range base in the *T. obscura* Assemblage Zone XI; equivalent to the *T. pseudothiessenii* Biozone of Clayton *et al.* (2003).

McLean *et al.* (2005) recorded the range bases of *Raistrickia aculeata*, *Latensina trileta, Biharisporites haaksbergensis* and *Knoxisporites* cf. *glomus* at the lower limit of the equivalent North Sea W6b Sub-biozone (figure 2.5). Apart from *R. aculeata*, only *L. trileta* is recorded offshore western Ireland. As indicated in section 6.2.3, the range base of the taxon appears to be restricted to the *Thymospora pseudothiessenii* Biozone. McLean *et al.* (2005) also recorded a number of taxa with range tops at the W6b Sub-biozone lower limit. Offshore western Ireland, most species occur too infrequently to be useful for defining the *R. aculeata* Sub-biozone lower limit, or are recorded in younger biozones. *Apiculatasporites spinosaetosus* is recorded in two samples from well 26/28-1; one assigned to the *T. pseudothiessenii* Biozone, the other assigned to the Duckmantian age *Microreticulatisporites nobilis* Biozone. In 34/5-1 the last stratigraphic occurrence is recorded just 4.5'/1.4m below the lower limit of the *T. pseudothiessenii* Biozone and in 36/16-1 the taxon is recorded in just one sample, assigned to the *M. nobilis* Biozone. The last stratigraphic occurrences of *Vestispora tortuosa* in wells 36/16-1 and 34/5-1 are assigned to the *T. pseudothiessenii* Biozone and the taxon is recorded at the *Vestispora fenestrata/T. pseudothiessenii* Biozone boundary in 26/28-4a. However, the last stratigraphic occurrence in 26/28-2 is recorded within the *V. fenestrata* Biozone and may tentatively define the lower limit of the *R. aculeata* Sub-biozone. The last stratigraphic occurrence of *Savitrisporites nux* is consistently recorded in the *T. pseudothiessenii* Biozone. Whether this is due to reworking or a reflection of the true range top is difficult to determine, but the occurrences make the taxon unsuitable for marking the *R. aculeata* Sub-biozone lower limit. *Alatisporites pustulatus* occurs very infrequently offshore western Ireland, although in 34/5-1 the last stratigraphic occurrence may tentatively mark the sub-biozone lower limit. In 36/16-1, the taxon is recorded in two samples with the last stratigraphic occurrence recorded in the *T. pseudothiessenii* Biozone. Rare occurrences of *Reticulitriletes reticulocingulum* are recorded in samples assigned to the *T. pseudothiessenii* and *M. nobilis* Biozones in 26/28-1. Rare occurrences in 13/3-1 and 36/16-1 are assigned to the *M. nobilis* Biozone. *Reticulatisporites polygonalis* is recorded in samples assigned to the *T. pseudothiessenii* Biozone in 26/28-1 and the taxon is recorded in one sample, assigned to the *M. nobilis* Biozone in 34/5-1. The taxon is absent from other wells that encounter the *V. fenestrata* Biozone. In 34/5-1, *Reticulitriletes mediareticulatus* is recorded in a sample assigned to the *T. pseudothiessenii* Biozone with the next deepest occurrence recorded in the lowermost *V. fenestrata* Biozone. A single occurrence in 13/3-1 is recorded in Duckmantian age strata and the taxon is absent from other wells that penetrate the *V. fenestrata* Biozone. Overall, the occurrence data suggests that none of the species listed in McLean *et al.* (2005) are considered reliable marker taxa for the base of the *R. aculeata* Sub-biozone offshore western Ireland.

In wells where the lower limit of the *Raistrickia aculeata* Sub-biozone is very tentatively identified, it is possible to assign the remaining lower part of the *Vestsispora fenestrata* Biozone to the *Torispora securis* Sub-biozone (figure 2.7). The intervals assigned to the sub-biozone are characterised by occurrences of the index taxon.

McLean *et al.* (2005) also recorded the range top of *Verrucosisporites microverrucosus* in the middle of the North Sea W6b Sub-biozone, corresponding to the middle of the *Raistrickia aculeata* Sub-biozone. Rare occurrences in wells 13/3-1 and 26/28-3 are assigned to the *Thymospora pseudothiessenii* Biozone. The sole occurrence in 26/28-1 and the last stratigraphic occurrence in 26/28-2 are assigned to the Cantabrian age *Angulisporites splendidus* Biozone. McLean *et al.* also recorded the range tops of *Radiizonates faunus, Radiizonates tenuis* and *Raistrickia fulva* in the middle of the W6b Biozone. However, as noted in section 6.2.2, the range tops offshore western Ireland occur in proximity to the lower limit of the *T. pseudothiessenii* Biozone.

Comparison with other localities

North Sea

As noted above, McLean *et al.* (2005) recorded the range bases of *Vestispora fenestrata* and *Torispora securis* in proximity to the lower limit of the North Sea W6 Biozone. Offshore western Ireland, the taxa are also used to tentatively define the lower limit of the equivalent *V. fenestrata* Biozone. However, taxa with range tops recorded at the lower limit of the W6 Biozone i.e. *Grumosisporites varioreticulatus* and *G. papillosus* do not occur consistently enough to define the lower limit of the *V. fenestrata* Biozone offshore western Ireland.

None of the species that define the W6b/W6a Sub-biozone boundary in McLean *et al.* (2005) are considered reliable marker taxa for the equivalent *Raistrickia aculeata*/*Torispora securis* Sub-biozone boundary offshore western Ireland.

Onshore Great Britain

The *Torispora securis* Assemblage Zone X of onshore Great Britain (Smith and Butterworth 1967) corresponds to the *Vestispora fenestrata* Biozone of Clayton *et al.* (2003) (figure 2.1). The range bases of *T. securis* and *V. fenestrata* also mark the lower limit of Assemblage Zone X. The zone is additionally characterised by occurrences of *Punctatosporites granifer, Acanthotriletes triquetrus* and *Cirratriradites megaspinosus*. As noted above, the stratigraphic range of *P. granifer* may extend into the Duckmantian offshore western Ireland. *A. triquetrus* is only recorded in the *V. fenestrata* Biozone of well 26/28-3. Occurrences of *C. megaspinosus* characterise the *V. fenestrata* Biozone of wells 13/3-1, 26/28-1, 34/5-1, 26/28-2, but are restricted to the *Angulisporites splendidus* Sub-biozone in well 36/16-1. Assemblage Zone X is also characterised by occurrences of *Florinites mediapudens, Cristatisporites solaris, Vestispora laevigata* and *Triquitrites bransonii*. The taxa are recorded in almost all of the intervals assigned to the *V. fenestrata* Biozone offshore western Ireland.

Western Europe

In most Western European localities, the range base of *Torispora securis* is restricted to the lower Bolsovian. A lowermost Bolsovian range base is recorded in the Ruhr Basin (Grebe 1972), Belgium (Somers 1971, reported on in Peppers 1985) and the eastern part of northern France (Coquel 1976). The range base is recorded at a slightly higher stratigraphic level in the Bolsovian of the Netherlands (Van Wijhe and Bless 1974) and the western part of northern France (Loboziak 1974). Alpern *et al.* (1967)

recorded a range base close to the Duckmantian/Bolsovian boundary in the Saar-Lorraine Basin. The range base of *Vestispora fenestrata* is generally recorded in the lower Bolsovian of Western Europe. The range base is recorded in the lower Bolsovian of the Netherlands (Van Wijhe and Bless, 1974), Belgium (Somers 1971 reported on in Peppers 1985) and the Saar-Lorraine Basin (Alpern *et al.* 1967). However, the range base is recorded in the upper Bolsovian of the western part of northern France (Loboziak 1974) and the Ruhr Basin (Grebe 1972). The range base of the taxon even extends into the uppermost Duckmantian in the eastern part of northern France (Coquel 1976).

The Western European *Torispora securis* – *Torispora laevigata* (SL) Biozone of Clayton *et al.* (1977) corresponds to the *Vestispora fenestrata* Biozone of Clayton *et al.* (2003). Clayton *et al.* (1977) indicated that the range bases of *T. securis* and *V. fenestrata* define the SL Biozone lower limit, reflecting the ranges deemed to occur offshore western Ireland. As noted above, taxa with range tops recorded at the lower limit of the SL Biozone i.e *Grumosisporites varioreticulatus* and *R. fulva*, are not of use in defining the lower limit of the *V. fenestrata* Biozone offshore western Ireland. Clayton *et al*. (1977) also recorded the range base of *Punctatosporites granifer* in the lowermost part of the SL Biozone. As noted above, the taxon is recorded in samples assigned to the *V. fenestrata* Biozone, offshore western Ireland. However, occurrences are also recorded in Duckmantian age cuttings samples. Clayton *et al.* (1977) additionally recorded the range bases of *Lundbladispora gigantea*, *Latensina trileta* and *Disaccites striatiti* in the SL Biozone. Offshore western Ireland, the first stratigraphic occurrences of *L. gigantea* and *L. trileta* are restricted to the *Thymospora pseudothiessenii* Biozone. However, the first stratigraphic occurrences of *D. striatiti* are restricted to the *V. fenestrata* Biozone.

Eastern Canada

In Eastern Canada, Barss and Hacqubard (1967) identified the upper Bolsovian age *Torispora* Zone B and the lower Bolsovian age *Vestispora* Zone A (figure 2.11). The first stratigraphic occurrences of *Torispora securis* and *Torispora laevigata* define the lower limit of the *Torispora* Zone. The range base of *Vestispora fenestrata* marks the lower limit of the *Vestispora* Zone and the Duckmantian-Bolsovian Substage boundary. Although occurrences of *V. fenestrata* in well 36/16-1, offshore western Ireland have been recorded in cuttings samples assigned to the lowermost Bolsovian and Duckmantian Substages, it is noted that the first stratigraphic occurrences of the taxon in wells 34/5-1 and 13/3-1 are recorded in samples shallower than the top Duckmantian. Barss and Hacquebard also recorded the range tops of *Murospora kosankei, Speciososporites laevigatus* and *Vestispora irregularis* at the *Torispora* Zone lower limit. The taxa are not recorded offshore western Ireland. The authors additionally recorded the range tops of *Vestispora magna, Vestispora cancellata, Vestispora costata, Endosporites globiformis* and *Savitrisporites nux* at the biozone boundary. Offshore western Ireland, the range tops of *V. magna, V. costata, E. globiformis* and *S. nux* are commonly recorded in the *Thymospora pseudothiessenii* Biozone.

6.2.4 *Triquitrites sculptilis* Biozone (lowermost Bolsovian)

The *Triquitrites sculptilis* Biozone of Clayton *et al.* (2003) is tentatively identified in wells 13/3-1, 34/5-1 and possibly in well 36/16-1. The base of the biozone corresponds to the base of the Bolsovian Substage. Offshore western Ireland, the intervals tentatively assigned to the *T. sculptilis* Biozone are characterised by occurrences of the index taxon. The range top of the taxon is recorded in the Cantabrian with the range base extending at least into the Duckmantian Substage i.e. below the base of the *T. sculptilis* Biozone. McLean *et al.* (2005) also recorded a Duckmantian age range base in the North Sea.

McLean *et al.* (2005) recorded the range top of *Cristatisporties connexus* at the lower limit of the equivalent North Sea W5b Sub-biozone (figure 2.5). McLean *et al.* also recorded the range tops of a number of additional taxa including *Ahrensisporites guerickei* in proximity to the boundary. Offshore western Ireland, the last stratigraphic occurrence of *C. connexus* marks the lower limit of the *Triquitrites sculptilis* Biozone and the base of the Bolsovian Substage in well 34/5-1 and possibly 26/28-1. The taxon is not recorded in wells 13/3-1 and 36/16-1. The last stratigraphic occurrence of *A. guerickei* has been recorded at various levels offshore western Ireland. In 26/28-1, the last stratigraphic ocurrence of rare *A. guerickei* is recorded 131'/40m above the last stratigraphic occurrence of *C. connexus*, potentially reflecting the range recorded in the

North Sea. However, sporadic occurrences of the taxon have also been recorded in the middle of the *Vestispora fenestrata* Biozone in 34/5-1, in samples assigned to the *Thymospora pseudothiessenii* Biozone in 26/27-1b, in samples assigned to both *T. pseudothiessenii* and *V. fenestrata* Biozones in 36/16-1 and 26/28-2, and in the *T. pseudothiessenii/V. fenestrata* Biozone in 26/28-3. Based on range data from the North Sea (McLean *et al.* 2005) and onshore Great Britain (Smith and Butterworth 1967) the occurrences would be considered reworked. However, they may reflect the true range of the taxon, as it is noted that *A. guerickei* has been recorded in the upper Bolsovian of the Pas-de-Calais Coalfield, northern France (Loboziak 1974), in similar age strata from the eastern part of northern France (Coquel 1976) and in the middle Bolsovian of the Saar-Lorraine Basin (Alpern *et al.* 1967).

In the absence of *Cristatisporites connexus* in well 13/3-1, the lower limit of the *Triquitrites sculptilis* Biozone and the Bolsovian Substage is very tentatively positioned at the sole occurrence of *Lophotriletes granoornatus*, which coincides with the only occurrence of *Ahrensisporites guerickei* in the well. Butterworth (1984) recorded the range top of *L. granoornatus* at the Bolsovian Substage lower limit in north-western Europe and it is noted that the last stratigraphic occurrence of the taxon in 34/5-1 is recorded at the same depth as as the last stratigraphic occurrence of *C. connexus*. However, in other wells, the species is either absent or too infrequent in occurrence to be of use at this stratigraphic level. In 36/16-1, *C. connexus* and *L. granoornatus* are both absent and the only occurrences of *A. guerickei* are recorded in samples assigned to the *Thymospora pseudothiessenii* and *Vestispora fenestrata* Biozones. As a result, the last stratigraphic occurrence of *Lophotriletes* cf. *gibbosus* is very tentatively used to position the Bolsovian Substage lower limit, based on range data from Butterworth (1984). Again, the species is either absent or too infrequent in occurrence to be of use in other wells and rare, possibly reworked occurrences have also been recorded in the Asturian of well 26/28-3 and the Bolsovian of well 26/28-2.

Additional species listed by McLean *et al.* (2005) that possess range tops in proximity to the Duckmantian-Bolsovian Substage boundary in the North Sea are either absent from the offshore western Irish well sections i.e. *Adelisporites multiplicatus, Dictyomonolites swadei, Paleospora fragila* and *Tantillis triquetrus* or occur too infrequently at this stratigraphic level to be useful for palynostratigraphy i.e.

Camptotriletes bucculentus, Murospora intorta and *Densosporites duriti.* McLean *et al.* also recorded the range top of *Radiizonates* cf. *striatus* just above the substage boundary in the North Sea. Offshore western Ireland, the taxon occurs infrequently and is often recorded in strata assigned to biozones younger than the *Triquitrites sculptilis* Biozone. Although the last stratigraphic occurrence in 34/5-1 is recorded at the same depth as the last stratigraphic occurrence of *C. connexus*, in 36/16-1 the taxon is recorded in the lower part of the *Vestispora fenestrata* Biozone. The sole occurrence in 26/28-2 is recorded in the uppermost *V. fenestrata* Biozone and the taxon is absent from wells 13/3-1 and 26/28-1. McLean *et al.* also recorded the range base of *Punctatosporites rotundus* in proximity to the Duckmantian/Bolsovian Substage boundary. However, the rare occurrences of the taxon in wells 13/3-1, 26/28-1, 26/28-2 and 26/28-3 are restricted to the *Thymospora psudothiessenii* Biozone. The taxon is absent from well 36/16-1.

6.2.5 *Microreticulatisporites nobilis* Biozone (Duckmantian)

The *Microreticulatisporites nobilis* Biozone of Clayton *et al.* (2003) is tentatively recorded in wells 34/5-1, 13/3-1, 26/28-1, 26/27-1b, 36/16-1, 26/26-1 and 19/5-1. With the exception of well 19/5-1, only rare occurrences of *M. nobilis* are recorded in the intervals assigned to the biozone. The range base of the index taxon and the range top of *Sinuspores sinuatus* should define the lower Duckmantian age biozone base (figure 2.7). Offshore western Ireland, three wells (27/5-1, 26/27-1b and 19/5-1) encounter this stratigraphic level, but the biozone lower limit can only be very tentatively identified in one well. In 27/5-1, the lower limit is tentatively positioned at the first and only stratigraphic occurrence of the index taxon. The occurrence is recorded 78'/24m shallower than the last stratigraphic occurrence of *Schulzospora rara,* which marks the Langsettian/Duckmantian Substage boundary (section 6.2.6). *S. sinuatus* is not recorded in the well and occurrences of *S.* cf. *sinuatus* are restricted to a single Langsettian age sample. In 26/27-1b, occurrences of *M. nobilis* are recorded in cuttings samples deeper than the last stratigraphic occurrence of *S. rara* and the Langsettian/Duckmantian Substage boundary. Again, *S. sinuatus* is not recorded in the well and occurrences of *S.* cf. *sinuatus* are restricted to a single Langsettian age sample. In 19/5-1, occurrences of *M. nobilis* are recorded in cuttings samples assigned to the Langsettian age *Radiizonates aligerens* Biozone. The deepest occurrence in sidewall core is recorded 197'/60m above the Langsettian/Duckmantian Substage boundary. The last stratigraphic occurrence of *S. sinuatus* is recorded in Langsettian age strata, 80'/24m below the Langsettian/Duckmantian Substage boundary. As it is difficult to confirm if occurrences of *M. nobilis* in Langsettian age cuttings samples are in-situ or caved, a range base extending into the Langsettian Substage cannot be ruled out.

McLean *et al.* (2005) recorded the range base of *Microreticulatisporites nobilis* in proximity to the North Sea W4b Sub-biozone lower limit, which correponds to the base of the *M. nobilis* Biozone of Clayton *et al.* (2003) (figure 2.5). McLean *et al.* also recorded the range tops of *Sinuspores sinuatus*, *Spelaeotriletes pretiosus windsorensis* and *Densosporites* cf. *spinosus* at the sub-biozone lower limit. As indicated above, rare occurrences of *S. sinuatus* are restricted to Langsettian age strata offshore western Ireland. Both *S. pretiosus windsorensis* and *D.* cf. *spinosus* are not recorded.

6.2.5.1 *Vestispora magna* and *Lycospora noctuina noctuina* Sub-biozones (Duckmantian)

Clayton *et al.* (2003) subdivided the *Microreticulatisporites nobilis* Biozone into the *Vestispora magna* and *Lycospora noctuina noctuina* Sub-biozones. The first stratigraphic occurrence of the index taxon should mark the lower limit of the *V. magna* Sub-biozone (figure 2.7). Offshore western Ireland, *V. magna* is recorded very infrequently in Duckmantian age samples. In intervals assigned to the *V. magna* Sub-biozone wells in 19/5-1 and 26/26-1, the index taxon is only recorded in single samples. The index taxon is absent from intervals assigned to the sub-biozone in wells 13/3-1, 26/28-1, 34/5-1 and 36/16-1.

The lower limit of the *Vestispora magna* Sub-biozone is tentatively identified in wells 19/5-1 and 36/16-1. Due to the rare occurrence of the index taxon, alternative taxa are required to define the sub-biozone lower limit. McLean *et al.* (2005) recorded the range tops of a number of taxa in proximity to the lower limit of the equivalent North Sea W5a Sub-biozone (figure 2.5). However, the taxa are of limited use offshore western Ireland. *Savitrisporites concavus* is recorded in well 36/16-1, but the last stratigraphic occurrence is recorded in the upper part of the *Vestispora fenestrata*

Biozone. In well 19/5-1, the taxon is only recorded in the lowermost Duckmantian. Other taxa with range tops at the W5a/W4c Sub-biozone boundary are either absent offshore western Ireland i.e. *Deltoidospora smithii* and *Camptotriletes corrugatus* or are too rare in occurrence to be of use i.e. *Raistrickia microhorrida*.

Alternatively, the range top of *Lycospora noctuina noctuina* can be used to constrain the *Vestispora magna/L. noctuina noctuina* Sub-biozone boundary. McLean *et al.* (2005) recorded the range top of the taxon just below the equivalent North Sea W5a/W4c Sub-biozone boundary (figure 2.5). The *L. noctuina noctuina* Sub-biozone is recorded in wells 19/5-1, 27/5-1 and 26/27-1b and is characterised by occurrences of the index taxon. In 19/5-1, the *V. magna/L. noctuina noctuina* Sub-biozone boundary is tentatively constrained by the last stratigraphic occurrence of *L. noctuina noctuina*. The sub-biozone boundary is not recorded in wells 27/5-1 and 26/27-1b due to faulting/unconformity. The index taxon is absent from equivalent age strata in well 36/16-1.

In well 36/16-1, in the absence of *Lycospora noctuina noctuina* and *Vestispora magna*, the first occurrence of *Triquitrites sculptilis*, recorded in sidewall core, is used to very tentatively position the *Vestispora magna* Sub-biozone lower limit. McLean *et al.* (2005) recorded the range base of *Triquitrites sculptilis* at the base of the W5a Sub-biozone. However, in 19/5-1, it is noted that the taxon is recorded in a Duckmantian age sidewall core sample, 400'/122m below the last stratigraphic occurrence of *Lycospora noctuina noctuina*. The taxon is also recorded in Langsettian age cuttings samples, although the occurrences may be caved. Overall, there is uncertainty regarding the true range base of the taxon offshore western Ireland.

McLean *et al.* (2005) also recorded the first stratigraphic occurrence of *Punctatosporites granifer* in proximity to the North Sea W5a Sub-biozone lower limit. Offshore western Ireland, the first stratigraphic occurrence is recorded in a number of wells, although at varying stratigraphic levels. In 13/3-1, 34/5-1 and 36/16-1, the taxon is restricted to samples assigned to the *Vestispora fenestrata* Biozone and/or *Thymospora pseudothiessenii* Biozone. Infrequent occurrences are recorded in the *Microreticulatisporites nobilis* Biozone of 26/28-1 and possible caved occurrences are recorded in cuttings samples assigned to the lower Duckmantian of well 27/5-1 and the

Langsettian of 26/27-1b. The taxon is not recorded in 19/5-1. McLean *et al.* also recorded the first stratigraphic occurrence of *Cuneisporites rigidus* at the sub-biozone boundary. However, the taxon is not encountered offshore western Ireland.

6.2.6 *Sinuspores sinuatus* Biozone (lowermost Duckmantian)

The range top of *Schulzospora rara* defines the lower limit of the *Sinuspores sinuatus* Biozone and the base of the Duckmantian Substage in Clayton *et al.* (2003) (figure 2.7). This event can be identified in three offshore western Irish wells (19/5-1, 26/27-1b and 27/5-1). As indicated in section 6.2.5, the range top of *S. sinuatus* should mark the *Sinuspores sinuatus/Microreticulatisporites nobilis* Biozone boundary. The *S. sinuatus* Biozone should therefore be characterised by occurrences of the index taxon. However, as indicated in section 6.2.5, of the three wells that encounter this stratigraphic level offshore western Ireland, *S. sinuatus* is only recorded in 19/5-1 with a last stratigraphic occurrence recorded 80'/24m below that of *Schulzospora rara* and the top of the Langsettian Substage. The index taxon is absent from wells 27/5-1 and 26/27-1b, although *S.* cf. *sinuatus* is recorded in a single Langsettian age sample in both wells.

In 27/5-1, the first stratigraphic occurrences of *Radiizonates tenuis* and *Radiizonates faunus* are recorded in proximity to the Langsettian/Duckmantian Substage boundary and the *Sinuspores sinuatus* Biozone lower limit. The first stratigraphic occurrence of *R. tenuis* is recorded just 3'/1m shallower than the last stratigraphic occurrence of *Schulzospora rara*. The first stratigraphic occurrence of *R. faunus* is recorded in a cuttings sample 65'/20m deeper than the last stratigraphic occurrence of *S. rara*. In 19/5-1, occurrences of *R. tenuis* are recorded in cuttings samples assigned to the Langsettian age *Radiizonates aligerens* Biozone (although it is possible that occurrences are caved). The first stratigraphic occurrence of *R. faunus* is recorded 50'/15m shallower than the last stratigraphic occurrence of *S. rara*. In 26/27-1b, occurrences are recorded in cuttings samples assigned to the upper Langsettian age *S. rara* Biozone. In the North Sea, McLean *et al.* (2005) recorded the range bases of *R. tenuis* and *R. faunus* in proximity to the Langsettian/Duckmantian Substage boundary and the corresponding W3/W4 Biozone boundary (figure 2.5). McLean *et al.* (2004) noted the first stratigraphic occurrences of the taxa 33'/10m below the last stratigraphic occurrence of *S. rara* in the Duckmanton railway cutting of onshore Great Britain and 65’/20m deeper in the Murdoch gas field of the North Sea.

McLean *et al.* (2005) also recorded the range top of *Radiizonates striatus* in proximity to the North Sea W3/W4 Biozone boundary (figure 2.5). In 27/5-1, the last stratigraphic occurrence of *R. striatus* is recorded 23’/7m shallower than the last stratigraphic occurrence of *Schulzospora rara*. The last stratigraphic occurrence is also recorded in the lower Duckmantian of wells 19/5-1 and 26/27-1b and rare occurrences have been recorded in the upper Duckmantian age *Vestispora magna* Sub-biozone in wells 36/16-1 and 34/5-1. Overall, evidence from offshore western Ireland suggests the stratigraphic range of the taxon extends into the Duckmantian Substage.

McLean *et al.* (2005) additionally recorded the last stratigraphic occurrence of *Apiculatasporites variocorneus* in proximity to the North Sea W3/W4 Biozone boundary. Offshore western Ireland, the last stratigraphic occurrence in 27/5-1 is recorded 213’/65m below that of *Schulzospora rara*, in a sample assigned to the mid *Radiizonates aligerens* Biozone of Clayton *et al.* (2003) (section 6.2.8). The taxon is not recorded in wells 19/5-1 or 26/27-1b, possibly because this stratigraphic level is not encountered. The remaining taxa recorded by McLean *et al.* (2005) that possess range tops in proximity to the Langsettian/Duckmantian Substage boundary are not recorded in the three Irish well sections - notably *Hymenospora murdochensis, Dictyotriletes karadenizinsis, Acanthotriletes echinatoides* and *Trinidulus diamphidios.*

Comparision with other localities

North Sea

The North Sea W4b, W4c and W5a Sub-biozones of McLean *et al.* (2005) correspond to the *Microreticulatisporites nobilis* Biozone of Clayton *et al.* (2003). The W5b Sub-biozone corresponds to the *Triquitrites sculptilis* Biozone (figure 2.5). As indicated in section 6.2.4, McLean *et al.* recorded the range top of *Cristatisporites connexus* at the base of the W5b Sub-biozone, which corresponds to the base of the Bolsovian Substage in the North Sea. As indicated above, the range top of the taxon also marks the base of the *Triquitrites sculptilis* Biozone and the Bolsovian Substage offshore western Ireland. However as noted in section 6.2.4, additional taxa that possess range tops in proximity to the Duckmantian/Bolsovian boundary of the North Sea are either absent, occur very infrequently or are recorded in younger biozones offshore western Ireland.

The W4c/W5a Sub-biozone boundary recorded in the North Sea by McLean *et al.* (2005) corresponds to the boundary between the *Vestispora magna* and *Lycospora noctuina noctuina* Sub-biozones of Clayton *et al.* (2003) (figure 2.5). McLean *et al.* recorded the range base of *V. magna* at the W4c/W5a Sub-biozone boundary. As indicated in section 6.2.5.1, *V. magna* is recorded too infrequently at this stratigraphic level offshore western Ireland to be of use in defining the *V. magna*/*L. noctuina noctuina* Sub-biozone boundary. Instead, the range top of *L. noctuina noctuina* is used. The range top of the taxon is recorded just below the W4c/W5a Sub-biozone boundary in the North Sea. A number of additional taxa that possess range tops in proximity to the North Sea W4c/W5a Sub-biozone boundary are either absent, occur very infrequently or are recorded in younger biozones offshore western Ireland (see section 6.2.5.1). McLean *et al.* also recorded the range base of *Triquitrites sculptilis* at the W4c/W5a Sub-biozone boundary. The first stratigraphic occurrence possibly marks the *V. magna*/*L. noctuina noctuina* Sub-biozone boundary in well 36/16-1. However, in well 19/5-1, the taxon is recorded in a sidewall core sample below the last stratigraphic occurrence of *L. noctuina noctuina* and in Langsettian age cuttings samples.

McLean *et al.* (2005) recorded the range base of *Microreticulatisporites nobilis* at the base of the lower Duckmantian age W4b Sub-biozone. This corresponds to the lower limit of the *M. nobilis* Biozone of Clayton *et al.* (2003). In the Murdoch gas field of the North Sea, McLean *et al.* (2004) recorded the first stratigraphic appearance of the *M. nobilis* approximately 115'/35m above the top Langsettian. As noted above in section 6.2.5, the true range base of *M. nobilis* offshore western Ireland is difficult to determine. Evidence from well 27/5-1 tentatively suggests that the first stratigraphic occurrence of *M. nobilis* may occur in the lower Duckmantian. However, occurrences in Duckmantian and Langsettian age cuttings samples from the 19/5-1 and 26/27-1b wells suggest an older range base cannot be ruled out. McLean *et al.* (2005) also recorded the range tops of *Sinuspores sinuatus, Spealeotriletes pretiosus windsorensis* and *Densosporites* cf. *spinosus* at the base of the W4b Sub-biozone. Offshore western Ireland, the range top of *S. sinuatus* appears to be restricted to the Langsettian. *S. pretiosus windsorensis* and *D.* cf. *spinosus* are not recorded.

The range top of *Schulzospora rara* marks the base of the North Sea W4 Biozone of McLean *et al.* (2005), the lower limit of the *Sinuspores sinuatus* Biozone recorded offshore western Ireland and the Langsettian/Duckmantian Substage boundary in both localities. A number of additional taxa with range tops recorded at the North Sea Langsettian/Duckmantian boundary by McLean *et al.* show contrasting range tops offshore western Ireland. Taxa include *Apiculatasporites variocorneus* and *Radiizonates striatus*. Several other taxa recorded in the North Sea are absent offshore western Ireland (see section 6.2.6). McLean *et al.* (2005) also recorded the range bases of *Radiizonates tenuis* and *R. faunus* in proximity to the North Sea Duckmantian/Langsettian Substage boundary. It is possible that the taxa show similar range bases offshore western Ireland.

Onshore Great Britain

The *Vestispora magna* Assemblage Zone IX of onshore Great Britain (Smith and Butterworth, 1967) corresponds to the *Triquitrites sculptilis* Biozone and *V. magna* Sub-biozone of Clayton *et al.* (2003) (figure 2.1). Smith and Butterworth recorded the range bases of *T. sculptilis, Cristatisporites solaris* and *V. magna* at the lower limit of Assemblage Zone IX, noting a rarity and sometimes absence of the taxa until the coals above the Mansfield (Aegiranum) Marine Band at the Duckmantian/Bolsovian boundary. Offshore western Ireland, a similar rarity of *V. magna* in the upper Duckmantian is also noted. However, there is uncertainty regarding the true range base of *T. sculptilis*.

The *Dictyotriletes bireticulatus* Assemblage Zone VIII of Smith and Butterworth (1967) corresponds to the *Lycospora noctuina noctuina* Sub-biozone and *Sinuspores sinuatus* Biozone of Clayton *et al.* (2003). Smith and Butterworth indicated that the lower limit of the zone and the Langsettian/Duckmantian Substage boundary is marked by the range bases of *Radiizonates tenuis/faunus* and *Endosporites globiformis*, in addition to the range top of *Schulzospora rara*. As indicated above, the range bases of

R. tenuis and *R. faunus* offshore western Ireland possibly occur in proximity to the Langsettian/Duckmantian boundary. The range top of *S. rara* also marks the Langsettian/Duckmantian boundary (section 6.2.7). The first stratigraphic occurrences of *E. globiformis* offshore western Ireland are recorded in the upper Langsettian. In 26/27-1b, *E. globiformis* is recorded in samples, including sidewall core, deeper than the last stratigraphic occurrence of *S. rara* and the Langsettian/Duckmantian boundary. In 27/5-1 and 19/5-1, the first stratigraphic occurrences are recorded in cuttings samples 66'/20m and 190'/58m respectively deeper than the last stratigraphic occurrence of *S. rara* and the Langsettian/Duckmantian boundary. It is noted that McLean *et al.* (2004) also recorded *E. globiformis* in Langsettian age strata from the Duckmanton railway cutting of onshore Great Britain and in the Murdoch Gasfield of the North Sea.

Additional species identified by Smith and Butterworth (1967) as typical of the lower Assemblage Zone VIII i.e. *Dictyotriletes bireticulatus*, *Densosporites sphaerotriangularis, Cristatisporites connexus, Cingulizonates loricatus, Radiizonates* cf. *striatus* and *Vestispora tortuosa* are also typical of the lower Duckmantian recorded in wells 27/5-1, 19/5-1 and 26/27-1b.

In the Duckmanton railway cutting, onshore Great Britain, McLean *et al.* (2004) recorded the first stratigraphic appearance of *Microreticulatisporites nobilis* approximately 427'/130m above the last stratigraphic occurrence of *Schulzospora rara*. This reflects the lower Duckmantian age first stratigraphic occurrence of *M. nobilis* recorded in well 27/5-1, offshore western Ireland. However, data from other wells suggests a range base in proximity to the Duckmantian/Langsettian boundary cannot be ruled out.

Western Europe

The *Microreticulatisporites nobilis-Florinites junior* (NJ) Biozone of Western Europe (Clayton *et al.* 1977) corresponds to the *Triquitrites sculptilis, M. nobilis* and *Sinuspores sinuatus* Biozones of Clayton *et al.* (2003) (figure 2.1). The NJ Biozone lower limit marks the base of the Duckmantian Substage and is defined by the range bases of the index taxa in addition to the range tops of *Schulzospora rara* and

Sinuspores sinuatus. The range base of *M. nobilis* has been recorded in proximity to the Duckmantian/Langsettian boundary in the Netherlands (Van Wijhe and Bless, 1974) and northern France (Loboziak 1974, Coquel 1976). Grebe (1972) recorded a lower Duckmantian age range base in the Ruhr Basin. It is also noted that a middle Duckmantian age range base was recorded in Belgium by Somers (1971), reported on by Peppers (1985). The Western European Zone II of Coquel *et al.* (1976) roughly corresponds to the NJ Biozone (figure 2.1). The lower limit of the zone is also defined by the range bases of *M. nobilis* and *F. junior* in addition to the range tops of *S. rara* and *S. sinuatus*.

As indicated in section 6.2.5, the true range base of *Microreticulatisporites nobilis* offshore western Ireland is difficult to confirm. A range base in proximity to the Duckmantian/Langsettian boundary, reflecting the range recorded by Clayton *et al.* (1977) cannot be ruled out. Offshore western Ireland, the first stratigraphic occurrence of *Florinites junior* is recorded at the Langsettian/Duckmantian boundary in 19/5-1, in the lower Duckmantian of 26/27-1b and in an upper Langsettian age sidewall core sample in 27/5-1. The Langsettian age range tops of *Schulzospora rara* and *Sinuspores sinuatus* recorded offshore western Ireland (section 6.2.7) reflect the range tops recorded by Clayton *et al.* (1977).

In Western Europe, the range base of *Vestispora magna* is recorded at various stratigraphic levels. In the Ruhr Basin, Grebe (1972), recorded rare occurrences extending into the lower Duckmantian. In the Netherlands, Van Wijhe and Bless (1974) recorded a mid Duckmantian range base with only rare occurrences encountered in the Duckmantian. Coquel (1976) recorded a range base in the lower Bolsovian of northern France. The rare occurrences encountered in the upper Duckmantian of offshore western Ireland reflect the infrequency recorded at the same stratigraphic level in the Netherlands.

The range base of *Triquitrites sculptilis* is recorded at various stratigraphic levels in Western Europe. It is noted that Grebe (1972) recorded infrequent occurrences of *T. sculptilis* extending into Langsettian age strata of the Ruhr Basin. Loboziak (1974) and Coquel (1976) recorded a range base in the upper Duckmantian of northern France. Van Wijhe and Bless (1974) recorded a mid/lower Duckmantian age range base in the Netherlands. As indicated in section 6.2.5.1, there is uncertainty regarding the true range base of the taxon offshore western Ireland.

The range top of *Radiizonates striatus* has been recorded at various stratigraphic levels in Western Europe. Grebe (1972) recorded a top Langsettian range top in the Ruhr Basin, Van Wijhe and Bless (1974) recorded a lower Duckmantian age range top in the Netherlands, Neves (1964) also recorded a lower Duckmantian range top in Spain, and Loboziak (1974) recorded occurrences extending into the Bolsovian of northern France. The Duckmantian age range top recorded offshore western Ireland resembles the ranges recorded in the Netherlands and Spain.

Eastern Canada

The Cumberland Group is the main Duckmantian age lithostratigraphic unit of the Atlantic Provinces in Eastern Canada. Two miospore biozones (Zones F and G) were assigned to the Cumberland Group by Barss, reported on by Belt (1965) (figure 2.8). According to Barss in Hacquebard (1972), the lower part of Zone F is characterised by occurrences of *Savitrisporites nux, Densosporites* spp. and the acme of *Lycospora* spp. The upper Zone G (also considered to be a transition zone) contains elements of Zone F, but is also characterised by the first appearance of *Vestispora cancellata*.

Offshore Eastern Canada, Barss *et al.* (1979) indicated that the oldest Westphalian age rocks recorded are assigned to a '*Vestispora* Zone' that spans the upper Duckmantian to lower Bolsovian, appearing to integrate the Bolsovian age *Vestispora* (A) Zone and Zone G (figure 2.8). In the Gulf of St. Lawrence, the *Vestispora* Zone was recorded in the Bradelle L-49 well (figure 10.9) and is characterised by an assemblage including *Calamospora mutabilis*, *Camptotriletes* cf. *C. bucculentus, Cristatisporites* cf. *C. connexus, Densosporites anulatus, D.* cf. *intermedius, Dictyotriletes bireticulatus, R. mediareticulatus, Grumosisporites* cf. *G. varioreticulatus, Knoxisporites stephanephorus, Raistrickia* cf. *R. superba, Savitrisporites nux, Triquitrites sculptilis, Vestispora costata,* and *Vestispora toruosa.* In well Irishtown No. 1, also located in the Gulf of St. Lawrence, the *Vestispora* Zone assemblage comprised occurrences of *Calamospora microrugosa, Vestispora costata, V. profunda* and *V. tortuosa.* In the North Sydney P-05 well, located in the Sydney Basin, offshore eastern Nova Scotia, the *Vestispora* Zone assemblage comprised *Vestispora tortuosa*, *V. costata* and *V. magna*. In the Grand Banks, offshore eastern Newfoundland, well Hermine E-94 encountered an assemblage including *Apiculatasporites* sp., *Calamospora microrugosa*, *Convolutispora* sp., *Cyclogranisporites* sp., *Dictyotriletes* sp., *Endosporites* sp., *Florinites pumicosus*, *F. similis*, *Savitrisporites nux* and *Vestispora costata*. The assemblages are similar to that recorded in the *Triquitrites sculptilis* Biozone and *Vestispora magna* Sub-biozones of offshore western Ireland.

Utting *et al.* (2010) introduced the *Vestispora magna* Biozone based on assemblages from Spicers Cove and the Joggins section of Nova Scotia (Appendix III). The authors tentatively assigned the biozone to the late Duckmantian (figure 2.9). Utting *et al.* defined the biozone based on the first stratigraphic occurrences of *Microreticulatisporites nobilis, Mooreisporites fustis* and *Vestispora magna.* The biozone is also characterised by common occurrences of *Florinites mediapudens, Florinites pumicosus, Lycospora pellucida, Lycospora pusilla, Mooreisporites fustis, Schopfipollenites ellipsoides* and *Potonieisporites elegens*. Based on the first stratigraphic occurrences of *V. magna* and *M. nobilis* and a lack of taxa with range bases that characterise the Bolsovian of offshore western Ireland i.e. *Vestispora fenestrata* and *Torispora securis*, it is possible to correlate the *V. magna* Biozone of Utting *et al.* with the Duckmantian of offshore western Ireland. It may also be possible to correlate the *V. magna* Biozone of Utting *et al.* with the upper Duckmantian age *V. magna* Sub-biozone of offshore western Ireland based on the first stratigraphic occurrence of the index taxon. However, as the taxon is very rare in occurrence at this stratigraphic level offshore western Ireland, any correlation would be very tentative. The remaining taxa that characterise the *V. magna* Biozone of Utting *et al.* are less useful for stratigraphic correlation.

6.2.7 *Schulzospora rara* Biozone (Langsettian)

Offshore western Ireland, the upper Langsettian age *Schulzospora rara* Biozone is recorded in wells 27/5-1, 19/5-1 and is very tentatively identified in 26/27-1b. As indicated in section 6.2.6, the range top of the index taxon defines the lower limit of the succeeding *Sinuspores sinuatus* Biozone and the Langsettian/Duckmantian Substage boundary. The range top of *Radiizonates aligerens* defines the lower limit of the *S. rara* Biozone in wells 27/5-1 and 19/5-1 (figure 2.7). The last stratigraphic occurrence of *R. aligerens* also marks the equivalent North Sea W2/W3 Biozone boundary in McLean *et al.* (2005) (figure 2.5). The last stratigraphic occurrence of *R. aligerens* is recorded 95'/29m deeper than the last stratigraphic occurrence of *Schulzospora rara* in well 27/5-1 and 80'/24m deeper in well 19/5-1. Based on the absence of *R. aligerens* the biozone lower limit is not recorded in 26/27-1b. It is noted that only very rare occurrences of *S. rara* are recorded in the intervals assigned to the *S. rara* Biozone offshore western Ireland.

6.2.8 *Radiizonates aligerens* Biozone and *Vestispora cancellata* Biozone (Langsettian)

The *Radiizonates aligerens* Biozone of Clayton *et al.* (2003) is recorded in wells 27/5-1 and 19/5-1 offshore western Ireland. As indicated in section 6.2.7, the last stratigraphic occurrence of the index taxon marks the lower limit of the succeeding *Schulzospora rara* Biozone. The index taxon is recorded moderately frequently in the intervals assigned to the *R. aligerens* biozone.

There is uncertainty regarding the presence of the preceeding *Vestispora cancellata* Biozone offshore western Ireland. McLean *et al.* (2005) recorded the range bases of a number of taxa at the North Sea W2a/W2b Sub-biozone boundary, which roughly corresponds to the boundary between the *Radiizonates aligerens* Biozone and the *V. cancellata* Biozone (figure 2.5). In 19/5-1, the first stratigraphic occurrences of *Endosporites globiformis* and *Vestispora pseudoreticulata* may roughly mark the biozone boundary. However, occurrences in 27/5-1 are restricted to samples shallower than the upper limit of the *R. aligerens* Biozone. Hence there is uncertainty regarding the true range bases of the taxa offshore western Ireland.

McLean *et al.* also recorded the range tops of a number of taxa at the W2a/W2b Sub-biozone boundary. However, in general, the taxa are not useful for marking the base of the *Radiizonates aligerens* Biozone offshore western Ireland. The taxa include *Kraeuselisporites ornatus, Triquitrites* cf. *protensus, Cristatisporites splendidus, Dictyotriletes probireticulatus, Waltzispora polita* and *Convolutispora laminosa.* In well 27/5-1, the last stratigraphic occurrence of *T.* cf. *protentus* is recorded at the *Radiizonates aligerens/Schulzospora rara* Biozone boundary and occurrences are recorded in the lowermost Duckmantian of well 19/5-1. Rare occurrences of *D. probireticulatus* in wells 19/5-1, 26/27-1b and 36/16-1 are recorded in lower Duckmantian age strata. A single occurrence of *W. polita*, recorded in 27/5-1, may very roughly mark the *V. cancellata/R. aligerens* Biozone boundary. *Kraeuselisporites pseudoornatus* is recorded in 27/5-1, with occurrences extending into the lower Duckmantian. It is noted that McLean (1993) also recorded occurrences of the taxon in the Duckmantian of the North Sea.

In addition there is an absence of *Vestispora cancellata* in the two wells (27/5-1 and 19/5-1) that potentially encounter the stratigraphic level of the *V. cancellata* Biozone. The lower limit of the *Vestispora cancellata* Biozone and the lower limit of the roughly equivalent North Sea W2a Sub-biozone of McLean *et al.* (2005) should be defined by the first stratigraphic occurrence of the index taxon (figure 2.5). Overall, the *V. cancellata* Biozone cannot be identified offshore western Ireland with any confidence.

Comparison with other localities

North Sea

As indicated in sections 6.2.6 and 6.2.7, the range tops of *Schulzospora rara* and *Radiizonates aligerens* recorded offshore western Ireland reflect the range tops recorded in the North Sea by McLean *et al.* (2005).

Western Europe

In Western Europe, the range top of *Schulzospora rara* is typically recorded in close proximity to the Langsettian/Duckmantian Substage boundary, reflecting the range recorded offshore western Ireland. The range top is recorded at the substage boundary in the Ruhr Basin (Grebe 1972), Belgium (Somers 1971 reported on in Peppers 1985) and just below the top Langsettian in the eastern part of northern France (Coquel 1976). It is also noted that Van Wijhe and Bless (1974) recorded extremely rare occurrences of *S. rara* in Langsettian age strata from the Netherlands; reflecting the rarity of the taxon at this stratigraphic level offshore western Ireland. Van Wijhe and

Bless deemed the taxon unsuitable for use as an index taxon due to its seldom occurrence. In the Western European localities listed above, the range top of *Radiizonates aligerens* is typically recorded at a slightly older stratigraphic level than that of *Schulzospora rara*, reflecting the range recorded offshore western Ireland.

Clayton *et al.* (1977) assigned the *Radiizonates aligerens* (RA) Biozone to the upper Langsettian of Western Europe. The biozone corresponds to the *Schulzospora rara*, *R. aligerens* and *Vestispora cancellata* Biozones of Clayton *et al*. (2003) (figure 2.1). As indicated in section 6.2.6, Clayton *et al.* (1977) recorded the last stratigraphic occurrences of *S. rara* and *Sinuspores sinuatus* at the boundary between the RA Biozone and the succeeding *Microreticulatisporites nobilis – Florinites junior* Biozone, corresponding to the Langsettian/Duckmantian Substage boundary. Offshore western Ireland, the taxa show similar range tops. However, in contrast to offshore western Ireland, Clayton *et al.* (1977) indicated that the range top of *R. aligerens* may also extend to the top of the Langsettian Substage. In the zonal scheme of Coquel *et al*. (1976), the range tops of *S. rara* and *S. sinuatus* were recorded at the boundary between Assemblage Zones I and II, corresponding to the Langsettian/Duckmantian Substage boundary (figure 2.1). Coquel *et al.* additionally recorded the range top of *R. aligerens* a little below the upper limit of Zone I. The ranges recorded by Coquel *et al.* correspond to the ranges recorded offshore western Ireland in the present study.

Clayton *et al.* (1977) recorded the range base of infrequent *Radiizonates aligerens* and the range tops of both *Spelaeotriletes triangulus* and *Spelaeotriletes arenaceus* at the lower limit of the RA Biozone. Although the first stratigraphic occurrence of *R. aligerens* is recorded above the deepest sample in well 27/5-1, there is an absence of *S. triangulus* and *S. arenaceus*, suggesting that the mid Langsettian stratigraphic level represented by the base of the RA Biozone has not been encountered. In 19/5-1, occurrences of *R. aligerens* extend to an unconformable contact with Arnsbergian age strata.

Onshore Great Britain

The range tops of *Schulzospora rara* and *Radiizonates aligerens* recorded offshore western Ireland resemble those recorded onshore Great Britain by Smith and

Butterworth (1967). Smith and Butterworth assigned two assemblage biozones to the upper Langsettian. The *S. rara* Assemblage Zone VII corresponds to the *S. rara* Biozone of Clayton *et al.* (2003) and the *R. aligerens* Assemblage Zone VI corresponds to the *R. aligerens* and *Vestispora cancellata* Biozones of Clayton *et al.* (figure 2.1). Smith and Butterworth recorded the range top of *S. rara* at the upper limit of the *S. rara* Assemblage Zone VII and the range top of *R. aligerens* at the upper limit of the *R. aligerens* Assemblage Zone VI. Smith and Butterworth also indicated that the *S. rara* Assemblage Zone VII is characterised by occurrences of *Vestispora tortuosa, Densosporites sphaerotriangularis, Dictyotriletes bireticulatus* and *Cristatisporites connexus*. The taxa also characterise the *S. rara* Biozone assemblage recorded offshore western Ireland. Smith and Butterworth indicated that in addition to *R. aligerens*, Assemblage Zone VI is characterised by occurrences of *Florinites mediapudens, Endosporites zonalis, Pityosporites westphalensis, D. sphaerotriangularis, Laevigatosporites* spp. and *C. connexus*. With the exception of *P. westphalensis* and *E. zonalis*, the taxa also characterise the equivalent age stratigraphic intervals in wells 27/5-1 and 19/5-1. The first stratigraphic occurrence of *E. zonalis* in 27/5-1 and 19/5-1 is recorded at the same depth as the last stratigraphic occurrence of *R. aligerens*. *P. westphalensis* is absent from both wells.

McLean *et al.* (2004) developed a high-resolution palynostratigraphy for the Langsettian/Duckmantian boundary at the Duckmanton railway cutting, onshore Great Britain. The authors recorded the last stratigraphic occurrence of *Schulzospora rara* 33’/10m shallower than the Langsettian/Duckmantian Substage boundary, defined by the base of the Vanderbeckei Marine Band. The authors also recorded the last stratigraphic occurrence of *Radiizonates striatus* 33’/10m deeper than the last stratigraphic occurrence of *S. rara*. This is in contrast to the mid Duckmantian range top recorded offshore western Ireland. McLean *et al.* also recorded the last stratigraphic occurrence of *Apiculatasporites variocorneus* just 13’/4m deeper than that of *S. rara.* In addition, the last stratigraphic occurrence of *R. aligerens* was recorded 311’/95m deeper than that of *S. rara*. Offshore western Ireland, rare occurrences of *A. variocorneus* are restricted to samples that are deeper than the last stratigraphic occurrence of *R. aligerens* (section 6.2.6). McLean *et al.* also recorded occurrences of *Endosporites globiformis* in deeper samples than the last stratigraphic occurrence of *R. aligerens*. This is also noted in well 19/5-1, offshore western Ireland.

However, in well 27/5-1, the first stratigraphic occurrence of *E. globiformis* is recorded just above the last stratigraphic occurrence of *R. aligerens*.

Eastern Canada

In Eastern Canada, Barss, reported on by Belt (1965) identified the Langsettian age Zone E in the Riversdale Lithostratigraphic Group (figure 2.8). According to Hacquebard (1972), the biozone is characterised by occurrences of *Laevigatosporites* spp., the first stratigraphic occurrence of *Triquitrites* spp., *Reticulatisporites polygonalis* and *Savitrisporites nux*. Offshore western Ireland, the first stratigraphic occurrence of *S. nux* is recorded at the base of the Brigantian Substage. The first stratigraphic occurrences of *Triquitrites* spp. are recorded well into the Viséan. Occurrences of *R. polygonalis* at this stratigraphic level offshore western Ireland are very rare. A single occurrence of *R. polygonalis* is recorded 80'/24m below the top Langsettian in 19/5-1, and a single occurrence in 27/5-1 is recorded 112'/34m above the top Langsettian.

In 2010, Utting *et al.* introduced the *Raistrickia fulva* Biozone based on miospore assemblages from Spicers Cove and the Joggins section of Nova Scotia (figure 2.9, Appendix III). The authors tentatively dated the biozone as lower Langsettian in age. The biozone is defined by the first stratigraphic occurrences of *Dictyotriletes muricatus, Granasporites irregularis, Laevigatosporites minimus, Laevigatosporites minor, Laevigatosporites vulgaris, Latosporites minutus, Lycospora rotunda, Microreticulatisporites concavus, Punctatosporites* spp. and *Raistrickia fulva*. Rare *Cirratriradites saturni* were also recorded in the biozone. Utting *et al.* indicated that the first stratigraphic occurrences of *Laevigatosporites, Latosporites* and *Punctatosporites* define the biozone. The authors also suggested that the presence of *C. saturni* dated the biozone as no older than Langsettian in age based on its range in the British Isles. Utting *et al.* also suggested that the presence of *Spelaeotriletes arenaceus* indicated an age no younger than the mid Langsettian.

Offshore western Ireland, *Raistrickia fulva* is recorded throughout the Langsettian age intervals recorded in wells 19/5-1, 27/5-1 and 26/27-1b. The taxon is not recorded in lower Namurian and Viséan age strata, although a questionnable occurrence is recorded in the Arnsbergian age *Apiculatisporis variocorneus* Sub-biozone in well 26/26-1. Lower Langsettian to Chokerian age strata is not recorded offshore western Ireland either due to unconformities or due to the total depth of wells being reached in younger strata. It is possible that the range base of the taxon is in the upper Namurian as Butterworth (1984) recorded a mid Kinderscoutian range base in Western Europe. However, as this cannot be confirmed, there is little confidence in correlating the *R. fulva* Biozone of Eastern Canada with offshore western Ireland using the index taxon. The first stratigraphic occurrences of other taxa from the *R. fulva* Biozone assemblage are recorded at a variety of stratigraphic levels offshore western Ireland. The first stratigraphic occurrence of *Lycospora rotunda* is recorded 50'/15m shallower than the Langsettian upper limit in 19/5-1 and throughout the upper Langsettian interval in 27/5-1. Butterworth (1984) recorded a mid Langsettian range base in north-western Europe. The first stratigraphic occurrence of *Laevigatosporites vulgaris* is recorded in a cuttings sample at the upper limit of the Langsettian Substage in 19/5-1 and is recorded throughout the upper Langsettian interval in 27/5-1. Butterworth (1984) also recorded a mid Langsettian range base in north-western Europe. The first stratigraphic occurrence of *Laevigatosporites minimus* is recorded in the upper Langsettian age *Schulzospora rara* Biozone of 27/5-1 but is absent from 19/5-1. Butterworth (1984) recorded a Marsdenian age range base in north-western Europe. *Punctatosporites* spp. is recorded throughout the upper Langsettian in 27/5-1 although the taxon is absent from 19/5-1. Clayton *et al.* (1977) indicated that the range base of the genus is recorded at the base of the upper Langsettian age *Radiizonates aligerens* (RA) Biozone in Western Europe. *Latosporites* spp. is restricted to Stephanian age strata in 27/5-1 and is not recorded in 19/5-1. *Laevigatosporites minor* is recorded in sidewall core assigned to the Pendleian age *Verrucosisporites morulatus* Sub-biozone in 19/5-1. *Microreticulatisporites concavus* is recorded in sidewall core assigned to the Brigantian age *Tripartites vetustus* Biozone in 19/5-1 and the first stratigraphic occurrence is also recorded in the biozone. *Dictyotriletes muricatus* and *Granasporites irregularis* are not recorded in either 19/5-1 or 27/5-1. The first stratigraphic occurrence of *Cirratriradites saturni* is recorded at the base of the *Radiizonates aligerens* Biozone in 19/5-1 and in the middle of the *R. aligerens* Biozone in 27/5-1. Butterworth (1984) recorded a base Langsettian range base in Western Europe. It is possible that a similar range exists offshore western Ireland, however, this cannot be confirmed, as the base of the Langsettian has not been encountered.

It may be possible to roughly correlate the Langsettian age *Raistrickia fulva* Biozone with the Langsettian of offshore western Ireland, based on the first stratigraphic appearances of *Lycospora rotunda, Laevigatosporites vulgaris, Punctatosporites* spp. and *Cirratriradites saturni.* However, based on the presence of *Spelaeotriletes arenaceus,* it is likely that the *R. fulva* Biozone is older than the Langsettian intervals encountered offshore western Ireland. In the North Sea, the range top of the taxon occurs at the base of the W2 Biozone (McLean *et al.* 2005). This roughly corresponds to the base of the *Vestispora cancellata* Biozone of Clayton *et al.* (2003) (figure 2.1). The absence of *S. arenaceus* in the Langsettian intervals encountered offshore western Ireland suggests the sections are younger than the *R. fulva* Biozone of Eastern Canada. In addition, key taxa that define the upper Langsettian of offshore western Ireland and Western Europe (i.e *Schulzospora rara* and *Radiizonates aligerens)* are absent from the Eastern Canadian sections.

Utting *et al.* (2010) also introduced the *Raistrickia saetosa* Biozone based on miospore assemblages from the Joggins section of Nova Scotia (figure 2.9, Appendix III). The authors tentatively dated the biozone as ?Yeadonian to Langsettian in age. The biozone is defined by the first stratigraphic occurrences of *Lophotriletes microsaetosus, Florinites similis, Raistrickia abdita, Raistrickia saetosa, Schopfipollenites ellipsoides* and a *Potonieisporites / Florinites / Wilsonites / Guthoerlisporites* monosaccate complex.

Offshore western Ireland, the first stratigraphic occurrence of *Lophotriletes microsaetosus* is recorded in the Langsettian age *Radiizonates aligerens* Biozone of 27/5-1 and occurrences are restricted to Duckmantian age strata in 19/5-1. *Florinites similis*, *Raistrickia saetosa, Schopfipollenites ellipsoides, Raistrickia abdita* and *Florinites* spp. are recorded throughout the Langsettian interval in 27/5-1. The first stratigraphic occurrence of *R. abdita*, a single occurrence of *F. similis* and the first stratigraphic occurrence of *R. saetosa* are recorded in the *Radiizonates aligerens* Biozone of 19/5-1. The first stratigraphic occurrence of *S. ellipsoides* is recorded in the Brigantian of 19/5-1. *Wilsonites* spp. and *Guthoerlisporites* spp. are not recorded in either well. *Potonieisporites* spp. is only recorded in the Stephanian age interval of 27/5-1, and the genus is not recorded in the Westphalian age interval in 19/5-1.

Again, due to the absence of lower Langsettian to Chokerian age strata offshore western Ireland, it is difficult to confirm if first stratigraphic occurrences recorded in the upper Langsettian intervals represent the true range base of taxa. Butterworth (1984) recorded the range bases of *Raistrickia abdita* and *Raistrickia saetosa* in the Marsdenian of Western Europe, *Lophotriletes microsaetosus* in the Arnsbergian, *Florinites similis* in the Alportian and *Schopfipollenities ellipsoides* at the base Pendleian. Overall, it is likely that the stratigraphic interval represented by the *R. saetosa* Biozone has not been encountered offshore western Ireland.

6.2.9 Missing stratigraphy

Due to the presence of unconformities, lower Langsettian to Chokerian age strata is not recorded offshore western Ireland.

6.2.10 *Lycospora subtriquetra* Biozone (upper Arnsbergian)

The *Lycospora subtriquetra* Biozone of Clayton *et al.* (2003) corresponds to the *L. subtriquetra - Kraeuselisporiets ornatus* (SO) Biozone of onshore Great Britain (Owens *et al.* 2004), the SO Biozone of Western Europe (Clayton *et al.* 1977) and the N3 Biozone of the North Sea (McLean *et al.* 2005) (figure 2.1). Offshore western Ireland, the lowermost part of the *L. subtriquetra* Biozone is recorded in well 26/26-1. The range base of the index taxon should define the biozone lower limit (figure 2.7). Occurrences of *L. subtriquetra* in sidewall core are recorded in the interval assigned to the biozone, although caved occurrences are also recorded in Courceyan age cuttings samples.

The *Lycospora subtriquetra* Biozone lower limit in 26/26-1 is constrained by the last stratigraphic occurrences of *Tricidarisporites balteolus*, *Cingulizonates* cf. *capistratus* and the sole occurrence of *Triquitrites marginatus*. The last stratigraphic occurrence of *C.* cf. *capistratus* is recorded 38’/11.5m shallower than the last stratigraphic occurrences of *T. balteolus* and *T. marginatus*. McLean *et al.* (2005) recorded the range tops of *T. balteolus* and *C.* cf. *capistratus* in proximity to the lower limit of the equivalent North Sea N3 Biozone, although the range top of *T. marginatus* was recorded at the older N2a/N2b Sub-biozone boundary (figure 2.5). Owens *et al.* (2004) recorded the range top of *T. marginatus* at the lower limit of the equivalent SO Biozone of onshore Great Britain, although it is noted that the authors recorded the range top of *C.* cf. *capistratus* at the stratigraphically older Pendleian/Arnsbergian Substage boundary (figure 2.4).

The *Lycospora subtriquetra* Biozone recorded in 26/26-1 is also characterised by occurrences of *Kraeuselisporites ornatus* and the sole occurrence of *Apiculatasporites variocorneus*. This assemblage also appears at the base of the SO Biozone of onshore Great Britain (Owens *et al.* 2004) and Western Europe (Clayton *et al.* 1977). *Camptotriletes superbus* also characterises the SO Biozones of Great Britain and Western Europe, although the taxon is absent from well 26/26-1. Clayton *et al.* (1977) additionally recorded the range base of *Cirratriradites rarus* just above the SO Biozone lower limit in Western Europe. An absence of the species in samples assigned to the *L. subtriquetra* Biozone in 26/26-1 possibly suggests that only the lowermost part of the biozone is present in the well.

McLean *et al.* (2005) recorded the first stratigraphic occurrences of *Densosporites sphaerotriangularis* and *Florinites* spp. at the lower limit of the equivalent North Sea N3 Biozone (figure 2.5). Representatives of *Florinites* spp. are recorded in samples assigned to the *Lycospora subtriquetra* Biozone in 26/26-1, but also occur in deeper cuttings samples, possibly due to caving. *D. sphaerotriangularis* is not recorded in the well. McLean *et al.* also recorded the range tops of *Rotaspora fracta* and *Dictyotriletes vitilis* in proximity to the N3 Biozone lower limit. However, neither taxa are recorded in 26/26-1. Owens *et al.* (2004) additionally recorded the range tops of *Rotaspora knoxi, Triquitrites trivalvis* and *Tripartites vetustus* at the lower limit of the SO Biozone onshore Great Britain (figure 2.4). In 26/26-1, the last stratigraphic occurrence of *R. knoxi* is recorded below the *Lycospora subtriquetra* Biozone lower limit. Neither *T. trivalvis* nor *T. vetustus* are recorded in the well.

6.2.10.1 *Apiculatisporis variocorneus* Sub-biozone (upper Arnsbergian)

The *Apiculatisporis variocorneus* Sub-biozone of Clayton *et al*. (2003) is identified in well 26/26-1 based on the first and only occurrence of the index taxon. The taxon is recorded in sidewall core just above the lower limit of the *Lycospora subtriquetra* Biozone. The lower limit of the sub-biozone corresponds to the lower limit of the *L. subtriquetra* Biozone (figure 2.7). Owens *et al.* (2004) also recorded the first stratigraphic occurrence of *A. variocorneus* at the lower limit of the equivalent *L. subtriquetra - A. variocorneus* (SV) Sub-biozone of onshore Great Britain (figure 2.4). The authors additionally recorded the range tops of *Schulzospora campyloptera, Crassispora maculosa, Microreticulatisporites concavus* and *Bellispores nitidus* at the SV/SR Sub-biozone boundary. In 26/26-1, *C. maculosa/kosankei* is recorded in samples assigned to the *A. variocorneus* Sub-biozone. However, the last stratigraphic occurrences of *Schulzospora* spp. and *B. nitidus* are restricted to samples deeper than the sub-biozone lower limit. *M. concavus* and *S. campyloptera* are absent from the well. Hence the assemblage recorded in the *A. variocorneus* Sub-biozone does not closely resemble that of the SV Sub-biozone.

Comparison with other localities

Western Europe, onshore Great Britain and the North Sea

As noted above, the *Lycospora subtriqeutra* Biozone of Clayton *et al.* (2003) corresponds to the *L. subtriquetra - Kraeuselisporiets ornatus* (SO) Biozone of onshore Great Britain (Owens *et al.* 2004), the Western European *L. subtriquetra – K. ornatus* (SO) Biozone of Clayton *et al.* (1977) and the N3 Biozone of the North Sea (McLean *et al.* 2005). The interval assigned to the *L. subtriquetra* Biozone offshore western Ireland is characterised by a miospore assemblage that also appears at the base of the SO Biozone in Great Britain and Western Europe; notably *L. subtriqeutra, K. ornatus* and *Apiculatasporites variocorneus*. In contrast, McLean *et al.* (2005) only recorded the range bases of *Densosporites sphaerotriangularis* and *Florinites* spp. at the N3 Biozone lower limit in the North Sea.

The range tops of *Tricidarisporites balteolus* and *Cingulizonates* cf. *capistratus,* recorded offshore western Ireland at the *Lycospora subtriquetra* Biozone lower limit reflect the range tops recorded in the North Sea by McLean *et al.* (2005) at the equivalent N3 Biozone lower limit. In contrast, Owens *et al.* (2004) recorded the range top of *C.* cf. *capistratus* at the stratigraphically older Arnsbergian Substage lower limit, onshore Great Britain. However, the range top of *Triquitrites marginatus,* also recorded at the *L. subtriquetra* Biozone lower limit offshore western Ireland, reflects the range top recorded onshore Great Britain by Owens *et al.* In contrast, the range top in the North Sea is recorded at the N2a/N2b Sub-biozone boundary, which corresponds to the middle of the stratigraphically older *Mooreisporites trigallerus* Biozone of Clayton *et al.* (2003).

The *Crassispora kosankei* Assemblage Zone IV of onshore Great Britain (Smith and Butterworth, 1967) corresponds to the upper part of the *Mooreisporites trigallerus* Biozone and the *Lycospora subtriquetra* Biozone of Clayton *et al.* (2003) (figure 2.1). Smith and Butterworth recorded the range base of *C. kosankei* and the range tops of *Rotaspora* spp. and *Tripartites* spp. at the lower limit of the Assemblage Zone. Offshore western Ireland, *C. kosankei* is recorded in sidewall core assigned to the Pendleian age *Verrucosisporites morulatus* Sub-biozone of well 19/5-1 and the first stratigraphic occurrence is recorded in cuttings samples assigned to a possible Pendleian/Brigantian Substage boundary. Occurrences of *Rotaspora* spp. in 26/26-1 are restricted to samples below the lower limit of the *Apiculatisporis variocorneus* Sub-biozone. *Tripartites* spp. is not recorded in the well.

6.2.11 *Mooreisporites trigallerus* Biozone? (Arnsbergian)

The *Mooreisporites trigallerus* Biozone has not been identified offshore western Ireland. Occurrences of the index taxon are restricted to a single sample in well 26/28-3 and considered reworked.

6.2.12. *Cingulizonates* cf. *capistratus* Biozone (upper Brigantian – top Pendleian) and *Bellispores nitidus* Sub-biozone (upper Brigantian).

The *Cingulizonates* cf. *capistratus* Biozone and *Bellispores nitidus* Sub-biozone of Clayton *et al.* (2003) are recorded in wells 19/5-1 and 26/26-1. The biozone and sub-biozone lower limit in 19/5-1 is defined by the first stratigraphic occurrence of *C.* cf. *capistratus*, which is also recorded in sidewall core. The first stratigraphic occurrence of *B. nitidus* is recorded in a cuttings sample 250'/76m deeper, although it is possible that the occurrence is caved. In 26/26-1, the first stratigraphic occurrence of *C.* cf. *capistratus* is considered caved. The biozone lower limit is positioned at a sample depth marked by the sole occurrence of *B. nitidus* and the second deepest occurrence of *C.* cf. *capistratus*. McLean *et al.* (2005) also recorded the range bases of *C.* cf. *capistratus* and *B. nitidus* in proximity to the lower limit of the equivalent N1 Biozone and N1a Sub-biozone of the North Sea (figure 2.5). Owens *et al.* (2004) additionally recorded the range base of *C.* cf. *capistratus* at the lower limit of the equivalent *C.* cf. *capistratus – Bellispores nitidus* (CN) Biozone of onshore Great Britain and indicated that the range base of *B. nitidus* is potentially coincident (figure 2.4).

The *Cingulizonates* cf. *capistratus* Biozone of Clayton *et al.* (2003) also corresponds to the *Bellispores nitidus - Reticulatisporites carnosus* (NC) Biozone of Western Europe (Clayton *et al.* 1977). Clayton *et al.* (1978) proposed that the lower limit of the NC Biozone in the British Isles should be defined by the range base of *C.* cf. *capistratus* due to rarity of the index taxa. Clayton (1985) also noted that the first stratigraphic occurrences of *Crassispora kosankei, Florinites* spp. and *Schopfipollenites ellipsoides* occur in proximity to the base of the Namurian Stage in Western Europe, although the author indicated that occurrences were too rare to be used for recognising the boundary. In 19/5-1, the first stratigraphic occurrence of *C. kosankei* is recorded in a cuttings sample at a possible Brigantian/Pendleian, Namurian/Viséan boundary. The first stratigraphic occurrence of *S. ellipsoides* is recorded in the uppermost Brigantian and the first stratigraphic occurrence of *Florinites* spp. is restricted to Westphalian age strata.

Ideally the lower limit of the *Cingulizonates* cf. *capistratus* Biozone offshore western Ireland would be constrained by the range tops of taxa. McLean *et al.* (2005) recorded the range top of *Cribrosporites cribellatus* at the equivalent North Sea N1 Biozone lower limit and the range top of *Kraeuselisporites* sp. A in proximity to the biozone base (figure 2.5). Unfortunately, neither taxa are recorded in the two Irish wells sections that encountered this stratigraphic level. Species listed in Clayton *et al.* (1978) that possess range tops at the *Bellispores nitidus-Reticulatisporites carnosus* (NC) Biozone lower limit in the British Isles are generally too rare to be of use or are absent from the offshore western Irish well sections. *Dictyotriletes sagenoformis* is only recorded in well 26/26-1, in a single sample assigned to the *Apiculatisporis variocorneus* Sub-biozone. *Stenozonotriletes coronatus* is recorded in samples considerably deeper than the *C.* cf. *capistratus* Biozone lower limit in wells 19/5-1 and 26/26-1. *Chaetospherites pollenisimilis, C. cribellatus* and *Tripartites distinctus* are not recorded in either well. Other species listed with range bases that define the NC Biozone lower limit are rare or absent. *Convolutispora varicosa* is recorded in one sample from 19/5-1, within the interval assigned to the *C.* cf. *capistratus* Biozone. *Reticulatusporites carnosus* is restricted to one Westphalian age sample from 19/5-1.

6.2.12.1 *Verrucosisporites morulatus* Sub-biozone (Pendleian)

The *Verrucosisporites morulatus* Sub-biozone of Clayton *et al.* (2003) is recorded in well 19/5-1. Owens *et al.* (2004) recorded the range base of the index taxon at the lower limit of the equivalent *V. morulatus* Sub-biozone of onshore Great Britain (figure 2.4). In 19/5-1, occurrences of the index taxon at this stratigraphic level are rare. In the interval assigned to the sub-biozone, the taxon is recorded in one sample. However, *V. morulatus* is also recorded in two sidewall core samples assigned to the lower Brigantian age *Tripartites vetustus* Biozone of Clayton *et al.* (2003). The Pendleian age *V. morulatus* Sub-biozone cannot be assigned to this depth as the Brigantian/Pendleian boundary is positioned significantly shallower. Hence it is possible that the range base of *V. morulatus* extends into the lower Brigantian of offshore western Ireland.

The *Verrucosisporites morulatus* Sub-biozone lower limit and the Brigantian/Pendleian boundary in 19/5-1 is positioned at the last stratigraphic occurrence of *Crassispora aculeata*. The range top of the taxon defines the lower limit of the equivalent North Sea N1b Sub-biozone of McLean *et al.* (2005) (figure 2.5).

Owens *et al.* (2004) recorded the range top of the taxon just above the lower limit of the equivalent *Verrucosporites morulatus* Sub-biozone of onshore Great Britain.

Owens *et al.* (2004) also recorded the first stratigraphic occurrences of *Ahrensisporites guerickei, Potioneisporites elegans* and rare *Crassispora kosankei* at the lower limit of the *Verrucosisporites morulatus* Sub-biozone of onshore Great Britian (figure 2.4). In 19/5-1, the first stratigraphic occurrence of *A. guerickei* is recorded just 30'/9m shallower than the last stratigraphic occurrence of *C. aculeata.* The first stratigraphic occurrence of *C. kosankei* is recorded in a cuttings sample 359'/109m deeper, although it is possible that occurrences are caved. *P. elegans* is not recorded in the well. McLean *et al.* (2005) also recorded the first stratigraphic occurrences of *Grumosisporties inaequalis, Grumosisporties rufus, Radiizonates striatus* and *Proprisporites laevigatus* in proximity to the lower limit of the North Sea N1b Sub-biozone. In 19/5-1 an occurrence of *G. inaequalis* is recorded just below (40'/12m) the last stratigraphic occurrence of *C. aculeata.* A single deeper occurrence may be caved. *G. rufus* is only recorded in one sample but within the interval assigned to the *V. morulatus* Sub-biozone. *R. striatus* is not recorded at this stratigraphic level in the well.

Onshore Great Britain, Owens *et al.* (2004) recorded the last stratigraphic occurrences of *Raistrickia nigra*, *Reticulatisporites carnosus* and *Rotaspora fracta* at the boundary between the *Verrucosisporites morulatus* Sub-biozone and the succeeding *Mooreisporites trigallerus – Rotaspora knoxi* (TK) Biozone (figure 2.4). In the North Sea, McLean *et al.* (2005) recorded the range tops of *R. nigra, Grumosisporties inaequalis, Acanthotriletes falcatus, Stenozonotriletes coronatus, Grumosisporties verrucosus, Verrucosisporites nodosus* and *Vestispora lucida* at or in proximity to the equivalent the N1b/N2a Sub-biozone boundary (figure 2.5). In 19/5-1, the upper limit of the *V. morulatus* Sub-biozone is missing due to an unconformity. The first downhole occurrences of *R. fracta* and *G. inaequalis* are recorded in the first sample below the unconformity and the first downhole occurrence of *R. nigra* is recorded 120'/37m deeper. *R. carnosus* is only recorded as a reworked occurrence in the overlying Westphalian age strata and *S. coronatus* is only recorded in samples significantly deeper than the sub-biozone lower limit. *A. falcatus, G. verrucosus, V. nodosus* and *V. lucida* are not recorded in the well.

Occurrences of *Anapiculatisporites globulus* and *Schulzospora ocellata* characterise the interval assigned to the *Verrucosisporites morulatus* Sub-biozone in 19/5-1. Butterworth (1984) also recorded the range bases of the taxa in the Pendleian of Western Europe. Clayton *et al.* (1977) additionally indicated that the range bases of *Proprisporites laevigatus* and *Secarisporites lobatus* occur at the same stratigraphic level as that of *V. morulatus* in Western Europe. However, the taxa are not recorded in wells 19/5-1 or 26/26-1.

The lower part of the *Cingulizonates* cf. *capistratus* Biozone not assigned to the *V. morulatus* Sub-biozone in well 19/5-1 is assigned to the *Bellispores nitidus* Sub-biozone of Clayton *et al.* (2003). The sub-biozone is characterised by occurrences of the index taxon. As indicated in section 6.2.12, the interval assigned to the *C.* cf. *capistratus* Biozone in 26/26-1 is also assigned to the *B. nitidus* Sub-biozone.

Comparison with other localities

Western Europe, onshore Great Britain and the North Sea

As noted above, the *Cingulizonates* cf. *capistratus* Biozone recorded offshore western Ireland correponds to the *C.* cf. *capistratus - Bellispores nitidus* (CN) Biozone of onshore Great Britain (Owens *et al.* 2004), the *B. nitidus - Reticulatisporites carnosus* (NC) Biozone of the British Isles (Clayton *et al.* 1978, Clayton 1985) and Western Europe (Clayton *et al.* 1977) in addition to the N1 Biozone of the North Sea (McLean *et al.* 2005) (figure 2.1). The *C.* cf. *capistratus* Biozone recorded offshore western Ireland resembles the CN Biozone of Owens *et al.,* the NC Biozone of Clayton (1985) and the N1 Biozone of McLean *et al.* in that the biozone lower limits are defined by the first stratigraphic occurrence of *C.* cf. *capistratus*. The first stratigraphic occurrence of *B. nitidus* also characterises the biozones. In contrast to the N1 Biozone of the North Sea, occurrences of *Cribrosporites cribellatus* and *Kraeuselisporites sp.* A are not recorded at the lower limit of *C.* cf. *capistratus* Biozone offshore western Ireland.

The *Verrucosisporites morulatu*s Sub-biozone recorded offshore western Ireland correponds to the *V. morulatus* Sub-biozone of onshore Great Britain (Owens *et al.* 2004) and the N1b Sub-biozone of the North Sea (McLean *et al.* 2005). Evidence from well 19/5-1 suggests the range base of *V. morulatus* offshore western Ireland does not define the sub-biozone lower limit. Occurrences indicate the stratigraphic range extends into the lower Brigantian. This contrasts with the base Pendleian range base recorded by Owens *et al*. onshore Great Britain. The range top of *Crassispora aculeata* defines the lower limit of the sub-biozone offshore western Ireland, reflecting the range recorded in the North Sea by McLean *et al.* Owens *et al.* (2004) recorded the range top of the taxon just above the lower limit of the *V. morulatus* Sub-biozone onshore Great Britain. The base Pendleian range base of *Ahrensisporites guerickei* offshore western Ireland reflects the range base recorded in the North Sea and onshore Great Britian. A number of taxa with range bases recorded at the lower limit of the *V. morulatus* Sub-biozone of onshore Great Britian and the N1b Sub-biozone of the North Sea are not recorded at this stratigraphic level offshore western Ireland or are recorded in deeper cuttings samples which may be caved.

The *Rotaspora knoxi* Assemblage Zone III Biozone of Smith and Butterworth (1967) corresponds to the upper *Cingulizonates* cf. *capistratus* Biozone / *Verrucosisporites morulatus* Sub-biozone and most of the *Mooreisporites trigallerus* Biozone of Clayton *et al.* (2003) (figure 2.1). The authors used the first stratigraphic occurrence of *Convolutispora cerebra, Vestispora lucida, Savitrisporites nux* and *Bellispores nitidus* to distinguish between Assemblage Zone III and the older *Diatomozonotriletes saetosus* Assemblage Zone II. In 19/5-1, *C. cerebra* is recorded in a single sample which is assigned to the *V. morulatus* Sub-biozone. The taxon is absent from 26/26-1 and *V. lucida* is absent from both wells. Occurrence data from offshore western Ireland suggests the range base of *B. nitidus* occurs in proximity to the lower limit of the *C.* cf. *capistratus* Biozone. In 19/5-1, *S. nux* is recorded in sidewall core samples assigned to the Brigantian age *Tripartites vetustus* Biozone, reflecting the range base recorded in the North Sea by McLean *et al.* (2005) and contrasting with the range base recorded by Smith and Butterworth (1967).

Eastern Canada

The *Reticulatisporites carnosus* Biozone of Utting and Giles (2008) was recorded in the Barachois Group of southwest Newfoundland and dated as ?Pendleian to Arnsbergian in age (figure 2.9). The biozone was characterised by the first stratigraphic occurrences of *Anapiculatisporites baccatus, Corrugitriletes radiatus, Crassispora kosankei, Cribrosporites cribellatus, Dictyotriletes castaneaeformis, Florinites pumicosus, Granulatisporites microgranifer, Grumosisporites rufus, Grumosisporites verrucosus, Microreticulatisporites concavus, Potonieisporites elegans, Reticulatisporites carnosus, Reticulatisporites polygonalis, Savitrisporites nux* and *Waltzispora planiangulata.* The appearance of rare and sporadic occurrences of monosaccate pollen *Florinites* spp. and *Potonieisporites elegens* were considered key events.

In the 19/5-1 well, offshore western Ireland, the first stratigraphic occurrence of *Crassispora kosankei* is recorded in a cuttings sample assigned to the upper Brigantian age *Bellispores nitidus* Sub-biozone. *Grumosisporites rufus* is recorded in a single sample assigned to the *V. morulatus* Sub-biozone. *Microreticulatisporites concavus*, *Savitrisporites nux* and *Waltzispora planiangulata* are recorded in sidewall core samples assigned to the Brigantian age *Tripartites vetustus* Biozone. The first stratigraphic occurrences of *M. concavus* and *S. nux* are also recorded in the *T. vetustus* Biozone, although the first stratigraphic occurrence of *W. planiangulata* is recorded in a cuttings sample assigned to the uppermost *Triquitrites marginatus* Biozone. The first stratigraphic occurrence of *Anapiculatisporites baccatus* is recorded in a sidewall core sample at the lower limit of the upper Brigantian age *B. nitidus* Sub-biozone. Occurrences of *Florinites* spp., *Reticulatisporites carnosus, Reticulatisporites polygonalis* and *Granulatisporites microgranifer* are restricted to the Westphalian interval. *Corrugitriletes radiatus, Cribrosporites cribellatus, Dictyotriletes castaneaeformis, Grumosisporites verrucosus* and *Potonieisporites elegens* are not recorded in the well.

In 26/26-1, *Anapiculatisporites baccatus* is recorded in a sidewall core assigned to the Arnsbergian age *Apiculatisporis variocorneus* Sub-biozone, but also in deeper cuttings samples. The first stratigraphic occurrence of *Dictyotriletes castanaeformis* and the sole occurrence of *Reticulatisporites carnosus/polygonalis* are restricted to the *A. variocorneus* Sub-biozone. As *Crassispora kosankei* and *Savitrisporites nux* are recorded in cuttings samples throughout the well section, some occurrences are likely to be caved. The first stratigraphic occurrence of *Florinites* spp. is recorded in cuttings samples assigned to Asbian age strata. All other taxa, including *Potonieisporites elegans*, are absent from the well.

Overall, the first stratigraphic occurrences of the taxa that define the *Reticulatisporites carnosus* Biozone of Eastern Canada are recorded at a variety of stratigraphic levels offshore western Ireland. As a result, correlation between Eastern Canada and offshore western Ireland is difficult. A number of taxa whose first stratigraphic occurrences define the *Reticulatisporites carnosus* Biozone are also recorded in sidewall core samples that are older than Pendleian and Arnsbergian in age; notably *Microreticulatisporites concavus*, *Savitrisporites nux* and *Waltzispora planiangulata.* It may be possible to correlate the *R. carnosus* Biozone with offshore western Ireland using the first stratigraphic appearance of *Crassispora kosankei*. As indicated above, the first stratigraphic appearance in 19/5-1 is recorded below the Pendleian-Brigantian boundary. However, as the occurrence is in a cuttings sample, the range base may be younger.

The *Grandispora spinosa – Ibrahimispores magnificus* (SM) Biozone of Utting (1987) has been recorded in the Codroy and Deer Lake Groups of western Newfoundland, the lower Mabou Group of Nova Scotia, the uppermost Windsor Group of Nova Scotia and the Shepody and Clarmont formations of New Brunswick. Utting and Giles (2004) and Utting *et al.* (2010) tentatively dated the biozone as latest Brigantian to Pendleian in age. The biozone is defined by the first stratigraphic occurrences of *G. spinosa, I. magnificus, Raistrickia nigra, Schulzospora bilunata* and *Tricidarisporites arcuatus*. The first stratigraphic occurrences of the genera *Ibrahimispores* and *Schulzospora* also define the biozone.

Offshore western Ireland, the range base of *Raistrickia nigra* is deemed to occur in proximity to the lower limit of the Asbian age *Triquitrites marginatus* Biozone (section 6.2.14). In 19/5-1, the first stratigraphic occurrence of *Grandispora spinosa* is recorded in a cuttings sample assigned to the upper part of the *T. marginatus* Biozone.

The deepest occurrence in sidewall core is recorded at the lower limit of the upper Brigantian age *Bellispores nitidus* Sub-biozone. The first stratigraphic occurrence of *Tricidarisporites arcuatus* is recorded in sidewall core assigned to the *T. marginatus* Biozone. A single occurrence of *Ibrahimispores magnificus* is restricted to Westphalian age strata and *Schulzospora bilunata* is absent from the well. The first stratigraphic occurrence of *Ibrahimispores* spp. is recorded in a sidewall core sample assigned to the upper part of the Brigantian age *Tripartites vetustus* Biozone. The first stratigraphic occurrence of *Schulzospora* spp. is recorded in a cuttings sample assigned to the Asbian/Holkerian age *Schulzospora campyloptera* Biozone. The deepest occurrence in sidewall core is assigned to the *T. marginatus* Biozone. In 26/26-1, *G. spinosa, I. magnificus, S. bilunata, Ibrahimispores* spp., *R. nigra, T. arcuatus* are not recorded. *Schulzospora* spp. is recorded in cuttings samples throughout the well section.

Overall, the first stratigraphic occurrences of the taxa that define the SM Biozone of Eastern Canada are recorded at a variety of stratigraphic levels offshore western Ireland. It is also noted that a number of the taxa whose first stratigraphic occurrences define the SM Biozone are recorded offshore western Ireland in sidewall core samples that are older than Brigantian and Pendleian in age. However, it may be possible to roughly correlate the upper Brigantian in Eastern Canada and offshore western Ireland based on the first stratigraphic occurrence of *Ibrahimispores* spp.

International correlation

As noted in section 2.5, Clayton *et al.* (1990) noted that the first stratigraphic appearance of *Florinites* spp. and *Potonieisporites elegans* is an early Serpukhovian event in Western Europe. *Florinites* spp. also appears at a similar level in the USA and the Ukraine. *P. elegans* is not recorded offshore western Ireland. Occurrences of *Florinites* spp. in 19/5-1 are restricted to the Westphalian interval that unconformably overlies the Pendleian age strata. In 26/26-1, the first stratigraphic occurrence of *Florinites* spp. is recorded in a cuttings sample assigned to the Asbian age *Triquitrites marginatus* Biozone. However, it is possible that the occurrences are caved. The deepest occurrence in sidewall core is recorded in the Arnsbergian age *Apiculatisporis variocorneus* Sub-biozone which would fit with the early Serpukhovian event.

6.2.13 *Tripartites vetustus* Biozone (Brigantian)

The *Tripartites vetustus* Biozone of Clayton *et al.* (2003) is recorded in well 19/5-1 and is tentatively identified in 26/26-1. The index taxon is recorded infrequently at this stratigraphic level. The lower limit of the biozone in 19/5-1 is positioned at least as deep as first stratigraphic occurrence of the index taxon. The depth coincides with the first stratigraphic occurrence of *Savitrisporites nux*. McLean *et al.* (2005) recorded the range bases of the two taxa in proximity to the lower limit of the equivalent North Sea V5 Biozone (figure 2.5). The range bases also mark the lower limits of the equivalent *T. vetustus-Rotaspora fracta* (VF) Biozones of the British Isles (Clayton *et al.* 1978, Clayton 1985) and Western Europe (Clayton *et al.* 1977). McLean *et al.* (2005) and Clayton *et al.* (1977) also recorded the range base of *Crassispora maculosa* in proximity to the lower limit of the V5 and VF Biozones. In 19/5-1, an occurrence of *C. maculosa* in sidewall core is recorded 172'/52m deeper than the first stratigraphic occurrence of *T. vetustus*. Due to the infrequency of *T. vetustus* at this stratigraphic level, it is possible that the lower limit of the *T. vetustus* Biozone extends to the occurrence of *C. maculosa* in sidewall core. A significantly deeper occurrence of *C. maculosa* in a cuttings sample is considered caved.

It is questionnable as to whether the *Tripartites vetustus* Biozone can be identified in well 26/26-1. Although the index taxon is not recorded in the well, an interval containing occurrences of *Crassispora maculosa/kosankei,* and *Savitrisporites nux* very tentatively suggests a biozone no older and no younger than the *T. vetsustus* Biozone.

Murospora margodentata is recorded in a single sidewall core sample assigned to the lower part of the *Tripartites vetustus* Biozone in 19/5-1. The taxon is also recorded in a cuttings sample assigned to the *T. vetustus / Triquitrites marginatus* Biozone boundary in 26/26-1. Based on range data from the North Sea, the British Isles and Western Europe, occurrence of the taxon confirms a biozone no younger than the lower *T. vetustus* Biozone and no older than the mid *T. marginatus* Biozone of Clayton *et al.* (2003). The range top of the taxon is recorded in the lower V5 Biozone of the North Sea (McLean *et al.* 2005) and in the lower VF Biozone of the British Isles

(Clayton *et al.* 1978, Clayton 1985). The range base of the taxon is recorded in the mid V4 Biozone of the North Sea (McLean *et al.* 2005) and in the mid NM Biozone of the British Isles (Clayton *et al.* 1978, Clayton 1985).

McLean *et al.* (2005) and Clayton *et al.* (1977, 1978) recorded the range bases of *Rotaspora fracta* and *Tripartites non-guerickei, Rotaspora knoxi* and *Triquitrites trivalvis* at the lower limit of the North Sea V5 Biozone and the VF Biozone of the British Isles and Western Europe. In 19/5-1, the first stratigraphic occurrences of *R. fracta* and *T. non-guerickei* are recorded within the interval assigned to the *T. vetustus* Biozone. *R. knoxi* and *T. trivalvis* are only recorded in samples assigned to younger biozones. *R. fracta, T. non-guerickei* and *T. trivalvis* are absent from well 26/26-1 and *R. knoxi* is absent from the interval tentatively assigned to the *T. vetustus* Biozone. Clayton *et al.* (1977, 1978) also recorded the range bases of *Grandispora spinosa, Diatomozonotriletes saetosus* and *Spencerisporites radiatus* at the lower limit of the VF Biozone. In 19/5-1, *G. spinosa* is recorded within the interval assigned to the *T. vetustus* Biozone, but also in a cuttings sample deeper than the biozone lower limit. The taxon is absent in 26/26-1. *D. saetosus* is absent in both 19/5-1 and 26/26-1. *S. radiatus* is absent in 19/5-1 but is recorded in a sample shallower than the interval assigned to the biozone in 26/26-1.

A number of taxa with range tops recorded at the lower limit of the North Sea V5 Biozone (McLean *et al.* 2005) (figure 2.5) are either absent or too rare to be useful for defining the *Tripartites vetustus* Biozone lower limit offshore western Ireland. In 19/5-1, *Triquitrites comptus* and *Potonieisporites delicatus* only occur in single samples outside the interval assigned to the *T. vetustus* Biozone. *Corbulispora cancellata, Murospora parthenopia* and *Verrucosisporites eximius* are absent from the well. *P. delicatus, C. cancellata, M. parthenopia* and *V. eximius* are not recorded in 26/26-1. However, occurrences of *Triquitrites marginatus* var. *comptus* may mark the boundary between the *T. vetustus* and *Triquitrites marginatus* Biozones in 26/26-1.

Species listed in Clayton *et al.* (1977, 1978) with range tops at the VF Biozone lower limit or within the biozone are either absent or too rare to be useful offshore western Ireland. In 19/5-1, *Verrucosisporites baccatus, Cribrosporites cribellatus* and *Murospora parthenopia* are absent, *Perotrilites tessellatus* and *Potoniespores delicatus* occur in single samples deeper than the biozone lower limit. All of the taxa are absent from well 26/26-1.

Comparison with other localities

Western Europe, onshore Great Britain and the North Sea

As noted above, the *Tripartites vetustus* Biozone of Clayton *et al.* (2003) recorded offshore western Ireland corresponds to the equivalent V5 Biozone of the North Sea (McLean *et al.* 2005) and the *T. vetustus* - *Rotaspora fracta* (VF) Biozone of the British Isles (Clayton *et al.* 1978, Clayton 1985) and Western Europe (Clayton *et al.* 1977).

The range base of *Tripartites vetustus* marks the lower limits of the above biozones. However, occurrences of the index taxon at this stratigraphic level offshore western Ireland are infrequent. As a result, the range bases of *Savitrisporites nux*, and *Crassispora maculosa* are used to constrain the *T. vetustus* Biozone lower limit. The range bases of the taxa are also recorded in proximity to the North Sea V5 Biozone lower limit of McLean *et al.* (2005) and at the VF Biozone lower limit (Clayton *et al.* 1977). It is noted that Pereira (1999) also defined the base of the equivalent *Savitrisporites nux* (SN) in Portugal using the first stratigraphic occurrence of the index taxon (figure 2.6).

As noted above, a number of additional taxa with range bases recorded at the lower limit of the North Sea V5 Biozone and VF Biozone of the British Isles and Western Europe are not useful for defining the lower limit of the *T. vetustus* Biozone offshore western Ireland. The taxa are either restricted to younger biozones i.e *Rotaspora knoxi* and *Triquitrites trivalvis,* or are recorded within the *T. vetustus* Biozone, but in samples shallower than the lower limit i.e *Rotaspora fracta* and *Tripartites non-guerickei*.

The *Diatomozonotriletes saetosus* Assemblage Zone II of onshore Great Britain, recorded by Smith and Butterworth (1967), roughly corresponds to the lower *Cingulizonates* cf. *capistratus* Biozone, the *Tripartites vetustus* Biozone and the upper

Triquitrites marginatus Biozone of Clayton *et al.* (2003) (figure 2.1). Smith and Butterworth indicated that the assemblage could be distinguished from other assemblages by the presence of the genus *Diatomozonotriletes*. Species of *Tripartites* and *Rotaspora* also make first stratigraphic appearances within the assemblage. In 19/5-1, the genus *Diatomozonotriletes* is recorded in a single sample, which is assigned to the *T. vetustus* Biozone. However, in 26/26-1, the genus is also recorded in a single sample, assigned to the younger *Lycospora subtriquetra* Biozone. In 19/5-1, the first stratigraphic occurrence of *Tripartites* spp. is recorded in proximity to the lower limit of the *T. vetustus* Biozone. The first stratigraphic occurrence of *Rotaspora* spp. is recorded at a possible boundary between the *T. vetustus* Biozone and the *C.* cf. *capistratus* Biozone. In 26/26-1, the deepest non-caved occurrence of *Rotaspora* spp. is recorded in the *C.* cf. *capistratus* Biozone. *Tripartites* spp. is not recorded in the well.

Eastern Canada

The *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Biozone of Utting (1987) was recorded in the Upper Codroy Group of south-western Newfoundland and the upper Windsor Group of Nova Scotia. Utting and Giles (2004) assigned the Biozone to the Brigantian Substage (figure 2.9). The biozone is defined by the first stratigraphic occurrences of *Knoxisporites triradiatus, Rugospora corporata* var. *verrucosa, Schopfipollenites acadiensis* and *Secarisporites remotus*. The first stratigraphic occurrence of the genus *Schopfipollenites* also characterises the biozone. A *Crassispora maculosa – Spelaeotriletes arenaceus* palynofacies was also recorded in the upper part of the biozone in south-western Newfoundland. The range bases of the index taxa define the palynofacies.

In well 19/5-1, the first stratigraphic occurrences of *Secarisporites remotus, Schopfipollenites* spp. and the sole occurrence of *Knoxisporites triradiatus* are recorded in the upper Brigantian age *Bellispores nitidus* Sub-biozone. In 26/26-1, occurrences of *K. triradiatus, Rugospora corporata* and *Schopfipollenites* spp. are restricted to Duckmantian age strata unconformably overlying the Mississippian age section. *S. remotus* is absent from 26/26-1 and *S. acadiensis* is absent from both wells. Offshore western Ireland, the range base of *Crassispora maculosa* is recorded in stratigraphically older strata than the range bases of *S. remotus, Schopfipollenites* spp. and *K. triradiatus*. The first stratigraphic occurrence of *C. maculosa* is recorded at the lower limit of the Brigantian age *Tripartites vetustus* Biozone in 19/5-1. The first stratigraphic occurrence of *Spelaeotriletes arenaceus* is assigned to the Arnsbergian age *Apiculatisporis variocorneus* Sub-biozone in 26/26-1 although the taxon is not recorded in 19/5-1. Overall, occurrence data from 19/5-1 suggests it may be possible to correlate the AT Biozone of Eastern Canada with the *Bellispores nitidus* Sub-biozone of offshore western Ireland based on the first stratigraphic occurrences of *S. remotus, Schopfipollenites* spp. and *K. triradiatus.* Alternatively, the base of the *C. maculosa – S. arenaceus* palynofacies of Eastern Canada could be correlated with the base of the *Tripartites vetustus* Biozone of offshore Western Europe using the range base of *C. maculosa*.

Intercontinental correlation

Clayton *et al.* (1990) indicated that the first stratigraphic appearance of *Tripartites vetustus* in the upper Viséan may enable correlation between Western Europe, the midcontinent U.S.A, the Donets Basin of the Ukraine and Gansu, China (section 2.5). The first stratigraphic occurrence of the taxon in the upper Viséan age *T. vetustus* Biozone of well 19/5-1 suggests it may be possible to correlate offshore western Ireland with these localities at this stratigraphic level.

6.2.14 *Triquitrites marginatus* Biozone (upper Asbian)

The *Triquitrites marginatus* Biozone of Clayton *et al.* (2003) is recorded in well 19/5-1 and tentatively recorded in 26/26-1. Clayton (1985) indicated that the range bases of *Raistrickia nigra* and *T. marginatus* mark the lower limit of the equivalent *R. nigra – T. marginatus* (NM) Biozone of the British Isles (figure 2.1). Clayton *et al.* (1977) also recorded the range base of *R. nigra* at the lower limit of the equivalent NM Biozone of Western Europe (figure 2.2). McLean *et al.* (2005) recorded the range base of *R. nigra* in proximity to the lower limit of the equivalent V4 Biozone of the North Sea, but recorded the range base of *T. marginatus* in the middle of the older V3 Biozone (figure 2.5).

In well 19/5-1, the lower limit of the *Triquitrites marginatus* Biozone is positioned at least as deep as the second deepest occurrence of the index taxon. The occurrence is recorded in sidewall core, 90'/27m shallower than the second deepest occurrence of *Raistrickia nigra*. The first stratigraphic occurrences of *T. marginatus* and *R. nigra* are recorded in significantly deeper cuttings samples and are potentially caved. It is difficult to determine if the second stratigraphic occurrence of *R. nigra* is in-situ or caved due to its occurrence in a cuttings sample. As a result, the lower limit of the *T. marginatus* Biozone is positioned either at the second stratigraphic occurrence of *R. nigra* or at the occurrence of *T. marginatus* in sidewall core.

Offshore western Ireland, there is an absence of species whose range tops mark the equivalent lower limits of the North Sea V4 Biozone (McLean *et al*. 2005) (figure 2.5) and the NM Biozone of Western Europe (Clayton *et al.* 1977). The range top of *Verrucosisporites congestus* defines the lower limit of the V4 Biozone and the range tops of *Tripartites distinctus* and *Ahrensisporites duplicatus* mark the lower part of the NM Biozone. The taxa are not recorded in 19/5-1. However, an occurrence of *Potonieisporites delicatus* in a single sample, 90'/27m shallower than the first stratigraphic occurrence of *Raistrickia nigra* may help constrain the *Triquitrites marginatus* Biozone lower limit in 19/5-1. Clayton *et al.* (1977) recorded the range top of the taxon in the lower part of the Western European NM Biozone, although it is noted that McLean *et al.* (2005) recorded the range top of the taxon at the top of the equivalent V4 Biozone in the North Sea.

Other taxa with range bases that occur in proximity to the North Sea V4 Biozone lower limit of McLean *et al*. (2005) are either absent in the 19/5-1 well or are too rare in occurrence to be of use. *Monilospora mutabilis, Murospora parthenopia and Spelaeotriletes arenaceus* are both absent in 19/5-1 and *Remysporites magnificus* is only recorded in one sample, just above the upper biozone limit. Clayton *et al.* (1977) also recorded the range bases of *Kraeuselisporites echinatus, M. mutabilis* and *M. parthenopia* at the NM Biozone lower limit and the range bases of *Densosporites* cf. *velatus, M. parthenopia and M. mutabilis* taxa in the middle of the biozone. All of the taxa are absent from the 19/5-1 well. Clayton *et al.* (1978) indicated that the lower limit of the NM Biozone of the British Isles is also defined by the first stratigraphic occurrence of *Rotaspora ergonulii* and *Tripartites distinctus*. *T. distinctus* is absent in the 19/5-1 well and *R. ergonulii* is only recorded in a single sample, shallower than the *Triquitrites marginatus* Biozone upper limit.

The upper limit of the *Triquitrites marginatus* Biozone is identified in well 26/26-1. The biozone boundary is tentatively positioned based solely on the occurrence of *Triquitrites marginatus* var. *comptus*. McLean *et al.* recorded the range top of *T. comptus* at the boundary between the equivalent V4 Biozone and the succeeding V5 Biozone of the North Sea.

6.2.14.1 *Murospora margodentata* and *Murospora parthenopia* Sub-biozones

The *Triquitrites marginatus* Biozone of Clayton *et al.* (2003) is sub-divided into the *Murospora margodentata* and *Murospora parthenopia* Sub-biozones (figure 2.7). McLean *et al.* (2005) also subdivided the North Sea V4 Biozone into the equivalent V4a and V4b Sub-biozones; the sub-biozone boundary defined by the range base of *M. margodentata* (figure 2.5). Clayton *et al.* (1978) and Clayton (1985) also subdivided the NM Biozone of the Britain Isles into the equivalent *M. margodentata - Rotaspora ergonulii* (ME) and *Tripartites distinctus - M. parthenopia* (DP) Sub-biozones using the range base of *M. margodentata* (figure 2.1). The *T. marginatus* Biozone recorded in wells 19/5-1 and 26/26-1 cannot be sub-divided into the *M. margodentata* and *M. parthenopia* Sub-biozones of Clayton *et al.* (2003). *M. margodentata* is only recorded in one sample from the 19/5-1 well, which is assigned to the lower *Tripartites vetustus* Biozone. The index taxon *M. parthenopia* is also absent from the well. *M. margodentata* is recorded in one sample in 26/26-1, at the upper limit of the *T. marginatus* Biozone. McLean *et al.* also recorded the range top of *Murospora mutabilis* at the V4a/V4b Sub-biozone boundary. However, the taxon is absent from both 19/5-1 and 26/26-1 wells.

Comparison with other localities

Western Europe, onshore Great Britain and the North Sea

As noted above, the first stratigraphic occurrence of *Triquitrites marginatus* and *Raistrickia nigra* (excluding obvious caved occurrences of *T. marginatus*) mark the lower limit of the *T. marginatus* Biozone offshore western Ireland. The range bases also mark the lower limit of the equivalent *R. nigra – T. marginatus* (NM) Biozone of the British Isles (Clayton 1985). Clayton *et al.* (1977) also recorded the range base of *R. nigra* at the lower limit of the NM Biozone of Western Europe. McLean *et al.* (2005) recorded the range base of *R. nigra* at the lower limit of the equivalent North Sea V4 Biozone, but recorded the range base of *T. marginatus* below the biozone lower limit. Other species with range tops that mark the lower limits of North Sea V4 Biozone (McLean *et al*. 2005) and the NM biozone of Western Europe (Clayton *et al.* 1977) are either absent or too rare in occurrence to be useful for palynostratigraphy offshore western Ireland.

6.2.15 *Schulzospora campyloptera* Biozone (lower Asbian to mid Holkerian)

McLean *et al.* (2005) recorded the range tops of taxa including *Schopfites claviger* and the range base of *Schulzospora* spp. at the lower limit of the V3 Biozone; the North Sea equivalent of the *Schulzospora campyloptera* Biozone of Clayton *et al*. (2003) (figure 2.5). Based on range data from the North Sea, the lower limit of the *S. campyloptera* Biozone in 19/5-1 is positioned at either the last stratigraphic occurrence of *S. claviger* or at the first stratigraphic occurrence of *Schulzospora* spp. which is 695'/211m shallower. Occurrences of the index taxon are restricted to samples assigned to younger biozones.

McLean *et al.* (2005) also recorded the range tops of *Raistrickia clavata, Raistrickia corynoges, R. polyptcha* and *Convolutispora circumvallata* at the lower limit of the V3 Biozone. The taxa are absent in 19/5-1. McLean *et al.* additionally recorded the range top of *Perotrilites tessellatus* in the lower part of the V3 Biozone. A single occurrence in 19/5-1 is assigned to the younger *Triquitrites marginatus* Biozone. It is noted that this approximates to the range top of the taxon recorded in the British Isles by Clayton *et al.* (1978). The range base of *Schulzospora* spp. recorded offshore western Ireland may also reflect the range recorded by Clayton *et al.* (1978) in the British Isles. The authors indicated that the range base of *Schulzospora* spp. is recorded at the top of the Holkerian Substage, correponding to the middle of the *Schulzospora campyloptera* Biozone of Clayton *et al.* (2003).

Comparison with other localities

Eastern Canada

Utting and Giles (2004) assigned an Asbian age to the *Knoxisporites stephanephorus* Concurrent Range Zone of Eastern Canada (figure 2.10). The authors recorded the first stratigraphic occurrences of *Auroraspora solisorta, Knoxisporites probolos, Knoxisporites stephanephorus* and *Spelaeotriletes tuberosus* within the biozone. Out of the above taxa, only *K. stephanephorus* is recorded offshore western Ireland. In well 19/5-1, the first stratigraphic appearance is recorded in the lower Asbian, which reflects the range base recorded in Eastern Canada and potentially enables correlation between the two localities. In contrast, Clayton (1985) and McLean *et al.* (2005) recorded a mid Arundian age range base for the taxon in the British Isles and North Sea (section 6.2.16).

6.2.16 *Knoxisporites stephanephorous* Biozone (Holkerian to Arundian)

In 19/5-1, the strata between the lower limit of the *Schulzospora campyloptera* Biozone and the well TD is tentatively assigned to a biozone no younger than the *Knoxisporites stephanephorus* Biozone of Clayton *et al*. (2003) (figure 2.7).

The *Knoxisporites stephanephorus* Biozone corresponds to the *K. stephanephorus* - *Knoxisporites triradiatus* (TS) Biozone of the British Isles (Clayton 1985) (figure 2.1). Higgs *et al.* (1988b) identified the TS Biozone in Sligo and Lough Allen, in the northwest of Ireland. The authors recorded the first stratigraphic occurrences of the two index taxa at the biozone lower limit. In the North Sea, McLean *et al.* (2005) recorded the range base of *K. stephanephorus* at the lower limit of the equivalent V2 Biozone and the range base of *K. triradiatus* in the lower part of the biozone (figure 2.5).

Offshore western Ireland, the base of the *Knoxisporites stephanephorous* Biozone cannot be identified using the range bases of *K. stephanephorus* or *Knoxisporites triradiatus*. In 19/5-1, the first stratigraphic occurrence of *K. stephanephorus* is recorded in a lower Asbian age sample assigned to the uppermost part of the *S.*

campyloptera Biozone (section 6.2.15). A single occurrence of *K. triradiatus* is recorded in a sample assigned to the *Cingulizonates* cf. *capistratus* Biozone. It is noted that Utting and Giles (2004) recorded the range base of *K. triradiatus* in the Brigantian age *Schopfipollenites acadiensis – K. triradiatus* (AT) Biozone of Eastern Canada (section 6.2.13). Occurrences of *Lycospora pusilla* recorded in the 19/5-1 interval confirm a biozone no older than the *L. pusilla* Biozone of Clayton *et al.* (2003) and an age no older than the Chadian Substage (figure 2.7).

6.2.17 ?*Schopfites claviger* Biozone (Courceyan)

In the lowermost part of 26/26-1, based on range data from the North Sea, an assemblage including *Schopfites claviger, Raistrickia clavata* and *Convolutispora circumvallata/cancellata* indicate a biozone no younger than the North Sea V2 Biozone, equivalent to the *Knoxisporites stephanephorus* Biozone of Clayton *et al.* (2003). An absence of *Lycospora pusilla* tentatively suggests a biozone no younger than the Courceyan age *S. claviger* Biozone of Clayton *et al.* The presence of *S. claviger* also confirms a biozone no older than the *S. claviger* Biozone. However, it is noted that *L. pusilla* is rarely recorded in the entire Carboniferous succession in 26/26-1.

Overall, the interval in 26/26-1 is tentatively assigned to the *S. claviger* Biozone of Clayton *et al.* (2003). The *S. claviger* Biozone corresponds to the *Schopfites claviger – Auroraspora macra* (CM) Biozone of Clayton *et al.* (1977) (figure 2.1).

6.1.18 Comparison with original zonal scheme of Clayton *et al.* (1977)

In total, 15 biozones and 10 sub-biozones from the revised Western European miospore zonal scheme of Clayton *et al.* (2003), can be recognised offshore western Ireland, although with varying levels of confidence. This compares with the 11 biozones that can be recognised using the original zonal scheme of Clayton *et al.* (1977) for the same Courceyan to Cantabrian age stratigraphic interval (see Appendix VII).

6.3 POSSIBLE CORRELATIONS WITH EASTERN CANADA

Based on the findings in section 6.2, there is potential for correlation between the Carboniferous of offshore western Ireland and Eastern Canada at a number of levels;

1. First stratigraphic occurrence of *Cordaitina* at the base of the Autunian Stage. The first stratigraphic occurrence of *Cordaitina* offshore western Ireland is recorded in proximity to the base of the lower Autunian age VC Biozone of Clayton *et al.* (1977). In Eastern Canada, Barss and Hacquebard (1967) recorded the range base of the genus at the equivalent *Vittatina* Biozone lower limit (section 6.2.1).

2. The first stratigraphic occurrence of *Angulisporites splendidus* at the base of the Cantabrian Substage. The first stratigraphic occurrence of *Angulisporites splendidus* marks the base of the *A. splendidus* Sub-biozone of Clayton *et al.* (2003) recorded offshore western Ireland and the base of the Cantabrian Substage recorded in the Sydney Coalfields of Eastern Canada by Cleal *et al.* (2003) and Dimitrova and Cleal (2008) (section 6.2.2.1).

3. The first stratigraphic occurrence of *Thymospora obscura*. Barss and Hacquebard (1967) recorded the range base of *T. obscura* at the lower limit of the Asturian age *Thymospora* Zone in Eastern Canada. Evidence from offshore western Ireland suggests the range base of the taxon occurs in proximity to this stratigraphic level, enabling a rough correlation with Eastern Canada (section 6.2.2.2).

4. The first stratigraphic occurrence of *Torispora securis*. Barss and Hacquebard recorded the range base of *T. securis* at the base of the mid Bolsovian age *Torispora* Zone. The range base of the taxon offshore western Ireland most likely occurs in the lower Bolsovian, enabling a rough correlation (section 6.2.3).

5. The first stratigraphic occurrence of *Vestispora magna* and *Microreticulatisporites nobilis*. In Eastern Canada, the first stratigraphic occurrences of *M. nobilis* and *V. magna* are recorded in the Duckmantian age *V. magna* Biozone of Utting *et al.* (2010). As both taxa are rare at this stratigraphic level offshore western Ireland, any correlation will be very tentative. However, if present, the first stratigraphic

occurrences may enable correlation with the Duckmantian Substage of offshore western Ireland (section 6.2.5).

6. The first stratigraphic occurrence of *Ibrahimispores* spp. The first stratigraphic appearance of *Ibrahimispores* in Eastern Canada is recorded in the latest Brigantian to Pendleian age *Grandispora spinosa – Ibrahimispores magnificus* (SM) Biozone of Utting (1987) and Utting and Giles (2004). The first stratigraphic occurrence offshore western Ireland is recorded in the upper part of the Brigantian age *Tripartites vetustus* Biozone, potentially enabling correlation at this stratigraphic level (section 6.2.12).

7. The first stratigraphic occurrence of *Crassispora maculosa*. Offshore western Ireland, the first stratigraphic occurrence is recorded at the lower limit of the Briganitan age *Tripartites vetustus* Biozone of Clayton *et al.* (2003). In Eastern Canada, the range base is recorded in the *C. maculosa - Spelaeotriletes arenaceus* palynofacies of the Briganitan age *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Biozone of Utting (1987) and Utting and Giles (2004) (section 6.2.13). The first stratigraphic occurrence enables a rough correlation of Briganitan age strata.

8. The first stratigraphic occurrence of *Knoxisporites stephanephorus.* Offshore western Ireland, the first stratigraphic occurrence of *K. stephanephorus* is recorded in a lower Asbian age sample assigned to the uppermost part of the *S. campyloptera* Biozone. In Eastern Canada, the range base of the taxon is recorded in the Asbian age *Knoxisporites stephanephorus* Concurrent Range Zone of Utting and Giles (2004) (section 6.2.15), enabling correlation at this stratigraphic level.

6.4 A REVISED MIOSPORE ZONAL SCHEME FOR OFFSHORE WESTERN IRELAND

Based on the results of section 6.2, the following revised miospore zonal scheme is proposed for offshore western Ireland. Ranges of key taxa are shown in figure 6.21.

***Potonieisporites* spp. – *Cordaitina* spp. Biozone (?lower Autunian)**

The *Potonieisporites* spp. – *Cordaitina* spp. Biozone is tentatively recorded in wells 34/15-1 and 12/2-1z. The lower limit of the biozone is marked by the transition from a mixed spore and monosaccate pollen assemblage to an assemblage dominated by monosaccate pollen, notably *Potonieisporites* spp. This palynological event is recorded at the boundary between the upper Stephanian age *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone and the lower Autunian age *Vittatina costabilis* (VC) Biozone of Western Europe (Clayton *et al.* 1977). It is therefore likely that the *Potonieisporites* spp. – *Cordaitina* spp. Biozone corresponds to the VC Biozone.

The range top of *Endosporites globiformis* also marks the lower limit of the *Potonieisporites* spp. – *Cordaitina* spp. Biozone offshore western Ireland. The first stratigraphic appearance of *Cordaitina* is additionally recorded in proximity to the lower limit. However, the absence of *Vittatina* spp. suggests the *Potonieisporites* spp. – *Cordaitina* spp. Biozone may instead be uppermost Stephanian in age, corresponding to the upper part of the Western European NBM Biozone of Clayton *et al.* (1977).

***Potonieisporites* spp. – *Endosporites globiformis* Biozone (base undefined to Stephanian C)**

The *Potonieisporites* spp. – *Endosporites globiformis* Biozone corresponds to the Western European *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone of Clayton *et al.* (1977). The biozone is tentatively recorded in well 34/15-1. The biozone may be present in 12/2-1z, however, there is significant uncertainty regarding the age of the interval (section 6.2.1). The biozone is characterised by a mixed assemblage of spores and monosaccate pollen. Taxa recorded in both 34/15-1 and 12/2-1z include representatives of *Potonieisporites*, *Florinites*, *Cadiospora*, *Calamospora*, *Lycospora* and occurrences of *E. globiformis*. The range top of *E. globiformis* marks the biozone upper limit. The range top of *Lycospora* is also recorded in the biozone. An absence of *Vestispora fenestrata* and *Angulisporites splendidus* helps to distinguish the biozone from the older *A. splendidus*

– *Cheleidonites* spp. Biozone (see below). The lower limit of the biozone is not encountered offshore western Ireland.

In 12/2-1z, taxa including *Thymospora pseudothiessenii*, *Spinosporites,* rare *Vittatina* and *Crassispora kosankei* are also recorded in the interval tentatively assigned to the biozone. However, as there is significant uncertainty regarding the age of the interval, the range data from 12/2-1z is not included in figure 6.21.

The *Potonieisporites* spp. – *Endosporites globiformis* Biozone also corresponds to Zone VI of Coquel *et al.* (1976) (figure 6.21).

Thymospora pseudothiessenii **Biozone (upper Bolsovian to at least Cantabrian)**

The range base of the index taxon defines the lower limit of the *Thymospora pseudothiessenii* Biozone. The biozone lower limit is upper Bolsovian in age. The biozone corresponds to the Western European *T. pseudothiessenii* Biozone of Clayton *et al.* (2003). The range bases of *Spinosporites*, *Lundbladispora gigantea* and *Latensina trileta* are also recorded in the lowermost part of the biozone. Occurrences of *Cadiospora magna, Punctatosporites oculus* and *Mooreisporites* cf. *inusitatus* characterise the biozone, although there is uncertainty regarding the range bases of the taxa offshore Western Ireland. The range top of *Dictyotriletes bireticulatus* provides a rough approximation for the biozone lower limit, although occurrences are very rare at this stratigraphic level. The range tops of rare *Radiizonates tenuis* and *Radiizonates faunus* also provide a rough approximation for the biozone lower limit. The range top of *Raistrickia fulva* possibly occurs in proximity to the lower limit. The biozone also corresponds to the W7 Biozone of the North Sea (McLean *et al.* 2005), the Assemblage Zones XI, XII and XIII of onshore Great Britain (Smith and Butterworth 1967, Smith 1987) and the Western European *T. obscura – Thymospora thiessenii* (OT) Biozone of Clayton *et al.* (1977) (figure 6.21). The upper part of the biozone extends into the Cantabrian, however the upper limit has not been encountered offshore western Ireland.

Angulisporites splendidus – Cheleidonites spp. Sub-biozone (Cantabrian to undefined top)

The range bases of *Angulisporites splendidus* and *Cheleidonites* spp. define the lower limit of the sub-biozone. The lower limit corresponds to the base of the Cantabrian Substage. Occurrences of both index taxa are rare. The sub-biozone corresponds with the Cantabrian age Western European *A. splendidus* Sub-biozone of Clayton *et al.* (2003). The present study has not been able to confirm the age of the sub-biozone upper limit offshore western Ireland (figure 6.2.1).

In addition to the index taxa, the sub-biozone is also characterised by occurrences of *Vestispora fenestrata, Thymospora* spp.*, Latensina trileta, Torispora securis, Endosporites globiformis, Endosporites zonalis, Westphalensisporites irregularis, Crassispora kosankei* and *Lycospora* with rare occurrences of *Potonieisporites* and *Spinosporites*.

Assemblage Zones XII and XIII of onshore Great Britain (Smith 1987) correlate with the *A. splendidus – Cheleidonites* spp. Sub-biozone (figure 6.21).

Thymospora obscura Sub-biozone (Asturian)

The Asturian age *Thymospora obscura* Sub-biozone is tentatively identified offshore western Ireland. The sub-biozone corresponds to the Western European *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003). The range bases of *Schopfites dimorphus, Cirratiriradites annulatus, T. verrucosa,* and *Savitrisporites camptotus* are recorded within the sub-biozone. Occurrences of the taxa are very rare. The range base of the index taxon tentatively marks the sub-biozone lower limit as there is some uncertainty regarding the exact age of the event offshore western Ireland (section 6.2.2.2). The range tops of *Lophotriletes microsaetosus, Vestispora costata* and *Florinites junior* possibly occur in proximity to the base of the Asturian, although evidence from offshore western Ireland is limited. The sub-biozone also corresponds to the W7b and W7c Sub-biozones of the North Sea (McLean *et al.* 2005) (figure 6.21).

Westphalensisporites irregularis Sub-biozone (upper Bolsovian)

If the Asturian age *Thymospora obscura* Sub-biozone can be identified offshore western Ireland, the remaining upper Bolsovian part of the *Thymospora pseudothiessenii* Biozone can be assigned to the *Westphalensisporites irregularis* Sub-biozone. The sub-biozone corresponds to the Western European *W. irregularis* Sub-biozone of Clayton *et al.* (2003). Occurrences of the index taxon define the sub-biozone.

Vestispora fenestrata – Torispora securis Biozone (Bolsovian)

The lower limit of the biozone is defined by the first stratigraphic occurrences of *Vestispora fenestrata* and *Torispora securis*. The biozone corresponds to the Bolsovian age *V. fenestrata* Biozone of Clayton *et al.* (2003). The range base of *Disaccites striatiti* also occurs within the biozone. Unfortunately, the lower limit of the biozone is not constrained by the range top of a taxon. The biozone corresponds to the Western European *T. securis – Torispora laevigata* (SL) Biozone of Clayton *et al.* (1977), the W6 Biozone of the North Sea (McLean *et al.* 2005) and the *T. securis* Assemblage Zone X of onshore Great Britain (Smith and Butterworth 1967) (figure 6.21).

Radiizonates tenuis – Microreticulatisporites nobilis Biozone (Duckmantian to lower Bolsovian)

The *Radiizonates tenuis – Microreticulatisporites nobilis* Biozone corresponds to the Western European *Triquitrites sculptilis, M. nobilis* and *Sinuspores sinuatus* Biozones of Clayton *et al.* (2003). The biozone lower limit corresponds to the base of the Duckmantian Substage. The range top of *Schulzospora rara* defines the lower limit of the biozone, although occurrences of the taxon are very rare. The range base of *R. tenuis* possibly occurs in proximity to base of the biozone. The biozone is additionally characterised by occurrences of *Radiizonates faunus* and infrequent occurrences of *M. nobilis*.

The biozone corresponds to the Western European *M. nobilis – Florinites junior* (NJ) Biozone of Clayton *et al.* (1977), the W4 and W5 Biozones of the North Sea (McLean *et al.* 2005) in addition to the *Dictyotriletes bireticulatus* Assemblage Zone VIII and *Vestispora magna* Assemblage Zone IX of onshore Great Britain (Smith and Butterworth 1967) (figure 6.21).

The *Radiizonates tenuis – Microreticulatisporites nobilis* Biozone is tentatively sub-divided into three sub-biozones (see below).

Triquitrites sculptilis **Sub-biozone (lower Bolsovian),** ***Cristatisporites connexus - Lophotriletes granoornatus*** **Sub-biozone (upper Duckmantian) and** ***Lycospora noctuina noctuina*** **Sub-biozone (lower Duckmantian)**

The lower Bolsovian age *Triquitrites sculptilis* Sub-biozone is characterised by occurrences of the index taxon. The lower limit of the sub-biozone and the base of the Bolsovian Substage is defined by the range tops of *Cristatisporites connexus* and *Lophotriletes granoornatus.*

The upper Duckmantian age *Cristatisporites connexus* - *Lophotriletes granoornatus* Sub-biozone is characterised by occurrences of the index taxa. The lower limit of the sub-biozone is defined by the range top of *Lycospora noctuina noctuina*.

The *Lycospora noctuina noctuina* Sub-biozone is characterised by occurrences of the index taxon. The lower limit corresponds the base of the *Radiizonates tenuis-Microreticulatisporites nobilis* Biozone and the Duckmantian Substage lower limit.

The *Triquitrites sculptilis* Sub-biozone corresponds to the Western European *T. sculptilis* Biozone of Clayton *et al.* (2003) and the W5b Sub-biozone of the North Sea (McLean *et al.* 2005). The *Cristatisporites connexus* - *Lophotriletes granoornatus* Sub-biozone corresponds to the *Vestispora magna* Sub-biozone of Clayton *et al.* (2003). Occurrences of *V. magna* are very rare at this stratigraphic level offshore western Ireland. The *C. connexus* - *L. granoornatus* Sub-biozone also corresponds to the W5a Sub-biozone of the North Sea (McLean *et al.* 2005) and the lower part of the *Vestispora magna* Assemblage Zone IX of onshore Great Britain (Smith and

Butterworth 1967) (figure 6.21). The *Lycospora noctuina noctuina* Sub-biozone corresponds to the Western European *L. noctuina noctuina* Sub-biozone and *Sinuspores sinuatus* Biozone of Clayton *et al.* (2003). The sub-biozone also corresponds to the W4 Biozone of the North Sea (McLean *et al.* 2005) and the *Dictyotriletes bireticulatus* Assemblage VIII of onshore Great Britain (Smith and Butterworth 1967) (figure 6.21).

As *Cristatisporites connexus*, *Lophotriletes granoornatus* and *Lycospora noctuina noctuina* generally occur infrequently offshore western Ireland and have not been recorded in all wells that penetrate this stratigraphic level, the *Triquitrites sculptilis*, *Cristatisporites connexus* - *Lophotriletes granoornatus* and *L. noctuina noctuina* Sub-biozones are only tentatively included within the revised zonal scheme.

Schulzospora rara Biozone (uppermost Langsettian)

The *Schulzospora rara* Biozone is characterised by occurrences of the index taxon. The range top of *S. rara* defines lower limit of the succeeding *Radiizonates tenuis – Microreticulatisporites nobilis* Biozone in addition to the Langsettian/ Duckmantian Substage boundary. The range top of *Radiizonates aligerens* defines the lower limit of the *S. rara* Biozone. As *S. rara* is very rare in occurrence at this stratigraphic level offshore western Ireland, the biozone may be difficult to identify based solely on occurrences of the index taxon. The *S. rara* Biozone corresponds to the Western European *S. rara* Biozone of Clayton *et al.* (2003), the *S. rara* Assemblage VII of onshore Great Britain (Smith and Butterworth 1967), the W3 Biozone of the North Sea (McLean *et al.* 2005) and the upper part of the Western European *Radiizonates aligerens* (RA) Biozone of Clayton *et al.* (1977) (figure 6.21).

Radiizonates aligerens Biozone (upper Langsettian)

The *Radiizonates aligerens* Biozone is characterised by occurrences of the index taxon. The range top of *R. aligerens* defines the lower limit of the succeeding *Schulzospora rara* Biozone. The biozone replaces both *R. aligerens* and *Vestispora cancellata* Biozones of Clayton *et al.* (2003) as the *V. cancellata* Biozone cannot be recorded with confidence offshore western Ireland. The range tops of rare

Apiculatasporites variocorneus and *Sinuspores sinuatus* are also restricted to the biozone. The lower limit of the biozone is not encountered offshore western Ireland.

The biozone corresponds to the *Radiizonates aligerens* Assemblage VI of onshore Great Britain (Smith and Butterworth 1967), the lower part of the Western European *R. aligerens* (RA) Biozone of Clayton *et al.* (1977) and the W2 Biozone of the North Sea (McLean *et al.* 2005) (figure 6.21).

***Lycospora subtriquetra* - *Apiculatasporites variocorneus* Biozone (upper Arnsbergian)**

The *Lycospora subtriquetra – Apiculatasporites variocorneus* Biozone corresponds to the Western European *L. subtriquetra* Biozone and *A. variocorneus* Sub-biozone of Clayton *et al.* (2003). The range bases of *L. subtriquetra* and *A. variocorneus* mark the lower limit of the biozone. The range tops of *Tricidarisporites balteolus*, *Cingulizonates* cf. *capistratus* and *Triquitrites marginatus* occur in proximity to the biozone lower limit. The upper limit of the biozone is not recorded offshore western Ireland.

The biozone also corresponds to the lower part of the *Lycospora subtriquetra – Kraeuselisporites ornatus* (SO) Biozone and the *L. subtriquetra - A. variocorneus* Sub-biozone of onshore Great Britain (Owens *et al.* 2004), the lower part of the SO Biozone of Western Europe (Clayton *et al.* 1977), the lower part of the N3 Biozone and the N3a Sub-biozone of the North Sea (McLean *et al.* 2005) and part of the lower *Crassispora kosankei* Assemblage IV of onshore Great Britain (Smith and Butterworth 1967) (figure 6.21).

***Cingulizonates* cf. *capistratus* Biozone (upper Brigantian to Pendleian)**

The base of the *Cingulizonates* cf. *capistratus* Biozone is defined by the range base of the index taxon, with the range base of *Bellispores nitidus* occurring in proximity to the lower limit. The biozone is also characterised by occurrences of *Rotaspora fracta, Grumosisporties inaequalis* and *Raistrickia nigra*. The upper limit of the biozone is not recorded offshore western Ireland.

The biozone corresponds to the Western European *Cingulizonates* cf. *capistratus* Biozone of Clayton *et al.* (2003), the *C.* cf. *capistratus – Bellispores nitidus* (CN) Biozone of onshore Great Britain (Owens *et al.* 2004) the N1 Biozone of the North Sea, the *B. nitidus - Reticulatisporites carnosus* (NC) Biozone of Clayton *et al.* (1977), the lower *Rotaspora knoxi* Assemblage Zone III and upper *Diatomozonotriletes saetosus* Assemblage Zone II of onshore Great Britain (Smith and Butterworth 1967) (figure 6.21).

Crassispora kosankei Sub-biozone (Pendleian) and *Bellispores nitidus* Sub-biozone (upper Brigantian)

The *Cingulizonates* cf. *capistratus* Biozone is sub-divided into the upper *Crassispora kosankei* and lower *Bellispores nitidus* Sub-biozones. The sub-biozones correspond to the Western European *Verrucosisporites morulatus* and *B. nitidus* Sub-biozones of Clayton *et al.* (2003).

The range top of *Crassispora aculeata* defines the *Crassispora kosankei* Sub-biozone lower limit. The range base of rare *C. kosankei* is recorded in proximity to the sub-biozone lower limit. The range base of rare *Ahrensisporites guerickei* is also recorded at the sub-biozone lower limit. Occurrences of *Verrucosisporites morulatus* characterise the sub-biozone although the range base of the taxon is recorded in the lower Brigantian of offshore western Ireland. The *Bellispores nitidus* Sub-biozone is characterised by occurrences of the index taxon; the lower limit corresponds to the base of the *Cingulizonates* cf. *capistratus* Biozone. The sub-biozones also correspond to the N1b and N1a Sub-biozones of the North Sea and the *V. morulatus* and *C.* cf. *capistratus* Sub-biozones of onshore Great Britain (Owens *et al.* 2004) (figure 6.21).

Tripartites vetustus – Savitrisporites nux Biozone (Brigantian)

The lower limit of the *Tripartites vetustus – Savitrisporites nux* Biozone is defined by the range bases of the index taxa. Occurrences of *T. vetustus* at this stratigraphic level are infrequent. The range base of *Crassispora maculosa* occurs in proximity to the biozone lower limit and the range top of *T. marginatus* var. *comptus* may also mark the base of the biozone. The biozone corresponds to the Western European *T. vetustus* Biozone of Clayton *et al.* (2003), the *T. vetustus – Rotaspora fracta* (VF) Biozones of onshore Great Britain (Owens *et al.* 2004) and Western Europe (Clayton *et al.* 1977), the V5 Biozone of the North Sea and part of the *Diatomozonotriletes saetosus* Assemblage Zone II of onshore Great Britain (Smith and Butterworth 1967) (figure 6.21).

Triquitrites marginatus **Biozone (upper Asbian)**

The lower limit of the *Triquitrites marginatus* Biozone is tentatively defined by the range bases of the index taxon and *Raistrickia nigra*. The biozone corresponds to the Western European *T. marginatus* Biozone of Clayton *et al*. (2003), theV4 Biozone of the North Sea (McLean *et al*. 2005), the *Triquitrites marginatus – Raistrickia nigra* (NM) Biozone of the British Isles (Clayton *et al.* 1978), the upper part of the *Grumosisporites verrucosus* Assemblage Zone I and the lower part of the *Diatomozonotriletes saetosus* Assemblage Zone II of onshore Great Britain (Smith and Butterworth (1967) (figure 6.21).

Schulzospora **spp. Biozone (upper Holkerian to lower Asbian)**

The range top of *Schopfites claviger* defines the lower limit of the *Schulzospora* spp. Biozone. The range base of *Schulzospora* spp. is recorded within the biozone. The biozone corresponds to the Western European *Schulzospora campyloptera* Biozone of Clayton *et al.* (2003). Occurrences of *S. campyloptera* offshore western Ireland are restricted to younger biozones. The biozone also corresponds to the *Perotrilites tessellatus – S. campyloptera* (TC) Biozone of the British Isles (Clayton 1985) and the middle part of the *Grumosisporites verrucosus* Assemblage Zone I of onshore Great Britain (Smith and Butterworth 1967) (figure 6.2.1).

Lycospora pusilla **Biozone (undefined base to lower Holkerian)**

The biozone is characterised by occurrences of *Lycospora pusilla* and *Schopfites claviger*. As indicated above, the range top of *S. claviger* marks the biozone upper limit. The lower limit of the biozone has not been encountered offshore western

Ireland, but is likely to be no older than Chadian in age based on the range of *L. pusilla* in Western Europe. The biozone corresponds to the Western European *Knoxisporites stephanephorus* Biozone of Clayton *et al.* (2003). Key taxa that define the *K. stephanephorus* Biozone of Clayton *et al.* are restricted to younger biozones offshore western Ireland.

The *Lycospora pusilla* Biozone of offshore western Ireland corresponds to the V2 Biozone of the North Sea (McLean *et al.* 2005), the *Knoxisporites stephanephorus* - *Knoxisporites triradiatus* (TS) Biozone of the British Isles (Clayton 1985) and part of the Western European *Lycospora pusilla* (Pu) Biozone of Clayton *et al.* (1977) (figure 6.2.1).

Schopfites claviger **Biozone (Uppermost Courceyan)**

The biozone is characterised by occurrences of *Schopfites claviger* and an absence of *Lycospora pusilla*. The biozone corresponds to the *S. claviger* Biozone of Clayton *et al.* (2003).

6.5 CONCLUSIONS

15 biozones and 10 sub-biozones from the revised Western European miospore zonal scheme of Clayton *et al.* (2003) can be recognised offshore western Ireland. This is an increase from the 11 biozones that can be recognised using the original scheme of Clayton *et al.* (1977) for the same Courceyan to Cantabrian age stratigraphic interval. Biozones from the 2003 zonal scheme are recognised with varying levels of confidence. As biozones are generally defined based on the first stratigraphic occurrence of the index taxon, the range tops and bases of alternative taxa are often required to define biozone limits if the index taxa are rare in occurrence or considered caved. Range data from the North Sea, onshore Great Britain and Western Europe are used.

Using the 2003 zonal scheme of Clayton *et al.*, the *Thymospora pseudothiessenii* Biozone, *Angulisporites splendidus* Sub-biozone, *Westphalensisporites irregularis* Sub-biozone, *Vestispora fenestrata* Biozone, *Torispora securis* Sub-biozone, *Triquitrites sculptilis* Biozone, *Lycospora noctuina noctuina* Sub-biozone, *Radiizonates aligerens* Biozone, *Lycospora subtriquetra* Biozone, *Cingulizonates* cf. *capistratus* Biozone, *Verrucosisporites morulatus* Sub-biozone, *Bellispores nitidus* Sub-biozone, *Tripartites vetustus* Biozone and *Triquitrites marginatus* Biozone are identified in a number of well sections and are characterised by occurrences of the respective index taxa. The *Torispora verrucosa* Sub-biozone, *Raistrickia aculeata* Sub-biozone, *Microreticulatisporites nobilis* Biozone, *Vestispora magna* Sub-biozone, *Schulzospora rara* Biozone, *Apiculatisporis variocorneus* Sub-biozone and *Schopfites claviger* Biozone can also be identified, although occurrences of the index taxa are rare in the intervals assigned to the biozone. Index taxa are absent from the intervals assigned to the *Sinuspores sinuatus*, *Vestispora cancellata*, *Schulzospora campyloptera* and *Knoxisporites stephanephorus* Biozones.

Miospore assemblages considered to be upper Stephanian in age are tentatively assigned to the *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone of Clayton *et al.* (1977). Assemblages considered to be lower Autunian in age are tentatively assigned to the *Vittatina costabilis* (VC) Biozone of Clayton *et al.* (1977).

The Carboniferous palynostratigraphy of offshore western Ireland and Eastern Canada can be correlated based on eight palynological events ranging from lower Asbian to base Autunian in age.

Due to the rarity of a number of index taxa from the scheme of Clayton *et al.* (2003), a possible alternative Carboniferous miospore biozonation comprising 14 biozones and 8 sub-biozones is proposed for offshore western Ireland.

CHAPTER 7

LITHOLOGIES AND DEPOSITIONAL ENVIRONMENTS OF THE OFFSHORE WESTERN IRISH CARBONIFEROUS

7.1 INTRODUCTION

This chapter outlines the temporal and spatial variation in depositional environments that can be identified in the offshore western Irish region throughout the Carboniferous. Existing lithological and palaeontological datasets are integrated with the revised palynostratigraphic interpretations outlined in section 6.2. Lithological and palaeontological data are sourced from oil company geological reports, composite logs, lithology logs, mud logs and biostratigraphy reports. Existing interpretations of the depositional environments are also derived from oil company geological and biostratigraphy reports in addition to published literature (e.g. Tate and Dobson 1989). Interpretations of the depositional environments made in the present study are compared with those from other localities in the North Atlantic region, with particular emphasis on onshore Ireland, Great Britain and Eastern Canada. The interpretations are also incorporated into a series of palaeogeographic timeslices for the North Atlantic region at key stages throughout the Carboniferous (chapter 10, figures 10.2 to 10.8).

7.2 LITHOLOGIES AND DEPOSITIONAL ENVIRONMENTS OF THE OFFSHORE WESTERN IRISH CARBONIFEROUS

The Courceyan to Cantabrian age biozones listed below are from the Western European miospores zonal scheme of Clayton *et al.* (2003). The upper Stephanian and lower Autunian age NBM and VC Biozones are from the zonal scheme of Clayton *et al.* (1977).

7.2.1 ?*Schopfites claviger* Biozone (Courceyan), *Knoxisporites stephanephorus* Biozone (mid Arundian to mid Holkerian) and *Schulzospora campyloptera* Biozone (mid Holkerian to mid Asbian)

In 26/26-1, the interval tentatively assigned to the Courceyan age *Schopfites claviger* Biozone is predominantly characterised by sandstones that are clear to very light grey buff, non-calcareous, fine to coarse grained, with angular to rounded, variably sorted grains and show local occurrences of pyrite (figure 7.6). Intercalations of siltstone, grey brown carbonaceous claystone and traces of anhydrite are also recorded. At the base of the interval, fine grained to pebbly sandstones overlie basement schists and gneiss. Tate and Dobson (1989) suggested that the sediments were deposited directly onto exposed basement. The authors also inferred that the 197'/60m of sediments overlying the basement possess a 'terrestrial aspect'.

The clastic deposits of 26/26-1 contrast with the equivalent age shallow marine Waulsortian limestone deposits of central and southern Ireland, southwest Wales and Somerset, Great Britain (sections 10.2.2.1 and 10.2.1.2). An absence of marine fauna or marine microfossils in the 26/26-1 interval suggests non-marine deposition. However, there are similarities with coeval deposits in the Midland Valley of Scotland. Mudstones, sandstones and cementstones with nodular evaporites, gypsum pseudomorphs and dessication features are interpreted as being deposited in a hypersaline environment (Guion *et al.* 2000) (section 10.2.1.2). The traces of anhydrite in the 26/26-1 interval suggests the sediments may have been deposited under similar conditions. Non-marine alluvial and lacustrine sediments of Late Devonian to Tournaisian age are also recorded in Eastern Canada, in addition to fossiliferous restricted marine deposits (section 10.3.2).

In 19/5-1, the top of the upper Holkerian to lower Asbian age *Schulzospora campyloptera* Biozone is positioned at either 7000'/2134m SWC or 7190'/2192m. The base is positioned at either 7625'/2324m or 8320'/2536m. It is likely that the upper Arundian to lower Holkerian age *Knoxisporites stephanephorus* Biozone extends to the well total depth (TD) of 8479'/2584m (figure 7.4). Arkosic sandstones dominate the intervals assigned to the biozones. They are typically grey to green/grey, very fine to medium grained, very poorly sorted, chloritic and micromicaceous. Grains are sub-angular to angular and well cemented. The sandstones typically grade to grey or grey/brown siltstones. Occasional beds of grey to green/grey, non-calcareous shale are also recorded. Palaeoservices (1978) recorded fresh, angular feldspars in the sandstones and roughly cyclical fining upward sequences, which Tate and Dobson (1989) also identified on the gamma ray log. In the upper part of the *S. campyloptera* Biozone (from 7160'/2182m to 7283.5'/2220m) red, red/brown and purple sandstones, siltstones and claystones are recorded.

An absence of marine fauna or marine microfossils suggests the lithologies were not deposited in a fully marine environment. Both Palaeoservices (1978) and Robeson *et al.* (1988) concluded that the cyclical arkosic sandstones were deposited in a continental to possibly marginal marine, high-energy environment. The authors inferred that successive rejuvenation of the sediment source resulted in the cyclical deposition. Palaeoservices also suggested that the reddened lithologies at the top of the interval are indicative of oxidising continental conditions.

The arkosic sandstones may be comparable with the Arundian to Holkerian age Mullaghmore Sandstone Formation, recorded in the northern region of onshore Ireland (section 10.2.2.1 and figure 10.2). The formation also comprises grey, feldspathic sandstones and grey shales in addition to rare limestones. A marine to marginal marine deltaic depositional environment was inferred (Sevastopulo and Wyse Jackson 2009). Within the formation, Graham (1996) also recorded fluvial point bar cross-stratified sandstones with rootlet beds and palaeosols. It is possible that the succession in 19/5-1 was also deposited in a fluvio-deltaic environment.

Coeval deposits in the Maritimes Basin of Eastern Canada are dominated by evaporites (see section 10.3.3). Anhydrite and halite rich deposits of the lower Windsor Group major cycle 1 and Lower Codroy Group are recorded in localities including the Gulf of St Lawrence, the Grand Banks and St Georges Bay Basin of southwest Newfoundland (figure 10.2).

7.2.2 *Triquitrites marginatus* Biozone (Asbian)

In 19/5-1, between 259'/79m and 449'/137m of strata (6742'/2055m SWC to 7000'/2134m SWC or 7190'/2192m) is assigned to the Asbian age *Triquitrites marginatus* Biozone (figure 7.4). As indicated in section 7.2.1, reddened clastics are recorded from 7160'/2182m to 7190'/2192m. Brick red and red/brown claystones, siltstones and sandstones also dominate the overlying 40'/12 of strata (7020'/2140m to

7160'/2182m). Traces of white anhydrite are additionally recorded. From 6850'/2088m to 7020'/2140m, sandstones are light green to green/grey, sometimes off-white to grey with green and orange mottling. They are fine to coarse grained with sub-rounded to sub-angular, poorly sorted grains and are variably feldspathic, chloritic and pyritic. Interbedded mudrocks comprise red/brown or grey claystones, dark grey to brown shales and red/brown siltstones. In the upper part of the biozone (6742'/2055m to 6850'/2088m), sandstones are brown, calcareous and fine grained, with sub-angular, poorly sorted grains. They are interbedded with brown, calcareous siltstones, dark brown, calcareous, carbonaceous and pyritic shales and minor micritic to biosparitic limestones.

In 19/5-1, Palaeoservices (1978) recorded a lack of 'in place' microfauna below 6879'/2097m. The authors concluded that sediments recorded from 6879'/2097m to 7230'/2204m were deposited in a non-marine environment. The reddened lithologies recorded below 7020'/2140m indicate sub-aerial exposure and oxidation although traces of anhydrite may represent minor restricted marine influence and seawater evaporation. In contrast, Palaeoservices suggested that lithologies assigned to the upper part of the *Triquitrites marginatus* Biozone (6740'/2054m to 6879'/2097m) were deposited in a marine, sub-littoral environment. The conclusion was based on microfaunal content, although details of the taxa recorded are not provided. Tate and Dobson (1989) concluded that the interval assigned to the *T. marginatus* Biozone represents the transition from continental deposition to the open marine deposition associated with the overlying *Tripartites vetustus* Biozone (section 7.2.3).

In 26/26-1, at least 82'/25m (3405'/1038m to stratigraphic break between samples 3487'/1063' and 3556'/1084m) of strata is assigned to the *Triquitrites marginatus* Biozone (figure 7.6). The interval is characterised by sandstones interbedded with siltstones and claystones/shales. Sandstones are colourless to light grey or buff, fine to medium and locally coarse grained with sorted, angular grains. They are locally pyritic, occasionally glauconitic, calcareous and chloritic. Siltstones are green-grey to brown-grey, non-calcareous, occasionally glauconitic and pyritic. Claystones/shales are light grey, locally green-grey, dark grey-brown and grey-black, non-calcareous, generally carbonaceous, occasionally glauconitic and pyritic. Traces of anhydrite are also recorded. The 26/26-1 Final Well Report (1981) tentatively inferred a terrestrial to marginal marine depositional environment for the interval based on the presence of glauconite but absence of microfauna.

7.2.2.1 Comparison with other localities

Clastic dominated strata assigned to the *Triquitrites marginatus* Biozone in wells 19/5-1 and 26/26-1 contrast with the carbonates deposited across much of onshore Ireland in Asbian times (section 10.2.3.1). Shallow marine carbonates and basinal deposits typify the Asbian age strata of central and southern Ireland. In northwest Ireland, cherty limestones and mudbank limestones with marine fauna characterise the Asbian age Dartry Limestone Formation (Sevastopulo and Wyse Jackson 2009). However, there are some similarities with the late Asbian age Meenymore and Glenade Sandstone Formations of northwest Ireland. The Meenymore Formation comprises grey shales with marine fauna, fine grained laminated limestones and dolomites, dessication cracks and evaporites, interpreted as coastal sabkha deposits (Sevastopulo and Wyse Jackson 2009) (section 10.2.3.1). Traces of anhydrites recorded in the 26/26-1 and 19/5-1 well sections may also represent minor episodes of seawater evaporation. Overlying the Meenymore Formation, the Glenade Sandstone Formation comprises grey, fairly mature quartzose sandstones with plant material, interpreted as deltaic deposits (Sevastopulo and Wyse Jackson 2009) (section 10.2.3.1). The interval of brown sandstones, brown siltstones, carbonaceous shales and minor limestones recorded in the uppermost part of the *T. marginatus* Biozone in 19/5-1 may be laterally equivalent to the Glenade Sandstone Formation.

7.2.3 *Tripartites vetustus* Biozone (Brigantian)

In 19/5-1, between 971’/296m and 1220’/372m of strata is assigned to the *Tripartites vetustus* Biozone (5520’/1683m SWC or 5770’/1759m to 6742’/2055m SWC) (figure 7.4). The lowest 452’/138m (6290’/1917m to 6742’/2055m) is dominated by thickly bedded micritic and biosparitic limestones. The limestones are interbedded with and grade to light brown calcareous shales and light brown marls, which are occasionally reddened. The limestone/mudrock succession is succeeded by 30’/9m (6260’/1908m to 6290’/1917m) of conglomeritic sandstone comprising granitic clasts in a quartz-rich sand matrix. The granite is composed of polycrystalline quartz and orange potassium feldspar, with minor pyrite and chlorite. The conglomerate is succeeded by 360'/110m (5900'/1798m to 6260'/1908m) of interbedded sandstones, shales and claystones. Sandstones are typically clear to milky with orange and green specks. They are fine to medium, occasionally coarse grained with sub-angular to sub-rounded grains that include orange feldspars, green chlorite and pyrite specks. Shales are typically grey to grey/brown, calcareous to non-calcareous, carbonaceous, variably pyritic with occasional crinoid fragments. Limestones are again dominant from 5520'/1683m to 5900'/1798m, interbedded with shales, siltstones, claystones, and occasional sandstones. Limestones are off-white to dark grey/brown, predominantly biomicritic, occasionally biosparitic and occasionally sandy. Shales are dark grey/brown, slightly calcareous, carbonaceous and pyritic with occasional fossil fragments. Sandstones are generally disaggregated, predominantly clear to milky, medium to coarse grained with angular to sub-angular, poorly sorted grains that are occasionally feldspathic.

From 5000'/1524m to 6308'/1923m, Palaeoservices (1978) recorded an assemblage of calcareous, benthic foraminiferids of the *Endothyrid* group. The authors indicate that *Archaediscus karreri, Endothyra bowmani, E. globulosa, Stacheia marginulinoides* and *Tetrataxis paleotrochus* also characterise late Viséan strata in Great Britain. A rich ostracod fauna was also recorded, dominated by small smooth *Bythocyprids* and several species of *Bairdia* resembling "that from onshore Viséan sections in England, Belgium and Germany". Palaeoservices noted that *Draffania biloba* (encountered in samples below 5830'/1777m) is restricted to late Viséan strata in Great Britain. Small specimens of *Archaediscus* spp. and several ostracods including *Kirkbya* cf. *plicata* were recorded between 6530'/1990m and 6720'/2048m. An abundance of land plant derived debris was also recorded to a depth of 6470'/1972m. Palaeoservices assigned a marine, sub-littoral depositional environment to the interval 5000'/1524m to 6879'/2097m. This includes the entire interval assigned to the *Tripartites vetustus* Biozone. The abundance of terrestrially derived plant material recorded to a depth of 6470'/1972m suggests proximity to land.

In 26/26-1, 390'/119m of strata (3015'/919m to 3405'/1038m) is tentatively assigned to the *Tripartites vetustus* Biozone (figure 7.6). Siltstones, claystones/shales and thin sandstones dominate the lower part of the interval (3261'/994m to 3405'/1038m). Siltstones are green grey to brown grey, non-calcareous and locally glauconitic.

Claystones/shales are generally grey, non-calcareous, carbonaceous, occasionally glauconitic and pyritic. Sandstones are clear to light grey buff, fine to medium and locally very coarse grained with angular to sub-rounded and variably sorted grains. They are occasionally glauconitic, chloritic and locally pyritic. Traces of anhydrite are also recorded in addition to a streak of anhydritic, pyritic limestone at 3304'/1007m. The 26/26-1 Final Well Report (1981) indicates that strata below 3261'/994m are devoid of microfauna. The upper part of the interval assigned to the biozone (3015'/919m to 3261'/994m) comprises interbedded limestones, siltstones, claystones and thin sandstones. The 26/26-1 Final Well Report indicates that limestones in the interval 2926'/892m to 3261'/994m are "off-white to light grey-buff, hard, superficial oolitic coated, bioclastic crinoidal recrystallised lime packstones to pack/grainstones". Claystones/shales are dark grey and green-grey, pyritic and locally grade to siltstone. The thin sandstones are clear to milky light grey, loose to hard, locally calcareous, fine to medium and locally coarse grained with angular to rounded grains and show occasional traces of anhydrite. The 26/26-1 Final Well Report also records a sparse microfauna in the interval 2887'/880m to 3261'/994m. Representatives of the foraminiferal families *Ammodiscidae, Endothyridae* and *Palaeotextulariidae*, possible specimens of the ostracod genera *Healdianella* and *Cavellina* and a mould of a *Hollinellid* were recorded. Bennett (2008) indicates *Cavellina* was associated with marginal and brackish depositional environments in the Carboniferous. Both *Healdia* and *Hollinella* inhabited shallow marine environments.

Based on the absence of microfauna, the 26/26-1 Final Well Report (1981) tentatively assigned a terrestrial to marginal marine depositional environment to samples below 3261'/994m. The occasional presence of glauconite in the interval does suggest some marine influence and it is possible that the traces of anhydrite were formed by seawater evaporation. The Final Well Report suggests the limestone composition and faunal content of the succeeding interval (2887'/880m to 3261'/994m) infers deposition on an open marine shallow shelf. Overall, a depositional environment evolving from non-marine/marginal marine to shallow marine is inferred for the interval assigned to the *T. vetustus* Biozone (figure 10.3).

7.2.3.1 Comparison with other localities

Palaeoservices (1978) suggested that the lower Brigantian age micritic and biosparitic marine limestones recorded in 19/5-1 from 6470'/1972m to 6742'/2055m are potentially equivalent to the Dartry limestone recorded in the northwest of onshore Ireland (see sections 7.2.2 and 10.2.3.1). The correlation would have to be diachronous as Sevastopulo and Wyse Jackson (2009) indicate the Dartry limestone is Asbian in age. Lower Briganitan age deposits in northwest Ireland are assigned to the Bellavally Formation. The formation comprises laminated micrites, evaporites and shales deposited in an environment alternating between shallow marine with normal salinity, to intertidal and supratidal with hypersalinity (Sevastopulo and Wyse Jackson, 2009) (see section 10.2.3.1). Although the limestone dominated interval in 19/5-1 includes micrites, there is an absence of evaporites, suggesting the marine depositional environment was not alternating between normal and hypersalinity. The interval in 19/5-1 may instead be comparable with the shelfal limestones that dominated large parts of southern and central Ireland in the Brigantian, for example the limestones of the Galway-Roscommon Shelf (see section 10.2.3.1, figure 10.3). There is also a similarity with the Asbian and Brigantian age limestones of the shallow water, periodically emergent Armagh-Cookstown Shelf of north-eastern Ireland (see section 10.2.3.1, figure 10.3). It is possible that the red/brown claystones and shales recorded in 19/5-1 from 6350'/1936m to 6420'/1957m also represent a period of sub-aerial exposure.

Palaeoservices (1978) suggested that the overlying interval of conglomeritic sandstones, arkosic sandstones, minor shales and claystones recorded in 19/5-1 between 6110'/1862m and 6290'/1917m are possibly laterally equivalent to the Glenade Sandstone, recorded in the Lough Allen Basin area of northwest Ireland (see section 10.2.3.1). Again the correlation would have to be diachronous due to the Asbian age of the Glenade Sandstone. The fairly mature, quartzose, Glenade Sandstone, as described in Sevastopulo and Wyse Jackson (2009), also contrasts lithologically with the poorly sorted arkoses of 19/5-1. However, it is possible that the conglomerate and sandstone dominated interval in 19/5-1 reflects a period of early Brigantian uplift. This would be coeval with the uplift that affected the Fintona region of County Tyrone, Northern Ireland, resulting in the deposition of conglomerates and sandstones of the Brigantian age Ballyreagh Conglomerate Formation (see section 10.2.3.1, figure 10.3).

The overlying interval of biomicritic limestones, sandstones, siltstones, claystones and shales, recorded in 19/5-1 from 5520'/1683m to 5900'/1798m represents the start of a succession of alternating clastics and carbonates that extend into the upper Brigantian age *Bellispores nitidus* Sub-biozone. Tate and Dobson (1989) inferred that the alternations are the product of marine transgressive-regressive cycles. Palaeoservices (1978) suggested the succession is comparable to the Brigantian age Bellavally and Carraun Shale Formations recorded in the Lough Allen Basin area of northwest Ireland. As indicated previously, fossiliferous micrites, evaporites and shales of the Bellavally Formation were deposited in an environment alternating from shallow marine with normal salinity, to intertidal and supratidal with hypersalinity. The overlying Carraun Shale Formation predominantly comprises dark grey shales and mudstones with limestones. Stromatolites and evaporite pseudomorphs in the lower limestones suggest episodes of very shallow conditions (Sevastopulo and Wyse Jackson 2009) (see section 10.2.3.1 and figure 10.3). Although there are similarities with the 19/5-1 deposits, in particular the cyclical shallow marine nature and the presence of fossiliferous micrites, the absence of evaporites in the 19/5-1 section suggests the depositional environment did not become as shallow as that in the northwest Ireland region.

The interval assigned to the *Triquitrites vetustus* Biozone in 26/26-1 also shows similarities with the Bellavally Formation, notably the presence of evaporites, marine limestones and shales, potentially reflecting deposition in both hypersaline and shallow marine environments.

7.2.4 *Cingulizonates* cf. *capistratus* Biozone; *Bellispores nitidus* Sub-biozone (upper Brigantian)

In 19/5-1, between 1230'/375m and 1480'/451m of strata is assigned to the *Bellispores nitidus* Sub-biozone (4290'/1308m to 5520'/1683m SWC or 5770'/1759m) (figure 7.4). The lowest part (5000'/1524m to 5520'/1683m) is characterised by a continuation of the alternating carbonates and clastics recorded in the upper part of the

Tripartites vetustus Biozone (see section 7.2.3). Limestones alternate with claystones, shales, siltstones and sandstones. Limestones are generally grey/brown, occasionally white, micritic to microcrystalline and often contain brachiopod and/or crinoidal debris. Siltstones are grey to grey/brown, micaceous, occasionally dolomitic, variably calcareous, carbonaceous and pyritic. Sandstones are clear to white to light grey, very fine to coarse grained with angular to sub-rounded, often loose grains. Shales are grey and micromicaceous. Claystones are generally grey, soft and sticky. As noted in section 7.2.3, Palaeoservices (1978) recorded an assemblage of late Viséan, calcareous, benthic foraminiferids of the *Endothyrid* group and a rich ostracod fauna in the interval 5000'/1524m to 6308'/1923m. The authors inferred a marine, sub-littoral depositional environment for the interval.

Succeeding the interval of alternating clastics and carbonates is a clastic dominated succession of interbedded claystones, sandstones, siltstones and rare limestones (from 4590'/1399m to 5000'/1524m). Sandstones are clear to white, fine to medium grained with sub-angular to sub-rounded, moderately to well sorted grains and local traces of pyrite. Claystones are grey, siltstones are grey or grey/brown and locally carbonaceous. Limestones are off-white to grey/brown, microcrystalline to biomicritic, often containing crinoid and brachiopod fragments. In the interval 4590'/1399m to 5000'/1524m, Palaeoservices (1978) recorded common occurrences of marine faunal elements and *Endothyrid* foraminiferids that include *Climacammina* cf. *patula*, *Endothyra* spp., *Loeblichia ammonoides* and *Tetrataxis* sp. 1. The authors also recorded an abundance of plant debris. Palaeoservices inferred a marine, sub-littoral depositional environment for the interval. Robeson *et al.* (1988) suggested that the abundance of plant debris reflects proximity to land.

The upper part of the interval assigned to the *Bellispores nitidus* Sub-biozone (4290'/1308m to 4590'/1399m) is characterised by interbedded sandstones, claystones, siltstones and rare coals. Sandstones are white to grey, firm to hard, fine to medium grained, well sorted with carbonaceous specks. Siltstones are grey and occasionally pyritic. Coals are black, hard and vitreous. Palaeoservices (1978) described the faunal content of the interval as restricted to rare bivalve fragments and gastropods. The authors inferred a paralic, coal forming swamp and fluvio/deltaic depositional environment. The overlying Pendleian age *Verrucosisporites morulatus* Sub-biozone is characterised by similar lithologies and the same depositional environment is inferred (section 7.2.6).

In 26/26-1, at least 164’/50m (2851’/869.0m to 3015’/919m) of strata is assigned to the *Bellispores nitidus* Sub-biozone (figure 7.6). The interval comprises a continuation of the interbedded limestones, claystones, shales and thin sandstones recorded in the uppermost part of the *Tripartites vetustus* Biozone (section 7.2.3). As indicated in section 7.2.3, the 26/26-1 Final Well Report recorded a sparse microfauna of foraminifera and possible specimens of shallow marine and marginal marine to brackish ostracods in the interval 2887’/880m to 3261’/994m. The 26/26-1 Final Well Report suggests the limestone composition and faunal content of the interval indicates deposition on an open marine shallow shelf.

7.2.4.1 Comparison with other localities

As indicated in section 7.2.3.1, Tate and Dobson (1989) suggested that the alternating shallow marine carbonates and clastics recorded in the lower part of the *Bellispores nitidus* Sub-biozone in 19/5-1 (from 5000’/1524m to 5520’/1683m) and in the *Tripartites vetustus* Biozone to a depth of 5900’/1798m are the product of marine transgressive-regressive cycles. Palaeoservices (1978) suggested that the interval 5000’/1524m to 5900’/1798m is comparable to the Brigantian age Bellavally and Carraun Shale Formations recorded in the Lough Allen Basin of northwest Ireland (section 7.2.3.1). As noted in section 7.2.3.1, there are some lithological similarities, in particular the cyclical shallow marine nature and the presence of fossiliferous micrites. However, the absence of evaporites in 19/5-1 suggests the depositional environment did not become as shallow as that recorded in the northwest of Ireland. In contrast, the interval of shallow marine bioclastic limestones, claystones and thin sandstones with traces of anhydrite assigned to the *Bellispores nitidus* Sub-biozone in 26/26-1 reflect deposition in a predominantly shallow marine environment, but potentially with minor episodes of hypersalinity.

Cyclical deposition also characterises Brigantian age strata in various other localities. Limestone-siltstone-sandstone-coal Yoredale cyclothems recorded in northern England, the Midland Valley of Scotland and the North Sea are attributed to the cyclical progradation of deltas (Cope *et al.* 1992) (see section 10.2.3.2 and figure 10.3). Brigantian age cyclical deposition is also recognised in the Windsor Group major cycles 3 and 4 of Atlantic Canada (see section 10.3.4 and figure 10.3). The cycles comprise numerous thin fossiliferous marine carbonates alternating with terrestrial clastics and evaporites. The deposits are also inferred to be the product of repeated marine transgressions and regressions (Von Bitter *et al.* 2007).

As indicated above, Palaeoservices (1978) interpreted the interval of grey claystones, moderately sorted sandstones and bioclastic limestones recorded in the middle part of the *Bellispores nitidus* Sub-biozone in 19/5-1 (from 4590'/1399m to 5000'/1524m) as marine, sub-littoral deposits. The deposits may be laterally equivalent to the Brigantian and lower Pendleian age Rossmore Mudstones recorded eastwards in Coalisland, County Tyrone, Northern Ireland. Lithologies comprise dark mudstones that grade to shallow-water burrowed siltstone and fine sandstone (see section 10.2.4.1).

In 19/5-1, the interval of interbedded sandstones, claystones, thin coals and siltstones recorded in the upper part of the *Bellispores nitidus* Sub-biozone (from 4290'/1308m to 4590'/1399m) and interpreted as paralic, coal forming swamp and fluvio/deltaic deposits are also recorded in the overlying Pendleian age *Verrucosisporites morulatus* Sub-biozone (see section 7.2.6). The deposits show similarities with Pendleian age strata recorded in the north of onshore Ireland, in particular the Pendleian age 'Millstone Grit' succession of Coalisland, County Tyrone and the ?upper Brigantian to Pendleian age Ballyvoy Sandstone Formation of the Ballycastle coalfield, County Antrim (see section 7.2.6.1). Palaeoservices (1978) indicate the sporadic occurrences of bivalves and gastropods recorded in 19/5-1 between 4100'/1250m and 4520'/1378m suggest possible interdigitation of marine and non-marine facies. There are also similarities with the 'upper Viséan to lower Namurian age' interval penetrated by well Verrazano L-77 in the Belle Isle Sub-basin of St Anthony Basin, Atlantic Canada (see section 7.2.6.1).

7.2.5 Well 35/15-1, Porcupine Basin

As noted in Appendix VI.XVIII, due to high maturation levels and poor recovery of in-situ miospores, the 35/15-1 Carboniferous section can only be roughly dated. The interval 8750’/2667m to 12100’/3688m (TD) is considered Viséan/Namurian in age.

The lowermost 105’/32m of strata in 35/15-1 (11995’/3656m to 12100/3688m TD) is dominated by sandstones with claystone and siltstone stringers. Sandstones are white to grey, fine to coarse grained, occasionally glauconitic and show graded bedding. An overlying 200’/61m interval (11795’/3595m to 11995’/3656m) comprises interbedded sandstones, claystones and limestones. Limestones are cryptocrystalline calcilucites; white to grey, argillaceous, pyritic and partly carbonaceous. Claystones are dark grey to black, very calcareous, pyritic and micromicaceous with trace fossils. The claystones grade to siltstone, which in turn grade to white to grey, pyritic, carbonaceous sandstones.

The succeeding 770’/235m (11025’/3360m to 11795’/3595m) of strata comprise interbedded siltstones and sandstones with rare claystones. Siltstones are dark grey, slightly calcareous, pyritic and carbonaceous. They grade to dark grey, very fine grained sandstones. Sandstones are also transluscent to milky, medium to coarse grained, with angular to sub-angular, poorly sorted grains. Rare claystones are grey, non-calcareous to calcareous and pyritic. An overlying 30’/9m of conglomerate (10990’/3350m to 11020’/3359m) is succeeded by 590’/180m (10400’/3170m to 10990’/3350m) of fining upwards cycles, comprising interbedded sandstones, calcareous siltstones, bioclastic limestones and thin dolomites. Limestones form the basal members of the cycles. They are white to cream to pale green, hard, crystalline and fossiliferous with occasional pyrite. Sandstones are often orthoquartzitic, transluscent to white, slightly calcareous, locally carbonaceous, pyritic, very fine to fine grained, with sub-rounded to sub-angular, moderately sorted grains and occasional coarse fragments. Minor sandstones are grey, hard, very fine grained and mottled with carbonaceous material. Siltstones are grey, calcareous, pyritic, micromicaceous, arenaceous and grade to dark grey pyritic shales. Traces of dolomite are buff, hard, cryptocrystalline and carbonaceous.

The succeeding 605'/184m (9795'/2986m to 10400'/3170m) is dominated by sandstones and shales. Sandstones are typically clear to white, locally mottled grey, hard, siliceous and pyritic, fine to medium grained, with sub-angular to sub-rounded, fairly sorted grains, a minor calcitic cement and occasional rounded lithic inclusions. The sandstones are interbedded with dark grey to black claystones/shales that are very carbonaceous, micromicaceous, slightly calcareous and pyritic.

From 9695'/2955m to 9795'/2986m, a tuffaceous unit is recorded. The tuffs are grey, locally dark grey, mottled, speckled, occasionally banded and in places show ignimbritic texture, amygdales with mineral fillings, patchy calcite and traces of pyrite. From 8395'/2559m to 9290'/2832m, thin limestone beds are recorded. The limestones are calciluitites, white to grey, crypto to microcrystalline, argillaceous, silty, with a trace of fossils. Interbedded sandstones are clear to light grey, hard, very fine to fine grained, sub-rounded to rounded, well sorted, with a calcareous cement. Siltstones are also recorded. A thin Tertiary sill is noted at 8300'/2530m.

Although Church *et al.* (1981) recorded microfaunal specimens throughout the Carboniferous interval (figure 7.18), the authors indicate that the only in-situ material is echinoderm debris recorded from 11840'/3609m to 11880'/3621m, indicative of marine deposition. Overall, Robeson *et al.* (1988) suggested the entire Carboniferous interval implies a marginal marine to marine depositional environment. Tate and Dobson (1989) envisioned an oscillating terrestrial, marginal marine to marine environment. The authors also tentatively suggested a Viséan age based on the occurrence of limestones and volcanics. The interval of fining upwards cycles, comprising interbedded sandstones, calcareous siltstones, bioclastic limestones and thin dolomites (from 10400'/3170m to 10990'/3350m) may correspond to the alternating shallow marine carbonates and clastics recorded in the lower part of the *Bellispores nitidus* Sub-biozone and in the *Tripartites vetustus* Biozone of 19/5-1.

7.2.6 *Cingulizonates* cf. *capistratus* Biozone (upper Brigantian to Pendlian); *Verrucosisporites morulatus* Sub-biozone (Pendleian)

In 19/5-1, 270'/82m (4020'/1225m to 4290'/1308m) of strata is assigned to the Pendleian age *Verrucosisporites morulatus* Sub-biozone (figure 7.4). The interval comprises interbedded sandstones, claystones and rare coals. Sandstones are typically off-white to buff to grey, very fine to medium grained with sub-angular to rounded, moderately sorted grains. Coals are thin, black, hard and vitreous. Claystones are typically grey, carbonaceous and slightly dolomitic. Robeson (1988) also recorded *Botryococcus* in a cuttings sample from 4260'/1298m. As indicated in section 7.5, Palaeoservices (1978) recorded rare bivalve fragments and gastropods in the interval 4100'/1250m to 4520'/1378m. The authors inferred a paralic, coal forming swamp and fluvio/deltaic depositional environment for the interval, indicating that the sporadic occurrences of bivalves and gastropods suggest possible interdigitation of marine and non-marine facies.

7.2.6.1 Comparision with other localities

A diachronous transition from mixed carbonate-clastic to predominantly clastic deposition occurred close to the base of the Namurian in many areas of Britain and Ireland (Guion *et al.* 2000). Pendleian age deposits, comparable to that of the 19/5-1 well, are recorded in the northeast and northwest of onshore Ireland (section 10.2.4.1 and figure 10.4). In Coalisland, County Tyrone, the Pendleian to Langsettian age 'Millstone Grit' comprises sandstones, seatearths, coal and fossiliferous marine shales. The Millstone Grit overlies the Brigantian to Pendleian age Rossmore Mudstones (see section 7.2.4.1). In the Ballycastle coalfield of County Antrim, the ?upper Brigantian to Pendleian age Ballyvoy Sandstone Formation comprises sandstones, mudrocks and coals with evidence for brief marine inundations. In the locality of Thur Mountain, in the Lough Allen area of northwest Ireland, the Pendleian age Briscloonagh Sandstone Formation comprises turbiditic sandstones, deltaic shallow water sandstones and seatearths. The exclusively non-marine Pendleian age Ballinamallard Mudstone Formation at Fintona, County Tyrone comprises mudstones with carbonate nodules and sandstones with ripple marks and dessication cracks. In Milltown, northwest Ireland, the Greenan Sandstone Formation comprises non-marine, feldspathic sandstones. The Pendleian age strata of northeast and northwest Ireland contrasts with that of central and southern Ireland, which are dominated by shallow marine and basinal marine deposits (Sevastopulo 2009) (see section 10.2.4.1 and figure 10.4).

Comparable deposits are also recorded in areas of onshore Great Britain (see section 10.2.4.1). In particular, the Limestone Coal Formation in the Midland Valley of Scotland comprises cyclical alternations of fluvio-deltaic sandstones, mudstones and coals. In South Wales, the Pendleian to Marsdenian age Basal Grit Group comprises alternating shallow marine sandstones, deeper marine goniatite bearing mudstones and coastal plain fine-grained sediments with thin coals (Guion *et al.* 2000).

The Pendleian age interval in 19/5-1 also shows some similarities with the 'upper Viséan to lower Namurian age' succession of alternating sandstones (with traces of pyrite, coal, and glauconite) and shales with minor amounts of dolomitic limestones penetrated by well Verrazano L-77 in the Belle Isle Sub-basin of St Anthony Basin, Atlantic Canada (section 10.3.7). A non-marine to marginal marine depositional environment is tentatively inferred. Elsewhere in the Maritimes Basin, Pendleian age deposits are typically characterised by non-marine, coal-poor clastics or by evaporites and coal-poor clastics (see section 10.3.5, figure 10.4).

7.2.7 *Lycospora subtriquetra* Biozone; *Apiculatisporis variocorneus* Sub-biozone (upper Arnsbergian)

In 26/26-1, at least 10'/3m (2685'/818.5m SWC to 2695'/821.5m) of strata is assigned to the upper Arnsbergian age *Apiculatisporites variocorneus* Sub-biozone (figure 7.6). The interval is characterised by alternating sandstones, siltstones and claystones. Sandstones are off-white to light buff, mainly fine-grained with angular to sub-rounded, well-sorted grains. The sandstones are locally calcareous, argillaceous, lignitic, glauconitic and pyritic. Siltstones are grey to light brownish grey, locally carbonaceous, micaceous, glauconitic and occasionally calcareous. Claystones are grey, black, carbonaceous, occasionally pyritic and micaceous. Occasional laminations of carbonaceous material are also recorded. The 26/26-1 Final Well Report (1981) indicates that although marine fauna are absent from samples shallower than 2887'/880m, acritarchs are recorded. The authors inferred a marginal marine to terrestrial depositional environment.

7.2.7.1 Comparison with other localities

Comparable marginal marine to non-marine, clastic-rich deposits of equivalent age are recorded in the northwest and northeast of onshore Ireland, although commonly in association with marine deposits (section 10.2.4.1, figure 10.5). These include the Pendleian to Langsettian age Millstone Grit of Coalisland, County Tyrone (see section 7.2.6.1). In the localities of Slieve Anierin and the Lackagh Hills of northwest Ireland, fossiliferous marine shales of the lower Arnsbergian age Gowlaun Shale Formation are overlain by sandstones and coal seams of the Lackagh Sandstone Formation. In the Kingscourt area of County Cavan, the lower Arnsbergian age Carrickleck Sandstone is possibly fluviatile in origin. It is succeeded by ammonoid bearing shales of the Arnsbergian age Carrickleck Shale (Sevastopulo 2009). In contrast, the Arnsbergian age deposits of central and southern Ireland are exclusively marine in origin (see section 10.2.4.1, figure 10.5)

Arnsbergian age marginal marine to non-marine deposits are also recorded in areas of onshore Great Britain, again in association with marine deposits. To the north of the Craven Fault Zone in northern England, Yoredale cyclothems comprise cycles of marine limestones overlain by coarsening upwards shales and sandstones of deltaic and alluvial origin. In the Midland Valley of Scotland, the Arnsbergian age Upper Limestone Formation is dominated by deltaic and shallow marine clastics. In South Wales, the Basal Grit Group comprises alternations of shallow marine sandstones, deeper marine, goniatite bearing mudstones and coastal plain fine-grained sediments with thin coals (Guion *et al.* 2000) (section 10.2.4.2, figure 10.5).

The interval in 26/26-1 also shows some similarities with the ‘upper Viséan to lower Namurian age’ deposits penetrated by well Verrazano L-77 in the Belle Isle Sub-basin of St Anthony Basin, Atlantic Canada (see sections 10.3.7 and figure 10.5). Elsewhere in the Maritimes Basin, Arnsbergian age clastics are alluvial, alluvial fan or debris flow in origin (see section 10.3.6 and figure 10.5).

7.2.8 *Schulzospora rara*, *Radiizonates aligerens* and *Vestispora cancellata* Biozones (Langsettian)

In 27/5-1, a 95’/29m interval is assigned to the *Schulzospora rara* Biozone (5774’/1760m to 5869’/1789m), the *Radiizonates aligerens* Biozone (5869’/1789m to 6066’/1849m) and the *Vestispora cancellata* Sub-biozone (6106’/1861m to 6266’/1910m TD) (figure 7.14). Lithologies are characterised by interbedded siltstones, thin sandstones and thin coals. Sandstones are typically white to light grey, hard, quartzitic, very fine to fine grained, well sorted and well cemented. The sandstones become reddened towards the top of the *S. rara* Biozone. Siltstones are white, light green, grey or brown, micaceous, non-calcareous to calcareous and sometimes contain carbonaceous flecks. Coals are black, hard, shiny, blocky, brittle and pyritic. Occurrences of *Botryococcus* recorded at 5879’/1792m, 5892’/1796m and 6266’/1910m indicate freshwater to brackish conditions. Acritarchs recorded in samples from 5860’/1786m, 5869’/1789m, 5919’/1804m, 5942’/1811m and 6174’/1882m indicate episodes of marine influence. Millennia Stratigraphic Consultants (1996) assigned a “transitional to nearshore marine” depositional environment to the entire interval.

In 19/5-1, 80’/24m of strata (3710’/1131m to 3790’/1155m) is assigned to the *Schulzospora rara* Biozone and 110’/34m (3790’/1155m to 3900’/1189m) to the *Radiizonates aligerens* Biozone (figure 7.4). Odell and Thomas (1978) recorded a succession of grey and red-brown claystones interbedded with thin coals and light grey, fine to medium grained sandstones with sub-angular to sub-rounded grains. It is noted that the 19/5-1 composite and mud logs indicate the claystones are only grey in colour. Odell and Thomas indicate the interval tentatively assigned to the *Vestispora cancellata* Sub-biozone (3900’/1189m to unconformity between 3990’/1216m and 4020’/1225m) is characterised by white to pale grey sandstones with sub-angular to sub-rounded, moderately sorted grains and occasional beds of claystone. Palaeoservices (1978) recorded occurrences of sphaeroidal siderite from 3780’/1152m to 3870’/1180m and dark grey, pyritic claystones from 3030’/924m to 3880’/1183m. This study recorded acritarchs in a cuttings sample from 3710’/1131m. Robeson (1988) recorded acritarchs in a cuttings sample from 3830’/1167m and a sidewall core sample from 3930’/1198m. Robeson also recorded *Botryococcus* in cuttings samples from 3710’/1131m, 3800’/1158m, 3830’/1167m, 3860’/1177m, 3870’/1180m, 3880’/1183m and 3990’/1216m. Both Palaeoservices (1978) and Odell and Thomas (1978) proposed a paralic, coal forming swamp and fluvio-deltaic depositional environment for the Langsettian age interval. Odell and Thomas suggest the Langsettian age interval and the overlying Duckmantian age interval represent a “typical paralic coal measures succession of interbedded distributary channel sands with carbonaceous siltstones, claystones and coals representing interdistributary swamps, lake and over-bank floodplain deposits, probably deposited in a deltaic flood plain depositional environment”. Sporadic episodes of marine influence are inferred from the acritarch occurrences.

In 26/27-1b, lithologies assigned to the tentatively identified *Schulzospora rara* Biozone comprise grey siltstones, carbonaceous claystones with coaly streaks and fine grained, poorly sorted sandstones (figure 7.7). A single acritarch occurrence is recorded in a cuttings sample from the top of the interval.

Overall, based on the similarities in lithological and palynomorph content, a paralic, coal measures type, fluvio-deltaic depositional environment with coal swamps is inferred for the Langsettian age intervals (figure 10.6). Occurrences of *Botryococcus* confirm freshwater to brackish conditions. Rare acritarchs, if *in-situ*, indicate that both localities were affected by sporadic marine incursions.

7.2.8.1 Comparison with other localities

Deposits of similar age and composition to the offshore Irish sections are recorded in areas of onshore Great Britain. Most of the upper Langsettian and Duckmantian age strata in Britain’s coalfields were deposited on an extensive, low-lying water logged delta/alluvial plain with shallow lakes, ideal for the formation of coals. Upper Langsettian age marine bands are rare, with only the top Langsettian Vanderbeckei Marine Band being recorded (Guion *et al.* 2000). Localities include the Pennines Province, South Wales and the Midland Valley of Scotland (see section 10.2.5.3, figure 10.6). Guion *et al.* indicate that clastic sediments were deposited in fluvial channels, lacustrine crevasse splays, lacustrine deltas and overbank floods. In the Pennines Province, major fluvial channel sand bodies are 33’/10m to 66’/20m thick and minor channels are up to 33'/10m in thickness. Siltstones, sometimes with thin sandstones dominate overbank flood deposits. Lake deposits comprise mudstones with ostracods such as *Geisina* and *Carbonita*, non-marine bivalves and fish. Siderite formed in reducing conditions on the lake floors. The filling of lakes and the abandonment of channel systems resulted in the development palaeosols and peat mires - the precursors to coal formation. Grey seatearths represent poorly drained areas. Red, cream or mottled, seatearths represent better drained, oxidising conditions. It is possible to apply the depositional model from the Pennines Province to the offshore western Irish deposits. For example, the occasional reddening of claystones in 19/5-1, if correctly recorded, most likely represents episodes of better drainage and the oxidation of seatearths.

Onshore Ireland, upper Langsettian age deposits recorded in the Leinster coalfield are comparable with that of offshore western Ireland. Higgs and O'Connor (2005) assigned a succession of coals, shales, thin sandstones and siltstones with non-marine bivalve horizons and rare occurrences of *Lingula* to the upper Langsettian age *Radiizonates aligerens* (RA) Biozone of Clayton *et al.* (1977) (see section 10.2.5.1). A similar depositional environment to that inferred for offshore western Ireland is likely, although with possibly less marine influence based on the absence of acritarchs (figure 10.6). In contrast, sandstones, mudstones and pedogenic limestones of the late Langsettian to Duckmantian age Tullanaglare Mudstone Formation in Milltown, northwest Ireland are coal-poor with no evidence for marine influence (Sevastopulo 2009) (see section 10.2.5.1 and figure 10.6).

In Eastern Canada, Langsettian age successions recorded in sub-basins of the Maritimes Basin show similarities with the upper Langsettian deposits of offshore western Ireland. Miospore assemblages from the Joggins, Springhill Mines and Ragged Reef Formations of the Cumberland Basin are assigned to the Langsettian age *Raistrickia fulva* Biozone of Utting *et al.* (2010) (see section 10.3.9, figures 10.9 and 10.15). In coastal exposures at Joggins, Nova Scotia (figure 10.9) the Joggins Formation is characterised by transgressive-regressive cycles. The cycles comprise brackish bay limestones with oligohaline fauna overlain by prograding coastal plain channelised sandstones, followed by coal rich units that were deposited on a retrograding coastal plain dominated by peat mires (Falcon-Lang 2003, see section

10.3.9). Falcon-Lang indicates that although the Cumberland Basin was probably hundreds of kilometres from open marine waters, the cyclical marine transgressions enabled the development of the short-lived brackish bays. With the exception of the limestone deposits, there are lithological similarities with the Langsettian age sections recorded in 27/5-1 and 19/5-1. Short lived, marine transgressions also appear to have affected the offshore western Ireland area. Deposits of the younger, alluvial dominated Springhill Mines Formation comprise grey, sideritic mudrocks, grey sandstones, thick coal seams and fine-grained red strata. The overlying Ragged Reef Formation comprises thick, multistoried channelised sandstone units interbedded with red siltstones (Utting *et al.* 2010, see section 10.3.9).

7.2.9 *Microreticulatisporites nobilis* Biozone; *Vestispora magna* and *Lycospora noctuina noctuina* Sub-biozones (Duckmantian). *Sinuspores sinuatus* Biozone (lower Duckmantian)

In 27/5-1, 79’/24m of strata (5695’/1736m to 5774’/1760m) is tentatively assigned to the *Sinuspores sinuatus* Biozone (figure 7.14). The interval is characterised by claystones, siltstones and fine-grained sandstones. Claystones are dark grey or variegated red brown and green grey, carbonaceous and slightly dolomitic. Siltstones are white to light grey, carbonaceous with plant fragments, micromicaceous, occasionally slightly calcareous, grading in part to very fine grained sandstone. Sandstones are white, light grey and also reddish, very fine to fine grained and well cemented. The presence of acritarchs in cuttings samples from 5722’/1744m, 5732’/1747m, 5741’/1750m and a sidewall core sample from 5774’/1760m imply marine influence.

Overlying the *Sinuspores sinuatus* Biozone, 239’/73m of strata (5456’/1663m to 5695’/1736m) is assigned to the *Lycospora noctuina noctuina* Sub-biozone (figure 7.14). Lithologies comprise interbedded sandstones, siltstones, claystones and coal. Sandstones are typically white to light grey, hard, very fine grained, quartzitic, well cemented, sometimes with carbonaceous laminae, sometimes very calcareous and grade locally to siltstone. Towards the top of the interval, sandstones are dark red-brown and purple. Siltstones are typically light grey, light green or dark grey, variably calcareous, micaceous and carbonaceous. Towards the top of the interval, siltstones are light red-brown, purple and green-grey. Claystones are dark grey, black or light green/grey, variably calcareous and often very carbonaceous. Coals are black, moderately hard with a crumbly to brittle break. A 16'/5m dolerite sill is dark grey to black, with phenocrysts of pink feldspar and clear quartz in a groundmass of ferro-magnesian minerals. This study also recorded sporadic occurrences of acritarchs in the interval. Millennia Stratigraphic Consultants (1996) suggested a "transitional to nearshore marine" depositional environment for the Duckmantian age interval. Overall, the lithologies suggest a continuation of the paralic coal measures depositional environment assigned to the underlying Langsettian interval (section 7.2.8). Sporadic occurrences of acritarchs suggest occasional marine influences. Reddened lithologies most likely represent areas of the delta plain with better drainage and oxidation.

In 26/27-1b, the interval assigned to the *Microreticulatisporites nobilis* and *Sinuspores sinuatus* Biozones (8800'/2682m to 9100'/2774m) is characterised by interbedded siltstones, claystones, sandstones and thin coals (figure 7.7). Siltstones are light grey, claystones are grey to brown-grey and micromicaceous or grey to black and carbonaceous with coal streaks. Sandstones are fine grained and poorly sorted. This study recorded acritarchs in cuttings samples from 8800'/2682m and 8900'/2713m. King *et al.* (1981) suggested the entire Carboniferous interval in 26/27-1b was deposited in a transitional, deltaic environment with extensive coal swamp development.

In 36/16-1, 952'/290m of strata is assigned to the *Lycospora noctuina noctuina* Sub-biozone (7348'/2240m to unconformable contact with Arnsbergian at 8300'/2530m) (figure 7.19). Below 7720'/2353m, lithologies comprise interbedded sandstones and claystones. Tate and Dobson (1989) recorded fining upwards sequences in the interval. Sandstones are grey, very fine to fine grained, often well sorted, variably carbonaceous and variably calcareous. Claystones are grey, micromicaceous and non to slightly calcareous. Below 7720'/2353m, King *et al.* (1979) recorded occurrences of siderite and pyrite in addition to fragments of gastropods, ammonoids, bivalves and crinoids. King *et al.* also recorded specimens of the ostracods *Geisina* sp. and *Cavellina*/*Healdia* sp. Bennett (2008) notes that *Healdia* inhabited shallow marine environments while *Cavellina* tolerated marginal marine and brackish environments in Carboniferous times. The author also indicates that *Geisina* inhabited freshwater, marginal and brackish environments. Robeson (1988) also recorded *Botryococcus* in a cuttings sample from 8100'/2469m. Above 7720'/2353m, lithologies comprise interbedded claystones, thin coals and sandstones. Sandstones are grey to brown, very fine to fine grained, variably calcareous and carbonaceous and locally grade to siltstone. Claystones are grey to grey-brown, micromicaceous, sometimes silty and typically non-calcareous. Coals are black and brittle with a conchoidal fracture.

Overlying the *Lycospora noctuina noctuina* Sub-biozone in 36/16-1, 1148'/350m of strata is assigned to the *Vestispora magna* Sub-biozone (6200'/1890m to 7348'/2240m). Lithologies comprise interbedded claystones, siltstones, sandstones and nine thin coals. Claystones are grey to dark brown and non to slightly calcareous. Siltstones are grey to dark grey, non to slightly calcareous, variably micromicaceous and carbonaceous. Sandstones are white to light grey, slightly to very calcareous, very fine to fine grained with angular to sub-angular, well sorted grains. Coals are typically black and vitreous with a conchoidal fracture. A thin dolomitic limestone is recorded at the base of the sub-biozone. King *et al.* (1979) recorded siderite throughout the interval in addition to rare occurrences of the freshwater ostracod *Carbonita* and the freshwater to marginal marine to brackish ostracod *Geisina*. King *et al.* also recorded acritarchs in two samples from the interval, including a sidewall core sample from 7000'/2134m. Robeson (1988) recorded acritarchs and *Botryococcus* sp. in a cuttings sample from 6810'/2076m.

For the entire Carboniferous interval in 36/16-1, King *et al.* (1979) inferred a paralic, predominantly non-marine depositional environment with periodic marine influences. Based on the interpretations of Tate and Dobson (1989), the coarsening upwards claystone-sandstone sequences recorded below 7720'/2353m and assigned to the lower part of the *Lycospora noctuina noctuina* Sub-biozone are interpreted as prograding pro-delta deposits. Marine deposition is also indicated by the macrofaunal debris and by the possible occurrence of *Healdia*. A sandstone rich unit recorded from 7800'/2377m to 7940'/2420m may represent delta front mouthbar deposits. Also based on Tate and Dobson (1989), the coal bearing strata with fining upwards sequences assigned to the upper part of the *L. noctuina noctuina* Sub-biozone are interpreted as delta top abandonment and swamp facies. A continuation of delta top deposition is inferred for the interval of claystones, siltstones, sandstones and thin coals assigned to the *Vestispora magna* Sub-biozone. Occurrences of *Carbonita* confirm the presence of fresh-water environments. Occasional episodes of marine influence are inferred by the occurrence of rare acritarchs.

In 26/28-1, strata assigned to the *Vestispora magna* Sub-biozone extend from either 10121'/3085m or 10253'/3125m to 10876'/3315m (TD) (figure 7.8). Duxbury *et al.* (1979) recorded an absence of microfauna at these depths. The lower part of the sub-biozone (10630'/3240m to 10876'/3315m) comprises a conglomeritic unit overlain by thickly bedded, sharp-based sandstones, interbedded with siltstones and mudstones. The conglomerate comprises well-rounded, predominantly quartzitic pebbles in a medium to very coarse sandstone matrix. The overlying sandstones are generally white, hard, quartzitic, occasionally feldspathic, fine to medium grained, with occasional coarse to granule size grains and a siliceous cement. Grains are sub-angular and poorly sorted. On the gamma ray log, the sandstone beds show stacked fining upwards cycles. Siltstones are grey, grey-brown, and non to slightly calcareous. Mudstones are grey and non-calcareous. Robeson *et al.* (1988) suggested a braided river depositional environment. The upper part of the interval assigned to the *V. magna* Sub-biozone (10121'/3085m or 10253'/3125m to 10630'/3240m) is dominated by siltstones and mudstones with thin beds of sandstone, limestone and coal. Siltstones are grey, brown or white, micaceous, non-calcareous to calcareous and non to very carbonaceous. Mudstones are white, brown, grey or green-grey, non to very calcareous and slightly carbonaceous to carbonaceous. Sandstones are white to light grey or brown, typically quartzitic, very fine to fine-grained, moderately to well sorted, with a calcitic/dolomitic or siliceous cement. The sandstones often grade to sandy limestones or siltstone/mudstone. Both coarsening and fining upward sequences can be recognised on the gamma ray log. Robeson *et al.* suggest the progradation and gradual abandonment of lobes around an alluvial delta resulted in the coarsening and fining upwards cycles. The rare coals reflect an infrequency in swamp development.

In 34/5-1, the basal 295'/90m of strata (4587'/1398m to 4882'/1488m TD) encountered in the well is assigned to the *Vestispora magna* Sub-biozone (figure 7.15). The interval comprises sandstones interbedded with coals, siltstones and shales. Sandstones are white, hard, very fine to fine-grained with angular to sub-angular, well sorted grains. Shales are grey, black and carbonaceous. Siltstones are grey, slightly carbonaceous with traces of pyrite. At the base of the interval, a white, very hard, very fine grained quartzite is recorded. Tate and Dobson (1989) interpreted the overall succession as delta top facies.

In 13/3-1, 1015'/309m of strata (3340'/1018m to 4355'/1327m) is assigned to the *Vestispora magna* Sub-biozone (figure 7.3). Lithologies are characterised by interbedded sandstones, siltstones, mudstones and eight coal seams. Sandstones are white to grey, hard, generally very fine to medium grained, occasionally coarse grained, poorly sorted to sorted, non to partly calcareous, often slightly to moderately carbonaceous, locally micaceous and often grade to siltstone. Siltstones are dark grey, slightly to very micaceous, sometimes laminated and sometimes carbonaceous. Mudstones are medium to very dark grey and slightly to moderately micaceous. Coals are black and brittle. Both Robeson *et al.* (1988) and Love *et al.* (1978) recorded a number of fining upwards sequences dominated by sandstone at the base, succeeded by increasing amounts of siltstones and mudstones before terminating with a coal. Robeson (1988) recorded acritarchs in one cuttings sample from 3870'/1180m. Towards the base of the interval, 65'/20m of contact metamorphic rocks are recorded. At 4355'/1327m, a medium grained gabbro is recorded. Love *et al.* (1978) inferred a delta top coal swamp depositional environment for the interval. The fining upwards cycles terminating in coals are interpreted as coal measures cyclothems. Tate and Dobson (1989) also inferred a delta top depositional environment.

In 19/5-1, 680'/207m of strata is assigned to the *Microreticulatisporites nobilis* and *Sinuspores sinuatus* Biozones (3030'/924m to 3710'/1131m) (figure 7.4). The upper 220'/67m (3030'/924m to 3250'/991m) is also assigned to the *Vestispora magna* Sub-biozone. The interval is characterised by interbedded sandstones, claystones, coal and siltstones. Sandstones are white to light grey, very fine to medium grained, with sub-angular to sub-rounded, poorly to moderately sorted grains. The sandstones are sometimes pyritic, carbonaceous and micaceous, often with a dolomitic or siliceous cement. Claystones are light red to brown/grey, mudstones are dark brown to black, very carbonaceous and lignitic. Siltstones are yellow, grey and micaceous, becoming dark grey and carbonaceous with depth. Coals are dark brown to brown and lignitic in part. The lower 459'/140m of the Duckmantian age interval is characterised by similar lithologies. Robeson (1988) recorded both acritarchs and *Botryococcus* in a cuttings sample from 3280'/1000m, *Botryococcus* in a cuttings sample from 3610'/1100m and scolecodonts in a cuttings sample from 3660'/1116m. Palaeoservices (1978) also recorded occurrences of sphaeroidal siderite. Odell and Thomas (1978) inferred a continuation of the paralic coal measures, delta top depositional environment assigned to the Langsettian age interval (section 7.8). If *in-situ*, the rare occurrences of acritarchs and scolecodonts indicate occasional marine influences.

In summary, the majority of Duckmantian age deposits recorded offshore western Ireland are attributed to a paralic, deltaic depositional environment. Subtle lateral variations in the depositional environment are noted. Deposits assigned to the *Lycospora noctuina nocuina* Sub-biozone in 36/16-1 record the transition from prograding pro-delta and mouth-bar deposition to coal bearing delta top deposition. Further north in the Slyne Basin, strata assigned to the *L. noctuina noctuina* Sub-biozone in 27/5-1 are interpreted as delta top deposits. Rare marine palynomorphs in both wells indicate occasional marine influences. Deposits assigned to the upper Duckmantian age *Vestispora magna* Sub-biozone in 13/3-1, 19/5-1, 34/5-1 and 36/16-1 are typically characterised by interbedded sandstones, siltstones, shales/claystones and thin coals, interpreted as delta top and coal swamp deposits. Marine influences appear to be restricted to wells 13/3-1 and 36/16-1, inferred by the presence of rare acritarchs.

7.2.9.1 Comparison with other localities

As noted in section 7.2.8.1, much of the Duckmantian age strata in the coalfields of onshore Great Britain were deposited in an extensive, low-lying, water logged delta/alluvial plain with shallow lakes and coal swamps (Guion *et al.* 2000) (section 10.2.5.3). Marine transgressions were rare in the upper Langsettian and lower Duckmantian, but became common again in the upper Duckmantian (Guion *et al.* 2000). Duckmantian age strata are also recorded in sub-basins of the Maritimes Basin, Eastern Canada. Deposits show similarities with that of offshore western Ireland, notably the dominance of coal-bearing clastics. In the Cumberland Basin, deposits of the Duckmantian age Spicers Cove Formation comprise conglomerates associated with thin coals and fossil trees (Utting *et al.* 2010) (section 10.3.9, figure 10.15). In the Sydney Basin, the upper Duckmantian to lower Asturian age South Bar Formation comprises stacked alluvial sandstones, coarsening upwards siltstone-sandstone units, mudstones and thin sulphur-rich coals with occurrences of agglutinated foraminifera (see section 10.3.10 and figure 10.17). An alluvial braidplain with peat mires depositional environment is envisioned with brackish bays (possibly lagoonal or estuarine) developing during periodic marine inundations (Tibert and Gibling 1999). In the Gulf of St Lawrence and Prince Edward Island, Duckmantian age deposits assigned to the Bradelle Formation comprise thick multistoried sandstones, grey and red mudrocks and coals (Giles and Utting 1999) (see section 10.3.10, figure 10.17). In the Central Basin of New Brunswick, Member B of the Clifton Formation comprises grey sandstones, minor red sandstones, grey and red mudrocks and coals. The formation is dated as Duckmantian at its base and extends into the Bolsovian and possibly lower Asturian (Jutras *et al.* 2005) (figure 10.14 and section 10.3.10).

Onshore Ireland, outcrops of Duckmantian age strata are scarce and restricted to the locality of Milltown in northwest Ireland (section 10.2.5.1). A key difference compared to the offshore western Irish deposits is the absence of coal. As indicated in section 7.2.8.1, the late Langsettian to Duckmantian age Tullanaglare Mudstone Formation comprises sandstones, mudstones and pedogenic limestones. The succeeding Drumlish Conglomerate Formation comprises proximal alluvial fan conglomerates (Sevastopulo 2009). Sevastopulo notes that a miospore assemblage from close to the base of the formation confirms a Duckmantian age.

7.2.10 *Triquitrites sculptilis* Biozone (lower Bolsovian)

In 34/5-1, 108'/33m of strata is assigned to the *Triquitrites sculptilis* Biozone (4478'/1365m to 4587'/1398m) (figure 7.15). Lithologies comprise a continuation of the interbedded very fine to fine grained, well sorted sandstones, grey siltstone/claystones and thin coals recorded in the underlying *Vestispora magna* Sub-biozone. In 36/16-1, the 190'/58m of strata assigned to the *T. sculptilis* Biozone comprise siltstones, claystones and thin sandstones (figure 7.19). Siltstones are grey and slightly calcareous, claystones are grey, slightly calcareous in places and locally very carbonaceous. Sandstones are white to light grey, fine to very fine grained and calcareous. King *et al.* (1979) recorded siderite throughout the interval. King *et al.* also recorded the ostracod *Hypotetragona* sp. in three cuttings samples from the upper part of the biozone. Dr. Carys Bennett (pers. comm. July, 2009) indicates the genus was associated with marine environments in the Carboniferous. In 13/3-1, between 510'/155m and 1050'/320m of strata (2290'/698m or 2830'/863m to 3340'/1018m) is assigned to the *T. sculptilis* Biozone. Lithologies are characterised by a continuation of the alternating sandstones, siltstones, mudstones and coals assigned to the underlying *V. magna* Sub-biozone, although with an increased frequency of coals. A dolomite stringer with algal matrix is also recorded at 3220'/981m, while Robeson (1988) recorded *Botryococcus* in a single cuttings sample from 3340'/1018m. Love *et al.* (1978) suggested a delta top, coal swamp depositional environment for the interval.

In summary, the lithologies assigned to the *Triquitrites sculptilis* Biozone in wells 34/5-1, 36/16-1 and 13/3-1 most likely represent a continuation of the delta top depositional environment assigned to the underlying upper Duckmantian age strata. Coals recorded in 13/3-1 and 34/5-1 confirm the presence of coal forming swamps. If *in-situ*, the occurrences of *Hypotetragona* indicate episodes of marine influence in the 36/16-1 locality.

7.2.11 *Vestispora fenestrata* Biozone; *Raistrickia aculeata* and *Torispora securis* Sub-biozones (Bolsovian)

In 34/5-1, the 869'/265m (3609'/1100m to 4478'/1365m) tentatively assigned to the *Torispora securis* Sub-biozone is characterised by interbedded sandstones, siltstones/claystones and fifteen coal seams (figure 7.15). Sandstones are white to yellow, very fine to fine grained, with angular to sub-rounded, well sorted grains and a feldspathic or siliceous cement. Claystones are grey, non calcareous to calcareous, variably micaceous, often carbonaceous, locally dolomitic with traces of pyrite. Siltstones are grey to grey-green, locally sandy and variably calcareous, dolomitic and carbonaceous. Both Robeson (1988) and Church *et al.* (1980) recorded sporadic occurrences of *Botryococcus* in cuttings samples from the interval. Church *et al.* also recorded the marginal marine to brackish ostracod *Cavellina* sp. in a cuttings sample from 3937'/1200m. Succeeding the *T. securis* Sub-biozone, 168'/51.2m of strata is tentatively assigned to the *Raistrickia aculeata* Sub-biozone (3441'/1048.8m to 3609'/1100m). The interval is characterised by interbedded grey, micaceous claystones, siltstones and thin beds of sandstone. One coal seam is recorded. Tate and

Dobson (1989) inferred a delta top depositional environment for the intervals assigned to both sub-biozones.

In 13/3-1, between 510'/155m and 1050'/320m of strata (1780'/543m to 2290'/698m or 2830'/863m) is assigned to the *Torispora securis* Sub-biozone (figure 7.3). Alternating sandstones, siltstones, mudstones and coal seams characterise the interval. Sandstones are grey, grey-brown, sometimes white, hard, carbonaceous, very fine to medium grained, with sub-angular to sub-rounded, moderately sorted grains. Cements are usually siliceous, occasionally calcareous. Siltstones are grey, brown or black, micaceous and carbonaceous. Mudstones are dark grey to brown, silty and carbonaceous. Coals are black, hard and brittle with a conchoidal fracture. They are quite frequent in occurrence. Robeson (1988) recorded *Botryococcus* in a single cuttings sample at 1870'/570m. As in the Duckmantian age interval, Love *et al.* (1978) recorded a number of fining upwards sequences dominated by sandstone at the base, succeeded by increasing amounts of siltstones and mudstones, terminating with coal. Love *et al.* suggest the repeated sequences are typical coal measures cyclothemic deposits, indicative of a delta top coal swamp depositional environment.

In 36/16-1, between 712'/217m and 732'/223m of strata (5280'/1609m or 5300'/1615m to 6012'/1832m SWC) is assigned to the *Torispora securis* Sub-biozone (figure 7.19). Lithologies comprise claystones, siltstones, sandstones, rare coal and limestones. Claystones are dark brown, grey or black in colour, non to slightly calcareous and sometimes carbonaceous. Siltstones are grey, often carbonaceous and calcareous. Sandstones are white to grey, well sorted, very fine to fine grained, non to very calcareous, sometimes micromicaceous and carbonaceous. A thin limestone is dark grey to black in colour, micromicaceous and carbonaceous. King *et al.* (1979) recorded siderite in cuttings samples assigned to the lower part of the sub-biozone in addition to infrequent occurrences of pyrite. King *et al.* also recorded acritarchs in a cuttings sample from 5400'/1646m and a sidewall core sample from 5450'/1661m. Robeson (1988) recorded acritarchs in a cuttings sample from 5900'/1798m and *Botryococcus* in cuttings samples from 5600'/1707m and 5900'/1798m. Also in 36/16-1, between 280'/85m and 300'/91m of strata is assigned to the *Raistrikia aculeata* Sub-biozone (5000'/1524m to 5280'/1609m or 5300'/1615m). Lithologies comprise claystones, siltstones and a thin coal. Claystones are brown to grey, variably micaceous, calcareous and carbonaceous. Siltstones are grey to brown, carbonaceous, non to slightly calcareous and micaceous. King *et al.* (1979) recorded the ostracod *Bairdia* sp. in a cuttings sample from 5150'/1570m and a possible occurrence of the marginal marine to brackish ostracod *Cavellina* sp. in the 5170'/1576m cuttings sample. Bennett (2008) indicates that *Baridia* was restricted to shallow marine environments in the Carboniferous. King *et al.* also recorded acritarchs in cuttings samples from 5200'/1585m and 5300'/1615m and Robeson (1988) additionally recorded *Botryococcus* in the 5200'/1585m cuttings sample. King *et al.* inferred a paralic, dominantly non-marine depositional environment with periodic marine influence for the entire Carboniferous succession in 36/16-1.

In Block 26/28, the *Torispora securis* Sub-biozone is recorded in wells 26/28-2 and 26/28-3. In 26/28-2, a 253'/77m interval (8596'/2620m to 8848'/2697m TD) is assigned to the sub-biozone (figure 7.9). The interval is dominated by thickly bedded sandstones which are typically brown, occasionally colourless to white, quartzitic, slightly calcareous to calcareous, often carbonaceous, very fine to fine grained with sub-angular to sub-rounded, moderately sorted grains. Traces of glauconite are also recorded. The deepest sandstones in the interval are colourless to white with fine to coarse, occasionally very coarse, sub-angular to rounded grains that are predominantly loose. The sandstones are interbedded with varicoloured, non-calcareous mudstones. In 26/28-3, a 92'/28m interval (8399'/2560m to 8491'/2588m TD) assigned to the sub-biozone is dominated by quartzite (figure 7.10). The rock is colourless, off-white to grey-green, mottled, firm to hard, micaceous, chloritic and pyritic, with coarse to very coarse, angular grains.

In Block 26/28, intervals assigned to the *Raistrickia aculeata* Sub-biozone are dominated by mudrocks. In 26/28-1 and 26/28-2, lithologies comprise mudstones and siltstones with thin beds of sandstone and limestone (figures 7.8 and 7.9). Thin coals are restricted to 26/28-2. Mudstones are variably coloured (grey, yellow, grey green, black, grey brown and red brown), occasionally calcareous and sometimes carbonaceous. Siltstones are white, light to dark grey, green grey, red-brown, variably micaceous and occasionally carbonaceous. Thin limestones are white to yellow/light brown, hard, crystalline and slightly argillaceous to sandy. Carbonaceous flecks are recorded in the limestones of well 26/28-2. Sandstones are white, light grey to light brown, quartzitic, occasionally calcareous and occasionally dolomitic with very fine to fine, sub-angular to sub-rounded, moderately to well sorted grains. In 26/28-2, sandstones are occasionally carbonaceous, micaceous and glauconitic. Robeson (1988) recorded rare occurrences of *Botryococcus* in both well sections and acritarchs in a single cuttings sample from 26/28-2. Robeson *et al.* (1988) suggested a fluvial overbank/delta swamp depositional environment for the intervals in 26/28-1 and 26/28-2.

In 26/28-3, a thin (66'/20m) interval tentatively assigned to the *R. aculeata* Sub-biozone is characterised by thin sandstones of similar composition to the above, interbedded with grey, non-calcareous mudstones (figure 7.10). In 26/28-4a, a core cut (7877'/2401m to 7892'/2405.65m) from strata assigned to the *R. aculeata* Sub-biozone (figure 7.11) was described by Mayall (1982). The lower part of the core is characterised by grey siltstones and occasional fine sandstones with ripple cross lamination, horizontal lamination, abundant plant fragments (including roots) and patches of siderite. Grey and brown mudstones characterise the upper part of the core and contain abundant plant fragments with siderite and calcite nodules. Athersuch *et al.* (1982) also recorded the acritarch *Veryhachium* sp. aff. *V. reductus* in a sample from the core. Mayall inferred a non-marine, fluvial depositional environment. The author concluded that "all the sediments represent overbank and interchannel environments; the silty interval in the lower part of the core may represent a levee deposit. The rare marine indicator (acritarch) suggests that the fluvial sediment may have accumulated on the most proximal part of a delta". Athersuch *et al.* also indicated that the acritarch occurrence represents "very tentative evidence for a thin marine horizon in a predominantly non-marine clastic interval".

In 26/29-1, lithologies assigned to the *Vestispora fenestrata* Biozone are dominated by siltstones and mudstones with laminae and thin layers of very fine grained sandstone and occasional occurrences of thicker sandstones (figure 7.12). Siltstones are very fine grained and grey-green in colour. Sandstones are typically grey, quartzitic, with very fine to fine, sub-angular to sub-rounded, moderately to poorly sorted grains. They are micaceous, well cemented, infrequently chloritic with carbonaceous laminae and occasional coaly partings. Mudstones are light grey, black, non-calcareous, carbonaceous, micromicaceous and grade to impure coal. Root traces are locally recorded. In core cut from 6010'/1832m to 6044'/1842.37m, Fielding (1983) recorded a predominance of siltstones and fine sandstones. A series of small-scale coarsening upwards sequences in the uppermost part of the core was identified. Fielding also noted abundant ripple cross lamination, parallel and uneven lamination, loading and water escape structures, rare small-scale trough cross-bedding, burrows, *in-situ* rootlets and possible siderite nodules. Carbonaceous laminae, small coaly fragments and possible non-marine bivalve remains were additionally identified. Fielding interpreted the cored sediments as non-marine fluvial or delta plain deposits, suggesting the fine-grained nature is indicative of interchannel floodplain deposition. Occasional sharply based sandstones were identified as minor crevasse splays resulting from channel bank breaching. Coarsening upward sequences were interpreted as minor mouthbar deposits of shallow water lacustrine deltas.

In 26/30-1, strata assigned to the *Vestispora fenestrata* Biozone is characterised by interbedded sandstones, shales and mudstones (figure 7.13). Thin beds of coal are restricted to depths above 5120'/1561m. Sandstones are white, clear, grey, green, occasionally brown, fine to coarse grained, with angular to sub-angular, sometimes rounded, poorly to well sorted grains, often with a calcareous and silty cement. From 5290'/1612m to 5355'/1632m, a reddened, coarse to very coarse grained sand is recorded. Shales are grey-green to red-brown, occasionally grey-white, calcareous and micaceous. Mudstones are grey, brown, red-green or grey-white, micaceous and calcareous. Occurrences of *Botryococcus* are recorded in a cuttings samples from 5190'/1582m and 5340'/1628m. From approximately 5593'/1705m to 5648'/1722m (TD), a coarsely crystalline granite is recorded, overlain by an orthoclase feldspar and quartz rich 'granite wash'. King *et al.* (1982) suggested a "continental to transitional" depositional environment for the interval.

In summary, paralic depositional environments are inferred for the intervals assigned to the *Torispora securis* and *Raistrickia aculeata* Sub-biozones (figure 10.7). Occurrences of *Botryococcus* confirm freshwater to brackish deposition. Rare marine ostracods and acritarchs represent sporadic marine influences in a number of wells.

As indicated previously, Love *et al.* (1978) inferred a delta top and coal swamp depositional environment for the coal-bearing strata assigned to the *T. securis* Sub-biozone in well 13/3-1. Tate and Dobson (1989) suggested the same depositional environment for the coeval coal-bearing strata in 34/5-1. A similar depositional environment is inferred for the strata assigned to the *R. aculeata* Sub-biozone, although the rarity of coals indicates only sporadic swamp formation. In 36/16-1, King *et al.* (1979) inferred a paralic, dominantly non-marine environment with periodic marine influences for the intervals assigned to the *T. securis* and *R. aculeata* Sub-biozones. Occurrences of *Botryococcus* confirm freshwater to brackish deposition and the rarity of coals suggest very occasional coal swamp formation. Sporadic episodes of marine influence are inferred from the presence of rare acritarchs in the *T. securis* Sub-biozone and the occurrence of acritarchs and *Bairdia* in the *R. aculeata* Sub-biozone.

As indicated above, Robeson *et al.* (1988) inferred a fluvial overbank/delta swamp depositional environment for the strata assigned to the *Raistrickia aculeata* Sub-biozone in 26/28-1 and 26/28-2. This corresponds with Mayall's (1982) interpretation of an overbank and interchannel depositional environment for the cored section of equivalent age in 26/28-4a. The varicoloured claystones in 26/28-1 and 26/28-2 are indicative of palaeosol formation and the thin, fine sandstones infer low energy deposition. Rare occurrences of *Botryococcus* confirm freshwater to brackish conditions and reddened lithologies reflect episodes of oxidising conditions. The rarity of coals indicates limited coal swamp formation. Rare acritarchs in 26/28-2 and 26/28-4a and the occasional presence of glauconite in 26/28-2 indicate episodes of marine influence. In 26/28-2, the fine sandstone and varicoloured mudstone facies extend into the upper part of the *T. securis* Sub-biozone, overlying possible channel sandstones. In 26/28-3, the coarse sandstones that characterise the *T. securis* Sub-biozone are also possible channel deposits. Fielding (1983) also interpreted the interval of fine sandstones and siltstones assigned to the *Vestispora fenestrata* Biozone in 26/29-1 as non-marine, fluvial or delta plain interchannel floodplain deposits. The succession of clastics and thin coals assigned to the *V. fenestrata* Biozone in 26/30-1 are also likely to represent delta top and coal swamp deposits.

7.2.11.1 Comparison with other localities

Guion *et al.* (2000) indicated that by the late Westphalian, peat mires in a number of areas of Great Britain had been largely replaced by calcretes and well-drained palaeosols in an alluvial setting as the climate became increasingly arid (see section 10.2.6.3). A similar transition is recorded in Block 28, indicated by the rarity of coals and the dominance of variegated mudrocks in the intervals assigned to the *Raistrickia aculeata* Sub-biozone. Reddened lithologies suggest periods of better drainage and oxidation. In 34/5-1, a decrease in the abundance of coal seams also characterises the transition from the *Torispora securis* Sub-biozone to the *R. aculeata* Sub-biozone. Coal poor strata additionally characterise the entire Bolsovian interval in 36/16-1. In the British Isles, marine transgressions ceased after the mid-Bolsovian Cambriense Marine Band (Guion *et al.* 2000). In contrast, the microfossil evidence above infers that sporadic marine incursions affected the offshore western Ireland region throughout the Bolsovian.

In the sub-basins of the Maritimes Basin, Eastern Canada, Bolsovian age strata share a number of characteristics with the coeval offshore western Irish successions. The Canadian deposits are similarly dominated by clastics, are often coal-bearing and often show evidence of marine influences (section 10.3.10 and figure 10.7). As indicated in section 7.2.9.1, Bolsovian age strata in the Sydney Basin (figure 10.9) is assigned to the South Bar Formation. Sandstones, shales and coals were deposited on an alluvial braidplain with peat mires. Brackish bays developed during marine inundations (Tibert and Gibling 1999) (see section 10.3.10). In the Gulf of St Lawrence and Prince Edward Island (figure 10.9), Bolsovian age strata is assigned to the Bradelle Formation and in some well sections, the lower part of the Green Gables Formation (figure 10.17). The Bradelle Formation comprises thick multistoried sandstones, grey and red mudrocks and coals. The Green Gables Formation comprises red fine grained rocks interbedded with sandstones, coals and minor grey mudrocks (Giles and Utting 1999). Both formations contain microfaunal evidence for restricted marine influences (Gibling *et al.* 2008) (see section 10.3.10). Bolsovian age outcrops of the Cumberland Basin in Pictou County, Nova Scotia (figure 10.9) are assigned to the Malagash Formation (figure 10.18). The formation comprises sandstones and red mudrocks, rootlets, calcrete-bearing vertisols and contains agglutinated foraminifera. An alluvial plain and restricted marine (estuarine) depositional environment is inferred (Naylor *et al.* 1998) (see section 10.3.10). In the Central Basin of New Brunswick and the Ristigouche Basin, New Brunswick and Quebec (figure 10.9), Bolsovian age strata is assigned to the clastic and coal-bearing Clifton Formation Member B (figure 10.14, see sections 7.2.9.1 and 10.3.10).

7.2.12 *Westphalensisporites irregularis* Sub-biozone (upper Bolsovian)

In 34/5-1, between 259'/78.8m and 357'/108.8m of strata (3084'/940m or 3182'/970m to 3441'/1048.8m) is assigned to the *Westphalensisporites irregularis* Sub-biozone (figure 7.15). The lower part of the interval is dominated by a white to light grey, very fine to fine grained calcareous sandstone with sub-angular to sub-rounded, poorly to well sorted grains. Grains are medium to coarse, sub-rounded and well sorted at the base of the unit. The upper part of the interval is characterised by claystones, siltstones and thin coals. Robeson (1988) recorded specimens of *Botryococcus* in the interval.

In Block 26/28, the *Westphalensisporites irregularis* Sub-biozone is recorded in wells 26/28-1, 26/28-2, 26/28-3 and 26/28-4a (figures 7.8, 7.9, 7.10 and 7.11). Lithologies assigned to the sub-biozone are dominated by mudstones and siltstones, with occasional occurrences of thin sandstones. Mudstones are grey or grey green, non to slightly calcareous and variably micaceous. Dark grey mudstones are carbonaceous. Sandstones are light grey to white, quartzitic, non to slightly calcareous, micaceous and carbonaceous with very fine to fine, moderately to well sorted, sub-angular to sub-rounded grains. In 26/28-1, siltstones are grey, green-grey or red-brown, micaceous to very micaceous, carbonaceous and non to slightly calcareous. Specimens of *Botryococcus* are also recorded.

In 26/27-1b, 203.8'/62m (8530'/2600m to 8733.8'/2662m) of strata assigned to the *Westphalensisisporites irregularis* Sub-biozone is dominated by siltstones, claystones and thin coals (figure 7.7). Siltstones are light grey, slightly calcareous and occasionally black with carbonaceous matter. Claystones are black, silty and organic rich, or light green-grey with red mottling and siderite spherules. Light to medium grey, slightly silty claystones are also recorded. A core cut from 8730'/2661m to

8747'/2666m is dominated by dark and medium grey carbonaceous claystones interbedded with grey, carbonaceous siltstones and grey, fine grained, poorly sorted, calcareous sandstones (26/27-1b Final Well Report, 1981). King *et al.* (1981) inferred a transitional, deltaic environment with coal swamp development for the entire Carboniferous interval in 26/27-1b.

In 36/16-1, 144'/44m of strata assigned to the *Westphalensisporites irregularis* Sub-biozone is characterised by grey to brown, slightly to very calcareous claystones and dark grey to brown, slightly calcareous siltstones (figure 7.18). King *et al.* (1979) recorded rare occurrences of the ostracod *Darwinula* sp. and the marine ostracod *Hypotetragona* spp. in cuttings samples from the interval. Bennett (2008) indicates *Darwinula* inhabited freshwater depositional environments in the Carboniferous. Specimens of *Spirorbis* were also recorded throughout the interval. As indicated in section 7.8, King *et al.* assigned a paralic, dominantly non-marine depositional environment with periodic marine influences to the entire Carboniferous succession in 36/16-1.

Overall, a paralic depositional environment with localised swamp development is inferred for deposits assigned to the *Westphalensisporites irregularis* Sub-biozone. Coal bearing clastics in 34/5-1 suggest a continuation of the delta top and swamp depositional environment assigned to the underlying *Vestispora fenestrata* Biozone. In Block 28, the coal-poor mudstone and siltstone dominated intervals suggest a continuation of the fluvial/delta top overbank and interchannel depositional environment assigned to the *Raistrickia aculeata* Sub-biozone. The siltstones, claystones and thin coals of 26/27-1b suggest a similar low energy environment although with coal swamp development. In 36/16-1, the argillaceous interval with occurrences of marine and freshwater ostracods suggest a continuation of the paralic depositional environment with periodic marine influences assigned to the *Vestispora fenestrata* Biozone.

7.2.13 *Torispora verrucosa* Sub-biozone (Asturian)

The *Torispora verrucosa* Sub-biozone is recorded in wells 13/3-1, 26/28-1, 26/28-2, 26/28-3, 26/27-1b, 34/5-1 and 36/16-1.

In 34/5-1, between 558'/170m and 656'/200m (2526'/770m to 3084'/940m or 3182'/970m) of strata is assigned to the sub-biozone (figure 7.15). The lower part of the sub-biozone (below 2871'/875m) comprises interbedded sandstones, siltstones, claystones and a single coal. Siltstones are grey and micaceous, sandstones are grey, fine to very fine grained and dolomitic. Claystones are grey and locally carbonaceous. The middle part of the sub-biozone (2674'/815m to 2871'/875m) comprises thin interbeds of siltstone, sandstone, claystone, limestone and five coal seams. Sandstones, siltstones and claystones are as described above, although claystones can also be calcareous. Limestones are thin and microcrystalline. The upper part of the sub-biozone (2526'/770m to 2674'/815m) comprises siltstones with thin beds of sandstone. Lithologies are as described above, although the sandstones are non-dolomitic.

Both Ducazeaux *et al.* (1981) and Church *et al.* (1980) recorded ostracods in cuttings samples throughout the sub-biozone interval. Occurrences of *Pseudoparaparchites* sp., *Eukloenella* sp. and *Paraparchites* sp. are recorded in the uppermost part of the sub-biozone (at 2543'/775m). Dr. Carys Bennett (2008 and pers. comm. July 2009) indicates that *Pseudoparaparchites* was restricted to marine environments in the Carboniferous, *Eukloedenella* inhabited freshwater and marine environments ('*Eukloenella'* may be a misspelling) and *Paraparchites* was associated with marginal marine, brackish and hypersaline environments. The 2543'/775m sample also marks the last downhole occurrence of *Pseudoparaparchites* sp. From 2575'/785m to 2625'/800m, the first downhole occurrences of *Whiplella* sp., *Hilboldtina* spp., *Sulcella* sp., *Healdia* sp. and *Knightina* sp. are recorded together with occurrences of *Eukloenella* sp., *Paraparchites* sp. and *Pseudobythocypris* sp. Bennett (2008) indicates *Whiplella* and *Hilboldtina* inhabited freshwater environments in the Carboniferous, *Sulcella* inhabited marginal and brackish environments. Dr. Carys Bennett (2008 and pers. comm. July 2009) indicates *Knightina* and *Healdia* were restricted to marine environments. At 2641'/805m the first downhole occurrence of the freshwater ostracods *Carbonita* sp. and *Darwinula* sp. are recorded in addition to the last downhole occurrences of *Eukloenella* sp. and *Paraparchites* sp. In the middle of the sub-biozone (2674'/815m to 2854'/870m), *Darwinula* sp., *Whiplella* spp., and *Hilboldtina* spp. are dominant with infrequent occurrences of *Carbonita* sp. and possible occurrences of *Geisina* sp. Rare *Shemonaella sp. and Pseudobythocypris* sp. are recorded at 2789'/850m. Dr. Carys Bennett (2008 and pers. comm. July 2009) indicates both genera were associated with marginal and brackish environments in the Carboniferous. *Darwinula* sp. and *Hilboldtina* spp. are recorded to a depth of 2920'/890m and 2887'/880m respectively. Church *et al.* (1980) indicate that the range tops of *Knightina, Sulcella* and *Shaemonella* are within the Late Palaeozoic, hence the specimens are not caved from the overlying Jurassic interval.

Robeson (1988) also recorded occurrences of *Botryococcus* from 3084'/940m to 3248'/990m. Ducazeaux *et al.* (1981) additionally recorded fish remains from 2575'/785m to 2854'/870m, gastropods from 2575'/785m to 2920'/890m and pyritic concretions from 2575'/785m to 2953m/900m. Robeson recorded a single acritarch in the 2608'/795m cuttings sample. Ducazeaux *et al.* inferred a marine to brackish depositional environment for the interval 2461'/750m to 2641'/805m and a brackish to freshwater depositional environment for the interval 2641'/805m to 2953'/900m.

Overall, a delta top depositional environment is inferred for the succession of sandstones, siltstones, shales and rare coal assigned the lower part of the *Torispora verrucosa* Sub-biozone (2871'/875m to 3084'/940m or 3182'/970m). Occurrences of *Darwinula* and *Hilboldtina* confirm freshwater conditions and *Botryococcus* confirms freshwater to brackish conditions. A similar environment is inferred for the succeeding interval (2674'/815m to 2871'/875m) of interbedded siltstones, sandstones, claystones, limestones and coals, dominated by freshwater ostracods. An episode of marginal marine to brackish deposition is represented by the occurrences of *Shemonaella* and *Pseudobythocypris* at 2789'/850m. The interval of interbedded siltstones and thin sandstones assigned to the upper part of the sub-biozone (2526'/770m to 2674'/815m) is characterised by an increased presence of *Paraparchites*, *Healdia* and *Sulcella* which suggests an increasing influence of marine and marginal marine to brackish conditions. The last stratigraphic occurrences of a number of freshwater ostracod genera are also recorded. The acritarch occurrence at 2608'/795m reflects the increasing marine influence. In the uppermost part of the interval, occurrences of *Pseudoparaparchites* and *Knightina* indicate marine influences. Rare occurrences of *Pseudobythocypris* also suggest episodes of marginal marine to brackish conditions and the occurrence of *Hilboldtina* at 2575'/785m also indicates some freshwater influences. Overall, Tate and Dobson (1989) suggested the succession represents a transition from delta-top to abandonment facies.

In Block 26/28, the intervals assigned to the *Torispora verrucosa* Sub-biozone are significantly more argillaceous than the succession encountered in 34/5-1. Lithologies recorded in wells 26/28-1, 26/28-2 and 26/28-3 are predominantly mudstones with rare limestones, rare coals and thin sandstones (figures 7.8, 7.9 and 7.10). Mudstones are often grey, grey-green and locally dark grey or grey-brown. They are variably carbonaceous, variably calcareous, pyritic and micaceous. Occasional red brown mudstones are also recorded, often towards the top of the sub-biozone. Sandstones are typically white to light grey, very fine to fine grained, with angular to sub-rounded, moderately to well sorted grains. The sandstones are variably carbonaceous, calcareous, pyritic and micaceous. Rare limestones are white, hard to friable, sandy and occasionally crystalline. Microfauna have not been recorded in any of the Asturian age intervals in Block 26/28 although rare occurrences of *Botryococcus* are recorded in 26/28-1 and 26/28-3. Robeson *et al.* (1988) suggested a fluvial overbank/delta top swamp depositional environment. Tate and Dobson (1989) suggest the mud-rich deposits represent a muddy alluvial swamp depositional environment; the red and grey claystones representing the varying oxidation states between poor to well drained pedogenic facies.

To the west of Block 26/28, 770'/235m of strata in 26/27-1b is assigned to the *Torispora verrucosa* Sub-biozone. (7760'/2365m SWC to 8530'/2600m) (figure 7.7). As in Block 26/28, lithologies are predominantly argillaceous, dominated by siltstones and claystones with infrequent sandy siltstones. Thin coals are more common than in Block 26/28, and lithologies appear to be more carbonaceous. Claystones are typically grey to black or variegated, slightly to very silty, micaceous in places, non to slightly calcareous with traces of coal. King *et al.* (1981) noted that red claystones are prominent above 8400'/2560m. Coals are black, hard and brittle. Siltstones are grey-white to black, non-calcareous, carbonaceous, micromicaceous and pyritic. Sandy siltstones are light to dark grey, silty, micaceous, non to slightly calcareous with black carbonaceous debris and rare pyrite. Microfauna have not been recorded in the interval, although *Botryococcus* is present. A core cut from 8213'/2503m to 8237'/2511m comprises red mottled claystones interbedded with grey and black claystones (26/27-1b Final Well Report, 1981). King *et al.* (1981) suggest the interval was deposited in a transitional, deltaic environment with coal swamp development. Robeson *et al.* (1988) interpreted the reddened lithologies as either representing periodic aridity or local emergence on the top of more positive (deltaic) sediment lobes. Rare acritarchs indicate sporadic marine influences.

In 36/16-1, 421'/128m (4435'/1352m to 4856'/1480m) of strata is assigned to the *Torispora verrucosa* Sub-biozone (figure 7.19). Lithologies comprise grey to dark grey-brown, slightly to very calcareous claystones, grey siltstones, thin beds of light grey, fine grained, carbonaceous and calcareous sandstones, a single thin coal and a thin bed of brown, microcrystalline limestone. In cuttings samples from the interval, King *et al.* (1979) recorded sporadic occurrences of the marine ostracods *Hypotetragona* spp., and *Bairdia* sp. in addition to occurrences of the freshwater ostracod *Darwinula* sp. Specimens of *Spirorbis* sp. were also recorded. Robeson (1988) additionally recorded acritarchs in a cuttings sample from 4640'/1414m. As indicated in earlier sections, King *et al.* inferred a paralic, predominantly non-marine depositional environment with periodic marine influences for the entire Carboniferous succession in 36/16-1.

Lithologies assigned to the *Torispora verrucosa* Sub-biozone in 13/3-1 are shown in figure 7.3. From 1505'/459m to 1740'/530m, interbedded sandstones, mudstones/claystones and siltstones are recorded. Sandstones are typically white to light grey, quartzitic, with fine to medium, sub-rounded to sub-angular grains in a siliceous, occasionally dolomitic cement. The sandstones are locally micaceous with occasional black carbonaceous specks. Occasional green colouration is attributed to chlorite or epidote. Mudstones are grey, firm to soft and grade to claystone. Reddish-brown, slightly calcareous and micaceous siltstones are recorded between 1600'/488m and 1640'/500m. From 1420'/433m and 1505'/459m, sandstones and mudstone contain possible glass shards. The lithologies are interpreted as tuffs and are interbedded with clear to white, medium to fine grained quartzitic sandstones. Possible tuffaceous lithologies are also recorded from 1300'/396m to 1420'/433m. The tuffaceous interval is succeeded by grey, silty claystones with mica and carbonaceous specks. Robeson (1988) recorded occurrences of *Botryococcus* throughout the interval assigned to the sub-biozone, including sidewall core samples from 1581'/482m and 1705'/520m. Robeson also recorded acritarchs in cuttings samples from 1290'/393m and 1690'/515m. No microfauna have been recorded. In terms of depositional environment, Love *et al.* (1978) suggested a delta top. Occurrences of *Botryococcus* recorded throughout the interval support this interpretation. Acritarchs indicate sporadic episodes of marine influence. Love *et al.* suggested the reddish brown shales recorded from 1600'/488m and 1640'/500m indicate sub-aerial exposure.

Overall, based on the interpretations of Robeson *et al.* (1988) and Tate and Dobson 1989), the mudstone dominated, occasionally reddened, coal-poor strata of Block 28 was deposited in a fluvial overbank/delta top or muddy alluvial swamp depositional environment. The mudstones probably represent palaeosol deposits. The reddened mudstones represent episodes of better drainage, sub-aerial exposure and oxidation. A predominantly argillaceous, coal-bearing interval in 26/27-1b infers a similar depositional environment although with more coal swamp development than in Block 28. Based on the interpretations of Tate and Dobson, a succession of sandstones, siltstones, claystones, coal, limestones and predominantly freshwater ostracods recorded in the lower and middle parts of the *Torispora verrucosa* Sub-biozone in 34/5-1 infer a delta top depositional environment with swamp development. Towards the top of the sub-biozone, the coal-poor interval of siltstones and thin sandstones with marine and marginal marine/brackish ostracods and rare acritarchs represent an increase in marine influence and possibly a transition to delta top abandonment facies. In 36/16-1, a claystone rich unit with thin beds of sandstone, rare coals and rare limestones is similar to the successions recorded in Block 28. Occurrences of freshwater ostracods, marine ostracods and rare acritarchs indicate an environment with both freshwater and marine influences. In well 13/3-1, the coal-poor succession of interbedded sandstones, mudstones/claystones, siltstones and possible tuffs are indicative of delta top deposition based on the interpretations of Love *et al.* (1978). Again, occasional red-brown beds indicate periods of sub-aerial exposure or better drainage. Occurrences of rare acritarchs indicate sporadic marine influences. Asturian to Cantabrian age palaeogeographic reconstructions are shown in figure 10.8.

7.2.13.1 Comparison with other localities

Asturian age strata is virtually absent onshore Ireland (Cope *et al.* 1992). Clayton *et al.* (1986) assigned the *Thymospora obscura – T. thiessenii* (OT) Biozone of Clayton *et al.* (1977) and an Asturian age to 125'/38m of strata recorded in borehole W80.5, drilled in the Wexford Outlier of south-eastern Ireland (see section 10.2.6.1, figure 10.8). The interval comprises black and greyish-black carbonaceous mudrock, dark grey mudrock with bivalve and rootlet rich horizons, grey silty mudrock with carbonate concretions, bituminous coal, siltstones and yellowish to greenish-grey, medium to fine grained sandstones that show fining upwards sequences and localised reddening. The authors suggested a coal swamp depositional environment.

As noted in section 7.2.11.1, by the late Westphalian, peat mires in areas of Great Britain had been largely replaced by calcretes and well-drained palaeosols in an alluvial setting due to an increasingly arid climate (Guion *et al.* 2000) (section 10.2.6.3). The coal-poor, occasionally reddened, Asturian age deposits of Block 26/28 and 13/3-1 and the coal poor deposits of 36/16-1 may reflect an increasingly arid climate. In southern England and South Wales, coal forming conditions generally persisted above the mid Bolsovian Cambriense Marine Band (Ramsbottom *et al.* 1978) and red beds are less frequently recorded. This also appears to be the case in the 34/5-1 locality. In contrast to the offshore western Irish sections, there is no evidence for marine incursions in the Asturian age successions of onshore Great Britain.

In the sub-basins of the Maritimes Basin, Eastern Canada, Asturian age strata share a number of characteristics with the coeval offshore western Irish successsions. The Canadian deposits are similarly clastic-rich, commonly coal-bearing and often show evidence for marine influences (figure 10.8). In the Sydney Basin (figure 10.9), Asturian age strata is assigned to the Sydney Mines Formation (see section 10.3.10, figure 10.17). The formation comprises stacked sequences of sandstones, grey and red mudstones, coal, dark limestone and calcrete (Gibling *et al.* 2008). The formation was deposited in alluvial plain, coastal plain and restricted marine environments (Batson and Gibling 2002). Assemblages of agglutinated foraminifera and thecamoebians recorded by Wightman *et al.* (1994) suggest that environments ranged from estuarine to marsh to freshwater. The presence of glauconite (McIlroy and Falcon-Lang 2006) and acritarchs (T.K. Dimitrova personnal communication in McIlroy and Falcon-Lang 2006) indicate marine influence. In the Gulf of St Lawrence and Prince Edward Island (figure 10.9), Asturian age strata is assigned to the Green Gables Formation (Bolsovian/Asturian to lower Stephanian) and in some well sections, to the uppermost part of Bradelle Formation (Duckmantian to Bolsovian/Asturian) (Giles and Utting 1999) (figure 10.17). As indicated in section 10.3.10, both formations are dominated by clastics and are coal bearing. Occurrences of agglutinated foraminifera indicate a depositional environment with restricted marine influence (Gibling *et al.* 2008). Asturian age outcrops of the Cumberland Basin, exposed in Pictou County, Nova Scotia (figure 10.9) are assigned to the Malagash Formation (figure 10.18). As indicated in section 10.3.10, the alluvial plain and restricted marine (estuarine) deposits comprise sandstones and red mudrocks, rootlets, calcrete-bearing vertisols with occurrences of agglutinated foraminifera. In the Central Basin of New Brunswick and the Ristigouche Basin of New Brunswick and Quebec (figure 10.9), Asturian age strata is tentatively assigned to the Clifton Formation Member B (section 10.3.10).

7.2.14 *Angulisporites splendidus* Sub-biozone (Cantabrian) of Clayton *et al.* (2003) and *Potonieisporites novicus-bharadwaji – Cheleidonites major* (NBM) of Clayton *et al.* (1977) (upper Stephanian B to Stephanian C)

The Cantabrian age *Angulisporites splendidus* Sub-biozone of Clayton *et al.* (2003) is recorded in wells 26/27-1b, 26/28-1, 26/28-2, 34/5-1 and 36/16-1. Strata tentatively assigned to the NBM Biozone of Clayton *et al.* (1977) are recorded in wells 12/2-1z and 34/15-1. The Carboniferous interval in 26/21-1 is dated as Stephanian in age.

In 26/28-1, between 33’/10m and 146’/44.4m (8973’/2735m to 9006’/2745m or 9119’/2779.4m SWC) of strata is assigned to the *Angulisporites splendidus* Sub-biozone (figure 7.8). The lower part of the interval assigned to the *Angulisporites splendidus* Sub-biozone comprises light to dark grey siltstones and grey to brown, micaceous and pyritic mudstones (figure 7.8). The upper part is characterised by varicoloured (grey, black, mauve, mustard, tan) non-calcareous mudstones interbedded with red-brown, micaceous, earthy and non-calcareous mudstones. Duxbury *et al.* (1979) recorded several specimens of the freshwater ostracod *Carbonita* sp. in cuttings samples from 8973’/2735m and 9006’/2745m. An additional, single, poorly preserved occurrence in Jurassic age strata (at 8924'/2720m) is considered reworked. A second genus *Shivaella* sp. was also recorded at 9006'/2745m. Bennett (2008) indicates *Shivaella* was restricted to shallow marine environments in the Carboniferous. Duxbury *et al.* indicate *Carbonita* and *Shivaella* are both Carboniferous genera, therefore have not been caved from the overlying Jurassic strata. No microfauna were recorded below 9071'/2765m. Both Simpson (1979) and Duxbury *et al.* (1979) suggested a "coal measures" type freshwater depositional environment for the interval 8973'/2735m to 9071'/2765m based on the specimens of *Carbonita*. The presence of *Shivaella* infers an episode of marine influence.

Strata assigned to the *Angulisporites splendidus* Sub-biozone in 26/28-2 comprise red-brown, silty mudstones which are occasionally slightly calcareous (figure 7.9). In 26/27-1b, claystones characterise the interval assigned to the sub-biozone (figure 7.7). The claystones are mottled red, yellow, brown-green and are non to slightly calcareous. At the base of the interval, grey, micromicaceous and slightly calcareous claystones are recorded. King *et al.* (1981) suggested that claystone recorded in a sidewall core from 7706'/2349m may be tuffaceous. This study recorded acritarchs in a sidewall core sample from the base of the interval.

In 34/5-1, the 115'/35m interval (2411'/735m SWC to 2526'/770m) assigned to the *Angulisporites splendidus* Sub-biozone is characterised by interbedded siltstones, claystones and sandstones (figure 7.15). Sandstones are light grey-green, slightly argillaceous, slightly calcareous, very fine to fine grained, with sub-angular, well sorted grains. Claystones and siltstones are grey in colour. In a cuttings sample from 2428'/740m, Church *et al.* (1980) recorded coarse, white, quartz fragments and fine sand grains in association with a red clay. However, it is possible that the lithologies are caved from similar deposits in the overlying Eocene to Cretaceous interval. In cuttings samples from 2461'/750m to 2526'/770m, Ducazeaux *et al.* (1981) recorded the ostracods *Pseudoparaparchites* sp. and *"Eukloenella"* sp. As noted in section 7.2.13, Dr. Carys Bennett (pers comm. July 2009) indicates that *Pseudoparaparchites* was restricted to marine environments in the Carboniferous, and *Eukloedenella* inhabited freshwater and marine environments. Church *et al.* (1980) also recorded a possible occurrence of the marginal marine to brackish ostracod *Pseudobythocypris* sp. in the 2428'/740m cuttings sample. Ducazeaux *et al.* also recorded pyritic concretions in cuttings samples from the interval. Church *et al.* suggested that specimens of *Nummulites* sp. recorded in cuttings samples are most likely to be caved from the overlying Eocene to Cretaceous strata. Overall, Ducazeaux *et al.* assigned a marine to brackish depositional environment to the interval 2461'/750m to 2641'/805m.

In 36/16-1, strata assigned to the *Angulisporites splendidus* Sub-biozone comprise siltstones and claystones (figure 7.19). Siltstones are green-grey to grey and slightly calcareous. Claystones are grey, black, carbonaceous, micaceous and non-calcareous. King *et al.* (1979) recorded occurrences of the marine ostracod *Hypotetragona* spp. throughout the interval. Sporadic occurrences of the freshwater ostracod *Carbonita* gr. *humulis* were recorded in samples from the middle of the sub-biozone and occurrences of *Spirorbis* and the freshwater ostracod *Darwinula* sp. were recorded in the lowermost part of the sub-biozone interval. King *et al.* indicate the range of *Hypotetragona* is Devonian to Carboniferous and is therefore unlikely to have been caved from the overlying Jurassica strata. Robeson (1988) also recorded acritarchs in the 4400'/1341m cuttings sample and King *et al.* recorded pyrite in cuttings samples from the interval. As indicated previously, King *et al.* inferred a paralic, dominantly non-marine depositional environment with periodic marine influences for the entire Carboniferous succession in 36/16-1. The microfaunal and palynological evidence above infer both marine and freshwater influences for the Cantabrian age interval.

In 26/21-1, the 148'/45m interval (6975'/2126m to 7123'/2171m) assigned to the Stephanian is dominated by siltstones and shales (figure 7.5). Siltstones are grey to white, slightly to very calcareous, slightly pyritic and interbedded with thin sandstones. Sandstones are light grey, quartzitic, pyritic, micaceous, calcareous and very fine grained with sub-angular, moderately sorted grains. In places, the sandstones are white, fine-grained, slightly calcareous, micaceous and carbonaceous. Shales are dark grey to black, micaceous, non-calcareous and organic rich with carbonised organic debris. No microfauna have been recorded in the interval. Rare acritarchs are recorded in cuttings samples from the interval 6975'/2126m to 7123'/2171m, although it is possible that the specimens are caved from the overlying Triassic strata.

In 34/15-1, 349'/106m (14239'/4340m to 14587.6'/4446m TD) of strata is assigned to the upper Stephanian age *Potonieisporites novicus-bharadwaji – Cheleidonites major*

(NBM) Biozone of Clayton *et al.* (1977). The interval is characterised by interbedded sandstones, shales, siltstones and thin limestones. In the lowest 39'/12m, shales are green-grey to dark grey, generally non-calcareous and carbonaceous. Siltstones are green-grey, carbonaceous, slightly calcareous, glauconitic and pyritic. Thin stringers of limestone are dark grey, locally cream, micaceous, partly sparitic and ostracod bearing. Cepek *et al.* (1977) identified the freshwater ostracod *Carbonita* cf. *secans* and the freshwater to marginal marine to brackish ostracod *Geisina arcuata* in a core sample from 14586.8'/4446.12m. Roveda *et al.* (1977) recorded the marine ostracod *Hypotetragona* sp. in a core sample from 14583'/4445m. In the overlying 284'/86.5m of strata (14265'/4348m to 14549'/4434.5m), shales are generally light to dark grey, variably micaceous, carbonaceous, locally very calcareous, partly pyritic, glauconitic and grade to siltstone. Sandstones are typically off-white to grey, locally red at shallower depths, fine to medium and locally coarse grained with sub-angular to sub-rounded, moderately sorted grains. They are calcareous, micaceous, with traces of glauconite and pyrite. From 14376'/4382m to 14549'/4434.5m, the sandstones contain clasts of grey shale and cream limestone. Below 14376'/4382m, thin limestone beds are cream, microcrystalline, partly argillaceous, very sandy, partly oosparitic and contain intraclasts. Above 14376'/4382m, traces of limestone are in part intraclasts, generally cream, microcrystalline, locally very argillaceous, partly pyritic with traces of sparite and macrofaunal fragments (forams, brachiopods and questionable trilobites). Minor red beds including red and brown shales and red brown siltstones are also recorded between 14265'/4348m and 14376'/4382m. Roveda *et al.* recorded sphaerosiderite in a cuttings sample from 14271'/4350m and lignite in cuttings samples to a depth of 14485'/4415m. The authors also identified poorly preserved examples of *Hypotetragona* sp. in the 14501'/4420m cuttings sample.

Roveda *et al.* (1977) suggested a predominantly continental depositional environment for the Stephanian age interval in 34/15-1 although noting that the occurrences of *Hypotetragona* indicate some marine influence. Robeson *et al.* (1988) tentatively inferred a "continental (marginal marine) environment". Tate and Dobson (1989) suggested a marginal marine to freshwater environment, interpreting the stringers of intraclast rich limestones as allochthonous marine deposits washed over an alluvial marsh. The authors also suggested the transition to red claystones and siltstones towards the top of the interval represent the development of well drained pedogenic facies.

In 12/2-1z, the interval very tentatively assigned to the NBM Biozone (14196'/4327m to 14639'/4462m or 14668'/4471m TD) is characterised by interbedded sandstones, limestones and claystones (see palynostratigraphic interpretation no.1, figure 7.1). From approximately 14518'/4425m to 14668'/4471m, interbedded claystones and sandstones are recorded. Claystones are non-calcareous and either dark brownish-red and dark grey or varicoloured greenish-grey and reddish-brown. Sandstone stringers, composed predominantly of loose quartz are grey to light olive grey, fine to very fine grained, very well sorted, micaceous, calcareous and occasionally carbonaceous. Rare coals are black, moderately hard, brittle and fissile. From 14386'/4385m to 14518'/4425m, sandstones similar to the above are recorded, although with traces of mica, pyrite and carbonaceous material. Claystones are greyish-brown and calcareous, becoming dark brownish-red, dark grey, silty and slightly dolomitic with depth. Stringers of hard limestone are also recorded. From 14196'/4327m to 14386'/4385m claystones are varicoloured (greenish-grey, greyish-black and reddish-brown), micromicaceous, microcarbonaceous, and grade to argillaceous sandstone. The claystones become medium grey and calcareous below 14321'/4365m. Sandstones are light brownish-grey, quartzitic, calcareous, fine to medium and frequently coarse grained, sporadically granule sized, with sub-rounded to rounded, very well sorted grains and traces of feldspar and nodular pyrite. Stringers of limestone are light to dark brownish-grey, cryptocrystalline, slightly argillaceous and very hard.

Overall, the Stephanian age deposits are typically coal-poor and often reddened. Based on the interpretations of Tate and Dobson (1989) a low-lying, coastal, alluvial swamp depositional environment is envisioned. In Block 28, varicoloured claystones interbedded with red-brown earthy claystones most likely represent palaeosol deposits with varying oxidation states. Common occurrences of the freshwater ostracod *Carbonita* and the rare occurrence of the marginal marine ostracod *Shivaella* in 26/28-1 suggest deposition in a predominantly freshwater environment with rare marine influences. The mottled red, yellow, brown-green claystones and grey claystones of 26/27-1b are also potential palaeosol deposits. Rare acritarchs indicate sporadic marine influences. To the west, in well 34/5-1, specimens of *Pseudoparaparchites,* *Eukloenella* and *Pseudobythocypris* indicate both marine and marginal marine influences. In well 36/16-1, both freshwater and marine influences are indicated by the occurrence of *Hypotetragona*, *Carbonita* and *Darwinula*. Based on the interpretations of Tate and Dobson (1989), the upper Stephanian age stringers of intraclast rich limestones in 34/15-1 are considered to represent allochthonous marine deposits washed in over the alluvial marsh. The rare occurrences of *Hypotetragona* towards the base of the interval and traces of glauconite throughout the interval confirm marine influence. The transition to red claystones and siltstones towards the top of the interval may represent the development of well drained pedogenic facies.

7.2.14.1 Comparison with other localities

Stephanian age strata is recorded in the sub-basins of the Maritimes Basin, Eastern Canada (section 10.3.10). As in the offshore western Irish sections, deposits are often reddened and contain evidence for episodic marine influences. In the Sydney Basin (figure 10.9), the lower Asturian to lower Stephanian age Sydney Mines Formation (figure 10.17) comprises sandstones, grey and red mudstones, coals, dark limestones and calcretes deposited in alluvial plain, coastal plain and restricted marine environments (sections 7.2.13.1 and 10.3.10). The Sydney Mines Formation is succeeded by unnamed Stephanian age red beds of the Pictou Group, reflecting the progression to a more arid climate (Gibling *et al.* 2008) (figure 10.17 and section 10.3.10). In the Gulf of St Lawrence and Prince Edward Island (figure 10.9), the Bolsovian/Asturian to lower Stephanian age Green Gables Formation is dominated by coal-bearing clastics. The overlying Stephanian age Cable Head Formation is typically dominated by thick multistoried sandstones with red, fine grained mudrocks and localised pedogenic carbonates (figure 10.17). Gibling *et al.* (2008) note that agglutinated foraminifera recorded in both formations indicate a depositional environment with episodes of restricted marine influence. The Stephanian to Lower Permian age Naufrage Formation comprises red siltstones and mudstones with pedogenic carbonates and sandstones (Giles and Utting 1999).

7.2.15 *Vittatina costabilis* (VC) Biozone (lower Autunian)

In 34/15-1, 525’/160m of strata is very tentatively assigned to the lower Autunian age *Vittatina costabilis* (VC) Biozone of Clayton *et al.* (1977) (figure 7.16). In the lower 367’/112m of the biozone (13871’/4228m to 14239’/4340m), claystones, siltstones, sandstones and thin limestones are recorded. Sandstones are generally off-white to light grey, calcareous, micaceous, locally very pyritic, occasionally glauconitic, fine to medium grained, with sub-rounded, moderately well sorted grains and traces of carbonaceous material. Claystones are predominantly brick-red, micromicaceous, locally slightly calcareous and grade to brown-red and mauve-brown, siltstones. Siltstones in turn grade to minor purple-brown and mauve-brown, fine grained, very argillaceous sandstones. Claystones are grey, locally calcareous, with traces of glauconite and black carbonaceous material. Also recorded in the interval are calcareous/dolomitic concretions and at 14025’/4275m, thin interclasts of cream micritic limestone with ostracods. The upper 157’/48m of strata assigned to the biozone (13714’/4180m to 13871’/4228m) is characterised by claystones, siltstones and sandstones. Claystones are reddened, siltstones are purple brown and very micaceous. Both contain inclusions of anhydrite. Sandstones are generally light pink to purple brown, anhydritic, slightly calcareous, fine to medium grained, with sub-angular, poorly to moderately sorted grains. Clasts of red and grey claystone, possible altered feldspars and local occurrences of black carbonaceous material are recorded within the sandstones. Anhydrite is present as vugular infillings as well as cement. Roveda *et al.* (1977) also recorded sphaerosiderite from 13796’/4205 to 14091’/4295m.

In 12/2-1z, the interval very tentatively assigned to the VC Biozone (13478’/4108m to 14176’/4321m) is characterised by interbedded sandstones and claystones (see palynostratigraphic reinterpretation no.1, figure 7.1). Sandstones are light brownish-grey, hard, quartzitic, calcareous, fine to medium and occasionally coarse grained, sporadically granulate, with well-sorted, sub-rounded to rounded, spherical grains. The sandstones contain traces of pinkish-orange feldspar and occasionally nodular pyrite. Claystones are greenish-grey, greyish-black, reddish brown, micromicaceous, non-calcareous, locally dolomitic, occasionally very sandy grading to argillaceous sandstone. Limestones are recorded as yellowish-grey rockflour.

Tate and Dobson (1989) propose that in the locality of well 34/15-1, the muddy, coastal swamp conditions that developed in the Stephanian continued into the lower Autunian. The authors suggest this was succeeded by a lagoonal to playa lake depositional environment, enabling the formation of evaporites recorded in the well section.

CHAPTER 8
PALYNOFACIES

8.1 INTRODUCTION AND DEFINITIONS

Until the widespread availability of hydrofluoric acid in the second half of the twentieth century, pre-Quaternary palynology was exclusively concerned with the study of palynomorphs for palaeobotany and biostratigraphy. The material that formed the bulk of the palynological organic matter (kerogen) in sediments and sedimentary rocks was almost entirely ignored. However, once the components of organic matter were recognised, it became apparent that its character could be used to help determine the depositional environment and hydrocarbon potential of the rock (Tyson 1995).

The concept of palynofacies was introduced by Combaz (1964) to “encompass the total complement of acid-resistant organic matter recovered from a sediment or sedimentary rock by palynological processing techniques using hydrochloric or hydrofluoric acid (HCl, HF), as seen under a microscope” (Batten 1996). Tyson (1995) subsequently defined a palynofacies as “a body of sediment containing a distinctive assemblage of palynological organic matter thought to reflect a specific set of environmental conditions, or to be associated with a characteristic range of hydrocarbon-generating potential”. Tyson defined palynofacies analysis as “the palynological study of depositional environments and hydrocarbon source rock potential based upon the total assemblage of particulate organic matter”.

8.2 AIM OF THE STUDY

The aim of the present study was to use palynofacies analysis to provide further information on the late Bolsovian, Asturian and Stephanian age depositional environments of offshore western Ireland. Of particular interest are the intervals in a number of well sections where microfaunal and palynological evidence indicates marine influences (chapter 7.2).

8.3 CLASSIFICATION OF ORGANIC MATTER

Although numerous classification schemes of palynological organic matter have been published, no universally-accepted scheme exists. Published schemes vary in terms of their complexity and degree of emphasis on the botanical source, morphology or preservation state of the organic particles. They are often tailored to suit the needs of a particular study. Examples of published classification schemes are outlined below and in figure 8.1.

Burgess (1974)

Under the heading ‘type of organic matter’, Burgess (1974) listed the following categories; ‘amorphous’, ‘finely disseminated O.M’, ‘herbaceous plant debris’, ‘woody plant debris’, ‘coaly fragments’ and ‘algal debris’. Subsequent usage has abbreviated the categories to ‘amorphous’, ‘woody’ ‘herbaceous’, ‘coaly’ and ‘algal’ (figure 8.1). The classification scheme is now deemed unsatisfactory due to the category names being a mixture of descriptive, genetic and botanical terms. ‘Herbaceous’ and ‘coaly’ are particularly unsuitable and misleading (Tyson 1995).

Bujak *et al.* (1977)

The classification scheme of Bujak *et al.* (1977) resembles that of Burgess (1974), although with renamed categories based on morphological terminology. The four categories are ‘amorphogen’, ‘phyrogen’, hylogen’ and ‘melanogen’. As outlined in Tyson (1995), Bujak *et al.* described the categories as follows; “phyrogen comprises all non-opaque recognizable plant matter that is not of a woody origin and includes plant cuticles, spores and dinoflagellate cysts. Hylogen includes non-opaque fibrous plant material of woody origin. Melanogen is all opaque organic material”. Amorphogen comprises “unorganised, structureless organic material which may be finely disseminated or coagulated into fluffy masses” (Coleman 1991). Although the terminology has been used in a number of studies (e.g. McPhilemy 1989; Coleman 1991; Connolly 2002), it has not been widely adopted (Tyson 1995).

Davies *et al.* (1991)

With the aim of describing the transition from the largely fluviatile, Late Devonian Old Red Sandstone, to the mainly marine, early Dinantian Lower Limestone Shale Group of South Wales, Davies *et al.* (1991) sub-divided organic matter into 'terrestrial' and 'marine' categories. The terrestrial category was further divided into four sub-categories; 'woody plant debris', 'non-woody tissue', 'spores' and 'tubes'. Woody plant debris comprises hylogen and melanogen. Non-woody tissue refers to platy or sheet-like fragments of organic matter presumed to represent non-woody and/or degraded plant material. The marine category comprises 'organic-walled microplankton' (which is further sub-divided into three groups plus *Botryococcus*) and 'scolecodonts'. A key limitation of the classification scheme is the absence of a category for amorphous organic matter (AOM), which is often present in a palynofacies.

Tyson (1993; 1995)

The detailed classification scheme of Tyson (1993) is outlined in Tyson (1995). Tyson (1995) also provided a comprehensive key to assist in the identification and classification of organic particles (see Tyson 1995, figure 20.5, p.354). The author sub-divided kerogen into 'structured' and 'unstructured' categories. The unstructured category comprises the 'amorphous' group, which is further sub-divided into 'AOM', 'resins' and 'gels' based on heterogeneity, fluorescence and outline. The 'structured' category comprises the 'phytoclast', 'palynomorph' and 'zooclast' groups. The phytoclast group is further sub-divided based on opacity, fluorescence and biostructure. The palynomorph group comprises the 'sporomorph', 'zoomorph' and 'phytoplankton' sub-groups which are also sub-divided. Overall, the incorporation of a wide range of sub-divisions makes the classification scheme suitable for most palynofacies studies.

Batten (1996)

Batten (1996) referred to the organic content of palynofacies as palynological matter (PM). The author sub-divided PM into four categories; 'palynomorphs', 'structured organic matter' (STOM), 'unstructured (structureless) organic matter' (USTOM) and 'reworked organic matter'. All categories (except reworked organic matter) are divided into sub-categories. USTOM for example is sub-divided into six sub-categories. Of particular interest to the present study are the sub-categories AOM of terrestrial origin (AOMT) and AOM of aquatic origin (AOMA) (see section 8.4.2.1).

Smith (1996)

The classification scheme of Smith (1996) follows the Amsterdam Palynological Organic Matter Classification, 2nd edition, as defined at Aix-en-Provence, France in September 1992. However, the scheme agreed upon in Amsterdam was not published and as a result is not widely accepted.

8.4 CLASSIFICATION SCHEME USED IN THIS STUDY

The classification scheme used in the present study (figure 8.2) is for the most part a simplified version of the Tyson (1993; 1995) scheme. Organic particles are subdivided into two categories; 'structured' and 'structureless'. The 'structured' category is sub-divided into the 'palynomorph', 'phytoclast' and 'zooclast' groups. The groups include a range of organic particles recognised in the present study. The 'structureless' category comprises AOM and resins. In contrast to the Tyson scheme, AOM is further sub-divided based on its fluorescence, with the aim of distinguishing AOM of liptinitic origin from AOM of lignitic origin (see section 8.4.2.1). Characteristics of the various groups recognised in the present study are outlined below.

8.4.1 Structured organic matter

Based on Tyson (1995), three types of organic particles can be classified as 'structured'; i) those with a well defined morphological structure such as palynomorphs, ii) fragments which at least partially preserve original botanical features and iii) angular to irregular particles with a distinct outline, definite structure, shape or fabric, indicating they were one part of a larger organised body or tissue.

8.4.1.1 Phytoclast group

As outlined in Tyson (1995), the term phytoclast was originally introduced by Bostick (1971) to describe “clay to fine sized particles of altered plant matter that are apparently derived from land plants”. Bostick (1974) added that phytoclasts “consist of plant spores and pollen, leaf cuticles and fragments that have bordered pits, ribs, fibers or cellular structure”. As Bostick (1971) also recognised ‘floccules’ (algal debris or liptinite) as a phytoclast component, the resulting definition included all particles of plant derived organic matter. A subsequent redefinition by Tyson (1995), that is followed in the present study, restricts the term to plant ‘clasts’ (broken pieces), excluding palynomorphs and AOM. Components of the phytoclast group recognised in the present study are outlined below.

Woody Tissue (Plate 10, figures 20 - 22).

Most fossilised phytoclasts are derived from the ligno-cellulosic tissues of terrestrial plants. Many represent fragments of heavily lignified mechanical support and vascular tissues of the secondary xylem (woody tissue). As lignin is highly stable, resistant and hydrophobic, the material has a high preservation potential (Tyson 1995).

Recognition and identification: Under transmitted light, woody tissue is light brown to very dark-brown/black in colour. Fragments are typically lath-shaped to equidimensional. They may show pitting, stripes/banding or a cross-hatched pattern. Most particles possess an angular outline. Woody tissue may also show a very faint, dull fluorescence. Tyson (1995) indicates that immature woody material shows a primary fluorescence, although it decreases rapidly with maturity reaching a minimum at vitrinite reflectance values of 0.4% - 0.7% Rr. Woody material is also known to acquire a slight fluorescence at vitrinite reflectance values of 0.9% - 1.3% Rr (McPhilemy 1988; 1989) (figure 8.3). At this rank, the formation of micrinite results in the generation of hydrocarbons which are adsorbed onto the woody particles (McPhilemy 1988).

Cortex Tissue (Plate 11, figures 1 - 3)

Cellulose forms the bulk of the internal non-lignified and non-vascular tissues (cortex) of plants (Batten 1996). As cellulose degrades faster than lignin, cortex tissues will degrade faster than the vascular lignified tissue of woody material. In ancient sediments, remains of cortex tissues seem to be most common in non-marine and deltaic facies (Tyson 1995).

Recognition and identification: Cortex tissue has a very fine cellular structure, and may be fibrous, ribbed or membranous in appearance. It is typically pale yellow to amber/light brown. Cortex tissue lacks fluorescence (Tyson 1995).

Cuticle (epidermal tissue) (Plate 10, figure 17)

Cuticle is the outermost covering of leaf and stem epidermis in most higher plants (Batten 1996). Most fossilised cuticular fragments are derived from leaves as they are frequently shed and possess a large surface area (Tyson 1995).

Recognition and identification: Under transmitted light, cuticle is typically thin, flimsy in appearance and pale yellow to colourless. It is recognised by its remnant cellular structure. Tyson (1995) indicated that cuticle fluoresces up to vitrinite reflectance values of 1% Rr. However, McPhilemy (1988; 1989) noted that cuticle may lose its fluorescence at different ranks and can show varying colour and intensity of fluorescence at any particular rank (figure 7.3).

Opaque phytoclasts (Plate 10, figures 18 and 19)

Most opaque organic matter in a palynological preparation can be identified as charcoal; formed by the exposure of terrestrial plant material to high temperatures under conditions of oxygen starvation (Cope 1981; Chaloner 1981). However, Tyson (1995) indicates there is a "complex continuum of variously charred or oxidized plant tissues", making it difficult to distinguish between truly opaque clasts and those which are very dark brown. As a result, this group most likely represents oxidised land plant tissue in addition to charcoal.

Recognition and identification: Opaque phytoclasts can be recognised by their definite outline and may show remnant cellular structure. Pyrite can usually be distinguished by its framboidal shape. Charcoal does not fluoresce (McPhilemy 1989).

8.4.1.2 Palynomorph group

Batten (1996) indicates that the term 'palynomorph' was introduced by Tschudy (1961) to represent all discrete, acid-resistant, organic-walled microfossils that may be encountered in a palynological preparation. Three sub-groups of the palynomorph group were recognised in the present study; sporomorphs (spores and pollen), organic walled phytoplankton (acritarchs, prasinophyte algae, chlorococcalean algae), and zoomorphs (foraminiferal linings and scolecodonts).

Sporomorphs (Plates 1 - 9)

The term 'sporomorph' is commonly used as a collective term for all terrestrial spores and pollen (Tyson 1995). Playford and Dettman (1996) defined 'spores' as the "durable reproductive cells of bryophytes and free sporing pteridophytic vascular plants". Jarzen and Nichols (1996) defined 'pollen' as the "male gametophyte of seed plants". As indicated in Playford and Dettman (1996), the term 'miospore' was introduced by Guennel (1952) to embrace small spores and pollen less than 200µm in diameter. For spores or pollen having diameters greater than 200µm, the term 'megaspore' is generally applied.

As the settling rates of miospores are comparable to those of fine silt, they tend to be most abundant in fine grained sediments (clays and silts). Their distributions can also be affected by transportation (predominantly by water rather than wind), parent plant distribution and degradation due to bacterial degradation and pyrite overgrowths (Batten 1996).

Recognition and identification: For morphological descriptions of spores and pollen encountered in the present study, see chapter 4. Sporomorph colour under transmitted light varies due to exine thickness, ornamentation and maturity. In a previous palynological study of samples from offshore western Ireland, Robeson (1988) used the spore colouration index (S.C.I) of Fisher (1980) to record the average body colour of *Lycospora* spp. in transmitted light and fluorescence colour in ultra-violet light (figures 8.7, 8.10, 8.13, 8.16). McPhilemy (1989) recorded miospore fluorescence ceasing at a vitrinite reflectance of ~1.2% Rr (figure 8.3).

Organic walled phytoplankton

Three types of organic walled phytoplankton were recorded in the present study; acritarchs, prasinophyte algae and chlorococcalean algae. Dinoflagellate cysts were also recorded in a number of samples, but are deemed to be caved due to their stratigraphic range.

Acritarchs (Plate 10, figures 1 - 7)

Strother (1996) defines acritarchs as "fossilised, organic-walled cysts of unicellular protists that cannot be assigned to known groups of organisms". The term, meaning "of uncertain origin" was introduced by Evitt (1963) as an informal taxon for all non-sporomorph and non-dinocyst palynomorphs that were of uncertain affinity or awaiting classification (Tyson 1995). The majority of acritarchs are probably the resting cysts of marine phytoplankton (Strother 1996).

Recognition and identification: The classification of acritarchs is based entirely on their diverse range of morphological characteristics. Most individuals consist of a single hollow vesicle (or theca) that may be ornamented with processes (often spines and muri) and sculpturing elements (Strother 1996). They also fluoresce under ultra-violet light. McPhilemy (1989) recorded fluorescence ceasing at a vitrinite reflectance of ~1.4% Rr (figure 8.3). In the present study, acritarchs are identified to a generic level but are not given full systematic treatment. Acritarch identification was assisted by Professor Reed Wicander (pers. comm., 16 September 2009).

Chlorococcalean algae (Botryococcus) (Plate 10, figure 13 - 14)

Most fossil forms of *Botryococcus* are best compared with the modern form *Botryococcus braunii* or left in open nomenclature (Batten 1996). Colonies of *B. braunii* are generally spherical, globular masses with radially arranged pyriform cells embedded in cups at the periphery (Tyson 1995). The majority of fossilised occurrences are associated with fossil assemblages that lack marine indicators, suggesting deposition in fresh or brackish environments. Tyson (1995) indicates that most fossil records of *Botryococcus* are from freshwater lacustrine, fluvial, lagoonal and deltaic facies. *Botryococcus* also generates large quantities of oil and is linked to type I kerogen (Batten and Grenfel 1996).

Recognition and identification: *Botryococcus* recorded in the present study are irregular but solid masses often showing evidence of the cell and cup morphology. Colour in transmitted light ranges from orange to red-brown. The algae fluoresces in ultra-violet light, showing brighter fluorescence than the surrounding miospores. McPhilemy (1989) recorded fluorescence ceasing at vitrinite reflectances of ~1.2% Rr (figure 8.3).

Prasinophyte algae (Leiosphaeridia) (Plate 10, figure 8)

Leiosphaeridia belong to the prasinophytes; a group of spherical palynomorphs with algal affinities. McPhilemy (1989) notes that leiospheres tolerated freshwater/brackish to marine environments (figure 8.3). In the Lower Carboniferous Ballagan Formation of Ayrshire, Stephenson *et al.* (2002) recorded *Leiosphaeridia* in association with *Botryococcus* spp. and *Circulisporites* spp. in samples from horizons interpreted as fresh or brackish water lagoonal deposits. Batten (1996) suggested that their presence is generally taken to indicate marine or brackish-marine conditions.

Recognition and identification: *Leiosphaeridia* are recognised by their spherical morphology, thin wall, common folding and brighter fluorescence than the surrounding miospores in a sample. McPhilemy (1988) indicated that alginite (a liptinitic maceral) shows a stronger fluorescence and shorter wavelength than sporinite of the same rank. The absence of a trilete mark can also help to distinguish

Leiosphaeridia from *Calamospora*. McPhilemy (1989) recorded the fluorescence of leiospheres ceasing at a vitrinite reflectance of ~1.2% Rr (figure 8.3).

Zoomorphs

Zoomorphs are animal derived palynomorphs. Zoomorphs recorded in the present study comprise scolecodonts and foraminiferal linings.

Scolecodonts (Plate 10, figure 16)

Scolecodonts are the part-calcified and chitinous mouth parts of marine polychaete annelid worms. They range from the Early Ordovician to Recent. The jaw apparatus consists of a number of parts held together by muscular and cuticular tissues which degrade soon after death, resulting in the majority of scolecodonts occurring as dispersed and separated elements (Tyson 1995).

Recognition and identification: Scolecodonts are typically 'saw-like' in appearance. McPhilemy (1989) indicated that scolecodonts do not fluoresce (figure 8.3). Only a single questionable scolecodont occurrence was recorded in the present study.

Foraminiferal linings (Plate 10, figure 12)

Foraminiferal linings are the "acid resistant organic remains (chitinous tectin) found in palynological preparations which are thought to be the inner linings of microforaminiferal tests". They are indicative of marine depositional environments, although they are also recorded in variable salinity estuarine marshes (Batten 1996).

Recognition and identification: Very rare foraminiferal lining occurrences were recorded in the present study. The linings shows a series of chambers connected by a centrally developed neck. They do not fluoresce.

8.4.1.3 Zooclasts

Zooclasts are non-palynomorph organic particles derived from animals (Batten 1996).

Arthropod cuticle (Plate 10, figures 9 - 11)

Fragments of invertebrate cuticle are often recorded in palynological samples of Palaeozoic age. Eurypterid cuticles are the most commonly reported arthropod remains, occurring as sheets, spines and tooth-like structures. Arthropods are encased by cuticle. It comprises a permanent innermost chitinous layer and a sclerotized outer portion that is periodically discarded. Most Eurypterids are thought to have inhabited near-shore brackish or fresh water environments but some genera are associated with marine environments (Miller 1996).

Recognition and identification: In samples from the present study, arthropod cuticle takes the form of spinose structures. Specimens typically comprise a single spine around 30-70µm in length, often with a number of very small spines (2-4µm in length) towards the base. The spines are typically brown under transmitted light and are often attached at the base to a paler fragment of cuticle. Specimens are sometimes deformed or folded which helps to distinguish them from scolecodonts. Specimens were confirmed as arthropod fragments by Professor Paul A. Selden (pers. comm. 27 July 2009) although classification to a genus level was not possible.

8.4.2 Structureless

Tyson (1995) defined 'structureless' organic matter as particles that "do not have any recognisable botanical features or organised internal fabric and are usually without consistent shapes". In the classification scheme of Tyson (1993; 1995) the structureless category includes AOM, resins and gels. In the present study, structureless organic matter refers to AOM and resins.

8.4.2.1 Amorphous organic matter (AOM) (Plate 11, figure 4)

Application of the term 'amorphous' to organic matter implies a lack of distinct shape, outline and structure (Batten 1996). Tyson (1995) defined AOM as being typically heterogeneous (e.g. granular or grumose), comprising an amorphous matrix with a variety of structured or pseudoamorphous inclusions and frequently lacking a distinct sharp outline in transmitted light. Inclusions may comprise phytoclasts, palynomorphs, pyrite and other mineral detritus. Ultra-violet light can be used to reveal structured components within or obscured by the amorphous matrix in transmitted light (Tyson 1995; Batten 1996).

In the classification scheme of Tyson (1995), material classified as AOM is inferred to have originated from marine phytoplankton and bacteria. In contrast, Batten (1982, 1983, 1996) identified both marine and non-marine sources (figure 8.4). Batten (1996) distinguished between AOM of terrestrial origin (AOMT) and AOM of aquatic origin (AOMA). The author indicated that degradation of terrestrially derived structured organic matter can result in "degraded tissues in which all or almost all signs of original composition have been obliterated; finely divided amorphous substances derived from non-cuticular leaf and other cellulosic tissues; and many particles that are too small to show any structure". Batten suggested that AOMT may dominate palynofacies associated with shallow, fresh to brackish water lacustrine-lagoonal and marsh-swamp environments. Batten (1982; 1983) noted that AOM from an algal source (freshwater or marine) fluoresced under ultra-violet light. AOM from a woody source lacked fluorescence and AOM sourced from plant cuticle showed some fluorescence. As cortex tissue also lacks fluorescence under ultra violet light (Tyson 1995), it is likely that amorphous material derived from cortex will also lack fluorescence. Batten (1982; 1983) noted that AOM of woody origin was typically brown to black in colour in transmitted light. AOM of algal or cuticular origin was yellow to brown in colour (figure 8.4).

In a palynofacies study of four Lower Carboniferous borehole sections from northwest Ireland, McPhilemy (1989) erected a classification scheme for organic particles with little or no structure (see figure 8.5). Categories varied according to the thermal maturity of the sample and preservation of the organic matter. McPhilemy (1988; 1989) indicated that if organic matter is not degraded or over-mature, its fluorescence can be used to determine its origin. Samples from three boreholes were thermally over-mature. However, vitrinite reflectance values from borehole WB3, located in County Armagh, Northern Ireland ranged from 0.9% to 1.1% Rr and organic matter was well preserved. 'Fluffy' aggregates, yellow to grey in transmitted light were classified as 'semi-amorphous kerogen'. McPhilemy distinguished between semi-amorphous kerogen of liptinitic origin (algae, spores and cuticle) and that of a lignitic (woody) origin. The author noted that semi-amorphous kerogen derived from algae or spores fluoresced, while that of cuticular origin only sometimes fluoresced. Material of a lignitic (woody) origin showed no fluorescence or a very faint, dull fluorescence. The author also indicated that out of the liptinitic macerals, alginite shows a stronger fluorescence and shorter wavelength than sporinite of the same rank. Cutinite may show a varying colour and intensity of fluorescence at any particular rank. McPhilemy noted that the fluorescence of liptinite is usually lost at a vitrinite reflectance of ~1.3% Rr. In samples from borehole WB3, bright yellow fluorescing semi-amorphous kerogen was interpreted as liptinitic in origin. Material that possessed no fluorescence or a faint, dull fluorescence was interpreted as being lignitic (woody) in origin.

In the present study, heterogeneous organic matter that lacked a distinct shape, structure and sharp outline in transmitted light was categorised as AOM. Particles showing any indication of an original structure were classified as structured organic matter. The AOM typically appeared 'granular' to 'fluffy' under transmitted light. A distinction was made between fluorescing AOM and AOM that showed no fluorescence or very faint, dull fluorescence (figure 8.2). It was noted that samples analysed in the present palynofacies study are of a rank less than or equal to that of borehole WB3 sampled by McPhilemy (1988; 1989). Samples were also reasonably preserved. It was therefore assumed that fluorescing AOM would have liptinitc affinities and AOM derived from woody tissue or cortex would show no fluorescence or possibly a very faint, dull fluorescence. However, it was essential to appreciate that care needs to be taken when interpreting the source of amorphous material based on its fluorescence. Degraded plankton-derived AOM can lack fluorescence and be misidentified as amorphous material of woody origin (Tyson 1995).

8.4.2.2 Resins

Resins are a natural product of higher plants, occurring as internal cell or void-filling secretions, or as extracellular secretions on the stem or leaf (Tyson 1995).

Recognition and identification: Resins can be distinguished from AOM by their homogeneous nature and high relief. They often show conchoidal fractures and fluoresce under ultra violet light.

8.5 OTHER PALAEOENVIRONMENTAL INDICATORS

8.5.1 Pyritisation of palynomorphs (Plate 10, figure 15)

In conditions of lowered oxygen levels, the activity of sulphate reducing bacteria results in the production of hydrogen sulphide (H_2S), which may react with iron to form pyrite. Palynomorphs can become pyritised under such conditions. Pyrite is typically abundant in marine deposits. Fresh to brackish non-marine and hypersaline environments are less suited to pyrite production due to low sulphate levels (Batten 1996). As a result, the pyritisation of palynomorphs is a potential indicator of marine influenced depositional environments.

8.6 METHODS

8.6.1 Sample preparation

Sample depths from four offshore western Irish wells (13/3-1, 26/28-1, 34/5-1 and 36/16-1) were selected for palynofacies analysis. Depths that had previously shown microfossil evidence for marine influence were included. A combination of new samples and existing slides from the PhD thesis of Robeson (1988) were analysed. All were derived from cuttings samples. New samples (Appendix V.II) were processed in HF acid as described in section 3.3.1.1 After samples were decanted and neutralised, fluorite crystals and other minerals were removed by gentle boiling in HCl and gentle sieving. Oxidation was avoided as the process will alter and eventually destroy organic matter. The samples were mounted as in section 3.3.1.1. Slides of unoxidised, sieved organic matter prepared by Robeson were selected for analysis. It is noted that Robeson followed the same method of processing unoxidised samples as the present study.

There are limitations to the preparation technique. Sieving can fragment the AOM component. The process will also remove material less than 20µm in size, therefore influencing the content of the sample.

8.6.2 Counting

In order to quantify the relative proportions of organic matter components in a given sample, a random field of view at 25x magnification was photographed using a digital camera attached to a Leitz transmitted light microscope. The photograph was imported into Adobe Illustrator and a 10 x 10 grid overlain. Individual grid squares were $2cm^2$ in size. Photographs were printed and particles identified using transmitted light and fluorescence light microscopy (section 3.4). Particles of fluorescing AOM were distinguished from AOM with no fluorescence or very faint, dull fluorescence.

A finer acetate grid was then used to sub-divide each of the 10 x 10 squares into 25 smaller squares. The number of smaller squares taken up by each particle was counted. The proportion of phytoclasts, AOM and palynomorphs in the field of view was then calculated and expressed as a percentage. The procedure was repeated with a new random field of view and the results normalised. The process was repeated until statistical errors were minimised. Although time consuming, the method is deemed more suitable than the alternative method of individual particle counting (e.g. Coleman 1991). If a group consists of particles that are large in size but small in number, particle counting would give a misleading result on the proportion of the organic matter represented by that component.

Unoxidised slides were scanned through and occurrences of *Botryoccoccus*, acritarchs, scolecodonts, *Leiosphaeridia,* foraminiferal linings, arthropod cuticle and caved dinoflagellate cysts were logged. The number of palynomorphs showing pyritisation out of the first one hundred counted was also recorded.

8.7 GRAPHICAL REPRESENTATION OF DATA

If a sample is considered to be marine in origin, further information on the depositional palaeoenvironment can be determined by plotting the relative proportions of AOM, phytoclasts and palynomorphs on an AOM-phytoclast-palynomorph ‘APP’ ternary plot of Tyson (1993; 1995) (figure 8.6). The APP plot comprises nine fields representing different marine depositional environments. The plot “picks out differences in relative proximity to terrestrial organic matter sources…and the redox status of the depositional environments that control AOM preservation” (Tyson 1995). The APP plots have been successfully applied to Mesozoic and Cenozoic marine facies (Tyson 1995) and Palaeozoic sediments (e.g. Connelly 2002; Heal 2009; Patterson 2009).

A key limitation of the APP plot in the present study is its restriction to marine sediments. As a result, the plotting of terrestrial facies will incorrectly assign a marine depositional environment. Also, as relative proportions rather than absolute quantities are plotted, a decrease in the proportion of a given group may not represent a true reduction in quantity. It may instead reflect a significant increase in the quantity of another group.

8.8 RESULTS OF PALYNOFACIES ANALYSIS

8.8.1 Well 26/28-1

Cuttings samples from 2865m, 2915m and 2925m are assigned to the upper Bolsovian age *Westphalensisporites irregularis* Sub-biozone of Clayton *et al.* (2003) (figure 8.7). Robeson (1988) recorded scolecodont spp. in the 2915m and 2925m samples. In the present study, two *Micrhystridium* acritarch specimens were recorded at 2865m, although no additional exclusively marine palynomorphs were encountered in the 2915m and 2925m samples. The presence of scolecodonts and rare acritarchs indicate some marine influence. *Botryococcus* was recorded in all three samples with rare occurrences of *Leiosphaeridia* (<1% of sample) at 2865m and 2925m. Between 10 and 12% of palynomorphs show pyritisation. Samples are dominated by phytoclasts, with AOM not exceeding 10% of the total organic matter content. In transmitted light the AOM is grey to brown in colour, showing no fluorescence or a very faint, dull fluorescence under ultra-violet light.

Cuttings samples from 2805m and 2785m are assigned to the Asturian age *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003). *Botryococcus* was recorded in both samples with rare *Leiosphaeridia* (<1% of sample) at 2785m. 20% of palynomorphs show pyritisation at 2805m and 39% at 2785m. Samples also show an increase in AOM content to 26% and 22% respectively. AOM is dominated by the non to very faint fluorescing material described above. Very small amounts of brightly fluorescing AOM are also recorded (<1% of the sample at 2785m and 2% at 2805m). The fluorescing AOM is yellow-gold in transmitted light and fluoresces bright yellow under ultra-violet light. Fluorescence is brighter than the surrounding palynomorphs. Phytoclasts account for 57% of the organic matter at 2805m and 51% at 2785m. The absence of exclusively marine microfossils is notable, although the presence of pyritised palynomorphs may indicate some marine influence.

In the 2765m cuttings sample, a single, questionable scolecodont occurrence is recorded together with *Botryococcus* and rare *Leiosphaeridia* (<1% of sample). 50% of palynomorphs show pyritisation. A significant percentage of the organic matter comprises AOM (59%) largely at the expense of phytoclast content (decreasing to 18%). The AOM is dominated by the bright yellow fluorescing material described above, accounting for 48% of the organic matter. 11% comprises the non to very low fluorescing AOM described above.

Sample depth 2745m is assigned to the *Angulisporites splendidus* Sub-biozone of Clayton *et al.* (2003). In a cuttings sample from 2745m, Duxbury *et al.* (1979) recorded the shallow marine ostracod *Shivaella* sp. in addition to numerous occurrences of the freshwater ostracod *Carbonita* sp. The present study recorded a single acritarch specimen, *Botryococcus* and rare *Leiosphaeridia* (<1% of sample). 24% of palynomorphs show pyritisation. Again, AOM constitutes a significant portion (51%) of the organic matter. Bright yellow fluorescing AOM as described above accounts for 41% of the organic matter and 10% comprises AOM with no fluorescence or very faint fluorescence. 26% of the remaining organic material comprises phytoclasts with 23% palynomorphs.

In a number of samples from 26/28-1, occasional phytoclast specimens (mainly woody tissue) show partial degradation to non or very faintly fluorescing amorphous material.

8.8.1.1 APP plots and AOM origin

In the present study, very rare occurrences of exclusively marine palynomorphs were recorded in samples from 26/28-1. Two sample depths (2805m and 2785m) lacked exclusively marine palynomorphs. Pyritised palynomorphs were recorded in all samples, possibly indicating marine influences. The freshwater to brackish algae *Botryococcus* was also recorded in all sample depths, including those in which exclusively marine palynomorphs or ostracods were present. Similarly, the marine ostracod *Shivaella* sp. was recorded in the same cuttings sample as the freshwater ostracod *Carbonita* sp. The occurrence of marine and non-marine indicators in the same cuttings sample may be due to a number of factors; (i) if marine and non-marine horizons are thinly bedded, cuttings from both can be incorporated into the same sample. (ii) Caving within the borehole can introduce younger material from a different depositional environment to the interval being sampled. (iii) The freshwater to brackish microfauna/flora may be washed into a marine depositional environment, or vice versa. As a result, samples containing evidence for marine deposition are tentatively interpreted as being marine.

If all AOM recorded in samples from 26/28-1 is assumed to be of marine origin, plotting the proportions of AOM, phytoclasts and palynomorphs on an APP diagram of Tyson (1993; 1995) indicates that depositional environments included heterolithic oxic shelf, shelf to basin transition and distal dysoxic-anoxic shelf (figure 8.8). However, based on the information in section 8.4.2.1, the grey-brown AOM with no fluorescence or very faint, dull fluorescence recorded in 26/28-1 is most likely to be sourced from woody tissue and possibly cortex. AOM of plant cuticle origin may also lack fluorescence, but tends to be yellow-brown in transmitted light at the level of maturity recorded in 26/28-1 (figure 8.4). The occasional presence of phytoclasts (woody tissue) showing partial degradation to amorphous material of similar appearance also suggests a lignitic origin. If the lignitic AOM is included as part of the marine AOM on the APP plot, misleading results will be given.

The bright yellow fluorescing AOM in 26/28-1 is likely to have a liptinitic origin. As the fluorescence was deemed brighter than the surrounding palynomorphs, an algal source is assumed (see section 8.4.2.1). Tentatively assuming the source to be marine algae rather than freshwater algae, the fluorescing amorphous material is plotted on the APP diagram as AOM with the non-fluorescent amorphous material reassigned to the 'phytoclast' group (figure 8.9). Marine depositional environments inferred from the APP plot range from distal dysoxic-anoxic shelf at 2745m and 2765m to heterolithic oxic shelf (proximal shelf) for the deeper samples. Samples from 2805m and 2875m are very tentatively plotted due to the absence of exclusively marine microfossils. It is also stressed that as the algal derived AOM could be from a freshwater source rather than marine, the depositional environments indicated by the APP plot may be inaccurate.

It is also possible that some of the fluorescing AOM is caved. Unoxidised slides from the overlying Jurassic interval in 26/28-1 also contain bright yellow fluorescing AOM, resembling that recorded in the Carboniferous samples. The 26/28-1 Completion Report (1981) indicates the 12 ¼" borehole was drilled to 2765m prior to the 9 5/8" casing shoe being set at 2758m. This suggests that when cuttings from 2765m and 2745m were collected, the Jurassic interval in the borehole was exposed. Dinoflagellates recorded in the 2745m and 2765m samples confirm the presence of caved material (figure 8.7). The cuttings samples collected from 2785m and 2805m should have been protected from caved Jurassic material by the 9 5/8" casing. This may explain the significantly higher fluorescing AOM content in samples from 2745m and 2765m. As a result, the environments inferred from the APP plot for samples from 2765m and 2745m are potentially inaccurate due to the possible presence of caved AOM.

8.8.2. Well 36/16-1

As indicated in section 7.2, King *et al.* (1979) recorded the marine ostracods *Hypotetragona* spp. and *Bairdia* sp. in cuttings samples assigned to the *Angulisporites splendidus*, *Torispora verrucosa* and *Westphalensisporites irregularis* Sub-biozones of Clayton *et al.* (2003). In samples analysed in the present study, all AOM is dark brown-grey to black under transmitted light, showing no fluorescence or very occasionally faint, dull fluorescence under ultra-violet light. Occasional phytoclasts (woody tissue and opaque particles) show partial degradation to non-fluorescing amorphous matter.

Samples from 5200-10’ and 5400-10’ are assigned to the *Raistrickia aculeata* and *Torispora securis* Sub-biozones respectively. Although no ostracods have been recorded at these depths, King *et al.* (1979) recorded acritarch spp., inferring some marine influence (figure 8.10). Robeson (1988) recorded occurrences of *Botryococcus* and the present study recorded arthropod cuticle. Organic matter is dominated by phytoclasts (86% at 5200-10’ and 82% at 5400-10’) with just 1% AOM in each sample. A similar palynofacies is recorded in a sample from 5000-10’, although with an absence of marine palynomorphs.

Sample depth 4900-10’ is assigned to the *Westphalensisporites irregularis* Sub-biozone. The occurrence of *Hypotetragona* sp. suggests some marine influence. In the present study, a single, dark and possibly reworked *Micrhystridium* acritarch, arthropod cuticle, *Botryococcus* and rare *Leiosphaeridia* (<1% of sample) were recorded. 49% of the organic matter comprises phytoclasts with 34% AOM and 17% palynomorphs. 22% of palynomorphs show pyritisation.

Sample depths 4770-80’, 4640-50’, 4570-80’, 4520-30’, 4480-90’ and 4450-60’ are assigned to the *Torispora verrucosa* Sub-biozone. King *et al.* did not record microfauna at either 4770-80’ or 4640-50’. In the present study, *Botryococcus* was recorded in both sample depths. Occurrences of arthropod cuticle were encountered at 4770-80’. Rare *Leiosphaeridia* (<1% of sample) and a single, dark, fragmented and probably reworked *Veryhachium* acritarch were recorded in the 4640-50’ sample. Phytoclast content increases to 78% at 4770-80’ and 89% at 4640-50’, largely at the expense of AOM (reducing to 4% and 0.5% respectively). 20% of palynomorphs at 4770-80’ and 10% at 4640-50’ show pyritisation. Overall, the absence of exclusively marine microfossils at 4770-80’ may suggest non-marine deposition. A non-marine depositional environment is also possible for the 4640-50’ sample depth if the acritarchs recorded are reworked.

Occurrences of *Hypotetragona* sp. and *Bairdia* sp. in the 4570-80’ cuttings sample, indicate some marine influence. *Botryococcus,* a single foraminifera lining and rare *Leiosphaeridia* (<1% of sample) were recorded in the present study. AOM content increases to 40% with 45% phytoclasts and 15% palynomorphs. 23% of palynomorphs show pyritisation. At 4520-30’, King *et al.* (1979) recorded an absence of microfauna. *Botryococcus* and arthropod cuticle were recorded in the present study. AOM content decreases to 15% and phytoclast content increases to 76%. 15% of palynomorphs show pyritisation. The absence of exclusively marine microfossils at 4520-30’ may suggest non-marine deposition, although the pyritisation of palynomorphs could reflect some marine influence.

At 4480-90’, King *et al.* (1979) recorded *Bairdia* sp., the freshwater ostracod *Darwinula* sp. and the tube-worm *Spirorbis* sp. Taylor and Vinn (2006) indicate fossilised “*Spirorbis”* colonised freshwater, brackish, hypersaline and marine environments during the Devonian to Triassic. In the present study, occurrences of *Botryococcus* and rare *Leiosphaeridia* (<1% of sample) were recorded. 27% of palynomorphs show pyritisation. The proportion of AOM increases to 53% with 30% phytoclasts and 17% palynomorphs. At 4450-60’ King *et al.* (1979) recorded unidentified ostracod spp. and *Spirorbis* sp. The present study recorded *Botryococcus*, arthropod cuticle and rare *Leiosphaeridia* (<1% of sample). Two small *Veryhachium* acritarchs and two foraminiferal linings indicate some marine influence. 42% of the sample comprises AOM, with 35% phytoclasts and 22% palynomorphs. 35% of palynomorphs show pyritisation. Overall, microfossil assemblages from 4450-60’ and 4480-90’ indicate marine to freshwater influences.

Sample depths 4400-10’, 4370-80’, 4340-50’ and 4330-40’ are assigned to the *Angulisporites splendidus* Sub-biozone. At 4400-10’, King *et al.* (1979) recorded unidentified ostracods. *Botryococcus,* arthropod cuticle, a single foraminifera lining and rare *Leiosphaeridia* (<1% of sample) were recorded in the present study. AOM content is 36% and phytoclasts account for 49% of the sample. 35% of palynomorphs show pyritisation. The single foraminifera lining may indicate some marine influence. At 4370-80’ King *et al.* (1979) recorded *Hypotetragona* sp. and the freshwater ostracod *Carbonita* gr. *humilis*. *Botryococcus*, arthropod cuticle, two specimens of foraminiferal lining, and rare *Leiosphaeridia* were recorded in the present study. AOM constitutes 35% of the organic matter, with 50% phytoclasts. 33% of palynomorphs show pyritisation. Overall, the microfossil assemblage indicates marine to freshwater influences.

At 4340-50’, King *et al.* (1979) recorded *Hypotetragona* sp. and unidentified ostracod spp. The present study recorded a single foraminifera lining and rare *Leiosphaeridia* (<1% of sample). Pyritisation of palynomorphs increases to 58%. AOM accounts for 89% of the organic matter with 8% phytoclasts and 3% palynomorphs. At 4330-40’, King *et al.* (1979) recorded two different species of *Hypotetragona*. *Botryococcus,* arthropod cuticle and rare *Leiosphaeridia* (<1% of sample) were recorded in the present study. The proportion of pyritised palynomorphs decreases to 22%. The proportion of AOM also drops to 15% with an increase in phytoclast content to 19%. Palynomorph content also drops to 6%. Overall, the presence of *Hypotetragona* in both samples indicates some marine influence.

8.8.2.1 APP plots and AOM origin

A number of sample depths from 36/16-1 contain exclusively marine ostracods or palynomorphs. However, it is noted that the marine palynomorphs recorded in this study were very rare. Samples 4520-30’, 4770-80’ and 5000-10’ do not contain exclusively marine microfossils, although the presence of pyritised palynomorphs may indicate some marine influence. It is also noted that the freshwater to brackish algae *Botryococcus* was recorded in almost every sample depth analysed (except 4340-50’), including depths that contain exclusively marine microfossils. Similarly, King *et al.* (1979) recorded freshwater ostracods (*Carbonita* and *Darwinula*) in a number of samples that contain exclusively marine ostracods (*Hypotetragona* and *Bairdia*). As outlined in section 8.8.1.1, a number of factors can lead to the presence of marine and non-marine microfossils in the same cuttings sample. As a result, samples containing evidence for marine deposition are tentatively interpreted as marine.

If the AOM recorded in samples from 36/16-1 is assumed to be of a marine origin, plotting the proportions of AOM, phytoclasts and palynomorphs in each sample on an APP plot indicates that marine depositional environments ranged from heterolithic oxic shelf (proximal shelf) to distal suboxic-anoxic basin (figure 8.11). However, based on the information in section 8.4.2.1, as the dark brown-grey to black AOM recorded in 36/16-1 shows no fluorescence or very occasional faint, dull fluorescence, it is most likely to have originated from woody tissue and possibly cortex. This is also indicated by the occurrence of woody tissue showing partial degradation to non-fluorescing amorphous material.

If the non-fluorescing AOM is reassigned to the phytoclast group, the proportions of phytoclasts, AOM and palynomorphs in each sample can be replotted on the APP diagram (figure 8.12). Marine depositional environments range from highly proximal shelf/basin to heterolithic oxic proximal shelf, reflecting the absence of marine AOM. As samples 4520-30', 4770-80' and 5000-10' do not contain exclusively marine microfossils, the samples are very tentatively plotted on the APP diagram.

8.8.3. Well 34/5-1

Samples from 775m to 940m are assigned to the *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003) (figure 8.13). Microfossils recorded at 940m include *Botryococcus,* arthropod cuticle and caved dinoflagellates. 36% of the organic matter comprises AOM with 34% phytoclasts and 30% palynomorphs. Although exclusively marine palynomorphs are not recorded, 40% of palynomorphs show pyritisation which may indicate some marine influence. All AOM is grey to brown in transmitted light, showing no fluorescence or very occasional faint, dull fluorescence under ultra-violet light. At 865m, Ducazeaux *et al.* (1981) recorded pyritic concretions, small gastropods and the freshwater ostracods *Darwinula* sp. and *Whiplella* sp. *Botryococcu*s and arthropod cuticle were recorded in the present study. The sample is dominated by phytoclasts (85%) with 4% AOM and 11% palynomorphs. Just 6% of palynomorphs show pyritisation. AOM resembles that recorded at 940m. A sample from 820m contains 61% phytoclasts, 25% AOM (as described above) and 14% palynomorphs. 21% of palynomorphs show pyritisation. No microfauna were recorded at the sample depth and the present study only recorded *Botryococcus*. The absence of exclusively marine microfossils at 940m, 865m and 820m possibly indicates non-marine deposition, although the pyritisation of palynomorphs at 940m and 820m may reflect some marine influence.

At 800m, Church *et al.* (1980) recorded the shallow marine ostracod *Healdia* sp. and possible occurrences of the marginal marine and brackish ostracod *Sulcella* sp. *Botryococcus* and single specimens of *Baltisphaeridium* and *Gorgonisphaeridium* acritarchs were recorded in the present study. 29% of palynomorphs show pyritisation. The organic matter comprises 52% AOM with 33% phytoclasts and 15% palynomorphs. AOM resembles that recorded in samples 940m and 865m. The occurrences of *Healdia* sp, and rare acritarchs indicate some marine influence.

At 795m Ducazeaux *et al.* (1981) recorded the freshwater ostracod *Whipplella* sp., the freshwater to marine ostracod *Eukloenella* sp., the marginal marine, brackish and hypersaline ostracod *Paraparchites* sp. in addition to small gastropods and fish remains. Robeson (1988) recorded acritarch specimens and this study recorded occurrences of *Botryococcus* and rare arthropod cuticle. 44% of palynomorphs show pyritisation. Organic matter comprises 33% AOM as described above, 51% phytoclasts and 16% palynomorphs. Overall the ostracod and acritarch occurrences indicate marine to freshwater influences. At 775m, Ducazeaux *et al.* (1981) recorded *Eukloenella* sp., *Paraparchites* sp. and the marine ostracod *Pseudoparaparchites* sp. *Botryococcus* and a single acritarch were recorded in the present study. 40% of palynomorphs show pyritisation. Samples are dominated by phytoclasts (89%), with 10% palynomorphs and just 1% AOM. The presence of *Pseudoparaparchites* sp. and the solitary acritarch indicates some marine influence.

Sample depths 770m, 750m and 740m are assigned to the *Angulisporites splendidus* Sub-biozone. The sample from 770m shows a similar palynofacies to the 775m sample although it is noted that the microfossil content is limited to *Botryococcus*, rare *Leiosphaeridia* (<1% of sample) and caved dinoflagellates. At 750m, Ducazeaux *et al.* (1981) recorded *Eukloenella* sp., *Pseudoparaparchites* sp., caved *Nummulites* and pyrite. The present study recorded rare *Leiospheridia* (<1% of sample) and caved dinoflagellates with 24% of palynomorphs showing pyritisation. Samples are again dominated by phytoclasts (90%) with just 6% AOM and 4% palynomorphs. The presence of *Pseudoparaparchites* sp. suggests some marine influence. At 740m, Ducazeaux *et al.* recorded caved *Nummulites*, plant debris and pyrite. Church *et al.* (1980) also recorded possible occurrences of the marginal marine to brackish ostracod *Pseudobythocypris* sp. *Botryococcus*, a single, small, acanthomorphic acritarchs and caved dinoflagellates were recorded in the present study. 90% of the organic matter comprises phytoclasts with 9% AOM and 1% palynomorphs. 25% of palynomorphs show pyritisation. In the 770m sample, all AOM is grey in transmitted light, showing no fluorescence under ultra-violet light. At 750m and 740m, small proportions of the organic matter (4% and 1% respectively) comprise AOM that is yellow-gold in transmitted light with a bright yellow fluorescence in ultra-violet light. Non fluorescing AOM as recorded at 770m is also present.

8.8.3.1. APP plot and AOM origin

Overall, very few exclusively marine palynomorphs were recorded in the present study. Acritarchs are very rare and scolecodonts absent. However, in a number of samples, a significant proportion of palynomorphs showed pyritisation, which may reflect marine influences. Exclusively marine ostracods have also been recorded in a number of sample depths. With the exception of the 750m sample, they are recorded in association with marginal marine to brackish ostracods. *Botryococcus* was also recorded in all sample depths studied except 750m.

As outlined in section 8.8.1.1, a number of factors including caving can lead to the presence of marine and non-marine microfossils in the same cuttings sample. As a result, samples containing marine microfossils are tentatively interpreted as marine deposits. If the AOM recorded in all samples is assumed to be of a marine origin, a series of marine depositional environments ranging from heterolithic, oxic proximal shelf to distal dysoxic-anoxic shelf are inferred from the APP plot (figure 8.14). However, based on the information in section 8.4.2.1, the AOM that shows no fluorescence or very faint, dull fluorescence is most likely to be of a woody and possibly cortex origin. The brightly fluorescing AOM recorded in samples 750m and 740m is likely to be sourced from liptinitic material, possibly algae. If the algal source is inferred to be marine rather than freshwater, the amorphous material can be plotted on the APP diagram as marine AOM with the non-fluorescent amorphous material reassigned to the ‘phytoclast’ group (figure 8.15). Depositional environments from the replotted APP diagram included highly proximal shelf/basin, marginal dysoxic-anoxic basin and heterolithic, oxic, proximal shelf. Samples from 940m, 865m, 820m and 770m are very tentatively plotted due to the absence of exclusively marine microfossils. However, the presence of pyritised palynomorphs may indicate some marine influence.

8.8.4 Well 13/3-1

Sample depths 1690-1700’, 1500-1520’, 1380’-1400’ and 1290-1320’ are assigned to the Asturian age *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003).

In a cuttings sample from 1690-1700’, Robeson (1988) recorded acritarchs, indicating some marine influence (figure 8.16). *Botryococcus* was recorded in the present study with 44% of palynomorphs showing pyritisation. 86% of the organic matter comprises phytoclasts with 5% AOM and 9% palynomophs. At 1500-1520’, this study recorded occurrences of *Botryococcus* and arthropod cuticle. A single *Micrhystridium* acritarch specimen indicates some marine influence. 73% of the organic matter comprises phytoclasts with 6% AOM and 21% palynomorphs. 15% of palynomorphs show pyritisation. The AOM in both samples is grey in transmitted light, lacking fluorescence under ultra-violet light.

In the 1380’-1400’ cuttings sample, *Botryococcus* and a single, dark, possibly reworked *Micrhystridium* acritarch were recorded. Just under 88% of the organic matter comprises phytoclasts with 12% palynomorphs and less than 1% AOM as described above. 22% of palynomorphs show pyritisation. In a cuttings sample from 1290-1320’, Robeson (1988) recorded *Botryococcus* and acritarchs. The current study additionally recorded arthropod cuticle and a single foraminiferal lining. The acritarchs and foraminiferal lining indicate some marine influence. 84% of the organic matter comprises phytoclasts, with 14% palynomorphs and 2% AOM as described above. 23% of palynomorphs show pyritisation

8.8.4.1 APP plot and AOM origin

Acritarchs are recorded in all samples studied from 13/3-1, indicating marine influences. However, the samples also contain the freshwater to brackish algae *Botryococcus*. As outlined in section 8.8.1.1, a number of factors can lead to the presence of marine and non-marine microfossils in the same cuttings sample. As a result, samples containing marine microfossils are tentatively interpreted as marine deposits.

If the AOM content of the samples is considered to be marine, a series of marine depositional environments ranging from heterolithic, oxic, proximal shelf to marginal dysoxic-anoxic basin are inferred from the APP plot (figure 8.17). However, based on the information in section 8.4.2.1, as the AOM shows no fluorescence, it is most likely to be of woody and possibly cortex origin. Assigning the non-fluorescing AOM to the phytoclast category and replotting the data on the APP diagram, depositional environments range from highly proximal shelf/basin to heterolithic, oxic, proximal shelf (figure 8.18).

8.9 SUMMARY OF PALYNOFACIES RESULTS

Assuming that the samples analysed were deposited under marine conditions, the results from the palynofacies analysis indicate that the majority of samples were deposited in very proximal environments. The APP plots indicate highly proximal shelf/basin, marginal dysoxic-anoxic basin and heterolithic, oxic, proximal shelf environments (fields I, II and III of the APP plot). This reflects the absence or rarity of AOM of marine origin and the high proportion of phytoclasts. Two Stephanian age samples from 26/28-1, containing significant proportions of AOM of possible marine algal origin are very tentatively assigned to a distal dysoxic-anoxic shelf environment (field VII).

As indicated in chapter 7.2, upper Bolsovian age lithological and microfossil data from well 26/28-1 suggests a fluvial or delta top depositional environment with periodic marine influences. A paralic depositional environment was inferred for coeval deposits in 36/16-1. Results from the APP plots for both wells suggest episodes of marine deposition in a heterolithic, oxic, proximal shelf environment.

Asturian age lithological and microfossil data from 26/28-1 suggests a fluvial/delta top, muddy alluvial swamp depositional environment. Delta top deposition was also inferred for coeval successions in 13/3-1 and 34/5-1, with a later phase of delta abandonment in the 34/5-1 locality. A paralic environment with freshwater and marine influences was indicated for the 36/16-1 locality. APP plots from the present study indicate episodes of heterolithic, oxic, proximal shelf deposition for the 26/28-1 and 34/5-1 successions. Episodes of deposition in heterolithic, oxic, proximal shelf and highly proximal shelf/basin environments are inferred for the 36/16-1 and 13/3-1 localities.

Lithological and microfossil data from Stephanian age strata suggest a low-lying, coastal, alluvial swamp environment with freshwater, marginal marine and marine influences for the 26/28-1, 34/5-1 and 36/16-1 well localities. The APP plot for 36/16-1 indicates episodes of deposition in heterolithic, oxic, proximal shelf and highly proximal shelf/basin environments. For the 34/5-1 succession, deposition in heterolithic oxic proximal shelf, marginal dysoxic-anoxic basin and highly proximal shelf/basin environments are inferred. Episodes of deposition on a distal dysoxic-anoxic shelf are tentatively inferred for the 26/28-1 locality.

Only very rare occurrences of exclusively marine palynomorphs were recorded during the present study. The freshwater to brackish algae *Botryococcus* was recorded in almost every sample depth analysed, including those that contain exclusively marine palynomorphs or microfauna. Rare occurrences of *Leiosphaeridia* were also recorded in a number of samples. Pyritised palynomorphs were recorded in every sample analysed, potentially indicating marine influences. As outlined in section 8.8.1.1, the presence of both marine and non-marine indicators in a cuttings sample may be due to i) the sampling of thinly bedded marine and non-marine strata, ii) caving within the borehole or iii) mixing within the depositional environment. As a result, samples that contain marine microfossils can only be tentatively interpreted as marine deposits.

The vast majority of AOM recorded lacks fluorescence and is likely to have been sourced from degraded woody tissue and possibly cortex. In many samples that contain exclusively marine microfossils, the AOM is entirely terrestrial in origin (e.g. samples from well 36/16-1). Fluorescing AOM of possible marine algal origin is restricted to Stephanian and Asturian age samples from 26/28-1 and Stephanian age samples from 34/5-1. However, occurrences in the two Stephanian age samples from 26/28-1 are potentially caved. This suggests that the distal dysoxic-anoxic shelf environment inferred by the APP plot for the two samples may be inaccurate. In the samples unlikely to be affected by caving, AOM of algal origin is only present in very small quantities. It is also possible that the source of the fluorescing AOM is freshwater algae.

As indicated in section 8.4.2.1, Batten (1996) indicated that AOM of terrestrial origin may dominate palynofacies associated with shallow, fresh to brackish water lacustrine-lagoonal and marsh-swamp environments. It is possible that many of the samples analysed in the present study could have been deposited in brackish water marginal marine environments such as lagoons or brackish bays. *Botryococcus* and *Leiosphaeridia* would be suited to such environments. Freshwater ostracods could be washed in by rivers and small numbers of exclusively marine microfauna/flora could be brought in via connections with the open sea or storm washovers. The environment would also be suitable for the marginal marine and brackish ostracods recorded in 34/5-1. Deposits from the environment could therefore include mixed freshwater, brackish and marine microfossil assemblages that are often recorded in the offshore western Irish samples.

8.10 COMPARISION WITH OTHER LOCALITIES

Davies *et al.* (1991)

Davies *et al.* (1991) analysed palynofacies associated with the early Dinantian (Courceyan) marine transgression in South Wales. Samples from environments including fluvial, coastal plain, peritidal, lagoonal, shoal/barrier, embayment and open marine shelf were studied. The organic matter classification scheme used is outlined in section 8.3 and figure 8.1. The absence of a category for AOM is notable. Relative abundance calculations were based on counts of 500 kerogen particles. The proportion of the samples showing pyritisation was visually estimated.

Fluvial samples were characterised by a predominance of woody plant debris and an absence of marine microfossils. Miospores accounted for 0% to ~20% of the sample content and pyritisation was very rare to absent. A sample from a rhizolith infested coastal plain horizon yielded rare scolecodonts. Approximately 5% of the palynofacies comprised miospores, with ~20% non-woody plant tissue and ~75% woody plant debris. Pyritisation was rare to absent. In lagoonal samples, marine microplankton were very rare to absent, restricted to occurrences of *Stelinium*, *Micrhystridium* and *Leiosphaeridia.* Scolecodont content ranged from <1% to 1-2%.

Possible *Botryococcus* occurrences were recorded in one of the three samples analysed and pyritisation was rare to moderate. Samples contained ~10-25% spores, ~10-20% non woody plant tissue and ~65-70% woody plant debris.

Peritidal deposits contained a higher proportion of miospores and marine indicators than the fluvial samples but differed from lagoonal deposits in the rarity and low diversity of marine components. Scolecodonts were very rare, with microplankton either absent or restricted to very rare occurrences of *Leiosphaeridia*. Samples contained ~35-40% spores, ~20-25% non-woody plant tissue and ~35-45% woody material (both hylogen and melanogen). Pyritisation was rare to extensive. In embayment (open lagoon) deposits, microplankton (including acritarchs and *Leiosphaeridia*) were very rare or accounted for 1-2% of the sample. Scolecodonts showed the same range of abundances. Samples typically contained abundant woody material (hylogen and melanogen) with up to 30% miospores and up to 25% non-woody plant tissue. Pyritisation was low to moderate and very rare occurrences of possible *Botryococcus* were recorded in one of the eight samples analysed. In open marine shelf deposits, scolecodonts and acritarchs were abundant (typically 3-10% of the sample). In some samples, leiospheres accounted for 3-10% of the organic matter. Samples were dominated by miospores and woody tissue (hylogen and melanogen). The deposits often contained possible *Botryococcus* specimens.

The marine microfossil bearing samples from offshore western Ireland assigned to fields I, II and III of the APP plot share a number of characteristics with the lagoonal deposits of South Wales. There are some similarities with the peritidal, coastal plain and embayment deposits. Occurrences of scolecodonts, *Leiosphaeridia*, *Botryococcus*, rare acritarchs, rare to moderate pyritisation and a high woody material content characterise the lagoonal samples of South Wales and the offshore Irish samples. However, it is noted that scolecodonts were sometimes more abundant in the samples from South Wales. The peritidal and coastal plain deposits of South Wales were also characterised by rare marine palynomorph occurrences and often showed extensive pyritisation. However, in contrast to a number of the offshore Irish samples, marine palynomorphs were restricted to scolecodonts. The peritidal deposits also showed a higher sporomorph content than the offshore Irish samples. Embayment (open lagoon) samples were similar to the offshore Irish samples in terms of the diversity of marine palynomophs recorded (both acritarchs and scolecodonts), although specimens were more abundant in the South Wales deposits. Samples from open marine shelf deposits contrast with those from offshore Irish by containing higher proportions of marine palynomorphs.

McPhilemy (1989)

McPhilemy (1989) recorded a series of palynofacies in late Tournaisian to early Viséan non-marine to nearshore marine sediments from north-western Ireland. In borehole WB3, from County Armagh, sediments comprised a succession of shallow water intertidal to supratidal deposits, deltaic sandstones and delta top deposits. McPhilemy indicated that scolecodonts were very rare throughout the sequence and in-situ acritarchs were only recorded in one sample. Palynofacies that show some resemblance to the offshore western Irish samples are outlined below.

Palynofacies 8 of McPhilemy (1989) was recorded towards the top of the Drumman More Sandstones, in mudstones interpreted as delta top deposits. The palynofacies showed evidence of heavy pyritisation and rare scolecodonts. Between 4% and 24% of the organic matter comprised spores, the remainder often comprising a significant proportion of 'cellular plant tissue' in addition to black and brown woody material and gelified tissue. McPhilemy suggested a quiet, near source marine depositional environment. Palynofacies 5 was recorded in mudstones interpreted as marginal or restricted marine deposits. Samples showed some variation. A sample that contained 'low numbers' of scolecodonts, low numbers of leiospheres, very rare acritarchs and *Tasmanites* comprised 50% spores, 2% semi-amorphous kerogen and 48% phytoclasts (dominated by plant tissue and black wood). A second sample containing a low number of scolecodonts, small leiospheres and showing pyritisation comprised 6% semi-amorphous kerogen with 20% spores and 74% phytoclasts, dominated by plant tissue. A third sample did not contain scolecodonts or acritarchs, but comprised 80% semi-amorphous kerogen (section 8.4.2.1) that lacked fluorescence. Palynofacies 3 was recorded in an interval of micritic mudstones interpreted as shallow marine to intertidal deposits. Although the organic content of samples was poor, scolecodonts and pyritisation were recorded. Samples were dominated by melanogen or thin filmy tissue of indeterminate origin. No semi-amorphous organic matter was recorded.

Palynofacies 2 was recorded at the base of the micritic mudstones described above. Samples contained an abundance of spores (up to 64% of the organic matter), with semi-amorphous organic matter reaching abundances of 67%. Leiospheres were recorded but scolecodonts were absent. Acritarch occurrences were interpreted as being reworked. McPhilemy inferred a non-marine, possibly supratidal depositional environment.

Overall, the samples from offshore western Ireland show the most similarities to Palynofacies 8, particularly the rare marine palynomorph content, the proportion of sporomorphs and evidence of pyritisation. In Palynofacies 5 the low numbers of scolecodonts and acritarchs is a characteristic of the offshore Irish samples. However, the sample containing *Tasmanites* with a high proportion of spores contrasts with the offshore Irish samples, as does the sample with 80% semi-amorphous kerogen. The presence of scolecodonts and pyritisation in Palynofacies 3 is similar to the offshore Irish samples, although the poor organic content is a contrasting feature. Palynofacies 2 is similar to those samples from offshore western Ireland that lack exclusively marine microfossils. However, the sporomorph content is often higher in Palynofacies 2.

Richardson and Ahmed (1988)

Richardson and Ahmed (1988) undertook a palynofacies study of Upper Devonian strata from western New York State and Pennsylvania, U.S.A. Several palynofacies were recognised from open sea deep basin to slope, shelf and alluvial environments. Relative abundance calculations were based on 200 particle counts per sample. However, only relative abundance data for the palynomorph content (miospores, acritarchs and prasinophyte cysts) was given, with no detailed information on the relative proportions of other kerogen components.

Distal basinal shales were dominated by prasinophyte cysts. Acritarchs were rare, spores were sometimes abundant and organic matter was unstructured. Proximal basin and slope deposits comprised alternating shale and siltstone deposits. Siltstones were dominated by land derived plant material (structured wood and cuticle) with an abundance of spores. The material was interpreted as being derived from the continental shelf by density currents. Shale units were dominated by prasinophyte cysts, acritarchs and unstructured organic matter. Acritarchs accounted for ~5-35% of the palynomorphs recorded.

Open shelf deposits comprised shales, siltstones and sandstones. Macrofossils were often abundant. Spores were relatively abundant and preparations regularly contained structured land-derived plant fragments. Acritarchs typically accounted for ~15-60% of the palynomorph content and were more common than prasinophyte cysts. Nearshore shelf sediments/marine influenced alluvial plain sediments comprised grey and green shales, siltstones and sandstones. Marine fossils were restricted to a few bands and were low in diversity. The deposits were interbedded with non-marine red and grey shales, siltstones and sandstones that sometimes contained abundant plant remains. Spores usually dominated the palynological assemblages although acritarchs were abundant in some marine horizons. Acritarchs accounted for ~10%-25% of the palynomorph content, with ~8-15% prasinophytes. Continental lower flood plain deposits comprised red, green and grey shales and purple, brown or white medium to coarse sandstones. Palynomorphs consisted almost entirely of miospores and megaspores and were frequently associated with abundant structured plant material.

Based on the proportions of acritarchs and prasinophyte algae, the samples from offshore western Ireland are closest in composition to the nearshore shelf sediments/marine influenced alluvial plain deposits of Richardson and Ahmed (1988). With the exception of the continental lower flood plain deposits, the other environments studied by Richardson and Ahmed contain higher proportions of acritarchs and/or prasinophytes than the offshore Irish samples.

Coleman (1991)

Coleman (1991) studied the palynofacies of basinal and deltaic deposits from the Lower Carboniferous age Bedford Shale, Sunbury Shale and Borden Formations of east Kentucky, U.S.A. Palynofacies analyses were based on the counting of 300 particles per sample. Coleman recorded the relative proportions of four main categories; amorphogen, hylogen, melanogen and phyrogen (see classification scheme of Bujak *et al.* 1977, section 8.3). The author also distinguished between two types of amorphogen. Amorphogen I fluoresced and was considered algal in origin. Amorphogen II lacked fluorescence and was interpreted as being possibly derived from degraded spores and hylogen. The following three palynofacies were identified;

(i) The Tasminitid-Amorphogen I Palynofacies was recorded in samples from the Bedford Shale Formation. The Bedford Shale comprises dark grey mudstones with thin siltstones, interpreted as pro-delta deposits. The palynofacies was characterised by the presence of Amorphogen I (4.5-64%), hylogen (5-19%) and melanogen (17-46%). Palynomorphs comprised tasmanitids (1-3%), leiospheres (1-2%) and acritarchs (1-2%). Spores accounted for 9-37% of the sample content. One scolecodont was recorded. Coleman (1991) suggested that the high proportion of amorphogen indicated limited input of organic sediment into the basin.

(ii) The Amorphogen I Palynofacies was recorded in the Sunbury Shale Formation. The black shales were interpreted as quiet, basinal deposits. Amorphogen I accounted for 81-89% of the kerogen content. Leiospheres accounted for 1-5%, of the kerogen, acritarchs less than 1%, and spores 1-2%. Hylogen and melanogen together accounted for less than 12% of the kerogen.

(iii) The Melanogen Palynofacies was recorded in samples from the Henley Bed, Farmers Member, Nancy Member and Cowbell Member. Melanogen was the dominant kerogen type recorded (52-92%) with hylogen accounting for 4-16% of the overall kerogen content. Small amounts of degraded kerogen were also recorded. Amorphogen I was absent. Miospores accounted for 1-38% of the sample content with acritarchs accounting for 1-5%. Leiospheres accounted for <1-5% of the sample content with <1% scolecodonts also recorded. The Henley Bed was interpreted as a basinal deposit with small scale turbidites, the Farmers Member as turbiditic, the Nancy Member as a pro-delta shale and the Cowbell Member as the delta front deposit of the Borden Delta.

Coleman (1991) also analysed the palynofacies of deposits from Indiana, U.S.A. The Edwardsville Formation was deposited in a delta-top environment. <1% leiospheres <1% acritarchs and <1% scolecodonts were recorded in some samples from the formation. Amorphogen was absent in samples analysed, with spores accounting for

2-22% of the kerogen, melanogen comprising 17-79% and hylogen comprising 9-68%. The Spickert Knob Formation was interpreted as delta front deposits. Samples comprised 10-54% spores. The average hylogen plus melanogen content was 74% with melanogen dominating over hylogen. Acritarchs and scolecodonts were rare and very few leiospheres were recorded. Amorphogen was absent. The New Providence Shale was interpreted as pro-delta deposits. Amorphogen II (non fluorescing amorphous material of possible terrestrial origin) accounted for 1-40% of the kerogen, with 1-32% spores and 2-7% sheet-like hylogen. Acritarchs were common (1-3%). Coleman (1991) indicated that the frequent occurrence of acritarchs reflects fully marine conditions.

Compared to the offshore western Irish samples, most of the palynofacies analysed by Coleman (1991) contain higher proportions of marine palynomorphs. Based on the rarity of marine palynomorphs and dominance of phytoclasts, the offshore western Irish samples assigned to fields I, II and III of the APP plot are most comparable with the Edwardsville Formation delta-top deposits. However, the absence of Amorphogen II (amorphogen of terrestrial origin) in the Edwardsville Formation is a key difference. Amorphogen II is often recorded in the New Providence Shale, although acritarch occurrences are more abundant than in offshore Irish deposits.

The two samples from 26/28-1 tentatively assigned to a distal dysoxic-anoxic shelf environment resemble the Tasmanitid-Amorphogen I palynofacies with regards to the proportion of fluorescing AOM. However in contrast to the Tasmanitid-Amorphogen I palynofacies, the offshore Irish samples lack tasmanitids. Acritarchs are also more abundant in the American samples. Compared with the Amorphogen I palynofacies the 26/28-1 samples contain significantly lower proportions of fluorescing amorphous material.

Eastern Canada

As indicated in section 8.9, episodes of marginal marine deposition (e.g. lagoonal or brackish bay environments) may be responsible for the mixed marine and non-marine characteristics recorded in many of the samples from offshore western Ireland. The depositional environments may be comparable with those assigned to coeval deposits in Eastern Canada. As indicated in section 10.3.10, the upper Duckmantian to lower Asturian age South Bar Formation of Eastern Canada was deposited on a marine influenced alluvial braidplain. Marine inundations resulted in the development of brackish bays (possibly lagoonal or estuarine) in topographic lows. The presence of agglutinated foraminifera indicate brackish water environments (Tiber and Gibling 1999). The lower Asturian to Cantabrian age Sydney Mines Formation was deposited in alluvial plain, coastal plain and restricted marine environments (Batson and Gibling 2002). The presence of acritarchs in the formation (T.K. Dimitrova pers. comm. in McIlroy and Falcon-Lang 2006) and glauconite suggests marine influences (McIlroy and Falcon-Lang 2006). Wightman *et al.* (1994) recorded assemblages of agglutinated foraminifera and thecamoebians, indicating estuarine to marsh to freshwater depositional environments. McIlroy and Falcon-Lang (2006) also recorded an example of the exclusively marine *Zoophycos* group trace fossil in association with brackish water agglutinated foraminifera in strata of possible estuarine origin.

8.11 CONCLUSIONS

1. Exclusively marine palynomorphs (scolecodonts and acritarchs) were present in a number of the cuttings samples from offshore western Ireland but occurrences were very rare. The freshwater to brackish algae *Botryococcus* was present in almost every sample analysed. *Leiosphaeridia* was recorded in a number of samples although occurrences were rare. Pyritised palynomorphs were recorded in every sample analysed, possibly indicating marine influences. A number of samples contained both marine and non-marine indicators. This may be due to the sample containing cuttings from thinly interbedded marine and non-marine horizons, caving within the borehole or mixing within the depositional environment.

2. The vast majority of AOM recorded is of a terrestrial (woody tissue and possibly cortex) origin and lacks fluorescence. Brightly fluorescing AOM of possible marine algal origin is restricted to a small number of samples.

3. For the majority of samples analysed, APP plots indicate proximal marine depositional environments; highly proximal shelf/basin, marginal dysoxic-anoxic basin and heterolithic, oxic, proximal shelf (fields I, II and III). This reflects the absence or

rarity of AOM of marine origin and the high proportion of phytoclasts. Samples that do not contain exclusively marine microfossils are tentatively plotted on the APP diagram. A distal dysoxic-anoxic shelf depositional environment (field VII) is very tentatively inferred for two algal AOM dominated samples from 26/28-1. However, AOM in these samples may be caved or sourced from freshwater algae.

4. Marginal marine lagoonal or brackish bay depositional environments may account for the mixed non-marine and marine characteristics of many samples and the dominance of AOM of terrestrial origin. Similar depositional environments are recorded in the upper Duckmantian to lower Asturian age South Bar Formation and lower Asturian to Cantabrian age Sydney Mines Formation of Eastern Canada

5. Previous palynofacies studies outlined in section 8.10 are predominantly from Mississippian age sections. The marine deposits typically show a higher abundance of acritarchs and scolecodonts compared with samples from offshore western Ireland. This may reflect more marginal depositional environments for the offshore western Irish samples. Alternatively, this may reflect a higher abundance of the palynomorphs during Mississippian times.

CHAPTER 9
ISOTOPE ANALYSIS OF CARBONATES

9.1 INTRODUCTION AND AIMS OF THE STUDY

Isotopes are forms of the same element that have equal numbers of protons and electrons but different numbers of neutrons. They therefore possess slight differences in mass and energy, resulting in varying physical and chemical properties (Tucker and Wright 1990).

Over recent decades, studies have shown that the isotopic signature of marine carbonates has varied through geological time (e.g. Prokoph *et al.* 2008). The carbon and oxygen isotopic composition can be analysed in the form of CO_2 gas released from the sample with the addition of orthophosphoric acid (H_3PO_4). Carbon has two stable isotopes; ^{12}C and ^{13}C (^{13}C being 'heavier' due to its greater number of neutrons). Oxygen has three isotopes; ^{18}O, ^{17}O and ^{16}O (Tucker and Wright 1990). The carbon and oxygen isotopic compositions are reported in 'δ' notation ($\delta^{13}C$ and $\delta^{18}O$) as "parts per thousand (‰) difference between an isotopic ratio ($^{18}O/^{16}O$, $^{13}C/^{12}C$) in a sample compared to the same ratio in an international standard" (Marshall 1992) i.e.

$$\delta^{13}C = \frac{^{13}C/^{12}C \text{ sample} - {}^{13}C/^{12}C \text{ standard}}{^{13}C/^{12}C \text{ standard}} \times 1000$$

$$\delta^{18}O = \frac{^{18}O/^{16}O \text{ sample} - {}^{18}O/^{16}O \text{ standard}}{^{18}O/^{16}O \text{ standard}} \times 1000$$

Carbon and oxygen data are routinely referenced to the V-PDB (Vienna Pee-Dee Belemnite) standard. Oxygen may also be referenced to the SMOW (standard mean ocean water) standard. Compared to the standard, samples enriched in the heavier isotope have positive δ values and are termed 'heavy'. Samples with more negative δ values than the standard are referred to as isotopically 'light' (Fairchild *et al.* 1988).

The aim of the present study was to analyse the $\delta^{13}C$ and $\delta^{18}O$ composition of a selection of carbonates from offshore western Ireland to determine if they were precipitated in marine or non-marine environments. Of particular interest were the upper Bolsovian to Stephanian age intervals in a number of well sections where microfaunal and palynological evidence indicates marine influences (section 7.2).

9.2 VARIATION OF $\delta^{13}C$ AND $\delta^{18}O$ IN MARINE CARBONATES

9.2.1 CARBON ($\delta^{13}C$)

Carbon can exist in both oxidised and reduced forms. Oxidised inorganic carbon is largely contained in carbonate sediments while reduced organic carbon is incorporated into organic matter. The carbon isotopic composition of a marine limestone mainly reflects the $\delta^{13}C$ of the seawater from which it is precipitated. Long term changes in seawater $\delta^{13}C$ reflect variations in the ratio of organic carbon to carbonate carbon that is sedimented. An increased amount of organic carbon being buried results in ^{12}C being preferentially taken out of seawater. The seawater becomes isotopically heavier and the $\delta^{13}C$ values of carbonates precipitated are subsequently more positive. A secular trend of decreasing $\delta^{13}C$ values characterises the Late Precambrian to the Ordovician. This is followed by an increase in values through to the Permian with a subsequent slow decrease until the Recent. The $\delta^{13}C$ curve for marine carbonates correlates with the global sea-level curve. Sea level rise results in carbon being transferred from the sedimentary reservoir of reduced organic carbon (mainly mudrocks) to that of oxidised inorganic carbon in carbonates. Extensive carbonate sedimentation during high sea-level stands leads to marine limestones with more negative $\delta^{13}C$ values. Short term changes in the $\delta^{13}C$ of seawater can be related to black shale deposition and periods of oceanic anoxia. Much organic matter is deposited during these events, resulting in heavier seawater and the precipitation of carbonates with more positive $\delta^{13}C$ values. Short term fluctuations can also be related to changes in organic productivity and burial rates (Tucker and Wright 1990).

9.2.2 OXYGEN ($\delta^{18}O$)

The $\delta^{18}O$ of a carbonate precipitated from water predominantly depends on the $\delta^{18}O$ composition and temperature of the water (Nagarajan *et al.* 2008). On a broad scale, the $\delta^{18}O$ of marine carbonates show increasingly negative values back through the

Phanerozoic, in particular from the Permian to the Precambrian. This either reflects seawater depleted in ^{18}O or warmer waters. On a short-term timescale, the waxing and waning of ice sheets can also influence the δ^{18}O composition of seawater. Meltwater entering the oceans is usually negative with respect to the seawater. Carbonates precipitated post-glaciation will have lower δ^{18}O values (Tucker and Wright 1990).

It is also noted that the oxygen isotopic compositions of marine carbonates are prone to alteration during diagenesis (Hudson 1977).

9.3 δ^{18}O AND δ^{13}C VALUES FOR CARBONIFEROUS MARINE CARBONATES

9.3.1 Bruckschen *et al.* (1999)

To investigate trends in the isotopic composition of seawater during the Carboniferous, Bruckschen *et al.* (1999) analysed the δ^{18}O and δ^{13}C values of 444 brachiopod shells from Western Europe and the former USSR. δ^{13}C values for the Pennsylvanian Sub-system (318.1 ±1.3Ma to 299.0 ±0.8Ma) range from -1.85‰ to 6.84‰, with δ^{18}O values ranging from –15.32‰ to –0.80‰. For the Moscovian Stage (311.7Ma ±1.1 to 306.5 ± 1.0), δ^{13}C values range from -1.39‰ to 6.84‰ with δ^{18}O values ranging from –15.32‰ to –1.70‰ (figure 9.1).

9.3.2 Prokoph *et al.* (2008)

Prokoph *et al.* (2008) compiled an isotope database for marine carbonates, spanning the Phanerozic and extending into the Archean. The database contained over 55,000 published values including 39,000 values from low-Mg calcite shell material of Phanerozoic age. Carbon and oxygen isotope data for the shell material was divided into habitat subsets: (i) surface waters between 58°-90° palaeolatitudes ("high-latitude"); (ii) surface waters between 32°-58° paleolatitudes ("mid-latitude"); (iii) surface water between 32°N and 32°S paleolatitudes ("low-latitides"); (iv) "deep-sea" below 300m water depth.

The $\delta^{13}C$ values for low-latitude shell material of Carboniferous age ranged from approximately –4‰ to –9‰. $\delta^{18}O$ values ranged from approximately –13‰ to 0‰ (figure 9.1).

9.4 $\delta^{18}O$ AND $\delta^{13}C$ VALUES FOR NON-MARINE CARBONATES

9.4.1 Hudson (1977)

Hudson (1977) compiled ranges of $\delta^{13}C$ and $\delta^{18}O$ for a variety of non-marine carbonates. Ranges are presented as fields on a $\delta^{13}C$ and $\delta^{18}O$ cross-plot (figure 9.2). The ranges for freshwater limestones (field 7) represent values for Phanerozoic age limestones selected from a database of 183 samples compiled by Keith and Weber (1964). Soil calcite data (field 12) is based on values from modern day sediments and soils in northwest Europe recorded by Salomons (1975). Ranges for early diagenetic concretions (field 14) are largely based on values from Cretaceous and Jurassic carbonates (Hudson 1977).

Hudson (1977) also compiled ranges of $\delta^{13}C$ and $\delta^{18}O$ values for marine carbonates. Ranges for 'common marine limestones' (field 8) represent values for Phanerozoic age limestones selected from a database of 321 samples compiled by Keith and Weber (1964). Field 10 represents an envelope drawn around the mean isotopic compositions of the selected marine limestones (Hudson 1977). Hudson also includes ranges for Pleistocene age marine carbonates from Bermuda recorded by Gross (1964) (field 11).

9.5 METHODOLOGY

Thirteen cuttings samples from three offshore western Irish wells (26/28-1, 26/28-2 and 36/16-1) were selected for isotope analysis (Appendix VIII, figures 7.8, 7.9, 7.19). Cuttings samples that coincided with the occurrence of carbonates on composite logs were selected. Samples ranged from Duckmantian to Asturian in age.

The cuttings were thoroughly washed to remove drilling mud. Fragments of calcium carbonate ($CaCO_3$) were identified by placing small amounts (sub-samples) in dilute HCl. Eleven samples contained sufficient carbonate fragments for analysis. Two types of carbonate were often present in a sample. Brown to brown/purple, very finely crystalline, possibly micritic limestones were recorded in most samples and categorised as group A carbonates. Group B comprised a range of white to white-grey carbonates including a shell fragment identified in sample depth 4680-90’ from 36/16-1. The two groups of carbonates were analysed separately.

Samples were crushed into a fine powder using a pestle and mortar. Approximately 0.6mg of each sample was then weighed using a high-precision microbalance and placed into a round bottomed glass exetainer. Dr. Robbie Goodhue subsequently weighed ~0.6mg of Cranford dolomite (a working standard) and ~0.6mg of IAEA-CO-1 Marble (157) (an international standard) into other exetainers. The Cranford Dolomite has a $\delta^{13}C$ value of –8.15‰ (± 0.06) and a $\delta^{18}O$ value of –10.91‰ (± 0.11). Dr. Goodhue loaded the exetainers containing samples and standards into a CTC Analytics CombiPal auto sampler, where they were flushed with CP grade helium and treated with orthophosphoric acid (H_3PO_4). The CO_2 produced was introduced into a Thermo Delta^{plus} Continuous-flow isotope ratio mass spectrometer (CF-IRMS) via a Thermo Gas Bench II, using helium as the carrier gas. ISODAT software was used to record the resulting carbon and oxygen isotope signals. All carbon isotope data was reported relative to V-PDB and oxygen data was reported relative to V-SMOW. Replicates of the samples were also run.

9.6 RESULTS

$\delta^{13}C$ and $\delta^{18}O$ values from the initial and replicate runs are in general agreement, although one or two samples show slightly different values (see Appendix IX). This may be attributed to inhomogeneity within the sample (pers. comm. from Dr. Robbie Goodhue, 24 February 2010).

Comparing the results with the range of $\delta^{13}C$ and $\delta^{18}O$ given for Carboniferous marine carbonates by Prokoph *et al.* (2008) and for Pennsylvanian and Moscovian age marine carbonates by Bruckschen *et al.* (1999) (figure 9.1), the majority of offshore Irish samples plot outside the ranges given by the two authors. Two sample depths plot within the ranges given; sample 4B from 7340-50’ in 36/16-1 and sample 2B from 4680-90’ in 36/16-1. Sample 6A, from 2785m in 26/28-1 plots outside the ranges given by Bruckschen *et al.* (1999), although within the range given by Prokoph *et al.* (2008).

Compared with ranges of $\delta^{13}C$ and $\delta^{18}O$ for marine and non-marine carbonates compiled by Hudson (1977) (figure 9.2), many of the offshore western Irish samples plot within or in proximity to the freshwater limestone field (field 7) or the soil calcite field (field 12). Values for samples 4B and 2B plot just outside the range for 'common marine limestones' (field 8). Sample 6A plots within the range for Pleistocene age marine carbonates from Bermuda (field 11). Sample 12A plots in proximity to the range for early diagenetic concretions (field 14).

9.7 DISCUSSION

Overall, the majority of $\delta^{13}C$ and $\delta^{18}O$ values for the offshore western Irish samples plot outside the ranges given for marine carbonates by Prokoph *et al.* (2008), Bruckschen *et al.* (1999) and Hudson (1977). As indicated above, samples 4B and 2B plot within the ranges for marine carbonates given by Prokoph *et al.* and Bruckschen *et al.* but outside the range given by Hudson. As the ranges from Prokoph *et al.* and Bruckschen *et al.* are restricted to the Carboniferous, they are considered more suitable for comparison with the offshore Irish values than the ranges in Hudson. The larger, more recent datasets of Bruckschen *et al.* and Prokoph *et al.* are also more comprehensive than the dataset of Hudson.

Sample 4B was a white, hard, crystalline limestone from 7340-50' in 36/16-1. No other carbonates were recorded in the cuttings sample. The present study assigned the sample depth to the lowermost part of the Duckmantian age *Vestispora magna* Sub-biozone of Clayton *et al.* (2003). Lithological and microfossil data indicate a delta top depositional environment with occasional marine influences for the interval assigned to the sub-biozone (section 7.2.9). Although no marine microfossils have been recorded from the sample depth, the isotopic composition of the limestone suggests precipitation in a marine environment.

Sample 2B comprised a calcitic shell fragment from 4680-90' in 36/16-1. The present study assigns the sample depth to the Asturian age *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003). King *et al.* (1979) recorded *Spirorbis* sp. at 4680’ and 4690’, with unidentified ostracod spp. also recorded at 4690’. However, no exclusively marine microfossils have been recorded from the sample depth. A brown, hard, very finely crystalline limestone (sample 2A) was also recorded in the cuttings sample. Its isotopic composition plots outside the range for marine carbonates given by Bruckschen *et al.* (1999), Prokoph *et al.* (2008) and just outside the range for freshwater limestones (field 7) in Hudson (1977). As indicated in section 8.9, a depositional environment with episodes of marginal marine deposition (e.g. lagoonal) may be inferred for the Asturian age interval in 36/16-1. It is possible that marine microfauna could be washed into such environments. The presence of a marine shell fragment and a non-marine limestone in the same sample may reflect this depositional model.

It is also noted that carbonate samples 7A and 7B from 2925m in 26/28-1 plot outside the ranges for marine carbonates given by Bruckschen *et al.* (1999) and Prokoph *et al.* (2008). Sample 7A plots within the ranges for freshwater limestones given by Hudson (1977), and sample 7B plots in proximity to the field for soil calcites (figure 9.2). However, Robeson (1988) recorded scolecodonts spp. in a cuttings sample from the same depth (figure 8.7). Palynofacies analysis of organic matter from the sample depth recorded no further exclusively marine microfossils, although occurrences of *Botryococcus* and *Leiosphaeridia* were noted (section 8.8.1). A similar depositional model to that suggested above for sample depth 4680-90’ in 36/16-1 may be inferred. Alternately, the mixed marine and non-marine characteristics in both samples may be due to cuttings from thinly bedded marine and non-marine horizons being incorporated into the same sample. Caving within the borehole can also introduce younger material from a different depositional environment to the interval being sampled.

Sample 6A, from 2785m in 26/28-1 plots outside the isotopic range for Moscovian and Pennsylvanian age marine carbonates given by Bruckschen *et al.* (1999), but within the range for Carboniferous age marine carbonates given by Prokoph *et al.* (2008). The sample also plots within the field for Pleistocene marine carbonates in Bermuda given by Hudson (1977). It is most appropriate to compare the Pennsylvanian age values from the present study with the ranges from Bruckschen *et al.* Bruckschen *et al.* indicates that the $\delta^{13}C$ of Mississippian marine carbonates can reach values of –3.82;

significantly more negative than values recorded in the Pennsylvanian. This may be reflected in the range given by Prokoph *et al.* As sample 6A plots outside the range given for Pennsylvanian or Moscovian age marine carbonates by Bruckschen *et al.*, it is likely that it is non-marine. This is also suggested by the lack of marine macrofauna recorded at the sample depth (figure 8.7). In the palynofacies analysis of organic matter from 2785m, no exclusively marine palynomorphs were recorded (section 8.8.1). *Botryococcus* and *Leiosphaeridia* were present, 39% of palynomorphs showed pyritisation and <1% of the organic matter comprised AOM of algal origin. As indicated in section 8.9, Asturian age lithological and microfossil data from 26/28-1 suggests a fluvial/delta top, muddy alluvial swamp depositional environment. Palynofacies data from the Asturian interval (including sample 2785m) may indicate episodes of marginal marine deposition. It is possible that the isotopic composition of sample 6A reflects such an environment.

CHAPTER 10

PALAEOGEOGRAPHIC RECONSTRUCTIONS OF THE NORTH ATLANTIC REGION

10.1 CARBONIFEROUS PALAEOGEOGRAPHIC RECONSTUCTIONS

A series of Carboniferous palaeogeographic reconstructions for the North Atlantic region are shown in figures 10.2 to 10.8. The reconstructions incorporate interpretations of the offshore western Irish depositional environments during the Carboniferous, as outlined in the present study (chapters 7, 8 and 9). Data on depositional environments and palaeogeography from other localities in the North Atlantic region are also included (sections 10.2 to 10.6). The ages of the reconstructions with reference to the miospore zonal schemes of Western Europe, offshore western Ireland and Eastern Canada are shown in figure 10.1.

10.2 GREAT BRITAIN AND IRELAND

10.2.1 Late Courceyan to early Chadian

10.2.1.1 Onshore Ireland

During the Tournaisian, a major transgression flooded the Old Red Sandstone continent, moving northwards across Ireland. By Chadian times, the shallow sea had transgressed the Irish Midlands and reached Northern Ireland (Guion *et al.* 2000). Grey, fine-grained mound and sheet forming Waulsortian limestones were deposited across much of southern and central Ireland. In the South Munster Basin, black muds and calcareous turbidites were deposited in deeper water (Cope *et al.* 1992). In central Ireland, basin development resulted in the formation of the Shannon and Dublin Basins (Guion *et al.* 2000).

10.2.1.2 Great Britain

As in Ireland, large regions of Great Britain were flooded by the Tournaisian marine transgression. Late Courceyan to early Chadian age Waulsortian facies are recorded in southwest Wales and Somerset and by Chadian times the marine transgression had reached North Wales. Waulsortian facies also developed in the Peak District along the Staffordshire-Derbyshire borders (Cope *et al.* 1992). In the Northumberland and Solway Basins of northern England, Tournaisian deposits are dominated by fluvial sediments and fluvio-lacustine dolomitic limestone 'cementstones'. Deltas also periodically advanced from the northeast. In the Midland Valley of Scotland, the earliest Mississippian successions are dominated by calcareous mudstones, sandstones and cementstones. Nodular evaporites, halite and gypsum pseudomorphs and dessication features suggest deposition in a hypersaline environment (Guion *et al.* 2000).

10.2.2 Arundian and Holkerian

For Arundian to Holkerian age palaeogeographic reconstructions, refer to figures 10.1 and 10.2.

10.2.2.1 Onshore Ireland

By Arundian times, the Waulsortian facies that had characterised large areas of onshore Ireland in the late Courceyan and early Chadian had largely disappeared (Cope *et al.* 1992).

South Munster Basin

Arundian deposits of the South Munster Basin are characterised by highly condensed, mainly mudstone facies, representing a basin largely starved of sediment. Cherty mudstones and minor fine-grained limestone turbidites are recorded in the area around Bantry Bay, County Cork. To the north of the South Munster Basin, shelfal deposits are generally characterised by regularly bedded bioclastic limestones, although with some local variation. Early Arundian age tuffs are also recorded in northern County Cork (Cope *et al.* 1992).

Shannon Basin

Deposits of the Shannon Basin are characteristically more argillaceous than the surrounding shelfal deposits (see below). In northwest County Limerick, Waulsortian limestones are overlain by unfossiliferous mudrocks and thin beds of fine grained carbonates assigned to the Arundian age Rathkeale Formation (Sevastopulo and Wyse Jackson 2009).

Galway-Roscommon Shelf

The Galway-Roscommon Shelf covers an area extending from east County Clare and County Galway to counties Mayo and Roscommon. North of the Shannon Basin in counties Clare and Galway, Viséan age deposits are predominantly shallow water, shelf facies. The early Viséan to Holkerian age Tubber Formation comprises grey crinoidal packstones. Shallow water limestones also characterise the overlying Holkerian to Asbian age Burren Formation (Sevastopulo and Wyse Jackson 2009).

Dublin Basin

In Viséan Times, the Dublin Basin covered most of the Irish Midlands. In coastal sections of north County Dublin, the lower Viséan age Rush Formation is characterised by turbidite and sediment flow deposits comprising conglomerates interbedded with limestones, sandstones and shales. The upper 50m comprises early Arundian age resedimented oolitic sands. Elsewhere, deposits of the upper Tournaisian to Asbian age Lucan Formation comprise interbedded dark, cherty micrites and shales with horizons of graded skeletal limestone, interpreted as basinal hemipelagic deposits and distal turbidites (Sevastopulo and Wyse Jackson 2009).

Balbriggan Shelf

In Arundian and Holkerian times, the Balbriggan Shelf, located to the north of the Dublin Basin, was a high energy, shallow water depositional environment, characterised by the ooidal and skeletal sands of the Holmpatrick Formation. Fauna include corals and brachiopods (Sevastopulo and Wyse Jackson 2009).

Northern Region

In a number of localities north of Clew Bay, County Mayo, pale grey shallow water crinoidal limestones of the early Viséan to Arundian age Ballyshannon Limestone Formation are succeeded by dark, marine fossiliferous shales of the Arundian age Bundoran Shale Formation. Deltaic deposits of the Arundian to possibly Holkerian age Mullaghmore Sandstone Formation comprise grey, sometimes pebbly, feldspathic sandstones, grey shales and rare limestones. The formation is widespread, being recorded in a number of localities in the northern region of Ireland, including the Omagh syncline, the Sligo syncline and north Mayo. Much of the sandstone, shale and limestone is considered marine or marginal marine in origin and possesses a rich ichnofauna with scattered body fossils (Sevastopulo and Wyse Jackson 2009). Graham (1996) also identified fluvial channel deposits with a general north-northwest transport direction, rootlet beds and palaeosols. In places, the top of the Mullaghmore Sandstone Formation is oolitic, suggesting a period of reworking during sea level rise (Sevastopulo and Wyse Jackson 2009). Higgs (1984) assigned miospore assemblages from the formation to the *Knoxisporites triradiatus-K. stephanephorus* (TS) Biozone of Western Europe. Overlying the Mullaghmore Sandstone Formation in a number of localities are rhythmic alternations of limestone and shale with marine faunas assigned to the Benbulben Shale Formation and Glencar Limestone Formation. The formations extend into the Asbian (Sevastopulo and Wyse Jackson 2009).

10.2.2.2 Great Britain

By Arundian times, the Waulsortian facies that had characterised parts of Great Britain in the late Courceyan and early Chadian had largely disappeared. Muds and cherts were deposited across north Devon in a deep water basin. Peritidal carbonates accumulated in South Wales and the Mendip Hills. Arundian age shallow marine carbonates are recorded in North Wales, the Pennines, Lancashire and Yorkshire. The sea also encroached on the uplifted Alston and Askrigg blocks of northern England while limestone turbidites accumulated in the Craven Basin to the southwest. In the Midland Valley of Scotland, the Arundian was a time of major volcanic activity with the continued eruption of the Clyde Plateau Lavas. Deposits of the eastern Midland Valley are predominantly deltaic, sourced from the north, with locally developed coals and occasional marine incursions. To the east of the Scottish Highlands, in the North Sea, alluvial plain sediments are recorded with no evidence for marine incursions e.g. the Buchan Field. The south-western part of the Midland Valley is characterised by non-marine 'cementstone facies' (Cope *et al.* 1992). Cope *et al.* also indicate that marine deposits in the Clair Basin, to the west of the Shetland Islands are possibly Arundian in age.

10.2.3 Asbian/Brigantian

For Brigantian age palaeogeographic reconstructions, refer to figures 10.1 and 10.3.

10.2.3.1 Onshore Ireland

Shannon Basin

In the Shannon Basin, dark, cherty, fossiliferous limestones of the Durnish Limestone Formation overlie the Holkerian age Rathkeale Formation (see section 10.2.2.1). The succeeding Asbian age Shanagolden Formation also comprises dark marine limestones with a fauna of solitary corals. The overlying early Brigantian age Parsonage Formation comprises fine grained limestones with stripes of evaporites that are possibly replaced. They are succeeded by Brigantian age basinal limestones and shales of the Corgrig Lodge Formation, which are in turn followed by the Clare Shale Formation (Sevastopulo and Wyse Jackson 2009).

South Munster Basin

In the South Munster Basin, Asbian and Brigantian age strata assigned to the Lispatrick Formation comprise condensed, black, pyritic, deep water carbonaceous shales with subordinate carbonate beds (Sevastopulo and Wyse Jackson 2009).

Dublin Basin

In the Dublin Basin, hemipelagic basinal muds and distal turbidites of the Lucan Formation (see section 10.2.2.1) continued to be deposited into Asbian times. In the north-eastern part of the basin, grey, shale-free skeletal limestones of the Asbian age Naul Formation overlie the Lucan Formation and are interpreted as prograding deposits derived from the Balbriggan shelf. The Brigantian age Loughshinny Formation initially comprises coarse limestone breccias deposited by debris flows and turbidity currents, reflecting extensional tectonic activity within the basin. Younger parts of the formation comprise argillaceous limestones, dark shales and graded limestones that contain shallow water skeletal material (Sevastopulo and Wyse Jackson 2009).

Shelf north of the Dublin Basin

To the north of the Dublin Basin, shelfal deposits are recorded in the Kingscourt outlier. The Asbian age Mullaghfin Formation comprises packstones and wackestones with evidence for the development of carbonate build-ups and emergence. Deposition of shelfal carbonates continued into the early Brigantian; the Deer Park Formation comprises bedded grainstones and packstones equivalent in age to the lower part of the Loughshinny Formation in the Dublin Basin (Sevastopulo and Wyse Jackson 2009).

North Munster Shelf

In Viséan times, the broad North Munster Shelf existed between the South Munster, Shannon and Dublin Basins (Sevastopulo and Wyse Jackson 2009). To the south of the Dublin Basin, Brigantian age, shallow water platform bioclastic limestones are recorded around the Leinster and Slieve Ardagh Coalfields (Cope *et al.* 1992).

Galway-Roscommon Shelf

Shallow water, fossiliferous limestones characterise Asbian and Brigantian age strata of the Galway-Roscommon Shelf. The Holkerian to Asbian age Burren Formation comprises shallow water limestones and the overlying Brigantian age Slievenaglasha Formation is characterised by cyclical crinoidal limestones. In the East Clare Syncline, an isolated occurrence of volcanics is also recorded within the Slievenaglasha Formation (Sevastopulo and Wyse Jackson 2009).

Northern Region

In the Sligo Syncline, the Asbian age Dartry Limestone Formation comprises well-bedded, fine-grained, cherty limestones and unbedded or poorly bedded mudbank limestone deposits. Brachiopods, rare ammonoids and rare corals are recorded in the mudbank limestones. The late Asbian age Meenymore Formation predominantly comprises grey shales with horizons of ammonoids, gastropods, bivalves, ostracodes, crinoids, brachiopods and corals. They are interbedded with fine-grained laminated limestones and dolomites, interpreted as stromatolite deposits. Dessication cracks and evaporites are also recorded. The formation has been interpreted as coastal sabkha deposits. To the east, the Meenymore Formation of the Lough Allen Basin is succeeded by the late Asbian age Glenade Sandstone Formation. The Glenade Sandstone Formation comprises grey, fairly mature quartzose sandstones with plant material, generally interpreted as deltaic deposits. The overlying Bellavally Formation straddles the Asbian-Brigantian boundary. The formation comprises deposits of a normal salinity shallow marine environment alternating with deposits of intertidal to supratidal environments, which were commonly hypersaline. Shallow marine deposits comprise fossiliferous shales and micrites with ammonoids, rare gastropods, brachiopods and corals. Laminated limestones, evaporites and sandstones represent the littoral deposits. Lying close to or at the Asbian-Brigantian boundary is the Doobally Sandstone Member, a persistant sandstone unit. The Bellavally Formation is succeeded by the Brigantian age Carraun Shale Formation which comprises dark shales and mudstones, limestones and ammonioids. Stromatolites and evaporite pseudomorphs in the lower limestones suggest very shallow conditions. The younger limestones possibly reflect deeper conditions. North of the Clogher Valley Fault, at

Fintona, County Tyrone, localised uplift is inferred to have commenced at the beginning of the Brigantian. The uplift resulted in the deposition of alluvial fan conglomerates and sandstones of the Brigantian age Ballyreagh Conglomerate Formation. The deposits are succeeded by grey-red mudrocks and sandstones with ripples and dessication cracks, dated as late Brigantian or early Serpukhovian in age. To the north, Brigantian age non-marine sandstones were deposited as a result of the uplift to the south (Sevastopulo and Wyse Jackson 2009).

Further east, Asbian and Brigantian age fossiliferous limestones were deposited on the shallow water, periodically emergent Armagh-Cookstown Shelf. At Ballycastle, County Antrim, all Viséan age rocks are assigned to the Brigantian age Ballycastle Group and comprise a succession of non-marine sandstones, shales and coals. Sandstones are often red and dessication cracks are also recorded. Fossiliferous shales and limestones represent rare marine incursions. Early Brigantian age basalts and tuffaceous units are additionally recorded (Sevastopulo and Wyse Jackson 2009).

10.2.3.2 Great Britain

By Brigantian times, extensional tectonics had created a series of half grabens north of St George's Land High. Limestone facies were deposited across the East Midlands Shelf, reefs developed on a carbonate platform in Derbyshire and shelfal deposits are also recorded in North Wales. Outcrops of Brigantian age limestone recorded in South Wales are interpreted as being deposited on either side of a lagoon. In the Askrigg and Alston block region, and northwards into southern Scotland, Yoredale cyclothems are recorded. The cyclothems comprise repeated sedimentary sequences associated with the cyclical progradation of deltas into a shallow marine environment. The cycles commence with a shallow marine limestone, overlain by the coarsening upwards shale-siltstone-sandstone succession of a prograding delta, capped by alluvial and thin coal deposits of the delta top. Reefs also developed on the southern margin of the Askrigg block and in the central part of the Midland Valley of Scotland. Yoredale facies have also been recorded in North Sea boreholes. In southwest England, basinal deposits are characterised by cherts, goniatites and limestone turbidites. In south Cornwall, deltaic facies that include conglomerates suggest a rising landmass to the south. It is likely that the Craven Basin of Lancashire and Yorkshire connected with the Dublin Basin of

Ireland. Evidence of volcanicity is recorded on the Isle of Man, the Peak District and Little Wenlock in Shropshire (Cope *et al.* 1992).

10.2.4 Pendleian and Arnsbergian

A diachronous transition from mixed carbonate-clastic to predominantly clastic deposition occurred close to the base of the Namurian in many areas of Britain and Ireland (Guion *et al.* 2000). The transition was largely driven by erosion of uplifted areas coupled with climate change (Cope *et al.* 1992). Sub-basins established in the early Mississippian continued to influence Namurian sedimentation (Guion *et al.* 2000). Faunal evidence also supports the existence of sea connections to North America and the former U.S.S.R (Cope *et al.* 1992). For Pendleian and Arnsgbergian age palaeogeographic reconstructions refer to figures 10.1, 10.4 and 10.5.

10.2.4.1 Onshore Ireland

Northeast Ireland

Brigantian to Langsettian age rocks are recorded in Coalisland, County Tyrone. The base of the Pendleian is recorded within the Rossmore Mudstones; dark mudstones that grade to shallow-water burrowed siltstones and fine sandstones. The Rossmore Mudstones are overlain by a 'Millstone Grit' unit, the base of which is also Pendleian in age. The Millstone Grit comprises shales with marine fossils, sandstones that are commonly pebble bearing, seatearths and coals. Bivalves, gastropods, brachiopods and rare ammonoids are recorded in both the Rossmore Mudstones and Millstone Grit units. Although Arnsbergian age faunas have been identified, Mitchell (2004) used palynology to identify a major hiatus within the Millstone Grit, spanning the Arnsbergian to Marsdenian (Sevastopulo 2009).

In the Ballycastle coalfield, County Antrim, the ?upper Brigantian to Pendleian age Ballyvoy Sandstone Formation is dominated by sandstones with interbedded mudrocks and coals. There is also evidence for brief marine inundations (Sevastopulo 2009). Sevastopulo indicates that the succession is likely to have accumulated in a separate fault bounded basin.

Northwest Ireland

Pendleian and Arnsbergain age strata are recorded in a number of localities around Lough Allen in the northwest of Ireland. At Doagh, the Pendleian age Dergvone Shale Formation comprises dark ammonoid bearing shales interbedded with barren or sparsely fossiliferous shales. To the north, in the locality of Thur Mountain, rare turbiditic sandstones are recorded within the Dergvone Shale Formation. Sole marks indicate a transport direction from the north-northeast. The overlying Pendleian age Briscloonagh Sandstone Formation comprises turbiditic sandstones overlain by deltaic shallow water sandstones and a seatearth. In the locality of Slieve Anierin, the Pendleian is represented by ammonid bearing shales and barren grey shales of the Dergvone Shale Formation. In Slieve Anierin and the Lackagh Hills, the overlying Arnsbergian age Gowlaun Shale Formation predominantly comprises dark sparsely fossiliferous shales with ammonoid bearing marine bands. The succeeding Lackagh Sandstone Formation comprises coarse to pebbly sandstone with up to five coal seams. The youngest deposits in Slieve Anierin are the Arnsbergian age Bencroy Shale Formation which comprise dark ammonoid bearing shales, barren shales with clay ironstones, silty micaceous shales and thin sandstones (Sevastopulo 2009). To the south of the Lough Allen area, at the Slieve Carna outlier, Pendleian and Arnsbergian age shales are capped by Arnsbergian sandstones.

In the area of Fintona, County Tyrone, the Pendleian age Ballinamallard Mudstone Formation comprises greyish-red mudstones with carbonate nodules, and fine-grained sandstones with ripple marks and dessication cracks. The formation is considered non-marine (Sevastopulo 2009).

In Milltown, located between the Castle Archdale fault and the Omagh thrust fault, the Greenan Sandstone Formation comprises non-marine, medium to coarse grained, purple-grey feldspathic sandstones with scattered clasts of metamorphic rocks. At its base are coarse breccias which rest on the Dalradian. Miospores found low in the formation suggest a Brigantian or Pendleian age (Sevastopulo 2009). Rhyolitic volcanic flows are also recorded towards the top of the formation (Mitchell 2004). Mitchell and Owens (1990) dated the upper part of the formation as lower Namurian in age (Sevastopulo 2009).

Dublin Basin

Near Summerhill, in County Meath, the base of the Pendleian is recorded within a sequence of basinal limestone and shales. Just above the base, beds of turbiditic sandstone are recorded. The Arnsbergian ammonoid band E2b is recorded in a sequence of dark shales with subordinate thin beds of fine sandstone (Sevastopulo 2009). In the Boyne Valley, the base of the Pendleian is recorded in basinal shales and thin limestones of the Donore Shale Formation. The overlying Pendleian age sandstone deposits of the Balrickard Sandstone Formation are considered deltaic in origin. The overlying Walshestown Shale Formation mainly comprises dark shales and contains upper Pendleian and Arnsbergian age ammonoid bands (Sevastopulo 2009).

In the Kingscourt area of County Cavan, the dark, ammonoid bearing Pendleian age Ardagh shale is overlapped to the north by the grey micaceous Ardagh Sandstone. Even further north, the lower Arnsbergian age, pebbly, possibly fluviatile Carrickleck Sandstone is recorded. This is succeeded by the ammonoid bearing dark shales of the Arnsbergian age Carrickleck Shale (Sevastopulo 2009).

Leinster Coalfield

In the Leinster Coalfield, Higgs (1986) tentatively dated the Coonbeg Chert Member of the Luggacurren Shale Formation as Arnsbergian in age. The member comprises thinly bedded, black spicular cherts and shales (Sevastopulo 2009). It is overlain by ammonoid bearing, grey to black shales of the Arnsbergian age Glenview Shale Member. The succeeding Arnsbergian to Chokerian age Black Trench Limestone Member comprises ammonoid bearing limestones and dark shales (Sevastopulo 2009).

South Munster Basin

Higgs (1990) dated interbedded dark mudrocks and fine grained sandstone turbidites of the White Strand Formation in south County Cork as Pendleian to possibly Alportian in age. Miospore assemblages were assigned to the NC, TK and SO Biozones of Clayton *et al.* (1977) (Sevastopulo 2009). Flute moulds indicate a current moving in a northerly direction. Higgs (1990) also recorded reworked Tournaisian age spores, suggesting that the sediments could be derived from an eroding Kinsale Formation to the south (Sevastopulo 2009). On Whiddy Island, County Cork, Jones and Naylor (2003) interpreted the Arnsbergian age East Point Formation as basin floor deposits. The formation comprises black, carbonaceous, sometimes pyritic mudrocks with rare thin beds of very fine sandstone (Sevastopulo 2009). Sevastopulo also indicates that the formation may extend into the Pendleian.

Shannon Basin

In the axial part of the Shannon Basin at Ballybunion, north County Kerry, shales of the Clare Shale Formation were deposited from late Brigantian times. The lower part of the formation (Brigantian to Arnsbergian in age) is characterised by black, ammonoid bearing shales. The upper part (Chokerian in age) comprises grey shale with darker ammonoid bearing horizons. Turbidite sedimentation of the Ross Sandstone commenced in the central trough during the Alportian and continued through the Kinderscoutian. The turbidites were sourced in the west and may correlate with early Namurian fluvio-deltaic deposits in the Porcupine Basin (section 7.2). The turbidite succession is sand dominated with sheet-like and channelised turbidites separated by goniatite-bearing shales. The overlying Gull Island Formation comprises a mudstone dominated package with thin turbidites and evidence for major slumps and slides, representing slope progradation into the basin. In Kinderscoutian and Marsdenian times, unstable shelf-edge deltas prograded into the basin (Guion *et al.* 2000).

10.2.4.2 Great Britain

In areas of northern England, to the north of the Craven Fault Zone, Yoredale type limestone-shale-sandstone cycles that characterised the upper Viséan continued until Kinderscoutian times. In South Wales, the Pendleian to Marsdenian age Basal Grit Group comprises shallow marine sandstones with shelly material interbedded with fine-grained coal bearing coastal plain sediments and deeper marine goniatite bearing mudstones. To the south, offshore open marine mudstones with goniatites are recorded (Guion *et al.* 2000). In Devon and Cornwall, the oldest Namurian rocks are

Arnsbergian in age and comprise turbiditic sandstones and shales (Ramsbottom *et al.* 1978). In the Midland Valley of Scotland, the Pendleian is represented by cyclical alternations of fluvio-deltaic sandstones, mudstones and coals of the Limestone Coal Formation. Non-marine bivalves and *Lingula* bands are common although few marine bands are recorded. The Arnsbergian age Upper Limestone Formation is dominated by deltaic and shallow marine clastic sediments. Six major flooding surfaces and additional thinner marine horizons are characterised by limestones and marine faunas (Guion *et al.* 2000). Basaltic volcanism in the Midland Valley was widespread during the Namurian. Lavas and tuffs are intercalcated with Limestone Coal Group sediments in North Ayrshire, West Lothian and Fife (Cope *et al.* 1992)

10.2.5 Langsettian and Duckmantian

For Langsettian age palaeogeographic reconstructions, refer to figures 10.1 and 10.6.

10.2.5.1 Onshore Ireland

Westphalian age strata are restricted to a small number of outcrops onshore Ireland. With the exception of deposits in the north-west of Ireland, the lower Westphalian of onshore Ireland comprises similar deposits to that recorded in the coalfields of Great Britain (Guion *et al.* 2000).

Leinster and Slieve Ardagh Coalfields

In the Leinster Coalfield, the first workable coal defines the base of the Moyadd Coal Formation (Sevastopulo 2009). Within the formation, Higgs and O'Connor (2005) identified three major cyclothemic sequences, comprising shales, siltstones and sandstones, two coal horizons and the *Cancelloceras cumbriense, Gastrioceras subcrenatum* and *Gastrioceras listerii* marine bands. Higgs and O'Connor assigned miospore assemblages from the Moyadd Coal Formation above the basal Langsettian age *G. subcrenatum* marine band to the lower Langsettian age *Triquitrites sinani – Cirratriradites saturni* (SS) Biozones of Clayton *et al.* (1977). The authors also assigned the overlying Clay Gall Sandstone Formation, a light-grey, medium-grained well to massively bedded sandstone, to the SS Biozone. Sevastopulo (2009) indicates that most of the sandstone unit is likely to be non-marine in origin. The overlying Coolbaun Coal Formation comprises several major cyclothemic sequences with coal seams (Higgs and O'Connor 2005). Higgs and O'Connor assigned miospore assemblages from the formation to the Langsettian age SS and *Radiizonates aligerens* (RA) Biozones of Clayton *et al.* (1977). The biozone boundary is placed just above the Double Fireclay Member which comprises two beds of grey fireclay, separated by an ammonoid-bearing marine band (Sevastopulo 2009). The part of the Coolbaun Coal Formation assigned to the SS Biozone comprises a basal shaly coal overlain by a succession of shales, siltstones and sandstones, with marine bands and horizons of non-marine bivalves (Sevastopulo 2009). The interval assigned to the RA Biozone comprises coals, shales, thin sandstones, siltstones and non-marine bivalve horizons. A *Lingula* band is also recorded just above the Double Fireclay Member (Higgs and O'Connor 2005). *Planolites opthalmoide* burrows are also recorded within the interval assigned to the RA Biozone. Non-marine bivalves are indicative of the *Carbonicola communis* Biozone. The youngest beds yield non-marine bivalves that are older than the *Anthroconaia modiolaris* Biozone which spans the Langsettian-Duckmantian boundary (Sevastopulo 2009).

To the west of the Leinster Coalfield, a succession in the Slieve Ardagh coalfield, is thought to be similar to that of the Lenister Coalfield, but biostratigraphical information is sparse (Sevastopulo 2009).

County Cork and County Limerick Coalfields

The Kanturk coalfield in County Cork is highly deformed with tight folding and thrusting (Guion *et al.* 2000). Two shale horizons in the succession have been tentatively correlated with the basal Langsettian age *Gastrioceras subcrenatum* and lower Langsettian age *Gastrioceras listeri* marine bands. A non-marine bivalve fauna from the highest beds is assigned to the lower Langsettian age *Carbonicola lenisulcata* Biozone. A thick sandstone probably correlates with the Clay Gall Sandstone of the Leinster coalfield (Sevastopulo 2009). In the Crataloe coalfield of north County Limerick, the *G. subcrenatum* and *G. listeri* marine bands are both recorded in a lower Langsettian age succession. A thick sandstone, correlated with the Clay Gall

Sandstone of the Leinster coalfields is recorded above the *G. listeri* horizon (Sevastopulo 2009).

Kingscourt area, County Cavan

In the Kingscourt area, a lower Langsettian age succession of sandstones, shales, seatearths and coals is overlain by Permian strata. The *Gastrioceras subcrenatum* marine band has been recorded in dark shales and a higher marine band is tentatively correlated with the lower Langsettian *Gastrioceras listeri* horizon (Sevastopulo 2009).

Northeast Ireland

In Coalisland, County Tyrone, a Langsettian age paralic succession with a number of coal seams is recorded. *Gastrioceras subcrenatum* is recorded in the Coalisland Marine Band, marking the base of the Langsettian. The *Carbonicola communis/Carbonicola lenisulcata* bivalve biozone boundary is also recorded in the sucession. Strata assigned to the *C. lenisulcata* Biozone comprise marine mudrocks, sandstone, non-marine mudrock, seatearths and coal. A similar succession is recorded in the interval assigned to the *C. communis* Biozone, although without the marine mudrocks (Sevastopulo 2009).

Northwest Ireland

In Milltown, located between the Castle Archdale fault and the Omagh thrust fault, the Slievebane Group was deposited in a fault bounded basin formed by rapid subsidence in the Duckmantian (Sevastopulo 2009). The late Langsettian to Duckmantian age Tullanaglare Mudstone Formation comprises grey-green sandstone and mudstone overlain by a pedogenic limestone. The succeeding Drumlish Conglomerate Formation comprises 1000m of conglomerates rich in volcaniclastic, metamorphic and granitic clasts, interpreted as proximal alluvial fan deposits, fed by braided streams flowing from the north. A miospore assemblage from close to the base of the formation confirms a Duckmantian age (Sevastopulo 2009). Guion *et al.* (2000) indicate the conglomerate was deposited as a result of rapid uplift on the margin of the basin, contemporaneous with similar early Westphalian events in Eastern Canada where localised subsidence occurred in narrow basins (see section 10.3.9).

10.2.5.2 Kish Bank Basin, Irish Sea

Located in the Kish Bank Basin, well 33/22-1 encountered 740m of Duckmantian to Asturian age strata lying unconformably on Lower Palaeozoic slates. The Duckmantian age interval comprises 153m of interbedded siltstones and sandstones with minor coals, interpreted as coal measures facies (Naylor *et al.* 1993).

10.2.5.3 Great Britain

In the coalfields of England and Wales, lower Langsettian age strata was deposited on delta plains punctuated by numerous marine transgressions. Marine bands are characterised by thin carbonaceous mudstones and coal seams are generally thin and rich in sulphur (Guion *et al.* 2000).

Most of the upper Langsettian and Duckmantian strata in Britain's coalfields were deposited in an extensive, low-lying water logged delta/alluvial plain with shallow lakes, ideal for the formation of coals. As a result, upper Langsettian and Duckmantian coal seams are more productive than lower Langsettian seams. Clastic sediments, deposited in fluvial channels, lacustrine crevasse splays, lacustrine deltas and overbank floods, show both fining upwards and coarsening upwards sequences. In the Pennines Province, major fluvial channels comprise sand bodies 10m to 20m thick and minor channels up to 10m in thickness. Overbank flood deposits typically comprise massive siltstones or siltstones with thin interbeds of sandstone. Mudrocks were commonly deposited in lakes colonised by ostracods such as *Geisina* and *Carbonita*, in addition to non-marine bivalves and fish. Siderite formed in reducing conditions on the lake floors, resulting in the formation of ironstone beds. The filling of lakes and the abandonment of channel systems resulted in the development palaeosols and peat mires - the precursor to coal formation. Grey seatearths represent poorly drained swamp areas. Red, cream or mottled, seatearths represent better drained, more oxidised conditions. Marine transgressions became rare in the upper Langsettian. Only one major marine band – the top Langsettian Vanderbeckei Marine

Band - is recorded in the upper Langsettian of the Pennine Province and South Wales. Marine transgressions became common again in the upper Duckmantian and Bolsovian (Guion *et al.* 2000).

Outcrops of Westphalian age strata in Scotland are mainly concentrated in the Midland Valley. Guion *et al.* (2000) indicate the Scottish Westphalian shows many similarities to that of the Pennines Province, except it is less marine influenced. However, the Vanderbeckei Marine Band is recorded in almost every coalfield (Ramsbottom *et al.* 1978). Horizons of marine or brackish fauna are also recorded towards the top of the Duckmantian. Coals in the lower Langsettian are generally thin, although the upper Langsettian and Duckmantian is characterised by numerous coal seams. The Langsettian of the Island of Arran is partially reddened, dominated by channelised sandstones, lacks coal and marine bands and is interpreted as the deposit of a proximal alluvial plain (Guion *et al.* 2000).

It is possible that deeper water conditions persisted in the Culm Basin of Cornwall and Devon (Guion *et al.* 2000). In the southern and central parts of the basin, the lower Langsettian to Bolsovian age Bude Formation comprises mudstones and laterally extensive sandstones with flute casts and tool marks that have been variously interpreted as turbidite deposits, shallow lake deposits or relatively deep water subaqueous fans (Guion *et al.* 2000). On the northern side of the basin, the Bideford Formation comprises coarsening upwards fluvial-dominated deltaic deposits (Guion *et al.* 2000).

10.2.6 Bolsovian and Asturian

For Bolsovian and Asturian to Cantrabrian age palaeogeographic reconstructions, refer to figures 10.1, 10.7 and 10.8.

10.2.6.1 Onshore Ireland

Bolsovian age strata is not recorded onshore Ireland and Asturian age strata is virtually absent (Cope *et al.* 1992). Clayton *et al.* (1986) assigned an Asturian age to the 38m of Carboniferous strata recorded in mineral exploration borehole W80.5, drilled in the

Wexford Outlier of south-eastern Ireland. The authors assigned the interval to a biozone no older than the *Thymospora obscura – Thymospora thiessenii* (OT) Biozone of Clayton *et al.* (1977) and indicated that occurrences of *Cadiospora magna* suggest an age no younger than the Asturian. Recycled Devonian to Tournaisian, late Viséan to early Namurian and early Westphalian age spores were also recorded. The interval comprises a lower unit of black and greyish black carbonaceous mudrock, capped by bituminous coal, overlain by grey, silty mudrock with carbonate concretions, followed by 8m of predominantly yellowish to greenish grey, reddened in places, medium to fine-grained fining upwards sandstone. It is succeeded by 11m of light to dark grey mudrock with bivalve and rootlet rich horizons, in turn overlain by 6m of siltstones and fine-grained sandstones, followed by dark carbonaceous mudrock. The top 1.2m comprises a fine to medium grained sandstone, strongly reddened below an unconformable contact with Permo-Triassic strata (Clayton *et al.* 1986). Based on palynological and lithofacies evidence, the authors suggested a coal swamp depositional environment. Recycled late Viséan or early Namurian and early Westphalian age spores also indicate contemporaneous erosion.

10.2.6.2 Kish Bank Basin, Irish Sea

As indicated in section 10.2.5.2, well 33/22-1 encountered 740m of Duckmantian to Asturian age strata lying unconformably on Lower Palaeozoic slates in the Kish Bank Basin. Naylor *et al.* (1993) indicate that the Bolsovian age interval comprises siltstone, sandstones, claystones and coals. The Asturian age section comprises coal, unfossiliferous grey siltstones, red shales and brown sandstones.

10.2.6.3 Great Britain

By Bolsovian and Asturian times, thrust sheets associated with the Variscan orogeny had propagated northwards forming a mountain chain across Cornwall and Devon, shedding clastic sediment northwards (Guion *et al.* 2000). Uplift and erosion of the Welsh and London-Brabent Highs also provided a source for Asturian age sediments (Cope *et al.* 1992). The climate became increasingly arid and by the late Westphalian, peat mires had been largely replaced by calcretes and well-drained palaeosols in an alluvial setting (Guion *et al.* 2000). Ramsbottom *et al.* (1978), Cope *et al.* (1992) and

Guion *et al.* (2000) all indicate that the late Westphalian of Great Britain largely comprises alluvial and floodplain deposits. The mid-Bolsovian age Cambriense Marine Band represents the last marine band recorded in the British Isles (Guion *et al.* 2000).

In many northern and midlands coalfields of England, coal forming conditions did not persist for long after the Cambriense marine incursion and red beds are commonly recorded (Ramsbottom *et al.* 1978). Coals recorded in the Bolsovian of the Pennines coalfield are thin, reflecting a change to better drained conditions and the transition from deltaic to fluvial deposition (Guion *et al.* 2000). In Cumbria, the red 'Whitehaven Sandstones Series' overlies grey coal measures with most of the reddening attributed to pre-Permian oxidative weathering. In the Canonbie Coalfield of southern Scotland, red beds lie conformably on grey coal bearing strata (Guion *et al.* 2000). In the West Midlands, red beds of the Bolsovian age Etruria Formation are overlain by fluvial deposits of the Asturian age Halesowen Formation. Calcretes reflect a moderately dry climate (Guion *et al.* 2000).

In southern England and South Wales, coal forming conditions generally persisted above the Cambriense Marine Band (Ramsbottom *et al.* 1978) and red beds are less frequently recorded. In the South Wales Coalfield, soon after the marine incursion, a major influx of sandstones, from rising Variscan Mountains to the south, spread north-eastwards forming the Pennant Measures, a thick sequence of Bolsovian and Asturian age alluvial sandstones, subordinate mudstones, palaeosols and coals. Similar deposits are recorded in the Kent, Forest of Dean, Oxford-Berkshire and Bristol-Somerst coalfields, although red beds are also recorded in the upper part of the last two coalfields (Guion *et al.* 2000). In the Midland Valley of Scotland, reddened alluvial sediments are also recorded (Cope *et al.* 1992). Guion *et al.* (2000) indicate that channel fill sandstones with calcretes and dessication cracks reflect deposition in a well-drained fluvial setting.

10.3 MARITIMES BASIN OF ATLANTIC CANADA

The Maritimes Basin of Atlantic Canada comprises a suite of Upper Palaeozoic strata extending from southwestern New Brunswick to the continental margin on the eastern

Grand Banks (Gibling *et al.* 2008). The Maritimes Basin contains a series of depocentres or component basins. The location of the basins, wells/boreholes and outcrops referred to in the following sections are shown in figure 10.9.

10.3.1 Stratigraphic groups

The Carboniferous stratigraphic groups currently recognised in the Maritimes Basin are shown in figure 10.10. The Carboniferous of Eastern Canada was initially subdivided into the Horton, Windsor, Canso, Riversdale, Cumberland and Pictou Groups, defined mainly on macrofloral and macrofaunal content (Hacquebard 1972) (figure 10.11). Subsequent revisions of the groups also incorporated lithostratigraphic criteria. Ryan *et al.* (1991) replaced the Canso Group with the Mabou Group and incorporated the Riversdale Group into the Cumberland Group. The authors also redefined the Cumberland and Pictou Groups based on the prevailing red or grey colouration of the strata and the presence or absence of coal. Local equivalents of the main stratal groups are associated with the development of localised depocentres or where fault activity within larger depocentres generated local basin-margin facies (Gibling *et al.* 2008) (figure 10.10).

The Carboniferous of Eastern Canada has also been subdivided into a number of biozones based on miospore content. As indicated in section 2.4, many of the spore zones proposed by Barss *in* Hacquebard (1972), Barss *in* Belt (1965) and Hacquebard and Barss (1967) (figure 10.11) are now superseded by zones proposed by Utting (1987), Utting *et al.* (1989; 2010), Martell *et al.* (1993) and Utting and Giles (2004; 2008) (figure 2.9). Biozones of Bolsovian to Autunian age are yet to be revised.

10.3.2 Late Devonian to Tournaisian

Horton Group and equivalents

A suite of linear, fault-bounded basins developed across Atlantic Canada in Late Devonian times. The Late Devonian to Tournaisian age basin fills are assigned to the Horton Group and its local equivalents (figure 10.10). Regionally, they typically comprise basal alluvial clastics, overlain by lacustrine and restricted marine deposits, followed by a succession of alluvial sediments. Basin margin alluvial fans with coarse conglomerates are also common. Restricted marine conditions in the middle of the group are indicated by the presence of echinoderms, calcareous algae, agglutinated foraminifera and ostracods (Gibling *et al.* 2008). Gibling *et al.* suggest a tongue of the Rheic Ocean extended between Laurussia and Gondwana, in proximity to Atlantic Canada.

Horton Group sediments have been recorded in the Gulf of St Lawrence (Giles and Utting 1999; 2001; 2003, Giles 2004) Prince Edward Island (Giles and Utting 1999) and possibly in the Sydney Basin (Giles 2009). In the southern Grand Banks, wells Gannet O-54, and Sandpiper 2J-77 penetrated shales and sandstones assigned to the Horton Group. Murre G-67 also encountered red slates that are deemed lithologically similar to the Horton Group (Bell and Howie 1990). In western Newfoundland, the equivalent Anguille Group is recorded in St. George's Bay Basin and the Deer Lake Basin (Gibling *et al.* 2008). Offshore northern Newfoundland, Haworth *et al.* (1976a,b) mapped the geology of the shelf and seafloor of St Anthony Basin using data from bedrock coring as well as magnetic, gravity and reflection seismic surveys. A Lower Mississippian unit, equivalent to the Anguille Group was identified and mapped based on its seismic character (Bell and Howie 1990). In the Cobequid Hills of mainland Nova Scotia, the equivalent Fountain Lake Group includes several kilometres of rhyolite and basalt dated as Fammennian to Tournaisian in age (Gibling *et al.* 2008).

10.3.3 Chadian to Asbian.

For Arundian-Holkerian age palaeogeographic reconstructions, refer to figures 10.1 and 10.2.

Windsor Group and equivalents

The Viséan age Windsor Group underlies much of the present Maritimes Basin area including northern Nova Scotia, the central carbonate platform of New Brunswick, the Gulf of St Lawrence, the Grand Banks and St Anthony Basin (Gibling *et al.* 2008). Coeval deposits in southwest Newfoundland are assigned to the Codroy Group (Howie

1988), those in west Newfoundland are assigned to the Deer Lake Group (Utting and Giles 2004) and deposits in New Brunswick and Quebec are assigned to the Percé Group (Gibling *et al.* 2008).

The Windsor and Codroy Groups are characterised by marine evaporites and carbonates, although non-marine to marginal marine clastics may be locally dominant (von Bitter *et al.* 2007). The groups record the initial transgression of the Atlantic Provinces by a shallow sea (Gibling *et al.* 2008) and up to thirty discrete transgressive-regressive events have been recorded (Lavoie *et al.* 2009). In contrast, the Percé Group and Deer Lake Group both lack marine strata (Jutras *et al.* 2007; Hamblin *et al.* 1997)

The Windsor Group was first subdivided biostratigraphically by Bell (1929) into two macrofaunal zones (upper and lower) and five subzones; A to E based on brachiopod and coral content (Howie 1988) (figure 10.12). Giles (1981) subsequently subdivided the Windsor Group into five major cycles (1-5) based on the recognition of five major transgressive-regressive cycles (figure 10.12). Von Bitter *et al.* (2007) indicate that major cycle boundaries are largely coincident with changes in macrofauna, conodonts, foraminifera and palynoflora.

Nova Scotia and south-western Newfoundland; Windsor/Codroy Group Cycles 1-2

Based on outcrop and borehole data from Nova Scotia and southwest Newfoundland, Von Bitter *et al.* (2007) assigned miospore assemblages from the Windsor/Codroy Group Cycle 1 to the Chadian to Holkerian age *Lycospora pusilla-Densosporites columbaris* Biozone of Utting and Giles (2004) and to the Asbian age *Knoxisporites stephanephorus* Biozone of Utting and Giles (2004) (figure 10.12). The lower part of Cycle 2 was dated as mid to late Asbian in age based on conodonts and foraminifera. Miospore assemblages from Cycle 2 were also assigned to the *K. stephanephorus* Biozone.

In terms of lithology, Von Bitter *et al.* (2007) indicate the base of Cycle 1 is typically characterised by laminated basinal marine carbonates with the local development of marine bioherms. Laminated carbonates are recorded in the Ship Cove Formation of south-western Newfoundland (figure 10.13) and the Macumber Formation of Nova Scotia (figure 10.12). Marine bioherm correlatives are recorded in the Big Cove Formation of south-western Newfoundland and the Gays River Formation of Nova Scotia (figure 10.12). The authors indicate the remainder of Cycle 1 is typically characterised by a thick succession of anhydrite and halite with thin beds of fine-grained clastics, as seen in the Carrolls Corner and Stewiacke Formations of Nova Scotia (figure 10.12). Utting and Giles (2004) assigned the Codroy Road Formation of the Lower Codoy Group, southwest Newfoundland to the *Lycospora pusilla-Densosporites columbaris* Biozone (figure 10.13). Outcropping in St. George's Bay lowlands the formation comprises approximately 100m of gypsum with rare thin shale partings. In borehole LR-98-1, drilled in promixity to the outcrop locality, the formation is dominated by anhydrite. Howie (1988) indicated that the anhydrite and halite of Cycle 1 formed as a result of seawater evaporation in restricted marine basins. The thick successions are interpreted as a composite of many transgressive and regressive episodes. Red beds typically cap the cycle, reflecting a period of subaerial exposure (von Bitter *et al.* 2007).

Von Bitter *et al.* (2007) indicate that Cycle 2 marks a change in stratigraphic character of both the Windsor and Codroy Groups with the appearance of thin fossiliferous marine carbonates, each representing one transgressive-regressive episode. Von Bitter *et al.* indicate that the lower part of Cycle 2 is typically characterised by thick evaporites alternating with marine carbonates and minor beds of non-marine siltstone. The upper part of the cycle comprises thin marine beds interbedded with non-marine strata and evaporites; as seen in the MacDonald Road Formation of Nova Scotia (figure 10.12).

Gulf of St Lawrence and Prince Edward Island; Windsor Group

In the Gulf of St Lawrence, Cap Rouge F-52 encountered a succession of Mabou, Windsor and Horton Group strata (Giles and Utting 2001). Giles and Utting correlated the well section with borehole SB-1, drilled into the Shubenacadie Basin of Nova Scotia (figure 6.13). The Windsor Group interval was subdivided into upper, middle and lower parts. A succession of halite, marine limestones and thick anhydrite beds assigned to the middle Windsor Group was correlated with the MacDonald Road

Formation of well SB-1 (assigned to Cycle 2 by Von Bitter *et al.* 2007). An interval assigned to the lower Windsor Group is dominated by halite with an anhydrite rich interval recorded towards the base. Giles and Utting assigned a miospore assemblage from the lower Windsor Group to the now redundant *Lycospora noctuina noctuina – Knoxisporites stephanephorus* (NS) Biozone of Utting (1987) (revised to the *Knoxisporites stephanephorus* Biozone by Utting and Giles 2004). The authors correlated the halite dominated interval with the Stewiacke Formation of SB-1 and the anhydrite rich interval with the Carrolls Corner Formation of SB-1 (both assigned to Cycle 1 by Von Bitter *et al.* 2007).

In a lithological and palynological study of well sections from Prince Edward Island and the Gulf of St Lawrence, Giles and Utting (1999) recorded Windsor Group strata in a number of wells. Palynological data summarised in Barss *et al.* (1979) and data from unpublished reports prepared for the Geological Survey of Canada was reassessed as part of the study. Giles and Utting sub-divided the Windsor Group sediments into upper, middle and lower parts. The middle Windsor Group was recorded in Green Gables no.1, Tyrone no.1, Hillsborough no.1, Irishtown no.1, Wellington no.1, Macdougall no.1 and Port Hill no.1. A miospore assemblage from the middle Windsor Group in Irishtown no.1 was dated as middle Viséan in age. The lower Windsor Group was recorded in Hillsborough no.1, Irishtown no.1 and Wellington no.1. The lower Windsor Group in Irishtown no.1 comprises an anhydrite dominated interval overlain by a halite dominated unit. Only the halite dominated interval was recorded in Hillsborough no.1 and only the anhydrite dominated interval was present in Wellington no.1. It is assumed that the middle and lower Windsor Group intervals correspond to the middle and lower Windsor Group units recorded in Cap Rouge F-52, correlated with Cycles 1 and 2 in borehole SB-1.

Northumberland Strait F-25 was drilled between Prince Edward Island and Cape Breton Island. Recent stratigraphic reinterpretations (Giles 2004) have been largely based on lithostratigraphic correlations. The well encountered a succession of Mabou, Windsor and Horton Group sediments. Again the Windsor Group was sub-divided into upper, middle and lower parts. Giles assigned a succession of interbedded anhydrite, limestone, siltstone and halite to the middle Windsor Group. An interval assigned to the lower Windsor Group comprises interstratified beds of halite and siltstone overlying a basal unit of anhydrite and limestone. Barss *et al.* (1979) indicate that miospore assemblages from the middle Windsor Group interval and part of the lower Windsor Group interval are dated as late Viséan in age.

The Bradelle L-49 and Brion Island no.1 wells are the only deep hydrocarbon exploration wells drilled in the north-central region of the Gulf of St Lawrence Basin (Giles and Utting 2003). Giles and Utting indicate that both wells encountered a succession of Westphalian to Stephanian age strata unconformably overlying Misissippian age strata. In Bradelle L-49, a 50m thick succession that includes oolitic and sparsely fossiliferous limestones is tentatively assigned to the middle Windsor Group. In Brion Island no.1, an interval of limestone bearing strata with interbedded anhydrite is also tentatively assigned to the middle Windsor Group (Giles and Utting 2003). With depth, the well encountered a halite dominated interval assigned to the lower Windsor Group, although Giles and Utting indicate the halite could represent a salt diapir.

Cape Breton Island; Windsor Group

In the Orangedale area of Cape Breton Island, Noranda-225-3 penetrated a Viséan age interval assigned to the Windsor Group. Cook and Giles (2003) subdivided the interval based on lithostratigraphy. A succession of halite, anhydrite, minor limestones and dolomite were assigned to the middle Windsor Group. An interval assigned to the lower Windsor Group comprises red and green siltstone, halite, potash and anhydrite/gypsum (Cook and Giles 2003).

Grand Banks; Windsor Group

Drilled into the Grand Banks, the Hermine E-94 well encountered 812.5m of strata assigned to the Windsor, Canso (Mabou), Riversdale (Cumberland) and Pictou Groups (Bell and Howie 1990). Bell and Howie (1990) indicate that Windsor Group lithologies comprise halite, anhydrite, dolomite and shale. While Barss *et al.* (1979) indicate that miospores from the Windsor Group interval are too highly carbonised and poorly preserved to used for dating, Lavoie *et al.* (2009) indicate that the evaporites encountered in Hermine E-94 are representative of the lower Windsor Group.

Also drilled into the Grand Banks, Gannet O-54 encountered Cretaceous strata overlying a succession of anhydrite, halite, dolomite and shales assigned to the Windsor Group, which in turn overlie Horton Group sediments (Bell and Howie 1990). Barss *et al.* (1979) dated miospore assemblages from the Carboniferous interval as Viséan and ?late Tournaisian to Viséan in age. Lavoie *et al.* (2009) indicate that the evaporites encountered in Gannet O-54 are representative of the lower Windsor Group.

Central Basin of New Brunswick and Ristigouche Basin of New Brunswick and Quebec; Percé Group

In the Central Basin of New Brunswick and the Ristigouche Basin of New Brunswick and Quebec, Arundian to Hokerian age thick groundwater calcretes of the Percé Group are assigned to the La Coulée Formation (Jutras *et al.* 2007) (figure 10.14). The authors suggest the phreatic calcrete hardpans developed in proximity to evaporitic basins associated with Windsor Group deposition.

10.3.4 Brigantian

For Brigantian age palaeogeographic reconstructions, refer to figure 10.1 and 10.3.

Nova Scotia and south-western Newfoundland; Windsor/Codroy Group; Cycles 3-4

Von Bitter *et al.* (2007) dated Cycle 3 of the Windsor/Codroy Group in Nova Scotia and southwest Newfoundland as early Brigantian in age based on conodonts, macrofauna and the first appearance of a miospore assemblage characteristic of the *Schopfipollenites acadiensis-Knoxisporites triradiatus* Biozone of Utting (1987). The authors assigned the base of the cycle to the Asbian-Brigantian boundary (figure 10.12). Von Bitter *et al.* further suggested that Asteroarchaediscid foraminifera recorded in Cycle 4 also support a Brigantian age (figure 10.12).

Gibling *et al.* (2008) indicate Cycles 3 and 4 comprise numerous minor cycles of thin fossiliferous marine carbonates intercalated with red beds. Spectral analysis by Giles and Boutilier (2003) suggest the cycles correspond to Milankovitch frequencies. Von Bitter *et al.* (2007) confirm that Cycles 3 and 4 in Nova Scotia and Newfoundland contain up to twelve marine limestones that alternate with thick terrestrial clastics. Fewer evaporites are present than in Cycles 1 and 2. A depositional environment alternating between marine and terrestrial due to repeated marine transgressions-regressions is envisioned. In borehole SB-1, drilled into the Shubenacadie Basin of Nova Scotia, Cycles 3 and 4 are recorded in the Greenoaks Formation which comprises marine limestones alternating with non-marine siltstones and anhydrite (Von Bitter *et al.* 2007) (figure 10.12). In the Codroy lowlands of south-western Newfoundland, Utting and Giles (2004) assigned the Woody Cape Formation of the Upper Codroy Group to the *Schopfipollenites acadiensis-Knoxisporites triradiatus* (AT) Biozone (figure 10.13). The authors indicate the lower part of the formation comprises intercalated sandstone, siltstone, shale and several marine limestones. The upper part comprises alternating red brown and grey mudstones and sandstones. At least two horizons also contain fossil tetrapod footprints. Inland, the Upper Robinsons River Formation/Mollichignick Member of the Codroy lowlands is assigned to the *Crassispora maculosa – Spelaeotriletes arenaceus* palynofacies (Utting and Giles 2004) of the AT Biozone (figure 10.13). Lithologies comprise grey to red sandstone with bivalves, ostracods, gastropods and cephalopods (Utting and Giles 2004). In the St George's Bay lowlands of south-western Newfoundland, part of the Upper Jeffreys Village Member is assigned to the *C. maculosa – S. arenaceus* palynofacies. Lithologies comprise red sandstones, siltstones, minor grey shales and rare marine carbonates (Utting and Giles 2004).

Gulf of St Lawrence and Prince Edward Island; Windsor Group

In the Cap Rouge F-52 well of the Gulf of St Lawrence, Giles and Utting (2001) correlated an interval assigned to the upper Windsor Group with the Green Oaks Formation of borehole SB-1, drilled into the Shubenacadie Basin of Nova Scotia (figure 10.12). The authors also assigned miospore assemblages from the upper Windsor Group interval to the *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Biozone. The interval is halite rich with red mudrocks, marine limestones, anhydrite and rare grey mudrocks (Giles and Utting 2001).

In a lithological and palynological study of well sections from Prince Edward Island and the adjacent Gulf of St Lawrence, Giles and Utting (1999) recorded the upper

Windsor Group in Green Gables no.1, Tyrone no.1 and Hillsborough no.1. In a reassessment of palynological data from Barss *et al.* (1979) and unpublished reports prepared for the Geological Survey of Canada, Giles and Utting (1999) assigned miospores assemblages recorded in the upper Windsor Group of Tyrone no. 1 to the *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Biozone. The interval assigned to the upper Windsor Group comprises limestones, sandstones, red mudrock, and anhydrite. In Green Gables no.1 and Hillsborough no.1, the upper Windsor Group is characterised by red mudrocks, limestone, halite and anhydrite.

In a reassessment of the stratigraphy of Northumberland Strait F-25, Giles (2004) assigned an interval of fine-grained red strata interbedded with limestones, sandstones and anhydrite to the upper Windsor Group, largely based on lithostratigraphic correlations. Barss *et al.* (1979) indicate that miospore assemblages from the interval are late Viséan in age.

Northern Gulf of St Lawrence; ?Mabou Group

The Bradelle L-49 and Brion Island no. 1 wells both encountered a succession of Westphalian to Stephanian age strata unconformably overlying Misissippian age strata in the north-central region of the Gulf of St Lawrence (Giles and Utting 2003). In Bradelle L-49, the Westphalian age Bradelle Formation unconformably overlies an interval of fine grained red strata with lesser grey colours, and channelised sandstones. Miospore assemblages recorded from the interval are tentatively assigned to the Brigantian age *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Biozone (Giles and Utting 2003). Giles and Utting tentatively assigned the interval to the Mabou Group, rather than the upper Windsor Group (as in the rest of the Gulf of St Lawrence) based on an absence of marine deposits. The interval overlies a succession of middle Windsor Group and Horton Group sediments. In Brion Island no.1, the Westphalian age Bradelle Formation unconformably overlies an interval of grey, fine-grained strata with minor red colouration, interbedded with channelised sandstones. Miospore assemblages recorded from the interval are tentatively assigned to the *Grandispora spinosa - Ibrahimispores magnificus* (SM) Biozone of Utting and Giles (1987) and the AT Biozone. Again Giles and Utting (2003) tentatively assigned the interval to the Mabou Group based on the absence of marine strata. The interval overlies strata assigned to the middle and possibly lower Windsor Group (section 10.3.3).

Cape Breton Island; Windsor Group

In the Orangedale area of Cape Breton Island, well Noranda 225-3 penetrated a Viséan age interval assigned to the Windsor Group. Cook and Giles (2003) subdivided the section based on lithostratigraphy. An interval assigned to the upper Windsor Group comprises interbedded red and green siltstones, anhydrite/gypsum and minor limestones. Middle and lower Windsor Group strata were also recorded (section 10.3.3).

Cumberland Basin; Mabou Group

In the Cumberland Basin of Nova Scotia and New Brunswick, late Viséan to early Namurian age strata are assigned to the Mabou Group (Utting *et al.* 2010) (figure 10.15). In coastal exposures near Joggins, Nova Scotia, the base of the Mabou Group is represented by the Middleborough Formation. The formation comprises fine-grained red beds with thin intercalcated sandstones and rare polymictic conglomerate, barren of miospores (Utting *et al.* 2010). It is succeeded by the Shepody Formation; a succession predominantly comprising grey fluviatile sandstones intercalated with red and grey mudrocks. The Shepody Formation type section is recorded near the southern tip of the Maringouin Peninsula of New Brunswick. Upper parts of the formation in both localities are characterised by lensoidal pebbly arkosic sandstones. Utting *et al*. (2010) assigned miospore assemblages from the lower part of the Shepody Formation in both type section and Joggins coastal section to the *Schopfipollenites acadiensis – Knoxisporites triradiatus* Biozone (figure 10.15).

Central Basin of New Brunswick and Ristigouche Basin of New Brunswick and Quebec; Percé Group

Jutras *et al*. (2007) indicate that in the Central Basin of New Brunswick the Asbian to Brigantian age Bonaventure Formation comprises red polymictic conglomerates channelised sandstones and pedogenic carbonates (Jutras *et al.* 2007) (figure 10.14).

The formation unconformably overlies the Arundian to Holkerian age La Coulée calcrete (see section 10.3.3) or sits directly on basement strata. The conglomerates are interpreted as fault controlled alluvial fan and proximal gravely-braidplain deposits. Conglomerates and non-marine sandstones of the Bonaventure Formation are also recorded in the Ristigouche Basin of New Brunswick and Quebec (Jutras and Prichonnet 2005).

10.3.5 Latest Brigantian to Pendleian

For Pendleian age palaeogeographic reconstructions, refer to figures 10.1 and 10.4.

Nova Scotia; Cycle 5 (uppermost Windsor and lowermost Mabou Groups), south-western Newfoundland; Codroy Group

Von Bitter *et al.* (2007) indicate that foraminiferal assemblages recorded at or near the base of Cycle 5 are considered to be latest Brigantian in age. The authors also recorded the first appearance of miospores characteristic of the latest Brigantian to Pendleian age *Grandispora spinosa – Ibrahimispores magnificus* Biozone of Utting (1987) at or near the base of Cycle 5 (figure 10.12). Based on data from Nova Scotia, Von Bitter *et al.* (2007) indicate that Cycle 5 commences with a marine carbonate; the highest marine carbonate in the Windsor Group. It is followed by a succession of anhydrite and halite. The cycle culminates in a succession of gypsum and grey siltstone of the Mabou Group Watering Brook Formation as lacustrine conditions replaced the cyclical marine/non-marine depositional setting of the Windsor Group. Cycle 5 in Nova Scotia therefore includes the boundary between the Windsor and Mabou Groups (von Bitter *et al.* 2007) (figure 10.12).

Utting and Giles (2004) assigned the upper part of the Upper Jeffreys Village Member (Codroy Group), recorded in the St George's Bay lowlands of southwest Newfoundland, to the *Grandispora spinosa-Ibrahimispores magnificus* Zone (figure 10.13). Lithologies include the Crabbs marine limestone, mudstone, sandstone and halite. Von Bitter *et al.* (2007) indicate the Crabbs limestone correlates with the highest Cycle 5 marine limestone in the Windsor Group of Nova Scotia.

Gulf of St. Lawrence and Prince Edward Island; Mabou Group

In the Gulf of St Lawrence, Cap Rouge F-52 encountered the Pomquet and Hastings Formations of the Mabou Group overlying Windsor and Horton Group strata (Giles and Utting 2001). Giles and Utting recorded miospore assemblages indicative of the *Grandispora spinosa - Ibrahimispores magnificus* (SM) Biozone in samples from both the Pomquet and Hastings Formations. Comparing the well section with that of borehole SB-1, drilled into the Shubenacadie Basin of Nova Scotia (figure 10.12), Giles and Utting correlated the Pomquet Formation with the Upper Watering Brook Formation of SB-1 and the underlying Hastings Formation with the Lower Watering Brook Formation. In terms of lithology, the Pomquet Formation interval comprises interstratified red siltstones, shales, sandstone and halite. The Hastings Formation is dominated by halite with lesser interbeds of grey shale (Giles and Utting 2001). The authors also correlated a carbonate at the very top of the interval assigned to the Windsor Group with the highest Windsor Group marine carbonate in borehole SB-1; assigned to the base of Cycle 5.

In a lithological and palynological study of well sections from Prince Edward Island and the adjacent Gulf of St Lawrence, Giles and Utting (1999) identified the Pomquet and Hastings Formations of the Mabou Group in a number of wells. In Green Gables no.1, Hillsborough no.1 and Tyrone no.1, the Pomquet Formation comprises interbedded red mudrocks, sandstones and minor grey mudrock. Based on a reassessment of palynological data from Barss *et al.* (1979) and from unpublished Geological Survey of Canada reports, Giles and Utting indicate that a miospore assemblage from the Pomquet Formation of Tyrone no.1 suggests a Viséan-Namurian age. The Hastings Formation is only recorded in Green Gables no.1 and comprises grey mudrock with thin beds of anhydrite (Giles and Utting 1999). The interval is undated with regards to palynology.

A stratigraphic reinterpretation of the Northumberland Strait F-25 well by Giles (2004) was largely based on lithostratigraphic correlations. Giles indicates the well was collered in red siltstones and sandstones of the Mabou Group before encountering a succession of Windsor and Horton Group strata. Miospores from the interval assigned to the Mabou Group were dated as ‘possibly early Namurian’ in age by Barss *et al.* (1979).

Deer Lake Basin, western Newfoundland; Deer Lake Group

In the Deer Lake Basin of west Newfoundland, miospores from the Rocky Brook Formation of the Deer Lake Group are assigned to the *Grandispora spinosa-Ibrahimispores magnificus* Zone (Hamblin *et al.* 1997) (figure 10.13). In this case, the authors indicate the formation comprises lacustrine and fluvial deposits of interbedded grey, green and red mudstones, red fine-grained sandstones, oolitic and stromatolitic dolostones and dark brown oil shales. The Rocky Brook Formation overlies the ‘late Viséan age’ North Brook Formation which comprises grey and red conglomerate, sandstone, siltstone and minor limestone attributed to debris flow and braided stream deposition on alluvial fan surfaces (Hamblin *et al.* 1997) (figure 10.3). The North Brook Formation lies unconformably on strata of the Tournasian age Anguille Group.

Cumberland Basin; Mabou Group

As noted in section 10.3.4, Utting *et al.* (2010) assigned miospores from the lower part of the Mabou Group Shepody Formation in the Cumberland Basin to the Brigantian age *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Biozone. The authors also assigned the middle and upper parts of the formation at the Maringouin Peninsula type section, New Brunswick to the *Grandispora spinosa – Ibrahimispores magnificus* Biozone (figure 10.15). The Shepody Formation predominantly comprises fluviatile grey sandstone intercalated with red and grey mudrocks.

In the Joggins coastal section of Nova Scotia, the Shepody Formation is succeeded by polymictic conglomerates, arkosic sandstones and grits of the Claremont Formation. The formation is approximately coeval with the Enrage Formation of New Brunswick (Utting *et al.* 2010). Utting *et al.* assigned the lowest beds of the Claremont Formation in the Joggins section to the *Grandispora spinosa – Ibrahimispores magnificus* Biozone (figure 10.15).

10.3.6 ?Pendleian to Arnsbergian

For Arnsbergian age palaeogeographic reconstructions, refer to figures 10.1 and 10.5.

Cumberland Basin; Mabou Group

As discussed in section 10.3.5, Utting *et al.* (2010) assigned the lowest beds of the Claremont Formation in the Joggins section of Nova Scotia to the *Grandispora spinosa – Ibrahimispores magnificus* (SM) Biozone. Utting *et al.* suggested that barren upper parts of the Claremont Formation and the coeval Enrage Formation of New Brunswick may be represented by the ?Pendleian to Arnsbergian age *Reticulatisporites carnosus* Biozone of Utting and Giles (2008).

In the Joggins section, the stratigraphic relationship between the Mabou Group Claremont Formation and the overlying Yeadonian to Langsettian age Cumberland Group Boss Point Formation is uncertain due to poor exposure (Utting *et al.* 2010). However, Gibling *et al.* (2008) confirm that Mabou Group deposits are unconformably overlain by Cumberland Group strata in the Cumberland Basin (figure 10.15).

South-western Newfoundland; Barachois Group

Utting and Giles (2008) assigned miospore assemblages from the Barachois Group of St George's Bay Basin, south-western Newfoundland to the *Reticulatisporites carnosus* Biozone (figure 10.16). The authors indicate that the Barachois Group either lies unconformably on pre-Carboniferous rocks or disconformably on Brigantian age strata of the Codroy Group. In the Codroy lowlands of St George's Bay Basin the Overfall Brook Member represents the basal part of the Barachois Group. Lithologies comprise coarse-grained arkosic sandstones, pebbly sandstones and conglomerates with subordinate red siltstones and grey mudrock. In the St. George's Bay lowlands, pebbly arkosic sandstones of the Brow Pond Lentil correlate with the Overfall Brook Member (Utting and Giles 2008) (figure 10.16). The authors indicate an alluvial fan deposition environment is likely. In the Codroy lowlands, the Searston Formation represents the Barchois Group above the Overfall Brook Member. The formation comprises multistoried arkosic fluviatile sandstone units with lensoidal pebbly intervals, intervening red siltstones, thin interbeds of grey mudrock, thin plane-bedded sandstones and infrequent horizons of pedogenic carbonate nodules. In the St George's Bay lowlands, strata assigned to an undivided Barchois Group include mudrocks, sandstones and thin coals (figure 10.16). Hyde *et al.* (1991) suggested an alluvial plain depositional environment with coal swamps, ponds and small lakes. Utting and Giles (2008) propose correlation of the undivided Barachois Group with the Searston Formation of the Codroy lowlands and additionally with the red mudrock dominated Mabou Group Pomquet Formation of the Antigonish Basin, Nova Scotia (figure 10.16).

Deer Lake Basin, western Newfoundland; Deer Lake Group

Utting and Giles (2008) suggest the Humber Falls Formation of the Deer Lake Basin is lithologically comparable and probably correlative with the Searston Formation of St George's Bay Basin (figure 10.16). Hamblin *et al.* (1997) indicate the Humber Falls Formation comprises thickly bedded, grey or red, medium to coarse grained sandstones in fining upwards units and thin fine grained sandstone beds.

10.3.7 Roughly dated Viséan/Namurian well sections

Grand Banks

In the Grand Banks, well Hermine E-94 encountered 812.5m of strata assigned to the Windsor, Canso (Mabou), Riversdale (Cumberland) and Pictou Groups (Bell and Howie 1990). Bell and Howie (1990) indicate that the Windsor Group lithologies comprise halite, anhydrite, dolomite and shale and the Canso (Mabou) Group comprises red shales and sandstones. Although Barss *et al.* (1979) indicated that miospores from the Windsor Group interval are too highly carbonised and poorly preserved to used for dating, Lavoie *et al.* (2009) indicate that the evaporites encountered in Hermine E-94 represent the lower Windsor Group (see section 10.3.3). Barss *et al.* also note that miospore assemblages from the Riversdale (Cumberland) and Canso (Mabou) Group are dated as ?late Viséan to Namurian in age.

Also drilled into the Grand Banks, Sandpiper 2J-77 encountered Early Jurassic/Late Triassic strata before penetrating 261.8m of Windsor Group anhydrite, shale and dolomite overlying shales and sandstones assigned to the Horton Group (Bell and Howie 1990). Barss *et al.* (1979) indicate that miospore assemblages from the Windsor group interval suggest a middle to late Viséan age.

St Anthony Basin

In St Anthony Basin, Haworth *et al.* (1976a,b) correlated bedrock cores with lithological units from onshore Newfoundland and regionally mapped the units based on their nonmagnetic and seismic character (Bell and Howie 1990). A Lower Mississippian unit was correlated with the Anguille Group based on petrographic analysis (section 10.3.2). A second unit comprising red and grey conglomerate, sandstone, siltstone, shale, limestone and evaporites was assigned to the Windsor/Codroy Group based on palynology and petrography (M.S. Barss and L.F. Jansa personal comments in Haworth *et al.* 1976b). Haworth *et al.* also noted the presence of a Missisippian-Pennsylvanian unit consisting of grey, red and brown sandstones, conglomerates and shales deemed similar to the Barachois Group of western Newfoundland (section 10.3.6).

Drilled into the Belle Isle Sub-basin of St Anthony Basin, Verrazano L-77 penetrated 'alternating beds of light grey, fine to medium grained sandstone with siliceous cement and traces of kaolinite, pyrite, coal, mica and glauconite and brown, red and dark grey indurated silty to sandy shale with minor amounts of hard dolomitic limestone' (Bell and Howie 1990). Based on miospore content, Barss *et al.* (1979) indicate the section was dated as upper Viséan to lower Namurian in age. To the southeast of St Anthony Basin, well Blue H-28 penetrated 822m of Carboniferous strata, comprising shales, sandstones and limestones, with shales and sandstones dominating the lower 598m (Dolby *et al.* 1979). Shales are generally carbonaceous, non-calcareous, grey to black in colour. Sandstones are white to grey and sometimes pink below. Siderite and haematite staining in the sandstone and rootlets are also recorded. Dolby *et al.* (1979) tentatively dated the interval as late Mississippian in age based on miospore content. Based on a personal comment from M.S. Barss, Bell and Howie (1990) indicate that late Viséan palynomorphs were identified in the lower sandstone and shale succession.

Dolby *et al.* (1979) indicate that the lithologies and presence of rare acritarchs suggest a shallow marine to transitional depositional environment.

10.3.8 Mississippian-Pennsylvanian unconformity

A prominent unconformity in the Maritimes Basin caps the Mabou Group and cuts down into older strata at a number of localities (figure 10.10). The unconformity is the combined result of tectonic activity associated with the collision of Laurussia and Gondwana in addition to base level change (Gibling *et al.* 2008). In well sections, from Prince Edward Island, Giles and Utting (1999) recorded the unconformity below the upper Namurian age Port Hood Formation of the Cumberland Group (see section 10.3.9). The unconformity is also recorded in the Cumberland Basin, underlying the Yeadonian to Langsettian age Boss Point Formation of the Cumberland Group (section 10.3.9).

A later episode of thermal subsidence resulted in a more widespread lower Westphalian age unconformity (see section 10.3.10).

10.3.9 Yeadonian to Langsettian

For upper Langsettian age palaeogeographic reconstructions, refer to figures 10.1 and 10.6.

Cumberland Group

Gibling *et al.* (2008) indicate that the basal strata of the Cumberland Group was deposited in fault controlled basins. The authors also note that the Cumberland Group appears to be absent over wide areas, in particular the Central Carboniferous Platform of New Brunswick.

Cumberland Basin; Lower Cumberland Group

In the extensional Cumberland Basin, lower Namurian age deposits of the Mabou Group are unconformably overlain by Lower Cumberland Group strata (Gibling *et al.*

2008). Exposed in coastal exposures near Joggins, Nova Scotia, the Lower Cumberland Group commences with alternating braided-fluvial, lacustrine and floodplain deposits of the Boss Point Formation (figure 10.15). The overlying Little River Formation comprises semi-arid to sub-humid fine-grained red beds (Gibling *et al.* 2008). Utting *et al.* (2010) assigned miospore assemblages from both Boss Point and Little River Formations to the ?Yeadonian to Langsettian age *Raistrickia saetosa* Biozone (figure 10.15).

The overlying Joggins Formation comprises stacked transgressive-regressive cycles (Gibling *et al.* 2008). Cycles commence with a basal transgression and the deposition of organic-rich limestones. The limestones contain an oligohaline fauna, indicating brackish open water conditions (Falcon-Lang 2003). The limestones are succeeded by prograding coastal plain deposits that include both grey and red units. Grey units are dominated by channelised sandstones and subhorizontal hetrolithic beds. They are interpreted as the deposits of a poorly drained coastal plain with large distributary channels and interdistributary wetlands. Red units include channelised sandstones and pedogenic carbonate nodules, interpreted as the deposits of a well drained alluvial plain. Overlying the prograding coastal plain deposits are coal rich units, interpreted as the deposits of a retrograding coastal plain dominated by temporarily persistant mires (Falcon-Lang 2003). The coals are succeeded by brackish, open-water limestones of the next cycle. Falcon-Lang indicates that ‘despite being positioned in an intra-continental setting, minimally hundreds of kilometers from open marine waters, brackish bay facies at Joggins attest to short-lived marine incursions during periods of elevated base level'.

The Joggins Formation is succeeded by alluvial deposits of the Springhill Mines Formation. In the Joggins coastal section, the formation comprises grey sideritic mudrocks with grey, medium-grained sandstones and numerous thick coal seams. Fine-grained red strata are intercalcated throughout (Utting *et al.* 2010). Utting *et al.* assigned miospore assemblages from the Joggins Formation and Springhill Mines Formation to the Langsettian age *Raistrickia fulva* Biozone (figure 10.15).

The succeeding Ragged Reef Formation comprises thick, multi-story channelised sandstone units interbedded with red siltstones. Pebbly lags characterise many of the thick channel units and lensoidal conglomeritic beds more than two metres in thickness typify channel units in the upper part of the section (Utting *et al.* 2010). In the Spicers Cove area of Nova Scotia, conglomerates associated with thin coals and fossil trees are informally named the Spicers Cove Formation. The authors assigned miospore assemblages from the Ragged Reef Formation in the Joggins coastal section to the *Raistrickia fulva* Biozone. Utting *et al.* also assigned miospore assemblages from the Spicers Cove Formation to the Duckmantian age *Vestispora magna* Biozone (figure 10.15).

Antigonish Basin of Nova Scotia and Gulf of St. Lawrence; Lower Cumberland Group

The Lower Cumberland Group Port Hood Formation is recorded in the Antigonish Basin of Nova Scotia. Palynological studies aiming to reinterpret the age of the formation are still in progress (Utting and Giles 2008).

The Port Hood Formation is also recorded in wells Tyrone no.1 East Point E-49, Green Gables no.1 and Hillsborough no.1 in the Gulf of St. Lawrence (Giles and Utting 1999). The intervals are characterised by channelised sandstones, red mudrock and grey mudrock. Minor coals are also recorded in Tyrone no.1 and coaly shales and pedogenic carbonate are present in Hillsborough no 1. Based on a reassessment of palynological data summarised in Barss *et al.* (1979) in addition to unpublished reports prepared for the Geological Survey of Canada, Giles and Utting (1999) indicate that miospores from the formation in Green Gables no.1 suggest a lower Namurian age. Miospore assemblages from the formation in Tyrone no.1 indicate both Namurian and Viséan-Namurian ages and single samples from Hillsborough no.1 and East Point E-49 are dated as Namurian in age.

10.3.10 Upper Duckmantian to Stephanian

For Bolsovian age palaeogeographic reconstructions, refer to figures 10.1, and 10.7. For Asturian to Cantabrian age palaeogeographic reconstructions, refer to figures 10.1 and 10.8.

By the early Westphalian, most parts of the Maritimes Basin were experiencing thermal subsidence. Large areas of the Maritimes Basin had coalesced into a single basin, partially or completely covering former uplands. The area was traversed by a large river system, draining eastwards from the Appalacian mountain chain to the southwest into a mid-Euramerican Sea. As a result, the widespread deposits of the Upper Cumberland, Morien and Pictou Groups are predominantly alluvial and in many places unconformably overlie older deposits (Gibling *et al*. 2008). Gibling *et al.* suggest that deposits may have covered most bedrock in Atlantic Canada, prior to a major period of exhumation and erosional stripping around 280 Ma.

Sydney Basin; Morien Group

Sedimentation recommenced in the Sydney Basin with deposition of Duckmantian age coal measures of the Morien Group (Gibling *et al.* 2008) (figure 10.17). The basin fill outcrops on Cape Breton Island, Nova Scotia and is recorded in offshore wells North Sydney P-05 and F-24 (see below) (Pasucci *et al.* 2000). The oldest formation is the upper Duckmantian to lower Asturian age South Bar Formation (Gibling *et al.* 2008). In outcrops on Cape Breton Island, the formation comprises an abundance of stacked, trough cross-bedded sandstones in addition to coarsening upwards siltstone-sandstone units, mudstones and sulphur-rich coals. Tibert and Gibling (1999) interpreted the cross-bedded sandstones as braided-fluvial deposits. The authors also recorded agglutinated foraminifera indicative of brackish water environments in coarsening upwards siltstone-sandstone units. The authors suggest that marine inundation of the alluvial braidplain resulted in the development of brackish bays (possibly lagoonal or estuarine) in topographic lows. The coarsening upward sequences are interpreted as the deposits of small deltas and crevasse splays that filled the bays. A rising water table associated with sea-level rise resulted in the ponding of freshwater on higher ground and the development of peat mires overlying the braided river sands. The peats are the precursor of sulphur-rich coals. Red and grey mudstones that show mottling and carbonaceous root traces are interpreted as palaeosols that formed in well-drained areas with low groundwater levels. In North Sydney P-05 and F-24, the South Bar Formation is dominated by sandstones with subordinate shales (Pasucci *et al.* 2000). A similar depositonal environment to that proposed by Tibert and Gibling (1999) is assumed.

The overlying Sydney Mines Formation extends from the lower Asturian into the Cantabrian (Gibling *et al.* 2008) (figure 10.17). The formation comprises stacked sequences of sandstones, grey and red mudstones, coal, dark limestone and calcretes. Coals and bivalve-ostracod limestones mark maximum flooding surfaces, while calcretes and palaeosols mark lowstands (Gibling *et al.* 2008). The formation was deposited in alluvial plain, coastal plain and restricted marine environments (Batson and Gibling 2002). Although freshwater ostracods and bivalves are commonly recorded and marine macrofauna such as conodonts, goinitites and ammoinods are absent, a number of lines of evidence suggest marine influence (Wightman *et al.* 1994). Wightman *et al.* proposed that the thin extensive nature of the coal seams on Cape Breton Island, Nova Scotia indicate a paralic depositional setting rather than freshwater. Gibling *et al.* (2008) suggest the high sulphur content of the coals reflects marine influence. Acritarchs have also been recorded in the formation (T.K. Dimitrova personnal communication in McIlroy and Falcon-Lang 2006) and the presence of glauconite also suggests marine influence (McIlroy and Falcon-Lang 2006). In samples from the Glace Bay area and Boularderie Island area of Cape Breton Island, Wightman *et al.* (1994) recorded assemblages of agglutinated foraminifera and thecamoebians, indicating that depositional environments ranged from estuarine to marsh to freshwater. On Boularderie Island, McIlroy and Falcon-Lang (2006) recorded an example of the exclusively marine *Zoophycos* group trace fossil in association with brackish water agglutinated foraminifera in lower Cantabrian age strata of possible estuarine origin.

The overlying Sydney Mines Formation is succeeded by unnamed Stephanian age red beds of the Pictou Group. The Stephanian age red-beds reflect the progression to a more arid climate (Gibling *et al.* 2008).

Offshore Sydney Basin

Drilled into the offshore Sydney Basin, wells North Sydney P-05 and F-24 encountered strata assigned to the Windsor/Horton and Mabou Group, unconformably overlain by a Morien Group succession assigned to the South Bar and Sydney Mines

Formations. The Morien Group deposits are succeeded by Pictou Group sediments (Giles 2009).

Pasucci (1999) indicates that Pictou Group deposits are characterised by red shales/siltstones with thin sandstones. The strata assigned to the Sydney Mines Formation comprise interbedded coals, limestones and thin sandstones and the South Bar Formation is dominated by thick, stacked sandstones. Barss *et al.* (1979) indicated that miospore assemblages from the Pictou Group in North Sydney P-05 were assigned to the Stephanian age *Potonieisporites* Zone of Barss and Hacquebard (1967). Assemblages from the Sydney Mines Formation were assigned to the Asturian age *Thymospora* Zone and assemblages from the South Bar Formation were assigned to the late Bolsovian age *Torispora* Zone (figure 2.9). Late Duckmantian to early Bolsovian age assemblages were assigned to a *Vestispora* Zone. Assemblages from the Mabou Group and uppermost Windsor/Horton Group were dated as late Viséan to early Namurian in age.

Gulf of St Lawrence and Prince Edward Island

In a lithological and palynological study of well sections from Prince Edward Island and the adjacent Gulf of St Lawrence, Giles and Utting (1999) identified Pennsylvanian age strata unconformably overlying the Lower Cumberland Group Port Hood Formation in the east and extending across Windsor Group strata to the west (see sections 10.3.3, 10.3.4, 10.3.9). Giles and Utting identified four formations of Westphalian to Stephanian age. Biostratigraphic ages were derived from a reassessment of palynological data summarised in Barss *et al.* (1979) in addition to Geological Survey of Canada unpublished reports (Giles and Utting 1999). However, Giles and Utting do not provide details of the revised palynostratigraphic framework. The authors indicate that the oldest strata above the unconformity are Duckmantian in age and assigned to the Bradelle Formation (figure 10.17). The top of the Bradelle Formation varies in age from Bolsovian to Asturian. The formation comprises thick multistoried sandstone bodies, grey and red mudrocks and coals. The overlying Bolsovian/Asturian to Stephanian age Green Gables Formation is typically dominated by red fine-grained rocks interbedded with sandstones, coals and minor grey mudrocks. The Stephanian age Cable Head Formation is typically dominated by thick multistoried sandstones interbedded with red-fine grained mudrocks with localised pedogenic carbonates. The Stephanian to Lower Permian age Naufrage Formation comprises red siltstones and mudstones with pedogenic carbonates and sandstones (Giles and Utting 1999). Gibling *et al.* (2008) indicate that agglutinated foraminifera recorded in the Bradelle, Green Gables and Cable Head Formations suggest a depositional environment with restricted marine influence.

Drilled into the north-central region of the Gulf of St. Lawrence Basin, wells Bradelle L-49 and Brion Island no. 1 encountered a succession of Westphalian to Stephanian age strata unconformably overlying strata assigned to the Mabou Group (Giles and Utting 2003). Giles and Utting dated the Westphalian to Stephanian age strata using an informal palynostratigraphic framework; the details of which are not provided. Duckmantian to Asturian age strata assigned to the Bradelle Formation unconformably overlie the Mabou Group in both wells (figure 10.17). The Bradelle Formation comprises grey mudrocks, coals, thick multistoried sandstone bodies and minor occurrences of red mudrocks. The overlying Asturian to Stephanian age Green Gables Formation is characterised by red, fine-grained rocks with interbedded sandstones, minor grey mudrocks and fewer coals than the underlying Bradelle Formation. The Stephanian age Cable Head Formation is dominated by thick multistoried sandstones with interbedded red siltstones and shales. The overlying Naufrage Fomation comprises red siltstones and mudstones with pedogenic carbonates and channelised sandstones (Giles and Utting 2003).

Cumberland Basin; Upper Cumberland and Pictou Groups

In the Cumberland Basin, the Malagash, Balfon, and Tatmagouche Formations span the Bolsovian to Stephanian (figure 10.18). Agglutinated foraminifera in the largely non-coal bearing Bolsovian to Asturian age Malagash Formation indicate a depositional environment with periods of restricted marine influence (Gibling *et al.* 2008). In outcrops located in Pictou County, Nova Scotia, Naylor *et al.* (1998) suggest that approximately 85% of the Malagash Formation comprises fluvial and floodplain deposits. Lithologies include thick fluvial sandstones, conglomerates, red mudrocks, rootlets and calcrete-bearing vertisols. Coals are rare, thin and impure. Approximately 12% of the formation comprises heterolithic facies characterised by grey siltstones with sandstone laminae interbedded with 5-30cm thick grey ripple bedded or massive sandstones. Agglutinated foraminifera are also recorded. Naylor *et al.* suggest the hetrolithic facies and brackish water foraminifera reflect estuarine and tidal influences during sedimentation.

Central Basin, New Brunswick and Ristigouche Basin, New Brunswick and Quebec; Cumberland and Pictou Groups, Clifton Formation, Members A-C

The Clifton Formation of the Central Basin of New Brunswick and the Ristigouche Basin of New Brunswick and Quebec can be divided into three members; A, B and C (Jutras *et al.* 2007) (figure 10.14). The formation was deposited in an alluvial depositional environment (Jutras and Prichonnet 2005). In the Central Basin, Member A comprises a basal quartzose conglomerate overlain by a quartz arenite. The member disconformably overlies the Yeadonian to Duckmantian age Red Pine Brook Formation. Member B comprises a thick succession of grey sandstone, minor red sandstone, grey mudrock, red mudrock and coal. The formation is dated as Duckmantian at its base and extends into the Bolsovian and possibly lower Asturian. Clifton Formation Member C is an incompletely exposed and undated succession, predominantly comprising red beds (Jutras and Prichonnet 2005). Jutras *et al.* (2007) correlated Members A and B with the Cumberland Group and Member C with the Pictou Group of the Maritimes Basin.

Grand Banks

In the Grand Banks, well Hermine E-94 encountered strata assigned to the Windsor Group, Canso (Mabou) Group and Riversdale (Cumberland) Group unconformably overlain by 69m of Pictou Group strata (Bell and Howie 1990). Bell and Howie (1990) indicate the Riversdale (Cumberland) Group comprises red sandstones, conglomerates, shales and dolomite, and the Pictou Group comprises red sandstones and shales. Barss *et al.* (1979) indicate that miospore assemblages from the uppermost part of the Riversdale (Cumberland) Group are assigned to a late Duckmantian to early Bolsovian age *Vestispora* Zone. Barss *et al.* also indicate that a sparse miospore assemblage from the Pictou Group could only be dated as ‘Westphalian’ in age.

10.4 SPAIN

The majority of Carboniferous outcrops in Spain are located in the Iberian Massif (Colmenero *et al.* 2002) (figure 10.19). For palaeogeographic reconstructions of the Spanish region, see figures 10.2 to 10.8.

10.4.1 Cantabrian Zone (Northern Iberian Massif)

Located in the north of the Iberian Massif, the Cantabrian Zone is subdivided into five tectonostratigraphic provinces (figure 10.19). Carboniferous strata of the Cantabrian Zone can be subdivided into six major stratigraphic sequences, outlined below (Colmenero *et al.* 2002).

Upper Fammennian/lower Tournaisian – Lowest Arnsbergian (Sequence 1)

Colmenero *et al.* (2002) indicate the formations of Sequence 1 were deposited in a marine setting following a Late Devonian - Early Carboniferous transgression. Outcropping in the western part of the Cantabrian Zone, the Baleas Formation (upper Famennian - lower Tournaisian) comprises skeletal grainstones and wackstones deposited in a shallow water, shelf sea. In the eastern part of the Cantabrian Zone, the Vegamián Formation (middle Tournaisian to lower Viséan) comprises shelf edge black shales and mudstones with chert lenses and phosphate nodules. Overlying both formations is the upper Tournaisian to lower Arnsbergian age Alba Formation. It comprises red nodular limestones with red shales and a radiolarite horizon. Pelagic fauna including cephalopods are common. The formation is interpreted as a marine condensed unit deposited on a pelagic platform in several hundred metres of water (Colmenero *et al.* 2002) (figure 10.2, 10.3 and 10.4).

Arnsbergian to Chokerian/Alportian (Sequence 2)

Sequence 2 records the onset of terrigenous supply from an orogen in the west of the Cantabrian Zone. In the west and south of the Cantabrian Zone, the Olleros Formation comprises stacked sequences of sand and shales interpreted as turbidites deposited in a foredeep basin. In the east and north, laminated dark grey limestones and mudstones of the Barcaliente Formation were deposited in a restricted shallow marine platform environment. Pseudomorphs of anhydrite and gypsum in the upper part of the formation suggest periods of evaporation (Colmenero *et al.* 2002) (figure 10.5)

Upper Namurian to Langsettian (Bashkirian) (Sequence 3)

Sequence 3 comprises both siliciclastic and carbonate lithologies. Limestones of the Valdeteja Formation were deposited on a carbonate platform, in the north-eastern part of the Ponga nappe province and on a carbonate ramp in the Picos de Europa province to the southeast. Carbonate platforms also developed on submarine highs in the Fold and Nappe province to the west. On the western and southern flanks of the carbonate platforms in the Fold and Nappe province, a shallowing upwards foredeep basin fill succession is recorded; the sediments derived from the orogen to the west. Basin and slope turbidites and breccias are overlain by shales, sandstones, coal and limestones deposited in a shallow water shelf and deltaic environments. The carbonate platforms acted as a barrier to sediment transport from the orogenic belt reaching areas of the Central Asturian coalfield province and Ponga nappe province, resulting in the deposition of red shales with chert and manganese nodules (Colmenero *et al.* 2002).

Late Langsettian to mid-late Asturian (Sequence 4)

Sequence 4 represents the spread of siliciclastic sedimentation across the Cantabrian Zone. Carbonate platforms only persisted in the Picos de Europa province and the north-eastern part of the Ponga nappe province. Terrigeneous deposits are dominant and frequently coal bearing. In the Fold and Nappe province, coal-bearing sandstone-mudstone alternations were deposited in a coastal deltaic environment with episodes of shallow marine and alluvial deposition. In the Central Asturian coalfield, sandstones, shales, limestones and rare coals deposited in a shallow marine and deltaic environment are succeeded by coal bearing sediments deposited in a deltaic environment with marine and alluvial episodes. To the east in the Picos de Europa province, the Picos de Europa Formation comprises carbonate shelf deposits. Southwards, in the Pisuerga-Carrión province, alluvial to deep water fan-deltaic sediments are suceeded by deep water shales, turbidites and conglomerates (Colmenero *et al.* 2002) (figures 10.6 and 10.7).

Upper Asturian to Stephanian B (Sequence 5)

Sequence 5 is bound by the Leonin and Asturian unconformities and is only recorded in the Pisuerga-Carrión, Picos de Europa and Ponga nappe provinces due to the advancement of the orogenic front. Sediments were either deposited in the foreland basin ahead of the advancing orogenic front or in intermontane basins. Foreland basin deposits are recorded in the Pisuerga-Carrión province and often show shallowing upwards successions. Deposits include deep water turbidites and olistoliths, shallow water sandstones and shales, lacustrine shales, rooted shales, channelised sandstones and coal seams. In the Ponga nappe province, coarse-grained clastic deposits and fossiliferous marine shales record the progradation of fan-delta systems into a semi-closed marine basin. Towards the southern part of the Picos de Europa province, the Picos de Europa Formation is conformably overlain by dark marls and marly limestones with rudstone and sandy grainstone tempestites (Colmenero *et al.* 2002) (figure 10.8).

Stephanian B to C (Sequence 6)

Foreland basin fill successions of Sequence 6 are recorded in the Pisuerga-Carrión and Picos de Europa provinces. In the Picos de Europa province, fluviatile sandstones, shales, marls, calcareous mudstones and rudstones are recorded. In the Gamonedo-Cabrales-Panes area, the terrigeneous deposits are succeeded by the Puentellés Formation. The formation comprises cyclical alternations of calcareous breccias and conglomerate, pebbly sandstones, graded and laminated sandy grainstones and bioturbated marls. The deposits are interpreted as flood-dominated alluvial to shelfal lobes entering a restricted marine carbonate ramp. Backstepping of the shelfal lobes enabled carbonate sedimentation to recommence, with the deposition of dark mudstones and boundstones. The Puentellés Formation is overlain by the Gzelian age Cavandi Formation, which comprises sandstone-mudstone turbidites. Successions in intermontane basins comprise alluvial fan-lake deposits with occasional marine influences. Strata assigned to Sequence 6 are overlain by a pre-Permian unconformity, representing the onset of the Alpine cycle (Colmenero *et al.* 2002).

10.4.2 Southern Iberian Massif

During the Early Carboniferous, two large marine basins were located in the southern part of the Iberian Massif. The Pedroches Basin of the Central-Iberian Zone and the Iberian Pyrite Belt Basin of the South Portuguese Zone were located either side of an emergent landmass; the Ossa Morena Zone (figure 10.2) (Colmenero *et al.* 2002).

Iberian Pyrite Belt Basin

The Iberian Pyrite Belt Basin comprises a lower unit; a Tournaisian to middle Viséan age volcano-sedimentary complex, characterised by felsic and mafic igneous rocks that interfinger with marine shales (figure 10.2). An upper unit, the upper Viséan to possibly lower Namurian age Culm Group comprises a Basal Shaly Unit of volcaniclastic sediments, limestones and calcareous sandstones interpreted as the product of reworked volcanic rocks in a shallow marine environment. The overlying Turbidite Formation comprises a turbiditic succession of shales, lithic sandstones and conglomerate intervals. The succeeding Shallow-Shelf Sandy Formation comprises a coarsening upward sequence of alternating shales and quartzose sandstones deposited in a coastal to shelf setting (Colmenero *et al.* 2002) (figures 10.3, 10.4 and 10.5).

Pedroches Basin

In the Guadiato area, a Tournaisian to middle Viséan age succession of mudrocks, sandstone, calcareous sandstones, minor limestones and volcanic rocks are interpreted as shallow marine shelf deposits (figure 10.2). The deposits are overlain by upper Viséan to possibly lower Namurian shallow water turbidites with hummocky cross stratification. Northwards in the Pedroches area, deeper water turbidites are recorded (figures 10.3, 10.4 and 10.5). Tournaisian to middle Viséan age lagoonal sediments are recorded in the Benajarafe area, located in close proximity to the Ossa Morena Zone landmass (Colmenero *et al.* 2002) (figure 10.2).

10.5 PORTUGAL

The South Portuguese Zone of Portugal almost entirely comprises Late Devonian to Moscovian age sedimentary rocks. Four geological domains are recognised in the SPZ. The Iberian Pyrite Belt was part of a Late Devonian shallow siliciclastic sea that underwent crustal extension during the Late Devonian, resulting in bimodal volcanism. The Pulo do Lobo Antiform is interpreted as a Variscan palaeo-accretionary prism. The Baixo Alentejo Flysch Group (BAFG) comprises south-westward prograding turbidites of late Viséan to Moscovian age deposited in a foreland basin. The Southwest Portugal Sector (SPS) comprises distal carbonate/shale platform deposits (Pereira *et al.* 2007).

10.5.1 Iberian Pyrite Belt

The stratigraphy of the Iberian Pyrite Belt comprises two units; a Late Devonian age Phyllite Quartzite Group (PQG) and a Late Devonian to mid/late Viséan age volcanic-sedimentary complex (VSC). The PQG comprises phyllites, quartzites, quartzwackes and shales with limestone lenses and nodules, interpreted as the deposits of a marine siliciclastic platform. The VSC comprises both intrusive and extrusive volcanic rocks with intercalations of black shales, siltstones, minor quartzwackes, siliceous shales, jaspers, cherts and a purple shale member. A deep submarine depositional environment is inferred (figure 10.2). The top of the VSC is tentatively positioned at the base of the NL Biozone of Portugal (Pereira *et al.* 2007), corresponding to the base of the Asbian age Western European *Triquitrites marginatus* Biozone of Clayton *et al.* (2003) (figure 10.20).

Conformably overlying the VSC are turbiditic successions of the Mértola Formation (figures 10.3 and 10.4). The top of the Mértola Formation is positioned at the top of the Portuguese NC Biozone (Pereira *et al.* 2007), corresponding to the top of the Western European *Cingulizonates* cf. *capistratus* Biozone of Clayton *et al.* (2003) (figure 10.20).

10.5.2 Baixo Alentejo Flysch Group

The Baixo Alentejo Flysch Group (BAFG) predominantly comprises gravity flow sediments and is subdivided into the Mértola, Mira and Brejeira Formations (Pereira *et al.* 2007). Miospore assemblages from the Mértola Formation are assigned to the NL, SN and NC Biozones of Portugal (figures 10.3, 10.4 and 10.20). The top of the overlying Mira Formation (figure 10.5) is tentatively positioned at the top of the upper Namurian age KV Biozone of Portugal. Succeeding the Mira Formation, the Brejeira Formation extends to the top of the OT Biozone of Portugal (Pereira *et al.* 2007) (figures 10.6, 10.7, 10.8 and 10.20).

10.5.3 Southwest Portugal Sector (SPS)

The Tercenas Formation is the oldest formation of the SPS. It comprises dark marine shales interbedded with thin sandy tempestites that grade upwards to tidal sandstones. The top of the formation corresponds to the VI Biozone of Portugal. The overlying Bordalete Formation comprises dark grey to black shales and siltstones that contain phosphatic nodules and goniatites. Tournaisian age Portuguese miospore biozones ranging from VI to PC are identified in the formation (Pereira *et al.* 2007) (figure 10.20).

A hiatus separates the Bordalete Formation from the succeeding Murração Formations. The Murração Formation comprises a lower member characterised by grey shales with carbonate and dolomitic intercalations, corals and trilobites. An upper member comprises dark grey or black shales and nodular limestones. A benthic marine fauna including goniatites are also recorded. The Murração Formation is interpreted as a deep open-marine pelagic carbonate platform to the south of the flysch basin (figures 10.2, 10.3 and 10.4). Portuguese miospore biozones ranging from Pu to NC are recognised in the formation (Pereira *et al.* 2007) (figure 10.20).

The overlying Quebradas Formation comprises black shales with intercalated carbonate and phosphoritic layers, lenses and nodules (figure 10.5). It is rich in fossils including ammonoids. Gonitites indicate an Arnsbergian to lower Langsettian age. The upper Namurian age KV and FR miospore biozones of Portugal are recognised.

The Quebradas Formation is succeeded by the Brejeira Formation (Pereira *et al.* 2007) (figures 10.6, 10.7, 10.8 and 10.20).

10.6 NORWAY

In the Oslo Graben of Norway, fossils recorded in the Knabberud Limestone Member suggest an episode of marine deposition in late Bashkirian or Moscovian times. The Knabberud Limestone is a member of the Tanum Formation which is otherwise dominated by coastal alluvial plain deposits. The fossil content of the limestone includes fusilinid foraminifera, molluscs, crinoid ossicles and possibly the remnants of brachiopods, tabulate corals, bryozoans, algae and arthropods (Bergstrom *et al.* (1985). The presence of a foraminifera specimen showing similarities to *Novella. evoluta mosquensis* suggests a Bashkirian or Moscovian age (Duckmantian to Asturian) (Olausson 1981) (figures 10.7 and 10.8).

CHAPTER 11
CONCLUSIONS

1. 15 biozones and 10 sub-biozones from the Western European miospore zonal scheme of Clayton *et al.* (2003) can be recognised offshore western Ireland, which is an increase from the 11 biozones recognised using the original zonal scheme of Clayton *et al.* (1977) for the same stratigraphic interval. Biozones from the 2003 zonal scheme are recognised with varying levels of confidence. As the biozones are generally defined based on the first stratigraphic occurrence of the index taxon, the range tops and bases of alternative taxa are required to define biozone limits if occurrences of the index taxa are infrequent, considered caved or absent in a given well section. Range data from the North Sea, onshore Great Britain and continental Western Europe are used.

Using the 2003 zonal scheme of Clayton *et al.*, the *Thymospora pseudothiessenii* Biozone, *Angulisporites splendidus* Sub-biozone, *Westphalensisporites irregularis* Sub-biozone, *Vestispora fenestrata* Biozone, *Torispora securis* Sub-biozone, *Triquitrites sculptilis* Biozone, *Lycospora noctuina noctuina* Sub-biozone, *Radiizonates aligerens* Biozone, *Lycospora subtriquetra* Biozone, *Cingulizonates* cf. *capistratus* Biozone, *Verrucosisporites morulatus* Sub-biozone, *Bellispores nitidus* Sub-biozone, *Tripartites vetustus* Biozone and *Triquitrites marginatus* Biozone are identified in a number of well sections and are characterised by occurrences of the respective index taxa. The *Torispora verrucosa* Sub-biozone, *Raistrickia aculeata* Sub-biozone, *Microreticulatisporites nobilis* Biozone, *Vestispora magna* Sub-biozone, *Schulzospora rara* Biozone, *Apiculatisporis variocorneus* Sub-biozone and *Schopfites claviger* Biozone can also be identified, although occurrences of the index taxa are rare in the intervals assigned to the biozone. Index taxa are absent from the intervals assigned to the *Sinuspores sinuatus*, *Vestispora cancellata*, *Schulzospora campyloptera* and *Knoxisporites stephanephorus* Biozones.

Miospore assemblages considered to be upper Stephanian in age are tentatively assigned to the *Potonieisporites novicus-bharadwajii* – *Cheleidonites major* (NBM) Biozone of Clayton *et al.* (1977). Assemblages considered to be lower Autunian in age are tentatively assigned to the *Vittatina costabilis* (VC) Biozone of Clayton *et al.* (1977).

2. An alternative miospore biozonation for offshore western Ireland is proposed to account for the rarity of occurrence of a number of index taxa used in the Clayton *et al.* (2003) zonal scheme. The 14 biozones and 8 sub-biozones are named after the taxon or taxa that define the zones.

3. The revised offshore western Irish palynostratigraphic framework enables high-resolution interpretations of the depositional environments and accurate correlation with coeval deposits in Eastern Canada and Western Europe. As a result, 7 Carboniferous palaeogeographic timeslices for the North Atlantic region can be created.

4. The Carboniferous palynostratigraphy of offshore western Ireland and Eastern Canada can be correlated based on eight palynological events:

    i. The first stratigraphic occurrence of *Cordaitina* enables correlation of the Autunian Stage lower limit.
    ii. The first stratigraphic occurrence of *Angulisporites splendidus* enables correlation of the Cantabrian Substage lower limit.
    iii. The first stratigraphic occurrence of *Thymospora obscura* enables a tentative correlation of the Asturian Substage lower limit.
    iv. The first stratigraphic occurrence of *Torispora securis* enables an approximate correlation of the mid - lower Bolsovian.
    v. The first stratigraphic occurrence of *Vestispora magna* and *Microreticulatisporites nobilis* enables correlation of the Duckmantian Substage.
    vi. The first stratigraphic occurrence of *Ibrahimispores* spp. enables correlation of the upper part of the Brigantian Substage.
    vii. The first stratigraphic occurrence of *Crassispora maculosa* enables an approximate correlation of Briganitan age strata.
    viii. The first stratigraphic occurrence of *Knoxisporites stephanephorus* enables correlation of the lower Asbian.

5. Palynofacies analysis of upper Bolsovian to Stephanian age strata from the Porcupine and Erris basins identified both marine and non-marine characteristics in a number of cuttings samples. This may reflect the mixing of cuttings from marine and non-marine horizons. Alternatively, the characteristics may reflect a marginal marine lagoonal or brackish bay depositional environment, with the marine palynomorphs being washed in. Such a depositional model would also account for the marine microfauna recorded at this stratigraphic level by previous studies.

$\delta^{13}C$ and $\delta^{18}O$ values for limestone samples from the intervals generally indicate non-marine deposition. The presence of a non-marine limestone and a marine shell fragment in one of the samples may reflect the lagoonal or brackish bay depositional model described above.

The inferred marginal marine lagoonal or brackish bay environments may be similar to coeval brackish bays/restricted marine environments recorded in the Maritimes Basin of Eastern Canada.

REFERENCES

26/26-1 FINAL WELL REPORT. 1981. *Porcupine Area, Final Well Report 26/26-1.* Joint venture Irish Shell Petroleum Development company Teorana and AGIP Ireland Ltd.

26/27-1b FINAL WELL REPORT. 1981. *Final Well Report 26/27-1b. Porcupine Basin, Offshore Ireland.* Chevron Oil Company of Ireland.

26/28-1 COMPLETION REPORT (Volume 1). 1979. BP Petroleum Development Ltd (Irish Branch). Report DUB 271.

26/30-1 FINAL WELL REPORT. 1982. *Ireland 26/30-1. Final Well Report.* Phillips Petroleum Company Ireland.

34/15-1 COMPLETION REPORT (Volume 1). 1977. *34/15-1 Porcupine Basin Offshore Ireland Completion Report Volume 1.* Deminex.

34/19-1 FINAL WELL REPORT. 1978. *Ireland Offshore: Porcupine Area, Final Well Report 34/19-1.* Joint venture Irish Shell Petroleum Development company Teorana and AGIP Ireland Ltd.

35/15-1 FINAL WELL REPORT. 1980. Phillips Petroleum Exploration U.K Ltd.

36/16-1 FINAL WELL REPORT. 1979. *36/16-1 Porcupine Basin, Ireland.* Chevron Oil Company of Ireland.

ALPERN, B. 1958. Description de quelque miospores du Permo-Carbonifère française. *Revue de Micropaléontologie*, **1**, 75-86.

ALPERN, B., LACHKAR, G. and LIABEUF, J. J. 1967. Le bassin houiller Lorrain peut-il fournir un stratotype pour le Wesphalien supérieur? *Review of Palaeobotany and Palynology,* **5**, 75-91.

ALPERN, B., CHOFFÉ, M., LACHKAR, G and LIABEUF, J. J. 1969. Synthèse des zonations palynologiques des Bassins houillers de Lorraine et de Saare. *Revue de Micropaléontologie,* **11**, 217-221.

ATHERSUCH, J., PALEY, W. J. and WONDERS, A. A. H. 1981. *The Biostratigraphy of the well 26/28-3, Porcupine Basin, Offshore Ireland.* BP Research Centre, Exploration and Production Division.

ATHERSUCH, J., PALEY, W. J. and WONDERS, A. A. H. 1982. *Biostratigraphy of the BP/Aran Wells 26/28-4 and 26/28-4a (Sidetrack), Porcupine Basin, Offshore Ireland.* BP Research Centre, Exploration and Production Division, Palaeontology Branch.

ATHERSUCH, J., BOOTH, G. A., POWELL, A. J., STRANK, A. R. E. and WELSH, A. 1983. *Biostratigraphy of the Well 26/29-1, Porcupine Basin, Offshore Western Ireland.* BP Research Centre, Exploration and Production Division, Stratigraphy Branch.

ATLANTIC GEOSCIENCE SOCIETY. 2001. *The last billion years.* Nimbus Publishing, Halifax, Canada, 212p.

BARSS, M. S. and HACQUEBARD, P. A. 1967. Age and the stratigraphy of the Pictou Group in the Maritime Provinces as revealed by fossil spores. *Geological Association of Canada, Special Paper* **4**, 267-282.

BARSS, M. S., BUJAK, J. P. and WILLAMS, G. L. 1979. Palynological zonation and correlation of sixty-seven wells, eastern Canada. *Geological Survey of Canada, Paper* **78-24**, 118p.

BATSON, P. A. and GIBLING, M. R. 2002. Architecture of channel bodies and paleovalley fills in high-frequency Carboniferous sequences, Sydney Basin, Atlantic Canada. *Bulletin of Canadian Petroleum Geology*, **50**, 38-157.

BATTEN, D. J. 1982. Palynofacies, palaeoenvironments and petroleum. *Journal of Micropalaeontology,* **1**, 107-114.

BATTEN, D. J. 1983. Identification of Amorphous Sedimentary Organic Matter by Transmitted Light Microscopy. *In* Brooks, J. *Petroleum Geochemistry and Exploration of Europe*. Geological Society of London, Special Publication, Blackwell Scientific Publications, Oxford, **12**, 275-287.

BATTEN, D. J. 1996. Chapter 26A. Palynofacies and palaeoenvironmental interpretation. *In* Jansonius, J. and McGregor, D. C. *Palynology - Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, **3**, 1011-1064.

BATTEN, D. J. and GRENFELL, H. R. 1996. Chapter 7D. *Botryococcus. In* Jansonius, J. and McGregor, D. C. *Palynology - Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, **1**, 205-214.

BELL, W. A. 1929. Horton-Windsor district, Nova Scotia. *Geological Survey of Canada, Memoir,* **155**, 1-268.

BELL, J. S. and HOWIE, R. D. 1990. Chapter 4. Paleozoic geology. *In* Keen, M.J. and Williams, G.L. *Geology of the Continental Margin of Eastern Canada*, Geological Survey of Canada, Geology of Canada, **2**, 141–165

BENNETT, C. E. 2008. A review of the Lower Carboniferous colonisation of non-marine environments by ostracods. *Senckenbergiana lethaea*, **88**(1), 1-14.

BELT, E. S. 1965. Stratigraphy and sedimentology of the Mabou Group and related Middle Carboniferous facies. *Geological Society of America Bulletin*, **76**(7), 777-802.

BERGSTRÖM, J., BLESS, M. J. M. and PAPROTH, E. 1985. The marine Knabberud Limestone in the Oslo Graben. Possible implications for the model of Silesian palaeogeography. *Zeitschrift der Deutschen Geologischen Gesellschaft,* **136**, 181-194.

BIGNELL, R. D. and BLACK, J. A. 1980. *Offshore Ireland: Porcupine Basin. Licence 11/76. Completion Report, Well 26/21-1.* Gulf Oil (Ireland) Ltd.

BOSTICK, N. H. 1971. Thermal alteration of clastic organic particles as an indicator of contact and burial metamorphism in sedimentary rocks. *Geoscience and Man*, **3**, 83-92.

BOSTICK, N. H. 1974. Phytoclasts as indicators of thermal metamorphism, Franciscan assemblage and Great Valley Sequence (Upper Mesozoic), California. *Geological Society of America Special Paper*, **153**, 1-17.

BOUROZ, A. and DOUBINGER, J. 1977. Report on the Stephanian-Autunian boundary and on the contents of the Upper Stephanian and Autunian in their stratotypes. *In* Holub, V. M and Wagner, R. H. *Symposium on Carboniferous stratigraphy, IUGS Subcommission on Carboniferous Stratigraphy (SCCS) field and general meeting, Czechoslovakia, 1973*, Geological Survey, Prague, 147-169.

BRUCKSCHEN, P., OESMANN, S., and VEIZER, J. 1999. Isotope stratigraphy of the European Carboniferous: proxy signals for ocean chemistry, climate, and tectonics. *Chemical Geology,* **161**, 127-163.

BUJAK, J. P., BARSS, M. S. and WILLIAMS, G. L. 1977. Offshore eastern Canada – Part I and II: Organic type, color and hydrocarbon potential. *Oil and Gas Journal*, **75**(15), 96-100 and 198-2002.

BURGESS, J. D. 1974. Microscopic examination of kerogen (dispersed organic matter) in petroleum exploration. *Special Papers of the Geological Society of America*, **153**, 19-30.

BUTTERWORTH, M. 1984. *Pollen and spore biostratigraphy of the Phanerozoic in north-west Europe*. Unpublished report, British Micropalaeontological Society, Palynological Group, Cambridge, 2-9.

CALDER, J. H. 1998. The Carboniferous evolution of Nova Scotia. *In* Blundell, D. and Scott, A. C. *Lyell: the past is the key to the present.* Geological Society of London, Special Publication, **143**, 296-331.

CEPEK, P., GRAMANN, F., KEMPER, E., KOCH, W., MADLER, K. and MULLER, H. 1977. *Final Micropalaeontological Report of 34/15-1.* Federal Institute for Geosciences and Natural Resources, Hannover.

CHALONER, W. G. 1989. Fossil charcoal as an indicator of palaeoatmospheric oxygen level. *Journal of the Geological Society*, **146**(1), 171-174.

CHATEAUNEUF, J. J. 1973. Palynologie des faisceaux productifs du basin central des Asturias (Espagne). *Septième Congrès Internationale de Stratigraphie et de Géologie du Carbonifère, Krefeld, 1971, compte rendu*, **2**, 297-321, 5 pl.

CHURCH, J. W., FENTON, J. P. G., FOOTITT, R., HARRISON, D. J., HASKINS, C. W and NEVILLE, R. S. W. 1979. *Amoco 12/13-1a offshore Ireland Well: Biostratigraphy of* *the Interval 2830'-9414'.* Robertson Research International Limited. Report No. 2471.

CHURCH, J. W., FOOTITT, R. and NEVILLE, R. S. W. 1980. *The biostratigraphy of the interval 740m to 1400.78m of the 34/5-1 well situated West of Ireland, submitted by Elf-Aquataine.* Robertson Research International Limited. Report No. 2562P/A.

CHURCH, J. W., DENISON, C. N., FOOTITT, R., HARRISON, D. J., HASKINS, C. W and NEVILLE, R. S. W. 1981. *Phillips 35/15-1 offshore Ireland well: biostratigraphy of the interval 2050' – 12096' T.D.* Robertson Research International Limited. Report No. 2578P/A.

CLARKE, R. F. A. 1965. British Permian saccate and monosulcate miospores. *Palaeontology*, **8**, 322-354, pl.40-44.

CLAYTON, G. 1985. Dinantian miospores and intercontinental correlation. *Dixième Congrès Interational de Stratigraphie et de Géologie du Carbonifère, Madrid, 1983, compte rendu*, **4**, 9-23

CLAYTON, G., COQUEL, R., DOUBINGER, J., GUEINN, K. J., LOBOZIAK, S., OWENS, B. and STREEL, M. 1977. Carboniferous miospores of Western Europe: illustration and zonation. *Mededelingen Rijks Geologische Dienst,* **29**, 1-71.

CLAYTON, G., HIGGS, K., KEEGAN, J. B and SEVASTOPULO, G. D. 1978. Correlation of the palynological zonation of the Dinantian of the British Isles. *Palinologia,* **1**, 137-47.

CLAYTON, G., SEVASTOPULO, G. D and SLEEMAN, A. G. 1986. Carboniferous (Dinantian and Silesian) and Permo-Triassic rocks in south County Wexford, Ireland. *Geological Journal,* **21**, 355-374.

CLAYTON, G., LOBOZIAK, S., STREEL, M., TURNAU, E. and UTTING, J. 1990. Palynological events in the Mississippian (Carboniferous) of Europe, North Africa and North America. *Courier Forschungsinstitut Senckenberg,* **130**, 79-84.

CLAYTON, G., OWENS, B. and McLEAN, D. 2003. *Carboniferous palynostratigraphy: recent developments in Europe.* Proceedings of the XVth International Congress on Carboniferous and Permian Stratigraphy. Abstracts Netherlands, Utrecht University.

CLEAL, C. J. 1984. The recognition of the base of the Westphalian D Stage in Britain. *Geological Magazine,* **121**, 125-129.

CLEAL, C. J., DIMITROVA, T. K. H. and ZODROW, E. L. 2003. Macrofloral and palynological criteria for recognising the Westphalian – Stephanian boundary. *Newsletters on Stratigraphy*, **39**, 181-208.

COMBAZ, A. 1964. Les palynofaciès. *Revue de Micropaléontologie*, **7**, 205-18.

COLEMAN, U. 1991. *Palynology and intercontinental correlation of Upper Devonian and Lower Mississippian Rocks from Kentucky and Indiana U.S.A.* Unpublished PhD Thesis, Department of Geology, Trinity College Dublin, 209p.

COLMENERO, J. R., FERNANDEZ, L. P., MORENO, C., BAHAMONDE, J. R. BARBA, P., HEREDIA, N. and GONZALEZ, F. 2002. Carboniferous. *In* Gibbons,W., Moreno, M. T. *The Geology of Spain*. Geological Society of London, 93–116.

COMPTON, P. M. 1983. *Ireland, Porcupine Basin Well 26/29-1. Evaluation Report.* BP Petroleum Development Limited (Irish Branch).

CONNELLY, J. 2002. *A study of the effects of thin dyke intrusions on mudrock.* Unpublished PhD Thesis, Department of Geology, Trinity College Dublin, 249p + appendices.

COOK, L. and GILES, P. S. 2003. Stratigraphy and structure of the Orangedale Salt Deposit, Windsor Group, central Cape Breton Island, Nova Scotia. Geological Survey of Canada, Open File 1529

COOPER, B. S. and COLLINS, A. G. 1981. *Report on the Maturity Evaluation of the Phillips 35/15-1 Well, Porcupine Basin, Offshore Ireland.* Robertson Research International Limited.

COPE, M. J. 1981. Products of natural burning as a component of the dispersed organic matter of sedimentary rocks. *In* Brooks, J. *Organic maturation studies and fossil fuel exploration*. Academic Press, London, 89-109.

COPE, J. C. W., GUION, P. D., SEVASTOPULO, G. D. and SWAN, A. R. H. 1992. Carboniferous. *In* Cope, J. C. W., Ingham, J. K. & Rawson, P. F. *Atlas of Palaeogeography and Lithofacies.* Geological Society, London, Memoir, **13**, 153p.

COQUEL, R. 1976. Etude palynologique de la Série houillère dans l'unité de production de Valenciennes du Basin Houiller du Nord de la France. *Palaeontographica*, *Abt. B,* **156**, 12-64.

COQUEL, R., DOUBINGER, J., and LOBOZIAK, S. 1976. Les microspores guides du Westphalian à l'Autunian d' Europe occidentale. *Revue du Micropaleontologie,* **18**(4), 200-212.

CORNET, W. B., BURGESS, J., LOCKWOOD, R., NATIONS, M. P., SCOTT, K. E., SEIGLIE, G., and SHAFFER, B. 1980. *The Lithostratigraphic and Biostratigraphic analysis of the Gulf Ireland 26/21-1 Well, Porcupine Basin, Offshore Ireland.* Gulf Research and Development Company.

COTTLE, J and EVANS, T. G. 1982. *Ireland, Porcupine Basin Licence 4/76, Well 26/28-4a, ST, Evaluation Report.* BP Petroleum Development Ltd (Irish Branch).

CRAWLEY, J., COTTLE, J. and FISHER, W. C. 1981. *Ireland, Porcupine Basin. Well 26/28-4 and 4a. Geological Completion Report.* BP Petroleum Development Ltd. (Irish Branch).

CROISILE, M. 1981. *Offshore Ireland Porcupine Basin Licence 1/76. Geological Report, Well 34/5-1*. Elf Aquataine (Ireland) Ltd.

DAVIES, J. R., McNESTRY, A and WATERS, R. A. 1991. Palaeoenvironments and palynofacies of a pulsed transgression; the Late Devonian and early Dinantian (Lower Carboniferous) rocks of Southeast Wales. *Geological Magazine*, **128**(4), 355-380.

DETTMANN, M. E. 1963. Upper Mesozoic microfloras from south-eastern Australia. *Proceedings of the Royal Society of Victoria*, **77**, 1-148.

DIMITROVA, T. K. H., CLEAL, C. J., and THOMAS B. A. 2005. Palynology of late Westphalian-early Stephanian coal-bearing deposits in the eastern South Wales Coalfield. *Geological Magazine*; **142**(6), 809–821.

DIMITROVA, T. K. H and CLEAL, C. J. 2008. The late Westphalian D – Early Cantabrian palynology of Europe and the Canadian Maritimes. Geosciences 2008 Abstract.

DOLBY, G., OLIVER, E. M. and THORNE, B. V. A. 1979. *The micropalaeontology, palynology and stratigraphy of the Texaco et al. Blue H-28 Well.* Robertson Research Canada Limited. Exploration Report No. 205.

DUCAZEAUX, J., JARDINE, S., DURIF, P. and GROSDIDIER, E. 1981. *Porcupine 34/5-1 Well (Ireland) Biostratigraphical Report*. SNEA (P) Direction Exploration Laboratoire de Geologie de Boussens.

DUXBURY, S., ROSE, J. F. and WILLIAMS, J. E. 1979. *Biostratigraphy of the BP/Aran 26/28-1 Well Porcupine Basin, Offshore Ireland.* BP Research Centre, Exploration and Production Division. EPR/LPN 3690.

ENTERPRISE OIL, 1996. *Well IRE 27/5-1 Geological Completion Report.*

EVITT, W. R. 1963. A discussion and proposals concerning fossil dinoflagellates, hystrichospheres and acritarchs, I & II. *Proceedings of the National Academy of Sciences of the United States of America*, **49**(2), 158-164.

FAEGRI, A and IVERSEN, J. 1950. *Textbook of modern pollen analysis*. Copenhagen.

FAIRCHILD, I., HENDRY, G., QUEST, M. and TUCKER, M., 1988. Chemical analysis of sedimentary rocks. *In* Tucker, M. *Techniques in Sedimentology*. Blackwell Scientific Publications, Oxford, 274-354.

FALCON-LANG, H. J. 2003. Response of Late Carboniferous tropical vegetation to transgressive-regressive rhythms, Joggins, Nova Scotia. *Journal of the Geological Society, London,* **160**(4), 643-648.

FIELDING, C. R. 1983. *Sedimentology and diagenesis of the Jurassic and Carboniferous intervals of 26/29-1 and the reservoir potential of Jurassic sands in the 26/28 and 26/29 blocks, Porcupine Basin, offshore Ireland.* BP Petroleum Development (Overseas) Exploration Department, Sedimentology Branch. Report No. UK 5477.

FISHER, M. J., BARNARD, P. C and COOPER, B. S. 1980. Organic maturation and hydrocarbon generation in the Mesozoic sediments of the Svendrop Basin, Arctic Canada. *Proceedings IV International Palynological Conference, Lucknow (1976-77),* **2**, 581-588.

GEARHART GEODATA SERVICES LTD. 1980. *End of Well Report for BP Petroleum Development Ltd. Well 26/28-2. Volume 1.*

GIBSON, H. J, MOORE, M. E. and WATSON, P. G. 1996. *Thermal History Reconstruction in Well 27/5-1 West of Ireland Using Apatite Fission Track Analysis and Vitrinite Reflectance.* Geotrack Report #625.

GIBLING, M. R., CULSHAW, N., RYGEL, M. C. and PASCUCCI, V. 2008. Chapter 6. The Maritimes Basin of Atlantic Canada: Basin Creation and Destruction in the Collisional Zone of Pangea. *In* Miall, A. D. *The Sedimentary Basins of the United States and Canada.* Elsevier, 211-244.

GIDMAN, J. 1981. *Ireland, Porcupine Basin Well 26/28-3. Geological Completion Report.* BP Petroleum Development Ltd. (Irish Branch). Report DUB 435.

GILES, P. S. 1981. Major transgressive-regressive cycles in middle to late Viséan rocks of Nova Scotia. *Nova Scotia Department of Mines and Energy, Paper* **81-2**, 1-27.

GILES, P. S. 2004. *Stratigraphic and structural interpretation of the HB Fina Northumberland Strait F-25 well, western Maritimes Basin, eastern Canada.* Geological Survey of Canada, Open File 1840.

GILES, P. S. 2009. *The Maritimes Basin – mute witness to continental collision and Carboniferous to Early Permian polar glaciation. From* Hydrocarbon systems in the Paleozoic basins of eastern Canada - Presentations at the Calgary 2007 workshop; Lavoie, D; Pinet, N; Castonguay, S; Dietrich, J; Giles, P; Fowler, M; Thériault, R; Laliberté, J. Y; St. Peter, C; Hinds, S; Hicks, L; Klassen, H. Geological Survey of Canada, Open File 5980, 113p.

GILES, P. S. and UTTING, J. 1999. *Maritimes Basin stratigraphy - Prince Edward Island and adjacent Gulf of St. Lawrence*. Geological Survey of Canada, Open File 3732

GILES, P. S. and UTTING, J. 2001. *Shell-Amoco Cap Rouge F-52, Gulf of St. Lawrence, eastern Canada.* Geological Survey of Canada, Open File 3204.

GILES, P. S. and UTTING, J. 2003. *Carboniferous stratigraphy of the Bradelle L-49 and Brion Island wells, central and northern Gulf of St. Lawrence, Maritimes Basin, eastern Canada.* Geological Survey of Canada, Open File 1679.

GILES, P. S. and BOUTILIER, R. 2003. *Spectral analysis of degraded synthetic time series – Modelling spectra of the orbital periods from the Late Viséan Windsor Group of Atlantic Canada.* Geological Society of America, Northeastern Section Annual Meeting, Abstracts, **35**, p.11.

GRAHAM, J. R. 1996. Dinantian river systems and coastal sedimentation in northwest Ireland. *In* Strogen, P., Somerville, I. D., and Jones, G. Ll. *Recent advances in Lower Carboniferous geology*. Geological Society Special Publication, **107**, 183-206.

GRAHAM, J. R. 2009. Chapter 9. Devonian. *In* Holland, C. H. and Sanders, I. S. *The Geology of Ireland.* Dunedin Academic Press Ltd., Edinburgh, 175-214.

GREBE, H. 1971. A recommended terminology and descriptive method for spores. *Microfossiles organiques du Paléozoïque,* **4**, *Les spores*, 7-34.

GREBE, H. 1972. Die Verbreitung der Mikrosporen im Ruhrkarbon von der Bochumer Schichten bis zu den Dorstener Scichten (Westfal A-C). *Palaeontographica, Abteilung B*, **140**, 27-115, 12 pl.

GROSS, M. G. 1964. Variations in the $^{18}O/O^{16}$ and $^{13}C/C^{12}$ ratios of diagenetically altered limestones in the Bermuda Islands. *Journal of Geology,* **72,** 170-94.

GUEINN, K. J. and KING, A. D. 1979. Gulf Oil (Ireland) Ltd. Well 26/21-1 Stratigraphical / Paleontological Report on selected ditch samples. Paleoservices Ltd., Report No. 668.

GUENNEL, G. K. 1952. Fossil spores of the Alleghenian coals in Indiana. *Indiana Geological Survey, Report of Progress*, **4**, 1-40, pl. 1-4.

GUION, P. D., GUTTERIDGE, P. and DAVIES. S. J. 2000. Chapter 14. Carboniferous sedimentation and volcanism on the Laurussian margin. *In* Woodcock, N.H. & Strachan, R. *Geological History of Britain and Ireland.* Blackwell, Oxford, 227-270.

HACQUEBARD, P. A. 1972. The Carboniferous of Eastern Canada. *Septième Congrès Intionational de Stratigraphe et de Géologie du Carbonifère, Krefeld 1971, compte rendu,* **1**, 69-90.

HACQUEBARD, P. A. and BARSS, M. S. 1957. A Carboniferous spore assemblage , in coal from the South Nahanni River area, Northwest Territories. *Geological Survey of Canada Bulletin,* **40**, 1-63.

HAMBLIN, A. P., FOWLER, M. G., UTTING, J., HAWKINS, D. and LANGDON, G. S. 1997. Stratigraphy, palynology and source rock potential of lacustrine deposits of the Lower Carboniferous (Viséan) Rocky Brook Formation, Deer Lake Subbasin, Newfoundland. *Bulletin of Canadian Petroleum Geology*, **45**(1), 25-53.

HAWORTH, R. T., GRANT, A. C. and FOLINSBEE, R. A. 1976a. Geology of the continental shelf of southeastern Labrador. *Report of Activities, Part C, Geological Survey of Canada, Paper* **76-1C**, 61-70.

HAWORTH, R. T., POOLE, W. H., GRANT, A. C. and SANFORD, B. V. 1976b. Marine geoscience survey northeast of Newfoundland. *Report of Activities, Part A, Geological Survey of Canada*, *Paper* **76-1A**, 7-15.

HEAL, S. E. 2009. *Palynological correlation of Mississippian (Carboniferous) stages in Western Europe and the USA*. Unpublished PhD Thesis, Department of Geology, Trinity College Dublin, 444p + appendices.

HECKEL, P. H. and CLAYTON, G. 2006. The Carboniferous System. Use of the new official names for the subsystems, series and stages. *Geologica Acta*, **4**(3), 403-407.

HIGGS, K. 1986. The stratigraphy of Namurian rocks of the Leinster coalfield. *Geological Survey of Ireland Bulletin*, **3**, 257-276.

HIGGS, K. 1990. Upper Viséan and lower Namurian miospore assemblages from County Cork, Ireland. *Irish Journal of Earth Sciences*, **10**, 109-114.

HIGGS, K. T. 1984. Stratigraphic palynology of the Carboniferous rocks in northwest Ireland. *Geological Survey of Ireland Bulletin*, **3**, 171-201.

HIGGS, K. T., CLAYTON, G. and KEEGAN, J. B. 1988. Stratigraphic and systematic palynology of the Tournaisian rocks of Ireland. *Geological Survey of Ireland, Special Paper* **7**, 1-93.

HIGGS, K. T., McPHILEMY, B., KEEGAN, J. B. and CLAYTON, G. 1988b. New data on Palynological boundaries within the Irish Dinantian. *Review of Palaeobotany and Palynology*, **58**, 61-68.

HIGGS, K. T. and O'CONNOR, G. 2005. Stratigraphy and Palynology of the Westphalian Strata of the Leinster Coalfield, Ireland. *Irish Journal of Earth Sciences*, **23**, 65-84.

HOWIE, R. D. 1988. Upper Palaeozoic Evaporites of Southeastern Canada. *Geological Survey of Canada Bulletin* **380**, 1-120.

HUDSON, J. D. 1977. Stable isotopes and limestone lithification. *Journal of the Geological Society of London*, **133**(6), 637-660.

HYDE, E. S., KALKREUTH, W. D., and UTTING, J. 1991. Petrology, palynology, and depositional environment of coals of the Upper Carboniferous Barachois Group (Westphalian A and C), south-western Newfoundland. *Canadian Journal of Earth Sciences*, **28**, 1905-1924.

INOSOVA, K. I., SHVARTSMAN, E. G. and KRUSINA, A. K. 1976. *Atlas of microspores and pollen from the Upper Carboniferous and Lower Permian of the Donets Basin.* Nedra, Moscow, 159p.

JARZEN, D. M. and NICHOLS, D. J. 1996. Chapter 9. Pollen. *In* Jansonius, J & McGregor, D.C. *Palynology: principles and applications*. American Association of Stratigraphic Palynologists Foundation, **1**, 261-291.

JERZYKIEWICZ, J. 1987. Latest Carboniferous (Stephanian) and Early Permian (Autunian) palynological assemblages from the Intrasudetic Basin, southwestern Poland. *Palynology,* **11**, 117–131.

JONES, P. C. and NAYLOR, D. 2003. Namurian rocks of Whiddy Island, west Cork: a sedimentological outline and palaeogeographical implications. *Irish Journal of Earth Sciences*, **21**, 115-132.

JUTRAS, P. and PRICHONNET, G. 2005. Record of Late Mississippian tectonics in the new Percé Group (Viséan) of eastern Gaspésie, Quebec. *Canadian Journal of Earth Sciences*, **42**, 815-832.

JUTRAS, P., MacRAE, A. and UTTING, J. 2007. Viséan tectonostratigraphy and basin architecture beneath the Pennsylvanian New Brunswick Platform of eastern Canada. *Bulletin of Canadian Petroleum Geology*, **55**, 217-236.

KEITH, M. L. and WEBER, J.N. 1964. Carbon and oxygen isotopic composition of selected limestones and fossils. *Geochimica et Cosmochimica Acta,* **28**, 1787-816.

KING, A. D., GUEINN, K. J. and MEYRICK, R.W. 1979. *Well 36/16-1 Porcupine Basin Stratigraphical/Palaeontological final report*. Palaeoservices Ltd., Report No. 646.

KING, A. D., MEYRICK, R. W., GUEINN, K. J and WILKINSON, G. C. 1981. *Well 26/27-1b, Porcupine Basin. Stratigraphical/Paleontological Final Report.* Palaeoservices Ltd., Report No. 838.

KING, A. D., MEYRICK, R. W. and GUEINN, K. J. 1982. *Well 26/30-1, Porcupine Basin, Offshore Ireland. Stratigraphical/Paleontological Final Report.* Palaeoservices Ltd. Report No. 984.

LAVEINE, J.-P. 1977. Report on the Westphalian D. *In* Holub, V. and Wagner, R.H. *Symposium on Carboniferous Stratigraphy.* Geological Survey, Prague, 71–87.

LAVOIE, D., PINET, N., DIETRICH, J., HANNIGAN, P., CASTONGUAY, S., HAMBLIN, A. P. and GILES, P. 2009. *Petroleum Resource Assessment, Paleozoic successions of the St. Lawrence Platform and Appalachians of eastern Canada*. Geological Survey of Canada, Open File 6174, 275p.

LEYTHAEUSER, D., SCHAEFER, R. G. and CORNFORD, C. 1977. *Final Geochemical Report of 34/15-1.* Programmgruppe Für Erdöl und Organische Geochemie Der Kernforschungsanlage Jülich GmbH.

LOBOZIAK, S. 1974. Considerations palynologiques sur le Westphalian d'Europe occidentale. *Review of Palaeobotany and Palynology*, **18**, 271-289.

LOVE, C. F., NEVILLE, R. S. W. and UNDERWOOD, J. 1978. *Biostratigraphy of the Texaco 13/3-1 Offshore Ireland Well: Interval Examined 1230'-4480'.* Robertson Research International Limited. Report No. 2374.

MARTEL, A. T., MCGREGOR, D. C. and UTTING, J. 1993. Stratigraphic significance of Upper Devonian and Lower Carboniferous miospores from the type area of the Horton Group, Nova Scotia. *Canadian Journal of Earth Science,* **30**, 1091-1098.

MARSHALL, J. D. 1992. Climatic and oceanographic isotopic signals from the carbonate rock record and their preservation. *Geological Magazine,* **129**(2), 143-160.

MAYALL, M. J. 1982. *Sedimentology and diagenesis of the Jurassic and Carboniferous intervals of 26/28-4a and the reservoir potential of the Jurassic sands in the 26/28 block, Porcupine Basin, offshore Ireland.* BP Petroleum Development (Overseas) Exploration Department Sedimentology Branch.

McILROY, D. and FALCON-LANG, H. J. 2006. Discovery of a *Zoophycos*-group trace fossil (?*Echinospira Girotti*) in the Middle Pennsylvanian Sydney Mines Formation of Nova Scotia, and its palaeoenvironmental implications. *Atlantic Geology*, **42**, 31-35.

McLEAN, D. 1993 *A palynostratigraphic classification of the Westphalian of the Southern North Sea Carboniferous Basin.* Ph.D. Thesis, University of Sheffield.

McLEAN, D., OWENS, B. and BODMAN, D. 2004. Palynostratigraphy of the Upper Carboniferous Langsettian Stage boundary in Britain. *In* Beaudoin, A. B. and Head, M. J. *The Palynology and Micropalaeontology of Boundaries*. Geological Society, London, Special Publications, **230**, 123-135.

McLEAN, D., OWENS, B. and NEVES, R. 2005. Carboniferous miospore biostratigraphy of the North Sea. *In* Collinson, J. D., Evans, D. J., Holliday, D. W and Jones N. S. *Carboniferous hydrocarbon geology: the southern North Sea and surrounding areas*. Occasional Publications series of the Yorkshire Geological Society, **7**, 13-24.

McLEAN, D., BEK, J., OWENS, B and OLIWKIEWICZ-MIKLASIŃSKA, M. 2006. A structural reinterpretation of the enigmatic Carboniferous miospore *Pteroretis* Felix & Burbridge 1961 emend. nov. *Palynology*, **30**, 17-32.

McNEILL, J., BARRIE, F. R., BURDET, H. M., DEMOULIN, V., HAWKSWORTH, D. L., MARHOLD, K., NICOLSON, D. H., PRADO, J., SILVA, P. C., SKOG, J. E., WIERSEMA, J. H. and TURLAND, N. J. 2007. *International Code of Botanical Nomenclature (Vienna Code) adopted by the Seventeenth International Botanical Congress Vienna, Austria, July 2005*. Gantner, Ruggell, 568p.

McPHILEMY, B. 1988. The value of fluorescence microscopy in routine palynofacies analysis: Lower Carboniferous successions from counties Armagh and Roscommon, Ireland. *Review of Palaeobotony and Palynology*, **56**, 345-359.

McPHILEMY, B. 1989. *Palynology and Palynofacies of some Lower Carboniferous sections in northwest Ireland,* Volumes **1-3**. Unpublished PhD Thesis, Department of Geology, Trinity College Dublin.

MECKLENBURGH, R. 2004. *Well IRE 12/2-1z "Dooish Deepwater Exploration" Final Well Report. Volume 1: Geological and Petrophysical Evaluation*. Shell Ireland Operations.

MILLENNIA STRATIGRAPHIC CONSULTANTS 1996. *Enterprise Well 27/5-1, Slyne Trough. Biostratigraphic analysis of the interval 437-1910m (TD).* Project No: 201/96.

MILLENNIA STRATIGRAPHIC CONSULTANTS 2004. *Biostratigraphic analysis of the Enterprise Wildcat Exploration Well 12/2-1z (interval: 3841-4471m) Rockall Trough, Licence 2/94, West of Ireland.* Project No: 557/03.

MILLER, M. A. 1996. Chapter 13E. Invertebrate cuticular fragments. *In* Jansonius, J. and McGregor, D. C. *Palynology - Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, **1**, 381-382.

MITCHELL, W. I. 2004. Carboniferous. *In* Mitchell, W. I. *The geology of Northern Ireland: our natural foundation* (2nd edition). Geological Survey of Northen Ireland, Belfast, 79-116.

MITCHELL, W. I. and OWENS, B. 1990. The geology of the western part of the Fintona Block, Northern Ireland: evolution of Carboniferous basins. *Geological Magazine*, **127**, 407-426.

NAGARAJAN, R., SIAL. A. N., ARMSTRONG-ALTRIN, J. S., MADHAVARAJU, J. and NAGENDRA, R. 2008. Carbon and oxygen isotope geochemistry of Neoproterozoic limestones of the Shahabad Formation, Bhima basin, Karnataka, southern India. *Revista Mexicana de Ciencias Geologicas,* **25**(2), 225-235.

NAYLOR, R. D., ARCHER, A. W., CHANDLER, F. W. and FRALICK, P. W. 1998. Fluvio-estuarine sedimentation in the Late Carboniferous Malagash Formation of Nova Scotia, Canada. *Nova Scotia Department of Natural Resources, Report of Activities 1998*, 71-89.

NAYLOR, D., HAUGHEY, N., CLAYTON, G. and GRAHAM, J. R. 1993. The Kish Bank Basin, offshore Ireland. *In* Parker, J. R. *Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference* (London 1992), 845-855

NAYLOR, D. and SHANNON, P. M. 2009. Chapter 17. Geology of Offshore Ireland. *In* Holland, C. H. and Sanders, I. S. *The Geology of Ireland.* Dunedin Academic Press Ltd., Edinburgh, 405-460.

NAYLOR, D. and SHANNON, P. M. 2011. *Petroleum Geology of Ireland.* Dunedin Academic Press Ltd, Edinburgh, 262p.

NEVES, R. 1958. Upper Carboniferous plant spore assemblages from the *Gastrioceras subcrenatum* horizon, North Staffordshire. *Geological Magazine*, **95**, 1-19.

NEVES, R. 1961. Namurian plant spores from the southern Pennines, England. *Palaeontology*, **4**, 247-279.

NEVES, R. 1964. The stratigraphic significance of the small spore assemblages of the La Camocha Mine, Gijon, N. Spain. *Cinquième Congrès International de Stratigraphie et de Géologie du Carbonifère, Paris 1963, compte rendu*, **3**, 1063-1069.

NEVES, R. and OWENS, B. 1966. Some Namurian camerate miospores from the English Pennines. *Pollen et Spores*, **8**, 337-360.

NEVES, R., GUEINN, K. J., CLAYTON, G., IOANNIDES, N. and NEVILLE, R. S. W. 1972. A scheme of miospore zones for the British Dinantian. *Septième Congrès Internationale de Stratigraphie et de Géologie du Carbonifère, Krefeld, 1971, compte rendu*, **1**, 347-53.

NEVES, R., GUEINN, K. J., CLAYTON, G., IOANNIDES, N., NEVILLE, R. S. W. and KRUSZEWSKA, K. 1973. Palynological correlations within the lower Carboniferous of Scotland and northern England. *Royal Society of Edinburgh*, *Transactions,* **69**, 23-70.

ODELL, R. T. and THOMAS, I. W. 1978. *Rockall Basin 19/5-1 Completion Report*. Amoco Ireland Exploration Company.

ODELL, R. T. and WALKER, D. 1979. *Rockall Basin 12/13-1 and 12/13-1a Completion Report*. Amoco Ireland Exploration Company.

OLAUSSEN, S. 1981. Marine incursion in Upper Palaeozoic sedimentary rocks of the Oslo Graben region, Southern Norway. *Geological Magazine*, **118**, 699-702.

OWENS, B. 1996. Chapter 18D. Upper Carboniferous Spores and Pollen. *In* Jansonius, J. and McGregor, D. C. *Palynology - Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, **2**, 597 – 606.

OWENS, B., NEVES, R., GUEINN, K. J., MISHELL, D. R. F., SABRY, H. S. M. Z. and WILLIAMS, J. E. 1977. Palynological division of the Namurian of northern England and Scotland. *Proceedings of the Yorkshire Geological Society*, **41**, 381-398.

OWENS, B., McLEAN, D. and BODMAN, D. 2004. A revised palynozonation of British Namurian deposits and comparisons with eastern Europe. *Micropaleontology*, **50**(1), 89-103.

PALAEOSERVICES LTD. 1978. *Well 19/5-1 (Donegal Basin) Final Report.* Project No. 56B.

PALEOCHEM LTD. GEOCHEMICAL CONSULTANTS. 1982. *Geochemical Evaluation of cuttings samples and sidewall cores from the Porcupine Basin Well: 26/30-1, Offshore Eire*. Petroleum Geochemistry Report Prepared for Phillips Petroleum Europe-Africa, Inc.

PALEY, W. J. and ATHERSUCH, J. 1980. *Biostratigraphy of the BP/Aran 26/28-2 Well, Porcupine Basin, Offshore Ireland.* BP Research Centre, Exploration and Production Division. EPR/LPN 3705.

PASCUCCI, V., GIBLING, M. R. and WILLIAMSON, M. A. 2000. Late Paleozoic to Cenozoic history of the offshore Sydney Basin, Atlantic Canada. *Canadian Journal of Earth Sciences*, **37**, 1143-1165.

PATTERSON, N. W. 2009. *A palynological investigation of Mississippian strata in West Virginia and Kentucky, USA*. Unpublished PhD Thesis, Department of Geology, Trinity College Dublin.

PEPPERS, R. A. 1985. Comparison of miospore assemblages in the Pennsylvanian System of the Illinois Basin with those in the upper Carboniferous of western Europe. *In* Sutherland, P. K. and Manger, W. L. *Neuvième Congrès International de Stratigraphie et de Gèologie du Carbonifère Biostratigraphy, compte rendu* **2**, 483–502.

PEREIRA, Z. 1999. Palinoestratigrafia do Sector Sudoeste da Zona Sul Portuguesa. *Communicações Instituto Geológico e Mineiro Portugal,* **86**, 25-57.

PEREIRA, Z., MATOS, J., FERNANDES, P. and OLIVEIRA, J. T. 2007. Devonian and Carboniferous palynostratigraphy of the South Portuguese Zone, Portugal – An overview. *Communicações Geológicas*, **94**, 53-79.

PLAYFORD, G. 1962. The Lower Carboniferous microfloras of Spitsbergen. *Palaeontology*, **5**, 550-678.

PLAYFORD, G. 1971. Lower Carboniferous spores from the Bonaparte Gulf Basin, Western Australia and Northern Territory. *Australia Bureau of Mineral Resources Bulletin*, **115**, 1-104.

PLAYFORD, G. and DETTMANN, M. E. 1996. Chapter 8. Spores. *In* Jansonius, J. and McGregor, D. C. *Palynology: principles and applications*. American Association of Stratigraphic Palynologists Foundation, **1**, 227-260.

POTONIÉ, R. and KREMP, G. O. W. 1955. Die sporae dispersae des Ruhrkarbons, ihre Morphographie und Stratigraphie mit Ausblicken auf Arten andere Gebeite und Zeitabschnitte: Teil I. *Palaeontographica B*, **98**, 1-136.

POTONIÉ, R. 1956-1975. Synopsis der Gattungen der Sporae Dispersae, 7 vols: I-VI, *Beihefte zum geologischen Jahrbuch* **23**(1956), **31**(1958), **39**(1960), **72**(1966), **87**(1970) and **94**(1970); VII, *Fortschritte in der Geologie von Rheinland und Westfalen* **25**(1975).

PUNT, W., HOEN, P. P., BLACKMORE, S., NILSSON, S. and LE THOMAS, A. 2007. Glossary of pollen and spore terminology. *Review of Palaeobotany and Palynology*, **143**(1-2), 1-81.

PROKOPH, A., SHIELDS, G. A. and VEIZER, J. 2008. Compilation and time-series analysis of marine carbonate δ^{18}O, δ^{13}C, ^{87}Sr/^{86}Sr and δ^{34}S databases through Earth history. *Earth Science Reviews*, **87**, 113-134.

RAMSBOTTOM, W. H. C., CALVER, M. A., EAGER, R. M. C., HODSON, F., HOLLIDAY, D. W., STUBBLEFIELD, C. J. and WILSON, R. B. 1978. A correlation of the Silesian rocks of the British Isles. *Geological Society of London, Special Report*, **10**, 1-82.

RAISTRICK, A. 1934. Correlation of coal seams by microspore content, pt. 1. The seams of Northumberland. *Transactions of the Institute of Mining Engineers,* **88**, 142-153.

RAINEY, D. I. 1980. *Ireland, Porcupine Bain. Well 26/28-2. Geological Completion Report.* BP Petroleum Development Ltd.

RAVN, R. L. 1986. Palynostratigraphy of the lower and middle Pennsylvanian coals of Iowa. *Iowa Geological Survey Technical Paper*, **7**, 1-245.

RICHARDS, D. P. J. 1982. *Ireland, Porcupine Basin, Well 26/29-1. Geological Completion Report*. BP Petroleum Development Ltd (Irish Branch).

RICHARDSON, J. B. and AHMED, S. 1989. Miospores, zonation and correlation of Upper Devonian sequences from Western New York State and Pennsylvania. *In* McMillan, N. J., Embry, A. F. and Glass, D. J. Devonian of the World, v.3, Palaeontology, Palaeoecology and Biostratigraphy. *Canadian Society of Petroleum Geologists, Calgary, Memoir,* **14**, 541-558.

ROBESON, D. 1988. Investigation of the palynostratigraphy and thermal maturation of Carboniferous rocks in the western Irish offshore. Unpublished Ph.D. thesis, Department of Geology, Trinity College Dublin.

ROBESON, D., BURNETT, R. and CLAYTON, G. 1988. The Upper Palaeozoic Geology of the Porcupine, Erris and Donegal Basins, Offshore Ireland. *Irish Journal of Earth Sciences,* **9**(2), 153-175.

ROVEDA, V. L., KING, A. D. and LISTER, T. R. 1977. *Final Stratigraphical/Paleontological Report of 34/15-1.* Paleoservices Ltd.

RYAN, R. J., BOEHNER, R. C. and CALDER, J. H. 1991. Lithostratigraphic revisions of the upper Carboniferous to lower Permian strata in the Cumberland Basin, Nova Scotia and the regional implications for the Maritimes Basin in Atlantic Canada. *Bulletin of Canadian Petroleum Geology,* **39**, 289–314

SALOMONS, W. 1975. Chemical and isotopic composition of carbonates in recent sediments and soils from western Europe. *Journal of Sedimentary Petrology*, **45**, 440-449.

SCHOPF, J. M., WILSON, L. R. and BENTALL, R. 1944. An annotated synopsis of Paleozoic fossil spores and the definition of generic groups. *Illinois Geological Survey of Report of Investigations*, **91**, 1-73.

SEVASTOPULO, G. D. 2009. Chapter 11. Carboniferous: Mississippian (Serpukhovian) and Pennsylvanian. *In* Holland, C. H. and Sanders, I. S. *The Geology of Ireland.* Dunedin Academic Press Ltd., Edinburgh, 269-294.

SEVASTOPULO, G. D. and WYSE JACKSON, P. N. 2009. Chapter 10. Carboniferous: Mississippian (Tournaisian and Viséan). *In* Holland, C. H. and Sanders, I. S. *The Geology of Ireland.* Dunedin Academic Press Ltd., Edinburgh, 215-268.

SHANNON, P. M. and NAYLOR, D. 1998. An assessment of Irish offshore basins and petroleum plays. *Journal of Petroleum Geology*, **21**, 125-152.

SHANNON, P. M., CORCORAN, D. V. and HAUGHTON, P. D. W. 2001. The petroleum exploration of Ireland's offshore basins: introduction. *In* Shannon, P. M., Haughton, P. D. W. and Corcoran, D. V. *The Petroleum Exploration of Ireland's Offshore Basins.* Geological Society, London, Special Publications, **188**, 1-8

SIMPSON, I. R. 1979. *Ireland, Porcupine Basin Well 26/28-1 Geological Completion Report*. BP Petroleum Development Ltd (Irish Branch). Report DUB 273.

SMITH, A. H. V. 1987. Stratigraphic ranges of selected miospores in coal seams of Upper Coal Measures age in Oxfordshire and S.E. Warwickshire. *Journal of Micropalaeontology*, **6**, 21–37.

SMITH, J. 1996. A palynofacies analysis of the Dinantian (Asbian) Glenade Sandstone Formation of the Leitrim Group, northwest Ireland. *Geological Society, London, Special Publications*, **107**(1), 437-448.

SMITH, A. H. V. and BUTTERWORTH, M. A. 1967. Miospores in the coal seams of the Carboniferous of Great Britain. *Special Papers in Palaeontology*, **1**, 1-324, pl. 1-27.

STAPLIN, F. L. 1960. Upper Mississippian plant spores from the Golata Formation, Alberta, Canada. *Palaeontographica B*, **107**, 1-40.

STEPHENSON, M., WILLIAMS, M., MONAGHAN, A., ARKLEY, S. and SMITH, R. 2002 Biostratigraphy and palaeoenvironments of the Ballagan Formation (lower Carboniferous) in Ayrshire. *Scottish Journal of Geology,* **38**(2), 93-111.

STROTHER, P. K. 1996. Chapter 5. Acritarchs. *In* Jansonius, J. and McGregor, D. C. *Palynology - Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, **1**, 81-106.

STUART, I. A. 1978. *Texaco Ireland Ltd. Final Geological Report. Ireland 13/3-1.*

TATE, M. P. and DOBSON, M. R. 1989. Pre-Mesozoic geology of the western and north-western Irish continental shelf. *Journal of the Geological Society of London*, **146**, 229-240.

TAYLOR, P. D. and VINN, O. 2006. Convergent morphology in small spiral worm tubes ("*Spirorbis*") and its palaeoenvironmental implications. *Journal of the Geological Society, London,* **163**, 225-228.

TIBERT, N. E. and GIBLING, M. R. 1999. Peat accumulation on a drowned coastal braidplain: the Mullins Coal (Upper Carboniferous), Sydney Basin, Nova Scotia. *Sedimentary Geology*, **128**, 23-38.

TRAVERSE, A. 1988. *Paleopalynology*. Unwin Hyman, Boston. 600p.

TSCHUDY, R. H. 1961. Palynomorphs as indicators of facies environments in Upper Cretaceous and lower Tertiary strata, Colorado and Wyoming. *Wyoming Geological Association, Guidebook, 16th Annual Field Conference*, 53-59, 1pl.

TSCHUDY, R. H. and SCOTT, R. A. 1969. *Aspects of Palynology*. Wiley, New York, 510p.

TUCKER, M. E. and WRIGHT, V. P. 1990. *Carbonate Sedimentology*. Blackwell Scientific Publications, London, 482p.

TURNER, N. and SPINNER, T. 1993. A palynostratigraphic study of the Namurian-Westphalian deltaic sequences of the southern central Pennine Basin, Derbyshire, England. *Review of Palaeobotany and Palynology*, **77**, 23-43.

TYSON, R. V. 1993. Palynofacies analysis. *In* Jenkins, D. G. *Applied Micropaleontology*. Kluwer Academic Publishers, Dordrecht, 153-191.

TYSON, R. V. 1995. *Sedimentary organic matter: organic facies and palynofacies.* Chapman and Hall, London, 615p.

UTTING, J. 1987. Palynology of the Lower Carboniferous Windsor Group and Windsor - Canso boundary beds of Nova Scotia, and their equivalents in Quebec, New Brunswick and Newfoundland. *Geological Survey of Canada, Bulletin*, **374**, 1-93.

UTTING, J. KEPPIE, J. D. and GILES, P. S. 1989. Palynology and Stratigraphy of the Lower Carboniferous Horton Group, Nova Scotia. *Geological Survey of Canada, Bulletin*, **396**, 117-143.

UTTING, J. and GILES, P. S. 2004. Biostratigraphical implications of new palynological data from the Mississippian of Newfoundland and Nova Scotia, Canada. *Memoirs of the Association of Australasian Palaeontologists*, **29**, 115–160.

UTTING, J. and GILES, P. S. 2008. Palynostratigraphy and lithostratigraphy of Carboniferous Upper Codroy Group and Barachois Group, southwestern Newfoundland. *Canadian Journal of Earth Sciences*, **45**, 45–67.

UTTING, J., GILES, P. S. and DOLBY, G. 2010. Palynostratigraphy of Mississippian and Pennsylvanian rocks, Joggins area, Nova Scotia and New Brunswick, Canada. *Palynology*, **34**(1), 43-89.

VAN WIJHE, D. H. and BLESS, M. J. M. 1974. The Westphalian of the Netherlands with special reference to miospore assemblages. *Geologie en Mijnbouw*, **53**(6), 295-328.

VISSCHER, H. 1971. The Permian and Triassic of the Kingscourt outlier, Ireland - a palynological investigation related to regional stratigraphical problems in the Permian and Triassic of western Europe. *Geological Survey of Ireland, Special Paper,* **1**, 1–114.

VISSCHER, H., HUDDLESTON SLATTER-OFFERHAUS, M. G. and WONG, T. E. 1974 Palynological assemblages from "Saxonian" deposits of the Saar-Nahe Basin (Germany) and the Dôme de Barrot (France). An approach to chronostratigraphy. *Review of Palaeobotany and Palynology*, **17**, 39–56.

VON BITTER, P. H., GILES, P. S. and UTTING, J. 2007. Biostratigraphic correlation of major cycles in the Windsor and Codroy groups of Nova Scotia & Newfoundland, Atlantic Canada with the Mississippian substages of Britain and Ireland. *In* Wong, Th. E. Proceedings of the XVth International Congress on Carboniferous and Permian Stratigraphy. Utrecht, the Netherlands, 10-16 August 2003. Royal Netherlands Academy of Arts and Sciences, 513-534.

WAGNER, R. H., FERNANDEZ-GARCIA, L. and EAGAR,. R. M. C. 1983. *Geology and palaeontology of the* Guardo Coalfield *(NE León – NW Palencia), Cantabrian Mountainss*. Instituteo Geologico y Minero de España; Madrid.

WAGNER, R. H. 1984. Megafloral zones of the Carboniferous. *Neuvième Congrès International de Stratigraphie et de Géologie du Carbonifère, Washington*, *compte rendu,* **2**, 109-134.

WARRINGTON, G. 1984. *Permian and Triassic Stratigraphic Units and Distribution of Selected Palynomorphs.* Unpublished report, British Micropalaeontological Society, Palynological Group, Cambridge.

WARRINGTON, G. 1996. Chapter 18E. Permian spores and pollen. *In* Jansonius, J. and McGregor, D. C. *Palynology - Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, **2**, 607-619.

WHITAKER, M. F. 1981. Palynological data sheet. *In* Joint venture Irish Shell Petroleum Development company Teorana and AGIP Ireland Ltd. *Porcupine Area, Final Well Report 26/26-1.*

WIGHTMAN, W. G., SCOXT, D. B., MEDIOLI, F. S. and GIBLING, M. R. 1994. Agglutinated foraminifera and thecamoebians from the Late Carboniferous Sydney Coalfield, Nova Scotia: palaeoecology, palaeoenvironments and palaeogeographic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **106**, 187-202.

ZIEGLER, P. A. 1982. *Geological Atlas of Western and Central Europe. 1st Edition*. Shell Internationale Petroleum Maatschappij, B. V., 130p.

APPENDIX I

WELL INFORMATION

Well	Operator	Basin	Latitude / Longitude	Spud date	Water depth (m)	Total Depth (TD)	Well Status
12/2-1z	Enterprise Energy Ireland Ltd	Rockall	55°55’ 20.593’’N 09°39’ 08.769’’W	20 May 2003 (sidetrack date)	1476	14668’/ 4471m	P&A (gas cond. disc.)
12/13-1	Amoco Ireland	Erris	55°37’ 03.65’’N 09°30’ 38.25’’W	16 June 1979	480	9414’/ 2869m	P&A
13/3-1	Texaco Ireland Ltd	Donegal	55°53’ 18.678’’N 08°30’ 08.214’’W	27 May 1978	131	4483’/ 1366m	P&A
19/5-1	Amoco Ireland	Erris	54°57’ 42.213’’N 10°02’ 00.109’’W	28 June 1978	116	8479’/ 2584m	P&A
26/21-1	Gulf Oil Ireland	Porcupine	53°11’ 15.522’’N 12°49’ 46.446’’W	7 Sept 1979	338	7139’/ 2176m	P&A
26/26-1	Shell	Porcupine	53°04’ 44.691’’N 12°51’ 57.612’’W	1 June 1981	363	4121’/ 1256m	P&A
26/27-1b	Chevron	Porcupine	53°05’ 17.04’’N 12°43’ 59.40’’W	26 April 1981	383	9223’/ 2811m	P&A
26/28-1	BP	Porcupine	53°02’ 29.182’’N 12°33’ 31.729’’W	12 June 1979	374	10876’/ 3315m	Oil flows 5589 b/d P&A
26/28-2	BP	Porcupine	53°02’ 26.290’’N 12°34’ 49.240’’W	11 July 1980	378	8848’/ 2697m	Oil flows 1490 b/d P&A
26/28-3	BP	Porcupine	53°04’ 15.000’’N 12°31’ 26.680’’W	26 May 1981	364	8491’/ 2588m	P&A
26/28-4a	BP	Porcupine	53°04’ 24.649’’N 12°27’ 41.982’’W	22 July 1981	350	7933’/ 2418m	P&A
26/29-1	BP	Porcupine	53°04’ 31.175’’N 12°20’ 42.998’’W	17 Sept 1982	321	6043’/ 1842m	P&A
26/30-1	Phillips	Porcupine	53°06’ 33.590’’N 12°06’ 00.862’’W	19 May 1982	249	5648’/ 1722m	P&A
27/5-1	Enterprise Oil	Slyne	53°55’ 09.706’’N 11°06’ 27.595’’W	29 April 1996	200.5	6266’/ 1910m	P&A
34/5-1	Elf	Porcupine	52°59’ 27.472’’N 13°10’ 43.940’’W	18 July 1980	289	4882’/ 1488m	P&A
34/15-1	Deminex	Porcupine	52°34’ 31.408’’N 13°07’ 22.020’’W	4 June 1977	482	14586’/ 4446m	P&A
34/19-1	Shell	Porcupine	52°26’ 15.23’’N 13°20’ 15.07’’W	31 May 1978	426	10525’/ 3208m	P&A
35/15-1	Phillips	Porcupine	52°34’ 54.299’’N 12°06’ 43.803’’W	24 June 1980	311	12100’/ 3688m	P&A
36/16-1	Chevron	Porcupine	52°28’ 37.166’’N 11°56’ 18.288’’W	24 May 1979	250	9006’/ 2745m	P&A

APPENDIX II

PREVIOUS BIOSTRATIGRAPHIC INTERPRETATIONS

Previous biostratigraphic interpretations for the 19 offshore western Irish study wells are outlined below. Results for the Carboniferous interval and the strata immediately above are typically shown.

12/2-1z

Millennia Stratigraphic Consultants (2004). Palynology.

12941.7’/3944.67m - 13403’/4085.40m	Lower Cretaceous – Middle Jurassic
13408.7/4087.01m - 13566’/4135m	Permian
13576’/4138m - 13960’/4255m	Lower Permian; Asselian
13999’/4267m - 14176’/4321m	Indeterminate
14196’/4327m - 14659’/4468m	Late Carboniferous; Westphalian C (Bolsovian)
14668’/4771m (TD)	Late Carboniferous; Westphalian B (Duckmantian)

12/13-1

Church *et al.* (1979). Palynology.

7310’/2228m - 9414’/2869m (TD)	?Triassic

13/3-1

Love *et al.* (1978). Palynology.

1230’/375m - 1740’/530m	Stephanian B – Westphalian D (Asturian)
1740’/530m - 1760’/536m	Fault
1760’/536m - 4355’/1327m	Westphalian C – B (Bolsovian – Duckmantian)

Robeson (1988). Palynology - using Clayton *et al.* (1977).

1260’/384m - 1290’/393m	Indeterminate
1290’/393m - 1740’/530m	Westphalian D (Asturian) (OT Biozone)
1740’/530m - 1780’/542m	Stratigraphic break (fault)
1780’/542m - 3340’/1018m	Westphalian C (Bolsovian) (SL Biozone)
3340’/1018m - 4350’/1326m	Westphalian B (Duckmantian) (NJ Biozone)
4350’/1326m - 4483’/1366m (TD)	Tertiary Gabbro

19/5-1

Palaeoservices (1978). Palynology and microfauna.

2925’/892m - 3030’/924m	Late Permian
3030’/924m - 3390’/1033m	Westphalian C (Bolsovian) – late Westphalian B (Duckmantian)
3390’/1033m - 3790’/1155m	Westphalian B (Duckmantian)
3790’/1155m - 3880’/1183m	Late Westphalian A (Langsettian)
Unconformity	
3880’/1183m - 4100’/1250m	Namurian; ?Arnsbergian/?Pendleian
4100’/1250m - 5000’/1524m	Early Namurian; Pendleian – late Visean; Brigantian
5000’/1524m - 6308’/1723m	Visean; Brigantian
6308’/1723m - 7230’/2204m	Visean; Asbian
7230’/2204m - 8280’/2524m	Visean
8280/2524m - 8479’/2584m	?Early Visean; pre-Asbian

Robeson (1988). Palynology - using Clayton *et al.* (1977).

3000’/914m - 3030’/924m	Upper Permian
3030’/924m - 3790’/1155m	Westphalian B (Duckmantian) (NJ Biozone)
3790’/1155m - 3930’/1198m	Upper Westphalian A (Langsettian) (RA Biozone)
~3960’/1207m	Unconformity
3960’/1207m - 4140’/1262m	Arnsbergian (TK/NC Biozones)
4140’/1262m - 5160’/1573m	Pendleian, Brigantian (NC/VF Biozones)
5160’/1573m - 6570’/2003m	Brigantian (VF Biozone)
6570’/2003m - 7625’/2324m	Asbian (NM Biozone)
7625’/2324m - 8479’/2584m (TD)	Holkerian (TC/TS Biozones)

26/21-1

Gueinn and King (1979). Carboniferous interval dated using palynology.

6650’/2027m - 6670’/2033m	Triassic/Permian (Rhaetian or older)
6975’/2126m	Late Carboniferous (early Autunian/Stephanian)
7103’/2165m - 7123’/2171m	?Late Carboniferous
7126’/2172m - 7139’/2176m	Late Carboniferous or older

26/26-1

26/26-1 Final Well Report (1981) and Whitaker (1981). Carboniferous interval dated using palynology.

2428’/740.2m - 2507’/764m	Lower Cretaceous
2614.1’/796.8m	Westphalian B (Duckmantian)
2685.3’/818.5m – 2723.1’/830.0m	Namurian A (lower Namurian)
2810.99’/856.8m	No older than late Visean
2900.2’/884.0 - 3487.5’/1063.0m	Visean
3625-35’/1105-08m - 3556’/1084m	Probably late Tournaisian

26/27-1b

King *et al.* (1981). Carboniferous interval dated using palynology.

7050’/2149m - 7706’/2349m	Kimmeridgian-Oxfordian
7706’/2349m - 8525’/2598m	Westphalian D (Asturian)
8525’/2598m - 8995’/2742m	Westphalian C (Bolsovian)
8995/2742m - 9230’/2813m (TD)	Westphalian B (Duckmantian)

26/28-1

Duxbury *et al*. (1979). Palynology and microfauna.

7956’/2425m - 7775’/2370m	Bathonian to Bajocian
8973’/2735m? - 9184.3’/2799.4m	Stephanian A/B
9184.3’/2799.4m - 9334’/2845m	Stephanian to Westphalian D (Asturian)
9334’/2845m - 10138’/3090m	Westphalian D (Asturian)
10138’/3090m - 10758.7’/3279.3m	Westphalian (?D) (Asturian)

Robeson (1988). Palynology - using Clayton *et al.* (1977).

8504’/2592m(SWC) - 8973’/2735m	Middle Jurassic - Bathonian
8973’/2375m - 9203’/2805m	Stephanian (ST Biozone)
9203’/2805m - 10138’/3090m	Westphalian D (Asturian) - upper Westphalian C (Bolsovian) (OT Biozone)
~10138’/3090m	Stratigraphic break (fault)
10138’/3090m – 10876’/3315m	Westphalian B (Duckmantian) (NJ Biozone)

26/28-2

Paley and Athersuch (1980). Palynology.

6868’/2093.5m - 7283’/2220m	Middle Jurassic – Bathonian
7349’/2240m - 7415.6’/2260.3m	Age indeterminate
7447’/2270m	Stephanian
7497’/2285m - 8048’/2453?m	Westphalian D (Asturian)
8218’/2505m - 8350’/2545m	Westphalian C/D (Bolsovian/Asturian)
8514’/2595m – 8842’/2695m	Westphalian C (Bolsovian)

Robeson (1988). Palynology - using Clayton *et al.* (1977).

7021’/2140m - 7447’/2270m	Middle Jurasic (Bathonian)
7747’/2270m - 7546’/2300m	Stephanian A-B (ST Biozone)
7546’/2300m - 8251’/2515m	Westphalian D (Asturian) (OT Biozone)
8251’/2515m - 8848’/2697m	Westphalian C (Bolsovian) (SL Biozone)

26/28-3

Athersuch *et al.* (1981). Carboniferous interval dated using palynology

7349’/2240m – 7792’/2375m	Middle Jurasic (Bathonian)
7877’/2401m	? Stephanian
7907’/2410m – 8104’/2470m	Age indeterminate
8186’/2495m – 8317’/2535m	Westphalian (undifferentiated)
8350’/2545m – 8415’/2565m	Westphalian C to D (Bolsovian to Asturian)

Robeson (1988). Palynology - using Western European miospore zonal scheme of Clayton *et al.* (1977).

7526’/2294m SWC - 7874’/2400m	Middle Jurassic (Bathonian)
7874’/2400m - 8366’/2550m	Westphalian D (Asturian) (OT Biozone)
8366’/2550m – 8491’/2588m(TD)	Upper Westphalian C (Bolsovian) (SL Biozone)

26/28-4a

Athersuch *et al.* (1982). Carboniferous interval dated using palynology.

7497’/2285m - 7795’/2376m	Jurassic; Bathonian to late Bajocian
7867’/2398m - 7933’/2418m (TD)	Westphalian C to D (Bolsovian to Asturian)

26/29-1

Athersuch *et al.* (1983). Carboniferous core samples dated using palynology.

5487.1’/1672.5m - 5902’/1799m	Undifferentiated Middle Jurassic
6016’/1833.8m – 6027.8’/1837.3m	Westphalian C (Bolsovian)

26/30-1

King *et al.* (1982). Carboniferous interval dated using palynology.

4450’/1356m - 4762’/1451m	Jurassic (Callovian/Bathonian)
4762’/1451m - 5090’/1551m	?Jurassic
5090’/1551m - 5260’/1603m	Westphalian C (Bolsovian)
5260’/1603m - 5640’/1719m	Carboniferous and Basement

27/5-1

Millennia Stratigraphic Consultants (1996). Carboniferous interval dated using palynology.

4632/1412m - 5381’/1640m	Triassic-Permian (Mercia Mudstone to Zechstein groups)
5390’/1643m - 5426’/1654m	Westphalian C (Bolsovian)
5446’/1660m - 5564’/1696m	Westphalian B (Duckmantian)
5574’/1699m - 5853’/1784m	Westphalian B-A (Duckmantian-Langsettian)
5879’/1792m – 6266’/1910m	Westphalian A (Langsettian)

34/5-1

Ducazeaux *et al.* (1981). Carboniferous interval dated largely using palynological data with additional microfaunal evidence.

2264’/690m - 2280’/695m	Eocene/Paleocene
2411’/735m	?Stephanian
2493’/760m - 3104’/946m	Westphalian D (Asturian)
3925.5’/1196.5m - 4245’/1294m	Westphalian C to B (Bolsovian to Duckmantian)
4397.9’/1340.5m - 4590’/1399m	Lower part of Westphalian B (Duckmantian)

Church *et al.* (1981). Carboniferous dated largely using palynological data with additional microfaunal evidence.

2428’/740m - 4595.68’/1400.78m	Stephanian B – Westphalian B (Duckmantian)

Robeson (1988). Palynology - using Clayton *et al.* (1977).

2280'/695m	Tertiary (Eocene)
2395'/730m - 2428'/740m	Cretaceous (Albian)
2526'/770m - 2608'/795m	?Stephanian A-B (ST Biozone)
2608'/795m - 3084'/940m	Westphalian D (Asturian) (OT Biozone)
3084'/940m - 4587'/1398m	Westphalian C (Bolsovian) (ST Biozone)
4587'/1398m - 4882'/1488m (TD)	Westphalian B (Duckmantian) (NJ Biozone)

34/15-1

Roveda *et al.* (1977). Palynology.

11942'/3640m - 13222'/4030m	Jurassic (Bathonian-Bajocian)
13222'/4030m - 14239'/4340m	Early Permian (Autunian) -
14239'/4340m - 14587.58'/4446.35m	Early Permian - Carboniferous (Autunian - Stephanian)

34/19-1

34/19-1 Final Well Report (1978). Carboniferous interval dated using palynology.

9783'/2982m - 10332.8'/3149.5m	Jurassic - Lower Cretaceous
10509.87'/3203.45 - 10517.91/3205.9m	Carboniferous (upper Stephanian) – Lower Permian

35/15-1

Church *et al.* (1981). Carboniferous interval dated using palynology.

7370'/2246m - 8260'/2518m	Early Cretaceous (Albian-?Barremian)
8260'/2518m - 8750'/2667m	Indeterminate (?Early Carboniferous)
8750'/2667m - 9140'/2786m	Early Carboniferous
9140'/2786m - 12096'/3687m	Indeterminate (?Early Carboniferous)

36/16-1

King *et al.* (1979). Carboniferous interval dated using palynology.

4130'/1258m - 4300'/1311m	Cretaceous
4300'/1311m - 4900'/1494m	Westphalian D (Asturian)
4900'/1494m - 6012'/1832m	Westphalian C (Bolsovian)
6012'/1832m - 7348'/2240m	Westphalian C/late Westphalian B (Bolsovian/Duckmantian)
7348'/2240m - 9005'/2745m (TD)	Late Westphalian B (Duckmantian) - ?late Namurian

Robeson (1988). Palynology - using Clayton *et al.* (1977).

4200’/1280m	Cretaceous
4330’/1320m - 4370’/1332m	Stephanian A-B (ST Biozone)
4370’/1332m - 4850’/1478m	Westphalian D (Asturian) (OT Biozone)
4850’/1478m - 6200’/1890m	Westphalian C (Bolsovian) (SL Biozone)
6200’/1890m - 8190’/2496m	Westphalian A-B (Langsettian-Duckmantian) (NJ, RA, SS Biozones)
8190’/2496m - 9011’/2747m (TD)	Namurian A (Chokerian, Arnsbergian, Pendleian) (TK, NC Biozones).

APPENDIX III

MIOSPORE ZONATION OF EASTERN CANADA

***Emphanisporites rotatus* – *Hymenozonotriletes explanatus* Assemblage Zone** (Utting *et al.* 1989)

Characteristic species; *Emphanisporites rotatus, Retusotriletes incohatus, R. triangulatus, R. crassus, Cymbosporites acutus, Verrucosisporites nitidus, Raistrickia corynoges, Hymenozonotriletes explanatus, Knoxisporites literatus, Lophozonotriletes malevkensis, Latosporites* sp., *Umbonatisporites abstrusus* and *U. distinctus*.

Probable age; Lower Courceyan. Utting *et al.* (1989) indicated that the assemblage is typical of the Western European *Kraeuselisporites hibernicus – Umbonatisporites distinctus* (HD) Biozone as defined by Clayton (1985) and Higgs *et al*. (1988).

***Vallatisporites vallatus* Assemblage Zone** (Utting *et al.* 1989),
***Umbonatisporites abstusus* – *Umbonatisporites distinctus* Assemblage Subzone** (Utting *et al.* 1989)

First appearances; *Raistrickia clavata, Retusotriletes crassus, Rugospora minuta, Spelaeotriletes cabotii, Spelaeotriletes pretiosus, Vallatisporites vallatus* and *V. verrucosus.*

Last appearances*; Umbonatisporites abstrusus, U. distinctus.*

Abundance characteristics*; Spelaeotriletes cabotii* abundant, *Vallatisporites vallatus* common.

Probable age; Upper Courceyan. Utting *et al.* (1989) suggested that the first stratigraphic appearance of rare specimens of *Spelaeotriletes* var. *pretiosus* and the occurrence of both *Vallatisporites vallatus* and *Raistrickia clavata* throughout the sub-biozone indicate an age no older than the Western European *Spelaeotriletes pretiosus – Raistrickia clavata* (PC) Zone as defined by Clayton (1985) and Higgs *et al.* (1988).

***Spelaeotriletes cabotii* Assemblage Subzone** (Utting *et al.* 1989)

First appearances; *Crassispora trychera, Schopfites claviger*

Last appearance*; Raistrickia corynoges*

Abundance characteristics*; Spelaeotriletes cabotti* abundan*t, Vallatisporites vallatus* common. Rare *Crassispora trychera, Schopfites claviger.*

Probable age; Late Courceyan. Based on the appearance of rare *Crassispora trychera* and *Schopfites claviger*, Utting *et al.* (1989) correlated the subzone with a stratigraphic horizon near the upper part of the Western European *Spelaeotriletes pretiosus – Raistrickia clavata* (PC) Zone.

***Spelaeotriletes pretiosus* Assemblage Zone** (Utting *et al.* 1989)

First appearance; *Auroaspora macra.*

Abundance characteristics; a predominance of *Spelaeotriletes* var. *pretiosus* distinguishes the biozone from the *Vallatisporites vallatus - Spelaeotriletes cabotii* assemblage.

Probable age; Late Courceyan. Utting *et al.* (1989) correlated the zone with a stratigraphic horizon near the boundary of the Western European *Spelaeotriletes pretiosus – Raistrickia clavata* (PC) and *Schopfites claviger – Auroraspora macra* (CM) Biozones as defined by Clayton (1985) and Higgs *et al.* (1988).

***Colatisporites decorus – Schopfites claviger* Assemblage Zone** (Utting *et al.* 1989)

First appearances; non recognised

Abundance characteristics; *Auroraspora macra, Colatisporites decorus, Crassispora trychera, Punctatisporites glaber* and *P. irrasus* are common to abundant. *Crassispora trychera, Schopfites claviger* and *Verrucosisporites nitidus* are present.

Probable age; Late Courceyan. Based on the similarity in spore assemblages, Utting *et al.* (1989) correlated the zone with the *Schopfites claviger – Auroraspora macra* (CM) Zone of Western Europe as defined by Clayton (1985) and Higgs *et al.* (1988).

***Lycospora pusilla – Densosporites columbaris* Concurrent Range Zone** (Utting and Giles 2004)

First appearances; *Lycospora pusilla, Lycospora noctuina, Densosporites columbaris*

Last appearance; non recognised

Abundance characteristics; *Colatisporites decorus, Crassispora trychera, Punctatisporites glaber* and *Spelaeotriletes echinatus* are common to abundant.

Palynological event; earliest occurrence of the genus *Lycospora.*

Age; Chadian to Arundian. Based on the appearance of *L. pusilla*, Utting and Giles (2004) correlated the zone with the *Lycospora pusilla* (Pu) Biozone of Western Europe, as defined by Clayton (1985).

***Knoxisporites stephanephorus* Concurrent Range Zone** (Utting and Giles 2004)

First appearances; *Auroraspora solisorta, Knoxisporites probolos, Knoxisporites stephanephorus, Spelaeotriletes tuberosus*

Abundance characteristics; *Crassispora trychera* and *Rugospora minuta* are abundant.

Probable age; Asbian. Utting and Giles (2004) tentatively correlated the zone in part with the *Knoxisporites triradiatus – K. stephanephorus* (TS) Zone of Clayton (1985) based on the appearance of *K. stephanephorus*. Utting and Giles indicate that the first appearance of the *K. triradiatus* is in the younger *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Biozone; therefore later than in Western Europe.

***Schopfipollenites acadiensis* – *Knoxisporites triradiatus* (AT) Zone** (Utting 1987, Utting and Giles 2004; von Bitter *et al.* 2007)

First appearances; *Knoxisporites triradiatus, Rugospora corporate* var. *verrucosa, Schopfipollenites acadiensis* and *Secarisporites remotus*.

Abundance characteristics; *Crassispora trychera* and *Rugospora minuta* are generally abundant.

Palynological events; Earliest occurrence of genus *Schopfipollenites.*

Probable age; Brigantian. Although the zone only contains a few taxa in common with the Brigantian of Western Europe, in the upper part of the zone in south-western Newfoundland, *Crassispora maculosa* and *Spelaeotriletes arenaceus* are recorded. The earliest occurrence of *C. maculosa* is recorded in the Brigantian age Western European *Tripartites vetustus* - *Rotaspora fracta* (VF) zone of Clayton *et al.* (1977) (Utting *et al*. 2010)

***Grandispora spinosa* – *Ibrahimispores magnificus* Zone** (Utting 1987; Utting and Giles 2004: von Bitter *et al*. 2007).

First appearances; *Grandispora spinosa, Ibrahimispores magnificus, Raistrickia nigra, Schulzospora bilunata* and *Tricidarisporites arcuatus.*

Abundance characteristics; *Crassispora trychera* and *Rugospora minuta* are generally abundant.

Palynological events; Earliest occurrences of genera *Ibrahimispores* and *Schulzospora*.

Probable age; Latest Brigantian to Pendleian? A Brigantian age was initially proposed by Utting and Giles (2004) based largely on the fact that *Grandispora spinosa* first appears in the Brigantian age Western European *Tripartites vetustus-Rotaspora fracta* (VF) Biozone of Clayton *et al.* (1977). Utting *et al.* (2010) suggest that the appearance of *Ibrahimispores magnificus* may indicate an early Pendleian age, based on its range in Europe.

***Reticulatisporites carnosus* Assemblage Zone** (Utting and Giles 2008)

First appearances; *Anapiculatisporites baccatus, Corrugitriletes radiatus, Crassispora kosankei, Cribrosporites cribellatus, Dictyotriletes castaneaformis, Florinites pumicosus, Granulatisporites microgranifer, Grumosisporites rufus, Grumosisporites verrucosus, Microreticulatisporites concavus, Potonieisporites elegans, Reticulatisporites carnosus, Reticulatisporites polygonalis, Savitrisporites nux, Waltzispora planiangulata.*

Abundance characteristics; *Reticulatisporites carnosus* is consistently present, but not common. *Crassispora maculosa, Cribrosporites cribellatus, Grandispora spinosa, Grumosisporites rufus, Kraeuselisporites ornatus, Microreticulatisporites concavus, Raistrickia nigra, Savitrisporites nux* and *Verrucosisporites morulatus* are rare. Common to abundant in some samples are *Anapiculatisporites baccatus, Crassispora kosankei*, *Granulatisporites microgranifer, Lycospora noctuina, L. pusilla* and *Waltzispora planiangulata*. Monosaccate pollen *Florinites* spp. and *Potonieisporites elegans* are rare and sporadic.

Palynological events; First rare and sporadic occurrence of monosaccate pollen *Florinites* spp. and *Potonieisporites elegans*.

Probable age; ?Pendleian-Arnsbergian. Utting and Giles (2008) indicate that based on range data from the North Sea (McLean *et al.* 2005), the presence of rare *Florinites* spp. and *Potonieisporites elegans* indicate an age no older than the Arnsbergian Substage. However, Clayton *et al.* (1977) recorded *P. elegans* in the Pendleian of northern England. In Great Britain and the North Sea, the range base of *Reticulatisporites carnosus* is recorded in the upper Brigantian. The range top in Britain is recorded at the top of the Pendleian Substage. *Crassispora kosankei* and *Grumosisporites rufus* have range bases in the Pendleian and the range base of *Kraeuselisporites ornatus* is recorded in the upper Arnsbergian (Owens *et al.* 2004; McLean *et al.* 2005). According to Owens *et al.* and McLean *et al.* the association of

R. nigra, V. morulatus, G. verrucosus, M. concavus and *R. carnosus* suggests an age no younger than Arnsbergian. Overall Utting and Giles (2008) propose a Pendleian to Arnsbergian age for the base of the *Reticulatisporites carnosus* Zone and a top no younger than Arnsbergian in age.

Raistrickia saetosa **Assemblage Zone** (Utting *et al.* 2010)

First appearances; *Lophotriletes microsaetosus, Florinites similis, Apiculatisporis abditus, Raistrickia saetosa, Schopfipollenites ellipsoides, Potonieisporites /Florinites/Wilsonites/Guthoerlisporites* PFWG monosaccate complex.

Abundance characteristics*;* Common to abundant are *Florinites pumicosus, Lycospora pellucida, Lycospora pusilla, Potonieisporites elegans, Schopfipollenites ellipsoides* and taxa of the PFWG monosaccate complex.

Probable age; Yeadonian? to Langsettian. Utting *et al*. (2010) suggested that the presence of *Apiculatisporites spinulistratus* indicates an age close to the Yeadonian/Langsettian boundary. This is based on range data from the North Sea (McLean *et al.* 2005). Occurrences of *Apiculatisporites abditus* also suggest a Marsdenian or younger age. *Raistrickia saetosa* is also known to occur in the Marsdenian to Langsettian of Britain (Turner and Spinner 1993).

Palynological events; The base of the biozone is marked by an increase in the abundance of gymnosperm pollen of the PFWG monosaccate complex

Raistrickia fulva **Concurrent Range Zone** (Utting *et al.* 2010)

First appearances; *Dictyotriletes muricatus, Granasporites irregularis, Laevigatosporites minimus, Laevigatosporites minor, Laevigatosporites vulgaris, Latosporites minutus, Lycospora rotunda, Microreticulatisporites concavus, Punctatosporites* spp.*, Raistrickia fulva*.

Abundance characteristics; Common to abundant; *Lycospora pellucida, Lycospora pusilla, Lycospora rotunda, Potonieisporites elegans*. Present to common are members of the PFWG monosaccate complex and small monolete species of *Laevigatosporites, Latosporites* and *Punctatosporites*. Occurrences of *Cirratriradites rarus* are rare and *Cirratriradites saturni* are extremely rare.

Probable age; Langsettian. Utting *et al.* (2010) indicated that the presence of *Cirratriradites saturni* suggests an age no older than the Langsettian based on its range in the British Isles (Owens *et al.* 2004). The presence of *Spelaeotriletes arenaceus* suggests an age no younger than the mid-Langsettian based on range data from the North Sea and Western Europe (McLean *et al.* 2005; Clayton *et al.* 2003).

Palynological events; Earliest occurrences of small species of monolete genera *Laevigatosporites, Latosporites* and *Punctatosporites*.

Vestispora magna **Assemblage Zone** (Utting *et al.* 2010)

First appearances; *Microreticulatisporites nobilis, Mooreisporites fustis, Vestispora magna.*

Abundance characteristics. Common to abundant occurrences of *Florinites mediapudens, Florinites pumicosus, Lycospora pellucida, Lycospora pusilla, Mooreisporites fustis* and *Schopfipollenites ellipsoides. Potonieisporites elegans*, along with the PFWG monosaccate complex are common.

Palynological event; Earliest occurrence of the genus *Vestispora*.

Probable age; late? Duckmantian. Utting *et al.* (2010) suggested that the first stratigraphic appearance of *Microreticulatisporites nobilis* in the *Vestispora magna* Zone indicates an age no older than Duckmantian. This was based on the range of the taxon in the North Sea (McLean *et al.* 2005). The absence of *Torispora* spp. and *Vestispora fenestrata* also suggests an age no younger than the lower Bolsovian, based on ranges of the taxa in Western Europe (Clayton *et al.* 2003). *Savitrisporites nux, Raistrickia fulva, Vestispora tortuosa* and *Reticulatisporites polygonalis* are all recorded in the zone and have their last occurrence in the Bolsovian age W6 Biozone of the North Sea (McLean *et al.* 2005).

***Vittatina* Zone E, *Potonieisporites* Zone D, *Thymospora* Zone C, *Torispora* Zone B, *Vestispora* Zone A** (Barss and Hacquebard 1967)

Proposed by Barss and Hacquebard (1967), Zones A and B were dated as Bolsovian in age, Zone C as Asturian, Zone D as Stephanian and Zone E as early Permian (?Autunian) in age. The biozones were named after the most diagnostic genus present. Ranges of key taxa recorded in the zones are shown in figure 2.11.

APPENDIX IV

EXISTING PALYNOLOGICAL SLIDES USED IN STUDY

Well	Data Source		
	PAD Sample Store	TCD Geological Museum	Millennia Stratigraphic Consultants
12/2-1z			*
12/13-1			
13/3-1		Robeson (1988). Derived mainly from cuttings, some SWC.	
19/5-1		Robeson (1988). Derived mainly from cuttings, some SWC.	
26/21-1			
26/26-1			
26/28-1		Robeson (1988). Derived mainly from cuttings, some SWC.	
26/28-2		Robeson (1988). Derived from cuttings	
26/28-3		Robeson (1988). Derived mainly from cuttings, some SWC.	
26/28-4a			
26/27-1b	King *et al.* (1981). Derived from SWC, core and cuttings.		
26/29-1			
26/30-1			
27/5-1			Millennia Stratigraphic Consultants (1996). Derived mainly from cuttings, some SWC
34/5-1		Robeson (1988). Derived from cuttings.	
34/15-1			
34/19-1			
35/15-1	Unknown author.		
36/16-1		Robeson (1988). Derived mainly from cuttings, some SWC	

* Palynological slides prepared for well 12/2-1z were requested from Millennia Stratigraphic Consultants, but could not be provided.

APPENDIX V
SAMPLE DATA

V.I SAMPLES PROCESSED FOR PALYNOSTRATIGRAPHY

Sample source codes;

PAD – Petroleum Affairs Division, Ireland.

NHM – Natural History Museum, London, UK.

SLR – SLR Consulting, Ireland.

Well	Depth (m)	Cuttings /Core	Remarks	Sample Code	Sample Source
27/5-1	1642	Cuttings		AH1	PAD
27/5-1	1645	Cuttings	Barren	AH2	PAD
27/5-1	1651	Cuttings		AH4	PAD
27/5-1	1660	Cuttings	Coal sample	AH7	PAD
27/5-1	1663	Cuttings		AH8	PAD
27/5-1	1669	Cuttings		AH9	PAD
27/5-1	1672	Cuttings		AH10	PAD
27/5-1	1678	Cuttings		AH12	PAD
27/5-1	1684	Cuttings		AH14	PAD
27/5-1	1693	Cuttings		AH17	PAD
27/5-1	1702	Cuttings		AH20	PAD
27/5-1	1705	Cuttings		AH21	PAD
27/5-1	1714	Cuttings		AH24	PAD
27/5-1	1717	Cuttings	Coal sample	AH25	PAD
27/5-1	1720	Cuttings		AH26	PAD
27/5-1	1726	Cuttings		AH28	PAD
27/5-1	1732	Cuttings	Coal sample	AH30	PAD
27/5-1	1738	Cuttings		AH32	PAD
27/5-1	1753	Cuttings		AH36	PAD
27/5-1	1756	Cuttings	Coal sample	AH37	PAD
27/5-1	1759	Cuttings		AH38	PAD
27/5-1	1768	Cuttings	Coal sample	AH41	PAD
27/5-1	1771	Cuttings		AH42	PAD
27/5-1	1780	Cuttings		AH45	PAD
27/5-1	1786	Cuttings		AH48	PAD
27/5-1	1789	Cuttings		AH49	PAD
27/5-1	1792	Cuttings		AH50	PAD
27/5-1	1804	Cuttings		AH55	PAD
27/5-1	1807	Cuttings	Coal sample	AH56	PAD
27/5-1	1819	Cuttings		AH60	PAD
27/5-1	1825	Cuttings		AH61	PAD
27/5-1	1828	Cuttings		AH62	PAD
27/5-1	1834	Cuttings	Coal sample	AH64	PAD
27/5-1	1849	Cuttings		AH69	PAD
27/5-1	1861	Cuttings		AH72	PAD

27/5-1	1870	Cuttings	Coal sample	AH75	PAD
27/5-1	1882	Cuttings		AH79	PAD
27/5-1	1894	Cuttings		AH83	PAD
27/5-1	1900	Cuttings		AH85	PAD

Well	Depth (m)	Cuttings /Core	Remarks	Sample Code	Sample Source
12/2-1z	4308.5	SWC	Barren	AH98	SLR
12/2-1z	4316.4	SWC	Barren	AH97	SLR
12/2-1z	4324	Cuttings		R4	PAD
12/2-1z	4325.7	SWC	Barren	AH93	SLR
12/2-1z	4333	Cuttings		R6	PAD
12/2-1z	4342	Cuttings		R8	PAD
12/2-1z	4344.11	SWC	Barren	AH92	SLR
12/2-1z	4360	Cuttings		R11	PAD
12/2-1z	4375	Cuttings		R13	PAD
12/2-1z	4378	SWC	Barren	AH91	SLR
12/2-1z	4384	Cuttings		R15	PAD
12/2-1z	4396	Cuttings		R17	PAD
12/2-1z	4397	SWC	Barren	AH89	SLR
12/2-1z	4408	Cuttings		R18	PAD
12/2-1z	4426	Cuttings		R20	PAD
12/2-1z	4441	Cuttings		R22	PAD
12/2-1z	4459	Cuttings		R24	PAD
12/2-1z	4468	Cuttings		AH106	PAD
12/2-1z	4471	Cuttings		R27	PAD

Well	Depth (m)	Cuttings /Core	Remarks	Sample Code	Sample Source
26/21-1	2036	Cuttings		PE1	PAD
26/21-1	2054	Cuttings		PE3	PAD
26/21-1	2081	Cuttings		PE6	PAD
26/21-1	2105	Cuttings		PE8	PAD
26/21-1	2114	Cuttings		PE9	PAD
26/21-1	2126	Cuttings		PE10	PAD
26/21-1	2135	Cuttings		PE11	PAD
26/21-1	2144	Cuttings		PE12	PAD

Well	Depth (m)	Cuttings /Core	Remarks	Sample Code	Sample Source
26/28-1	2770.6	Core		NHM3	NHM
26/28-1	2845	Cuttings	Coal sample	26/28-1 2845m Coal	PAD
26/28-1	2925	Cuttings	Coal sample	26/28-1 2925m Coal	PAD
26/28-1	3095	Cuttings	Coal sample Barren	26/28-1 3095m Coal	PAD

Well	Depth (m)	Cuttings /Core	Remarks	Sample Code	Sample Source
26/28-2	2355	Cuttings	Coal sample	26/28-2 2355m Coal	PAD
26/28-2	2373	SWC		NHM1	NHM
26/28-2	2401	SWC		NHM2	NHM
26/28-2	2525	Cuttings	Coal sample	26/28-2 2525m Coal	PAD

V.II SAMPLES PROCESSED FOR PALYNOFACIES ANALYSIS

Well	Depth (m)	Cuttings /Core	Remarks	Sample Code	Sample Source
34/5-1	775	Cuttings		PE18	PAD
34/5-1	800	Cuttings		PE20	PAD

Well	Depth (m)	Cuttings /Core	Remarks	Sample Code	Sample Source
36/16-1	4340-50	Cuttings		OST1	PAD
36/16-1	4480-90	Cuttings		OST3	PAD
36/16-1	4570-80	Cuttings		OST4	PAD

APPENDIX VI
SYSTEMATIC PALYNOLOGY

Anteturma SPORITES H. Potonié 1893.

Turma TRILETES Reinsch emend. Dettmann 1963.
Suprasubturma ACAMERATITRILETES Neves & Owens 1966.
Subturma AZONOTRILETES Luber emend. Dettmann 1963.
Infraturma LAEVIGATI Bennie & Kidston emend. Potonié 1956.

Genus CALAMOSPORA Schopf, Wilson and Bentall 1944.

Type species. *C. hartungiana* Schopf *in* Schopf, Wilson and Bentall 1944.
Diagnosis. See Schopf *et al.* (1944, p. 49).
Comparison. *Calamospora* differs from *Punctatisporites* Ibrahim emend. Potonié and Kremp 1954 in possessing contact areas, shorter laesurae and pronounced secondary folding.

Calamospora breviradiata Kosanke 1950.

Plate 1, figures 2 and 3.

1950 *Calamospora breviradiata* Kosanke, p. 41, pl. 9, fig. 4.

Holotype. Kosanke 1950, pl. 9, fig. 4. Maceration 579-B, slide 1.
Type locality. No. 2 Coal, Bureau County, Illinois, U.S.A.; Carbondale Group.
Diagnosis. (Smith and Butterworth 1967, p. 131, from Kosanke 1950, p. 41). 'Amb circular or irregular through folding. Laesurae ridged, one-third to one-half of radius. Contact area developed.'
Size in microns. (i) Holotype 65.1 x 57.7; 52-71, Schulze and 10% KOH (Kosanke 1950). (ii) 61(69)75, offshore western Ireland, this study.
Remarks. Radius of contact area is less than the length of the laesurae.
Comparison. The short, ridged laesurae and darkened contact areas distinguish *Calamospora breviradiata* from other similar size species of the genus.

Calamospora cf. *breviradiata* Kosanke 1950.

Plate 1, figure 5.

Description. (Smith and Butterworth 1967, p. 132). 'Amb generally circular. Laesurae distinct and straight, one-third to one-half of radius (average 10µm). Darkening of exine around proximal pole, not extending to limit of laesurae. Exine thin, but more robust than in some other species of the genus. Limited number of compression folds, generally occurring towards margin; sometimes virtually without folds.'

Size in microns. (i) 42(49)57, fum. HNO_3; Tillery Rider seam, Tirpentwys Colliery, South Wales Coalfield; lower Westphalian D (lower Asturian) (Smith and Butterworth 1967). (ii) 44(48)50, offshore western Ireland, this study.

Remarks. *Calamospora* cf. *breviradiata* is a smaller form of *C. breviradiata.*

Calamospora microrugosa (Ibrahim) Schopf *in* Schopf, Wilson and Bentall 1944.

Plate 1, figure 1.

1932 *Sporonites microrugosus* Ibrahim *in* Potonié, Ibrahim and Loose, p. 447, pl. 14, fig. 9.
1933 *Laevigati-sporites microrugosus* (Ibrahim) Ibrahim, p. 18, pl. 1, fig. 9.
1938 *Azonotriletes microrugosus* (Ibrahim) Waltz *in* Luber and Waltz, p. 10, pl. 1, fig. 1 and pl. A, fig. 1.
1944 *Calamospora microrugosus* (Ibrahim) Schopf, Wilson and Bentall, p. 52.
1952 *Leiotriletes microrugosus* (Ibrahim) Ishchenko, p. 15, pl. 2, fig. 19.
1955 *Calamotriletes microrugosus* (Ibrahim) Luber, p. 36, pl. 1, figs. 1-3.

Holotype. Ibrahim 1932, pl. 14, fig. 9. Preparation A42, c6 (1).

Type locality. Agir Seam, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 133, from description and diagnosis in Potonié and Kremp 1955, p. 49). 'Amb more or less circular, often very irregular due to compression folding. Laesurae weakly ridged, straight or flexuose, one-third of radius. Exine structureless, about 2/3µm in thickness. Secondary compression folds numerous.'

Size in microns. (i) Holotype 77, Schulze and KOH. (ii) 70-100, Schulze (Potonié and Kremp 1955). (iii) 62(82)104 Schulze and NH_4OH (Playford 1962); Spitsbergen; Lower Carboniferous. (iv) 83 & 95 (two specimens), offshore western Ireland, this study.

Calamospora mutabilis (Loose) Schopf, Wilson and Bentall 1944.

Plate 1, figure 4.

1932 *Calamiti ?-Sporonites mutabilis* Loose *in* Potonié, Ibrahim and Loose, p. 451, pl. 19, figs. 50a-c.
1932 *Calamiti ?-Sporonites mutabilis* Loose, p. 145.
1944 *Calamospora mutabilis* (Loose) Schopf, Wilson and Bentall, p. 52.

Holotype. Loose 1932, pl. 19, fig. 50b. Preparation I36, m.

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 134, from description and diagnosis in Potonié and Kremp 1955, p. 49). 'Amb round to oval with occasional tendancy to triangular shape. Laesurae slightly flexuose, about one-half of radius. Contact area recognizable. Exine about 1µm in thickness.'

Size in microns. (i) Holotype 126, Schulze. (ii) 65-130, Schulze (Potonié and Kremp 1955). (iii) 75-100, Schulze (Bharadwaj 1957). (iv) 70(80)100, offshore western Ireland (Robeson 1988).

Remarks. Contact areas are bound by faint curvaturae.

Comparison. The presence of curvaturae distinguishes *Calamospora mutabilis* from other similar sized species of the genus.

Calamospora parva Guennel 1958.

Plate 1, figure 8.

1958 *Calamospora parva* Guennel, p. 70-71, pl. 4, fig. 12, text-fig. 16.

Holotype. Guennel 1958, fig. 16, p. 71. Sample 66, slide 4104.

Type locality. Outcrop coal, Upper Block b zone, Daviess County, Indiana, U.S.A.; Pottsville Series.

Diagnosis. (Smith and Butterworth 1967, p. 136 from description in Guennel 1958, p. 70). 'Amb circular to elliptical. Laesurae one-third of radius. Exine thicker and darker in contact areas. Folding common.'

Size in microns. (i) Holotype 38; 32(37)45, Schulze (Guennel 1958). (ii) 37(45)55, fum. HNO_3; Cannel Seam, Bagworth Colliery, Leicestershire Coalfield, England; lower Westphalian B (lower Duckmantian) (Smith and Butterworth 1967). (iii) 44 (one specimen), offshore western Ireland, this study.

Remarks. Laesurae are simple with lengths of one-third to one-half of the radius (Smith and Butterworth 1967).

Calamospora pedata Kosanke 1950.

Plate 1, figure 6.

1950 *Calamospora pedata* Kosanke, p. 42, pl. 9, fig. 3.

Holotype. Kosanke 1950, pl. 9, fig. 3. Maceration 542-C, slide 3.

Type locality. No. 8 Coal, Peoria County, Illinois, U.S.A.; McLeansboro Group.

Diagnosis. (Smith and Butterworth 1967, p. 136, from description in Kosanke 1950, p. 42). 'Amb circular to sharply lenticular as a result of compression. Laesurae thin, but distinct, two-thirds of radius or more. Exine relatively thick 2-3µm.'

Size in microns. (i) Holotype 70.3 x 44.1; 41-75, Schulze and 10% KOH (Kosanke 1950). (ii) 58(66)72, offshore western Ireland, this study.

Remarks. Often only one major fold is present.

Comparison. The laesurae length, thick exine and relatively few folds distinguish *Calamospora pedata* from other species of the genus.

Calamospora straminea Wilson and Kosanke 1944.

Plate 1, figure 7.

1944 *Calamospora straminea* Wilson and Kosanke, p. 329, pl. 1, fig. 1.

1958 *Punctatisporites stramineus* (Wilson and Kosanke) Guennel, p. 68, pl. 4, figs. 5-8.

Holotype. Wilson and Kosanke 1944, pl. 1, fig. 1. Slide No. 276 P, circle 2.

Type locality. Coal from Angus Coal Company Mine, Iowa, U.S.A.; Des Moines Series.

Diagnosis. (Smith and Butterworth 1967, p. 137, from description in Wilson and Kosanke 1944, p. 329). 'Amb circular. Laesurae about one-half of radius. Frequent tapering and pointed compression folds. Exine 3μm thick.'

Size in microns. (i) 30-45, maceration method not known (Wilson and Kosanke 1944). (ii) 31(39)47, fum. HNO_3; seam at 56ft. 4in., Murton Colliery borehole, Durham Coalfield, England; upper Westphalian B (upper Duckmantian) (Smith and Butterworth 1967). (iii) 32 & 47 (two specimens), offshore western Ireland, this study.

Remarks. Laesurae are of unequal length and few compression folds are present. Specimens also possess a darker contact area.

Genus **LEIOTRILETES** Naumova emend. Potonié and Kremp 1954.

Type species. *L. sphaerotriangularis* (Loose) Potonié and Kremp 1954.

Diagnosis. See Potonié and Kremp (1954, p. 120).

Remarks. A number of workers (e.g. Ravn 1986, McLean 1993) follow the practice of Staplin (1960) in referring triangular, laevigate, trilete spores to the post-Palaeozoic genus *Deltoidospora* Miner 1935.. Staplin suggested that separation in time is not a valid reason for separate form-genera. However, Playford (1962) indicated that although the argument of Staplin is valid, the problem is not confined to *Leiotriletes*. The relationships between comparatively characterless form-genera such *Calamospora* and *Punctatisporites* Ibrahim emend. Potonié and Kremp 1954 and their Mesozoic equivalents are equally unresolved. As the genera *Calamospora* and *Punctatisporites* are still in common usage, the genus *Leotriletes* is retained. This follows the practice of workers such as Playford (1962) and Smith and Butterworth (1967).

Leiotriletes sphaerotriangularis (Loose) Potonié and Kremp 1954.

Plate 1, figure 9.

1932 *Sporonites sphaerotriangularis* Loose *in* Potonié, Ibrahim and Loose, p.451, pl. 18, fig. 45.

1933 *Laevigati-sporites sphaerotriangularis* (Loose) Ibrahim, p. 20.

1944 *Punctati-sporites sphaerotriangularis* (Loose) Schopf, Wilson and Bentall, p. 31.
1950 *Plani-sporites sphaerotriangularis* (Loose) Knox, p. 316, pl. 17, fig. 214.
1954 *Leiotriletes sphaerotriangularis* (Loose) Potonié and Kremp, p. 120.

Holotype. Potonié and Kremp 1955, pl. 11, fig. 107 after Loose. Preparation IV21, f_2 (m/ol).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p.123, translated from Potonié and Kremp 1955, p.41). 'Amb triangular, sides in part slightly convex. Laesurae extend nearly to equator. Exine weakly infrapunctate.'

Size in microns. (i) Holotype 43.5, Schulze. (ii) 40-60, Schulze (Potonié and Kremp 1955). (iii) 30-66, fum. HNO_3 (Horst 1955). (iv) 38(46)55, fum. HNO_3; Swallow Wood Seam, Denaby Main Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (v) 37 & 40 (two specimens) offshore western Ireland, this study.

Leiotriletes tumidus Butterworth and Williams 1958.

Plate 1, figure 10.

1958 *Leiotriletes tumidus* Butterworth and Williams, p. 128, pl. 32, figs 10-12.

Holotype. Smith and Butterworth 1967, pl. 1, fig. 11. Preparation no. T32/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Kilsyth Coking Seam at 1,097ft. 0in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth, p. 124, from Butterworth and Williams 1958, p. 359) '…elongated triangular in outline; spore coat smooth. Proximal hemisphere tumid; trilete rays long, typically with ray folds.'

Size in microns. (i) Holotype 46; 34(42)52 (23 specimens), fum. HNO_3 (Butterworth and Williams 1958).

Genus **SINUSPORES** Artüz emend Ravn 1986.

Type species. *S. sinuatus* Artüz emend Ravn 1986.

Diagnosis. (Ravn 1986, p. 80). Miospores trilete. Amb circular. Exine laevigate or nearly so. A broad rounded subequatorial thickening of the exine connects the end of the rays to form a curvaturae.

Sinuspores sinuatus Artüz emend Ravn 1986.

Plate 1, figure 12.

1957 *Sinuspores sinuatus* Artüz, p. 254, pl. 7, fig. 48.
1958 *Punctatisporites densoarcuatus* Neves, p. 6, pl. 2, fig. 7.
1958 *Punctatisporites coronatus* Butterworth and Williams, p. 360, pl. 1, fig. 12.
1961 *Punctatisporites sinuatus* (Artüz) Neves, p. 252.
1986 *Sinuspores sinuatus* Artüz emend. Ravn, p. 80, pl. 23, figs. 9-12.

Holotype. Artüz 1957, pl. 7, fig. 48. Preparation I, 30, 1c.

Type locality. Büyük Seam, Zonguldak Coalfield, Turkey; Westphalian A.

Diagnosis. (Ravn 1986, p. 80). Miospores conforming to the characteristics of the genus. Trilete rays straight, distinct, 2/3 to 3/4 of radius, often open. Exine thick (5µm or more), commonly with low, irregular folds which may be arranged adjacent to the curvaturae thickening.

Size in microns. (i) Holotype 120; 90-130, maceration method not known (Artüz 1957). (ii) 80(117)140, Schulze and KOH (Neves 1958); roof shales of Six Inch Seam, North Staffordshire Coalfield, England; Namurian C. (iii) 75(102)116 (13 specimens), fum. HNO_3 (Butterworth and Williams 1958); Shale Seam at 663ft. 6in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A. (iv) 83 (one specimen), offshore western Ireland, this study.

Comparison. Distinguished from members of the genus *Punctatisporites* by its large size and low, irregular folds.

Sinuspores cf. *sinuatus*

Plate 1, figure 11.

Size in microns. (i) 40(55)70 (20 Specimens), Southern North Sea, (McLean 1993). (ii) 61 &72, (two specimens), offshore western Ireland, this study.

Remarks. Specimens assigned to *Sinuspores* cf. *sinuatus* are smaller forms of the type species.

PUNCTATISPORITES Ibrahim emend. Potonié and Kremp 1954.

Type species. *P. punctatus* Ibrahim 1933.

Diagnosis. See Potonié and Kremp (1954, p. 120).

Comparison. Compared with *Calamospora,* species belonging to the genus *Punctatisporites* possess a thicker exine and show less folding.

Punctatisporites aerarius Butterworth and Williams 1958.

Plate 1, figure 13.

1958 *Punctatisporites aerarius* Butterworth and Williams, p. 360, pl. 1, figs. 10, 11.

Holotype. Smith and Butterworth 1967,pl. 1, fig. 17. Preparation T33/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Lower Garscadden Ironstone Seam at 1,010 ft. 2in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 125, restated from Butterworth and Williams 1958, p. 360). 'Amb circular. Laesurae slightly longer than one-half of radius. Exine minutely granulate, up to 4µm in thickness.'

Size in microns. (i) Holotype 83 x 75, (ii) 55(74)92 (21 specimens), fum. HNO_3 (Butterworth and Williams 1958). (iii) 67, (one specimen), offshore western Ireland, this study.

Remarks. Margin is smooth to minutely indented. Grana are only just visible at the margin.

Comparison. *Punctatisporites punctatus* (Ibrahim) Ibrahim 1933 possesses a thinner exine, longer laesurae and is less consistently circular (Smith and Butterworth 1967).

Punctatisporites glaber (Naumova *in* Luber and Waltz) Playford 1962.

Plate 1, figure 15.

1938 *Azonotriletes glaber* Naumova *in* Luber and Waltz, p. 8, pl. 1, fig. 2.
1962 *Punctatisporites glaber* (Naumova) Playford, p. 576-577, pl. 78, figs. 15,16.

Holotype. Luber and Waltz (1938, pl. 1, fig. 2).

Description. (Playford 1962, p. 576). 'Spores radial, trilete; equatorial outline circular. Laesurae distinct, simple, straight, length one-third to two-thirds spore radius. Exine 1.5-2μm thick, laevigata (corroded specimens finely punctuate); rarely folded.'

Size in microns. (i) 32(52)70, (38 specimens) (Playford 1962). (ii) 36(42)51, offshore western Ireland, this study.

Punctatisporites minutus Kosanke 1950.

Plate 1, figure 16.

1950 *Punctatisporites minutus* Kosanke, p. 15, pl. 16, fig. 3.

Holotype. Kosanke 1950, pl. 16, fig 3. Maceration 584, slide 7.

Type locality. ?Woodbury Coal, Jasper County, Illinois, U.S.A.; McLeansboro Group.

Diagnosis. (Smith and Butterworth 1967, p. 126, from description in Kosanke 1950, p. 15). 'Originally spherical in shape with the spore coat variously folded. Laesurae distinct, two-thirds of radius, lips slightly developed. Exine 1-1.5μm thick and minutely punctate.'

Size in microns. (i) Holotype 29; 27-33, Schulze and 10% KOH (Kosanke 1950). (ii) 22(27)32 (18 specimens), fum. HNO_3; Shale Seam at 663ft 6in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A (Smith and Butterworth 1967). (iii) 26(30)33, offshore western Ireland, this study.

Remarks. No detectable sculpture at spore margin, folding is slight or absent.

Comparison. *Punctatisporites minutus* is distinguished from other species of the genus by its smaller size.

Punctatisporites obesus (Loose) Potonié and Kremp 1955.

Plate 1, figure 17.

1932 *Sporonites obesus* Loose *in* Potonié, Ibrahim and Loose, p. 451, pl. 19, fig. 49.
1934 *Laevigatosporites obesus* Loose, p. 145.
1944 ?*Calamospora obesus* (Loose) Schopf, Wilson and Bentall, p. 52.
1955 *Punctatisporites obesus* (Loose) Potonié and Kremp, p. 43, pl. 11, fig. 124.

Holotype. Loose 1932, pl. 19, fig. 49. Preparation III 6, e_4 (m).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 127, from description in Loose 1934, p. 145). 'Amb circular to oval. Laesurae one-third of radius. Exine laevigate to punctate, up to 5µm in thickness.'

Size in microns. (i) Holotype 117, Schulze. (ii) 100-130, Schulze (Potonié and Kremp 1955). (iii) 94(106)125, (8 specimens), fum. HNO_3; various horizons, Great Britain; Westphalian B to D (Duckmantian to Asturian) (Smith and Butterworth 1967). (iv) 106, (one specimen), offshore western Ireland, this study.

Punctatisporites punctatus (Ibrahim) Ibrahim 1933.

Plate 1, figure 14

1932 *Sporonites punctatus* Ibrahim *in* Potonié, Ibrahim and Loose, p. 448, pl. 15, fig. 18.
1933 *Punctati-sporites punctatus* Ibrahim, p. 21, pl. 2, fig. 18.

Holotype. Ibrahim 1932, pl. 15, fig. 18. Preparation B29, fl (ul).

Type locality. Ägir Seam, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 129, from Ibrahim 1933, p. 21). 'Amb circular to triangular. Laesurae reach to the equator. Exine 1-2µm thick; punctate; margin somewhat rough.'

Size in microns. (i) Holotype 77, Schulze and KOH. (ii) 50-80, Schulze (Potonié and Kremp 1955). (iii) 59(74)89 (14 specimens), fum. HNO_3; Swallow Wood Seam at 1,475ft. 0in., Kellingley borehole, Yorkshire Coalfield, England; Westphalian B

(Duckmantian) (Smith and Butterworth 1967). (iv) 61 (one specimen), offshore western Ireland, this study.

Genus **WALTZISPORA** Staplin 1960.

Type species. *W. lobophora* (Waltz) Staplin 1960.
Diagnosis. See Staplin (1960, p.18).

Waltzispora polita (Hoffmeister, Staplin and Malloy) Smith and Butterworth 1967.

Plate 1, figure 18.

1955 *Granulati-sporites politus* Hoffmeister, Staplin and Malloy, p. 389, pl. 36, fig. 13.
non 1960 *Leiotriletes politus* (Hoffmeister, Staplin and Malloy) Love, p. 111, pl. 1, fig. 1.
1967 *Waltzispora polita* (Hoffmeister, Staplin and Malloy) Smith and Butterworth, p. 159, pl. 6, fig. 14.

Holotype. Hoffmeister, Staplin and Malloy 1955, pl. 36, fig. 13. Preparation 6, ser. 15,718.
Type locality. Shale at 2,077ft., Carter No. 3 borehole (TCO-82), Webster County, Kentucky, U.S.A.; Hardinsburg Formation, Chester Series.
Diagnosis. (Smith and Butterworth 1967, p. 159, from description in Hoffmeister, Staplin and Malloy 1955, p. 389). 'Amb subtriangular; interradial margins concave or slightly convex, radial margins rounded. Trilete suture broad, two-thirds to three-quarters of radius. Surface smooth to infrapunctate. Exine moderately thin.'
Size in microns. (i) Holotype 37.5, 26-38, HF (Hoffmeister, Staplin and Malloy 1955). (ii) 36 & 36 (two specimens), offshore western Ireland, this study.
Remarks. In proximal view, the junction between radial and interradial margins is angular due to the rounded apices projecting laterally.

Infraturma APICULATI Bennie & Kidston emend. Potonié 1956.

Genus **ANAPICULATISPORITES** Potonié and Kremp 1954.

Type species. *A. isselburgensis* Potonié and Kremp 1954.

Diagnosis. See Potonié and Kremp (1954, p. 133).

Remarks. Use of this genus follows the practice of Playford (1971) and Ravn (1986). The genus comprises circular and rounded triangular miospores in which apiculate ornament is restricted to the distal surface and extends to the equator (including in interradial regions). Certain species which are strongly triangular and possess ornamentation which does not extend to the equator in interradial regions are transferred to the genus *Anacanthotriletes* Ravn 1986 (see Ravn 1986 p. 65-66). Ravn (1986) also regarded the genus *Anaplanisporites* Jansonius 1962 as a junior synonym of *Anapiculatisporites*. This practice is also followed.

Anapiculatisporites baccatus (Hoffmeister, Staplin and Malloy) Ravn 1986.
Plate 1, figure 19.

1955 *Punctatisporites? baccatus* Hoffmeister, Staplin and Malloy, p. 392, pl. 36, fig. 2.

1958 *Anaplanisporites baccatus* (Hoffmeister, Staplin and Malloy) Butterworth and Williams, p. 363, pl. 1, fig. 25.

1967 *Anaplanisporites baccatus* (Hoffmeister, Staplin and Malloy) emend. Smith and Butterworth, p. 166, pl. 7, figs. 1-5.

1986 *Anapiculatisporites baccatus* (Hoffmeister, Staplin and Malloy) Ravn, p. 85, pl. 23, figs. 2, 3.

Holotype. Hoffmeister *et al.* 1955, pl. 36, fig. 2. Preparation 8, ser. 19,087.

Type locality. Shale at 2,075ft., Carter No. 3 borehole (TCO-82), Webster County, Kentucky, U.S.A; Hardinsburg Formation, Chester Series.

Diagnosis. (Smith and Butterworth 1967, p. 166, emended from Hoffmeister, Staplin and Malloy 1955, p. 392). 'Amb circular to subcircular; laesurae slightly ridged, equal in length to spore radius. Ornamentation confined to distal surface; comprises numerous discrete coni with tapered to narrowly pointed apices; these number 35 to 45 at margin; height of coni 0.5-2µm, basal diameter 0.5-1.5µm. Exine thin.'

Size in microns. Holotype 29; 26-46, HF (Hoffmeister, Staplin and Malloy 1955). (ii) 22(26)30, fum. HNO_3; Bottom Busty Seam at 419ft 6in., Houghton Colliery borehole (14SW.3), Durham Coalfield, England, Westphalian A (Langettian) (Smith and Butterworth 1967). (iii) 30.5, (one specimen), offshore western Ireland, this study.

Anapiculatisporites globulus (Butterworth and Williams) Ravn 1986.

Plate 1, figure 20.

1958 *Apiculatisporis globulus* Butterworth and Williams, p. 363, pl. 1, figs. 26, 27.

1967 *Anaplanisporites globulus* (Butterworth and Williams) Smith and Butterworth p. 167, pl. 7, figs. 26, 27.

1986 *Anapiculatisporites globulus* (Butterworth and Williams) Ravn, p. 85, pl. 23, fig 5.

Holotype. Smith and Butterworth 1967, pl. 7, fig. 6. Preparation T38/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Cloven Seam at 1,764ft. 2 in., Queenslie Bridge borehole, Central Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 167, emended from Butterworth and Williams 1958, p. 363). 'Amb broadly rounded to triangular. Laesurae simple, straight, one-half to two-thirds of radius. Ornament restricted to distal surface, variable, consisting of small coni or verrucae, widely and irregularly spaced; approximately 15 to 30 project at equator. Proximal face laevigate.'

Size in microns. Holotype 38; 32(36)46, fum. HNO_3 (Butterworth and Williams 1958). (ii) 36 (one specimen), offshore western Ireland, this study.

APICULATASPORITES Ibrahim emend. Ravn 1986.

Type species. *A. spinulistratus* (Loose) Ibrahim 1933.

Diagnosis. See Ravn (1986, p. 38). '

Remarks. The present study follows Ravn (1986) who argued for the synonymy of the genera *Apiculatasporites* and *Apiculatisporis*. *Apiculatasporite*s has priority over *Apiculatisporis.*

Apiculatasporites spinulistratus (Loose) Ibrahim 1933.

Plate 2, figure 1.

1932 *Sporonites spinulistratus* Loose *in* Potonié, Ibrahim and Loose, p. 450, pl. 18, fig. 47.

1933 *Apiculata-sporites spinulistratus* (Loose) Ibrahim, p. 37.

1934 *Apiculati-sporites spinulistratus* Loose, p. 153.

1934 *Apiculati-sporites globosus* Loose, p. 152, pl. 7, fig. 14.

1944 *Punctati-sporites spinulistratus* (Loose) Schopf, Wilson and Bentall, p. 31.

1950 *Spinoso-sporites spinulistratus* (Loose) Knox, p. 314.

1955 *Planisporites spinulistratus* (Loose) Potonié and Kremp, p. 71, pl. 14, figs. 214-19.

Holotype. Potonié and Kremp 1955, pl. 14, fig. 214 after Loose 1932. Preparation IV9, d4 (m/or).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 176, translated from Potonié and Kremp 1955 p. 71). '….amb circular. Laesurae about two-thirds radius. Over 90 coni on the equatorial margin.'

Size in microns. (i) Holotype 53, Schulze. (ii) 45-75, Schulze (Potonié and Kremp 1955). (iii) 32(70-90)160, fum. HNO_3 (Horst 1955). (iv) 38(57)87, fum. HNO_3; Swallow Wood Seam, Denaby Main Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (v) 36(61)75, offshore western Ireland, this study.

Description. (Smith and Butterworth 1967, p. 176). 'Amb generally circular, rarely rounded - triangular. Laesurae simple, often of unequal length, with one or more laesurae curved; maximum length, two-thirds to full radius length; range 14-30µm (average 20µm). Height of coni generally 1µm but may reach about 2.5µm; diameter of base generally equals or exceeds height; on any individual spore the ornament is more or less uniform in size. Density of ornament also varies between individuals; the space between coni may equal, or somewhat exceed, their base dimensions. Exine 1.5µm thick, often with single compression fold.'

Comparison. *Crassispora kosankei* (Potonié and Kremp) Bharadwaj 1957 emend. Smith and Butterworth 1967 possesses a similar ornamentation to *Apiculatasporites spinulistratus* but lacks a definite trilete mark. *A. spinulistratus* also lacks a crassitude.

Apiculatasporites aculeatus (Ibrahim emend. Smith and Butterworth) Ravn 1986.

Plate 1, figure 21.

1933 *Apiculati-sporites aculeatus* Ibrahim, p.23, pl. 6, fig. 57.

1944 *Punctati-sporites aculeatus* (Ibrahim) Schopf, Wilson and Bentall, p. 30.

1950 *Spinoso-sporites aculeatus* (Ibrahim) Knox, p. 313.

1955 *Apiculatisporites aculeatus* (Ibrahim) Potonié and Kremp, p. 78, pl. 14, figs. 235, 236, 241.

1967 *Apiculatisporis aculeatus* (Ibrahim) emend. Smith and Butterworth, p. 170, pl. 7, figs 12, 13.

1986 *Apiculatasporites aculeatus* (Ibrahim emend. Smith and Butterworth) Ravn, p. 39, pl. 5, figs. 6, 7.

Holotype. Potonié and Kremp 1955, pl. 14, fig. 235 after Ibrahim. Preparation A27, d26 (or).

Type locality. Ägir Seam, Ruhr Coalfield, Germany; top of Westphalian B (top Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 170, emended from diagnosis and description in Potonié and Kremp 1955, p. 78). 'Amb circular, subcircular, or rounded-triangular. Laesurae simple and straight, about one-half radius. Coni narrow and pointed, about 2.5μm in height; basal diameter somewhat less, bases not in contact. Number of coni projecting from margin variable, mostly between 25 and 35.'

Size in microns. (i) Holotype 53; Schulze and KOH. (ii) 50-60, Schulze (Potonié and Kremp 1955). (iii) 32(43)58, fum. HNO_3; High Hazel Seam, Thorne Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 36(43)47, offshore western Ireland, this study.

Apiculatasporites latigranifer (Loose) Ravn 1986.

1932 *Sporonites latigranifer* Loose in Potonié, Ibrahim and Loose, p.452, pl. 19, fig. 54

1934 *Granulati-sporites latigranifer* Loose, p. 147.

1944 *Punctati-sporites latigranifer* (Loose) Schopf, Wilson and Bentall, p. 31.

1950 *Spinoso-sporites latigranifer* (Loose) Knox, p. 314.

1955 *Apiculatisporites latigranifer* (Loose) Potonié and Kremp, p. 79, pl. 14, figs. 244-245.

1967 *Apiculatisporis latigranifer* (Loose) Smith and Butterworth, p.172.

1986 *Apiculatasporites latigranifer* (Loose) Ravn, p. 39, pl. 6, fig. 7.

Holotype. Potonié and Kremp 1955, pl. 14, fig. 244 after Loose, Preparation III36, b_1 (ul).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 172, translated from Potonié and Kremp 1955, p. 79) '…laesurae greater than one-half radius. Coni somewhat openly distributed.'

Size in microns. (i) Holotype 78, Schulze. (ii) 55-90, Schulze (Potonié and Kremp 1955)

Apiculatasporites cf. *latigranifer*

Plate 2, figure 2.

Description. (Smith and Butterworth 1967, p. 172). 'Amb circular. Laesurae simple, straight, sometimes of unequal length, largest dimension between two-thirds and three-quarters of radius. Coni slightly variable in shape and size, bases usually equal to, or less than, heights which are generally between 1µm and 2.5µm. Coni well separated; number projecting from margin 15 to 25. Long portions of amb may be without ornament due to the localized distribution of coni. Generally without folds. Exine about 1.5 - 2µm thick.'

Size in microns. The size range of offshore western Irish specimens (64(69)72) fall within limits given by Potonié and Kremp for *Apiculatasporites latigranifer*.

Remarks. Differs from the type species in possessing more prominent ornamentation.

Apiculatasporites spinososaetosus (Loose) Ravn 1986.

Plate 1, figure 22.

1932 *Sporonites spinososaetosus* Loose in Potonié, Ibrahim and Loose, p. 452, pl. 19, fig. 55.

1933 *Apiculati-sporites spinososaetosus* (Loose) Ibrahim, p. 24.

1944 *Raistrickia spinososaetosus* (Loose) Schopf, Wilson and Bentall, p. 56.

1955 *Apiculatisporites spinosaetosus* (sic) (Loose) Potonié and Kremp, p. 80, pl. 14, figs 249.

1962 *Apiculatisporis spinosaetosus* (sic) (Loose) Piérart, tab. 2.

1967 *Apiculatisporis spinososaetosus* (Loose) Smith and Butterworth, p. 173, pl. 7, figs. 22, 23.

1986 *Apiculatasporites spinososaetosus* (Loose) Ravn, p. 40, pl. 5, fig. 18.

Holotype. Potonié and Kremp 1955, pl. 14, fig. 249; after Loose. Preparation I2, h.

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis (Smith and Butterworth 1967, p. 173, emended from diagnosis in Potonié and Kremp 1955, p. 80). 'Amb rounded-triangular. Laesurae one-half to two-thirds of radius. Ornament of loosely packed coni and bacula having heights more or less the same as basal diameters and generally less than 5µm. Between 15 and 30 elements project from margin.'

Size in microns. (i) Holotype 74, Schulze. (ii) 50-80, Schulze (Potonié and Kremp 1955). (iii) 38(50)60, fum. HNO_3; Dunsil Seam, Frickley Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 46(54)65 (four specimens), offshore western Ireland, this study.

Apiculatasporites variocorneus (Sullivan) Ravn 1986.

Plate 1, figure 23.

1964 *Apiculatisporis variocorneus* Sullivan, p. 363, pl. 58, figs. 4-8

1986 *Apiculatasporites variocorneus* (Sullivan) Ravn, p. 41, pl. 6, fig. 8, 9.

Holotype. Sullivan 1964, pl. 58, fig. 4. Preparation SMUD/1.

Type locality. Edgehills Coal, Drybrook Sandstone, Forest of Dean Coalfield, England; ?Westphalian A (?Langsettian).

Diagnosis. (Smith and Butterworth 1967, p. 173, from Sullivan 1964, p. 363). '….amb irregularly circular to oval; exine ornamented with cones and spines which range from 0.5 to 5.5µm in height; ornament variable in size, shape and density even on individual specimens, usually absent from intertectal areas.'

Size in microns. (i) 40(60)78, HF and 2% KOH (Sullivan 1964). (ii) 41(59)80, fum. HNO_3; Ganister Clay Seam at 214ft. 10in., Keverstone borehole (47 NE. 17), Durham Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967). (iii) 42(59)67, offshore western Ireland, this study.

Description. Trilete, acamerate miospores. Circular to oval amb, trilete mark rarely visible. Laesurae extend between one half and two thirds of spore radius. Ornamentation comprises coni and spines in varying proportions. Distal ornamentation up to 5µm in height and basal width. Elements are often closely spaced. Proximal ornamentation less than 2µm in height. Between 30 and 45 elements project from the amb. Exine often shows compressional folds.

Comparison. *Apiculatasporites variocorneus* is distinguished from other species of the genus by the uneven development of ornament.

CONVERRUCOSISPORITES Potonié and Kremp 1954.

Type species. *C. triquetrus* (Ibrahim) Potonié and Kremp 1954.
Diagnosis. See Potonié and Kremp (1954, p. 137).

Converrucosisporites cameronii (de Jersey 1962) Playford and Dettmann 1965.

Plate 2, figure 3.

Description. (Cornet and Traverse 1975). 'Isospores radial, trilete. Amb usually subtriangular with broadly rounded apices and sides slightly concave to slightly convex; amb sometimes subsphercial. Laesurae extend almost to, but rarely reach, equatorial margin and are usually bordered by narrow, slightly elevated lips. Kyrtomes prominently to weakly developed, not always present. Laesurae frequently bordered by arcuate folds concave toward proximal pole. Exine variably sculptured with a mixture of rounded or blunt-topped verrucae, large and small bacula, broad and narrow-based coni, rare clavae and grana. Sculpture comprehensive, although usually more scattered and reduced proximally. Distal and equatorial sculpture randomly spaced, distance between larger elements frequently greater than their diameter. Bases of sculptural elements usually joined to form a low, imperfect ridge system or incipient reticulum. When elements are large and closely spaced, many are fused into elongate, irregular tugae. Sculpture usually dominated by one type: verrucate 0.8-1.8µ in diameter and height, bacula 0.8-1.4µ high, coni 0.5-1.0µ high and clavae about 1.0µ high. Exine 0.4-0.8µ thick (exclusive of sculpture), single layered. Equatorial diameter (60 specimens) ranges from 33µ to 51µ (median 42µ), 90% of grains between 36µ and 49µ.'
Size in microns. (i) 33(42)51, Hartford Basin, Connecticut and Massachusetts, U.S.A (Cornet and Traverse 1975). (ii) 42(46)50, offshore western Ireland, this study.

CADIOSPORA (Kosanke) Venkatachala and Bharadwaj 1964.

Type species. *C. magna* Kosanke 1950.

Diagnosis. See Venkatachala and Bharadwaj (1964, p. 166).

Cadiospora magna Kosanke 1950.

Plate 2, figure 4

1950 *Cadiospora magna*, Kosanke, p.50, pl. 16, fig. 1.
1954 *Gravisporites sphaera* (Butterworth and Williams) Bharadwaj, p. 514, text-fig. 2.

Holotype. Kosanke 1950, pl. 16, fig. 1. Preparation 600, slide 15.

Type locality. La Salle Coal, Bureau County, Illinois, U.S.A.; McLeansboro Group.

Diagnosis. (Smith and Butterworth 1967 p. 145 from description in Kosanke 1950, p.50). '…the trilete rays vary in length from 40-45 microns. The suture is distinct and the lips vary in thickness from 4-5 microns on either side of the suture. The lips appear to continue as thickenings in association with the arcuate ridge. The apex of the rays (trilete aperture) is open or closed. The rays divide at the terminus of the rays and interradially become the arcuate ridge. The spore coat is minutely punctate to finely granulose, and measures 6-8 microns in thickness.'

Size in microns. (i) Holotype 117.6 x 111.3; 100-117.6, Schulze and 10% KOH (Kosanke 1950). (ii) 67(98)119 (10 specimens) Schulze; various Westphalian D (Asturian) coals (Smith and Butterworth 1967). (iii) 58(78)96 (20 specimens), fum. HNO_3, for *C. sphaera* (Butterworth and Williams 1954). (iv) 61(88)112, offshore western Ireland, this study.

Description. Acamerate, trilete miospores with a circular amb and distinct trilete mark. Laesurae are greater than 2/3 of the spore radius in length and show broad lips up to 5μm in thickness which merge with ridged curvaturae. Ornamentation comprises small, closely spaced grana (less than 0.5μm in height) and verrucae (up to 6μm in width and height), which occur in clusters or as single projections.

CYCLOGRANISPORITES Potonié and Kremp 1954.

Type species. *C. leopoldii* (Kremp) Potonié and Kremp 1954.

Diagnosis. See Potonié and Kremp (1954, p. 126).

Cyclogranisporites aureus (Loose) Potonié and Kremp 1955.

Plate 2, figure 6.

1934 *Reticulati-sporites aureus* Loose, p. 155, pl. 7, fig. 24.

1944 *Punctati-sporites aureus* (Loose) Schopf, Wilson and Bentall, p. 30.

1950 *Plani-sporites aureus* (Loose) Knox, p. 315.

1955 *Cyclogranisporites aureus* (Loose) Potonié and Kremp, p. 61, pl. 13, figs. 184-6.

Holotype. Potonié and Kremp 1955, pl. 13, fig. 184 after Loose. Preparation IV1, e_5 (ul).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 142, translated from Potonié and Kremp 1955, p. 61). 'Amb circular. Laesurae one half to two-thirds of radius. Grana over 1µm in diameter; 70 to 100 project at the margin.'

Size in microns. (i) Holotype 55.5, Schulze and KOH. (ii) 50-80, Schulze (Potonié and Kremp 1955). (iii) 59(72)82, (22 specimens), fum. HNO_3; unnamed seam, Bickershaw Colliery, Lancashire Coalfield, England, Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 54(65)74, fum. HNO_3; Parkgate seam, Grange Colliery, Yorkshire Coalfield, England; Westphalian A (Langsettian). Occasional specimens up to 99µm have been recorded (Smith and Butterworth 1967). (v) 58 & 59 (two specimens) offshore western Ireland, this study.

Cyclogranisporites minutus Bharadwaj emend. Ravn 1986.

Plate 2, figure 7.

1957 *Cyclogranisporites minutus* Bharadwaj, p. 83, pl. 23, figs. 22, 23.

1957a *Cyclogranisporties parvus* Bharadwaj, p. 83, pl. 23, figs. 7, 8.

Non 1977 *Cyclogranisporites parvus* (Lakhanpal, Sah and Dube) Anderson, p. 74 (9.3), pl. 72, figs. 1-9.

1960 *Cyclogranisporites* cf. *minutus* Bharadwaj; Staplin, p. 9, pl. 1, fig. 28.

1964 *Cyclogranisporites* cf. *minutus* Bharadwaj; Sullivan, p. 360, pl. 57, figs. 17, 18.

1967 *Cyclogranisporites* cf. *minutus* Bharadwaj; Smith and Butterworth, p. 143, pl. 4, figs. 4-7.

1986 *Cyclogranisporites minutus* Bharadwaj emend. Ravn, p. 31, pl. 3, figs. 3, 4.

Holotype. Bharadwaj 1957, pl. 22, fig. 22. Preparation 7314/2.

Type locality. Wahlschied Seam, Gottelborn Colliery, Saar Coalfield, Germany; Stephanian A.

Diagnosis. (Ravn 1986, p. 31, modified from Bharadwaj 1957a and Smith and Butterworth 1967). 'Trilete miospores, amb circular, trilete rays straight, simple, extending two-thirds to three-fourths of radius, often asymmetrical in arrangement and length. Larger specimens tend to display poorly-defined darkenings along the rays. Exine thin, often heavily folded. Ornament of uniform minute grana 0.5-1.0µm in diameter, separated from one another by spaces equal to or slightly greater than their diameter, on both proximal and distal surfaces, 50 to 100 grana project from margin.'

Size in microns. (i) Holotype 40; 34-43, Schulze (Bharadwaj 1957). (ii) 33(40)44, offshore western Ireland, this study.

Cyclogranisporites multigranus Smith and Butterworth 1967.

Plate 2, figure 5.

1967 *Cyclogranisporites multigranus* Smith and Butterworth, p. 144, pl. 4, figs. 10-13.

Holotype. Smith and Butterworth 1967, plate 4, fig. 12. Preparation T91/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Seam at 491ft. 10in., Seafield No. 2 borehole, East Fife Coalfield, Scotland; Westphalian B (Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p. 144). 'Amb circular; margin minutely notched. Laesurae simple, faint, often of unequal length, one-third to two-thirds of radius. Exine covered by minute grana less than 0.5µm in diameter and height, tightly packed; more than 100 project at margin. Narrow compression folds usually occur.'

Size in microns. (i) Holotype 53; (38(47)55, fum. HNO_3 Seam at 491ft. 10in., Seafield No. 2 borehole, East Fife Coalfield, Scotland; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (ii) 40(50)55, offshore western Ireland (Robeson 1988). (iii) 39(46)53, offshore western Ireland, this study.

Comparison. Compared to *Cyclogranisporites minutus*, the exine in *C. multigranus* is thicker, the ornament finer and the laesurae often shorter. The grana in *C. multigranus* are also in contact.

GRANASPORITES Alpern emend. Ravn *et al.* 1986.

Type species. *G. medius* (Dybová and Jachowicz) Ravn *et al.* 1986.
Diagnosis. See Ravn *et al.* (1986 p. 428).

Granasporites medius (Dybová and Jachowicz) Ravn *et al.* 1986.

Plate 2, figure 13.

1957 *Granisporites medius* Dybová and Jachowicz, p.77, pl. 10, figs 1,2.
1959 *Granasporites irregularis* Alpern, p. 139, pl. 1, figs. 7-9.
1966 *Cappasporites distortus* Urban, p. 114, pl. 1, figs. 1-14.
1967 *Apiculatisporis irregularis* (Alpern) Smith and Butterworth, p. 171, pl. 7, figs. 18,19.
1986 *Granasporites medius* (Dybová and Jachowicz) Ravn *et al.* p. 429, pl. 1, figs. 1-8, pl. 2, figs. 1-5.

Holotype. Dybová and Jachowicz (1957, pl. 10, fig. 1).
Diagnosis. Same as for genus.
Size in microns. (i) 35(60)90, Ravn *et al.* (1986), (ii) 47(52)57, offshore western Ireland, this study.
Comparison. *Crassispora kosankei* (Potonié and Kremp) Bharadwaj emend. Smith and Butterworth 1967 is similar to *Granasporites medius*, but possesses a distinct equatorial crassitude, a thicker exine and a conate ornament.

GRANULATISPORITES Ibrahim emend. Potonié and Kremp 1954.

Type species. *Granulatisporites granulatus* Ibrahim 1933.
Diagnosis. See Potonié and Kremp (1954, p. 126).
Comparison. *Granulatisporites* is distinguished from other genera by its regular, granulate ornamentation and triangular amb.

Granulatisporites microgranifer Ibrahim 1933.

Plate 2, figure 9.

1933 *Granulati-sporites microgranifer* Ibrahim, p. 22, pl. 5, fig. 32.

1938 *Azonotriletes microgranifer* (Ibrahim) Luber in Luber and Waltz, pl. 7, fig. 92.

1955 *Granulatisporites microgranifer* Ibrahim; Potonié and Kremp, p. 58, pl. 12, figs. 149-151.

Holotype. Ibrahim 1933, pl. 5, fig. 32, Potonié and Kremp 1955, pl. 12, fig. 149 after Ibrahim. Preparation B29, a2 (o/1).

Type locality. Ägir Seam, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 140, translated from Potonié and Kremp 1955, p. 58). 'Amb triangular with more or less concave sides. Approximately 100 grana on the margin'.

Size in microns. (i) Holotype 32.5, Schulze and KOH. (ii) (25?)30-40, Schulze (Potonié and Kremp, 1955). (iii) 18(23)28, fum. HNO_3; Chemiss Seam, Michael Colliery, East Fife Coalfield, Scotland; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 25(35)38, offshore western Ireland (Robeson 1988). (v) 22 & 25 (two specimens) offshore western Ireland, this study.

Remarks. Laesurae one-half to two-thirds of spore radius. Grana are barely discernable at the equator.

Comparison. *Granulatisporites microgranifer* is distinguished from other species of the genus by its finer ornament.

Granulatisporites granulatus Ibrahim 1933.

Plate 2, figures 10 and 11.

1933 *Granulati-sporites granulatus* Ibrahim, p. 22, pl. 6, fig. 51.

1955 *Granulatisporites granulatus* Ibrahim; Potonié and Kremp, p. 58, pl. 12, figs. 157-60.

Holotype. Ibrahim 1933, pl. 6, fig. 51. Preparation D57, b7 (ul).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 140, translated from Potonié and Kremp 1955, p.58). 'Amb triangular; sides generally slightly convex, rarely concave. About 55 grana on the margin; grana rather more than 1µm in diameter.'

Size in microns. (i) Holotype 31, Schulze and KOH. (ii) 25-35, Schulze (Potonié and Kremp 1955). (iii) 22(27)35, fum. HNO_3; Shilbottle Seam at 201ft. 1in., New Moor Hall borehole, Northumberland Coalfield, England; Viséan (Smith and Butterworth 1967). (iv) 26(35)38, offshore western Ireland (Robeson 1988)

Remarks. Specimens from offshore western Ireland may show either concave or slightly convex sides. Up to 50 grana project from amb.

Comparison. Coarser ornamentation distinguishes *Granulatisporites granulatus* from *Granulatisporites adnatoides* (Potonié and Kremp) Smith and Butterworth 1967.

Granulatisporites adnatoides (Potonié and Kremp) Smith and Butterworth 1967.

Plate 2, figure 12.

1955 *Leiotriletes adnatoides* Potonié and Kremp, p. 38, pl. 11, figs. 112-15.

1967 *Granulatisporites adnatoides* (Potonié and Kremp) Smith and Butterworth, p. 139, pl. 3, figs. 12-14.

Holotype. Potonié and Kremp 1955, pl. 11, fig. 112. Preparation 607/2.

Type locality. Baldur Seam, Brassert Colliery, Ruhr Coalfield, Germany; lower Westphalian C (lower Bolsovian).

Diagnosis (Smith and Butterworth 1967, p. 139, emended from diagnosis in Potonié and Kremp 1955, p. 38). 'Amb triangular, sides slightly concave to slightly convex, angles broadly rounded. Laesurae simple, straight, reaching almost to amb. Exine very finely granulate.'

Size in microns. (i) Holotype 36; 30-40, Schulze (Potonié and Kremp 1955). (ii) 27(31)38 fum. HNO_3; Kilnhurst Seam, Cadeby Main Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967).

Remarks. Grana are less than 0.5µm in size (oil required).

Granulatisporites minutus Potonié and Kremp 1955.

Plate 2, figure 13.

1955 *Granulatisporites minutus* Potonié and Kremp p. 59, pl. 12, figs. 147, 148.

Holotype. Potonié and Kremp 1955, pl. 12, fig. 147. Preparation 607/5, KT 14.4.123,9.

Type locality. Baldur Seam, Brassert Colliery, Ruhr Coalfield, Germany; lower Westphalian C (lower Bolsovian).

Diagnosis. (Smith and Butterworth 1967, p.141, expanded from Potonié and Kremp 1955, p. 59). 'Amb triangular, angles broadly rounded, sides concave. Laesurae straight, simple, sometimes open, one-half to three-quarters of spore radius in length; contact areas sometimes darker. Ornament of discrete grana, slightly less than 1µm in diameter; uneven in distribution; 35 to 40 project at the equator. Exine very thin, folding frequent.'

Size in microns. (i) Holotype 23, ~20-25, Schulze (Potonié and Kremp 1955). (ii) 18(24)28, fum. HNO_3; Rushy Park Seam, Sutton Manor Colliery, Lancashire Coalfield, England, Westphalian A (Langsettian) (Smith and Butterworth 1967). (iii) 16(21)25, fum HNO_3; Seam at 1,588ft. 4 in., Musselburgh No. 1 borehole, Lothians Coalfield, Scotland; Westphalian B (Duckmantian) (Smith and Butterworth 1967).

Remarks. The smaller size and coarser ornament distinguishes *Granulatisporties minutus* from *G. microgranifer*.

LOPHOTRILETES Naumova emend. Potonié and Kremp 1954.

Type species. *Lophotriletes gibbosus* (Ibrahim) Potonié and Kremp.

Diagnosis. See Potonié and Kremp (1954, p.129).

Lophotriletes commissuralis (Kosanke) Potonié and Kremp 1955.

Plate 2, figures 14 and 15.

1950 *Granulatisporites commissuralis* Kosanke, p. 20, pl. 3, fig. 1.

1955 *Lophotriletes commissuralis* (Kosanke) Potonié and Kremp, p. 73, pl. 14, figs. 222, 223.

Holotype. Kosanke 1950, p. 3, fig. 1. Preparation 486-B, slide 22.

Type locality. Friendsville Coal, Wabash County, Illinois, U.S.A.; McLeansboro Group.

Diagnosis. (Smith and Butterworth 1967, p. 156 from description in Kosanke 1950, p. 20). 'Outline triangular, angles rounded, sides concave. Tetrad mark distinct, extending for three-quarters of spore radius; margin of commissure slightly raised, in part broken by granulations. Exine (1-2µm thick) coarsely granulate, grana closely spaced.'

Size in microns. (i) Holotype 29.5 x 26; 25-34, Schulze and 10% KOH (Kosanke 1950). (ii) 24(29)35 (18 specimens) Schulze and 5% KOH; seam at 739ft. 10 in., Alveley No. 1 borehole, Forest of Wyre Coalfield, England, Westphalian D (Asturian) (Smith and Butterworth 1967). (iii) 25(26)28, offshore western Ireland, this study.

Remarks. Coni are less than 1µm in height.

Comparison. The species is distinguished from other members of the genus by its finer grade of coni.

Lophotriletes gibbosus (Ibrahim) Potonié and Kremp 1955.

1933 *Verrucosi-sporites gibbosus* Ibrahim, p. 25, pl. 6, fig. 49.
1938 *Azonotriletes gibbosus* (Ibrahim) Luber in Luber and Waltz, pl. 7, fig. 91.
1944 *Granulati-sporites gibbosus* (Ibrahim) Schopf, Wilson and Bentall, p. 33.
1950 *Verrucoso-sporites gibbosus* (Ibrahim) Knox, p. 317, pl. 17, fig. 232.
1954 *Lophotriletes gibbosus* (Ibrahim) Potonié and Kremp, p. 129.
1955 *Lophotriletes gibbosus* (Ibrahim) Potonié and Kremp, p. 74, pl. 14, figs 220, 221.

Holotype. Potonié and Kremp 1955, pl. 14, fig. 220 after Ibrahim. Preparation B61, e5 (ul).

Type locality. Ägir Seam, Ruhr Coalfield; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 156, from description and diagnosis in Potonié and Kremp 1955, p. 74). 'Amb triangular; sides more or less concave; angles markedly rounded. Trilete rays more than two-thirds of radius; tecta rather high, vertex sharp, slightly flexuose. Ornament of small coni differing slightly in size; apices rounded, seldom flat, about 40 project at the equator. Width of coni generally equal to height, but may sometimes be greater. The narrow spaces between the coni give rise to a negative reticulum.'

Size in microns. (i) Holotype 46, Schulze and KOH. (ii) 40-50, Schulze (Potonié and Kremp 1955).

Lophotriletes cf. *gibbosus*

Plate 2, figure 16.

Size in microns. (i) 29(34)41, fum. HNO_3; lower bed of Brockwell Seam at 635ft. 3in., Sharpess Point borehole, Durham Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967). (ii) 32(35)48, offshore western Ireland (Robeson 1988), (iii) 31(35)39, offshore western Ireland, this study.

Description. (Smith and Butterworth 1967, p.157). 'Amb triangular, sides concave, angles broadly rounded. Laesurae indistinct, extending about two-thirds of spore radius. Ornament of sharply tapering coni, 3-4μm high, 2-3μm wide at the base, unequal in size; about 35 project from the amb. Height of coni approaches that of spinae of *Acanthotriletes.* Exine moderately thick, seldom folded.'

Remarks. The taxon is used *sensu* Smith and Butterworth 1967, p. 157, pl. 6, fig. 9. The size range of *Lophotriletes* cf. *gibbosus* is smaller than that of the type species.

Lophotriletes granoornatus Ärtuz 1957.

Plate 2, figure 17.

1957 *Lophotriletes granoornatus* Ärtuz, p. 244, pl.2 , fig. 13.

Holotype. Artüz 1957, pl. 2, fig. 13. Preparation II14, 2e.

Type locality. Büyük Seam, Zonguldak Coalfield, Turkey, Westphalian A (Langsettian).

Diagnosis. (Smith and Butterworth 1967, p. 244, translated from Artüz 1957, p. 244). 'Triangular with angles rounded; sides slightly concave….tetrad mark about two-thirds of radius, rays regular. Exine ornamented with discrete grana which are also evident at the equator'.

Size in microns. (i) Holotype 37, 35-41, (Artüz 1957). (ii) 27(35)44, fum. HNO_3; Swallow Wod Seam, Denaby Main Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iii) 32(38)42, offshore western Ireland (Robeson 1988). (iv) 31 & 42 (2 specimens) offshore western Ireland, this study.

Description. (Smith and Butterworth 1967, p. 244). 'Amb triangular, angles broadly rounded, sides slightly concave or straight. Laesurae simple, one-half to two-thirds of spore radius. Ornament of coni 1-2µm in diameter; apices pointed, rounded, or slightly flattened, bases not touching; about 50 project at the equatorial margin. Exine moderately thick. Folding fairly frequent.'

Comparison. The fine ornamentation of *Lophotriletes granoornatus* distinguishes it from other species of comparable size.

Lophotriletes microsaetosus (Loose) Potonié and Kremp 1955.

Plate 2, figure 18.

1932 *Sporonites microsaetosus* Loose *in* Potonié, Ibrahim and Loose, p. 450, pl. 18, fig. 40.
1933 *Setosi-sporites microsaetosus* (Loose) Ibrahim, p. 26.
1934 *Setosisporites microsaetosus* (Loose) Loose, p. 148.
1944 *Granulatisporites microsaetosus* (Loose) Schopf, Wilson and Bentall, p. 33.
1950 *Spinoso-sporites microsaetosus* (Loose) Knox, p. 314, pl. 17, fig. 203.
1955 *Lophotriletes microsaetosus* (Loose) Potonié and Kremp, p. 74, pl. 14, figs. 229-30.

Holotype. Potonié and Kremp, 1955, pl. 14, fig. 299 after Loose. Preparation IV6 f_2 (ul).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p.158, from diagnosis and description in Potonié and Kremp 1955, p.74). 'Amb triangular with more or less concave sides and markedly rounded angles. Trilete rays weakly flexuose, almost reach equator. Coni moderately pointed, height about equal to basal width, 2-2.5µm; about 35 project at equator. The coni are so closely spaced as to give the appearance of a negative reticulum.'

Size in microns. (i) Holotype 39, Schulze. (ii) 25-40, Schulze (Potonié and Kremp 1955). (iii) 21(30)39, fum. HNO_3; seam at 1,754ft. 11in., Sandon Bank borehole, Cannock Chase Coalfield, England; Westphalian C (Bolsovian) (Smith and

Butterworth 1967). (iv) 30(35)45, offshore western Ireland (Robeson 1988), (v) 31 & 42 (two specimens) offshore western Ireland, this study.

Lophotriletes cf. *microsaetosus* (Loose) Potonié and Kremp 1955.

Plate 2, figure 19.

1955 *Lophotriletes microsaetosus* (partim) (Loose) Potonié and Kremp, p. 74, pl. 14, fig. 230.

?1958 *Lophotriletes microsaetosus* (Loose) Potonié and Kremp in Guennel, p. 63, pl. 3, fig. 10.

?1960 *Lophotriletes commissuralis* (Kosanke) Potonié and Kremp; Imgrund, p.164, pl. 15, figs. 66-68.

Size in microns. (i) 19(23)29, fum. HNO_3; Barncraig Seam, Michael Colliery, East Fife Coalfield, Scotland; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (ii) 20(26)32, fum. HNO_3; Rams Seam, Wheatsheaf Colliery, Lancashire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iii) 16(20)24, (13 specimens) fum. HNO_3; Slyving Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth 1967). (iv) 25(30)33, offshore western Ireland, this study.

Description. (Smith and Butterworth 1967, p.158-159). ‘Amb triangular, sides concave, angles rounded. Laesurae partly concealed by ornament, about two-thirds of spore radius in length. Ornament of coni up to 2µm in height and basal width, tapering or rounded, sometimes varying on single specimens; 30 to 35 project from amb.’

Remarks. The taxon is used *sensu* Smith and Butterworth (1967, p. 158, pl. 6, figs 10, 11).

Comparison. *Lophotriletes* cf. *microsaetosus* is smaller than the type species. *L. commissuralis* is larger with a finer and more closely spaced ornament.

ACANTHOTRILETES (Naumova) Potonié and Kremp 1954.

Type species. *A. ciliatus* (Knox) Potonié and Kremp.

Diagnosis. See Potonié and Kremp (1954, p. 133).

Comparision. The long and tapering spinae distinguish the genus from *Lophotriletes.*

Acanthotriletes castanea Butterworth and Williams 1958.

Plate 2, figure 20.

1948 Knox, p. 158, fig. 18.
1958 *Acanthotriletes castanea* Butterworth and Williams, p. 365, pl. 1, fig. 35.

Holotype. Smith and Butterworth 1967 p.174, plate 8, fig. 7. Preparation T42/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Garibaldi Ironstone Seam at 1,058ft. 3in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 177, from diagnosis and description in Butterworth and Williams 1958, p. 365). 'Outline circular or broadly rounded-triangular. Laesurae simple, not always visible, never prominent, extending for two-thirds to three-quarters of spore radius. Ornament of spinae having basal diameter 2µm or less and length up to 8µm tapering uniformly to a sharp point, generally slightly bent and occasionally sharply incurved. Distance between spinae about 2-5µm; 30 to 50 occur round the margin. Exine thin.'

Size in microns. (i) Holotype 46 x 40; 31-47 (10 specimens), Schulze and 5% KOH (Butterworth and Williams 1958). (ii) 30(40)45, offshore western Ireland, Robeson (1988).

Acanthotriletes echinatus (Knox) Potonié and Kremp 1955.

Plate 2, figure 22.

1950 *Spinoso-sporites echinatus* Knox, p. 313, pl. 17, fig. 208.
1955 *Acanthotriletes echinatus* (Knox) Potonié and Kremp, p. 84.

Neotype. Smith and Butterworth (1967) T86/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Splint Seam, Cadzow Colliery, Central Coalfield, Scotland; Westphalian B (Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 178, from Knox 1950, p. 313). 'Outline circular. Triradite mark one-third of spore radius. Ornament of spinae 5-8µm long, 5µm apart.'

Size in microns. (i) Neotype 26, fum. HNO_3. (ii) 25, Schulze (Knox 1950). (iii) 12(20)28, fum. HNO_3 type locality. (iii) 20(25)35, offshore western Ireland, Robeson (1988).

Remarks. Amb can be circular, oval or rounded-triangular. The exine is very thin.

Acanthotriletes falcatus (Knox) Potonié and Kremp 1955.

Plate 2, figure 21.

1948 18K, Knox, p. 157, fig. 15.
1950 *Spinoso-sporites falcatus* Knox, p. 313, pl. 17, fig. 205.
1955 *Acanthotriletes falcatus* (Knox) Potonié and Kremp, p. 84
1958 *Acanthotriletes falcatus* (Knox) Potonié and Kremp; Butterworth and Williams, p. 366, pl. 1, figs. 37, 38.

Neotype. Smith and Butterworth 1967, plate 8, fig. 11. Preparation T41/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Possil Main Seam at 600ft. 2 in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 178, from Knox 1950, p. 313). ‘Triangular, triradiate mark extending to the margin. Surface with spinose processes, 5-7µm long, straight or curved and spaced 3-5µm apart.’

Size in microns. (i) Neotype 42, fum. HNO_3. (ii) 55, Schulze (Knox 1950). (iii) 29(36)47, fum. HNO_3 (Butterworth and Williams 1958). (iv) 36 (one specimen), offshore western Ireland, this study.

Remarks. Sides of amb are concave. Spines are up to 4µm wide at the base, tapering sharply.

Acanthotriletes triquetrus Smith and Butterworth 1967.

Plate 2, figure 23.

1967 *Acanthotriletes triquetrus* Smith and Butterworth, p. 179, pl. 8, fig. 13.

Holotype. Smith and Butterworth 1967 pl. 8, fig. 13. Preparation T92/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Seam at 1,413 ft. 6in., Darkslade borehole, Cannock Chase Coalfield, England; Westphalian C (Bolsovian).

Diagnosis. (Smith and Butterworth 1967 p.179). ‘Amb triangular, angles rounded, sides concave. Laesurae distinct, simple, frequently open; length one-half to two-thirds of spore radius. Ornament of hair-like spinae, approximately 2μm long, slightly tapering, or truncate 2-3μm apart. Exine very thin, occasionally folded.’

Size in microns. (i) Holotype. 37; 19(26)37; Schulze; type locality. (ii) 29 (one specimen), offshore western Ireland, this study.

Comparison. Possesses shorter spinae than *Acanthotriletes echinatus*.

PUSTULATISPORITES Potonié and Kremp 1954.

Type species. *P. pustulatus* Potonié and Kremp 1954.

Diagnosis. See Potonié and Kremp (1954, p. 134).

Pustulatisporites papillosus (Knox) Potonié and Kremp 1955.

Plate 2, figure 24.

1948 Type 16K Knox, text-fig. 13.

1950 *Triquitrites papillosus* Knox, p. 327, pl. 17, fig. 234.

1955 *Putulatisporites papillosus* (Knox) Potonié and Kremp, p. 82.

Lectotype. Smith and Butterworth 1967 Plate 7, fig. 9. p. 167. T84/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Dunfermline Splint Seam, Lumphinnans No. 1 borehole, West Fife Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 168; from Butterworth and Williams 1958, p. 365). ‘Amb triangular, sides slightly concave, straight, or slightly convex, angles rounded or truncate, outline modified to varying degree by ornament. Laesurae simple, straight, extending almost to margin. Ornament distal, of widely spaced verrucae, or short bacula, up to 5μm in diameter and 8μm in height, slightly tapering with blunt or well-rounded apices; ornamentation variable on any one specimen; proximal surface laevigate. Exine moderately thick.’

Size in microns. (i) Lectotype 45, Schulze. (ii) 37(50)65 Schulze (Butterworth and Williams 1958); Namurian A. (iii) 43(46)49, offshore western Ireland, this study.

Pustulatisporites pustulatus Potonié and Kremp 1954.

Plate 2, figure 25.

1954 *Pustulatisporites pustulatus* Potonié and Kremp, p. 134, pl. 20, fig. 256.

Holotype. Potonié and Kremp 1955, pl. 14, fig. 256. Preparation 485 VII.
Type locality. Ägir Seam, Friedrich Thyssen 2/5 (Wehofen) Colliery, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).
Diagnosis. (Smith and Butterworth 1967, translated from Potonié and Kremp 1954, p. 134). 'Amb rounded-triangular. Laesurae two-thirds radius, sometimes open. Outline smooth, apart from the well-spaced, very low pyramidal protuberances on the exine, which number about 15 at the equator and which are rarely pointed and only faintly recognizable. Exine thin.'
Size in microns. (i) Holotype 66; Schulze (Potonié and Kremp 1955). (ii) 50-70 (6 specimens); fum. HNO_3; various localities and horizons, British coalfields (Smith and Butterworth 1967). (iii) 49, (one specimen), offshore western Ireland, this study.
Comparison. *Pustulatisporites papillosus* has a more triangular amb and more prominent ornament.

RAISTRICKIA Schopf, Wilson and Bentall emend. Potonié and Kremp 1954.

Type species. *R. grovensis* Schopf, Wilson and Bentall 1944.
Diagnosis. See Potonié and Kremp (1954, p.85).

Raistrickia abdita (Loose) Schopf *et al.* 1944.

Plate 3, figure 2.

1932 *Sporonites abditus* Loose in Potonié, Ibrahim, and Loose, p. 451, p. 19, fig. 53.
1933 *Verrucosi-sporites abditus* Loose, p. 154.
1944 *?Raistrickia abditus* (Loose) Schopf, Wilson and Bentall, p. 55.
1950 *Verrucoso-sporites abditus* (Loose) Knox, p. 317.

1955 *Apiculatisporites abditus* (Loose) Potonié and Kremp, p. 78, pl. 14, figs. 237-9.

Holotype. Potonié and Kremp 1955, pl. 14, fig. 237 after Loose. Preparation IV29, e_4 (m/or).
Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (Duckmantian).
Diagnosis. (Smith and Butterworth 1967, p.170, based on 'no satisfactory diagnosis being published'). 'Amb round to oval or rounded-triangular. Laesurae simple, straight, one-half to three-quarters of radius. Sculpture reduced or absent from proximal face. Coni with rounded apices, variable in size; mostly 5-10 in height, diameter at base more or less equal to height. Bases of coni almost touch. 20 to 30 project from margin.'
Remarks. In his revision of *Apiculatasporites*, Ravn (1986) argued that the species is better placed in the genus *Raistrickia* based on its ornament of blunt, often truncated coni.
Size in microns. (i) Holotype 78 x 55.5 Schulze. (ii) 50-70, tentative range based on six specimens isolated from British coals of varying age by fuming nitric acid (Smith and Butterworth 1967). (iii) 47(52)58, offshore western Ireland, this study.

Raistrickia fulva Ärtuz 1957.

Plate 2, figures 26 and 27.

1957 *Raistrickia fulva* Ärtuz, p. 246, pl. 3, fig. 19.

Holotype. Ärtuz 1957, pl. 3, fig. 19. Preparation 1I15, 6d.
Type locality. Sülü Seam, Zonguldak Coalfield, Turkey; Westphalian A (Langsettian).
Diagnosis. (Smith and Butterworth 1967 from description in Ärtuz 1957, p. 246). 'Rounded-triangular. Laesurae reach margin. Exine covered by 4-5µm, finger-shaped warts which are distinctly recognizable at the amb.'
Size in microns. Holotype 45, 40-55, maceration method not stated (Ärtuz 1957). (ii) 38(52)69, fum. HNO_3; Woodfield Seam at 1,468 ft. 10 in., Caldwell Ashley House borehole, South Derbyshire Coalfield, England; Westphalian A (Langsettian) (Smith

and Butterworth 1967). (iii) 40(45)50, offshore western Ireland (Robeson 1988). (iv) 38(49)61, offshore western Ireland, this study.

Description. Acamerate and trilete, with a rounded-triangular amb. Laesurae are between two thirds and three-quarters of the radius in length, often obscured by ornamentation. Ornament predominantly comprises bacula, with additional occurrences of coni and verrucae. Bacula can reach 5µm in height, but are typically less than 3µm. Basal widths can reach 8µm. Generally between 15-20 processes project from the margin.

Comparison. Distinguished from other species of *Raistrickia* by the low, broad based bacula.

Raistrickia saetosa (Loose) Schopf, Wilson and Bentall 1944.

Plate 3, figures 5 and 6.

1932 *Sporonites saetosus* Loose *in* Potonié, Ibrahim and Loose, p. 452, pl. 19, fig. 56.
1933 *Setosi-sporites saetosus* (Loose) Ibrahim, p. 26.
1944 *Raistrickia saetosus* (Loose) Schopf, Wilson and Bentall, p. 56.

Holotype. Potonié and Kremp 1955, pl. 15, fig. 264 after Loose 1932. Preparation I11, c.

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis (Smith and Butterworth 1967, p.181 translated from Potonié and Kremp 1955, p.87) '….laesurae two-thirds radius, bacula up to 14µm in length, varying in size, ends partly cleaved.'

Size in microns. (i) Holotype 78, Schulze. (ii) 60-90, Schulze (Potonié and Kremp 1955). (iii) 41(50)62, (20 specimens), fum. HNO_3; High Hazel Seam, Thorne Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 42(51)61, offshore western Ireland, this study.

Description. Acamerate, trilete miospores, with a round to oval amb. Laesurae are between one half and three-quarters of the radius in length and often obscured by ornamentation. Ornament comprises bacula up to 12µm in length with widths of up to 5µm. Bacula may show gently tapering or expanding sides. Ends of processes are often cleaved.

Comparison. *Raistrickia superba* (Ibrahim) Schopf, Wilson and Bentall 1944 is smaller with shorter, thinner bacula.

Raistrickia aculeata Kosanke 1950.

Plate 3, figure 1.

1950 *Raistrickia aculeata* Kosanke, p. 46, pl. 10, fig. 9.

Holotype. Kosanke 1950, pl. 10, fig. 9. Preparation 490-A, slide 5.

Type locality. McCleary's Bluff Coal, Illinois, U.S.A.; McLeansboro Group.

Diagnosis. (Smith and Butterworth 1967 p. 180, from description in Kosanke 1950, p. 46). 'Laesurae simple, about two-thirds radius, inconspicuous. Ornament of numerous, long and slightly tapering, blunt spines, 7-10μm in length and 2-2.5μm in breadth.'

Size in microns. (i) Holotype 69 x 65, 62-74, Schulze and 10% KOH (Kosanke 1950). (ii) 40(51)60, (23 specimens) fum. HNO_3; seam at 3,199ft., Upton borehole, Oxfordshire Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth 1967). (iii) 40(55)58, offshore western Ireland (Robeson 1988).

Description. (Smith and Butterworth 1967 p. 180). 'Amb circular to rounded-triangular. Laesurae not always visible. The processes almost cover the entire exine; they taper gently from the base, or about the mid-point of the length; apices pointed, rounded, or truncate, not usually apiculate. Exine thin and frequently with minor folds.'

Raistrickia superba (Ibrahim) Schopf, Wilson and Bentall 1944.

1933 *Setosi-sporites superbus* Ibrahim, p. 27, pl. 5, fig 42.

1944 *Raistrickia superbus* (Ibrahim) Schopf, Wilson and Bentall, p. 56.

Holotype. Potonié and Kremp 1955, pl. 15, fig. 262 after Ibrahim. Preparation B25, a5 (or).

Type locality. Agir Seam, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 182, translated from Potonié and Kremp 1955, p. 88) '…laesurae reach nearly to equator. Bacula 4-8µm long, in part fairly thick; some of them conical in shape.'

Raistrickia cf. *superba* (Ibrahim) Schopf, Wilson and Bentall 1944.
Plate 3, figure 3.

Description. (Smith and Butterworth 1967 p.182). 'Amb oval. Laesurae simple, two-thirds to nearly length of radius, sometimes obscured by ornament. Bacula 5-10µm in height and 2-4µm in breadth; thinner forms predominate; somewhat irregularly distributed. Density of bacula very variable, in some specimens they may be separated by as much as 20µm. In profile the maximum width of the bacula occurs about the mid-point or near the top, or they may be of uniform width; tips rounded or truncate and slightly apiculate. Exine thin to moderately thick; narrow marginal folds usually apparent.'

Size in microns. (i) 37(47)55, 13 specimens, fum. HNO_3; High Hazel Seam, Thorne Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (ii) 29(42)53, offshore western Ireland, this study.

Remarks. Specimens of *Raistrickia* cf. *superba* may show great variation in bacula morphology and distribution.

Comparison. The greater variation in bacula morphology distinguishes *Raistrickia* cf. *superba* from *R. saetosa*. In addition, the bacula of *R.* cf. *superba* are generally shorter and thinner with fewer projecting from the margin.

Raistrickia nigra Love 1960.
Plate 3, figure 4.

1960 *Raistrickia nigra* Love, p. 114-115, pl. I, fig 5.

Holotype. Love 1960, pl. I, fig 5, slide PSB 296m/8.

Type locality. Pumpherston Shell Bed, South Queensferry, Scotland.

Diagnosis. (Love 1960, p. 114). 'Circular; trilete rays more than half the spore radius; exine thick, baculae regular in form, short and thick, 5-6µm long, tips slightly variable, well spaced.'

Size in microns. (i) Holotype 73µm, 60-75, Pumpherston Shell Bed, South Queensferry, Scotland; (Love 1960). (ii) 50(70)75, offshore western Ireland, (Robeson 1988).

Comparison. Differs from other species of the genus by its even distribution of small regular baculae.

VERRUCOSISPORITES Ibrahim emend. Smith and Butterworth 1967.

Type species. *V. verrucosus* (Ibrahim) Ibrahim 1933.

Diagnosis. See Smith and Butterworth 1967, p. 147.

Comparison. Differs from *Camptotriletes* Naumova 1939 *ex* Potonié and Kremp 1954 and *Convolutispora* Hoffmeister *et al.* 1955 in possessing an ornamentation of more or less discrete elements, which may sometimes be confluent at their bases but do not anastomose to form a system of ridges (Smith and Butterworth 1967).

Verrucosisporites morulatus (Knox) Potonié and Kremp emend. Smith and Butterworth 1967.

Plate 3, figure 7.

1948 Type 20K Knox, text-fig. 23.
1950 *Verrucoso-sporites morulatus* Knox, p. 318, pl. 17, fig. 235
1955 *Verrucosisporites morulatus* (Knox) Potonié and Kremp, p.65.
1967 *Verrucosisporites morulatus* (Knox) Potonié and Kremp emend. Smith and Butterworth, p. 152, pl. 5, figs. 15, 16.

Lectotype. Smith and Butterworth 1967 p. 148, Plate 5, fig. 15. Preparation 369A (T/85/1 in collection of Coal Survey Laboratory, Sheffield).

Type locality. Sulphur Seam, Lindsay Colliery, East Fife Coalfield, Scotland, Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 152, emended from Butterworth and Williams 1958, p. 362). 'Amb circular to oval; margin modified by ornament. Laesurae simple, one-half to two-thirds of radius. Exine covered by well-defined, discrete verrucae, relatively loose packed and numbering 30 to 40 at the margin.

Verrucae more or less parallel-sided with flat to rounded apices; variable in size, up to 6µm in diameter and 4µm in height. Exine relatively thin.'

Size in microns. (i) Lectotype 58, Schulze. (ii) 50-80, Schulze and 5% KOH (Butterworth and Williams 1958). (iii) 58, offshore western Ireland, this study (one specimen).

Verrucosisporites microverrucosus Ibrahim 1933.

Plate 3, figures 10 and 11.

1933 *Verrucosisporites microverrucosus* Ibrahim, p. 25, pl. 7, fig. 60.
1944 *Punctati-sporites microverrucosus* (Ibrahim) Schopf, Wilson and Bentall, p. 31.
1950 *Verrucoso-sporites microverrucosus* (Ibrahim) Knox, p. 318, pl. 17, fig. 228.

Holotype. Potonié and Kremp 1955, pl. 13, fig. 200 after Ibrahim. Preparation B26, c2 (ur).

Type locality. Ägir Seam, Ruhr Coalfiled, Germany, top of Westphalian B (top Duckmantian).

Diagnosis (Smith and Butterworth 1967 p.151, from Ibrahim 1933, p.25 and Potonié and Kremp 1955, p.68). 'Amb oval to circular. Laesurae extend almost to equator. Verrucae round to slightly elongated, and 3-7µm in diameter, cover entire exine.'

Size in microns. (i) Holotype 56.5, Schulze and KOH. (ii) 45-75, Schulze (Potonié and Kremp 1955). (iii) 35(49)64, offshore western Ireland, this study.

Remarks. Specimens from offshore western Ireland have been recorded that are smaller than those recorded by Potonié and Kremp 1955.

Comparison. The species is distinguished from other members of the genus by its irregular shape and comparatively larger size of verrucae.

Verrucosisporites microtuberosus (Loose) Smith and Butterworth 1967.

Plate 3, figure 12.

1932 *Sporonites microtuberosus* Loose in Potonié, Ibrahim and Loose, p. 450, pl. 18, fig. 33.
1934 *Tuberculati-sporites microtuberosus* Loose, p. 147.
1944 *Punctatisporites microtuberosus* (Loose) Schopf, Wilson and Bentll, p. 31
1950 *Plani-sporites microtuberosus* (Loose) Knox, p.316, pl. 17, fig. 211.

1955 *Microreticulatisporites microtuberosus* (Loose) Potonié and Kremp, p. 100, pl. 15, figs. 273-7.
1957 *Planisporites microtuberosus* (Loose) Knox in Bharadwaj, p.87, pl. 23, figs. 13, 14.
1967 *Verrucosisporites microtuberosus* (Loose) Smith and Butterworth, p. 149-150, pl. 5, figs. 9-11.

Holotype. Potonié and Kremp 1955, pl. 15, fig. 273 after Loose. Preparation III50, C6 (or).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis (Smith and Butterworth 1967 p. 150, emended from Potonié and Kremp 1955, p. 100). 'Amb oval to circular; outline regularly notched. Laesurae simple, one-half to three-quarters of radius. Exine covered by small, bluntly conical verrucae, not exceeding 2µm in height, or breadth; closely packed; 70 to 100 project from margin. Exine thin with compression folds.'

Size in microns. (i) Holotype 67.5, Schulze. (ii) 55-85, Schulze (Potonie and Kremp 1955). (iii) 55(72)84, H_2O_2; lower bed of Chislet No. 2 Seam at 58ft. 9in., No. 30 upborehole, Chislet Colliery, Kent Coalfield, England, Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 57(69)86, offshore western Ireland, this study.

Comparison. *Verrucosisporites microtuberosus* differs from *Verrucosisporites donarii* Potonié and Kremp 1955 in having well developed compression folds and smaller verrucae. The amb is also usually oval rather than circular.

Verrucosisporites donarii Potonié and Kremp 1955.

Plate 3, figure 8.

1955 *Verrucosisporites donarii* Potonié and Kremp, p. 67, pl. 13, fig. 193.

Holotype. Potonié and Kremp 1955, pl. 13, fig. 193. Preparation 31/1.

Type locality. Donar Seam, Brasert Colliery, Ruhr Coalfield, Grmany; lower Westphalian C (lower Bolsovian).

Diagnosis. (Smith and Butterworth 1967 p. 149, from diagnosis in Potonié and Kremp 1955, p.67). 'Amb circular. Laesurae two-thirds of radius. Entire surface covered by verrucae of irregular shape, measuring about 2-3µm. More than 50 verrucae project at equator.'

Size in microns. (i) Holotype 71 Schulze (Potonié and Kremp 1955). (ii) 55-70, fum. HNO_3 and KOH (Piérart 1958). (iii) 43(60)79, fum. HNO_3; Slyving Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth 1967). (iv) 46(60)75, offshore western Ireland, this study.

Verrucosisporites verrucosus (Ibrahim) Ibrahim 1933.

Plate 3, figure 9.

1932 *Sporonites verrucosus* Ibrahim in Potonié, Ibrahim and Loose, p. 448, p. 15, fig. 17.
1933 *Verrucosi-sporites verrucosus* Ibrahim, p. 25, pl. 2, fig. 17.
1938 *Azonotriletes verrucosus* (Ibrahim) Luber in Luber and Waltz, pl. 7, fig. 17.
1944 *Punctati-sporites verrucosus* (Ibrahim) Schopf, Wilson, and Bentall, p. 32.
1950 *Verrucosi-sporites verrucosus* (Ibrahim) Knox, p.319, pl. 17, fig. 230.

Holotype. Potonié and Kremp 1955, pl. 13, fig. 196 and Smith *et al.* 1964, pl. 3, fig. 7 after Ibrahim. Preparation B29, d1 (o).

Type locality. Ägir Seam, Ruhr Coalfiled, Germany, top of Westphalian B (top Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p. 154, from diagnosis and description in Potonié and Kremp 1955, p. 69). 'Amb roughly oval to circular; outline with irregular protuberances ('grob-hockerig'). Laesurae two-thirds of radius. Surface densely covered by verrucae of irregular shape, 2-4µm in diameter; 45 to at least 50 verrucae project at margin. Spaces between verrucae less than their basal width.'

Size in microns. (i) Holotype 77, Schulze and KOH. (ii) 70-100 Schulze (Potonié and Kremp 1955). (iii) 52(69)94, H_2O_2; lower bed of Chislet No. 2 Seam at 58ft. 9in., No. 30 upborehole, Chislet Colliery, Kent Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 61(75)83, offshore western Ireland, this study.

Comparison. *Verrucosisporites verrucosus* has slightly larger verrucae than *V. donarii.*

Infraturma **MURONATI** Bennie and Kidston emend. Potonié 1956.

CAMPTOTRILETES Naumova 1939 ex Potonié and Kremp 1954.

Type species. *C. corrugatus* (Ibrahim) Potonié and Kremp 1954.
Diagnosis. See Potonié and Kremp (1954, p. 142).

Camptotriletes bucculentus (Loose) Potonié and Kremp 1955.
Plate 3, figure 13.

1934 *Verrucosi-sporites bucculentus* Loose, p. 154, pl.7, fig 15.
1944 *Punctati-sporites bucculentus* (Loose) Schopf, Wilson and Bentall, p.30
1950 *Verrucoso-sporites bucculentus* (Loose) Knox, p. 317
1955 *Camptotriletes bucculentus* (Loose) Potonié and Kremp, p. 104, pl. 16, figs. 287, 288.

Holotype. Potonié and Kremp 1955, pl. 16, fig. 287 after Loose. Preparation III94, d2 (m/or).
Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).
Diagnosis. (Smith and Butterworth 1967, p. 199, from diagnosis and description in Potonié and Kremp 1955, p. 104). ‘Amb round to triangular. Laesurae more or less reach to equator. Exine with loosely arranged striae and wart-like projections which appear at the amb as 20 or more stout ridges. The ornament is best developed distally.’
Size in microns. (i) Holotype 47.5, Schulze and KOH. (ii) 45-75 Schulze (Potonié and Kremp 1955). (iii) 50(56)67, (7 specimens), fum. HNO_3; various localities; Westphalian A and B (Langsettian and Duckmantian) (Smith and Butterworth 1967). (iv) 40(60)80, offshore western Ireland, (Robeson 1988). (v) 46(53)57, offshore western Ireland, this study.

Camptotriletes superbus Neves 1961.
Plate 3, figure 14.

1961 *Camptotriletes superbus* Neves, p. 257, pl. 31, fig. 8.

Holotype. Neves 1961, Plate 31, fig 8.

Type locality. Pot Clay Coal, Holymoorside, Derbyshire (Loc. 13). Yeadonian Stage.

Diagnosis. (Neves 1961, p. 257). 'Size 75-125µm (thirty specimens measured), holotype 119µm; equatorial outline subcircular; trilete rays long, three-quarters of the spore, tecta sharp and tapering. Exine ornamented with irregular, disjointed, subconical ridges.'

Size in microns. (i) Holotype 119, (ii) 75-125 (Neves 1961) (iii) 77(80)85, offshore western Ireland, this study.

CONVOLUTISPORA Hoffmeister, Staplin and Malloy 1955.

Type species. *C. florida* Hoffmeister, Staplin and Malloy 1955.

Diagnosis. See Hoffmeister, Staplin and Malloy (1955, p. 384).

Convolutispora jugosa Smith and Butterworth 1967.

Plate 3, figure 15.

1958 *Convolutispora* cf. *mellita* Hoffmeister, Staplin and Malloy; Butterworth and Williams, p. 372, pl. 2, figs. 20, 21.

1967 *Convolutispora jugosa* Smith and Butterworth, p. 186, pl. 10, figs 1-3.

Holotype. Smith and Butterworth (1967) Plate 10, figs. 1, 2. Preparation T49/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. 4in. coal at 191ft. 3in., Darnley No. 3 borehole, Central Coalfield, Scotland; Namurian A (Smith and Butterworth 1967).

Diagnosis. (Smith and Butterworth 1967 p. 186) 'Amb circular, margin irregularly undulose. Laesurae simple, straight or curved, one-half to two-thirds of radius. Proximal and distal ornament of closely spaced, broad, and low verrucae and branched rugulae with well-rounded apices; ornament mostly 5-10µm in basal width at margin and projecting 1.5-5µm from margin; length not exceeding 30µm in plan view. Width of ornament very variable due to anastomosing and branching; vermiculi about 1µm , angular spaces 2-3µm in width; 25 to 35 elevations project at margin. Exine, including sculpture, 8-10µm thick.'

Size in microns. (i) Holotype 112; 84(102)119 (21 specimens), fum. HNO_3; type locality. (ii) 122 (one specimen), offshore western Ireland, this study.

DICTYOTRILETES Naumova *ex* Potonié and Kremp emend. Ravn 1986.

Type species. *D. bireticulatus* (Ibrahim) Potonié and Kremp 1954 emend. Smith and Butterworth 1967.

Diagnosis. (Ravn 1986 p. 90) 'Miospores azonate, radial, trilete, amb roundly triangular to nearly circular. Distal surface ornamented by a distinct reticulum; proximal surface laevigate or nearly so. Muri extend to equator, where a continuous murus forms the boundary between the proximal and distal surfaces. Muri relatively low, height not more than twice the basal width.'

Remarks. The emended diagnosis of *Dictyotriletes* by Ravn (1986) restricts the genus to species in which the reticulate sculpture is confined to the distal surface. Species with reticulate ornamentation on both proximal and distal surfaces are transferred to the genus *Reticulitriletes* Mädler 1964 emend. Ravn 1986.

Dictyotriletes bireticulatus (Ibrahim) emend. Smith and Butterworth 1967.

Plate 3, figure 18.

1932 *Sporonites bireticulatus* Ibrahim in Potonié, Ibrahim, and Loose, p. 447, pl. 14, fig. 1.
1933 *Reticulati-sporites bireticulatus* Ibrahim, p. 35, pl. 1, fig. 1.
1934 *Reticulata-sporites bireticulatus* Ibrahim; Loose, pl. 7, fig. 28.
1950 *Reticulatisporites mediareticulatus* Ibrahim; Knox, p. 323, pl. 18, fig. 253.
1952 *Reticulatisporites mediareticulatus* Ibrahim; Balme, p. 176, text-fig. 1c.
1952 *Reticulatisporites* cf. *mediareticulatus* Ibrahim; Balme and Butterworth, pl. 48, figs. 4a, b.
1954 *Dictyotriletes bireticulatus* (Ibrahim) Potonié and Kremp 1954, p. 108.
1954 *Reticulati-sporites* cf. *mediareticulatus* Ibrahim; Butterworth and Millot, pl. 21, fig 8b.
1956 *Reticulatisporites mediareticulatus* Ibrahim; Butterworth and Millot, text-fig. 3 (8).
1967 *Dictyotriletes bireticulatus* (Ibrahim) Potonié and Kremp emend. Smith and Butterworth, p. 194, pl. 11, figs 14, 15.

Holotype. Potonié and Kremp 1955, pl. 16, fig. 296 after Ibrahim. Preparation B33, a4 (r).

Type locality. Agir Seam, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p. 194, emended from Potonié and Kremp 1955 p. 108). 'Amb rounded-triangular with convex sides and rounded angles; in equatorial view proximal profile slightly, distal profile strongly, convex; outline in polar view smooth to gently undulate, but in other compressions the muri project 2µm from margin. Laesurae not often visible, simple, straight, three-quarters or more of the spore radius. Reticulation covers entire distal surface but does not extend beyond equator. Polygonal-shaped lumina number between 15 and 25, size 2.5-12µm. Except in the peripheral region the shape and size of the lumina are very regular, diameter about 10µm. Muri approximately square in section; width somewhat less than 1.5µm. Exine thin, proximally laevigate, distally in lumina punctuate (?infrasculpture).'

Size in microns. (i) Holotype 57.5, Schulze and KOH. (ii) 40-60, Schulze (Potonié and Kremp 1955). (iii) 40(47)56, Schulze (Balme 1952). (iv) 27(35)39, fum. HNO_3; Harvey Seam at 564 ft. 2in., New Shildon borehole (42 SW. 20), Durham Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967). (v) 37(50)60 fum. HNO_3; 2 in. coal at 100ft. 2in., Common Gate borehole No. 1, Northumberland Coalfield, England; lower Westphalian A (lower Langsettian) (Smith and Butterworth 1967). (vi) 40(45)50, offshore western Ireland, (Robeson 1988). (vii) 33(41)45, offshore western Ireland, this study.

Dictyotriletes probireticulatus Butterworth and Madhi 1982.

Plate 3, figure 17.

1967 *Dictyotriletes bireticulatus* (Ibrahim) Smith and Butterworth, p. 194, in part.

1981 *Dictyotriletes* cf. *bireticulatus* (Ibrahim) Smith and Butterworth in Madhi, p. 169, pl.11, figs. 7-9.

1982 *Dictyotriletes probireticulatus* Butterworth and Madhi 1982 p. 490.

Holotype. Butterworth and Madhi 1982 Plate 1, fig. 11. Preparation M3, slide T.101 (M3/2).

Type locality. Upper Kellah Coal (M3), Kellah Burn section, near Featherstone.

Diagnosis. (Butterworth and Madhi 1982 p. 490); 'Spores radial, trilete. Amb triangular to subtriangular with broad, rounded apices and straight to convex sides.

Laesurae simple, straight, sometimes indiscernible, extending for about three-quarters of the spore radius. Exine less than 1.5µm in thickness, punctuate or very finely granulate, covered distally with a prominent reticulum; muri about 1.5µm in width and height, enclosing 20-34 lumina, rounded or polygonal in shape; 14-24 muri project at the equator. Exine occasionally folded.'

Size in microns. (i) Holotype 44; 33(43)51 (Butterworth and Madhi 1982). (ii) 37(50)60, 2in. coal at 100ft. 2in., Commongate borehole, Northumberland, lower Westphalian A (lower Langsettian) (Smith and Butterworth 1967). (iii) 33(41)48, Low Main Stringer Coal, Plenmeller Coalfield, Northumberland, lower Westphalian A (lower Langsettian) (Mahdi, 1981), (iv) 30(45)50, offshore western Ireland, (Robeson 1988). (v) 55-58, offshore western Ireland, this study (2 specimens).

Comparison. *Dictyotriletes probireticulatus* is generally larger than *D. bireticulatus* and possesses a greater number of lumina on its distal surface.

MICRORETICULATISPORITES Knox emend. Potonié and Kremp 1954.

Type species. *M. lacunosus* (Ibrahim) Knox *ex* Potonié and Kremp 1954.

Diagnosis. See Potonié and Kremp (1954, p. 143).

Microreticulatisporites nobilis (Wicher) Knox 1950.

Plate 4, figure 1.

1934 *Sporites nobilis* Wicher, p. 186, pl. 8, fig. 30.
1944 *Punctati-sporites nobilis* (Wicher) Schopf, Wilson and Bentall, p. 31.
1950 *Microreticulatisporites nobilis* (Wicher) Knox, p. 321, pl. 18, fig. 242.

Holotype. Potonié and Kremp 1955, pl. 15, fig. 279 after Wicher. Preparation IV X5, a_2 (u/r).

Type locality. Seam R_1, Wehofen Colliery, Ruhr Coalfield, Germany; Westphalian C (Bolsovian). (Seam R_1 in Wicher 1934 is a thin coal between the Seams Kobold and Loki and is not the authentic R_1 of the Ruhr Coalfield).

Diagnosis. (Smith and Butterworth 1967 p. 192 translated from Potonié and Kremp 1955, p. 101). 'Amb rounded triangular. Laesurae distinct, at least two-thirds radius; approximately 50 crenulations at margin. Muri rather broad.'

Size in microns. (i) Holotype 36, Schulze and KOH. (ii) 30-45, Schulze (Potonié and Kremp 1955). (iii) 32(37)43, fum. HNO_3; Sharlston Top Seam at 1,168 ft. 8in., Cross Hill borehole, Yorkshire Coalfield, England; Westphalian C (Bolsovian) (Smith and Butterworth 1967). (iv) 35(40)45, offshore western Ireland (Robeson 1988). (v) 33(38)42, offshore western Ireland, this study.

Description. Acamerate, trilete miospores with a triangular amb. Sides are straight or convex with rounded apices. Exine moderately thick. The trilete mark is sometimes distinct but may be obscured by ornamentation. Laesurae range from three-quarters to the full radius in length. Ornamentation comprises a reticulation of fine muri. Lumina are polygonal in shape and approximately 1µm in diameter. The equatorial margin is finely notched; the muri project as low coni. Between 30 and 40 elements project from the margin. The exine is typically without folds.

Comparison. *Microreticulatisporites concavus* Butterworth and Williams 1958 possesses concave sides. *M. sulcatus* (Wilson and Kosanke) Smith and Butterworth 1967 possesses fewer but larger muri.

Microreticulatisporites concavus Butterworth and Williams 1958.

Plate 4, figure 2.

1958 *Microreticulatisporites concavus* Butterworth and Williams, p. 367, pl. 1, figs. 55, 56.

Holotype. Smith and Butterworth 1967 Plate 11, fig 1, after Butterworth and Williams, pl. 1, fig. 56. Preparation T45/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Seam at 1,872ft. 7in., Righead borehole, West Fife Coalfield, Scotland, Namurian A.

Diagnosis. (Smith and Butterworth 1967 p.190, from Butterworth and Williams 1958, p. 367). 'Amb triangular, angle broadly rounded, interradial margins concave. Laesurae two-thirds radius. Ornamentation finely microreticulate, distinct, and regular.'

Size in microns. (i) Holotype 44; 30(40)52 Schulze and KOH (Butterworth and Williams 1958). (ii) 35(42)53, offshore western Ireland (Robeson 1988). (iii) 36(41)45, offshore western Ireland, this study.

Comparison. *Microreticulatisporites nobilis* possesses straight to convex sides.

Microreticulatisporites sulcatus (Wilson and Kosanke) Smith and Butterworth 1967.

Plate 4, figure 3.

1944 *Punctati-sporites sulcatus* Wilson and Kosanke, p. 331, pl.1, fig. 4.
1955 *Converrucosisporites sulcatus* (Wilson and Kosanke) Potonié and Kremp, p. 64.
1967 *Microreticulatisporites sulcatus* (Wilson and Kosanke) Smith and Butterworth, p. 193-194, pl. 11, figs. 9, 10.

Cotypes. Wilson and Kosanke 1944. Preparation 265 P, circle 1 and 266 P.

Type locality. Unspecified coal from Angus Coal Co. Colliery, Iowa, U.S.A.; Des Moines Series.

Diagnosis. (Smith and Butterworth 1967, p193 from Wilson and Kosanke 1944, p.331). 'Amb triangular to round. Laesurae simple, reaching to equator. Ornament of a dense, coarse, irregular reticulation enclosing minute areas (lumina) between them; some of reticulations may end in pronounced verrucate processes.'

Size in microns. (i) 30-40, maceration method not known (Wilson and Kosanke 1944). (ii) 36(42)51, fum. HNO_3; Trenchard Seam, Princess Royal Colliery, Forest of Dean Coalfield, England; upper Westphalian C (upper Bolsovian) (Smith and Butterworth 1967). (iii) 33(39)53, offshore western Ireland, this study.

Microreticulatisporites punctatus Knox 1950.

Plate 4, figure 4.

1948 37K Knox, p. 159; text-fig. 43.
1950 *Microreticulati-sporites punctatus* Knox, p.321.

Neotype. Smith and Butterworth 1967 pl 11, figs. 12, 13 after Butterworth and Williams 1958. Preparation T44/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. A bed of Milton Main Seam at 1,735 ft. 3in., Righead borehole, West Fife Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967 p.193 from diagnosis and description in Butterworth and Williams 1958, p.368). 'Amb oval. Laesurae simple, two-thirds radius. Exine with an extremely fine and regular microreticulation; margin finely crenulate.'

Size in microns. (i) Neotype 34; 26(34)39, Schulze and KOH (Butterworth and Williams 1958). (ii) 36, one specimen, offshore western Ireland, this study.

Remarks. Lumina are less than 2µm in diameter.

RETICULITRILETES Mädler 1964 emend. Ravn 1986.

Type species. *Reticulitriletes globosus* Mädler 1964.

Diagnosis. (Ravn 1986, p. 53). 'Miospores radial, trilete, azonate, originally spherical or nearly so. Trilete rays simple, straight. Both proximal and distal surfaces ornamented with a comprehensive reticulate sculpture consisting of muri of approximately equal height and width, enclosing more or less polygonal lumina of greater width than the muri. Reticulum may be imperfect and may be reduced or absent from areas in the immediate vicinity of the trilete mark.'

Remarks. The emendation of *Dictyotriletes* by Ravn (1986) to exclude forms with proximal and distal reticulation resulted in the transfer of many species to the genus *Reticulitriletes*.

Comparison. The reticulate sculpture of *Dictyotriletes* is confined to the distal surface.

Reticulitriletes falsus (Potonié and Kremp) Ravn 1986.

Plate 4, figure 7.

1955 *Dictyotriletes falsus* Potonié and Kremp, p. 109, pl. 16, figs. 303, 304.

1986 *Reticulitriletes falsus* (Potonié and Kremp) Ravn, p. 54, pl. 25, figs. 10-12.

Holotype. Potonié and Kremp 1955, pl. 16, fig. 303. Preparation 485/X.

Type locality. Ägir Seam, Friedrich Thyssen 2/5 (Wehofen) Colliery, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (See Smith and Butterworth 1967, p. 196, translated from Potonié and Kremp 1955, p. 109). 'Amb roughly circular, with 14-17 marginal bulges or projecting muri ('Randstrahlen'). Reticulum with broad muri and occasionally with small rounded projections at the corners of the lumina.'

Size in microns. (i) Holotype 48; 45-55, Schulze (Potonié and Kremp 1955). (ii) 40(46)52 (six specimens), fum. HNO_3, various localities, Yorkshire and Nottinghamshire Coalfields, England; Westphalian A (Langsettian) and B (Duckmantian) (Smith and Butterworth 1967).

Reticulitriletes mediareticulatus (Ibrahim) Ravn 1986.

Plate 4, figure 5.

1933 *Reticuli-sporites mediareticulatus* Ibrahim, p. 34, pl. 7, fig. 62.

1955 *Dictyotriletes mediareticulatus* (Ibrahim) Potonié and Kremp, p. 110, pl. 16, figs. 314, 315.

1967 *Dictyotriletes mediareticulatus* Potonié and Kremp emend. Smith and Butterworth, p. 197, pl. 11, figs. 22-24.

1986 *Reticulitriletes mediareticulatus* (Ibrahim) Ravn, p. 54, pl. 25, figs. 5, 6.

Holotype. Potonié and Kremp 1955, pl. 16, fig. 314 after Ibrahim. Preparation B20, a5 (ol).

Type locality. Ägir Seam, Ruhr Coalfield, Germany, top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 197, emended from diagnosis in Potonié and Kremp 1955, p. 110). 'Amb circular; outline undulate. Laesurae weakly ridged, one-half to two-thirds radius; width narrow, height low. Exine approximately 2.5µm in thickness, distinctly reticulate distally and proximally, except on contact areas where laevigate; 10 to 18 muri project at margin.'

Size in microns. (i) Holotype 65.5, Schulze and KOH. (ii) 50-80, Schulze (Potonié and Kremp 1955). (iii) 55(63)72, fum. HNO_3; seam at 903ft. 4in., Harry Stoke 'B' borehole, Bristol and Somerset Coalfield, England; lower Westphalian C (lower Bolsovian) (Smith and Butterworth 1967). (iv) 67, 63, two specimens, offshore western Ireland, this study.

Reticulitriletes reticulocingulum (Loose) Ravn 1986.

Plate 4, figure 6.

1932 *Sporonites reticulocingulum* Loose, in Potonié, Ibrahim and Loose, p. 450, pl. 18, fig. 41.

1934 *Reticulati-sporites reticulocingulum* (Loose) Loose, p. 156.

1944 ?*Punctati-sporites reticulocingulum* (Loose) Schopf, Wilson and Bentall, p. 31.

1967 *Dictyotriletes reticulocingulum* (Loose) Smith and Butterworth, p.198, pl. 11, figs. 27-29.

1970 *Dictyotriletes* cf. *reticulocingulum* (Loose) Smith and Butterworth 1967; Peppers, p. 112, pl. 9, fig. 13.

1986 *Reticulitriletes reticulocinguum* (Loose) Ravn, p. 54, pl. 25, figs. 7-9.

Holotype. Potonié and Kremp 1955, pl. 16, fig. 306 after Loose. Preparation IV44 a_2 (ul).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 198, from diagnosis in Potonié and Kremp 1955, p. 113). 'Amb more or less circular with about 15 to 20 small, membranous-linked marginal rays. Laesurae about two-thirds radius. Well-developed distal reticulum; proximal ornament more striate.'

Size in microns. (i) Holotype 45, Schulze. (ii) 40-60, Schulze (Potonié and Kremp 1955). (iii) 37(46)52, fum. HNO_3; High Hazel of Hatfield Seam, Thorne Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 40(50)55, offshore western Ireland (Robeson 1988). (v) 45, one specimen, offshore western Ireland, this study.

Infraturma **AURICULATI** Schopf emend. Dettmann 1963.

AHRENSISPORITES Potonié and Kremp 1954.

Type species. *Ahrensisporites guerickei* (Horst) Potonié and Kremp 1954.

Diagnosis. See Potonié and Kremp (1954, p. 155).

Ahrensisporites guerickei (Horst) Potonié and Kremp *ex* Horst 1955.

Plate 4, figures 8-10.

1943 *Triletes guerickei* Horst, pl.7, figs. 58,59, 61-64.

1954 *Ahrensisporites guerickei* (Horst) Potonié and Kremp, p. 155.

1955 *Ahrensisporites guerickei* (Horst) Potonié and Kremp *ex* Horst, p.178, pl. 23, figs. 58,59, 61-64.

Holotype. Horst 1955, pl. 23, fig.63. Preparation I6, 28·7 71·4.

Type locality. Seam VI, Karsten Central Colliery, Beuthen, Upper Silesia; Westphalian A (Langsettian).

Diagnosis. (Smith and Butterworth 1967 p. 201 expanded from Horst 1955, p. 178). 'Amb triangular; sides straight or slightly convex; angles truncate, rounded, or sometimes undulate. Laesurae straight, simple, may extend to kyrtome. Kyrtomes prominent, forming an unbroken ridge or crest, which at the angles of the spore may project beyond the amb. Kyrtomes about 5-7.5µm in width and height (measured as the projection beyond the amb in radial region); the roughly truncate radial projection of the kyrtomes is 20-30µm in width. Margin of kyrtome smooth to undulate, sometimes modified by ornament. Exine laevigate or more usually coarsely granulate. Grana loosely distributed, sometimes with scattered verrucae on, or between, kyrtomes. Exine about 2.5µm thick.'

Size in microns. (i) Holotype 68; 50-84 (50-68), fum. HNO_3 (Horst 1955). (ii) 42(51)61, fum. HNO_3 seam at about 2,776 ft., Colston Bassett (British Petroleum Co. Ltd.) borehole, Nottinghamshire Coalfield, England; Westphalian A (Langsettian) Smith and Butterworth 1967). (iii) 40(50)65, offshore western Ireland (Robeson 1988), (iv) 36(43)56, offshore western Ireland, this study.

Remarks. Three specimens from offshore western Ireland (this study) show smaller sizes than the ranges listed in Smith and Butterworth (1967) (radial angle to inter-radial angle measurement). Kyrtome width may be as narrow as 3µm.

TRIPARTITES Schemel 1950

Type species. *T. vetustus* Schemel 1950.

Diagnosis. See Schemel (1950, p.242)

Comparison. *Tripartites* differs from *Triquitrites* (Wilson and Coe) emend. Potonié and Kremp 1954 in terms of size, shape and plication of radial crassitudes.

Tripartites vetustus Schemel 1950.

Plate 4, figure 11.

1950 *Tripartites vetustus* Schemel, p. 242, pl. 40, fig. 11.

Holotype. Schemel 1950, pl. 40, fig. 11. Preparation in collection of Missouri Geological Survey.

Type locality. 24 in. coal about 550ft. above top of Madison formation, Daggett County, Utah, U.S.A.; Mississippian.

Diagnosis. (Smith and Butterworth 1967 p. 209 from description in Schemel 1950, p. 242). 'Amb subtriangular, angles broadly rounded or blunt, interradial margins moderately to strongly concave. Laesurae 1-2μm shorter than radius in length. Equatorial flange widest at corners and very narrow, or absent, in the interradial regions; plicated in the widest portions. Flange laevigate; remainder of exine laevigate to minutely punctuate.'

Size in microns. Holotype not stated.

Size	Height of flange	Length of flange	
30-40	10-15		Maceration method not known (Schemel 1950)
30(42)50	6-12	20-40	15 specimens, fum. HNO_3; upper bed of Kittlepurse Seam at 4,108 ft. 11in., Musselburgh No.1 borehole, Lothians Coalfield, Scotland; Namurian A (Smith and Butterworth 1967)
30(45)50			Offshore western Ireland (Robeson 1988).
41 & 42	8 & 8	28 & 25	Two specimens, offshore western Ireland, this study

Description. Trilete miospores with a triangular amb and distinct trilete mark. Sides are moderately to strongly concave, laesurae almost extend to the equatorial margin. The exine forms plicated auriculae at the radial margins, although interradial connections between auriculae are very narrow or absent. The remainder of the exine is laevigate.

Comparison. *Tripartites trilinguis* (Horst) Smith and Butterworth 1967 possesses auriculae which show greater lateral expansion, resulting in a trifoliate appearance. *Tripartites nonguerickei* Potonié and Kremp *ex* Smith and Butterworth 1967 possesses a thicker, granulate or verrucate exine and well developed interradial connections between radial crassitudes.

Tripartites nonguerickei Potonié and Kremp *ex* Smith and Butterworth 1967.

Plate 4, figure 12.

1943 *Triletes (Zonales) guerickei* Horst (thiesis), pl. 7, fig 60.

1955 *Ahrensisporites guerickei* Potonié and Kremp; Horst, p. 178, pl. 23, fig. 60

1956 *Tripartites nonguerickei* Potonié and Kremp p. 92.

1967 *Tripartites nonguerickei* Potonié and Kremp *ex* Smith and Butterworth, p. 207-208, pl. 13, figs. 1-3.

Holotype. Horst 1955, pl. 23, fig. 60. Preparation III41, 14.7 65.3.
Type locality. Hermann Seam, Porubaer Beds, Moravska-Ostrava; Namurian A.
Diagnosis. (Smith and Butterworth 1967, p.207). 'Amb subtriangular, angles broadly rounded with crenulated margins; sides straight or concave with smooth to irregularly undulate margins. Laesurae simple, straight, approximately two-thirds radius. Radial crassitudes with distal radial plications. Radial length, or height 5-12µm width 20-30µm often connected interradially by a flange about 2-3µm in width (not to be confused with marginal rim due to exine thickness) attached distally, but more or less coinciding with margin of the spore. Exine finely to coarsely granulate, or even verrucate; ornament reduced on contact face. Exine about 2.5µm thick.'
Size in microns. (i) Holotype not stated. (ii) 37(42)50, fum. HNO_3; Shale Seam at 663ft. 6in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A. (iii) 40(47)50, offshore western Ireland (Robeson 1988).

Tripartites trilinguis (Horst) Smith and Butterworth 1967.

1943 *Triletes (Zonales) trilinguis* Horst (thesis), pl. 7, figs. 55, 56.

1955 *Tripartites trilinguis* (Horst) Potonié and Kremp; Horst, p. 176, pl. 23, figs. 55, 56.

1956 *Tripartites trilinguis* (Horst) Potonié and Kremp, p. 92.

1957 *Tripartites cristatus* Dybová and Jachowicz, p. 141, pl. 36, figs. 3, 4.

1957 *Tripartites rugosus* Dybová and Jachowicz, p. 139, pl. 35, figs. 1-4.

1957 *Tripartites trifoliatus* Dybová and Jachowicz, p. 140, pl. 36, figs. 1, 2.

1958 *Tripartites ianthina* Butterworth and Williams, p. 373, pl. 3, figs. 7, 8.

1967 *Tripartites trilinguis* Horst emend Smith and Butterworth, p. 208, pl. 13, figs. 6-9.

Holotype. Horst 1955, pl. 23, fig. 56. Preparation IV39, 30.4 68.2.

Type locality. Flora Seam, Michael Colliery, Moravska-Ostrava; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p.208, emended from Horst 1955, p. 176). 'Amb trifoliate, margin crenulated. Laesurae simple, straight or slightly flexuose, one-half to two-thirds radius. Radial crassitudes prominent, rounded, plicated or corrugated, occupying greater part of the amb; radial length or height 2.5-6µm; width 24-32µm. Interradial areas short and deeply incised. Radial thickenings often distinctly connected by a narrow interradial marginal zone. Exine laevigate proximally; distally, small, well-spaced grana occur in radial areas in an arc between ends of laesurae and thickenings. Exine of spore body thin.'

Size in microns. (i) Holotype 51; 41-80, fum. HNO_3 (Horst 1955). (ii) 32(44)51, fum. HNO_3; Namurian A (Butterworth and Williams 1958). (iii) 40(50)60, offshore western Ireland (Robeson 1988).

Comparison. The auriculae of *Tripartites vetustus* are narrower (laterally).

MOOREISPORITES Neves 1958.

Type species. *M. fustis* Neves 1958.

Diagnosis. See Neves 1958, p. 7.

Comparision. *Triquitrites* (Wilson and Coe) emend. Potonié and Kremp 1954 shows thickening of the angles to form radial crassitudes.

Mooreisporites trigallerus Neves 1961.

1961 *Mooreisporites trigallerus* Neves, p. 256, pl. 31, fig. 5.

Holotype. Neves 1958, plate 31, fig. 5.

Type locality. Marine shale with *Hudsonoceras proteum*, Congleton Edge ganister quarry, Staffordshire.

Diagnosis. (Neves 1961, p. 256). 'Size range 55-80µm (thirty specimens measured), holotype 77µm; equatorial outline triangular; trilete rays short, half radius of the spore; apices of spore body ornamented with short, fused baculae.'

Description. Trilete, acamerate miospores with a triangular amb and straight or concave sides. The trilete mark is distinct, with straight laesurae that extend for up to three-quarters of the spore radius. The exine is ornamented with small, scattered coni.

Projecting baculae at the apices are up to 8µm in height and are fused towards the base to form a thickened area.

Size in microns. (i) Holotype 77; 55-80, thirty specimens, Neves (1961). (ii) 72 & 80, two specimens, offshore western Ireland, this study.

Comparison. *Mooreisporites fustis* Neves 1958 possesses heavier branching baculae in the apical regions with isolated baculae on other parts of the distal surface.

Mooreisporites fustis Neves 1958.

Plate 4, figure 14.

1958 *Mooreisporites fustis* Neves, p.7, pl. 1, fig. 1.

Holotype. Neves 1958, pl. 1, fig. 1. Preparation F 746, reference 648134.

Type locality. *Gastrioceras subcrenatum* marine shales, The Wash, Quarnford, North Staffordshire Coalfields, England; Namurian C.

Diagnosis. (Smith and Butterworth 1967, from Neves 1958, p. 7) '…tetrad rays up to one-half of spore body, apices ornamented with well-developed, thick bacula, similar elements may be dispersed on remainder of spore body.'

Size in microns. (i) Holotype 88 x 76; 60-90, Schulze and KOH (Neves 1958). (ii) 40(46)54, (7 specimens) fum. HNO_3; Gubeon Seam at 100ft. 2in., Common Gate No. 1 borehole, Northumberland Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967). (iii) 60 & 70, (2 specimens), fum. HNO_3; Lethemwell Seam, Frances Colliery, East Fife Coalfield, Scotland; ?Namurian (Smith and Butterworth 1967). (iv) 60(90)100, offshore western Ireland (Robeson 1988).

TRIQUITRITES (Wilson and Coe) emend. Potonié and Kremp 1954.

Type species. *T. arculatus* Wilson and Coe 1940.

Diagnosis. Potonié and Kremp (1954, p. 153).

Comparison. *Tripartites* possesses auriculae which are larger, more flange-like and crinkled.

Triquitrites sculptilis Balme emend. Smith and Butterworth 1967.

Plate 4, figures 15-17.

1952 *Triquitrites sculptilis* Balme, p. 181, text-fig. 1g.

1958 *Triquitrites bucculentus* Guennel, p. 73, pl. 5, figs. 1, 2, text-fig. 17.

1967 *Triquitrites sculptilis* Balme emend. Smith and Butterworth, p. 204, pl. 12, figs. 10-12.

Lectotype. Smith and Butterworth 1967, pl. 12, figs. 10, 11. Selected by Balme from his original preparation No. 234 (T70/1 in collection of Coal Survey Laboratory, Sheffield).

Type locality. Seam at 670ft. 10in., Manton Colliery No.4 Shaft, Yorkshire Coalfield, England; Westphalian C (Bolsovian).

Diagnosis. (Smith and Butterworth 1967, p. 204). ‘Amb irregularly triangular, sides more or less straight; angles sharply rounded, flat or lobed. In equatorial view proximal surface pointed; distal surface convex. Equatorial and distal margin in equatorial view irregularly undulate. Laesurae simple, straight, extend two-thirds radius to inner margin of radial crassitudes. Exine laevigate proximally, but distally variously ornamented by an irregular network of ridges and/or verrucae. Thickening of exine at angles variable; sometimes extends interradially to give narrow, equatorially thickened zone of uniform width. Exine moderately thick.’

Size in microns. (i) Lectotype 45; 25(37)45, Schulze and KOH; type locality. (ii) 27(31)37, fum. HNO_3; Sharlston Top Seam at 1,168 ft. 8 in., Cross Hill borehole, Yorkshire Coalfield, England; Westphalian C (Bolsovian) (Smith and Butterworth 1967). (iii) 30(40)50, offshore western Ireland (Robeson 1988).

Remarks. Verrucae are variable in height and width. The development of radial crassitudes varies between specimens and may be absent. If present, crassitudes may extend into interradial areas.

Triquitrites marginatus Hoffmeister, Staplin and Malloy 1955.

Plate 4, figure 20.

1955 *Triquitrites marginatus* Hoffmeister, Staplin and Malloy, p. 397, pl. 39, fig. 12.

Holotype. Hoffmeister, Staplin and Malloy 1955, Plate 39, fig. 12. Slide 1, ser. 15,789.

Type locality. Locality TCO-82, 2072 ft, Hardinsburg formation, U.S.A.

Description. (Hoffmeister, Staplin and Malloy 1955, p. 397). 'Spores radial, trilete; axial view sublenticular; proximal view subtriangular, radial margins convex, interradial margins concave; equatorial flange distinct, widest at radial margins, narrow or absent at the interradial margins; central body laevigate, flange faintly fluted, thicker than central body; trilete rays distinct, simple, almost equal to central body radius; spore coat relatively thick, lacking conspicuous folding, translucent; size range 42-61 microns, flange at radial positions 5.6-11 microns.'

Size in microns.

Holotype; overall size 45.8 x 49.3.

Size	Flange width	
42 & 42	2.5 & 3	2 specimens, offshore western Ireland, this study.

Triquitrites tribullatus (Ibrahim) Schopf, Wilson and Bentall 1944.

Plate 4, figure 22.

1932 *Sporonites tribullatus* Ibrahim in Potonié, Ibrahim and Loose, p. 448; pl. 15, fig 13.

1933 *Laevigati-sporites tribullatus* Ibrahim, p.20, pl. 2, fig. 13.

1934 *Valvisi-sporites tribullatus* (Ibrahim) Loose, p.152, pl. 7, fig 21.

1938 *Azonotriletes tribullatus* (Ibrahim) Luber in Luber and Waltz, pl. 7, fig. 88.

1944 *Triquitrites tribullatus* (Ibrahim) Schopf, Wilson, and Bentall, p.47.

Holotype. Potonié and Kremp 1955, pl. 17, fig. 319 after Ibrahim. Preparation B47, c3 (ul).

Type locality. Agir Seam, Ruhr Coalfield, Germany, top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p.205, translated from Potonié and Kremp 1956, p.90). 'Amb triangular. Laesurae reach more or less to the auriculae; auriculae only slightly inflated and more or less bilobed'.

Size in microns. (i) Holotype 62, Schulze and KOH. (ii) 40-70, Schulze (Potonié and Kremp 1966). (iii) 37(43)52, fum. HNO_3; seam at 436ft. 4in., Mapperley Colliery borehole, Nottinghamshire Coalfield, England; Westphalian A. (iv) 30(40)45, offshore western Ireland (Robeson 1988), (v) 39(40)43 (4 specimens), offshore western Ireland, this study.

Remarks. A number of specimens measured offshore western Ireland also fall into the size range for *Triquitrites bransonii* Wilson and Hoffmeister 1956 given below.

Comparison. *Triquitrites bransonii* is similar in appearance but smaller in size.

Triquitrites bransonii Wilson and Hoffmeister 1956

Plate 4, figure 18.

1956 *Triquitrites bransonii* Wilson and Hoffmeister, p.24, pl. 3, fig. 1.

Holotype. Wilson and Hoffmeister, pl. 3, fig. 1. Preparation No. 12A, WH6.

Type locality. Croweburg Coal, Stewart Mine, Oklahoma, U.S.A.; Des Moines Series.

Diagnosis. (Smith and Butterworth 1967 p 202, from description in Wilson and Hoffmeister 1956, p.24). 'Shape triangular-oblate. Laesurae distinct, extending to equator; lips slightly raised. Exine laevigate. Arcuate thickenings distinct, broadly oval to angular and of variable height, 4.5-7.0µm, width 9-16.5µm. Exine 1-1.5µm thick.'

Size in microns. (i) Holotype 35 x 37.5; 30-42, Schulze and NH_4OH (Wilson and Hoffmeister 1956). (ii) 31(35)41, fum. HNO_3; seam at 1,252 ft. 1in., Apley Barn borehole, Oxfordshire, England; Westphalian D (Asturian) (Smith and Butterworth 1967). (iii) 25(32.5)36, offshore western Ireland, this study.

Comparison. *Triquitrites tribullatus* is similar in appearance but larger in size.

Triquitrites spinosus Kosanke 1943.

Plate 4, figure 19.

1943 *Triquitrites spinosus* Kosanke, p. 205.

Holotype. Kosanke 1943; preparation No. 8004.

Type locality. Pomeroy No. 8A Seam, Princess Pat Colliery, Ohio, U.S.A.; Monongahela Series.

Diagnosis. (Smith and Butterworth 1967, p. 205 from description in Kosanke 1943, p. 128). Oval to elliptical in equatorial view, triangular in polar view; angles rounded or truncate. Laesurae extend nearly to margin of body, lips prominent. Exine laevigate and interspersed with spinae; conspicuous thickening of exine at angles; exine, except at angles, 1-2 μm thick.

Size in microns. Holotype not stated. (i) 45-55, Schulze (Kosanke 1943). (ii) 37(48)57 (15 specimens) fum. HNO_3; Coleford High Delf Seam, Northern United Colliery, Forest of Dean Coalfield, England; boundary Westphalian C/D (Bolsovian/Asturian) (Smith and Butterworth 1967).

Infraturma **CINGULATI** Potonié and Klaus 1954.

BELLISPORES Artüz 1957.

Type species. *B. nitidus* (Horst) Sullivan 1964.

Diagnosis. See Artüz (1957, p.254).

Bellispores nitidus (Horst) Sullivan emend Smith and Butterworth 1967.

Plate 4, figure 23.

1943 *Triletes nitidus* Horst (thesis), pl. 8, fig. 81.

1948 D 11 Knox, p. 157, fig. 8.

1955 *Lycospora nitida* (Horst) Potonié and Kremp in Horst, p.181, pl. 24, fig. 81.

1957 *Bellispores bellus* Artüz, p.255, pl. 7, fig. 49.

1957 *Simozonotriletes trilinearis* Artüz, p. 251, pl. 5, fig. 36.

1964 *Bellispores nitidus* (Horst) Sullivan, p. 375.

1967 *Bellispores nitidus* (Horst) Sullivan emend. Smith and Butterworth, p. 225, pl. 15, figs. 4-7.

Holotype. Horst 1955, pl. 24, fig. 81. Preparation IV53, 23.4 73.8.

Type locality. Justa Seam, Michael Colliery, Moravska-Ostrava; Namurian A.

Diagnosis. (Smith and Butterworth 1967 p.225 expanded from Horst 1955, p.181 and Artüz 1957, p. 255). 'Amb triangular with rounded angles and straight or, more commonly, concave sides. Outline undulate to crenulated, crenulations often more marked at angles. Laesurae simple, extending to inner margin of cingulum. In polar compression cingulum is 2.5-5μm in width. Relatively broad distal radial thickenings present, which extend from pole to equator and have more or less well-defined, crenulated margins; these are up to 10µm in width. Proximal surface laevigate, distal surface, including the cingulum, foveolate; lumina do not exceed 2µm in diameter.'

Size in microns. (i) Holotype 42; 33-43, fum. HNO_3 (Horst 1955). (ii) 28(36)45, HF and 2% KOH (Sullivan 1964 for *B. bellus*); Edgehills Coal, Forest of Dean Coalfield, England; ?Westphalian A (?Langsettian). (iii) 27(29)32, fum. HNO_3; ?Lyoncross Seam at 558ft. 10in., Darnley No.4 borehole, Central Coalfield, Scotland; Namurian A. (Smith and Butterworth 1967). (iv) 30(35)40, offshore western Ireland (Robeson 1988). (v) 30(32)33, offshore western Ireland, this study.

Comparison. *Savitrisporites concavus* Marshall and Smith 1965 lacks foveolae.

KNOXISPORITES Potonié and Kremp emend. Neves and Playford 1961.

Type species. *K. hagenii* Potonié and Kremp 1954.

Diagnosis. See Neves and Playford (1961, p.9).

Comparison. The distal bars of thickening distinguish *Knoxisporites* from *Stenozonotriletes.*

Knoxisporites stephanephorus Love 1960.

Plate 4, figures 24 and 25.

1960 *Knoxisporites stephanephorus* Love, p. 118, pl. 2, figs 1, 2.

Holotype. Love 1960 pl. II, fig 1. Slide S/29.

Type locality. Pumpherston Shell Bed, South Queensferry, Scotland.

Diagnosis. (Love 1960, p. 118). 'Circular in equatorial outline, globose; trilete rays long, with thickened or folded lip structures; exine laevigate, but bearing two thickened rings equatorially, with interradial connections, and a thickened region on the distal pole; folds sometimes accompanying the thickening; size range 40-90µm, holotype 70µm.'

Size in microns. (i) Holotype 70; 40-90, Pumpherston Shell Bed, South Queensferry, Lower Carboniferous, Scotland (Love 1960). (ii) 40(50)60, offshore western Ireland, (Robeson 1988).

Knoxisporites triradiatus Hoffmeister, Staplin and Malloy, 1955.

Plate 4, figures 26 and 27.

1955 *Knoxisporites triradiatus* Hoffmeister, Staplin and Malloy, p. 391, pl. 37, figs 11, 12.

Holotype. Hoffmeister, Staplin and Malloy 1955, pl. 37, fig. 12.

Diagnosis. See Hoffmeister Staplin and Malloy 1955, p.391.

ROTASPORA Schemel emend. Smith and Butterworth 1967.

Type species. *R. fracta* Schemel emend. Smith and Butterworth 1967.

Diagnosis. See Smith and Butterworth (1967, p. 226)

Rotaspora fracta Schemel emend. Smith and Butterworth 1967.

Plate 4, figure 28.

1967 *Rotaspora fracta* Schemel emend. Smith and Butterworth, p. 227, pl. 15, figs. 8-11.

Holotype. Schemel 1950, pl. 40, fig. 8. In collection of Missouri Geological Survey.

Type locality. 24 in. coal about 550ft. above top of Madison Formation, Daggett County, Utah, U.S.A.; Mississippian.

Diagnosis. (Smith and Butterworth 1967, p.227, emended from description in Schemel 1950, p. 242). 'Amb circular, sub-circular, or rounded-triangular. Body triangular, angles rounded, sides straight to slightly concave. Laesurae simple, slightly shorter than body radius. Width of zona roughly constant, thickened at periphery to form a rim. In compressed specimens the zona lies over the distal surface of the body in the radial positions thereby appearing narrower than in the interradial areas. Body and zona laevigate. Folding of the body infrequent.'

Size in microns. (i) 28-35, body 17-24; maceration method not known (Schemel 1950). (ii) 24-40, fum. HNO_3 (Butterworth and Williams 1958). (iii) 30(33)35, offshore western Ireland (Robeson 1988).

Rotaspora knoxi Butterworth and Williams 1958.

Plate 4, figure 29.

1948 Knox, p. 157, text-fig. 5.

1958 *Rotaspora knoxi* Butterworth and Williams, p. 378, pl. 3, figs. 21-23.

Holotype. Smith and Butterworth 1967 pl. 15, fig. 15. Preparation T56/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Lower Garscadden Ironstone Seam at 1,010ft. 2 in., Cawder Cuilt borehole, Central Coalfield, Scotland, Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 228, from Butterworth and Williams 1958, p. 378). 'Amb triangular, angles broadly rounded, sides convex; body triangular, less rounded. Laesurae simple, straight, extending two-thirds to three-quarters body radius. Zona broadest in interradial areas, narrow at angles; cingulum with narrow peripheral rim. Exine smooth, body vitreous in appearance.'

Size in microns. (i) Holotype 40; 26(32)44, fum. HNO_3 (Butterworth and Williams 1958). (ii) 30(35)45, offshore western Ireland (Robeson 1988).

Comparison. *Rotaspora knoxi* is distinguished from *R. fracta* by possessing an inner body that is convex or only slightly concave in outline.

RETICULATISPORITES Ibrahim emend. Neves 1964.

Type species. *R. reticulatus* Ibrahim 1932.

Diagnosis. See Neves (1964, p. 1066).

Comparison. This present study follows workers such as Smith and Butterworth (1967), McLean (1993) in interpreting the genus *Reticulatisporites* as cingulate. This distinguishes the genus from the azonate *Dictyotriletes* and *Reticulitriletes* genera.

Reticulatisporites polygonalis (Ibrahim) Loose emend. Smith and Butterworth 1967.

Plate 5, figure 1.

1932 *Sporonites polygonalis* Ibrahim in Potonié Ibrahim and Loose. P. 447, pl. 14, fig. 8.

1933 *Laevigati-sporites polygonalis* Ibrahim, p. 19, pl. 1, fig. 8.

1934 *Reticulati-sporites polygonalis* Ibrahim; Loose, p. 155, pl. 7, fig. 16.

1955 *Knoxisporites polygonalis* (Ibrahim) Potonié and Kremp, p. 117, pl. 16, fig. 318, text-fig. 33.

1964 *Reticulatisporites polygonalis* (Ibrahim) Neves, p. 1066.

1967 *Reticulatisporites polygonalis* (Ibrahim) Loose emend. Smith and Butterworth, p. 221, pl. 14, fig. 13.

Holotype. Potonié and Kremp 1955, pl. 16, fig. 318 after Ibrahim. Preparation A40, b5 (or).

Type locality. Ägir Seam, Ruhr Coalfiled, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 221, emended from Potonié and Kremp 1955, p. 117). 'More or less polygonal in polar compression, but shape very variable due to oblique compression or folding; outline smooth and undulate, due to radial thickenings. Laesurae simple or, if ridged, elevation slight; one-half to two-thirds of radius. Three zones of cingulum clearly defined, the inner broader than the outer zone. The degree of separation of these thickened zones varies. Exine ornament on distal surface prominent, but reduced proximally; pattern varies in detail but distally consists essentially of a single triangle, or a more or less polygonal structure formed by the bands which connect to the cingulum at inter-radial positions by three prominent muri. Proximally three bands arising in radial positions pass polewards from the cingulum to meet the laesurae; bands of thickening may also pass towards the proximal pole for short distances from other positions on the cingulum. Exine laevigate or scabrate (?infrasculpture); moderately thick.'

Size in microns. (i) Holotype 108, Schulze and KOH. (ii) 80-110, Schulze (Potonié and Kremp 1955). (iii) 79(91)102 (11 specimens), fum. HNO_3; seam at 2,015ft 4in., Cotgrave Wolds borehole, Nottinghamshire Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967). (iv) 80(100)120, offshore western Ireland (Robeson 1988). (v) 77(84)97, offshore western Ireland, this study.

Reticulatisporites reticulatus (Ibrahim) Ibrahim 1933.

Plate 5, figure 2.

1932 *Sporonites reticulatus* Ibrahim *in* Potonié, Ibrahim and Loose, p. 447, pl. 14, fig. 3.

1933 *Reticulati-sporites reticulatus* (Ibrahim) Ibrahim, p. 33, pl. 1, fig. 3.

Holotype. Smith and Butterworth 1967, pl 14, fig. 16 after Ibrahim. Preparation B5, b2 (or).

Type locality. Agir Seam, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 222 from Potonié and Kremp 1955, p. 112). 'Amb sub-circular, sub-angular, or more or less polygonal. Outline smooth, somewhat modified by radial ornament. Laesurae simple, straight, one-half to two-thirds of radius. In polar compression cingulum clearly differentiated into three zones. Exine ornament comprises bands of thickening which extend a short distance from equator to proximal pole and form a reticulate pattern distally. Muri broader than high; number of distal muri reaching equator 6 to 15, rarely more. Exine of proximal face and distal lumina laevigate, moderately thick.'

Size in microns. (i) Holotype 81, Schulze and KOH. (ii) 75-90, Schulze (Potonié and Kremp 1955). (iii) 74(82)94, Schulze and 5% KOH, 59(73)89, fum. HNO_3, Clown Seam, Shireoaks Colliery, Yorkshire Coalfield, England; upper Westphalian B (upper Duckmantian) (Smith and Butterworth 1967). (iv) 64 & 89 (two specimens) offshore western Ireland, this study.

Remarks. Specimens from offshore western Ireland possess muri up to 6μm in width and 2μm in height.

Reticulatisporites carnosus (Knox) Neves 1964.

1939 Type 1 Millott, p. 15, fig. 1, text-fig. 6.
1942 C6 Knox, p. 6, text-fig. 3.
1950 *Cirratriradites carnosus* Knox, p. 329, pl. 19, fig. 290.
1958 *Knoxisporites carnosus* (Knox) Butterworth and Williams, p. 369, pl. 2, figs. 8-10.
1964 *Reticulatisporites carnosus* (Knox) Neves, p. 1067.

Neotype. Plate 14, fig. 11. Preparation T47/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. 9 in. coal at 256ft. 11in., Darnley No.3 borehole, Central Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 220, from diagnosis in Butterworth and Williams 1958, p.369). 'Amb broadly rounded-triangular to subcircular; margin usually smooth, occasionally undulate to uneven or highly involute. Laesurae simple, straight, reaching almost to inner margin of cingulum. Cingulum differentiated into three zones which vary in their proportions within a single spore. Area enclosed by cingulum circular to rounded-triangular. Exine laevigate to infragranulate, radial thickenings may be developed; exine moderately thick.'

Size in microns. (i) Neotype 92; 67(80)94, fum. HNO_3 (Butterworth and Williams 1958. (ii) 60(80)100, offshore western Ireland (Robeson 1988).

SAVITRISPORITES Bharadwaj 1955.

Type species. *S. triangulus* Bharadwaj 1955.

Diagnosis. See Bharadwaj (1955, p.127).

Savitrisporites concavus Marshall and Smith 1965.

Plate 5, figures 5 and 6.

1965 *Savitrisporites concavus* Marshall and Smith, p. 661, pl. 99, figs. 9-12

1971 *Callisporites concavus* (Marshall and Smith) Loboziak, p. 55, pl. 7, figs. 27-28.

Holotype. Marshall and Smith 1965, pl 99, fig. 9. preparation T78/1.

Type locality. Non-coal seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B (lower Duckmantian).

Diagnosis. (Marshall and Smith 1965 p.61). 'Amb triangular, sides straight to strongly concave, margin more or less crenulated to smooth, apices pointed to narrowly rounded. Laesurae simple, straight, reaching inner margin of cingulum, suture often open. Proximal ornament, if present, of ridges bordering laesurae; distal ornament, if present, of irregular thickenings. Apical swellings often developed. Cingulum width often variable on any one specimen.'

Size in microns. (i) 29(34)43, Schulze and 5% KOH (Marshall and Smith 1965). (ii) 36(39.5)42, offshore western Ireland, this study.

Comparisons. *Savitrisporites nux* (Butterworth and Williams) Sullivan emend. Smith and Butterworth 1967 is larger, typically convex and possesses a regularly disposed distal ornament.

Savitrisporites nux (Butterworth and Williams) Sullivan emend. Smith and Butterworth 1967.

Plate 5, figures 3 and 4.

1958 *Callisporites nux* Butterworth and Williams, p.377, pl.3, figs. 24,25.
1964 *Savitrisporites nux* (Butterworth and Williams) Sullivan, p.373, pl.60, figs 1-5.
1967 *Savitrisporites nux* (Butterworth and Williams) Sullivan emend. Smith and Butterworth, p. 223, pl. 15, figs. 1-3.

Lectotype. Smith and Butterworth 1967, pl. 15, figs. 1, 2.
Type locality. Upper Hirst Seam at 2,310 ft. 4in., Brucefield borehole, West Fife Coalfield, Scotland; Namurian A.
Diagnosis. (Smith and Butterworth 1967 p.224, emended from Butterworth and William 1958, p. 377). 'Amb triangular with slightly convex to concave sides and broad rounded angles. Outline smooth to irregularly crenulated. Laesurae simple, distinct, extending to inner margin of cingulum. Cingulum up to about one-half of spore radius in width. Proximal ornament confined to a broad, low band of thickening on either side of each commissure. Distal ornament comprises coni and verrucae, or ridges of irregular height, formed by the coalescence of the bases of the individual elements.'
Size in microns. (i) Lectotype 58; 45(56)64, Schulze and 5% KOH (Butterworth and Williams, 1958). (ii) 30(47)60, fum. HNO_3 (Sullivan 1964); Edgehills Coal, Forest of Dean Coalfield, England; ?Westphalian A (?Langsettian) (Smith and Butterworth 1967). (iii) 45(55)65, offshore western Ireland (Robeson 1988). (iv) 39(49)58, offshore western Ireland, this study.
Remarks. Height of ornamentation is usually less than 5µm.
Comparisons. *Savitrisporites concavus* is smaller with typically concave sides.

STENOZONOTRILETES Naumova ex Ischenko emend. Potonié 1958.

Type species. *S. conformis* Naumova 1953.
Diagnosis. See Potonié (1958, p. 25).

Stenozonotriletes bracteolus (Butterworth and Williams) Smith and Butterworth 1967.

Plate 5, figure 7.

1958 *Lycospora bracteola* Butterworth and Williams, p. 375, pl. 3, figs. 26, 27.
1967 *Stenozonotriletes bracteolus* (Butterworth and Williams) Smith and Butterworth, p. 217, pl. 14, figs. 1-4.

Holotype. Smith and Butterworth 1967, pl. 14, fig.1. Preparation T57/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Lower Hirst Seam at 1,854ft. 2 in., Kincardine borehole, West Fife Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 217, from Butterworth and Williams 1958, p. 375). 'Amb circular to rounded-triangular, outline smooth to denticulate. Laesurae straight, extending to inner margin of cingulum. Exine covered by small grana. Cingulum approximately one-quarter of total spore radius.'

Size in microns. (i) Holotype 45; 36(43)54, Schulze (Butterworth and Williams 1958).

Stenozonotriletes lycosporoides (Butterworth and Williams) Smith and Butterworth 1967.

Plate 5, figure 8.

1958 *Anulatisporites lycosporoides* Butterworth and Williams, p. 378, pl. 3, figs. 28, 29.
1967 *Stenozonotriletes lycosporoides* (Butterworth and Williams) Smith and Butterworth, p. 218, pl.14, figs 5, 6.

Holotype. Smith and Butterworth 1967, pl. 14, fig 5. Preparation T58/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Chapelgreen Seam at 314ft. 2in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 218, from Butterworth and Williams 1958, p. 378). 'Amb circular to subcircular; margin smooth or very finely notched. Laesurae generally simple and straight, but may be ridged up to 1μm in width; extend to polar margin of cingulum. Cingulum 2.5-6μm in width or one-fifth to one-quarter of spore radius. Exine, including cingulum, laevigate or faintly granulate distally. Exine, except for cingulum, thin.'

Size in microns. (i) Holotype 33; 26(34)42 (23 specimens), fum. HNO_3 (Butterworth and Williams 1958). (ii) 25(40)45, offshore western Ireland, Robeson (1988). (iii) 42 (one specimen), offshore western Ireland, this study.

Infraturma **PSEUDOCINGULATI** Neves 1961.

SECARISPORITES Neves 1961.

Type species. *S. lobatus* Neves 1961.

Diagnosis. See Neves (1961, p. 260).

Secarisporites remotus Neves 1961.

Plate 5, figure 9.

1961 *Secarisporites remotus* Neves, p.262, pl. 32, figs. 8,9.

Holotype. Neves (1961, pl. 32, fig. 9).

Type locality. Non-marine roof shales of the Pot Clay Coal, Holymoorside, Derbyshire. Yeadonian Stage.

Diagnosis. (Neves 1961, p. 262). 'Size range 35-50µ (fifteen specimens measured), holotype 46µ; equatorial outline triangular, subcircular to ovate; exine ornamented with narrow ridges and small warts; outline of spore with rounded lobes of variable size.'

Size in microns. (i) Holotype 46; 35-50, Neves (1961). (ii) 30(40)45, offshore western Ireland, Robeson (1988).

Comparison. *Secarisporites lobatus* Neves 1961 is larger (55-85µ).

KRAEUSELISPORITES Leschik emend. Scheuring 1974.

Type species. *K. dentatus* Leschik emend. Scheuring 1974.

Diagnosis. See Scheuring (1974, p. 199).

Kraeuselisporites ornatus (Neves) Owens, Mishell and Marshall 1976.

Plate 5, figure 10.

1961 *Cirratriradites ornatus* Neves p. 269; pl. 33, fig. 3.
1976 *Kraeuselisporites ornatus* (Neves) Owens, Mishell and Marshall , p. 153-154, pl. 2, figs 2-4.

Holotype. Neves (1961), pl. 33, fig.3.

Type locality. Non-marine shale with Carbonicola exporrecta, Hiper Sick, Derbyshire. Yeadonian Stage.

Diagnosis. (Owens, Mishell and Marshall 1976, p. 153-154). 'Spores radial, trilete, camerate; equatorial outline rounded triangular to subcircular; in lateral profile the proximal surface is flattened, low pyramidal and the distal surface hemispherical. Exine composed of two layers, the intexine which forms a rounded triangular to subcircular inner body and the exoexine which completely surrounds the inner body and is extended in the equatorial plane to form a flange up to 14µm wide. Exoexine which is infrapunctate, differentially thickened over the distal surface with the thicker portion covering and extending equatorially beyond the margin of the spore body, resulting in the formation of a bizonate flange. Two layers of the exine sometimes closely appressed but may be variable separated in the equatorial plane and over part or the whole distal surface. Trilete mark distinct; laesurae straight, extending to or almost to the margin of the spore body; accompanied and frequently obscured by high flexuous folds of the exoexine which extend, decreasing in height, to the equatorial margin of the spore. Intexine thin, smooth. Exoeine variable in thickness. Distal surface bears a distinctive ornament of sharply pointed cones and spines. Height of elements 2-10µm high (commonly 2-5). Elements are frequently longer, more slender and spinose in form in the flange where they are more sparsely distributed.'

Size in microns. Equatorial diameter; (i) 80-110 (Neves 1961). (ii) 76-86 (Owens *et al.* 1976).

Comparison. *Kraeuselisporites echinatus* Owens, Mishell and Marshall 1976 is larger in size and possesses larger cones and spines.

Kraeuselisporites cf. *ornatus*

Plate 5, figure 11.

Description. Trilete, camerate miospores. Amb rounded triangular to subcircular. Trilete mark distinct, laesurae commonly extending to the amb. Intexine thin, laevigate, forming a rounded-triangular inner body. Exoexine surrounds the inner body and also forms a flange up to 6µm in width which may also be weakly striated. Distal surface of exoexine is ornamented with sharply pointed cones and tapering spines up to 10µm in height, but commonly 2-5µm. Ornament is more sparsely distributed on the flange.

Size in microns. Equatorial diameter; 55(64)72, offshore western Ireland, this study.

Comparison. Resembles *Kraeuselisporites ornatus*, but is smaller in size.

Suprasubturma **CAMERATITRILETES** Neves and Owens 1966.

Subturma **SOLUTITRILETES** Neves and Owens 1966.

Infraturma **PLANATI** Neves and Owens 1966.

ENDOSPORITES Wilson and Coe 1940.

Type species. *E. globiformis* (Ibrahim) Schopf *et al.* 1944 (=*E. ornatus* Wilson and Coe 1940)

Diagnosis. See Wilson and Coe (1940, p. 184).

Comparison. *Endosporites* differs from *Florinites* Schopf *in* Schopf *et al.* 1944 in the proximal attachment of the central body to the pseudosaccus and in having a granulate, or infragranulate, rather than infrareticulate exoexine (Smith and Butterworth 1967).

Endosporites globiformis (Ibrahim) Schopf, Wilson and Bentall 1944.

Plate 5, figures 14 and 15.

1932 *Sporonites globiformis* Ibrahim in Potonié, Ibrahim and Loose, p. 447, pl. 14, fig. 5.

1933 *Zonales-sporites globiformis* Ibrahim, p.28, pl. 1, fig. 5.

1938 *Zonotriletes globiformis* (Ibrahim) Luber in Luber and Waltz, pl. 8, fig. 103 and pl. B, fig. 30.

1944 *Endosporites globiformis* (Ibrahim) Schopf, Wilson and Bentall, p.45.

Holotype. Potonié and Kremp 1956, pl. 20, fig. 459 after Ibrahim. Preparation B33, d1 (or).

Type locality. Agir Seam, Ruhr Coalfield, Germany; top of Westphalian B (Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p. 271, translated from Potonié and Kremp 1956 p.161). 'Width of pseudosaccus at the equator greater than body radius.'

Size in microns. Holotype 131 (Potonié and Kremp 1956).

Pseudosaccus (maximum)	Body (along same axis)	Ratio body to pseudosaccus, %	
110-60			Schulze (Potonié and Kremp 1956)
62(87)109	30(40)54	39(46)53	Fum. HNO_3; Two Foot Seam at 1,410ft. 4in., Cross Hill borehole, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967).
104(131)161	37(56)78	34(42)51	Schulze and 5% KOH; High Hazel Seam at 2,181 ft. 5 in., Gate Farm borehole, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967).
74(92)112	34(41)57	39(45)52	Fum. HNO_3; High Hazel Seam (as above).
86(102)127	36(44)61	36(43)48	Offshore western Ireland, this study

Description. Trilete, camerate miospores with a distinct trilete mark and rounded-triangular amb. The intexine forms a rounded-triangular inner body which may also show compression folds. The exoexine forms a thin, granulate pseudosaccus with a weakly limbate margin. Laesurae are weakly ridged and extend to between one-half and the entire radius of the inner body. Folds on the exoexine can give the impression of the laesurae extending to the pseudosaccus margin. The inner body radius is up to 50% of the pseudosaccus width.

Comparison. *Endosporites. zonalis* (Loose) Knox 1950 is very similar but with a greater body to pseudosaccus ratio. Smith and Butterworth (1967) indicate that species of *E. globiformis* and *E. zonalis* overlap slightly in the ratio of their body to pseudosaccus dimensions. The authors proposed an arbitrary ratio of 50% to distinguish between the two species.

Endosporites zonalis (Loose) Knox 1950.

Plate 5, figures 12 and 13.

1934 *Zonales-sporites zonalis* Loose, p.148, pl. 7, fig 5.
1944 *Cirratriradites zonalis* (Loose) Schopf, Wilson and Bentall, p. 44.
1950 *Endosporites zonalis* (Loose) Knox, p. 332.

Holotype. Potonié and Kremp 1956, pl. 20, fig. 455 after Loose. Prepartion IV27, f_5 (m/ol).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, translated from Potonié and Kremp 1956). 'Width of pseudosaccus at the equator less than body radius.'

Size in microns. Holotype 95 (Potonié and Kremp 1956).

Pseudosaccus (maximum)	Body (along same axis)	Ratio body to pseudosaccus, %	
90-100			Schulze (Potonié and Kremp 1956).
69(83)104	38(48)60	46(57)72	Fum. HNO_3; Swallow Wood Seam, Denaby Main Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967)
61(78)100	33(50)61	48(65)77	Fum. HNO_3; Silkstone Seam, various localities, Yorkshire Coalfield, England (Smith and Williams 1957) Westphalian A (Langsettian).
61(89)103	44(53)61	56(61)72	Offshore western Ireland, this study

Comparison. Similar to *Endosporites globiformis* except that the ratio of body to pseudosaccus is different. Smith and Butterworth (1967) propose an arbitrary ratio of 50% to distinguish between the two species.

Infraturma **DECORATI** Neves and Owens 1966.

GRUMOSISPORITES Smith and Butterworth 1967.

Type species. *Grumosisporites verrucosus* (Butterworth and Williams) Smith and Butterworth 1967.
Diagnosis. See Smith and Butterworth (1967 p.228).
Comparison. Separation of exine layers distinguishes species of the genus *Grumosisporites* from those from *Camptotriletes, Dictyotriletes* and *Verrucosisporites.*

Grumosisporites varioreticulatus (Neves) emend. Smith and Butterworth 1967.

Plate 5, figures 16 and 18.

1958 *Dictyotriletes varioreticulatus* Neves, p.8, pl. 2, figs. 1a, b.
1967 *Grumosisporites varioreticulatus* (Neves) emend. Smith and Butterworth, p. 232, pl. 17, figs. 8-10.

Holotype. Neves 1958, pl. 2, fig. 1. Preparation F 7S1, reference 056550 in collection of Geological Department , Sheffield University.
Type locality. Roof shales of Six Inch Seam, Quarnford, North Staffordshire Coalfields, England; Namurian C.
Diagnosis. (Smith and Butterworth 1967, p.232, emended from Neves 1958, p. 8). 'Outline circular to oval. Laesurae straight, simple, two-thirds to three-quarters of radius. Exine layers well separated except in contact areas. Intexine thin. Ornament a slightly irregular and weakly defined reticulum; muri low. Approximately 25 small conical projections at margin.'
Size in microns. (i) Holotype 106; 70-110, Schulze and 10% KOH (Neves 1958). (ii) 67(78)89 (16 specimens), fum. HNO_3; various localities; Westphalian A and B (Langsettian and Duckmantian) (Smith and Butterworth 1967). (iii) 70(90)110, offshore western Ireland (Robeson 1988). (iv) 67(79)89, offshore western Ireland, this study.
Comparison. The poorly defined reticulate ornament of *Grumosisporites varioreticulatus* distinguishes it from other species of the genus.

Grumosisporites inaequalis (Butterworth and Williams) emend. Smith and Butterworth 1967.

Plate 5, figure 17.

1948 39K Knox, text-fig. 47.
1958 *Verrucosisporites inaequalis* Butterworth and Williams, p. 362, pl. 1, figs. 46, 47.
1967 *Grumosisporites inaequalis* (Butterworth and Williams) emend. Smith and Butterworth, p. 229, pl. 16, figs. 1-8.

Holotype. Smith and Butterworth 1967, plate 16, fig. 1 after Butterworth and Williams. Preparation T37/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Seam at 1,336 ft. 3 in., Righead borehole, West Fife Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 229 emended from diagnosis and description in Butterworth and Williams 1958, p. 362). 'Amb circular to oval; outline uneven. Laesurae straight, two-thirds of radius. Intexine thin and indistinct. Exoexine covered by irregularly shaped verrucae, 2-4µm in diameter, 15-20 projecting at the margin. Exoexine moderately thick.'

Size in microns. (i) Holotype 40; 29(37)47, Schulze and 5% KOH (Butterworth and Williams 1958). (ii) 30(40)45, offshore western Ireland (Robeson 1988).

SPELAEOTRILETES Neves and Owens 1966.

Type species. *S. triangulus* Neves and Owens 1966.

Diagnosis. See Neves and Owens (1966, p. 342-344)

Spelaeotriletes arenaceus Neves and Owens 1966.

Plate 5, figure 19.

1966 *Spelaeotriletes arenaceus* Neves and Owens, p. 345, pl. 2, figs. 1-3.

Holotype. Neves and Owens 1966, pl. 2, figs. 1-3.

Type locality. Lower Bentham Grit Coal, Greta River (G.R. SD 34633718) Lancashire. Sabdenian Stage. Namurian A.

Diagnosis. Trilete, camerate miospores with a convexly triangular amb. The trilete mark is usually distinct; rays almost extend to the margin of intexine and can be associated with narrow folds of the exoexine which almost reach the equatorial margin. The exoexine is infrapunctate and additional ornamentation can include small baculae, verrucae, pila and cones. Elements are 1-2µm in basal diameter and height, distributed with variable density.

Size in microns.

Overall diameter	Diameter of inner sac	
82-144	44-90	Neves and Owens (1966).
80(100)120		Offshore western Ireland (Robeson 1988).

Comparison. *Spelaeotriletes triangulus* Neves and Owens 1961 possesses ornament that is coarser, denser and more uniformly distributed than *S. arenaceus.*

Remarks. Offshore western Irish specimens commonly show intra-specific variation between *Spelaeotriletes arenaceus* and *S. triangulus* Neves and Owens 1966. The illustrated specimen is a typical indeterminate form.

Spelaeotriletes triangulus Neves and Owens 1966.

Plate 5, figure 19.

1966 *Spelaeotriletes triangulus* Neves and Owens, p. 345, pl. 1, figs. 1-3.

Holotype. Neves and Owens 1966, pl. 1, figs. 1-3.

Type locality. Pot Bank Coal, Congleton Edge Ganister Quarry (GR. SJ 869591), Staffordshire. Sabdenian Stage; Namurian A.

Diagnosis. (Neves and Owens 1966, p. 345). 'Spores radial, trilete, camerate; equatorial outline convexly triangular; outline of intexine sac subcircular. Trilete rays simple, reaching margin of inner sac; usually obscured by folding of exoexine; curvaturae imperfectae distinct as they delimit the proximal encroachment of ornament. Conspicuous ornament of sub-conical and verrucose elements which fuse laterally to form small groups of short irregular ridges. Elements 1-3µ basal diameter; 1-3µ high; densely set on the distal surface and equatorial border; confined on the proximal surface to the radial extremities. Contact faces large, without sculpture. Secondary folds common.'

Size in microns.

Overall diameter	Diameter of inner sac	
101-175	50-108	Neves and Owens (1966).

Remarks. Offshore western Irish specimens commonly show intra-specific variation between *Spelaeotriletes arenaceus* and *S. triangulus.* The illustrated specimen is a typical indeterminate form.

ANGULISPORITES Bharadwaj 1954.

Type species. *A. splendidus* Bharadwaj 1954

Diagnosis. See Bharadwaj 1954.

Comparison. A cingulate-like equatorial thickening of the saccus distinguishes the genus from *Endosporites.*

Angulisporites splendidus Bharadwaj 1954.

Plate 7, figure 18.

Diagnosis. See Bharadwaj (1954, p. 516, text-fig. 4).

Description. Trilete, camerate miospores with a rounded triangular to subcircular amb. Inner body (intexine) radius is two-thirds to three-quarters of the spore radius. The trilete mark is distinct; laesurae extend to the inner body margin, accompanied by folds that extend to the equatorial margin of the spore. The exoexine is infragranular or infrapunctate and has a thickened equatorial rim, up to one-half of the saccus in width.

Size in microns. Overall diameter; (i) 75, 82 (two specimens, offshore western Ireland, this study)

Subturma **MEMBRANATITRILETES** Neves and Owens 1966.

Infraturma **CONTINUATI** Neves and Owens 1966.

IBRAHIMISPORES Artüz emend Artüz 1971.

Type species. *I. microhorridus* Artüz 1957.

Diagnosis. See Artüz (1971, p.111).

Remarks. As there is uncertainty regarding the nature of the intexine and exoexine attachment in *Ibrahimispores*, its suprageneric placement is problematical (McLean 1993). McLean placed the genus in the Infraturma CONTINUATI based on its similarity with *Spinozonotriletes* Hacquebard emend. Neves and Owens 1966.

Ibrahimispores brevispinosus Neves 1961.

Plate 5, figure 20.

1961 *Ibrahimispores brevispinosus* Neves, p. 254-255, pl. 31, fig. 2

Holotype. Neves 1961, pl. 31, fig.2.

Type locality. Non-marine shales with *Carbonicola exporrecta*, Hipper Sick, Derbyshire. Yeadonian stage.

Diagnosis. (Neves 1961 p. 255). 'Size range 70-100µm (fifteen specimens measured), holotype 80µm; equatorial outline rounded-triangular; exine ornamented with stout, hollow pointed spines which are thickened at the tips.'

Size in microns. (i) Holotype 80; 70-100, (Neves 1961). (ii) 70(85)90, Offshore western Ireland, Robeson (1988) (iii) 89 & 97 (two specimens) offshore western Ireland, this study.

Infraturma **CINGULICAMERATI** Neves and Owens 1966.

CINGULIZONATES Dybová and Jackowicz emend. Butterworth *et al.* 1964.

Type species. *C. bialatus* (Waltz) Smith and Butterworth 1967.

Diagnosis. See Butterworth, Jansonius, Smith and Staplin *in* Staplin and Jansonius (1964, p. 105)

Comparison. *Cingulizonates* is distinguished from other genera by the presence of a cuesta.

Cingulizonates capistratus (Hoffmeister, Staplin and Malloy) Staplin and Jansonius 1964.

1955 *Densosporites capistratus* Hoffmeister, Staplin and Malloy, p.386, pl. 36, figs. 14, 15.
1964 *Cingulizonates capistratus* (Hoffmeister, Staplin and Malloy) Staplin and Jansonius, p. 105.

Holotype. Hoffmeister, Staplin and Malloy 1955, pl. 26, fig 15. Preparation 8, ser. 18,650.
Type locality. Shale at 2,072ft., Carter No. 3 borehole (TCO-82), Webster County, Kentucky, U.S.A.; Hardinsburg Formation, Chester Series.
Diagnosis. (Smith and Butterworth 1967 p. 261 from description in Hoffmeister, Staplin and Malloy 1955, p. 386). 'Outline convexly subtriangular. Rays with narrow ridges, extending to the inner edge of equatorial region. Thickened equatorial region divided into three zones, inner zone thick, middle zone variable in thickness, composed of radiating, crowded variable rods or cylindrical processes, outer zone thin and translucent, tapering to an even outer margin. Central area granulate; small coni sometimes present on outer zone.'
Size in microns. Holotype 46 x 41, inner zone 2.5, middle zone 2.5-3; 41-61, HF (Hoffmeister, Staplin and Malloy 1955).

*Cingulizonate*s cf. *capistratus* (Hoffmeister, Staplin and Malloy) Staplin and Jansonius 1964.

Plate 6, figure 1

1958 *Densosporites capistratus* Hoffmeister, Staplin and Malloy; Butterworth and Williams, pl. 3, figs. 44, 45.
1958 *Densosporites variabilis* (Waltz) Potonié and Kremp; Butterworth and Williams, pl. 3, figs. 32-34.

Size in microns.

Spore diameter	Cingulum width	
41(52)60	11(15)20	Fum. HNO_3; middle bed of Great Seam at 3,921 ft. 8in.,

		Musselburgh No. 1 borehole, Lothians Coalfield, Scotland; Namurian A (Smith and Butterworth 1967).
41(50)60	8(13)18	Fum. HNO_3; Oakwood Seam at 29ft. 6in., Cheswick borehole No. 108, Northumberland Coalfield, England; Namurian A (Smith and Butterworth 1967).
40(55)70		Offshore western Ireland (Robeson 1988).

Description. (Smith and Butterworth 1967 p. 261). '…the central area is foveolate compared with the granulate ornament of *C. capistratus sensu stricto*. The cingulum is somewhat greater than 50% of total diameter…'

Comparison. *Radiizonates aligerens* (Knox) Staplin and Jansonius 1964, possesses a broader cingulum and a longer trilete mark. Radiating struts on the cingulum are also more prominent.

Cingulizonates loricatus (Loose) Butterworth and Smith *in* Butterworth *et al.* 1964.

Plate 6, figure 2.

1932 *Sporonites loricatus* Loose in Potonié, Ibrahim and Loose, p.450, pl. 18, fig. 42.
1934 *Zonales-sporites loricatus* Loose, p. 151.
1944 *Densosporites loricatus* (Loose) Schopf, Wilson and Bentall, p. 40.
1964 *Cingulizonates loricatus* (Loose) Butterworth and Smith *in* Butterworth *et al.*, p. 1053, pl. 2, fig. 4.

Holotype. Potonié and Kremp 1956, pl. 18, fig 400 after Loose. Preparation III2, a_3 (ur).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p. 262, translated from Potonié and Kremp 1956, p. 119). 'Small indented ('korrodiert') form. Dark zone of cingulum broader than the light zone,which is clearly in contrast to it. Strong tetrad mark.'

Size in microns.

Holotype 41.5 Schulze (Potonié and Kremp 1956).

Spore diameter	Cingulum cuesta	Outer zone	
35-50			Schulze (Potonié and Kremp 1956)

32(41)48	3(4.5)6	1(4.2)6	Fum. HNO_3; Upper Flint Seam at 1,069ft. 2in., Madeley Wood No. 4 borehole, Coalbrookdale Coalfield, England; lower Westphalian B (lower Duckmantian) (Smith and Butterworth 1967).
24(34)40	2(3.5)4	1(3.5)5	Fum. HNO_3; Bottom Robins Seam at 843ft. 0in., Plantation borehole, Cannock Chase Coalfield, England; lower Westphalian C (lower Bolsovian) (Smith and Butterworth 1967).
35(45)50			Offshore western Ireland (Robeson 1988).

Description. (Smith and Butterworth 1967 p. 262). 'Amb rounded-triangular. Laesurae prominent, simple, flexuose, extending to inner margin of cingulum. Cingulum approximately 40% of total spore diameter. Central body or intexine thin, laevigate. Central proximal area of exoexine slightly rugose; central distal area granulate, or with small verrucae. Outer margin of cuesta minutely crenulated; outer thin part of cingulum minutely granulate, sometimes slightly plicated. Margin of spore slightly modified by grana and plications.'

Cingulizonates bialatus (Waltz) Smith and Butterworth 1967.

Plate 6, figure 3.

1938 *Zonotriletes bialatus* Waltz in Luber and Waltz, p. 22, pl. 4, fig 51.
1941 *Zonotriletes bialatus* var. *undulatus* Waltz in Luber and Waltz, p. 28, pl.5, figs. 71a, b.
1941 *Zonotriletes bialatus* var. *costatus* Waltz in Luber and Waltz, p. 29, pl.5, fig. 72.
1956 *Densosporites bialatus* (Waltz) Potonié and Kremp, p. 114.
1956 *Hymenozonotriletes bialatus* var. *undulatus* (Waltz) Ishchenko, pp. 63,64; pl. 12, figs. 135-7.
1957 *Cingulizonates tuberosus* Dybova and Jachowicz, p. 171, pl 53, figs. 1-4.
1958 *Densosporites striatus* (Knox) Butterworth and Williams, p. 380, pl.3, fig. 36.
1967 *Cingulizonates bialatus* (Waltz) Smith and Butterworth, p. 260, plate 21, figs 3,4.

Holotype. Not designated.

Type locality. Bed 6, Verkhni-Goubakhin Colliery, Kalinin Shaft, Kizel region, U.S.S.R.; Lower Carboniferous.

Diagnosis. (See Smith and Butterworth 1967 p. 260 from Waltz in Luber and Waltz 1941). 'Body rounded-triangular or ovate. Rays seldom seen but somewhat shorter than radius of spore body. Flange thin, broad, with undulating surface and irregular margin; inner edge thickened, smooth or striated, sometimes with large tubercles projecting into the thinner outer flange.'

Size in microns. (i) 70-80, Schulze (Luber and Waltz 1938). (ii) 25-60; body 20-35; flange 10-25 (Luber and Waltz 1941). (iii) 46(60)77; body 21(27)34, Schulze and NH_4OH (Playford 1963); Spitsbergen; Lower Carboniferous. (iv) 27(37)45; thickened part of cingulum 2(5)9, thin part 1(4)8, fum. HNO_3; Extra Seam at 25,89ft. 8in., Musselburgh No.1 borehole, Lothians Coalfield, Scotland; Namurian B or C. (v) 36(41)48; thickened area of cingulum 2(6)9, thin part 2(5)8, fum. HNO_3; seam at 32ft. 6in., Cheswick borehole No. 108, Northumberland Coalfield, England; Namurian A. (vi) 30(40)50 Offshore western Ireland (Robeson 1988).

Comparison. *Cingulizonates loricatus* lacks tubercles.

CIRRATRIRADITES Wilson and Coe 1940.

Type species. *C. maculatus* Wilson and Coe 1940.

Diagnosis. See Wilson and Coe (1940, p. 183).

Cirratriradites saturni (Ibrahim) Schopf, Wilson and Bentall. 1944.

Plate 6, figures 5 and 6.

1932 *Sporonites saturni* Ibrahim in Potonié, Ibrahim and Loose, p. 448, pl. 15, fig. 14.
1933 *Zonales-sporites saturni* Ibrahim, p. 30, pl. 2, fig. 14.
?1938 *Zonotriletes saturni* (Ibrahim) Luber in Luber and Waltz, pl. 8, fig. 102.
1944 *Cirratriradites saturni* (Ibrahim) Schopf, Wilson and Bentall, p. 44.

Holotype. Ibrahim 1932, pl. 15, fig. 14, Potonié and Kremp 1956, pl. 18, fig. 412 after Ibrahim. Preparation B26, d2 (ul).

Type locality. Ägir Seam, Ruhr Coalfield, Germany; top Westphalian B (top Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 258 translated from Potonié and Kremp 1956, p. 128). 'Amb rounded-triangular. Trilete rays distinct, extending to the equator. Only one, circular, polar fovea, which through constriction may give the appearance of two.'

Size in microns. Holotype 69.5, Schulze and KOH.

Size	Body Diameter	Zona Width	
70-100			Schulze (Potonié and Kremp 1956).
68(79)91	50(58)68	8(11)16	Schulze and 10% KOH; Bottom Robins Seam at 2,396ft. 11in., Spingslade Pool borehole, Cannock Chase Coalfield, England, Westphalian C (Bolsovian) (Smith and Butterworth 1967).
46(57)68	34(48)58	4(6)9	Fum. HNO_3; seam at 117 ft. 0 in., No. 2 Drift, St. Helen's No. 3 Colliery, Cumberland Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967).
70(80)100			Offshore western Ireland (Robeson 1988).
64(75)89	44(54)63	8(10)13	Offshore western Ireland, this study.

Description. Trilete, cinguli-zonate, camerate miospores with a convexly triangular amb. The trilete mark is distinct with ridged laesurae that extend to the equatorial margin. The intexine forms a rounded-triangular inner body which is coarsely granulate. The exoexine is extended to form a zona, which comprises an inner thickened zone and a wider, thinner, striated outer zone. Up to three foveolae are present in the polar region of the distal exoexine.

Comparison. Distinguished from other species of the genus by the presence of a broad striate zona and the presence of one to three distal foveolae.

Cirratriradites annuliformis Kosanke and Brokaw in Kosanke 1950.

1950 *Cirratriradites annuliformis* Kosanke and Brokaw *in* Kosanke, p. 35, pl. 7, fig. 6.

Holotype. Kosanke 1950, pl. 7, fig. 6. Preparation 596-A, slide 8.

Type locality. Grape Creek No. 6 Coal, Vermillion County, Illinois, U.S.A.; Carbondale Group.

Diagnosis. (Smith and Butterworth 1967, p. 257 from description in Kosanke 1950, p. 35). 'Amb round to round-triangular, margin irregular and minutely toothed. Laesurae extending to margin of zona. Exine minutely puncatate. Zona narrow, not striate, appears to originate proximally and distally of the equator of the spore body. Distal fovae may not be present. Body exine 2-3µm thick, zona 1-1.25µm thick.

Size in microns. Holotype 84 x 82.

Size	Body Diameter	Zona Width	
76-90			Schulze and 10% KOH (Kosanke 1950).
58(78)95	46(64)81	4(7)11	Schulze; seam at 729ft. 3in., Pie Rough (Keele No.1) borehole, North Stafordshire Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth 1967).

Comparison. Distinguished from other species by its relatively narrow, non-striate zona and minutely punctuate exine.

Cirratriradites cf. *annuliformis*

Plate 6, figure 4.

Size in microns.

Size	Body Diameter	Zona Width	
50	44	3	One specimen. Offshore western Ireland, this study.

Remarks. The specimen recorded offshore western Ireland resembles *Cirratriradites annuliformis,* but is smaller in size.

Cirratriradites megaspinosus (Ibrahim) Smith and Butterworth 1967.

Plate 6, figure 7.

1933 *Apiculati-sporites megaspinosus* Ibrahim, p. 24, pl.8, fig. 69.

1955 *Cristatisporites megaspinosus* (Ibrahim) Potonié and Kremp, p. 105.

1967 *Cirratriradites megaspinosus* (Ibrahim) emend. Smith and Butterworth, p. 257, pl. 20, figs. 32-34.

Holotype. Ibrahim 1933, pl. 8, fig.69. Preparation B27, b4 (ol).

Type locality. Ägir Seam, Ruhr Coalfield, Germany; top Westphalian B (top Duckmantian).

Diagnosis. (Smith and Butterworth 1967 emended from Ibrahim 1933, p.24). 'Amb circular to rounded-triangular; in equatorial view proximal surface slightly, distal surface strongly, convex; margin of zona irregularly crenulate. Laesurae simple, extending to inner edge of zona. Zona relatively narrow; width beyond equator 2.5-

6μm; outer zone more translucent than the inner zone, which may slightly overlap the equator. Zona pitted with circular and lenticular dissections. Proximal surface laevigate, distal surface covered with dispersed falcate spinae having a height of 4-9μm and breadth of 2.5-7μm. Exine infragranulate. Thickness of proximal exine about 2.5μm; distal exine thickness about 3.5μm.'

Size in microns. (i) Holotype 88.5 x 84.5, Schulze and KOH. (ii) 52(67)92 (15 specimens) fum. HNO_3; seam at 1,433ft. 0in., Hartswell Farm borehole, Nottinghamshire Coalfield, England; Westphalian C (Bolsovian) (Smith and Butterworth 1967). (iii) 50(65)75, offshore western Ireland (Robeson 1988).

CRASSISPORA Bharadwaj emend. Sullivan 1964.

Type species. *C. kosankei* (Potonié and Kremp) Bharadwaj emend. Smith and Butterworth 1967 (= *C. ovalis*) (Bharadwaj) Bharadwaj 1957).

Diagnosis. See Sullivan (1964, p. 375).

Crassipora kosankei (Potonié and Kremp) Bharadwaj emend. Smith and Butterworth 1967.

Plate 6, figure 9.

1955 *Planisporites kosankei* Potonié and Kremp, p. 71, pl. 13, figs. 208-213.

1957 *Crassispora kosankei* (Potonié and Kremp) Bharadwaj, p. 127.

1967 *Crassipora kosankei* (Potonié and Kremp) Bharadwaj emend. Smith and Butterworth, p. 234, pl. 19, figs. 2-4.

Holotype. Potonié and Kremp 1955, pl. 13, fig. 208. Preparation 565/V, KT 20.9 126.1

Type locality. Seam R1, Friedrich Thyssen 2/5 (Wehofen) Colliery, Ruhr Coalfield, Germany; Westphalian B (Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p. 234, emended from Potonié and Kremp 1955, p.71). 'Amb circular to sub-circular or oval; in equatorial view shape more or less lenticular, somewhat distorted by crassitudinous thickening at the equator. Laesurae simple, extending nearly to amb; not usually apparent, or split wide open to give a triangular-shaped tear in polar region. Exine with finely granulate or punctuate infrasculpture. Distal surface covered by small coni rarely exceeding 2µm in height or breadth, irregularly distributed, bases not touching; up to 5µm between coni which project at margin. Proximally, ornament is lacking or greatly reduced. Exine in region of crassitudinous thickening darker in colour than in polar region.'

Size in microns. (i) Holotype 79.8; 68-85, Schulze (Potonié and Kremp 1955). (ii) 47(63)84, fum. HNO_3; High Hazel Seam at 2,181 ft. 5 in., Gate Farm borehole Yorkshire Coalfield, England, Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iii) 54(59)64 offshore western Ireland, this study.

Comparison. *Crassispora maculosa* (Knox) Sullivan 1964 is larger and less densely ornamented.

Crassispora maculosa (Knox) Sullivan 1964.

Plate 6, figure 8.

1948 23K Knox, p. 158, fig. 26.
1950 *Verrucoso-sporites maculosus* Knox, p. 318.
1955 *Apiculatisporis maculosus* (Knox) Potonié and Kremp, p.78.
1964 *Crassispora maculosa* (Knox) Sullivan, p. 376.

Lectotype. Smith and Butterworth 1967 Plate 18, fig. 8.

Type locality. Dunfermline Splint Seam, Lumphinnans No. 1 Colliery, West Fife Coalfiled, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967 p. 235). 'Amb circular. Laesurae ridged; ridges narrow and flexuose, one-half to three-quarters of spore radius. Equatorial crassitude narrow and weakly developed. Exine with fine and dense granulate infrasculpture and distally covered at fairly regular intervals with grana and coni not exceeding 2µm in height. Proximal surface laevigate.'

Size in microns. (i) Lectotype 121x113; 100-120, Schulze (Knox 1950). (ii) 76(94)111, fum. HNO_3; Knightswood Gas Seam at 715ft. 4in., Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian A (Smith and Butterworth 1967). (iii) 90(100)110, offshore western Ireland (Robeson 1988). (iv) 83(89)94, (2 specimens) offshore western Ireland, this study.

Comparison. *Crassispora kosankei* is smaller and more densely ornamented.

Crassispora aculeata Neville 1968.

Plate 6, figure 10.

1968 *Crassispora aculeata* Neville p. 443-444, pl. 2, fig. 5

Holotype. Neville 1968 Plate 2, fig. 5. Sample F75.

Diagnosis. (Neville 1968 p. 443-444). 'Spores subcircular. Trilete mark prominent; the rays extend to, or nearly to, the spore margin and are accompanied by high ray folds. Apical papillae are usually visible in intertectal areas and strongly developed curvaturae are often seen. The crassitude is poorly developed and usually appears as only a slight darkening. The exine is about 1.5-2µm thick but usually there is at least one fold present. The exine is infrapunctate and bears spines on the distal surface which are present at the margin and overlap onto the proximal surface at the extremities of the rays. These spines rarely approach cones and range in length from about 1.5-14µm and in basal width from about 1-5.5µm. Between 10 and 30 spines occur at the equator but most frequently about 20 are present. On individual specimens they are fairly constant in size. The spines either taper gradually or have slightly bulbous bases and are often bent over near the tips. A mixture of these two types of spine can occur on individual specimens.'

Size in microns. (i) 56(73.6)96 (Neville 1968). (ii) 72(76)80 (2 specimens), offshore western Ireland, this study.

Comparison. *Crassispora maculosa* is similar in size, but possesses a denser ornament of smaller cones.

CRISTATISPORITES Potonié and Kremp emend. Butterworth, Jansonius, Smith and Staplin 1964.

Type species. *C. indignabundus* (Loose) Potonié and Kremp 1954.

Diagnosis. See Butterworth, Jansonius, Smith and Staplin in Staplin and Jansonius (1964, p. 108).

Comparison. Distinguished from other genera by its prominent distal sculpture.

Cristatisporites connexus Potonié and Kremp 1955.
Plate 6, figures 11 and 12.

1955 *Cristatisporites connexus* Potonié and Kremp, p. 106, pl. 16, fig. 291.

Holotype. Potonié and Kremp 1955, pl.16, fig. 291. Preparation 77e.

Type locality. Gas Boring KM 1, Ascheburg, Germany; lower Westphalian B (lower Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p.253 translated from Potonié and Kremp 1955, p.106). 'About 30 projections at the equator. Ornamental elements more or less interconnected to form ridges.'

Size in microns.

Spore Diameter	No. of equatorial projections	
Holotype 56 45-70	*Ca.* 30	Schulze (Potonié and Kremp 1955).
51(58)67	24(34)49	Schulze and 5% KOH; Lower Furnace Seam, Bradford Colliery, Lancashire Coalfield, England, lower Westphalian B (lower Duckmantian) (Smith and Butterworth 1967).
37(47)59	22(27)36	Fum. HNO_3; Yard of Tamworth Seam at 1,074 ft. 3in., Bolehall borehole, Warwickshire Coalfield, England; upper Westphalian A (upper Langsettian) (Smith and Butterworth 1967).
45(50)60	Up to 30	Offshore western Ireland (Robeson 1988).
39(54)69	22(36)46	Offshore western Ireland, this study.

Description. (Smith and Butterworth 1967 p.254) 'Amb subcircular. Laesurae not always apparent; may extend into the cingulum. Central body or intexine thin, ?laevigate; central proximal area of exoexine granulate. Cingulum and central distal area verrucate; verrucae closely packed and arranged in ridges or cristae on the cingulum, more widely spaced in the central area. Margin modified by projecting verrucae, some with setose tips; 22 to 50 verrucae have been counted on the equator.'

Comparison. *Cristatisporites connexus* is distinguished from other species of the genus by its ornament consisting solely of verrucae and its larger size.

Cristatisporites indignabundus (Loose) Potonié and Kremp emend. Staplin and Jansonius 1964.

Plate 6, figure 13.

1932 *Sporonites indignabundus* Loose in Potonié *et al.,* p. 451, pl. 19, fig. 51.
1934 *Apiculati-sporites indignabundus* Loose, p.153
1944 *Densosporites indignabundus* (Loose) Schopf, Wilson and Bentall, p. 40.
1954 *Cristatisporites indignabundus* (Loose) Potonié and Kremp, p. 142.
1964 *Cristatisporites indignabundus* (Loose) Potonié and Kremp emend. Staplin and Jansonius, p. 108-109, p. 19, figs 7-9, 12, 14, 20, text-fig.2c.

Holotype. Potonié and Kremp 1955, pl. 16, fig. 294 after Loose. Preparation IV24, d_4 (ol).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany, upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p. 254-255 from Staplin and Jansonius 1964). 'Spores trilete; subcircular to subtriangular; two-layered; intexine lines cavity of exoexine, but seldom seen; central proximal area of exoexine roughened to finely granulose, bounded by an irregular ring of hooked setose spines up to 2.5 microns long and 1.2 microns wide at their bases, sutural ridges flush with or slightly raised above the central proximal surface, narrow, often indistinct, terminated at the row of setae; zona beyond the setae almost psilate or bears scattered small granules or conical apiculae; spore margin irregular with scattered small coni that often have minute setose tips; on specimens where the distal sculpture carries to the equator, the margin is strongly irregular; distal surface sculptured with prominent warts that in part connect at their bases, individual warts up to 6 microns high and 4 microns wide, some warts have setose tips; warts become smaller and well separated towards the equatorial margin and are interspersed with small coni, the warts also may become smaller in the central distal area; inner wall of exoexine minutely foveolate distally; zona not clearly marked, width (measured from equator to outside of ring of setose spines) generally less than half spore radius.'

Size in microns.

Holotype 52.5 Schulze, (Potonié and Kremp 1955).

Spore diameter	No. of equatorial projections	
42(53)64	36(43)51	Fum. HNO_3; Brooch Seam at 2,350ft. 5in., Sandon Bank borehole, Cannock Chase Coalfield, England; upper Westphalian B (upper Duckmantian) (Smith and Butterworth 1967).
41(51)58	33(42)58	Fum. HNO_3; seam at 13ft. 11in., No. 6 Underground borehole, Madeley Wood Colliery, Coalbrookdale Coalfield, England; upper Westphalian B (upper Duckmantian) (Smith and Butterworth 1967)
40(55)60		Offshore western Ireland (Robeson 1988).
42(50)64	26(35)44	Offshore western Ireland, this study.

Criststisporites solaris (Blame) Butterworth and Smith (in Butterworth *et al.* 1964).
Plate 6, figures 14 and 15.

1952 *Densosporites solaris* Balme, text-figs 1a, b.
1956 *Densosporites solaris* Balme; Potonié and Kremp, p. 119, pl. 18, figs. 380, 381.

Lectotype. Smith and Butterworth 1967 Plate 20, fig 24. T69/1, Coal Survey Laboratory, Sheffield.

Type locality. Houghton Thin Seam at 766 ft. 5 in., Wentbridge No. 2 borehole, Yorkshire Coalfield, England; lower Westphalian C (lower Bolsovian).

Diagnosis. (Smith and Butterworth 1967 p. 255, from diagnosis in Balme 1952, p.175). 'Amb oval to subtriangular in equatorial view; proximal surface tetrahedral, distal surface hemispherical. Trilete sutures extend to inner margin of flange (cingulum). Exine of central polar region thin, finely punctate, and ornamented with small tubercles. The outer periphery of the flange indented and prolonged into flattened spinose projections, about 4µm in length. Similar projections also occur on the proximal and distal surfaces of the flange.'

Size in microns. Lectotype 49.5

Spore diameter	Cingulum width	
39(49)65	7-10	Schulze and 5% KOH (Balme 1952).
33(42)56	4(7)11	Schulze and 5% KOH; Bradford Yard Seam, Bradford Colliery,

		Lancashire Coalfield, England; Westphalian C (Bolsovian) (Smith and Butterworth 1967).
32(39)42	4(6)8	Offshore western Ireland, this study.

Comparison. *Cristatisporites indignabundus* is larger, with a wider cingulum.

DENSOSPORITES Berry emend. Butterworth, Jansonius, Smith and Staplin 1964.

Type species. *D. covensis* Berry 1937.

Diagnosis. See Butterworth, Jansonius, Smith and Staplin *in* Staplin and Jansonius (1964, p. 101).

Comparison. *Cingulizonates* differs from *Densosporites* in possessing a bizonate cingulum.

Densosporites anulatus (Loose) Schopf *et al.* 1944.

Plate 6, figure 16.

1932 *Sporonites anulatus* Loose *in* Potonié *et al.*, p. 451, pl. 18, fig. 44.
1934 *Zonales-sporites annulatus* (Loose) Loose, p. 151.
1944 *Denso-sporites annulatus* (Loose) Schopf *et al.,* p. 40.
1967 *Densosporites anulatus* (Loose) Smith and Butterworth, p. 239, pl. 19, figs. 5,6.

Holotype. Potonié and Kremp 1956, pl. 17, fig. 365 after Loose. Preparation III31, b_5 (m/or).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 239, translated from Potonié and Kremp 1956, p. 112). ‘Cingulum relatively uniform and smooth, having scaly structure. Amb smooth. Central area relatively much lighter than cingulum. Infragranulation obscure. Tetrad mark scarcely discernible.’

Size in microns.

Spore diameter	Cingulum width	
Holotype 37.5 35-60		Schulze (Potonié and Kremp 1956).
32(48)56	4(7)11	Fum. HNO_3; Lower Little Flint Seam at 1,196ft. 2in., Madeley Wood No. 4 borehole, Coalbrookdale Coalfield, England; upper Westphalian A (Langsettian) (Smith and Butterworth 1967).
26(34)42	4(7)9	Fum. HNO_3; Extra Seam at 2,589ft. 8in., Musselburgh No. 1 borehole, Lothians Coalfield, Scotland; Namurian B/C (Smith and Butterworth 1967).
28(33)43	5.5(8)11	Offshore western Ireland, this study.

Remarks. Laevigate inner body and cingulum. The cingulum makes up approximately 40% of the spore radius and may thin slightly at the equator. Schopf *et al.* (1944) proposed *D. annulatus* as a new combination prior to Smith and Butterworth (1967). The spelling of the specific epithet is discussed by Ravn (1986, p. 69). The present study follows Potonié and Kremp (1955) and most subsequent authors who chose to maintain the original spelling.

Comparison. The lack of ornamentation distinguishes *D. anulatus* from other species of the genus.

Densosporites intermedius Butterworth and Williams 1958.

Plate 6, figure 18.

1955 *Densosporites tenuis* Hoffmeister, Staplin and Malloy, p. 387, pl. 36, figs. 18, 19 and 23.
1958 *Densosporites intermedius* Butterworth and Williams, p. 379, pl. 3, figs. 38-39.

Holotype. Smith and Butterworth 1967 pl. 19, fig. 10. Preparation T61/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Seam at 2,082 ft. 2in., Righead borehole, West Fife Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 240, from diagnosis in Butterworth and Williams 1958, p. 379). ‘Outline round to round-triangular. Central area thin, unornamented, or slightly granular. Tetrad mark not always seen; rays narrow;

differentiated into a darker thicker inner zone and a lighter equatorial zone. Margin smooth or slightly notched.'

Size in microns.

Spore diameter	Cingulum width	
Holotype 56 35-36		Schulze and 5% KOH (Butterworth and Williams 1958).
37(43)51	8(11)15	Fum. HNO_3; upper bed of Marshall Green Seam at 325ft. 6 in., Callerton No. 23 borehole, Northumberland Coalfield, England; lower Westphalian A (lower Langsettian) (Smith and Butterworth 1967).
35(40)50		Offshore western Ireland, Robeson (1988).
42(47)51	8(12)14	Offshore western Ireland, this study.

Remarks. Proximal central area of exoexine is granulate.

Densosporites sphaerotriangularis Kosanke 1950.

Plate 6, figure 20.

1950 *Denso-sporites sphaerotriangularis* Kosanke, p. 33, pl. 6, fig. 7.

Holotype. Kosanke 1950, pl. 6, fig. 7. Preparation 520-A, slide 2.

Type locality. Bald Hill Coal, Williamson County, Illinois, U.S.A.; Tradewater Group.

Diagnosis. (Smith and Butterworth 1967, p. 242, from description in Kosanke 1950, p. 33). 'Outline rounded triangular. Proximal and distal central areas ornamented with widely spaced papillae. Tetrad mark distinct, 16-18µm long, extending into equatorial portion. Equatorial portion varying from 12.5 to 14.7µm wide; thickest at inner margin, transluscent at equator – the two portions sharply contrasted, but the junction is irregular due to a construction of small placating sheets. Folding lacking except at inner margin of thick wall.'

Size in microns.

Spore diameter	Cingulum width	
Holotype 50.4 x 48.3 46-59		Schulze and 10% KOH (Kosanke 1950).
39(47)60	7.5(11)17	Fum. HNO_3; Great Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, Westphalian D (Asturian) or Stephanian A (Cantabrian/Barruelian) (Smith and Butterworth 1967).
32(41)47	8(11)14	Offshore western Ireland, this study.

Densosporites pseudoannulatus Butterworth and Williams 1958.

Plate 6, figure 19.

1958 *Densosporites pseudoannulatus* Butterworth and Williams, p. 379, pl. 3, fig. 42.

Holotype. Smith and Butterworth 1967, pl 19, fig. 11. Preparation T59/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Seam at 2,082ft. 2in., Righead borehole, West Fife Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 241, from diagnosis in Butterworth and Williams 1958, p. 379). 'Amb round to subtriangular. Laesurae not always seen; rays simple, extending to edge of central area. Margin smooth or finely serrated. Central area thin, finely granulate, frequently showing arcuate folding at the margin. Cingulum massive, breadth roughly equal to radius of central area; uniform in thickness; smooth to slightly spinose and often with characteristic radial fractures on the interradial margin.'

Size in microns.

Spore Diameter	
Holotype 45 35(44)51	Schulze and 5% KOH (Butterworth and Williams 1958).
47	One specimen, offshore western Ireland, this study.

Comparison. Distinguished form other species of *Densosporites* by its lack of prominent ornamentation in addition to its broad, uniform, thick cingulum.

Densosporite gracilis Smith and Butterworth 1967.

Plate 6, figure 17.

1967 *Densosporites gracilis* Smith and Butterworth, p. 240, pl. 19, figs. 7,8.

Holotype. Smith and Butterworth 1967, pl 19, fig. 7. Preparation T90/1 in collection of Coal Survey Laboratory, Sheffield.
Type locality. Dicky Gobbler Seam at 625ft. 0in., Caldwell Ashley House borehole, South Derbyshire Coalfield, England; Westphalian B (Duckmantian).
Diagnosis. (Smith and Butterworth 1967, p. 240). 'Amb round to subtriangular or oval. Laesurae flexuose, extending almost to equator of spore. Cingulum (about 37% of total spore diameter) laevigate, granulate, vermiculate, or having small spinae; also often lobate and sometimes with dissections. Outline irregular. Central area granulate with dissections, or vermiculate.'
Size in microns.

Spore diameter	Cingulum width	
Holotype 35 27(35)42	4(6)10	Fum. HNO_3; type locality.
28(34)38	5(6)8	Fum. HNO_3; Barncraig Seam, Michael Colliery, East Fife Coalfield, Scotland; Westphalian B (Duckmantian) (Smith and Butterworth 1967).
30(36)41	5(6)9	Offshore western Ireland, this study

Comparison. *Densosporites sphaerotriangularis* possesses a wider cingulum.

Densosporites spinifer Hoffmeister, Staplin and Malloy 1955.

Plate 6, figure 22.

1955 *Densosporites spinifer* Hoffmeister, Staplin and Malloy p. 386, pl. 36, figs. 16, 17.

Holotype. Hoffmeister, Staplin and Malloy 1955, pl. 36, fig. 17, TCO-82. Preparation 3, ser. 19066.

Type locality. Shale at 2,075 ft., Carter No. 3 borehole (TCO-82), Webster County, Kentucky, U.S.A.; Hardinsburg Formation, Chester Series.

Diagnosis. (Smith and Butterworth 1967, p. 243, from description in Hoffmeister, Staplin and Malloy 1955, p. 386). 'Outline convexly triangular. Trilete rays not always distinct, extending into thickened equatorial region. Thickened equatorial region almost opaque, thinning only slightly at outer margin. Body coarsely granulate. Equatorial region with dense or scattered spinae, 2-6μm long, sometimes bifurcated; extremely variable in shape and disposition; spinae project at margin.'

Size in microns.

Spore diameter	Cingulum width	
Holotype 46 x 42 32-48		HF (Hoffmeister, Staplin and Malloy 1955).
31(36)46	5(8)11	Fum. HNO_3; South Seam at 4,455ft. 6in., Musselburgh No. 1 borehole, Lothians Coalfield, Scotland; Namurian A (Smith and Butterworth 1967).
33(40)53	6(9)15	Fum. HNO_3; Seam at 39ft. 10in., Cheswick borehole No. 110, Northumberland Coalfield, England; Namurian A (Smith and Butterworth 1967).
38	8	One specimen. Offshore western Ireland, this study.

Comparison. Compared with species of the genus *Cristatisporites, Densosporites spinifer* has a more clearly defined cingulum.

LYCOSPORA Schopf *et al.* emend. Somers 1972.

Type species. *L. micropapillata* (Wilson and Coe) Schopf, Wilson and Bentall 1944.

Diagnosis. See Somers (1972, p.54).

Lycospora pusilla (Ibrahim) Schopf *et al.* 1944.

Plate 6, figure 23 and 24.

1932 *Sporonites pusillus* Ibrahim in Potonié, Ibrahim and Loose, p. 448, pl. 15, fig. 19.
1933 *Zonales-sporites pusillus* Ibrahim, p. 32, pl. 2, fig. 20.
1938 *Zonotriletes pusillus* (Ibrahim) Waltz in Luber and Waltz, pl. 3, fig. 33 and pl. 8, fig. 105.

1944 *Lycospora pusillus* (Ibrahim) Schopf, Wilson and Bentall, p. 54.

Holotype. Potonié and Kremp 1956, pl. 17, fig. 351 after Ibrahim. Preparation B27, a1 (o).

Type locality. Agir Seam, Ruhr Coalfield, Germany; top Westphalian B (top Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 251, translated from Potonié and Kremp 1956, p. 103). 'Tecta straight, fine, ornamented with small grana. Cingulum about one-ninth of radius. Amb slightly and fairly regularly indented ('korrodiert'). Exine finely granulate.'

Description. Trilete, cinguli-zonate miospores with a circular or very slightly triangular amb. Outline is smooth or minutely indented. The trilete mark is distinct, the laesurae are slightly ridged and extend to the inner body (intexine) margin. The exoexine forms a narrow bizonate cingulum, comprising a narrow, darker, inner zone and a wider, thinner outer zone. Width of the cingulum can reach 3-4µm or approximately one-ninth to one-fifth of spore radius. The exine (including cingulum) is finely granulate.

Size in microns. (i) Holotype 38, Schulze and KOH. (ii) 30-40 Schulze (Potonié and Kremp 1956). (iii) 20(27)32, fum. HNO_3 Barnsley Seam, South Kirkby Colliery, Yorkshire Coalfield, England, Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 22(27)35, fum. HNO_3; Top Silkstone Seam, Elsecar Main Colliery, Yorkshire Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967). (v) 22(29)33, offshore western Ireland, this study.

Comparison. *Lycospora noctuina* var. *noctuina* Grebe 1972 possesses rugulae or verrucae on its distal surface. The cingulum in *Lycospora pellucida* (Wicher) Schopf, Wilson and Bentall 1944 constitutes one-fifth to one half of the spore radius.

Lycospora pellucida (Wicher) Schopf, Wilson and Bentall 1944.

Plate 6, figure 25.

1934 *Sporites pellucidus* Wicher, p. 186, pl. 8, fig. 29.

1944 *Lycospora pellucidus* (Wicher); Schopf, Wilson and Bentall, p. 54.

Holotype. Potonié and Kremp 1955, pl. 17, fig. 341 after Wicher. Preparation III B5, d1 (o/r).

Type locality. Seam R_1, Wehofen Colliery, Ruhr Coalfield, Germany; Westphalian C (Bolsovian).

Diagnosis. (Smith and Butterworth 1967, p. 250, expanded from Potonié and Kremp 1956, p. 102). 'Amb rounded-triangular; outline smooth to minutely indented. In equatorial view proximal profile pointed, distal profile convex. Laesurae ridged, straight or flexuose, narrow and seldom more than 1µm in height; they extend to the outer margin of the inner zone of cingulum and sometimes beyond. Cingulum comprises a darker inner zone and a lighter, flange like, outer zone. Total width of cingulum 4-8µm, or one-fifth to nearly one-half radius. Exine including cingulum and ridged portion of laesurae, granulate.'

Size in microns. (i) Holotype 46, Schulze and KOH. (ii) 35-50, Schulze (Potonié and Kremp 1956). (iii) 30(38)44, fum. HNO_3; Beamshaw Seam, South Kirkby Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967).

Comparison. *Lycospora pusilla* possesses a narrower cingulum.

Lycospora noctuina Butterworth and Williams emend. Smith and Butterworth 1967.

1958 *Lycospora noctuina* Butterworth and Williams p. 376, pl. 3, figs. 14,15.

Holotype. Plate 20, fig. 4. Preparation T54/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. 9 in. coal at 256 ft. 11in., Darnley No. 3 borehole, Central Coalfield, Scotland; Namurian A.

Diagnosis. (Smith and Butterworth 1967, p. 248, expanded from diagnosis in Butterworth and Williams 1958, p. 376). 'Amb round-triangular; outline smooth or minutely indented, sometimes undulate. Laesurae ridged, straight or flexuose, up to 2µm in width and height, extending to inner, thickened zone of cingulum and sometimes beyond. Cingulum, (including flange) relatively broad, 4-8µm in width. Exine of central area and inner zone of cingulum finely granulate. A small number of large grana or verrucae or rugulae 1-3µm broad and variable in length, occur distally in the central area within the cingulum; flange of cingulum laevigate, finely granulate, or with small circular, or radially elongate dissections. Exine of central area thin.'

Size in microns. (i) Holotype 36; 30-45, Schulze and 5% KOH (Butterworth and Williams 1958). (ii) 31(35)38, fum. HNO_3; seam at 419ft. 6 in., Houghton Colliery borehole, Durham Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967). (iii) 27(36)47, fum. HNO_3; seam at 31ft. 4 in., Culross No. 2 borehole, West Fife Coalfield, Scotland; Namurian A (Smith and Butterworth 1967).

Lycospora noctuina var. *noctuina* Somers 1972.

Plate 6, figures 26 and 27.

1972 *Lycospora noctuina* var. *noctuina* Somers p. 70, pl. 1, figs 1-3.

Size in microns. (i) 31(35)39, offshore western Ireland, this study.

Remarks. Somers (1972) indicates *Lycospora noctuina* var. *noctuina* possesses a verrucate and/or rugulate ornamentation. Somers also indicates that Langsettian age forms do not possess rugulae, only verrucae.

Comparisons. *Lycospora noctuina var. reticulata* Kruszewska contrasts by possessing a pseudoreticulate ornamentation of the central body. The verrucate and/or rugulate ornamentation of *L. noctuina var. noctuina* differentiates it from *L. pusilla.* The smooth margin of *L. noctuina var. noctuina* distinguishes it from *L. rotunda* Bharadwaj 1957.

Lycospora rotunda Bharadwaj 1957.

Plate 6, figures 28 and 29.

1957 *Lycospora rotunda* Bharadwaj, p. 103, pl. 27, figs. 10-12.

1957 *Lycospora nitida* Artüz, p. 250, pl. 5, fig. 34.

Non 1955 *Lycospora nitida* (Horst) Potonié and Kremp, p. 181, pl. 24, fig. 81.

1957 *Lycospora paulula* Artüz, p. 250, pl. 5, fig. 35.

1967 *Lycospora ?granulata* auct. Non Kosanke 1950; Smith and Butterworth, p. 247, pl. 20, figs. 1-3.

Holotype. Bharadwaj (1957, pl. 27, fig. 10)

Diagnosis. (see Bharadwaj 1957, p. 103).

Remarks. Smith and Butterworth (1967, p. 248) indicate that *Lycospora ?granulata* Kosanke 1950 and *Lycospora rotunda* are identical in size and possess the same granulate ornamentation.

Size in microns. (i) *Lycospora ?granulata;* 30-40, Schulze and 10% KOH (Kosanke 1950). (ii) *Lycospora ?granulata;* 27(32)37, fum. HNO_3; Barnsley Seam, South Kirkby Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iii) 29(31)34 (4 specimens) offshore western Ireland (this study).

Lycospora orbicula (Potonié and Kremp) Smith and Butterworth 1967.

Plate 6, figure 30.

1955 *Cylogranisporites orbiculus* Potonié and Kremp, p. 63, pl. 13, figs. 179-183.

1967 *Lycospora orbicula* (Potonié and Kremp) Smith and Butterworth, p. 249-250, pl. 20, figs. 179-183.

Holotype. Potonié and Kremp 1955, pl. 13, fig. 13, fig. 179. Preparation 607/2, KT 18.6 110.0.

Type locality. Baldur Seam, Brassert Colliery, Ruhr Coalfield, Germany, lower Westphalian C (lower Bolsovian).

Diagnosis. (Smith and Butterworth 1967, p. 249, emended from Potonié and Kremp 1955, p. 63). 'Amb more or less circular to oval; outline denticulate. Laesurae simple, reaching to, or nearly to, equator, sometimes indistinct. Exine finely granulate; ornament reduced or lacking on proximal surface. Cingulum indistinct, very narrow; does not extend polewards; less than 1µm in width, or less than one-tenth of spore radius. Exine thin, often with narrow folds.'

Size in microns. (i) Holotype 27; 25-35, Schulze (Potonié and Kremp 1955). (ii) 20(25)30, fum. HNO_3; Parkgate Seam, Grange Colliery, Yorkshire Coalfield, England, Westphalian A (Langsettian) (Smith and Butterworth 1967).

RADIIZONATES Staplin and Jansonius 1964.

Type species. *R. aligerens* (Knox) Staplin and Jansonius 1964.

Diagnosis. See Staplin and Jansonius (1964, p. 106).

Comparison. (Smith and Butterworth 1967 p. 263 from Hughes, Dettmann and Playford 1962, p.251). 'The strong radial ribs of the outer part of the cingulum and the indistinct intexine distinguish *Radiizonates* from *Cingulizonates*. *Cirratriradites* differs in having a zona, and in the distal part of the exoexine being thicker than the remainder of the exoexine'.

Radiizonates aligerens (Knox) emend. Staplin and Jansonius 1964.
Plate 7, figures 1 and 2.

1950 *Cirratriradites aligerens* Knox, p329, pl.19, fig. 288.

1964 *Radiizonates aligerens* (Knox) Staplin and Jansonius, p. 106, pl. 18, figs. 23-28, text-fig. 2r.

Neotype. Smith and Butterworth 1967, pl 21, figs. 9, 10. Knox did not designate a holotype. A neotype was selected by Staplin from Scottish material (T80/1 in collection of Coal Survey Laboratory, Sheffield).

Type locality. Glass Seam at 819ft. 8in., Monkton House borehole, Lothians Coalfield, Scotland; Westphalian A (Langsettian).

Diagnosis. (Smith and Butterworth 1963 p. 263 from Staplin and Jansonius 1964, p. 106). 'Spores trilete; subtriangular to sub-circular; two layered; intexine not usually visible; central proximal area of exoexine frequently lost, but when preserved, sutural features fine and extending to inner edge of zona, surface finely granulose; margin of central proximal area slightly raised, finely striate, sometimes with minute pits, sometimes overhangs the zona; zona extremely variable with irregular radial rib and gouge surfaces that extends to the equatorial margin on both the proximal and distal surfaces; central distal surface of exoexine commonly bears a few distinct warts or granules and is to a smaller or larger extent involved in the rib and gouge structure of the zona; specimens with thick zonae often have internal vacuoles; internally the exoexinal wall is finely pitted; zona width about the spore diameter; diameter 55-80 microns and perhaps slightly larger.'

Size in microns.

Spore diameter	Cingulum; inner zone width	Cingulum; outer zone width	
70-90			Schulze and 10% KOH (Knox 1950).
Neotype 59 47(59)76	4(5)7	10(13)16	Schulze and 5% KOH; type locality.
48(60)76	4(5)8	10(14)19	Fum. HNO_3; Brockwell Seam at 696ft. 8in., Spanish Battery borehole, Durham Coalfield, England; Westphalian A (Smith and Butterworth 1967).
50(70)80			Offshore western Ireland (Robeson 1988).
53(64)76	3(3.5)5	12(15)18	Offshore western Ireland, this study.

Description. Cinguli-zonate miospores with a subtriangular to subcircular amb. The trilete mark is typically obscured or indistinct. If seen, the laesurae extend to the intexine (inner body) margin. The inner body is typically laevigate. The exoexine forms a bizonate cingulum comprising a narrow, dark, inner zone and a significantly wider, thinner, outer zone with vacuoles. Specimens from offshore western Ireland generally show a slightly narrower inner zone (3-5µm) than those from the type locality and those described in Smith and Butterworth (1967). The exoexine also bears numerous radial plications and striations. Grana or small verrucae are often present on the central distal surface of the exoexine.

Comparison. *Radiizonates* cf. *difformis* (Kosanke) Staplin and Jansonius 1964, is smaller with a narrower outer zone of the cingulum.

Radiizonates tenuis (Loose) Butterworth and Smith *in* Butterworth *et al.* 1964.
Plate 7, figures 3 and 4.

1932 *Sporonites tenuis* Loose in Potonie, Ibrahim, and Loose, p. 450, pl.18, fig 34.
1934 *Zonales-sporites tenuis* Loose, p. 149.
1944 *Cirratriradites tenuis* (Loose) Schopf, Wilson, and Bentall, p. 44.
1956 *Densosporites tenuis* (Loose) Potonié and Kremp, p. 120, pl. 18, figs. 404-7.
1964 *Radiizonates tenuis* (Loose) Butterworth *et al.*, p. 1054, pl. 2, fig 13.

Holotype. Potonié and Kremp 1956, pl. 19, fig. 404 after Loose. Preparation IV78, d_6 (m).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B.

Diagnosis. (Smith and Butterworth 1967 p 266, translated from Potonié and Kremp 1956, p. 120). 'Large indented ('korrodiert') form. Broad cingulum, light zone of which is broader than dark zone, each clearly separated from the other. Tetrad mark long and prominent.'

Size in microns.

Spore diameter	Mean cingulum width	
Holotype 61		Schulze.
50-70		Schulze, Potonié and Kremp (1956).
32(42)54	9.5	Fum. HNO_3 Crank Seam, Gresford Colliery, North Wales Coalfield; Westphalian B (Duckmantian) (Butterworth and Williams, 1954).
40(50)58	12	Schulze and 5% KOH, as above.
35(50)60		Offshore western Ireland (Robeson 1988).
39(47.5)54	12.5	Offshore western Ireland, this study.

Description. Cinguli-zonate miospores with a rounded-triangular amb and a distinct trilete mark. Laesurae extend to the margin of the inner body (intexine) and sometimes into the inner cingulum. The intexine is laevigate. The bizonate cingulum is typically less than one-half of the spore radius in width. It comprises an inner thickened zone and an outer thinner zone. The inner zone is less than half of the total cingulum width. The cingulum is also characterised by bifurcating costae which may also anastamose.

Comparison. *Radiizonates tenuis* can be distinguished from *R. faunus* (Ibrahim) Smith and Butterworth 1967 by its lighter, outer zone of cingulum being broader than the dark inner zone and by its laevigate intexine.

Radiizonates faunus (Ibrahim) Smith and Butterworth 1967.

Plate 7, figure 5.

1932 *Sporonites faunus* Ibrahim in Potonié, Ibrahim and Loose, p. 447, pl. 14, fig. 4.
1933 *Zonales-sporites faunus* Ibrahim, p. 28, pl. 1, fig. 4.
1944 *Cirratriradites faunus* (Ibrahim) Schopf, Wilson and Bentall, p.44.
1956 *Densosporites faunus* (Ibrahim) Potonié and Kremp, p. 117, pl. 18, figs 385-92.
1967 *Radiizonates faunus* (Ibrahim) Smith and Butterworth, p. 264, pl. 21, figs. 12, 13.

Holotype. Ibrahim 1932, pl.14, fig.4, Potonié and Kremp 1956, pl. 18, fig. 385 after Ibrahim. Preparation B39, a5 (m).

Type locality. Ägir Seam, Ruhr coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967 p. 265, translated from Potonié and Kremp 1956, p. 117). 'Relatively large, broad, indented ('korrodiert') cingulum within which there are clearly differentiated light and dark zones, each of the same width. Central area markedly infragranulate. Tetrad mark long, prominent, and nodular, often seen extending into the cingulum.'

Size in microns.

Spore diameter	Mean cingulum width	
50-70		Schulze (Potonié and Kremp 1956).
34(44)53	7(11)14	Fum. HNO_3; No.15 Seam, Nantgarw Colliery, South Wales Coalfield; lower Westphalian C (lower Bolsovian) (Smith and Butterworth 1967).
34(42)56	8(11)15	Schulze and 10% KOH; Wyrley Yard Seam, Springslade Pool borehole, Cannock Chase Coalfiled, England; lower Westphalian C (lower Bolsovian) (Smith and Butterworth 1967).
40(50)55		Offshore western Ireland (Robeson 1988)
38(49)59	9(12)16	Offshore western Ireland, this study.

Radiizonates striatus (Knox) Staplin and Jansonius 1964.

Plate 7, figures 7 and 8.

1950 *Cirratriradites striatus* Knox, p. 330, pl. 19, fig. 289.
1957 *Densosporites marginata* Artüz, p. 252, pl6, fig. 42
1958 *Densosporites striatus* (Knox) Butterworth and Williams, p. 380, pl.3, fig. 36.
1964 *Radiizontes striatus* (Knox) Staplin and Jansonius, p. 106.

Neotype. Butterworth and Williams 1954, pl. 18, fig. 1. Specimen number PF 3009 (formerly 76486), Geological Museum, London. This specimen was one of two designated as hypotypes by Butterworth and Williams (Smith and Butterworth 1967).

Type locality. Ruabon Yard Seam, 388's Drift, Llay Main Colliery, North Wales Coalfield; upper Westphalian A (upper Langsettian).

Diagnosis. (Smith and Butterworth 1967 p. 265 from Butterworth and Williams 1954 p.757). 'Amb round to subtriangular. Cingulum divided into inner thickened, and outer thin zones; the former is plicated in well- preserved specimens, the placations extending into the thinner zone. Exine in polar areas thin, laevigate or granulate.'

Size in microns.

Spore diameter	Cingulum inner zone width	Cingulum outer zone width	
35(41)53	3(7)10	2(4)6.5	Fum. HNO_3 Type locality (Butterworth and Williams 1954).
36(46)58	5(8)11	2.5(5)9	Schulze and 5% KOH. Type locality (Butterworth and Williams 1954).
35(50)55			Offshore western Ireland (Robeson 1988)
40(44)50	8(8.5)9.5	2.5(4)5.5	Offshore western Ireland, this study.

Radiizonates cf. *striatus* (Knox) Staplin and Jansonius 1964.

Plate 7, figure 9.

Size in microns.

Spore diameter	Cingulum inner zone width	Cingulum outer zone width	
30(37.5)45	1.5(5.5)8.5	1.5(4)8.5	Fum. HNO_3; Bush Seam, Michael Colliery, East Fife Coalfield, Scotland; lower Westphalian B (lower Duckmantian) (Smith and Butterworth 1967).
30(38)45			Offshore western Ireland (Robeson 1988).
33(36)40	3(4)5.5	3(5)7	Offshore western Ireland, this study.

Comparison. Compared to *Radiizonates striatus, R.* cf. *striatus* is smaller in size and possesses a narrower inner thickened zone of cingulum.

Radiizonates difformis (Kosanke) Staplin and Jansonius 1964.

1950 *Cirratriradites difformis* Kosanke, p. 35, pl. 7, fig. 3.
1964 *Radiizonates difformis* (Kosanke) Staplin and Jansonius, p. 106.

Holotype. Kosanke 1950, pl. 7, fig. 3. Preparation 625-B, slide 7.

Type locality. Willis Coal, Gallatin County, Illinois, U.S.A.; Tradewater Group.

Diagnosis. (Smith and Butterworth 1967, p. 264, from description in Kosanke 1950, p. 35). 'Outline circular to subtriangular. Laesurae simple, distinct, generally extending into the flange. Large equatorial flange occasionally folded or slightly twisted. Exine of spore body reticulate with anastomosing ridges at periphery extending into the flange.'

Size in microns. Holotype 63 x 53.5, body 31.5; 52-68, Schulze and 10% KOH (Kosanke 1950).

Radiizonates cf. *difformis* (Kosanke) Staplin and Jansonius 1964.

Plate 7, figure 6.

Description. (Smith and Butterworth 1967 p. 264). 'Amb circular to subtriangular. Laesurae generally indistinct, extending into the flange. Equatorial flange divided into two parts, an inner, thicker part composed of ridges radiating from the edges of the spore body and extending into the outer, membranous part. Flange averages about 60% of total diameter. Spore body occasionally with verrucate ornament.'

Size in microns.

Spore diameter	Thickened inner area of cingulum	Thin outer area of cingulum	
42(47)54	3(6)8	7(9)12	Fum. HNO_3; ?Glass Seam at 2,071ft. 4in., Musselburgh No.1 borehole, Lothians Coalfield, Scotland; Westphalian A (Langsettian) (Smith and Butterworth 1967).
40(50)55			Offshore western Ireland (Robeson 1988).
39(46)53	3(4)5.5	5.5(8)10	Offshore western Ireland, this study.

Comparison. *Radiizonates difformis* is larger with a relatively narrower cingulum. *R. aligerens* is also larger with a broader outer area of cingulum and a less prominent inner cingulum.

SIMOZONOTRILETES Naumova *ex* Ischenko emend. Potonié and Kremp 1954.

Type species. *S. intortus* (Waltz) Potonié and Kremp 1954.

Diagnosis. See Potonié and Kremp (1954, p. 159).

Remarks. Hacquebard and Barss (1957) and other workers consider *Murospora* and *Simonozonotriletes* to be cogeneric with the former having priority. The present study follows workers such as Smith and Butterworth (1967) and McLean (1993) in retaining *Simonozonotriletes* and *Murospora* as separate genera. Reasons for keeping the genera separate are outlined in Smith and Butterworth (1967).

Comparison. Differs from *Triquitrites* by the presence of a continuous equatorial structure and *Tripartites* in not possessing plicated radial crassitudes.

Simozonotriletes intortus (Waltz) Potonié and Kremp 1954.

Plate 7, figure 10

1938 *Zonotriletes intortus* Waltz in Luber and Waltz, pl. 2, fig. 24.
1954 *Simozonotriletes intortus* (Waltz) Potonié and Kremp, p. 159.
1962 *Murospora intorta* (Waltz) Playford, p. 609, pl. 86, figs. 12, 13.

Holotype. Luber and Waltz 1938, pl. 2, fig. 24 (designated by Horst 1955).

Type locality. Moscow Brown Coal, Tournaisian.

Diagnosis. (Smith and Butterworth 1967, p. 237 from Sullivan 1958, p. 127). 'Trilete rays extend almost to margin of the central area; lips thin, intratectum narrow, remainder as for genus.'

Size in microns.

Overall Size	Body	
Lectotype ~60		Schulze.
35-110		Schulze and 10% KOH (Sullivan 1958).
49-68		Fum. HNO_3 (Horst 1955).
50(65)82	33(44)57	Schulze and NH_4OH (Playford 1962) Spitzbergen; Lower Carboniferous.

52(64)76	34(43)50	Fum. HNO_3; Greenses Seam at 147ft. 8in., Stamford borehole, Northumberland Coalfield, England; Visean, (Smith and Butterworth 1967).
46	31	One specimen, offshore western Ireland, this study.

Infraturma **POLYCAMERATI** Neves and Owens 1966.

ALATISPORITES Ibrahim emend. Smith and Butterworth 1967.

Type species. *A. pustulatus* (Ibrahim) Ibrahim 1933.

Diagnosis. See Smith and Butterworth (1967 p. 279).

Alatisporites hoffmeisterii Morgan 1955.

Plate 7, figure 11.

1955 *Alatisporites hoffmeisterii* Morgan, p. 37, pl. 2, figs. 1-8.

Holotype. Morgan 1955, pl. 2, fig. 1. Preparation D-54a. Leitz stage readings V-112.2, H-149.5.

Type locality. Rowe Coal, Wagoner County, Oklahoma, U.S.A.; Des Moines Series.

Diagnosis. (Smith and Butterworth 1967, p. 279, from Morgan 1955, p. 37). 'Body subtriangular; interradial margins commonly slightly concave to convex; angles well rounded. Laesurae simple, extending to, or nearly to, margin of body. Body verrucate. Exine about 3µm in thickness. Pseudosacci vary in number, ovate to elongate in outline; laevigate to finely granulate; about 1µm thick and overlapping body by as much as 16µm.'

Size in microns.

Overall size	Body size	
Holotype; 98	69 x 66	Schulze (Morgan 1955).
54(76)104	41(56)68	13 specimens, fum. HNO_3; seam at 670ft 2in., Garth Place borehole, South Wales Coalfield; Westphalian C (Bolsovian) (Smith and Butterworth 1967).
68(71)75	56(60)64	2 specimens, offshore western Ireland, this study.

Remarks. The saccus is subdivided into more than three sub-sacci.

Comparison. The saccus of *Alatisporites pustulaus* Ibrahim 1933 is subdivided into three sub-sacci. The body also appears microreticulate.

Alatisporites pustulatus (Ibrahim) Ibrahim 1933.

Plate 7, figure 12.

1932 *Sporonites pustulatus* Ibrahim *in* Potonié, Ibrahim and Loose, p. 448, pl. 14, fig. 12.

1933 *Alati-sporites pustulatus* (Ibrahim) Ibrahim, p. 32, pl. 1, fig. 12.

Holotype. Potonié and Kremp 1956, pl. 19, fig. 445 after Ibrahim. Preparation B36, b4 (u).

Type locality. Ägir Seam, Friedrich Thyssen 2/5 (Wehofen) Colliery, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 280, from Potonié and Kremp 1956, p. 155). 'Tripseudosaccate. Amb of body with well-rounded angles; body margin smooth to slightly crenulate. Outline of pseudosacci smooth. Laesurae reach to equator. Pseudosacci envelop entire proximal side, meeting along the line of the laesurae; distally, only the polar region (about one-half the diameter of the body) is free from the pseudosacci. Pseudosacci with fine, dense, granulate infrasculpture. Body ornamented by numerous small, sinuous folds of the pseudosaccus.'

Size in microns.

Overall size	Maximum body size	
Holotype 73; 70-90		Schulze and KOH (Potonié and Kremp 1956)
74(81)89	47(52)57	8 specimens; fum. HNO_3; various localities; Westphalian A to C (Langsettian to Bolsovian) (Smith and Butterworth 1967).
70(80)90		Offshore western Ireland, Robeson (1988).

Remarks. Body ornament is finely and densely rugulate-verrucate, which appears microreticulate. Exoexine forms saccus which is subdivided into three sub-sacci, one per interradial area.

Comparison. The body of *Alatisporites hoffmeisterii* possesses a verrucate ornamentation and does not appear microreticulate. The saccus is also subdivided into more than three sub-sacci.

Subturma indeterminate.
Infraturma indeterminate.

SCHULZOSPORA Kosanke 1950.

Type species. *S. rara* Kosanke 1950.

Diagnosis. See Kosanke (1950, p.53).

Comparison. *Schulzospora* is distinguished from *Endosporites* by the elliptical shape of its pseudosaccus and from *Florinites* Schopf *in* Schopf *et al.* 1944 by its clearly defined body and laesurae (Smith and Butterworth 1967).

Schulzospora rara Kosanke 1950.

Plate 7, figures 13 and 14.

1950 *Schulzospora rara* Kosanke, p. 53, pl. 13, figs. 5-8.
1950 *Planisporites ovatus* Knox, p.316, pl.17, fig. 222.
1952 *Endosporites ovatus* (Knox) Balme, p.180, text-fig. 1e.
1958 *Schulzospora ocellata* (Horst) Potonié and Kremp; Butterworth and Williams, pl. 4, fig. 15.

Holotype. Kosanke 1950, pl.13, fig. 8. Preparation 587,slide 8.

Type locality. Battery Rock Coal, Hardin County, Illinois, U.S.A.; Caseyville Group.

Diagnosis. (Smith and Butterworth 1967 p.273 from Kosanke 1950, p. 53). 'Outline elliptical, body spherical. Trilete rays at least 20µm in length, distinct, lips poorly developed. Pseudosaccus and body finely punctuate. Exine thin, not exceeding 2µm.'

Size in microns.

Holotype. 109.2 x 81.9, body 73.5 x 73.5 Schulze and 10% KOH (Kosanke 1950)

Overall dimension (max)	Overall dimension (min)	Body dimension (max)	Body dimension (min)	
54(67)83	38(50)60	40(51)62	32(42)56	Fum. HNO_3; Rushy Park Seam, Sutton Manor Colliery, Lancashire Coalfield, England; upper Westphalian A (upper Langsettian) (Smith and Butterworth 1967).
62(77)102	44(57)72	44(59)80	36(47)58	Fum. HNO_3; seam at 2,803 ft., Colston Bassett (British Petroleum Co. Ltd.) borehole, Nottinghamshire Coalfield, England; lower Westphalian A (lower Langsettian) (Smith and Butterworth 1967).
70(80)100				Offshore western Ireland (Robeson 1988).
65(72)78	53(56)58	47(48)50	43(46)47	Offshore western Ireland, this study.

Description. Trilete, camerate miospores with an oval or ovate amb. One end of the amb is typically blunter than the other. The inner body is circular to oval, the long axis being parallel to that of pseudosaccus. Laesurae are not always evident. When visible, they almost extend to the margin of the inner body. The intexine and exoexine are typically finely infrapunctate. The short axis of the inner body is almost the same width as the short axis of the spore. The long axis of inner body is approximately 3/4 of the spore long axis.

Comparison. Distinguished from *Schulzospora campyloptera* (Waltz) Hoffmeister, Staplin and Malloy 1955 by its more rounded shape and slightly smaller inner body.

Schulzospora campyloptera (Waltz) Hoffmeister, Staplin and Malloy 1955.

Plate 7, figure 15.

1884 No.619, Reinsch, p.60, pl. 22, fig. 231 D.

1938 *Zonotriletes campylopterus* Waltz in Luber and Waltz, p. 16, pl3, fig. 39, and pl. A, fig 15.

1955 *Schulzospora campyloptera* (Waltz) Hoffmeister, Staplin, and Malloy, p.396.
1958 *Dilobozonotriletes campylopterus* (Waltz) Ishchenko, p. 94, pl. 12, figs. 160, 161.

Holotype. Not known.

Type locality. Seam 46, Skakulin Colliery, Selizharovo, Moscow Basin.

Diagnosis. (See Smith and Butterworth 1967, p 274 translated from Luber and Waltz 1938). 'Outline approximately oval, pseudosaccus thin, of variable width, three or four times wider at equator than at poles giving the spore an oval rather than a round shape; pseudosacus margin crenulate. Laesurae indistinct, rays one-third to two-thirds spore radius, not all of equal length. Exine microreticulate, more distinct on the pseudosaccus than on the body.'

Size in microns.

Overall dimension (max)	Overall dimension (min)	Body dimension (max)	Body dimension (min)	
90-114	65-75	60-70		Schulze (Luber and Waltz 1938).
76(87)100	44(55)62	46(54)66	40(48)60	Fum. HNO_3; Greenses Seam at 147ft. 8in., Stamford borehole, Northumberland Coalfield, England; Visean (Smith and Butterworth 1967).
80-120				Offshore western Ireland (Robeson 1988).
90(92)93	56(57)58	56(58)61	53(56)58	Offshore western Ireland, this study (3 specimens).

Comparison. Compared to *S. rara, S. campyloptera* has a greater length to width ratio.

Suprasubturma indeterminate.

Subturma indeterminate.

Infraturma indeterminate.

PTERORETIS Felix and Burbridge emend. McLean *et al.* 2006

Type species. *P. primum* Felix and Burbridge emend. McLean *et al.* 2006

Diagnosis. See McLean *et al.* (2006, p. 19).

Pteroretis primum Felix and Burbridge emend. McLean *et al.* 2006

Plate 7, figure 16.

2006 *Pteroretis primum* Felix and Burbridge emend. McLean *et al.*, p. 21, pl. 1, figs. 1-4; pl. 2, figs. 1-3, pl. 3, figs. 1-3.

Holotype. Felix and Burbridge (1961, pl. 1, fig. 2).
Description. (see McLean *et al.* 2006).
Size in microns. (i) Overall equatorial diameter 105-135 (McLean *et al.* 2006). (ii) Overall equatorial diameter 117(131)155, (3 specimens) offshore western Ireland, this study.
Remarks. Specimens from offshore western Ireland reach larger sizes than those recorded by McLean *et al.* (2006).

Turma **MONOLETES** Ibrahim 1933.

Suprasubturma **ACAMERATOMONOLETES** Williams 1971.

Subturma **AZONOMONOLETES** Luber 1955.

Infraturma **LAEVIGATOMONOLETI** Dybová and Jachowicz 1957.

LAEVIGATOSPORITES Ibrahim 1933.

Type species. *L. vulgaris* (Ibrahim) Ibrahim 1933.
Diagnosis. See Potonié and Kremp (1954, p. 165).

Laevigatosporites minimus (Wilson and Coe) Schopf, Wilson and Bentall 1944.

Plate 7, figure 22.

1940 *Phaseolites minimus* Wilson and Coe, p. 183, pl. 1, text-fig. 5.
1944 *Laevigato-sporites minimus* (Wilson and Coe); Schopf, Wilson and Bentall, p. 37.

Holotype. Wilson 1958, pl. 1, fig. 5 after Wilson and Coe (1940). Preparation 121P.
Type locality. What Cheer Clay Products Company Mine, What Cheer, Keokuk County, Iowa, U.S.A.; Des Moines Series.

Diagnosis. (Smith and Butterworth 1967, p. 283). 'Amb oval, shape in equatorial view phaseolate. Laesurae simple, greater than one-half of spore diameter in length. Exine very thin, folding infrequent.'

Size in microns. (i) Holotype 25; length 20-30, width in equatorial view 16-20, Schulze and 25% NH_4OH (Wilson 1958). (ii) 20-35, Schulze (Potonié and Kremp 1956) (iii) 16(22)33, fum. HNO_3; Slyving Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth 1967).

Laevigatosporites vulgaris (Ibrahim) Ibrahim 1933.

Plate 7, figure 20.

1932 *Sporonites vulgaris* Ibrahim in Potonié, Ibrahim and Loose, p. 448, pl. 15, fig. 16.

1933 *Laevigato-sporites vulgaris* (Ibrahim) Ibrahim, p. 39, pl. 2, fig. 16.

1940 *Phaseolites desmoinesensis* Wilson and Coe, p. 182, pl. 1, fig. 4.

1944 *Laevigatosporites desmoinensis* (Wilson and Coe); Schopf, Wilson and Bentall, p.37.

Holotype. Potonié and Kremp 1956, pl. 19, fig. 429 after Ibrahim. Preparation B31, c6 (or).

Type locality Ägir Seam, Ruhr Coalfield, Germany; top of Westphalian B (Duckmantian).

Diagnosis (Smith and Butterworth 1967, p. 285 from Ibrahim 1933, p. 39). 'Amb oval, shape in equatorial view, phaseolate; margin smooth. Laesura about two-thirds of length of spore. Exine laevigate to fainty punctate (? infrasculpture), about 1µm thick.'

Size in microns. (i) Holotype 69.5; 56-77, Schulze and KOH (Ibrahim 1933). (ii) 56(72)83, fum. HNO_3; Prince Seam, Broomhill Colliery, Northumberland Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iii) 60(70)80, offshore western Ireland (Robeson 1988).

Comparison. Based on Smith and Butterworth (1967) *Laevigatosporites vulgaris* is assigned a size range of 65-100µm to distinguish it from the smaller *Laevigatosporites minor* Loose 1934.

Laevigatosporites minor Loose 1934.

Plate 7, figure 21.

1932 *Sporonites vulgaris* Ibrahim in Potonié, Ibrahim and Loose, in part.
1933 *Laevigato-sporites vulgaris* Ibrahim, in part.
1934 *Laevigatosporites vulgaris minor* Loose, p. 158, pl. 7, fig. 12.
1957 *Laevigatosporites minor* (Loose) Potonié and Kremp; Bharadwaj, p. 109, pl. 29, figs. 8,9.

Holotype. Loose 1934, pl. 7, fig. 12. Preparation V29, a.

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. As for *Laevigatosporites vulgaris.*

Size in microns. (i) Holotype 58.5, 40-70, Schulze and KOH (Loose 1934). (ii) 45-65, Schulze (Bharadwaj 1957). (iii) 33(48)63, Schulze; Fenton Seam, Houghton Main Colliery, Yorkshire Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967). (iv) 41(57)71, fum. HNO_3; Musselband Seam at 3,256 ft. 11in., Slatehole Farm borehole, Ayrshire Coalfield, Scotland; Westphalian A (Langsettian) (Smith and Butterworth 1967).

Comparison. Based on Smith and Butterworth (1967) *Laevigatosporites minor* is assigned a size range of 35-64μm to distinguish it from the larger *L. vulgaris* Ibrahim 1933.

LATOSPORITES Potonié and Kremp 1954.

Type species. *L. latus* (Kosanke) Potonié and Kremp 1954.

Diagnosis. See Potonié and Kremp (1954, p. 165).

Latosporites globosus (Schemel) Potonié and Kremp 1956.

Plate 7, figure 23.

1951 *Laevigato-sporites globosus* Schemel, p. 748, text-fig. 2.
1956 *Latosporites globosus* (Schemel) Potonié and Kremp, p. 140.

Holotype. Type specimen in collection of West Virginia Geological Survey.

Type locality. Mystic Coal of Appanoose and Madison Counties, Iowa, U.S.A.; Des Moines Series.

Diagnosis. (Smith and Butterworth 1967, p. 286 from description in Schemel 1951, p. 746). 'Spores monolete, bilateral; circular to subcircular in transverse plane; surface of spore densely and minutely punctuate; exine slightly thickened and opaque; suture extends from one-half to two-thirds the diameter of the spore, lips not prominent.'

Size in microns. (i) Mean diameter 19(24)30, maceration method not known (Schemel 1951). (ii) 15(22)30, fum. HNO_3; Yorkley Seam, Cannop Colliery, Forest of Dean Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth). (iii) 17(21)26, fum. HNO_3; Great Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth). (iv) 22(24)25, offshore western Ireland, this study.

PUNCTATOSPORITES Ibrahim emend. Alpern and Doubinger 1973.

Type species. *P. minutus* Ibrahim emend. Alpern and Doubinger 1973.

Diagnosis. See Alpern and Doubinger (1973, p. 36).

Comparison. The ornament of fine grana distinguishes *Punctatosporites* from other monolete genera such as *Laevigatosporites.*

Punctatosporites granifer Potonié and Kremp 1956.

Plate 8, figure 1 and 2.

1956 *Punctatosporites granifer* Potonié and Kremp, p. 142, pl. 19, fig. 442.

Holotype. Potonié and Kremp 1956, pl. 19, fig. 442. Preparation 671/4.

Type locality. Glücksburg Seam, Ibbenbüren, Germany; Westphalian C (Bolsovian).

Diagnosis. (Smith and Butterworth 1967 p. 288, from Potonié and Kremp 1956, pl. 19, fig. 442). 'Amb oval with a tendancy toward circular. Laesurae ridged, extends almost to equator. Margin rough due to grana, which cover entire exine; about 50 grana project at the periphery.'

Size in microns. (i) Holotype 30; 25-35, Schulze (Potonié and Kremp 1956). (ii) 21(28)37, fum. HNO_3; Yorkley Seam, Northern United Colliery, Forest of Dean

Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth 1967). (iii) 22(30)44, offshore western Ireland, this study.

Description. Monolete miospores with an oval to near circular amb in polar view. Laesura distinct to indistinct, simple, over one-half of the longest dimension and may extend to the equatorial margin. The exine is relatively thick, rarely folded and ornamented with grana. Grana are less than 1µm in diameter and may be slightly pointed.

Remarks. Specimens from offshore western Ireland reach sizes that are slightly larger than those recorded by Potonié and Kremp (1956) and Smith and Butterworth (1967).

Comparison. *Punctatosporites minutus* Ibrahim emend. Alpern and Doubinger 1973 has a thinner exine, and more commonly folded. *P. oculus* Smith and Butterworth 1967 has finer ornament and a thicker exine.

Punctatosporites minutus Ibrahim emend. Alpern and Doubinger 1973.

Plate 8, figure 3.

1933 *Punctato-sporites minutus* Ibrahim, p. 40, pl. 5, fig. 33.
1938 *Azonomonoletes minutus* (Loose); Luber in Luber and Waltz, pl. 8, fig. 112.
1957 *Granulatsporites minutus* (Ibrahim); Dybová and Jachowicz, p. 191.
1973 *Punctatosporites minutus* Ibrahim emend. Alpern and Doubinger, p. 42, pl. 11, figs. 1-26.

Holotype. Ibrahim 1933, pl. 19, fig. 439. Preparation A45, a1 (o).

Type locality. Ägir Seam, Ruhr Coalfiled, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p.288, from Potonié and Kremp 1956, p.143). 'Amb oval; shape in longitudinal equatorial view phaseolate. Laesura about two-thirds of longest dimension. Outline granulate.'

Size in microns. (i) Holotype 25.5, Schulze and KOH. (ii) 21-28, Schulze (Potonié and Kremp 1956). (iii) 21(29)40, Schulze and KOH; seam at 772ft. 9in., Bowsey Wood borehole, North Staffordshire Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth 1967). (iv) 18(22)27, Schulze and KOH; seam at 772ft. 9in., Bowsey Wood borehole, North Staffordshire Coalfield, England; Westphalian D (Asturian) (Smith and Butterworth 1967). (v) 22(25)28, offshore western Ireland, this study.

Comparison. *Punctatosporites minutus* has a thinner exine and is more commonly folded than *P. granifer.*

Punctatosporites oculus Smith and Butterworth 1967.

Plate 8, figures 4 and 5.

1956 (unpublished) *Laevigatosporites oculus* Williams (thesis) vol. 2, p. 20, pl. 3, fig. 16-18.
1967 *Punctatosporites oculus* Smith and Butterworth, p.289, pl. 24, figs 12-15.

Holotype. Plate 24, fig. 12. Preparation T20/1 in collection of Coal Survey Laboratory, Sheffield.

Type locality. Bull Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, England; Westphalian D (Asturian).

Diagnosis. (Smith and Butterworth 1967, p. 289). 'Amb circular to oval; outline smooth to minutely denticulate. Monolete mark simple, two-thirds to nearly full length of spore, often flexed at mid-point where sometimes jointed by a short indistinct ray. Exine scabrate, 2-4µm thick, sometimes folded.'

Size in micron. (i) Holotype 31; 17(24)32, fum. HNO_3; Bull Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, England; Westphalian D (Asturian). (ii) 28(35)45, offshore western Ireland, this study.

Remarks. Two specimens encountered offshore western Ireland are larger than the maximum specimen size recorded in Smith and Butterworth (1967).

Comparison. *Punctatosporites granifer* has coarser ornament and a thinner exine.

Punctatosporites rotundus Bharadwaj 1957.

Plate 8, figure 6.

Holotype Bharadwaj 1957a pl. 29, fig. 16. Preparation 7321/1.

Type locality. Kallenburg Seam, Kohlwald Colliery, Saar Coalfield, Germany; Westphalian D (Asturian).

Diagnosis. (Smith and Butterworth 1967, p. 290, from Bharadwaj 1957, p.111). '….spherical to subspherical; slit more than one-half the diameter but not reaching the equator; approximately 40 grana along the equator.'

Size in microns. (i) Holotype 23; 20-24, Schulze (Bharadwaj 1957). (ii) 15(20)22, fum. HNO_3; Mynyddislwyn Seam, Tirpentwys Colliery, South Wales Coalfield; Westphalian D (Asturian) (Smith and Butterworth 1967). (iii) 25(25)30, offshore western Ireland (Robeson 1988). (iv) 22(22)23, offshore western Ireland, this study.

Comparison. Distinguished from other species of the genus by its small size and circular shape.

THYMOSPORA Wilson and Venkatachala 1963b.

Type species. *T. thiessenii* (Kosanke) Wilson and Venkatachala 1963b.

Diagnosis. See Wilson and Venkatachala (1963 p.76)

Thymospora obscura (Kosanke) Wilson and Venkatachala 1963b.

Plate 8, figures 7-9.

1950 *Laevigato-sporites obscurus* Kosanke, p.29, pl.16, fig. 6.
1954 *Verrucosisporites obscurus* (Kosanke) Potonié and Kremp, p. 166.
1963b *Thymospora obscura* (Kosanke) Wilson and Venkatachala, p76, pl. 1, fig. 6.

Holotype. Kosanke 1950, pl. 16, fig. 6. Preparation 576, slide 14.

Type locality. New Haven coal, Gallatin County, Illinois, U.S.A.; McLeansboro Group.

Diagnosis. (Smith and Butterworth 1967 from description in Kosanke 1950, p.29) p291. 'Shape broadly oval. Outline irregular due to ornament. Laesurae two-thirds to three-quarters body length, somewhat distorted by ornament; lips slightly elevated and suture well defined. Exine 2-2.25µm in thickness, punctuate, folds rare.'

Size in microns. (i) Holotype 32 x 29; 28-34, Schulze and KOH (Kosanke 1950). (ii) 20(25)33, fum. HNO_3; Slyving Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, England, Westphalian D (Asturian). (iii) 25(30)35, offshore western Ireland (Robeson 1988). (iv) 25(28)33, offshore western Ireland, this study.

Description. Monolete, azonate miospores with an oval to subcircular amb and distinct monolete mark. Laesura simple, straight and extending up to three-quarters of the spore length. Ornamentation comprises verrucae. Verrucae can reach 2µm in basal width and up to 2µm in height. Bases are often confluent. Ornament is sufficiently large enough to modify the outline of the spore.

Remarks. Smith and Butterworth (1967) recorded verrucae with basal diameters of up to 2.5µm and a heights of up to 2µm (with most being smaller).

Comparison. *Thymospora thiessenii* (Kosanke) Wilson and Venkatachala 1963b (size range 14-24µm) shows a rugulate rather than verrucate ornamentation. *T. pseudothiessenii* (Kosanke) Wilson and Venkatachala 1963b is generally larger with a coarser ornamentation.

Thymospora pseudothiessenii (Kosanke) Wilson and Venkatachala 1963b.

Plate 8, figures 11 and 12.

1950 *Laevigato-sporites pseudothiessenii* Kosanke, p. 30, pl. 5, fig 10.

1956 *Verrucosisporites pseudothiessenii* (Kosanke) Potonié and Kremp, p. 144.

1963b *Thymospora pseudothiessenii* (Kosanke) Wilson and Venkatachala, p78, pl. 1, fig 7.

1973 *Thymospora pseudothiessenii* (Kosanke) Wilson and Venkatachala emend. Alpern and Doubinger, p. 76, pl. 18, figs. 1-28.

Holotype. Kosanke 1950, pl. 5, fig. 10. Prepartion 543-D, slide 4.

Type locality. No. 5 Coal, Fulton County, Illinois, U.S.A.; Carbondale Group.

Diagnosis. (Smith and Butterworth 1967, p. 291 from description in Kosanke 1950, p.30) 'Elongate to oval in plane of longitudinal symmetry, round or oval in transverse plane. Outline in both longitudinal and transverse planes broken by sculpturing of exine. Monolete laesura well over one-half spore length. Exine verrucate to obervermiculate and sometimes appearing reticulate. Exine 1.5-3.5µm thick.'

Size in microns. (i) Holotype 38 x 29; 26-46, Schulze and 10% KOH (Kosanke 1950). (ii) 26(32)35, fum. HNO_3, 6 in. coal at 720 ft. 8in., Alveley No. 1 borehole, Forest of Wyre Coalfield, England; Westphalian D (Asturian) Smith and Butterworth 1967). (iii) 33(42)48, Schulze and KOH, as above. (iv) 30(40)50, offshore western Ireland (Robeson 1988). (v) 28(40)48, offshore western Ireland, this study.

Description. Monolete, azonate miospores with an oval to subcircular amb and distinct monolete mark. Laesura simple, straight and extending to over one-half of the spore length. Ornamentation comprises verrucae. Verrucae can reach 7µm in basal width and up to 3µm in height. Bases are often confluent. Small grana may occasionally be present among the verrucae.

Comparison and Remarks. *Thymospora pseudothiessenii* is generally larger and possesses a coarser ornament than *Thymospora obscura*. The present study follows Smith and Butterworth (1967) in considering *Thymospora verrucosa* (Alpern) Wilson and Venkatachala 1963b (size range 25-35µm) to be a morphological varient of *T. pseudothiessenii* and should not be given separate taxonomic status.

TORISPORA (Balme) Doubinger and Horst 1961.

Type species. *T. securis* Balme emend. Alpern *et al.* 1965.

Diagnosis. See Doubinger and Horst (1961, p. 29).

Torispora securis Balme emend. Alpern, Doubinger and Horst 1965.

Plate 8, figures 13 and 14.

1952 *Torispora securis* Balme. P. 183, text-figs. 3a-d.

1957 *Torispora recta* Dybová and Jachowicz, p. 197, pl. 66, figs. 1-4.

1957 *Torispora speciosa* Dybová and Jachowicz, p. 198, pl. 68, figs. 1-4.

1957 *Torispora undulata* Dybová and Jachowicz, p. 197, pl. 67, figs. 1-4.

1965 *Torispora securis* Balme emend. Alpern, Doubinger and Horst, p. 570-571, pl. 1, fig. 1.

Lectotype. (Smith and Butterworth 1967, p. 293). Balme did not establish a holotype in 1952 but he subsequently designated as lectotype a specimen selected by Smith and Butterworth from the type locality (preparation T68/1 in the collection of the Coal Survey laboratory, Sheffield).

Diagnosis. (Smith and Butterworth 1967, p. 293 from Balme 1952, p. 183). ‘The spore is elliptical when viewed in full proximo-distal orientation, but its tendency to preservation in other planes of compression leads to distortion in many specimens. Margin finely notched. Laesurae distinct with well-marked straight, or curved, suture line parallel to the major axis of the spore. The exine is considerably thickened at one extremity of the spore and expanded into a crescentic or rectangular projection darker in colour than the remainder of the spore coat (crassitude). Exine of thinner areas punctuate, crassitude smooth or indeterminately marked.’

Size in microns. (i) Lectotype, total length 36, Schulze. (ii) Total length 26(34)44; maximum breadth of unthickened part of body 15(21)28; thickened projection, length 5(10)18, breadth 16(24)35, Schulze (Balme 1952) (iii) Total length 25(38)45 offshore western Ireland (Robeson 1988).

Remarks. There is extensive variation in the location, size and shape of crassitude thickening in specimens from offshore western Ireland. Occasional specimens only comprise the thickened portion of the exine, without the remainder of the spore body.

Comparison. *Torispora verrucosa* Alpern 1958 shows a verrucate or coarsely granulate ornamentation.

SPINOSPORITES Alpern 1958.

Type species. *S. spinosus* Alpern 1958.

Diagnosis. See Alpern (1958, p.81).

Comparison. *Acanthotriletes* is trilete.

Spinosporites spinosus Alpern 1958.

Plate 8, figures 15 and 16.

1958 *Spinosporites spinosus* Alpern, p. 81, pl. 2, fig. 41.

Holotype. Sondage Saint-Aubin II (Auvergne), couche 5; lame 430; cotes 39,3 x 120,6.

Diagnosis. See Alpern 1958, p. 81 (in French)

Description. Monolete, azonate miospores with an oval amb. Laesura are often indistinct. Exine ornamented with closely spaced spines 1-2µm in height with a basal width of 1µm. Folding of exine is common.

Size in microns. (i) Holotype 50 x 58. (ii) 25-55 (Alpern 1958). (iii) 30(48)50, offshore western Ireland (Robeson 1988). (iv) 31(35)42, offshore western Ireland, this study.

Turma **HILETES** Dettmann 1963.

Suprasubturma **ACAMERATIHILETES** Spode 1974.

Subturma **SOLUTIHILATES** Spode 1974.

Infraturma **EPITYGMATI** Spode *in* Smith and Butterworth 1967.

VESTISPORA (Wilson and Hoffmeister) Wilson and Venkatachala 1963a.

Type species. *V. profunda* Wilson and Hoffmeister 1956.

Diagnosis. See Wilson and Venkatachala (1963a, p.96)

Comparison. The possession of an operculum on the proximal surface distinguishes *Vestispora* from other genera.

Vestispora fenestrata (Kosanke and Brokaw) Wilson and Venkatachala emend. Spode *in* Smith and Butterworth 1967.

Plate 8, figure 21.

1950 *Punctati-sporites fenestratus* Kosanke and Brokaw in Kosanke, p. 15, pl. 2, fig. 10.

1963a *Vestispora fenestrata* (Kosanke and Brokaw) Wilson and Venkatachala, p. 99, pl.1, figs. 13,14.

1967 *Vestispora fenestrata* (Kosanke and Brokaw) Wilson and Venkatachala emend. Spode *in* Smith and Butterworth, p.296, pl.25, figs. 3-6.

Holotype. Kosanke 1950, pl.2, fig. 10. Preparation 474-A, slide 3.

Type locality. No. 6 Coal, Franklin County, Illinois, U.S.A.; Carbondale Group.

Diagnosis (Spode *in* Smith and Butterworth 1967, p. 296). 'Miospores having a thick exoexine which is perforated by numerous foveolae less than 3 microns in diameter and less than 3 microns apart. A foveolate operculum is present at the proximal pole.'

Size in microns. (i) Holotype 79.8 x 77.7; 68-85, Schulze and 10% KOH (Kosanke 1950). (ii) 50-88, Schulze and 5% KOH; various localities (Spode *in* Smith and Butterworth 1967). (iii) 60(75)80, offshore western Ireland (Robeson 1988).

Remarks. Laesurae seen only when circular to sub-circular operculum is detached. Compression folds are common.

Comparison. The lack of primary muri or costae and the development of a fine foevolate ornament distinguishes *Vestispora fenestrata* from other species of the genus.

Vestispora costata (Balme) Bharadwaj emend. Spode *in* Smith and Butterworth 1967.
Plate 8, figures 22 and 23.

1952 *Endosporites costatus* Balme, p.178, text-fig. 1f.
1957 *Vestispora costata* (Balme) Bharadwaj, p. 118, pl.24, figs. 36-40.
1958 *Glomospora costata* (Balme) Butterworth and Williams, p. 385.
1967 *Vestispora costata* (Balme) Bharadwaj emend. Spode *in* Smith and Butterworth, p. 295, pl. 25, figs. 1, 2.

Lectotype. Balme did not designate a holotype but a lectotype (T7/1) was subsequently chosen from the material deposited in the collection of the Coal Survey Laboratory, Sheffield (Smith and Butterworth 1967).

Type locality. Seam at 719ft. 3in., Manton Colliery, No. 4 Shaft Sinking, Yorkshire Coalfield, England; Westphalian C (Bolsovian) (Smith and Butterworth 1967, p295).

Diagnosis (Smith and Butterworth 1967 p. 295 from Spode 1967). 'Circular (spherical) miospores having a costate exoexine. The muri are arranged circumcentrically around the spore and are rarely branched. They intersect to enclose large polygonal lumina'.

Size in microns. (i) Lectotype 74 x 64; 60(79)104, Schulze (Balme 1952). (ii) 48(68)82, Schulze and 10% KOH; Winghay Seam at 2,034ft. 6in., Bowsey Wood borehole, North Staffordshire Coalfields, England; Westphalian C (Bolsovian) (Smith and Butterworth 1967). (iii) 52-88, Schulze and 5% KOH (Spode *in* Smith and Butterworth 1967). (iv) 70(85)90, offshore western Ireland (Robeson 1988). (v) 57(69)79, offshore western Ireland, this study.

Description. Trilete, camerate miospores with a circular to sub-circular amb. The trilete mark is often obscured, but when present, the laesurae extend for up to one-half of the spore radius. The inner body (intexine) is poorly defined. The exoexine is ornamented with costae; 1.5 - 3μm in width, up to 3μm in height and typically 10 - 20μm apart. Costae are arranged circumcentrically around the spore, are rarely branched and enclose large polygonal lumina.

Comparison. The rarity of costae branching distinguishes *V. costata* from other species of the genus.

Vestispora pseudoreticulata Spode *in* Smith and Butterworth 1967.
Plate 5, figure 19.

1952 *Reticulatisporites tortuosus* Balme (in part), p. 179.
1964 *Vestispora pseudoreticulata* Spode *in* Neves, p. 1233, pl. 3, figs. 1, 2.
1967 *Vestispora pseudoreticulata* Spode *in* Smith and Butterworth, p. 298, pl. 25, figs. 13, 14.

Holotype. Plate 1, fig. 33, Spode *in* Smith and Butterworth 1967.
Type locality. Barneley Seam, Yorkshire Coalfield, England; Westphalian B (Duckmantian)
Diagnosis. (Spode *in* Smith and Butterworth 1967 p299). 'Circular miospores, outline uneven due to presence of muri at the equator. The exoexine has an irregular extrareticulum composed of weak primary muri and a well-developed secondary reticulum between them. The lumina are 2-8µm in maximum diameter and separated by muri 1-3µm wide.'
Size in microns. (i) Holotype 122.6 x 101; 50-80, various localities, Yorkshire Coalfield, England; Schulze and 5% KOH (Spode *in* Smith and Butterworth 1967). (ii) 58(73)90, fum. HNO_3 ; Bottom Droughy Seam at 1,818ft. 6in., Plas Thomas borehole, North Wales Coalfield; lower Westphalian B (lower Duckmantian) (Smith and Butterworth 1967). (iii) 50(68)70, offshore western Ireland (Robeson 1988). (iv) 61 & 64, (two measurements), offshore western Ireland, this study.
Comparison. *Vestispora costata* has no secondary reticulum between the primary muri.

Vestispora tortuosa (Balme) Bharadwaj emend. Spode *in* Smith and Butterworth 1967.
Plate 8, figure 24.

1952 *Reticulatisporites tortuosus* Balme (in part), text-fig. 1d
1957b *Vestispora tortuosa* (Balme); Bharadwaj, p.119.
1957a *Cancellatisporites cancellatus* Dybova and Jachowicz, p. 111, pl.24, figs. 1-4.

1967 *Vestispora tortuosa* (Balme) Bharadwaj emend. Spode *in* Smith and Butterworth, p. 299, pl. 26, figs, 1, 2.

Lectotype. 'No holotype was designaed by Balme but a lectotype (T 72/1) has been chosen from material deposited by him in the collection of the Coal Survey Laboratory, Sheffield' (Smith and Butterworth 1967).

Type locality. Wheatworth Seam at 907 ft. 11in., Wentbridge No. 2 borehole, Yorkshire Coalfield, England; upper Westphalian B (upper Duckmantian).

Diagnosis. (Spode *in* Smith and Butterworth 1967 p 299). 'Miospores circular in shape, outline slightly uneven due to presence of primary muri 1-2μm wide and 1-1.5μm high. The muri are often branched and intersect to enclose polygonal lumina; they are sometimes carinate and may even show the development of a weak, secondary reticulum. Operculum, similarly ornamented, at proximal pole, covers the position of the trilete mark.'

Size in microns. (i) Lectotype 77; 65(86)100, Schulze (Balme 1952). (ii) 53-80, Schulze and 5% KOH; various localities (Spode *in* Smith and Butterworth 1967). (iii) 64(73)86, fum. HNO_3; seam at 491 ft. 10in., Seafield No. 2 borehole, East Fife Coalfield, Scotland, Westphalian B (Duckmantian) (Smith and Butterworth 1967). (iv) 70(80)90, offshore western Ireland (Robeson 1988).

Comparison. The presence of muri that often branch distinguishes *Vestispora tortuosa* from *V. costata*. Branching is rare in *V. costata*.

Vestispora laevigata Wilson and Venkatachala 1963a.

Plate 8, figure 20.

1956 (unpublished) *Ovaspora vitra* Williams, (thesis) vol. 2, p. 62, pl. 13, figs. 8-13

1963a *Vestispora laevigata* Wilson and Venkatachala, pl. 1, figs. 8-11.

Holotype. Wilson and Venkatachala 1963, pl. 1, fig. 8, Oklahoma Geological Survey specimen number WH 7-5.

Type locality. Croweburg Coal, Rogers County, Oklahoma, U.S.A.; Des Moines Series.

Diagnosis. (Smith and Butterworth 1967 from Wilson and Venkatachala 1963). 'Spores raial, trilete, spherical; … operculum…opening to expose the inner body which bears the trilete mark; inner body as well as exoexine laevigate; in some specimens the inner body folded to appear like outer ornamentation. Several specimens with faint scabrate ornamentation on the distal side have been observed'.

Size in microns. (i) Holotype 65.2 x 63.8; 60-75, operculum 25-32, maceration method not known (Wilson and Venkatachala 1963) (ii) Maximum overall diameter 62-90, Schulze and 5% KOH, various localities (Spode *in* Smith and Butterworth 1967). (iii) 67 & 70 (2 specimens) offshore western Ireland, this study.

Comparision. Distinguished from other species of *Vestispora* by its unornamented or faintly ornamented exoexine.

Vestispora magna (Butterworth and Williams) Wilson and Venkatachala emend.
Spode *in* Smith and Butterworth 1967.
Plate 8, figure 26.

1954 *Reticulatisporites magnus* Butterworth and Williams, p. 756, pl. 17, figs. 5, 6, text-fig. 1, fig. 5.

1963a *Vestispora magna* (Butterworth and Williams) Wilson and Venkatachala, p.99.

1967 *Vestispora magna* (Butterworth and Williams) Wilson and Venkatachala emend. Spode *in* Smith and Butterworth, p. 298, pl. 25, figs. 11, 12.

Holotype. Plate 25, fig. 11. Specimen no. PF 3007 (formerly 76484), Geological Survey Museum, London.

Type locality. Bottom Robins Seam, Pilot borehole, Lea Hall Colliery, Cannock Chase Coalfield, England; Westphalian C (Bolsovian).

Diagnosis. (Smith and Butterworth 1967 p. 298) 'Miospores having a characteristically strong, irregular, reticulate ornament. The primary muri may, or may not, be present whilst the secondary reticulum is strongly developed enclosing irregular, often elongate lumina. Operculum, similarly ornamented, at the proximal pole'.

Size in microns. (i) Holotype 84x78, fum. HNO_3. (ii) 67(92)127, Schulze and 10% KOH; 73(86)103, fum. HNO_3; (Butterworth and Williams 1954). (iii) 84(95)120, Schulze and 10% KOH; Smith Seam, Hafod Colliery, North Wales Coalfields; upper Westphalian B. (iv) 74(84)100, fum. HNO_3; Smith Seam at 1,885ft. 1in., Plas Thomas borehole, North Wales Coalfield; upper Westphalian B.

Comparison. The primary muri are coarser and the secondary muri more strongly developed than in other species of the genus. Lumina formed by both sets of muri are more irregular than in other species.

Anteturma **POLLENITES** Potonié 1931.
Turma **SACCITES** Erdtmann 1947.
Subturma **MONOSACCITES** Chitaley emend. Potonié and Kremp 1954.
Infraturma **TRILETESACCITI** Leschik 1956.

POTONIEISPORITES Bharadwaj 1954.

Type species. *P. novicus* Bharadwaj 1954.

Diagnosis. See Bharadwaj (1954, p.46).

Potonieisporites novicus Bharadwaj 1954.
Plate 9, figures 5 and 6.

Holotype. Bharadwaj, 1954, p.520, fig. 10.

Diagnosis. See Bharadwaj, 1954, p. 520.

Description. Monosaccate pollen grains with a subcircular to oval amb and a subcircular central body. The monolete suture is parallel to the longest axis. The length of the suture ranges from one-half to the full body length. The body shows concentric folding near its equatorial margin and typically shows two crescent-shaped folds oriented perpendicular to the long axis of the miospore. The saccus is thin and infrareticulate.

Size in microns.

Spore length	Spore Width	
114(115)117	72(76)81	Three specimens, offshore western Ireland, this study.

Potoneisporites elegans (Wilson and Kosanke) Wilson and Venkatachala emend. Habib 1966.
Plate 9, figure 4.

1944 *Florinites elegans* Wilson and Kosanke, p. 330, fig. 3.

1964 *Potonieisporites elegans* (Wilson and Kosanke) Wilson and Venkatachala, p. 67-68, figs. 1,2.

1966 *Potonieisporites elegans* (Wilson and Kosanke) Wilson and Venkatachala emend. Habib, p. 648-649, pl. 108, fig. 3.

Holotype. Wilson and Kosanke 1944, fig. 3, Slide No. 279P.

Type locality. Circle 1 Angus Coal Company Mine, two miles northeast of Oskaloosa, Mahaska County Iowa. Des Moines Series, Pennsylvanian System.

Diagnosis. (Habib 1966, p. 648). 'Monosaccate pollen grains; roundly elliptical in overall outline. Central body distinct, elliptical to circular in outline, characterized by prominent crescentic or lenticular folds which commonly transcect each other, though on opposite sides of the central body, at angles approaching ninety degrees; the transverse folds, always two, appear confined to the distal hemisphere at or near the juncture of the central body and saccus; the longitudinal folds, also two, are present on the proximal (free) hemisphere of the central body and trend along the maximum dimension of the body; ornamentation minutely punctuate to granulose. Saccus externally laevigata and internally moderately infra-reticulate, attached to central body only on its distal side. Tetrad mark prominent on proximal (free) side of saccus; it is essentially straight longitudinal, but occasionally T-shaped with a much reduced third suture, or even symmetrically (Y-shape) trilete.'

Size in microns.

Overall length	Central body	
180-210	100-105	Wilson and Kosanke (1944).
135-215	85-110	Habib (1966).
95(118)144		Butterworth *et al.* (1988) Westphalian A and B (Langsettian and Duckmantian) of Northern England.
150	72	One specimen, offshore western Ireland, this study.

Potonieisporites microsaccus Butterworth *et al.* 1988.

Plate 9, figure 7.

1982 *Potonieisporites* sp. A Nader, 1983 p. 276, pl. 23, figs 14-16.

1988 *Potonieisporites microsaccus* Butterworth *et al.* , p. 77, pl. 6, figs. 1, 2.

Holotype. Preparation A95, slide T.131/6 (A95/24), pl. 6, fig. 1.

Type locality. Bottom Brass Thill Seam at 377 ft. 9 in., Northumberland Offshore B.H. No. 3, Westphalian B (Duckmantian).

Diagnosis. (Butterworth *et al.* 1988, p. 77). 'Pollen grains, bilateral, monosaccate, monolete. Amb of saccus elliptical, occasionally almost circular, width of saccus generally 2/3 of length. Body circular or transversely oval, diameter approximately ½ of the length of the saccus or ¾ of its width. Laesura straight, sinuous or angularly bent, extends up to ¾ of the body length, sometimes open. Body with two sets of lenticular folds almost perpendicular to each other, laevigate or very finely punctuate. Saccus laevigate externally, microreticulate internally, lumina 1-2μm in diameter and tending to be coarser towards the equatorial margin.'

Size in microns.

Holotype 75

Overall length	
45(66.5)86.5	10 specimens, Butterworth *et al.* 1988.
58	One specimen, offshore western Ireland, this study.

LATENSINA Alpern 1958.

Type species. *L. trileta* Alpern 1958

Diagnosis. See Alpern 1958.

Latensina trileta Alpern 1958.

Plate 7, figure 19.

1958 *Latensina triletus* Alpern p. 86, pl. 2, fig. 55.

Holotype. Sondage Saint-Hilaire I (Auvergne), couche 2; lame 469; cotes 26,3 x 114,2.

Diagnosis. Alpern 1958, p. 86 (in French)

Description. Trilete pollen grains with an oval to subcircular amb. The trilete mark distinct to indistinct with short sutures. The intexine is thin and forms a subcircular inner body. The exoxine is also thin, infrareticulate and forms a narrow saccus surrounding the inner body. The outer margin of the saccus is striated and plicated.

Size in microns. (i) Holotype 70µ. (ii) 50(70)80, offshore western Ireland (Robeson 1988).

Infraturma **ALETESACCITI** Leschik 1956.

FLORINITES Schopf *in* Schopf, Wilson and Bentall 1944.

Type species. *F. mediapudens* (Loose) Potonié and Kremp 1956 (= *F. antiquus* Schopf, in Schopf, Wilson and Bentall, 1944).

Diagnosis. See Schopf, Wilson and Bentall (1944, p. 56).

Florinites junior Potonié and Kremp 1956.

Plate 8, figures 27 and 28.

1956 *Florinites junior* Potonié and Kremp, p. 168, pl. 21, figs.466-467.

Holotype. Potonié and Kremp (1956, pl. 21, fig. 466).

Diagnosis. See Potonié and Kremp (1956, p. 168).

Size in microns.

Maximum saccus dimension	
61(71)83	Offshore western Ireland, this study.

Description. Monosaccate pollen grains with an oval amb and a subcircular inner body (intexine). The trilete mark is distinct to obscured. Saccus width is greater than the radius of the inner body. The exoexine is thin and finely infrareticulate. The inner body is thicker than the exoexine, laevigate and commonly folded.

Comparison. In *Florinites mediapudens* (Loose) Potonié and Kremp 1956, the saccus width is equal to or less than the radius of the inner body.

Florinites mediapudens (Loose) Potonié and Kremp 1956.

Plate 8, figures 29 and 30.

1934 *Reticulata-sporites mediapudens* Loose, p. 158, pl. 7, fig. 8.

1956 *Florinites mediapudens* (Loose) Potonié and Kremp, p. 169, pl. 21, figs. 468-71.

1957 *Endosporites mediapudens* (Loose) Dybová and Jachowicz, p. 207, pl. 71, fig. 4.

1958 *Florinites pellucidus* (Wilson and Coe) Wilson, p. 99, pl. 1, fig. 3.

1965 *Florinipollenites mediapudens* (Loose) Laveine, p. 135.

1966 *Florinipollenites pellucidus* (Wilson and Coe) Coquel, p. 21.

Holotype. Potonié and Kremp 1956, pl. 21, fig. 468 after Loose. Preparation III4, b_4 (o).

Type locality. Bismarck Seam, Ruhr Coalfield, Germany; upper Westphalian B (upper Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 303, from Potonié and Kremp 1956, p. 169). 'Central body often distinct. Breadth of saccus surrounding central body as great as, or less than, radius of central body.'

Size in microns. Holotype 60, Schulze and KOH.

Maximum saccus dimension	
50-65	Schulze (Potonié and Kremp 1956).
51(63)78	Fum. HNO_3; seam at approximately 3,230 ft., Corringham borehole, Nottingham Coalfield, England; Westphalian C (Bolsovian) (Smith and Butterworth 1967).
50(58)72	Fum. HNO_3; Top Haigh Moor Seam at 1,532ft. 3in., Kellingley borehole, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967).
42(55)77	Fum. HNO_3; sea, at 819ft. 0in., Harry Stoke 'A' borehole, Bristol and Somerset Coalfield, England; Westphalian A (Langsettian) (Smith and Butterworth 1967).
50(62)70	Offshore western Ireland, this study.

Comparison. In *Florinites junior*, the saccus width is significantly greater than radius of inner body.

Florinites millotti Butterworth and Williams 1954.

Plate 8, figure 32.

1954 *Florinites millotti* Butterworth and Williams, p. 760, pl. 18, figs. 7, 8.

1966 *Florinipollenites millotti* (Butterworth and Williams) Coquel, p. 21, pl. 2, figs. 14, 15.

Holotype. Smith and Butterworth 1967, pl 26, fig 9. Specimen no. PF3013 (formerly 76490), Geological Survey Museum, London.

Type locality. Bottom 1 ft. 4 in. coal at 3,388 ft. 2 in., Upton borehole, Oxfordshire, England; Westphalian D (Asturian).

Diagnosis. (Smith and Butterworth 1967, p. 305, abbreviated from Butterworth and Williams 1954, p. 760). 'Amb broadly elliptical. Apparently alete. Body oval or almost circular, with main axis at right angles to length of grain. Saccus and body very thin; saccus appears microreticulate.'

Size in microns. Holotype, saccus 37 x 29, body 19 x 19 maceration method not known; saccus, max. 30(39)49, min. 23(30)37, Schulze; max. 32(37)48, min. 24(29)43 (22 specimens), fum. HNO_3; body, length 13-35, breadth 16-32, maceration not specified; (Butterworth and Williams 1954). (ii) Saccus 47 in length (two specimens), offshore western Ireland, this study.

Remarks. Exine is very thin and typically appears colourless.

Florinites pumicosus (Ibrahim) Schopf, Wilson and Bentall 1944.

Plate 9, figure 3.

1932 *Sporonites pumicosus* Ibrahim in Potonié, Ibrahim and Loose, p. 447, pl. 14, fig. 6.
1933 *Reticulata-sporites pumicosus* Ibrahim, p.38, pl. 1, fig. 6.
1938 *Zonaletes pumicosus* (Ibrahim) Luber in Luber and Waltz, pl. 8, fig. 110.
1944 *Florinites? pumicosus* (Ibrahim) Schopf, Wilson and Bentall, p. 59.

Holotype. Potonié and Kremp 1955, pl. 21, fig 472 after Ibrahim. Preparation B34, d4 (u).

Type locality. Ägir Seam, Ruhr Coalfield, Germany; top of Westphalian B (top of Duckmantian).

Diagnosis. (Smith and Butterworth 1967, p. 305 from Potonie and Kremp 1956, p. 169). 'Outline of central body very indistinct to unrecognizable. Saccus surrounding body where visible has breadth less than radius of central body.'

Size in microns.

Holotype 92.5, Schulze and KOH.

Maximum saccus dimension	
80-100	Schulze (Potonié and Kremp 1956).
77(93)117	Fum. HNO_3; Swallow Wood Seam, Denaby Main Colliery, Yorkshire Coalfield, England, Westphalian B (Duckmantian) (Smith and Butterworth 1967).
83(99)108	Offshore western Ireland, this study.

Remarks. Amb oval to nearly circular. Smith and Butterworth (1967) indicate the rarely seen central body is approximately circular in polar view.

Comparison. Resembles a large *Florinites* cf. *florini* Imgrund 1960.

Florinites florini Imgrund 1960

1960 *Florinites florini* Imgrund, p. 179, pl. 16, fig. 94.

Holotype. Imgrund 1960, pl. 16, fig. 94. Preparation A 33.

Type locality. Seam 4, Kaiping Basin, China; Lower Permian.

Diagnosis. (Smith and Butterworth 1967, p. 302, from Imgrund 1960, p. 179). 'Amb circular to moderately oval. Outline somewhat rough. Tetrad mark mostly not recognizable. Internal reticulum on the central body with a distinctly finer meshwork. Outline of central body frequently scarcely recognizable.'

Size in microns.

Holotype 46; 50-70 Schulze and KOH (Imgrund 1960).

Florinites cf. *florini*

Plate 8, figure 31.

Description. See Smith and Butterworth (1967), p. 302.

Remarks. The species is similar in size and shape to *F. mediapudens* but lacks a distinct body.

Size in microns.

Maximum saccus dimension	
42(51)60	Fum HNO_3; Slyving Vein Seam, Camerton Colliery, Bristol and Somerset Coalfield, England, Westphalian D (Asturian) (Smith and Butterworth 1967).
47(62)77	Fum. HNO_3; seam at 294ft. 2in., Margam No. 4 borehole , South Wales Coalfield; Westphalian C (Bolsovian) (Smith and Butterworth 1967).
50(66)79	Fum. HNO_3; Beamshaw Seam, South Kirkby Colliery, Yorkshire Coalfield, England; Westphalian B (Duckmantian) (Smith and Butterworth 1967).
61(68)78	Offshore western Ireland, this study.

Comparison. Smith and Butterworth (1967) suggest that *Florinites* cf. *florini* may be the saccus of *F. mediapudens.*

Florinites similis Kosanke 1950.

Plate 9, figure 2.

1950 *Florinites similis* Kosanke, p. 49, pl. 12, fig. 2.

Holotype. Kosanke 1950, pl. 12, fig. 2. Preparation 524-C, slide 2.

Type locality. No. 8 Coal, Peoria County, Illinois, U.S.A.; McLeansboro Group.

Diagnosis. (Smith and Butterworth, from description in Kosanke 1950, p. 49) 'Amb elongate-elliptical; body originally spherical, but due to compression is sharply folded. Apparently alete. Body minutely granulate. Saccus laevigate with reticulate infrasculpture. Lumina less than 3µm.'

Size in microns.

Holotype 133 x 92

Maximum saccus dimension	
124-42	Schulze and 10% KOH (Kosanke 1950).
112-61	(7 specimens). Fum. HNO_3; seam at 1,387ft. 4in., Gate Farm borehole, Yorkshire Coalfield, England; lower Westphalian C (lower Bolsovian) (Smith and Butterworth 1967).
116(129)142	Offshore western Ireland, this study.

APPENDIX VII
REVISED PALYNOSTRATIGRAPHY OF WELL SECTIONS

Revised palynostratigraphic interpretations for the 19 offshore western Irish well sections are outlined below. For each well, interpretations based on the Western European miospore zonal scheme of Clayton *et al*. (1977) are initially given. Interpretations based on the modified zonation of Clayton *et al*. (2003) are subsequently outlined.

VII.I Well 12/2-1z

Revised interpretations are based on palynological data from Millennia (2004) and the present study (figure 6.1). Data from both studies were derived from cuttings samples. Six sidewall core samples were processed in the present study, but found to be barren of palynomorphs.

Largely due to the lack of sidewall core samples, there are three alternative palynostratigraphic interpretations for the Carboniferous interval in 12/2-1z.

Interpretation 1.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

?*Vittatina costabilis* (VC) Biozone (lower Autunian) 13478'/4108m to 14176'/4321m

The interval tentatively assigned to the *Vittatina costabilis* (VC) Biozone is characterised by a limited miospore assemblage dominated by monosaccate pollen. Taxa include *Potonieisporites* spp., *Disaccites striatiti, Cordaitina* spp., *Limitisporites* spp. and *Cycadopites* spp. Although Clayton *et al.* (1977) recorded a predominance of monosaccate pollen in the VC Biozone of Western Europe, the authors also noted a persistent occurrence of *Vittatina* spp. with rare occurrences of *Lycospora* spp., *Laevigatosporites* spp., *Punctatosporites* spp. and *Spinosporites spinosus.* In 12/2-1z, these taxa are not recorded in the interval assigned to the VC Biozone. As a result, the interval cannot be assigned to the biozone with confidence.

Potonieisporites novicus - bharadwajii – Cheleidonites major (NBM) Biozone (upper Stephanian B - Stephanian C) 14196'/4327m to 14639'/4462m or 14668'/4471m

The consistent occurrence of *Potonieisporites novicus* and moderately frequent occurrence of *Cheiledonites* spp. in the interval 14196'/4327m to 14668'/4471m is characteristic of both *P. novicus-bharadwajii – Cheleidonites major* (NBM) and *Vittatina costabilis* (VC) Biozones of Clayton *et al.* (1977). The NBM/VC Biozone boundary is positioned at 14196'/4327m based on the last stratigraphic occurrence of *Endosporites globiformis*. Peppers (1985) noted that the range top of *E. globiformis* in Western Europe does not extend past the Stephanian Substage, corresponding to a biozone no younger than the NBM Biozone. Based on range data from Clayton *et al.* (1977), the absence of *Vestispora fenestrata* indicates a biozone no older than the NBM Biozone. If *in situ*, the occurrences of *Cheiledonites* spp. confirm a biozone no older than the *Angulisporites splendidus – Latensina trileta* (ST) Biozone of Clayton *et al*.

Clayton *et al.* (1977) recorded the last stratigraphic occurrence of *Crassispora kosankei* in the middle of the NBM Biozone and a marked reduction in the abundance of *Lycospora* spp. at the base of the VC Biozone. In 12/2-1z, the last stratigraphic occurrence of *C. kosankei* is recorded within the NBM Biozone interval at 14619'/4456m with the last stratigraphic occurrence of abundant *Lycospora* spp. at 14659'/4468m. Clayton *et al.* also recorded the range top of rare *Lycospora* spp. at the upper limit of the VC Biozone. In contrast, the last stratigraphic occurrence of *Lycospora* spp. in 12/2-1z is recorded at 14344'/4372m - within the interval assigned to the NBM Biozone. It is possible that the early disappearance of *Lycospora* spp. in 12/2-1z reflects the development of non-swamp-like conditions, as suggested by the absence of coals. Such an environment would be unsuitable for the parent plant of *Lycospora*. Clayton *et al.* also recorded the range tops of *Westphalensisporites irregularis* and *Florinites junior* in the middle of the NBM Biozone. Although a single occurrence of *F. junior* is recorded at 14629'/4459m, *W. irregularis* is absent from the well. Clayton *et al.* also recorded an abundance *Spinosporites spinosus* and *Thymospora* spp. in the NBM Biozone of Western Europe. However, occurrences in the 12/2-1z interval are infrequent.

The interval assigned to the NBM Biozone in 12/2-1z is also characterised by occurrences of *Disaccites non-striatiti*, *Lundbladispora gigantea*, *Florinites* spp., *Laevigatosporites* spp., *Triquitrites* spp., rare *Disaccites striatiti,* rare *Densosporites* spp. rare *Vittatina* spp. and rare *Latensina trileta*. The taxa are characteristic of the NBM Biozone in Clayton *et al*. (1977). However, a number of additional species that should characterise the biozone are not recorded in the 12/2-1z interval, notably *Candidispora* spp. and *Angulisporites splendidus*.

The miospore assemblage assigned to the NBM Biozone in 12/2-1z shows a number of similarities with the assemblages assigned to the Stephanian age *Potonieisporites* Zone of Barss and Hacquebard (1967) in the North Sydney P-05 well, located in the Sydney Basin, offshore Nova Scotia, Canada (Barss *et al*. 1979) (figure 10.9). Many of the species recorded in the *Potoneisporites* Zone of the P-05 well are also recorded in the interval assigned to the NBM Biozone in the well 12/2-1z, notably; *Apiculatasporites latigranifer, Cadiospora magna, Calamospora breviradiata, Calamospora pallida, Calamospora pedata, Calamospora microrugosa, Endosporites globiformis, Endosporites zonalis, Florinites mediapudens, Florinites junior, Florinites pumicosus, Florinites similis, Leiotriletes sphaerotriangularis, Lycospora pusilla, Potonieisporites novicus, Punctatosporites minutus, Raistrickia aculeata, Raistrickia saetosa, Triquitrites bransonii, Triquitrites spinosus* and *Verrucosisporites donarii.* Range data from Butterworth (1984) and Smith and Butterworth (1967) suggests the range tops of species such as *C. breviradiata, Leiotriletes sphaerotriangularis* and *C. microrugosa* are restricted to the mid Bolsovian in Western Europe. Unless reworked, the presence of the taxa in both 12/2-1z and P-05 wells suggests the ranges may extend into the late Stephanian of offshore western Ireland and offshore Eastern Canada.

Also recorded in the 12/2-1z interval are sporadic occurrences of miospores with ranges restricted to the Westphalian and/or Namurian in Western Europe. *Triquitrites triturgidus* (14649'/4465m to 14668'/4471m) is recorded in the lower Arnsbergian to mid Arnsbergian of north-western Europe (Butterworth 1984). *Raistrickia fulva* (14580'/4444m) shows a mid Kinderscoutian to upper Bolsovian range in the North Sea (McLean *et al.* 2005) and north-western Europe (Butterworth 1984). *Laevigatosporites vulgaris* is recorded from the mid Langsettian to top Duckmantian of north-western Europe (Butterworth 1984). *Densosporites anulatus* (14245'/4342m and 14668'/4471m) is recorded in Viséan to lower Bolsovian age strata of onshore Great Britain (Smith and Butterworth 1967). Interpretation 1 assumes that the occurrences above 14649'/4465m are not in-situ and instead reworked.

? Stratigraphic break into Arnsbergian age strata 14649'/4465m

It is possible that the occurrences of *Triquitrites triturgidus* from 14649'/4465m to 14668'/4471m represent an unconformable or faulted transition into Arnsbergian age strata. However, this interpretation is very tentative due to the absence of index taxa that define Arnsbergian age biozones in the Western European miospore zonal scheme of Clayton *et al.* (1977).

Interpretation 2.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

?*Vittatina costabilis* (VC) Biozone (lower Autunian) 13478'/4108m to 14176'/4321m

As in interpretation 1, samples from 13478'/4108m to 14176'/4321m are tentatively assigned to the lower Autunian age VC Biozone.

***Thymospora obscura* – *Thymospora thiessenii* (OT) Biozone to *Torispora securis* – *Torispora laevigata* (SL) Biozone (Bolsovian to lower Barruelian) 14196'/4327m to 14580'/4444m**

Range data from Butterworth (1984) and Clayton *et al.* (1977) suggests that occurrences of *Cadiospora magna* from 14245'/4342' to 14668'/4471m, *Spinosporites spinosus* from 14354'/4375m to 14570'/4441m and the sole occurrence of *Thymospora* spp. at 14344'/4372' indicate a biozone no older than the *Thymospora obscura* – *Thymospora thiessenii* (OT) Biozone of Clayton *et al.* (1977). This is assuming that occurrences are *in situ* and not caved. Occurrences of *Cheleidonites* spp. and *Vittatina* spp. in the interval are assumed to be caved from the overlying VC Biozone.

Range data from Butterworth (1984) suggests that occurrences of *Calamospora breviradiata* in the interval 14196'/4327m to 14668'/4471m indicate an age no younger than the mid Bolsovian, roughly corresponding to the mid *Torispora securis* –

Torispora laevigata (SL) Biozone of Clayton *et al.* (1977). The occurrences of *Leiotriletes sphaerotriangularis* from 14245'/4342m to 14629'/4459m and the sole occurrence of *Densosporites anulatus* at 14245'/4342m also indicate an age no younger than the mid Bolsovian. Clayton *et al.* recorded the range tops of *Dictyotriletes bireticulatus* and *Cingulizonates loricatus* in the lower part of the OT Biozone. As neither taxon are encountered in 12/2-1z, the OT/SL biozone boundary cannot be positioned with confidence. There is an additional absence of key taxa that characterise the SL Biozone of Clayton *et al.* (1977), notably *Torispora* spp., *Vestispora fenestrata* and *Savitrisporites nux*. Alternatively, it is possible that the occurrences of *C. breviradiata, L. sphaerotriangularis* and *D. anulatus* are reworked or that their ranges extend into the OT Biozone of offshore western Ireland.

?*Microreticulatisporites nobilis – Florinites junior* (NJ) Biozone (Duckmantian to lower Bolsovian) 14580'/4444m to 14639'/4462m or 14668'/4471m

Based on range data from Clayton *et al*. (1977), it may be possible to position the *Torispora securis – Torispora laevigata* (SL) / *Microreticulatisporites nobilis – Florinites junior* (NJ) Biozone boundary at 14580'/4444m based on the last (and only) stratigraphic occurrence of *Raistrickia fulva*. Range data from Butterworth (1984) also suggests that the last stratigraphic occurrence of *Laevigatosporties vulgaris* at 14609'/4453m indicates an age no younger than the top Duckmantian, corresponding to the upper part of the NJ Biozone. However, there is an absence of key taxa that should characterise the NJ Biozone, notably *M. nobilis*, *Dictyotriletes bireticulatus* and *Cingulizonates loricatus*. Only one occurrence of the index taxon *F. junior* is recorded - at 14629'/4459m. There is an additional absence of *Grumosisporites varioreticulatus – maculosa*, the range top of which defines the lower limit of the SL Biozone in Clayton *et al.* (1977). Overall, there is low confidence in the positioning of the SL/NJ Biozone boundary and in the NJ Biozone being present.

?Stratigraphic break into Arnsbergian age strata 14649'/4465m

Again it is possible that occurrences of *Triquitrites triturgidus* from 14649'/4465m to 14668'/4471m represent an unconformable or faulted transition into Arnsbergian age strata.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Thymospora pseudothiessenii Biozone/*Westphalensisporites irregularis* Sub-biozone (upper Bolsovian) 14196'/4327m to 14344/4372m

Based on the first and only stratigraphic occurrence of the index taxon, the *Thymospora pseudothiessenii* Biozone lower limit is very tentatively positioned at 14344'/4372m. As the occurrence could potentially be caved from the overlying VC Biozone and as occurrences of *Calamospora breviradiata* in shallower samples may suggest an age no younger than the mid Bolsovian, there is low confidence in the positioning of the biozone lower limit. McLean *et al.* (2005) recorded the range tops of *Dictyotriletes bireticulatus* and *Cingulizonates loricatus* at the lower limit of the equivalent North Sea W7 Biozone. However, both taxa are absent in well 12/2-1z. Occurrences of *Spinosporites spinosus* in deeper cuttings samples are potentially caved. Clayton *et al.* (1977) recorded the range base of the taxon at the lower limit of the equivalent OT Biozone of Western Europe. The interval is very tentatively assigned to the lower Bolsovian age *Westphalensisporites irregularis* Sub-biozone due to the absence of index taxa that define the Asturian age *Torispora verrucosa* or the Cantabrian age *Angulisporites splendidus* Sub-biozones of Clayton *et al.* (2003) (figure 2.7).

The interpretation assumes that occurrences of *Cheleidonites* spp. and *Vittatina* spp. in the interval 14196'/4327m to 14668'/4471m are caved from the overlying strata.

Vestispora fenestrata Biozone / *Raistrickia aculeata* Sub-biozone (Bolsovian) 14344'/4372m to ?14609'/4453m

The *Vestispora fenestrata* Biozone in 12/2-1z cannot be defined based on occurrences of the index taxon due to its absence in the well. There is an additional absence of *Torispora securis*, the range base of which defines the lower limit of the *T. securis* Sub-biozone of Clayton *et al.* (2003). However, *Raistrickia aculeata* is recorded in 12/2-1z from 14353'/4375m to 14668'/4471m. The range base of the taxon defines the lower limit of the *R. aculeata* Sub-biozone of Clayton *et al.* (2003). Its occurrence infers the presence of the *R. aculeata* Sub-biozone below 14344'/4372m.

?*Microreticulatisporites nobilis* Biozone (Duckmantian) 14609'/4453m to 14639'/4462m or 14668'/4471m

Range data from Butterworth (1984) suggests the last stratigraphic occurrence of *Laevigatosporties vulgaris* at 14609'/4453m indicates an age no younger than the top Duckmantian, corresponding to the top of the *Microreticulatisporites nobilis* Biozone of Clayton *et al.* (2003). However, there is an absence in the interval 14609'/4453m - TD of index taxa which define the *M. nobilis* Biozone and equivalent sub-biozones of Clayton *et al.* (2003) or taxa which define the corresponding North Sea biozones and sub-biozones of McLean *et al.* (2005). As a result there is very low confidence in the positioning of the biozone at this depth.

?Stratigraphic Break into Arnsbergian age strata 14649'/4465m

Again it is possible that occurrences of *Triquitrites triturgidus* from 14649'/4465m to 14668'/4471m represent an unconformable or faulted transition into Arnsbergian age strata.

Interpretation 2 assumes that the rarity of *Lycospora* spp. above 14659'/4468m may be due to unsuitable environmental conditions for the parent plant.

Interpretation 3.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

?*Vittatina costabilis* (VC) Biozone (lower Autunian) 13478'/4108m to 14176'/4321m

As in the previous interpretations, samples from 13478'/4108m to 14176'/4321m are tentatively assigned to the VC Biozone of Clayton *et al.* (1977).

Torispora securis – Torispora laevigata (SL) Biozone (Bolsovian) 14196'/4327m to 14580'/4444m

Based on range data from north-western Europe (Butterworth 1984), the occurrence of *Calamospora breviradiata* from 14196'/4327m to 14668'/4471m assigns the interval to a biozone no younger than the SL Biozone of Clayton *et al.* (1977). Also based on data in Butterworth, the occurrence of *Leiotriletes sphaerotriangularis* from

14245'/4342m to 14629'/4459m and the sole occurrence of *Densosporites anulatus* at 14245'/4342m indicate an age no younger than the middle Bolsovian. However, the interval lacks occurrences of *Torispora* spp. and *Vestispora fenestrata*; key taxa that define the Bolsovian age SL Biozone of Clayton *et al.* (1977).

Occurrences of *Thymospora* spp., *Cheleidonites* spp., *Vittatina* spp., *Spinosporites spinosus* and *Cadiospora magna* in the interval assigned to the SL Biozone are assumed to be caved from the overlying VC Biozone.

?*Microreticulatisporites nobilis – Florinites junior* (NJ) Biozone (Duckmantian to lower Bolsovian) 14580'/4444m to 14639'/4462m or 14668'/4471m

Based on range data from Clayton *et al.* (1977), the boundary between the SL and NJ Biozones is very tentatively positioned at the last and only stratigraphic occurrence of *Raistrickia fulva* at 14580'/4444m. Range data from Butterworth (1984) also suggests that the last stratigraphic occurrence of *Laevigatosporties vulgaris* at 14609'/4453m indicates an age no younger than the top Duckmantian, corresponding to the upper NJ Biozone. However, there is a lack of key taxa that characterise the NJ Biozone of Clayton *et al.* (1977); index taxon *M. nobilis* is absent and only one occurrence of *F. junior* is recorded. *Dictyotriletes bireticulatus, Cingulizonates loricatus, Grumosisporites varioreticulatus* and *G. maculatus* are also absent.

?Stratigraphic break into Arnsbergian age strata 14649'/4465m

Again it is possible that occurrences of *Triquitrites triturgidus* from 14649'/4465m to 14668'/4471m represent an unconformable or faulted transition into Arnsbergian age strata.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Vestispora fenestrata Biozone / *Raistrickia aculeata* Sub-biozone (Bolsovian) 14196'/4327m to ?14609'/4453m

Range data from Butterworth (1984) suggests the occurrences of *Calamospora breviradiata* in the interval 14196'/4327m to 14668'/4471m indicate an age no younger than the Bolsovian age SL Biozone, corresponding to the *Vestispora fenestrata* Biozone of Clayton *et al.* (2003). The range base of the index taxon should define the lower limit of the *V. fenestrata* Biozone. However, the taxon is not recorded in the well section. *Torispora securis* is also absent from the well. The range base of the taxon defines the lower limit of the *T. securis* Sub-biozone in Clayton *et al.* *Raistrickia aculeata* is recorded in 12/2-1z, tentatively assigning the interval 14344/4372m to 14609'/4453m to the *R. aculeata* Sub-biozone of Clayton *et al.* (2003). Occurrences of *Thymospora* spp., *Cheleidonites* spp., *Vittatina* spp., and *Spinosporites spinosus* are considered caved.

?*Microreticulatisporites nobilis* Biozone (Duckmantian) 14609'/4453m to 14639'/4462m or 14668'/4471m

Range data from Butterworth (1984) suggests the last stratigraphic occurrence of *Laevigatosporties vulgaris* at 14609'/4453m indicates an age no younger than the top Duckmantian, corresponding to the upper limit of the *Microreticulatisporites nobilis* Biozone. However, there is an absence in the interval 14609'/4453' to 14668'/4471m of index taxa that define the Duckmantian age *M. nobilis* Biozone or Duckmantian age sub-biozones of Clayton *et al.* (2003). There is an additional absence of taxa whose ranges limits define the equivalent North Sea biozones and sub-biozones of McLean *et al.* (2005). As a result, there is very low confidence in the identification of the *M. nobilis* Biozone in 12/2-1z.

?Stratigraphic break into Arnsbergian age strata 14649'/4465m

Again it is possible that occurrences of *Triquitrites triturgidus* from 14649'/4465m to 14668'/4471m may represent an unconformable or faulted transition into Arnsbergian age strata.

VII.II Well 12/13-1a

Revised palynostratigraphic interpretations are based on palynological data from Church *et al*. (1979) (figure 6.2).

Triassic 6570'/2003m - 7310'/2228m

Church *et al.* (1979) assigned a Late Triassic (Rhaetian) age to the interval 6570'/2003m to 7310'/2228m based on the presence of miospores including *Kraeuselisporites reissingeri, Ovalipollis ovalis* and ostracods that include *Darwinula* *major, Kinelinella* cf. *cookiana*, *Timiriasevia striatulus, Hungarella bristolensis* and *Pontocypris richardsoni*.

Undifferentiated Triassic - Middle Permian 7310'/2228m to 9210'/2807m

Church *et al.* (1979) only recovered impoverished palynomorph assemblages from sidewall core samples below 7310'/2228m. Although recovery from cuttings samples was good, the majority of specimens were considered caved. Church *et al.* indicate that cuttings samples from the interval 8000'/2438m to 9414'/2869m (TD) were dominated by *Classopolis torosus* and bisaccate pollen, which the authors recorded as being caved. An occurrence of questionable *Lunatisporites* sp. at 9210'/2807m and a retusoid spore at 9370'/2856m were considered *in situ*. Sample depth 9210'/2807m is potentially no older than Middle Permian in age based on the Kazanian age range base of *Lunatisporites* recorded in Traverse (1988). Based on lithological composition, Odell and Walker (1979) suggested a Zechstein (Middle Permian) age for the interval 9268'/2825m - 9331'/2844m which fits with the occurrence of *Lunatisporites* sp.

Church *et al.* (1979) recorded the Carboniferous taxon *Lycospora pusilla* in a sidewall core sample from 9310'/2838m. Church *et al.* considered the occurrence to be reworked, which agrees with the lithological conclusions of Odell and Walker (1979).

Undifferentiated ?Permian - ?Devonian 9331'/2844m to 9400'/2865m

At 9370'/2856m, Church *et al.* (1979) recorded retusoid spores and *Densosporites* spp. Based on the stratigraphic range of *Densosporites* in Traverse (1988) and Warrington (1984), the interval 9370'/2856m to 9400'/2865m could represent a continuation of Permian strata or be as old as Devonian in age. Odell and Walker (1979) identified an unconformity at 9331'/2844m based on baseline shifts on sonic and gamma ray logs (figure 6.2). The unconformity may represent the boundary between the Permian to Devonian age interval and the overlying Zechstein strata.

VII.III Well 13/3-1

Revised palynostratigraphic interpretations are based on palynological data from Robeson (1988), Love *et al.* (1978) and the present study (figure 6.3). In the 13/3-1 final geological report (Stuart 1978), an unconformity between the Carboniferous interval and overlying Miocene strata is positioned at 1241'/378m based on a combination of palynological, lithological and well log data.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Thymospora obscura – Thymospora thiessenii (OT) Biozone (upper Bolsovian to lower Barruelian). 1250'/381m to 1730'/527m SWC or extending to fault between samples 1740'/530m and 1780'/543m

Based on range data from Clayton *et al.* (1977) (figure 2.2), the first stratigraphic occurrence of *Thymospora* spp. (*Thymospora obscura, Thymospora pseudothiessenii*) and the sole occurrence of *Spinosporites spinosus*, recorded in the 1730'/527m sidewall core sample, mark the lower limit of the OT Biozone. Occurrences of the index taxon *Thymospora thiessenii* are restricted to a cuttings sample at 1700'/518m. Clayton *et al.* also recorded the range tops of *Cingulizonates loricatus* and *Dictyotriletes bireticulatus* in the lower part of the OT Biozone. In 13/3-1, occurrences of *C. loricatus* are recorded in samples as shallow as 1500'/457m. A single occurrence of *D.* cf. *bireticulatus* is recorded at 3550'/1082m. Clayton *et al.* additionally recorded the range bases of *Polymorphisporites* spp., *Candidispora* spp. and *Savitrisporites concavus* in the lower part of the OT Biozone. In 13/3-1, occurrences are limited to the presence of *S.* cf. *concavus* in the 1730'/527m sidewall core sample.

Butterworth (1984) recorded the range bases of *Cadiospora magna*, *Punctatosporites oculus* and *Punctatosporites rotundus* at the lower limit of the OT Biozone in north-western Europe. The first stratigraphic occurrence of *C. magna* in 13/3-1 is recorded in the 1730'/527m sidewall core sample, confirming the OT Biozone at this depth. The first stratigraphic occurrences of *P. oculus* and *P. rotundus* are recorded at 1700'/518m. The interval in 13/3-1 assigned to the OT Biozone is also characterised by occurrences of *Microreticulatisporites nobilis, Florinites junior, Westphalensisporites irregularis* and *Vestispora fenestrata.* An absence of taxa with range bases restricted to the *Angulisporites splendidus – Latensina trileta* (ST) Biozone of Clayton *et al.* (1977) i.e. *A. splendidus* and *Cheleidonites* spp., suggest the OT Biozone is the youngest to be recorded in the well.

It is possible that the OT Biozone extends to a fault positioned between 1740'/530m and 1780'/543m (see below). Taxa that define the OT Biozone are not recorded in the 1740'/530m sidewall core sample. However, this may reflect the moderate recovery of miospores from this depth.

Fault between sample depths 1740'/530m and 1780'/543m

Robeson (1988) recorded a jump in reflectance values from 0.94% to 1.53%Rr between sample depths 1740'/530m and 1780'/543m. The author inferred the presence of a fault between the sample depths.

Torispora securis – Torispora laevigata (SL) Biozone (Bolsovian). 1730'/527m SWC or 1780'/543m to 2290'/698m

Clayton *et al.* (1977) recorded the range bases of *Torispora* spp. and *Vestispora fenestrata* at the lower limit of the SL Biozone (figure 2.2). In 13/3-1, the first stratigraphic occurrences are recorded in cuttings samples at 2290'/698m and 2830'/863m respectively. The deepest occurrences of both taxa in sidewall core are recorded at 1730'/527m. Clayton *et al.* also recorded the range tops of *Grumosisporites varioreticulatus, Grumosisporites maculatus* and *Raistrickia fulva* at the SL Biozone lower limit. Both *G. varioreticulatus* and *G. maculatus* are absent from 13/3-1. A single occurrence of *R. fulva* is recorded at 2290'/698m, tentatively confirming the biozone lower limit at this depth, although it is noted that two occurrences of *R.* cf. *fulva* are recorded at 1390'/424m and 1630'/497m. Occurrences of *V. fenestrata* below 2290'/698m are considered caved.

Clayton *et al.* (1977) recorded the range base of *Punctatosporites granifer* and the range top of *Savitrisporites nux* just above the SL Biozone lower limit, with the range bases of *Disaccites striatiti* and *Lundbladispora gigantea* within the biozone. In 13/3-1 the first stratigraphic occurrence of *P. granifer* is recorded at 1790'/546m and the last stratigraphic occurrence of *S. nux* is recorded at 1390'/424m; occurrences which do not help constrain the biozone lower limit. The first stratigraphic occurrence of *D. striatiti* is recorded at 1780'/542m and the first stratigraphic occurrence of *L.* cf. *gigantea* is recorded in a cuttings sample at 2450'/747m. Overall, as the lower limit of the biozone is defined by a combination of the first stratigraphic occurrence of *T.*

securis and the last (and only) stratigraphic occurrence of *R. fulva,* there is some confidence in its positioning.

Microreticulatisporites nobilis – Florinites junior (NJ) Biozone (Duckmantian to lower Bolsovian) 2290'/698m to 4350'/1325m

Clayton *et al.* (1977) recorded the range bases of the index taxa at the lower limit of the NJ Biozone (figure 2.2). In 13/3-1, the first stratigraphic occurrences of *Microreticulatisporites nobilis* and *Florinites junior* are recorded in cuttings samples at 3340'/1018m and 2730'/832m respectively. An absence of taxa with range tops that define the biozone lower limit and the base of the Duckmantian Substage suggests that Langsettian age strata has not been penetrated by the well. The absence of *M. nobilis* and *F. junior* below 3340'/1018m may be due to the limited miospore recovery at these depths.

Clayton *et al.* (2003) Western European Zonal Scheme

Thymospora pseudothiessenii Biozone 1250'/381m to 1730'/527m SWC or extending to fault positioned between 1740'/530m and 1780'/543m

Based solely on the first stratigraphic occurrence of the index taxon, the lower limit of the *Thymospora pseudothiessenii* Biozone of Clayton *et al.* (2003) (figure 2.7) is positioned at the 1730'/527m sidewall core sample depth. The interval assigned to the biozone is characterised by fairly consistent occurrences of the index taxon.

As indicated above, the range base of *Spinosporites* spp. marks the lower limit of the equivalent OT Biozone of Clayton *et al.* (1977). Its first stratigraphic occurrence, recorded in the 1730'/527m sidewall core sample, also potentially positions the *T. pseudothiessenii* Biozone lower limit at this depth. The range base of *Cadiospora magna* is not deemed reliable for defining the lower limit of the *T. pseudothiessenii* Biozone offshore western Ireland as McLean *et al.* (2005) recorded sporadic occurrences of the taxon in the lower Bolsovian of the North Sea.

Occurrences of *Cingulizonates loricatus* in 13/3-1 are recorded in the interval assigned to the *T. pseudothiessenii* Biozone with the last stratigraphic occurrence recorded at 1500'/457m. As noted above, Clayton *et al.* (1977) recorded the range top of the taxon in the lower part of the OT Biozone of Western Europe. McLean *et al.* (2005) recorded the range top in proximity to the equivalent lower limit of the North Sea W7 Biozone (figure 2.5). McLean *et al.* also recorded the range top of *Dictyotriletes bireticulatus* at the lower limit of the W7 Biozone. Apart from a single occurrence of *D.* cf. *bireticulatus* recorded at 3550'/1082m, there is an absence of *D. bireticulatus* in the 13/3-1 well.

It is possible that the *T. pseudothiessenii* Biozone extends to the fault positioned between 1740'/530m and 1780'/543m, if it is assumed that the absence of *Thymospora* spp. in the 1740'/530m sidewall core sample is a reflection of the moderate miospore recovery at this depth.

***Torispora verrucosa* Sub-biozone (Asturian) 1250'/381m to 1730'/527m SWC or extending to fault positioned between 1740'/530m and 1780'/543m**

The Asturian age *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003) is tentatively identified in well 13/3-1. In the absence of the index taxon, ranges of alternative taxa are used to identify Asturian age strata. McLean *et al.* (2005) recorded the range base of *T. obscura* at the lower limit of the Asturian Substage in the North Sea (figure 2.5). In 13/3-1, the first stratigraphic occurrence of the taxon is recorded in the 1730'/527m sidewall core sample, assigning the sample depth to the *T. verrucosa* Sub-biozone. The additional occurrence of *Savitrisporites* cf. *concavus* at the same depth may also indicate an Asturian age based on the range of *S. concavus* in the North Sea.

The absence of *Angulisporites splendidus* suggests the lower Stephanian age *A. splendidus* Sub-biozone of Clayton *et al.* (2003) (figure 2.7) has not been peneterated by the well. Based on North Sea range data (McLean *et al.* 2005), the occurrence of *Endosporites zonalis* at 1250'/381m assigns an Asturian age to the shallowest Carboniferous sample. A number of additional taxa with range tops in the Asturian of the North Sea (McLean *et al.* 2005) are also recorded in the interval assigned to the *T. verrucosa* Sub-biozone in 13/3-1. McLean *et al.* recorded the range tops of *Vestispora magna* and *Triquitrites tribullatus* just above the Asturian lower limit. In 13/3-1, the last stratigraphic occurrences are recorded at 1690'/515m and 1500'/457m respectively. McLean *et al.* also recorded the range tops of *Florinites junior* and

Westphalensisporites irregularis in the lower Asturian. The last stratigraphic occurrences in 13/3-1 are recorded at 1705'/520m and 1320'/402m respectively. The range tops of *Vestispora laevigata*, *Endosporites zonalis* and *Alatisporites hoffmeisterii* are recorded in the mid-upper Asturian of the North Sea. The last stratigraphic occurrences in 13/3-1 are recorded at 1660'/506m, 1250'/381m and 1290'/393m respectively. McLean *et al.* also recorded the range base of *Lundbladispora gigantea* in the North Sea Asturian. Occurrences of *L.* cf. *gigantea* in 13/3-1 are recorded in cuttings samples at 1630'/497m and 2450'/747m.

It is noted that taxa with range tops recorded at the Bolsovian Substage upper limit in north-western Europe (Butterworth 1984) are recorded in the interval assigned to the *T. verrucosa* Sub-biozone in 13/3-1. The last stratigraphic occurrences of *Calamospora* cf. *breviradiata*, *Granulatisporites microgranifer* and *Vestispora costata* are recorded at 1581'/482m, 1700'/518m and 1581'/482m respectively. Occurrences of *Savitrisporites nux* are also consistently recorded in the interval assigned to the *T. verrucosa* Sub-biozone. The range top of the taxon is recorded in the middle of the Bolsovian in the North Sea (McLean *et al.* 2005) and in the lower SL Biozone of Western Europe (Clayton *et al.* 1977).

It is also possible that the *T. verrucosa* Sub-biozone extends to the fault positioned between 1740'/530m and 1780'/543m, if it is assumed that the absence of *T. obscura* from the 1740'/530m sidewall core sample is a reflection of the moderate miospore recovery at this depth.

Vestispora fenestrata **Biozone /** ***Torispora securis*** **Sub-biozone (Bolsovian) 1780'/543m to 2290'/698m or 2830'/863m**

In 13/3-1, the *Vestispora fenestrata* Biozone is assigned to strata directly below the fault positioned between 1740'/530m and 1780'/543m. The range base of the index taxon should define the lower limit of the biozone. The first stratigraphic occurrence is recorded in a cuttings sample at 2830'/863m, with the deepest occurrence in sidewall core recorded at 1730'/527m. Range data from the North Sea (McLean *et al.* 2005) indicates the range bases of *V. fenestrata* and *Torispora securis* occur in proximity to the lower limit of the equivalent W6 Biozone (figure 2.5). In 13/3-1, the first stratigraphic occurrence of *T. securis* is recorded in a cuttings sample from 2290'/698m, the deepest occurrence in sidewall core is recorded at 1730'/527m.

Ideally, the range tops of taxa would be used to constrain the *Vestispora fenestrata* Biozone lower limit. However, there is an absence in 13/3-1 of *Grumosisporites varioreticulatus* and *Grumosisporites papillosus;* taxa whose range tops mark the lower limits of the equivalent North Sea W6 Biozone and the SL Biozone of Western Europe. The range top of *Raistrickia fulva* was previously used to define the lower limit of the equivalent SL Biozone of Clayton *et al*. (1977). However, McLean *et al.* (2005) recorded the range top of the taxon in the upper part of the North Sea W6 Biozone. As a result, the taxon is deemed unreliable for defining the lower limit of the *V. fenestrata* Biozone in 13/3-1. Subsequently, the lower limit of the biozone is tentatively positioned between 2290'/698m and 2830'/863m; the depths of the first stratigraphic occurrences of *V. fenestrata* and *T. securis* in cuttings samples. As the lower limit is not constrained by the range tops of taxa, there is only moderate confidence in the positioning of the lower biozone limit.

An absence of *Raistrickia aculeata* in samples below the fault suggests the *R. aculeata* Sub-biozone of Clayton *et al.* (2003) is not recorded in the well. Other taxa with range bases that define the lower limit of the equivalent North Sea W6b Sub-biozone are absent from 13/3-1. Consequently, the interval assigned to the *Vestispora fenestrata* Biozone is also tentatively assigned to the *Torispora securis* Sub-biozone of Clayton *et al.* (2003) based on the presence of *T. securis* and absence of *R. aculeata.*

Triquitrites sculptilis **Biozone (lower Bolsovian) 2290'/698m or 2830'/863m to 3340'/1018m**

The lower limit of the *Triquitrites sculptilis* Biozone of Clayton *et al.* (2003) and the base of the Bolsovian Substage is tentatively positioned at 3340'/1018m based on the sole occurrences of *Ahrensisporites guereckei* and *Lophotriletes granoornatus.* Range data from the North Sea (McLean *et al.* 2005) indicates the range base of *T. sculptilis* extends into the Duckmantian. The index taxon is only recorded in one sample in the interval assigned to the biozone. The range top of *A. guerickei* occurs in proximity to the lower limit of the equivalent W5b Sub-biozone (and the Bolsovian/Duckmantian Substage boundary) in the North Sea (McLean *et al.* 2005). Butterworth (1984) recorded the range top of *L. granoornatus* at the top Duckmantian in north-western Europe. Other taxa recorded by McLean *et al.* that possess top Duckmantian range tops are absent from the 13/3-1 well, including *Cristatisporites connexus*, *Camptotriletes bucculentus* and *Murospora intorta*. Butterworth also recorded the range top of *Secarisporites remotus* at the top of the Duckmantian Substage in north-western Europe. However, the last stratigraphic occurrence in 13/3-1 is recorded at 2290'/698m. Overall, there is some uncertainty in the positioning of the biozone lower limit.

Microreticulatisporites nobilis Biozone and *Vestispora magna* Sub-biozone (Duckmantian) 3340'/1018m to 4350'/1326m

Based on range data from the North Sea (McLean *et al.* 2005) (figure 2.5), the occurrence of *Triquitrites sculptilis* in a cuttings sample at 3870'/1180m assigns the sample to a biozone no older than the *Microreticulatisporites nobilis* Biozone of Clayton *et al.* (2003). Taxa with range tops that define the base of the *M. nobilis* Biozone or the equivalent North Sea W4b Sub-biozone lower limit are not recorded in the well (i.e. *Sinuspores sinuatus*). The additional absence of taxa with range tops that that define the older *Sinuspores sinuatus*, *Schulzospora rara* or *Radiizonates aligerens* Biozones of Clayton *et al.* (2003) suggests the lower limit of the *M. nobilis* Biozone has not been encountered. This is despite the index taxon *M. nobilis* being absent from samples below 3340'/1018m.

The *Vestispora magna* Sub-biozone of Clayton *et al.* (2003) cannot be identified based on occurrences of the index taxon as the deepest occurrence is only recorded at 2830'/863m. Occurrences of *V.* cf. *magna* are recorded to a depth of 3350'/1021m. McLean *et al.* (2004) recorded the range base of *Triquitrites sculptilis* at the lower limit of the equivalent North Sea W5a Sub-biozone. Hence it may be possible to position the lower limit of the *V. magna* Sub-biozone at the first stratigraphic occurrence of *T. sculptilis* at 3870'/1180m. However, it is possible that the sub-biozone extends to the deepest sample depth (4350'/1326m) based on an absence of taxa that characterise the older *Lycospora noctuina noctuina* Sub-biozone of Clayton *et al.* (2003) or the equivalent North Sea W4 Biozone of McLean *et al.* (2005) (i.e. *L. noctuina noctuina*).

VII.IV Well 19/5-1

Revised interpretations are based on palynological data from Robeson (1988), Palaeoservices (1978) and the present study (figure 6.4).

Upper Permian 2925'/892m to 3000'/914m

Palaeoservices (1978) assigned a Late Permian age to a sidewall core sample at 2950'/899m based on an assemblage of acritarchs thought to resemble that of the Late Permian in Yorkshire, England. Palaeoservices also dated a cuttings sample at 2990'/911m as Late Permian in age based the occurrence of *Illinites delasaucei, Klausipollenites schaubergei, Lueckisporites virkkiae* and *Taeniaesporites noviaulensis.* Robeson (1988) assigned an Upper Permian age to a cuttings sample at 3000'/914m based on the occurrence of *L. virkkiae* although it is noted that Warrington (1984) recorded a range base in the mid Kungurian Stage of the Middle Permian. The interval assigned to the Upper Permian is also characterised by a lack of Carboniferous miospores.

Carboniferous 3030'/924m to 8410'/2563m

Carboniferous strata is identified at 3030'/924m based on the disappearance downhole of Permian age taxa and the first downhole occurrence of a Carboniferous miospore assemblage including *Lycospora pusilla* and *Endosporites globiformis*. This confirms the positioning of the Carboniferous/Upper Permian unconformity at 3030'/924m given in Palaeoservices (1978).

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Microreticulatisporites nobilis – Florinites junior (NJ) Biozone (Duckmantian to lower Bolsovian) 3030'/924m to 3710'/1131m

Based on range data from Clayton *et al.* (1977), the first downhole occurrence of *Raistrickia fulva* at 3030'/924m assigns the sample to a biozone no younger than the NJ Biozone (figure 2.2). An absence of *Vestispora fenestrata* and *Torispora* spp. suggests the upper limit of the NJ Biozone has not been encountered. Clayton *et al.* recorded the range bases of the taxa at the lower limit of the younger *Torispora securis – Torispora laevigata* (SL) Biozone.

Using range data from Clayton *et al.* (1977), the lower limit of the NJ Biozone is positioned at 3710'/1131m based on the last stratigraphic occurrence of *Schulzospora rara*. Clayton *et al* also recorded the range top of *Sinuspores sinuatus* at the biozone lower limit. In 19/5-1, the last stratigraphic occurrence is recorded just below the biozone base at 3790'/1155m. Clayton *et al.* additionally indicated that the range bases of the index taxa *Microreticulatisporites nobilis* and *Florinites junior* should mark the NJ Biozone lower limit. In 19/5-1, the first stratigraphic occurrence of *F. junior* is recorded at 3710'/1131m. The occurrence of *M. nobilis* in a sidewall core sample at 3650'/1113m confirms the presence of the NJ Biozone at this depth although occurrences in cuttings samples below 3710'/1131m at 3870'/1180m, 3888'/1185m, 3890'/1186m and 4290'/1308m are assumed to be caved. Clayton *et al.* also indicated that the last stratigraphic occurrence of *Bellispores* spp. should mark the lower part of the NJ Biozone. In 19/5-1, the last stratigraphic occurrence of *Bellispores nitidus* is recorded in a cuttings sample just below the biozone lower limit at 3790'/1155m. Samples assigned to the NJ Biozone in 19/5-1 are also characterised by occurrences of *Dictyotriletes bireticulatus, Vestispora costata* and *Cirratriradites saturni.* Overall there is confidence in the positioning of the biozone lower limit as it is based on the last stratigraphic occurrence of a taxon and therefore unaffected by caving.

Radiizonates aligerens **(RA) Biozone (Langsettian) 3710'/1131m to unconformity positioned between 3990'/1216m and 4020'/1225m**

As indicated above, based on range data in Clayton *et al.* (1977), the lower limit of the NJ Biozone in 19/5-1 is defined by the last stratigraphic occurrence of *Schulzospora rara* at 3710'/1131m. Very rare occurrences of the taxon are recorded in the preceding *Radiizonates aligerens* (RA) Biozone. The interval assigned to the RA Biozone is also characterised by occurrences of *Sinuspores sinuatus*.

It is inferred that the RA Biozone in 19/5-1 extends to an unconformity positioned between 3990'/1216m and 4020'/1225m (see below). Clayton *et al.* (1977) recorded the range base of *Radiizonates aligerens* at the lower limit of the biozone. In 19/5-1, the first stratigraphic occurrence of the taxon is recorded at 3990'/1216m. In addition, taxa with range tops that define the RA Biozone lower limit in Clayton *et al.*, i.e. *Spelaeotriletes triangulus* and *S. arenaceus* are only recorded below the unconformity.

Clayton *et al.* (1977) additionally recorded the range top of *Radiizonates aligerens* within the RA Biozone. In 19/5-1, the last stratigraphic occurrence of the index taxon is recorded in the uppermost part of the interval assigned to the biozone at 3790'/1155m. Samples assigned to the biozone are also characterised by occurrences of *Bellispores* spp. *(B. nitidus), Savitrisporites nux, Grumosisporites varioreticulatus, Reticulatisporites reticulatus, Chaetosphaerites pollenisimilis* and *Endosporites globiformis.* Clayton *et al.* indicated that the first stratigraphic occurrences of the genus *Punctatosporites* should also occur in the biozone. However, representatives of the genus are not recorded in the 19/5-1 well.

Clayton *et al*. (1977) also recorded the range bases of *Westphalensisporites irregularis* and *Disaccites non-striatiti* in the uppermost part of the RA Biozone. In 19/5-1, the first stratigraphic occurrence of *W. irregularis* is recorded at the biozone upper limit, although the first occurrence of *D. non-striatiti* is recorded considerably shallower at 3250'/991m.

Unconformity positioned between 3990'/1216m and 4020'/1225m

An unconformity juxtaposing Langsettian and Arnsbergian age strata is positioned between samples 3990'/1216m and 4020'/1225m based on the transition from samples containing predominantly Westphalian age miospores to an assemblage at 4020'/1225m dominated by taxa with range tops no younger than the lower Namurian. The assemblage recorded at 4020'/1225m includes taxa such as *Verrucosisporites morulatus, Rotaspora fracta, Cingulizonates* cf. *capistratus* and *Grumosisporites inaequalis* which indicate an age no younger than Arnsbergian. An unconformity rather than fault is inferred as the vitrinite reflectance recorded by Robeson (1988) shows little variation between samples.

Stenozonotriletes triangulus – Rotaspora knoxi (TK) Biozone (Arnsbergian) 4020'/1225m to 4140'/1262m

The TK Biozone is tentatively identified immediately below the unconformity based on the occurrence of *Cingulizonates* cf. *capistratus* at 4020'/1225m. Clayton *et al.* (1977) recorded the range top of the taxon at the base of the succeeding *Lycospora subtriquetra – Kraeuselisporites ornatus* (SO) Biozone (figure 2.2). The authors also indicated that the lower limit of the TK Biozone is defined by the first stratigraphic appearance of the index taxon *Stenozonotriletes triangulus.* However, the taxon is not recorded in 19/5-1. Alternatively, based on range data from Clayton *et al.*, the biozone lower limit is positioned at 4140'/1262m using the last stratigraphic occurrence of *Raistrickia nigra.* Clayton *et al.* also recorded the range top of the index taxon *Rotaspora knoxi* at the upper limit of the TK Biozone. However, in 19/5-1, the taxon is not recorded in samples shallower than 4290'/1308m.

Clayton *et al.* (1977) recorded the range bases of *Punctatisporites giganteus* and *Punctatisporites pseudopunctatus* at the TK Biozone lower limit with the range bases of *Mooreisporites fustis*, *Reinschospora speciosa* and range tops of both *Tripartites trilinguis* and *Rotaspora ergonulii* marking the lowermost part of the biozone. *P. giganteus, P. pseudopunctatus* and *R. speciosa* are not recorded in the 19/5-1 well and the first stratigraphic occurrence of *M. fustis* is recorded above the unconformity at 3990'/1216m. The last stratigraphic occurrence of *T. trilinguis* is reworked above the unconformity at 3870'/1180m and a solitary occurrence of *R. ergonulii* is recorded at 4810'/1466m. Clayton *et al.* also recorded the range tops of *Tripartites vetustus, Triquitrites marginatus* and *Spinozonotriletes uncatus* at the upper limit of the TK Biozone. In 19/5-1, the last stratigraphic occurrences are recorded at 4100'/1250m, 4140'/1262m and 4649'/1417m respectively. Overall, due to the absence of *Stenozonotriletes triangulus* and the rarity of *Rotaspora knoxi* at this stratigraphic level, there is only moderate confidence in the positioning of the biozone.

Bellispores nitidus – Reticulatisporites carnosus **(NC) Biozone (upper Brigantian to Pendleian) 4140'/1262m to 5520'/1683m SWC or 5770'/1759m**

Clayton *et al.* (1977) recorded the range base of *Bellispores* spp. at the NC Biozone lower limit (figure 2.2). In 19/5-1, the first stratigraphic occurrence of *Bellispores* spp. (index taxon *Bellispores nitidus*) is recorded in a cuttings sample at 5770'/1759m, tentatively marking the biozone lower limit due to the possibility of caving. An occurrence is also recorded in the 5000'/1524m sidewall core sample, confirming the biozone at this depth. The second index taxon *Reticulatisporites carnosus* is only recorded in a single sample at 3790'/1155m. Clayton *et al.* indicated the range bases of *Verrucosisporites morulatus*, *Secarisporites lobatus*, *Ahrensisporites* var. *ornatus*, *Crassispora kosankei*, *Proprisporites laevigatus* and *Potoneisporites elegans* should also occur within the biozone. In 19/5-1, the first stratigraphic occurrence of *C.*

kosankei is recorded within the interval assigned to the biozone at 4649'/1417m. However, *S. lobatus*, *A.* var. *ornatus*, *P. laevigatus* and *P. elegans* are not recorded in the well. Robeson (1988) recorded *V. morulatus* in a sidewall core sample at 6443'/1964m. This occurrence does not fit with the overall palynostratigraphic interpretation for the well, hence the range base may be older offshore western Ireland than in the rest of Western Europe. The NC Biozone in 19/5-1 is also characterised by occurrences of *Raistrickia nigra*.

Clayton (1985) indicated that the lower limit of the NC Biozone in Western Europe is defined by the range base of *Cingulizonates* cf. *capistratus.* Clayton also recorded the range bases of *Crassispora kosankei, Florinites* spp. and *Schopfipollenites ellipsoides* in proximity to the Namurian/Viséan boundary although it was noted that the taxa may be too rare in occurrence to be of use in recognising the boundary. In 19/5-1, the first stratigraphic occurrences of *C.* cf. *capistratus, C. kosankei,* and *S. ellipsoides* occur within the interval assigned to the NC Biozone at 5220'/1591m (SWC), 4649'/1417m, and 5000'/1524m (SWC) respectively. The first stratigraphic appearance of *Florinites* spp. is recorded just above the unconformity at 3990'/1216m.

In summary, the NC Biozone lower limit in 19/5-1 is either positioned at the first stratigraphic occurrence of *C.* cf. *capistratus* in the 5220'/1591m sidewall core sample or tentatively at the 5770'/1759m cuttings sample depth based on the first stratigraphic occurrence of *Bellispores* spp. As the lower limit is not positioned using the range top of a taxon, there is only moderate confidence in the positioning of the biozone base.

***Tripartites vetustus* – *Rotaspora fracta* (VF) Biozone (Brigantian) 5520'/1683m SWC or 5770'/1759m to 6742'/2055m SWC**

Clayton *et al.* (1977) defined the lower limit of the VF Biozone based on the range bases of a number of taxa including *Tripartites vetustus, Rotaspora fracta, Tripartites nonguericki, Triquitrites trivalvis, Rotaspora knoxi, Savitrisporites nux, Crassispora maculosa, Spencerisporites radiatus* and *Grandispora spinosa* (figure 2.2). Clayton (1985) also confirmed the range bases of *R. fracta*, *T. vetustus* and *G. spinosa* at the VF Biozone lower limit. In 19/5-1, the deepest occurrence of the taxa in sidewall core is that of *C. maculosa* at 6742'/2055m, confirming the presence of the biozone at this depth. The deepest occurrence is recorded in a cuttings sample at 7190'/2192m. The first stratigraphic occurrences of the index taxa *T. vetustus* and *R. fracta* are recorded in shallower cuttings samples at 6570'/2003m and 5770'/1759m respectively. The first stratigraphic occurrences of *T. trivalvis, R. knoxiae*, *T. non-guerickei* and *S. nux* are also recorded in shallower cuttings samples at 4110'/1253m 4649'/1417m, 6100'/1859m and 6570'/2003m respectively. The first stratigraphic occurrences of *G. spinosa* is recorded in cuttings samples at 6760'/2060m. *S. radiatus* is not recorded in the well. The biozone lower limit is positioned at least as deep as the occurrence of *C. maculosa* in the 6742'/2055m sidewall core sample. Occurrences of the above taxa in deeper cuttings samples may be caved.

Clayton *et al.* (1977) also recorded the range tops of *Verrucosisporites baccatus, Crassispora aculeata, Cribrosporites cribellatus* and *Perotrilites tessellatus* within the VF Biozone. In 19/5-1, the last stratigraphic occurrence of *C. aculeata* is recorded at 4290'/1308m, the only occurrence of *P. tesellatus* is recorded in a cuttings sample at 6760'/2060 and both *V. baccatus* and *C. cribellatus* are absent from the well. Overall, as the biozone lower limit is not constrained by the range tops of taxa, there is only moderate confidence in its positioning.

***Raistrickia nigra – Triquitrites marginatus* (NM) Biozone (Asbian) 6742'/2055m SWC to 7000'/2134m or 7190'/2192m**

Clayton *et al.* (1977) recorded the first stratigraphic appearances of *Raistrickia nigra, Densosporites* cf. *velatus, Murospora parthenopia, Monilospora mutabilis* and *Kraeuselisporites echinatus* at the NM Biozone lower limit. In 19/5-1, the first stratigraphic occurrence of *R. nigra* is recorded in a cuttings sample at 7190'/2191m. *K. echinatus* is only present in one sample at 4230'/1289m. The other taxa are absent from the well. Clayton *et al.* also identified a number of species with range tops in the lower part of the NM Biozone. Species include *Tripartites distinctus, Ahrensisporites duplicatus* and *Potonieisporites delicatus.* Species with range tops marking the middle of the biozone were additionally identified and include; *Densosporites* cf. *velatus, M. parthenopia* and *M. mutabilis.* In 19/5-1 only *P. delicatus* is recorded. A solitary occurrence of the taxon in a sidewall core sample at 7000'/2134m assigns the depth to a biozone no younger than the NM Biozone.

Clayton (1985) confirmed that the base of the NM Biozone in Western Europe is defined by the range bases of *Raistrickia nigra* and *Triquitrites marginatus*. In 19/5-1, the first stratigraphic occurrence of *T. marginatus* is recorded in a cuttings sample at 8410'/2563m, assigned to the Holkerian (see below). The second deepest occurrence is recorded in sidewall core from 7000'/2134m, confirming the biozone at this depth. The biozone lower limit is potentially positioned as deep as the first stratigraphic occurrence of *R. nigra* in the 7190'/2192m cuttings sample. However, it is possible that the occurrence is caved. Overall there is only moderate confidence in the positioning of the biozone lower limit at the 7000'/2134m sidewall core sample depth. The biozone lower limit could potentially be positioned at 7190'/2192m, however, the range tops of taxa are required to confirm this depth.

Clayton (1985) also subdivided the NM biozone into a lower *Tripartites distinctus - Murospora parthenopia* (DP) Sub-biozone and an upper *Murospora margodentata – R. ergonulii* (ME) Sub-biozone, based on the first stratigraphic appearance of *Murosporoa margodentata.* In 19/5-1, the taxon is only recorded once, above the NM Biozone upper limit, making subdivision of the biozone impossible.

***Perotrilites tessellatus – Schulzospora campyloptera* (TC) Biozone 7000'/2134m or 7190'/2192m to 7625'/2324m or 8320'/2536m**

Clayton *et al.* (1977) defined the lower limit of the TC Biozone and the Asbian Substage in Western Europe based on the first stratigraphic occurrence of *Schulzospora* spp. with the range bases of *Perotrilites tessellatus, Chaetosphaerites pollenisimilis, Verrucosisporites baccatus, Waltzispora planiangulata,* and *Crassispora aculeata* marking the lowermost part of biozone. In 19/5-1, the first stratigraphic occurrences of *Schulzospora* spp. and *C. aculeata* are recorded at 7625'/2324m and 8410'/2563m respectively. The first stratigraphic occurrences of *W. planiangulata*, *P. tessellatus* and *C. pollenisimilis* are recorded above the biozone upper limit at 6760'/2060m, 6760'/2060m and 3890'/1186m respectively. *V. baccatus* is not recorded in the well. Clayton *et al.* also indicated that the range bases of *Apiculatasporites porosus, Tripartites distinctus, Cribrosporites cribellatus* and *Potoneispores delicatus* occur in the upper TC Biozone. In 19/5-1, the first stratigraphic occurrence of *A. porosus* is recorded at 7190'/2192m, a single occurrence of *P. delicatus* is recorded at 7000'/2134m and both *T. distinctus* and *C. cribellatus* are absent. Clayton *et al.* further indicated that the range tops of *Schopfites claviger, Convolutispora circumvallata, Crassispora trychera, Diblisporites distinctus, Verrucosisporites nitidus, Raistrickia corynoges, Grandispora echinata, Auroraspora macra* and *Retusotriletes incohatus* mark the lower limit of the biozone. In 19/5-1, the last stratigraphic occurrence of *S. claviger* is recorded at 8320'/2536m and may define the biozone lower limit. *G. echinata* and *R. incohatus* are recorded in single samples at 7190'/2192m and 5770'/1759m respectively. *C. circumvallata, D. distinctus Verrucosisporites nitidus*, *R. corynoges* and *A. macra* are absent from the well. Overall, there is uncertainty regarding the positioning of the TC Biozone lower limit using range data from Clayton *et al.* (1977). The lower limit is either positioned based on the first stratigraphic occurrence of *Schulzospora* spp. at 7625'/2324m or on the last stratigraphic occurrence of *S. claviger* at 8320'/2536m.

The lower limit of the TC Biozone was subsequently repositioned by Clayton (1985) to the mid Holkerian and defined using the first stratigraphic appearance of *Schulzospora campyloptera*. However, in 19/5-1, the first stratigraphic occurrence of *S. campyloptera* is recorded in a sample assigned to the Brigantian age VF Biozone at 6443'/1964m. Clayton (1985) also introduced the mid Holkerian to mid Arundian age *K. triradiatus* - *K. stephanephorus* (TS) Biozone, indicating the range bases of the index taxa define the biozone lower limit. However in 19/5-1, *K. triradiatus* is only recorded in a single sample at 5160'/1573m. The first stratigraphic occurrence of *K. stephanephorus* is recorded at 7190'/2192; a depth potentially assigned to the TC Biozone upper limit. As a result the TS Biozone cannot be confidently identified in 19/5-1.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Microreticulatisporites nobilis Biozone (Duckmantian) 3030'/924m to undefined base

Based on range data from the North Sea (McLean *et al.* 2005), the last stratigraphic occurrences of *Cristatisporites connexus*, *Camptotriletes bucculentus* and *Ahrensisporites guerickei* at 3240'/988m assign the sample to a biozone no younger than the Duckmantian age *Microreticulatispories nobilis* Biozone of Clayton *et al.* (2003). The range tops of the taxa in the North Sea are recorded at or in proximity to the Duckmantian/Bolsovian Substage boundary (figure 2.5). The last stratigraphic occurrences in 19/5-1 potentially position the upper limit of the *Microreticulatisporites nobilis* Biozone and the Duckmantian/Bolsovian Substage boundary at 3240'/988m. However, an absence of taxa such as *Vestispora fenestrata*, *Torispora securis* and *Punctatosporites rotundus* which show Bolsovian age range bases in the North Sea (McLean *et al.* 2005) and Western Europe (Clayton *et al.* 1977; 2003) suggests the Duckmantian age *M. nobilis* Biozone is the youngest to be encountered in the well. In addition, the occurrence of *Laevigatosporites vulgaris* at 3030'/924m indicates an age no older than top Duckmantian based on range data from Butterworth (1984).

Clayton *et al.* (2003) indicate the lower limit of the *Microreticulatisporites nobilis* Biozone should be defined by the range base of the index taxon (figure 2.7). The range base is also recorded in proximity to the equivalent North Sea W4b Sub-biozone lower limit (McLean *et al.* 2005) (figure 2.5). In 19/5-1, the biozone lower limit is positioned at least as deep as 3650'/1113m based on the occurrence of the index taxon in sidewall core. However, the taxon is also recorded in deeper cuttings samples at 3660'/1116m, 3870'/1180m, 3880'/1183m, 3900'/1189m and 4290'/1308m. McLean *et al.* (2005) also recorded a number of taxa with range tops at the W4b Sub-biozone lower limit. In 19/5-1, the last stratigraphic occurrence of *Sinuspores sinuatus* is recorded in Langsettian age strata (see below) and both *Splelaeotriletes pretiosus windorensis* and *Densosporites* cf. *spinosus* are absent from the well. Overall, the biozone is deemed to extend at least to the occurrence of *M. nobilis* in sidewall core at 3650'/1113m. However, the biozone lower limit cannot be confidently positioned due to the deeper occurrences of the taxon in cuttings samples and the restriction of *S. sinuatus* to Langsettian age samples.

***Vestispora magna* Sub-biozone (Duckmantian) 3030'/924m to 3250'/991m or 3650'/1113m SWC**

Range data from McLean *et al.* (2005) indicates the first stratigraphic occurrence of *Vestispora magna* defines the lower limit of the W5a Sub-biozone; the North Sea equivalent of the *V. magna* Sub-biozone of Clayton *et al.* (2003). In 19/5-1, *V. magna* is only recorded in cuttings samples at 3070'/936m and 3540'/1079m.

McLean *et al.* identified a number of taxa with range tops that occur in proximity to the W5a Sub-biozone lower limit. In 19/5-1, the last stratigraphic occurrence of *Savitrisporites concavus* is recorded at 3610'/1100m and the last stratigraphic occurrence of *Lycospora noctuina noctuina* is recorded at 3250'/991m. The last stratigraphic occurrences of *L. noctuina noctuina* tentatively positions the *V. magna* Sub-biozone lower limit in proximity to this depth. McLean *et al.* (2005) also recorded the range base of *Triquitrites sculptilis* at the lower limit of the W5a Sub-biozone. In 19/5-1, an occurrence of *T. sculptilis* in sidewall core from 3650'/1113m may position the sub-biozone lower limit at this depth. Occurrences are also recorded in deeper cuttings samples to a depth of 3990'/1216m. As a result, there is very low confidence in the positioning of the sub-biozone lower limit at 3250'/991m.

***Lycospora noctuina noctuina* Sub-biozone (Duckmantian) 3250'/991m to undefined base**

If the boundary between the *Vestispora magna* Sub-biozone and the *Lycospora noctuina noctuina* Sub-biozone is positioned at 3250'/991m, the interval assigned to the *L. noctuina noctuina* Sub-biozone is characterised by infrequent occurrences of the index taxon. The interval is also is characterised by occurrences of *Cristatisporites solaris* and rare occurrences of *Savitrisporites concavus*. The lower limit of the sub-biozone corresponds to the lower limit of the *Microreticulatisporites nobilis* Biozone.

?*Sinuspores sinuatus* Biozone (lower Duckmantian) undefined top to 3710'/1131m

The upper limit of the *Sinuspores sinuatus* Biozone of Clayton *et al.* (2003) corresponds to the base of the *Microreticulatisporites nobilis* Biozone. As indicated above, the biozone boundary cannot be defined in 19/5-1. However, the base of the *Sinuspores sinuatus* Biozone and the Langsettian/Duckmantian Substage boundary can be defined based on the range top of *Schulzospora rara* (figure 2.7). The last stratigraphic occurrence in 19/5-1 is recorded at 3710'/1131m. McLean *et al.* (2005) also recorded the first stratigraphic occurrences of *Radiizonates faunus* and *Radiizonates tenuis* in proximity to the base of the equivalent North Sea W4a Sub-biozone. In 19/5-1, the first stratigraphic occurrences are recorded in cuttings samples at 3660'/1116m and 3880'/1183m respectively. The deepest occurrence in a sidewall core sample is recorded at 3650'/1113m. McLean *et al.* (2005) also recorded the range top of *R. striatus* in proximity to the Langsettian/Duckmantian Substage boundary. In

19/5-1, the last stratigraphic occurrence of the taxon is recorded at 3660'/1116m. Overall, due to the rarity of *S. rara*, there is only moderate confidence in the positioning of the biozone lower limit. The lower Duckmantian age *Sinuspores sinuatus* Biozone should be also characterised by occurrences of the index taxon. However, as indicated above, occurrences in 19/5-1 are restricted to Langsettian age samples.

Schulzospora rara Biozone (Langsettian) 3710'/1131m to 3790'/1155m

The lower limit of the upper Langsettian age *Schulzospora rara* Biozone of Clayton *et al.* (2003) is defined based on the range top of *Radiizonates aligerens* (figure 2.7). In 19/5-1, the last stratigraphic occurrence is recorded at 3790'/1155m. The range top also defines the base of the equivalent North Sea W3 Biozone of McLean *et al.* (2005). There is confidence in the positioning of the *S. rara* Biozone lower limit as the depth of the last stratigraphic occurrence of *R. aligerens* will be unaffected by caving. However, only very rare occurrences of the index taxon are recorded in the interval assigned to the *S. rara* Biozone.

Radiizonates aligerens Biozone (Langsettian) 3790'/1155m to 3900'/1189m

The lower limit of the *Radiizonates aligerens* Biozone of Clayton *et al.* (2003) is tentatively defined based on range data from the North Sea (McLean *et al.* 2005). The range bases of a number of taxa mark the lower limit of the W2b Sub-biozone, which is roughly equivalent to the *R. aligerens* Biozone (figure 2.5). The first stratigraphic occurrences of *Endosporites globiformis* and *Vestispora pseudoreticulata* in 19/5-1 are recorded in cuttings samples at 3900'/1189m and 3890'/1186m respectively which tentatively mark the *R. aligerens* Biozone lower limit. However, there is low confidence in the positioning of the biozone lower limit based on first stratigraphic occurrences in cuttings samples due to the risk of caving.

Taxa identified by McLean *et al.* (2005) with range tops at the lower limit of the North Sea W2b Sub-biozone are not very useful for marking the base of the *Radizonates aligerens* Biozone in 19/5-1 (figure 2.5). The last stratigraphic occurrence of *Triquitrites* cf. *protensus* is recorded in lower Duckmantian age strata at 3610'/1100m, *Kraeuselisporites* cf. *ornatus* is recorded in one sample at 7190'/2192m, occurrences of *Dictyotriletes probireticulatus* at 3030'/924m and 3240'/988m are assumed to be reworked and the last stratigraphic occurrence of *Waltzispora polita* is recorded below the unconformity at 4290'/1308m.

The interval assigned to the *Radiizonates aligerens* Biozone is also characterised by moderately frequent occurrences of the index taxon in addition to occurrences of *Bellispores nitidus*. Butterworth (1984) recorded a top Langsettian range top for *B. nitidus*. There are also reworked occurrences of miospores with range tops restricted to the Namurian, including; *Crassispora maculosa, Ibrahimispores magnificus, Densosporites triangularis* and *Reticulatisporites carnosus.*

A number of additional taxa are present in the interval 3790'/1155 to 3900'/1189m that possess range limits in the Langsettian of north-western Europe, according to range data from Butterworth (1984). Butterworth recorded the range top of *Converrucosisporites armatus* at the top of the Langsettian Substage. The last stratigraphic occurrence in 19/5-1 is recorded at 3800'/1158m. Butterworth also recorded the range bases of *Florinites millotti, Lophotriletes granoornatus*, *Vestispora tortuosa, Punctatisporites obesus and Alatisporites pustulatus* in the mid Langsettian. The first stratigraphic occurrences in 19/5-1 are recorded at 3880'/1183m, 3880'/1183m, 3960'/1207m 3870'/1180m and 3870'/1180m respectively.

?*Vestispora cancellata* Biozone (Langsettian) 3900'/1189m to unconformity between 3990'/1216m and 4020'/1225m

The upper limit of the *Vestispora cancellata* Biozone of Clayton *et al.* (2003) corresponds to the base of the *R. aligerens* Biozone. As indicated above, the biozone boundary is very tentatively identified in 19/5-1. The index taxon is also absent in the well.

If the *Vestispora cancellata* Biozone is present in 19/5-1, the absence of taxa with range tops that define the lower limit of the biozone or the roughly equivalent North Sea W2a Sub-biozone (i.e. *Spelaeotriletes arenaceus*) suggests the biozone extends to the unconformity positioned between 3990'/1216m and 4020'/1225m.

Unconformity between 3990'/1216m and 4020'/1225m

Palynological data suggests a stratigraphic break between samples 3990'/1216m and 4020'/1225m separating strata of Westphalian and Pendleian age (see above).

***Cingulizonates* cf. *capistratus* Biozone (upper Brigantian to Pendleian) 4020'/1225m to 5520'/1683m SWC or 5770'/1759m**

The interval assigned to the *Cingulizonates* cf. *capistratus* Biozone in 19/5-1 is characterised by frequent occurrences of the index taxon. Based on range data from the North Sea (McLean *et al.* 2005) and onshore Great Britain (Owens *et al.* 2004), the lower limit is positioned at least as deep as 5520'/1683m based on the first stratigraphic occurrence of *C.* cf. *capistratus* in a sidewall core sample at this depth.

McLean *et al.* (2005) and Owens *et al.* (2004) indicated that in addition to *Cingulizonates* cf. *capistratus*, the range base of *Bellispores nitidus* occurs in proximity to the lower limit of the equivalent North Sea N1 Biozone and the *Bellispores nitidus – Reticulatisporites carnosus* (NC) Biozone of onshore Great Britain (figures 2.4 and 2.5). In 19/5-1, the first stratigraphic occurrence of *B. nitidus* is recorded in a cuttings sample at 5570'/1759m. The lower limit may tentatively be positioned at this depth, although it is possible that the occurrence is caved. McLean *et al.* also recorded the last stratigraphic appearance of *Cribrosporties cribellatus* at the N1 Biozone lower limit. The species is absent in 19/5-1.

McLean *et al.* (2005) identified a number of additional taxa with range tops that mark the boundary between the N1 Biozone and the succeeding N2 Biozone (figure 2.5). The last stratigraphic occurrences of *Raistrickia nigra* and *Grumosisporites inaequalis* in 19/5-1 are recorded within the interval assigned to the *Cingulizonates* cf. *capistratus* Biozone at 4140'/1262m and 4020'/1225m respectively. Owens *et al.* (2004) also identified a number of additional taxa with range tops that mark the boundary between the NC Biozone and the succeeding *Mooreisporites trigallerus – Rotaspora knoxi* (TK) Biozone (figure 2.4). In 19/5-1, the last stratigraphic occurrence of *Verrucosisporites morulatus* is recorded at 4020'/1225m, the last stratigraphic occurrence of *Rotaspora fracta* at 3990'/1216m is deemed to be reworked and a single occurrence of *Reticulatisporites carnosus* at 3790'/1155m is also likely to be reworked. Owens *et al.* also recorded the first stratigraphic occurrence of

Stenozonotriletes triangulus and *Mooreisporites trigallerus* at the base of the TK Biozone. The absence of both taxa in 19/5-1 suggests the *C.* cf. *capistratus* Biozone is the youngest biozone to be recorded below the unconformity.

Verrucosisporites morulatus **Sub-biozone (Pendleian) 4020'/1225m to 4290'/1308m**

The lower limit of the *Verrucosisporites morulatus* sub-biozone is positioned at 4290'/1308m, based on the last stratigraphic occurrence of *Crassispora aculeata*. McLean *et al.* (2005) recorded the range top of the taxon at the lower limit of the Pendleian Substage and the equivalent North Sea N1b Biozone (figure 2.5). Owens *et al.* (2004) recorded the last stratigraphic occurrence of the taxon just above the Brigantian/Pendleian boundary of onshore Great Britain. Range data from McLean *et al.* and Owens *et al.* also indicate the first stratigraphic appearance of *Ahrensisporites guerickei* should occur in proximity to the *V. morulatus* Sub-biozone lower limit (figure 2.4 and 2.5). The first stratigraphic occurrence in 19/5-1 is recorded at 4260'/1298m. The presence of *Grumosisporites inaequalis* in a sidewall core sample at 4230'/1289m also confirms a biozone no older than the *V. morulatus* Sub-biozone based on range data from the North Sea.

McLean *et al.* (2005) recorded the range bases of *Crassispora kosankei* and *Grumosisporites inaequalis* at the lower limit of the equivalent North Sea N1b Sub-biozone. The first stratigraphic occurrences of *C. kosankei* and *G. inaequalis* in 19/5-1 are recorded in a cuttings sample at 4649'/1417m. The sample is positioned just below the 13 3/8" casing shoe at 4630'/1411m. The 19/5-1 drilling report indicates the well was drilled to 4649'/1417m before the casing shoe was set at 4630'/1411m. Hence it is possible that the occurrences of *C. kosankei* and *G. inaequalis* at 4649'/1417m are caved from shallower Carboniferous strata. The occurrences are therefore not particularly reliable for positioning the *Verrucosisporites morulatus* Sub-biozone lower limit.

The index taxon *Verrucosisporites morulatus* occurs infrequently in the interval assigned to the sub-biozone. Robeson (1988) also identified specimens in sidewall core samples at 6352'/1936m and 6443'/1964m. These depths are considerably deeper than the first stratigraphic occurrences of *Cingulizonates* cf. *loricatus* or *Bellispores nitidus*. Occurrences of *V. morulatus* in the sidewall core samples may represent the extension of the stratigraphic range of the taxon into the Viséan of offshore western Ireland. Alternatively, it is possible that the occurrences have been misidentified.

A number of taxa recorded by Butterworth (1984) with range bases at the Pendleian Substage lower limit in north-western Europe are recorded in the interval assigned to the *Verrucosisporites morulatus* Sub-biozone in 19/5-1. The first stratigraphic occurrences of *Cristatisporites pannosus, Anapiculatisporites globulus* and *Granulatisporites* cf. *piroformis* are recorded in cuttings samples at 4020'/1225m, 4400'/1341m and 4649'/1417m respectively. Overall, there is only moderate confidence in the positioning of the sub-biozone lower limit at 4290'/1308m due to the possible occurrence of the index taxon in significantly deeper sidewall core samples.

Bellispores nitidus **Sub-biozone (upper Brigantian) 4290'/1308m or 4649'/1417m to 5520'/1683m SWC or 5770'/1759m**

The lower limit of the *Bellispores nitidus* Sub-biozone of Clayton *et al.* (2003) corresponds to the lower limit of the *Cingulizonates* cf. *capistratus* Biozone. The interval assigned to the *B. nitidus* Sub-biozone is characterised by moderately frequent occurrences of the index taxon.

Tripartites vetustus **Biozone (Brigantian) 5520'/1683m SWC or 5770'/1759m to 6742'/2055m SWC**

In 19/5-1, the index taxon occurs fairly infrequently in the interval assigned to the *Tripartites vetustus* Biozone. Based on Clayton *et al.* (2003), the biozone lower limit should be defined by the range base of the index taxon. In 19/5-1, the first stratigraphic occurrence is recorded in a cuttings sample at 6570'/2003m.

McLean *et al.* (2005) identified taxa in addition to *Tripartites vetustsus* that possess range bases occurring in proximity to the lower limit of the equivalent North Sea V5 Biozone. Based on this range data, the lower limit of the *T. vetustus* Biozone in 19/5-1 is constrained by the occurrence of *Crassispora maculosa* in sidewall core from 6742'/2055m. A deeper occurrence of the taxon at 7190'/2192m is deemed to be caved based on the occurrence of *Potonieisporites delicatus* at 7000'/2134m (see below). The range bases of *Savitrisporites nux, Rotaspora knoxi, Rotaspora fracta* and *Tripartites nonguerickei* also mark the lower limit of the North Sea V5 Biozone. The first stratigraphic occurrences in 19/5-1 are recorded in cuttings samples at 6750'/2057m, 4649'/1417m, 5770'/1759m and 6100'/1859m respectively.

Most taxa identified by McLean *et al.* (2005) with range tops that mark the V5 Biozone lower limit are either absent, reworked or occur very rarely in 19/5-1. The occurrence of *Potonieisporites delicatus* in a single sample at 7000'/2134m, constrains the lower limit of the biozone. The lower part of the *Tripartites vetustus* Biozone in 19/5-1 is characterised by the only occurrence of *Murospora margodentata,* recorded in a sidewall core sample at 6308'/1923m. McLean *et al*. recorded the range top of the taxon in the lowermost V5 Biozone.

Triquitrites marginatus Biozone (Asbian) 6742'/2055m SWC to 7000'/2134m SWC or 7190'/2192m

Clayton (1985) indicated that the first stratigraphic occurrence of *Triquitrites marginatus* defines the lower limit of the NM Biozone in Western Europe (figure 2.1). Based on this range data, the lower limit of the equivalent *T. marginatus* Biozone in 19/5-1 is positioned at least as deep as an occurrence of the index taxon in the 7000'/2134m sidewall core sample. A single deeper occurrence in a cuttings sample at 8410'/2563m is deemed to be caved. It is noted that McLean *et al.* (2005) recorded the range bases of *T. marginatus* just below the lower limit of the equivalent North Sea V4 Biozone (figure 2.5). McLean *et al.* also recorded the range top of *Verrucosisporites congestus* at the biozone lower limit. Unfortunately there is an absence of the taxon in 19/5-1.

A number of additional taxa with range bases that mark the lower limit of the North Sea V4 Biozone are recorded in 19/5-1. The first stratigraphic occurrences of *Remysporites magnificus, Rotaspora* spp. and *Raistrickia nigra* are recorded in cuttings samples at 6500'/1981m, 5770'/1759m and 7190'/2192m respectively. The lower limit of the biozone may be positioned at the 7190'/2192m cuttings sample depth, although the occurrence is potentially caved. The deepest occurrence of the taxa in a sidewall core sample is that of *R. nigra* at 6443'/1964m.

Schulzospora campyloptera Biozone (upper Holkerian to lower Asbian) 7000'/2134m SWC or 7190'/2192m to 7625'/2324m or 8320'/2536m

The *Schulzospora campyloptera* Biozone of Clayton *et al.* (2003) corresponds to the V3 Biozone of the North Sea (McLean *et al.* 2005) (figure 2.5). In 19/5-1, *S. campyloptera* is only recorded in samples as deep as 6443'/1964m. Based on range data from the North Sea (McLean *et al.* 2005), the lower limit of the *S. campyloptera* Biozone is positioned either at the last stratigraphic occurrence of *Schopfites claviger* at 8320'/2536m or at the first stratigraphic occurrence of *Schulzospora* spp. at 7625'/2324m. McLean *et al.* also indicated that the first stratigraphic occurrence of *Perotrilites tessellatus* should characterise the lowermost part of the North Sea V3 Biozone. However, in 19/5-1, the sole occurrence of the taxon is recorded at 6760'/2060m. Overall, there is uncertainty regarding the positioning of the biozone lower limit.

Knoxisporites stephanephorus Biozone (upper Arundian to lower Holkerian) 7625'/2324m or 8320'/2536m to 8410'/2563m

The range base of the index taxon should define the lower limit of the *Knoxisporites stephanephorus* Biozone of Clayton *et al.* (2003). However, in 19/5-1 the first stratigraphic occurrence is recorded at 7190'/2192m; in the upper part of the *Schulzospora campyloptera* Biozone.

There is an additional absence of *Plicatispora scolecophora* and *Punctatisporites irrasus;* taxa with range tops that define the lower limit of the equivalent North Sea V2 Biozone of McLean *et al.* (2005). As a result, the *Knoxisporites stephanephorus* Biozone in 19/5-1 is tentatively deemed to extend to the deepest sample depth at 8410'/2563m. Occurrences of *Lycospora pusilla* at 8410'/2563m confirm the well has not penetrated Courceyan age strata.

VII.V 26/21-1

Palynostratigraphic interpretations are based on palynological data from Gueinn and King (1979) and the present study (figure 6.5). All data is from cuttings samples. Palynomorph recovery from samples was poor and palynomorphs were also highly carbonised.

Triassic (Norian - Rhaetian) 6670'/2033m to 6936'/2114m

Gueinn and King (1979) recorded specimens of *Classopolis/Corrollina* spp. and *Microreticulatisporites fuscus* in a cuttings sample from 6670'/2033m. If *in situ*, occurrences of *Classopollis* spp. and *M. fuscus* indicate an age no older than the Norian Stage of the Upper Triassic, based on range data from Warrington (1984). Warrington also recorded the range top of *M. fuscus* at the upper limit of the Triassic. The possible occurrence of *Porcellispora longdonensis* at 6827'/2081m also confirms an age no younger than Triassic based on range data from Warrington.

Range data from Warrington (1984) also suggests the first stratigraphic occurrence of *Kraeuselisporites reissingeri* in the 6936'/2114m cuttings sample indicates an age no older than the Norian Stage. In addition, occurrences of *Converrucosisporites cameronii* in the interval 6670'/2033m to 6906'/2105m confirm a Norian to Rhaetian age. The interval assigned to the Triassic is also characterised by occurrences of *Corrolina* spp.

Carboniferous 6975'/2126m to 7123'/2171m

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Angulisporites splendidus – Latensina trileta (ST) Biozone (upper Barruelian to Stephanian B) or *Potonieisporites novicus-bharadwaji – Cheleidonites major* (NBM) Biozone (upper Stephanian B to Stephanian C) 6975'/2126m to 7123'/2171m

Samples from the interval 6975'/2126m to 7123'/2171m are characterised by poor palynomorph recovery and preservation. The first downhole evidence for Carboniferous age strata is identified at 6975'/2126m based on the first downhole occurrence of common *Lycospora pusilla* recorded by Gueinn and King (1979). The Carboniferous/Triassic unconformity is positioned at this depth.

A single occurrence of *Angulisporites splendidus*, recorded at 6975'/2126m suggests a biozone no older than the *A. splendidus – Latensina trileta* (ST) Biozone of Clayton *et al.* (1977). The occurrence of common *Lycospora pusilla* and the presence of *A.*

splendidus at 6975'/2126m also confirm a biozone no younger than the *Potonieisporites novicus-bharadwaji – Cheleidonites major* (NBM) Biozone based on range data from Clayton *el al*. Peppers (1985) indicated that *Endosporites globiformis* is not recorded in strata younger than Stephanian in age in Western Europe. The first downhole occurrence of *Endosporites globiformis* at 6975'/2126m therefore indicates a biozone no younger than the NBM Biozone. Range data from Clayton *et al.* also indicates the occurrence of *Crassispora kosankei* at 6975'/2126m further constrains the sample to a biozone no younger than the mid NBM Biozone.

The occurrence of striate bisaccates at 6975'/2126m including *Protohaploxypinus* sp., *Lunatisporites* spp., and *Hamiapollenites* spp. in addition to the absence of *Vestispora fenestrata* is more characteristic of the NBM Biozone than the ST Biozone. However, the rarity of *Potonieisporites* spp. in the interval 6975'/2126m to 7123'/2171m is more characteristic of the ST Biozone, although the infrequency is possibly due to the poor productivity of the samples. Rare acritarchs are also recorded in the interval 6975'/2126m to 7123'/2171m, although it is possible that the specimens are caved from the overlying Triassic strata. Overall, due to the poor productivity of the samples it is difficult to determine if the interval should be assigned to the ST or NBM Biozone.

VII.VI Well 26/26-1

Revised interpretations are based on palynological data from the 26/26-1 Final Well Report (1981) and Whitaker (1981) (figure 6.6).

Cretaceous (Hauterivian) 2428'/740.2m SWC to 2557'/779.5m SWC

The 26/26-1 Final Well Report (1981) records the presence of Hauterivian age dinoflagellates in two sidewall core samples from 2428'/740.2m and 2557'/779.5m. Specimens include *Muderongia simplex, Muderongia tetracantha, Dingodinium albertii, Dingodinium cerviculum, Kleithriasphaeridium fasciatum* and *Phoberocysta neocomica*. The authors also suggested the presence of *Coronifer oceanica and Florentinia mantellii* at 2428'/740.2m confirm a late Hauterivian age.

Carboniferous 2614'/796.8m SWC to 3625-35'/1105-08m

Carboniferous strata is first encountered in the 2614'/796.8m sidewall core sample based on the first downhole occurrence of Carboniferous miospores including *Lycospora* spp. and *Endosporites globiformis*. This confirms the positioning of the Carboniferous/Cretaceous unconformity at 2602'/793m as given in the 26/26-1 Final Well Report (1981). The unconformity is positioned based on microfossil and lithological data.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Microreticulatisporites nobilis – Florinites junior (NJ) Biozone (Duckmantian) 2614'/796.8m SWC to stratigraphic break positioned between 2614'/796.8m and 2685'/818.5m sample depths

The sidewall core sample at 2614'/796.8m is assigned to a biozone no older than the NJ Biozone of Clayton *et al.* (1977) based on the sole occurrence of *Vestispora magna*. Butterworth (1984) indicated the range base of the taxon occurs within the NJ Biozone of north-western Europe. Occurrences of *Dictyotriletes castanaeformis* and *Knoxisporites triradiatus* in the 2614'/796.8m sample confirm an age no younger than the top Duckmantian based on range data from Butterworth (1984). There is an additional absence of *Torispora* spp. and *Vestispora fenestrata*; the range bases of which define the lower limit of the younger *Torispora securis – Torispora laevigata* (SL) Biozone. Index taxa *M. nobilis* and *F. junior* are not recorded in the interval assigned to the biozone, although Whitaker (1981) did record a specimen of *Microreticulatisporites* spp. in the 2614'/796.8m sample.

Stratigraphic break between 2614'/796.8m and 2685'/818.5m SWC

A stratigraphic break is identified between samples 2614'/796.8m and 2685'/818.5m. The break juxtaposes Duckmantian age strata at 2614'/796.8m assigned to the NJ Biozone against Arnsbergian age strata at 2685'/818.5m assigned to the *Lycospora subtriquetra – Kraeuselisporites ornatus* (SO) Biozone (see below). An unconformity is tentatively inferred based on the presence of reworked taxa in the 2614'/796.8m sample including *L. subtriquetra*, *Knoxisporites dissidus*, *Sinuspores sinuatus*, *Biannulatisphaerites simplex, Stenozonotriletes triangulus* and *Knoxisporites seniradiatus*.

Lycospora subtriquetra – Kraeuselisporites ornatus (SO) Biozone (upper Arnsbergian to Alportian) 2685'/818.5m SWC to 2695'/821.5m SWC

Clayton *et al.* (1977) indicate the lower limit of the *Lycospora subtriquetra – Kraeuselisporites ornatus* (SO) Biozone is marked by the range bases of *L. subtriquetra, K. ornatus*, *Apiculatasporites variocorneus* and *Camptotriletes superbus* (figure 2.2). The authors also noted the range base of *Cirratriradites rarus* occurring just above the biozone lower limit. In 26/26-1, the first stratigraphic occurrences of *L. subtriquetra* and *K. ornatus*, recorded in cuttings samples from 3625-35'/1105-08m and 3852'/1174m, are deemed to be caved. The deepest occurrence of the taxa in sidewall core is that of *L. subtriquetra* at 2695'/821.5m, confirming the biozone at this depth. The first stratigraphic occurrences of *A. varioreticulatus* and *C. rarus* are recorded in the 2685'/818.5m and 2614'/796.8m sidewall core samples respectively. *C. superbus* is not recorded in the well.

Clayton *et al.* (1977) also recorded the range tops of *Rotaspora knoxi, Tripartites vetustus, Triquitrites marginatus, Spinozonotriletes uncatus* and *Cingulizonates* cf. *capistratus* at the SO Biozone lower limit. In 26/26-1, the sole occurrence of *T. marginatus* is recorded in the 2690-2723'/820-30m cuttings sample. This suggests the occurrence of *Lycospora subtriquetra* in the 2695'/821.5m sidewall core sample may define the biozone lower limit. The last stratigraphic occurrences of both *R. knoxi* and *S. uncatus* are recorded at 2900'/884m and *T. vetustus* is not recorded in the well. Overall there is moderate confidence in the positioning of the SO Biozone lower limit at 2695'/821.5m.

Stenozonotriletes triangulus – Rotaspora knoxi (TK) Biozone (Arnsbergian) to *Bellispores nitidus – Reticulatisporites carnosus* (NC) Biozone (upper Brigantian to Pendleian) 2695'/821.5m to 2900'/884m

Clayton *et al.* (1977) defined the TK Biozone lower limit based on the range limits of a number of taxa (figure 2.2). However, the only taxon recorded in the 26/26-1 well is *Stenozonotriletes triangulus*. Clayton *et al.* recorded the range base of the taxon at the

TK Biozone lower limit. In 26/26-1, the taxon is restricted to cuttings samples below 2614'/796.8m with the first stratigraphic occurrence recorded at 3487'/1063m.

The lower limit of the NC Biozone of Clayton *et al.* (1977) is tentatively positioned at 2900'/884m, based on the sole occurrence of *Crassispora* (aff.) *aculeata*. Clayton *et al.* (1978) recorded the range top of the taxon at the lower limit of the NC Biozone in the British Isles. Clayton *et al.* (1978) also recorded the range tops of *Dictyotriletes sagenoformis, Cribrosporites cribellatus, Stenozonotriletes coronatus* and *Tripartites distinctus* in addition to the range bases of *Cingulizonates* cf. *capistratus, Bellispores nitidus, Convolutispora varicosa, Reticulatisporites carnosus* and *Schopfipollenites ellipsoides* at the NC Biozone lower limit. In 26/26-1, a sole occurrence of *D. sagenoformis* is recorded at 2685'/818.5m in strata assigned to the SO Biozone. The last stratigraphic occurrences of *S. coronatus* and *R. carnosus/polygonalis* are recorded in the 3320'/1012m and 2690-2723'/820-30m cuttings samples respectively. The first stratigraphic occurrence of *C.* cf. *capistratus* is recorded in the 3487'/1063m cuttings sample and the only occurrence of *S. ellipsoides* is recorded at 2614'/796.8m. The first and only stratigraphic occurrence of *Bellispores* spp. (*B. nitidus*) is recorded at 2900'/884m. The remaining taxa are absent from the well.

Clayton *et al.* (1977) additionally recorded the first stratigraphic occurrences of *Verrucosisporites morulatus, Secarisporites lobatus, Ahrensisporites guerickei* var. *ornatus, Crassispora kosankei, Proprisporites laevigatus* and *Potonieisporites elegans* at the lower limit of the NC Biozone in Western Europe. In 26/26-1, the first stratigraphic occurrence of *Crassispora kosankei* is recorded in the 3556'/1084m cuttings sample with the deepest sidewall core occurrence at 2685'/818.5m. All other species are absent from the well.

In summary, only the lower limit of the NC Biozone can be identified in the 26/26-1 well. The lower limit is tentatively positioned at the last and only stratigraphic occurrence of *Crassispora* (aff.) *aculeata* which coincides with the first and only stratigraphic occurrence of *Bellispores nitidus*. Due to the scarcity of *C. aculeata* in the well, and the occurrences of taxa such as *C.* cf. *capistratus* in deeper cuttings samples, there is low confidence in the positioning of the biozone lower limit.

***Tripartites vetustus – Rotaspora fracta* (VF) Biozone (Brigantian) 2900'/884m to stratigraphic break between samples 3487'/1063m and 3556'/1084m**

The VF Biozone is deemed to extend to a stratigraphic break, which represents a tentative transition to the Courceyan age *Schopfites claviger-Auroraspora macra* (CM) Biozone of Clayton *et al.* (1977). Clayton *et al.* recorded the range bases of *Tripartites vetustus, Rotaspora fracta, Tripartites nonguericki, Triquitrites trivalvis, Rotaspora knoxi, Savitrisporites nux, Crassispora maculosa, Spencerisporites radiatus* and *Grandispora spinosa* at the VF Biozone lower limit (figure 2.2). In 26/26-1, occurrences of *R. knoxi* and *S. nux* are recorded in the interval assigned to the biozone. The first stratigraphic occurrences at 3852'/1174m are associated with Dalradian metasediments and deemed to be caved. The first stratigraphic occurrence of *C. maculosa/kosankei* is recorded at 3405'/1038m and the sole occurrence of *S. radiatus* is recorded at 2900'/884m. Clayton *et al.* also recorded the range tops of *Cribrosporites cribellatus, Perotrilites tessellatus* and *Verrucosisporites baccatus* within the VF Biozone. However, the taxa are absent from the 26/26-1 well. In the British Isles, Clayton *et al.* (1978) additionally recorded the last stratigraphic occurrence of *Potoniespores delicatus* and *Murospora parthenopia* at the lower limit of the VF Biozone. However both taxa are also absent from the 26/26-1 well.

?*Schopfites claviger – Auroraspora macra* (CM) Biozone (Courceyan) 3556'/1084m to 3625-35'/1105-08m

Clayton *et al.* (1977) indicated that the range tops of *Auroraspora macra, Grandispora echinata, Crassispora trychera* and *Dibolisporites distinctus* mark the top of the *Lycospora pusilla* (Pu) Biozone in Western Europe (figure 2.2). The last stratigraphic occurrences in 26/26-1 are recorded at 3625-35'/1105-08m, 3556'/1084m, 3625-35'/1105-08m and 3763'/1147m respectively. The absence of the index taxon *Lycospora pusilla* in the interval 3556'/1084m to 3625-35'/1105-08m suggests a biozone no younger than the Courceyan *Schopfites claviger – Auroraspora macra* (CM) Biozone of Clayton *et al.* However, it is noted that the taxon is absent from most of the Carboniferous succession in 26/26-1. The presence of *Schopfites claviger* in the interval indicates a biozone no older than the CM Biozone based on range data from Clayton *et al.* Overall, the interval 3556'/1084m to 3625-35'/1105-08m is very tentatively assigned to the CM Biozone. The interval is deemed to extend to 3625-35'/1105-08m as deeper samples are associated with Dalradian metasediments.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Microreticulatisporites nobilis Biozone and *Vestispora magna* Sub-biozone (Duckmantian) 2614'/796.8m SWC to stratigraphic break positioned between 2614'/796.8m and 2685'/818.5m sample depths

The sidewall core sample at 2614'/796.8m is assigned to the *Vestispora magna* Sub-biozone and *Microreticulatisporites nobilis* Biozone of Clayton *et al.* (2003) based on the sole occurrence of *V. magna*. Clayton *et al.* indicated the range base of the index taxon defines the lower limit of the *V. magna* Sub-biozone. McLean *et al.* (2005) also recorded the range base of the taxon in proximity to the lower limit of the equivalent North Sea W5a Sub-biozone. The last stratigraphic occurrence of *Raistrickia microhorrida* in the same sample suggests a close proximity to the *V. magna* Sub-biozone lower limit. McLean *et al.* recorded the range top of the taxon in proximity to the W5a Sub-biozone lower limit. Occurrences of *Dictyotriletes castanaeformis* and *Knoxisporites triradiatus* in the 2614'/796.8m sample also confirm an age no younger than the top Duckmantian based on range data from north-western Europe (Butterworth 1984). An occurrence of *Cirratriradites rarus* also confirms an age no younger than the mid Duckmantian based on range data from the North Sea (McLean 1993). Index taxon *M. nobilis* is not recorded in the interval assigned to the biozone, although Whitaker (1981) did record a specimen of *Microreticulatisporites* spp. in the 2614'/796.8m sample.

Stratigraphic break between 2614'/796.8m and 2685'/818.5m SWC

As noted above, a stratigraphic break is identified between samples 2614'/796.8m and 2685'/818.5m juxtaposing Duckmantian age strata assigned to the *Vestispora magna* Sub-biozone against Arnsbergian age strata assigned to the *Lycospora subtriquetra* Biozone and *Apiculatisporis variocorneus* Sub-biozone of Clayton *et al.* (2003). An unconformity is tentatively inferred based on the occurrence of reworked taxa in the 2614'/796.8m sample.

Lycospora subtriquetra Biozone and *Apiculatisporis variocorneus* Sub-biozone (Arnsbergian) 2685'/818.5m SWC to 2695'/821.5m SWC

The 2685'/818.5m sidewall core sample is assigned to the *Lycospora subtriquetra* Biozone and *Apiculatisporis variocorneus* Sub-biozone of Clayton *et al.* (2003) based on occurrences of both index taxa. Owens *et al.* (2004) recorded the range bases of the taxa at the lower limit of the equivalent *Lycospora subtriquetra - Kraeuselisporites ornatus* (SO) Biozone of onshore Great Britain (figure 2.4). Range data from the North Sea (McLean *et al.* 2005) suggests the presence of *Florinites* spp. in the 2685'/818.5m sidewall core sample confirms a biozone no older the *L. subtriquetra* Biozone. Occurrences of *L. subtriquetra* are also recorded in the 2695'/821.5m sidewall core sample, confirming the biozone at this depth. Deeper occurrences are restricted to cuttings samples and may be caved.

The last stratigraphic occurrence of *Cingulizonates* cf. *capistratus*, recorded in the 2685'/818.5m sidewall core sample, tentatively confirms the biozone lower limit at 2695'/821.5m. In the North Sea, McLean *et al.* (2005) recorded the range top of the taxon in proximity to the N3 Biozone lower limit, which corresponds to the base of the *Lycospora subtriquetra* Biozone (figure 2.5). Occurrences at 2685'/818.5m are deemed to be "in proximity" to the lower biozone limit at 2695'/821.5m. However, it is noted that Owens *et al.* (2004) recorded the range top of the taxon at the base of the Arnsbergian Substage, onshore Great Britain (figure 2.4).

Range data from the North Sea also suggests the last stratigraphic occurrence of *Tricidarisporites balteolus* in the 2690-2723'/820-30m cuttings sample indicates close proximity to the lower limit of the *Lycospora subtriquetra* Biozone / *Apiculatisporis variocorneus* Sub-biozone. McLean *et al.* (2005) recorded the range top of the taxon in proximity to the lower limit of the North Sea N3 Biozone. The sole occurrence of *Triquitrites marginatus* in the 26/26-1 well is also recorded in the 2690-2723'/820-30m cuttings sample. Owens *et al.* (2004) recorded the range top of the taxon at the lower limit of the SO Biozone, although McLean *et al.* (2005) recorded the range top of the taxon in the middle of the older North Sea N2 Biozone. Owens *et al.* (2004) also recorded the range base of index taxon *Kraeuselisporites ornatus* at the lower limit of the SO Biozone. In 26/26-1, *K. ornatus* is recorded in the 2690-2723'/820-30m cuttings sample although the taxon is also present in the 2900'/884m, 3015'/919m, 3320'/1012m and 3852'/1174m cuttings samples. The deeper occurrences are assumed to be caved.

Whitaker (1981) noted a questionable occurrence of *Raistricka fulva* in the 2685'/818.5m sidewall core. As the taxon is not recorded in strata older than the mid Kinderscoutian in the North Sea (McLean *et al.* 2005) and north-western Europe (Butterworth 1984), is it likely that the occurrence is misidentified.

Undefined 2748'/837.5m to 2851'/869.0m

Samples between 2748'/837.5m and 2851'/869.0m show very poor productivity. Sidewall cores at 2748'/837.5m and 2851'/869.0m are barren while the 2810'/856.5m sample only contains specimens of the long ranging miospore *Savitrisporites nux*. As a result the interval remains undated.

***Cingulizonates* cf. *capistratus* Biozone / *Bellispores nitidus* Sub-biozone (upper Brigantian) top unknown to 2900'/884m**

Range data from the North Sea (McLean *et al.* 2005) and onshore Great Britain (Owens *et al.* 2004), suggests the sole occurrence of *Crassispora* (aff.) *aculeata* at 2900'/884m indicates a biozone no younger than the *Bellispores nitidus* Sub-biozone of Clayton *et al.* (2003). Range data from the North Sea and onshore Great Britain also suggests the occurrence of *Cingulizonates* cf. *capistratus* and *B. nitidus* in the 2900'/884m cuttings sample confirms a biozone no older then the *B. nitidus* Sub-biozone and the *C.* cf. *capistratus* Biozone. *B. nitidus* is not recorded in deeper samples, and an occurrence of *C.* cf *capistratus* in the 3487'/1063m cuttings sample is deemed to be caved (see below). There is an additional absence of taxa with range tops that define the equivalent biozone lower limits in the North Sea and onshore Great Britain. As a result, the *C.* cf *capistratus* Biozone and *B. nitidus* Sub-biozone can only be confirmed at the 2900'/884m sample depth. The upper limit of the *C. cf. capistratus* Biozone cannot be identified due to the poor productivity of samples between 2690-2723'/820-30m and 2900'/884m.

***Tripartites vetustus* Biozone (Brigantian) 3015'/919m to 3405'/1038m**

The *Tripartites vetustus* Biozone is very tentatively assigned to the interval 3015'/919m to 3320'/1012m based on the absence of *Cingulizonates* cf. *capistratus*, *Bellispores nitidus* and the presence of taxa such as *Savitrisporites nux* and *Crassispora maculosa/kosankei.* McLean *et al.* recorded the range bases of *S. nux* and *C. maculosa* at the lower limit of the equivalent V5 Biozone of the North Sea (figure 2.5). Index taxon *T. vetustus* is not recorded in the 26/26-1 well. The lower limit of the biozone is positioned at the last stratigraphic occurrence of *Triquitrites marginatus* var. *comptus* at 3405'/1038m (see below). As the lower limit of the *T. vetustus* Biozone should be defined by the first stratigraphic occurrence of the index taxon, there is low confidence in its positioning.

***Triquitrites marginatus* Biozone (Asbian) 3405'/1038m to stratigraphic break between samples 3487'/1063m and 3556'/1084m**

McLean *et al.* (2005) recorded the range top of *Triquitrites comptus* in proximity to the upper limit of the North Sea V4 Biozone, which corresponds to the top of the *Triquitrites marginatus* Biozone of Clayton *et al.* (2003) (figure 2.5). In 26/26-1, *T. marginatus* var. *comptus* is recorded at 2685'/818.5m, 3405'/1038m and 3625'/1105m. As the occurrence at 2685'/818.5m is considered reworked, the top of the *T. marginatus* Biozone is tentatively positioned at 3405'/1038m. A solitary specimen of *Murospora margodendata* is also recorded in the 3405'/1038m cuttings sample. Based on range data from the North Sea, the occurrence tentatively confirms a biozone no younger than the lower *Tripartites vetustus* Biozone of Clayton *et al.* (2003) and no older than the upper part of the *T. marginatus* Biozone. Index taxon *T. marginatus* is only recorded at 2723'/830m.

The *Triquitrites marginatus* Biozone extends to a stratigraphic break between samples 3487'/1063m and 3556'/1084m, representing a transition to Courceyan age strata.

?*Schopfites claviger* Biozone (Courceyan); 3556'/1084m to 3625-35'/1105-08m

Cuttings samples from the interval 3556'/1084m to 3625-35'/1105-08m are characterised by an influx of spores with ranges tops that indicate a biozone no younger than the *Knoxisporites stephanephorus* Biozone of Clayton *et al.* (2003). Based on range data from the North Sea (McLean *et al.* 2005), the last stratigraphic occurrences of *Raistrickia clavata*, *Convolutispora circumvallata/cancellata* and *Schopfites claviger* indicate biozone no younger than the *K. stephanephorus* Biozone. The absence of *Lycospora pusilla* in the interval suggests a biozone no younger than the upper Courceyan age *S. claviger* Biozone of Clayton *et al.* (2003). Based on range data from Higgs *et al.* (1988), the presence of *S. claviger* also indicates a biozone no older than the *S. claviger* Biozone of Clayton *et al.* As a result, the interval 3556'/1084m to 3625-35'/1105-08m is tentatively assigned to the *S. claviger* Biozone.

VII.VII Well 26/27-1b

Revised palynostratigraphic interpretations for well 26/27-1b are based on palynological data from King *et al.* (1981) and the present study (figure 6.7).

Jurassic 7702'/2348m

King *et al.* (1981) recorded the long-ranging Jurassic miospores *Eucommiidites troedssonii, Callialasporite*s spp., *Ischyosporites variegatus* and *Cerebropollenites mesozoicus* in the 7677'/2340m and 7702'/2348m sidewall core samples.

Carboniferous 7710'/2350m to 9230'/2813m

The first evidence for Carboniferous strata is recorded at 7710'/2350m based on the first downhole occurrence of common *Lycospora pusilla*. The unconformity between the Carboniferous and Jurassic intervals is positioned between the 7702'/2348m and 7710'/2350m sample depths, slightly shallower than the 7715'/2352m depth given in the 26/27-1b Final Well Report (1981).

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Angulisporites splendidus – Latensina trileta (ST) Biozone (upper Barruelian to Stephanian B) 7710'/2350m to 7760'/2365m SWC

Clayton *et al.* (1977) recorded the range bases of *Angulisporites splendidus* and *Cheleidonites* spp. at the lower limit of the ST Biozone (figure 2.2). In 26/27-1b, the first and only occurrence of *A. splendidus* is recorded in a sidewall core sample at 7760'/2365m, defining the biozone lower limit. *Cheleidonites* spp. is not recorded in the well. As the lower limit is defined by the occurrence of *A. splendidus* in sidewall core, there is confidence in the positioning of the biozone boundary. The occurrence of *Vestispora fenestrata* at 7760'/2365m confirms a biozone no younger than the ST Biozone based on range data from Clayton *et al.* The interval assigned to the biozone is also characterised by occurrences of taxa that typify the ST Biozone of Clayton *et al.*, notably *Latensina trileta, Westphalensisporites irregularis, Crassispora kosankei, Cirratriradites saturni, Florinites junior* and *Spinosporites spinosus.* However, a number of species recorded by Clayton *et al.* are not encountered in the well, notably *Candidispora* spp., *Polymorphisporites* spp. and *Vittatina* spp.

***Thymospora obscura – Thymospora thiessenii* (OT) Biozone (upper Bolsovian to lower Barruelian) 7760'/2365m SWC to 8733.8'/2662m SWC or stratigraphic break positioned between 8733.8'/2662m SWC and 8800'/2682m samples**

Based on range data from Clayton *et al.* (1977) (figure 2.2), the lower limit of the OT Biozone is positioned at least as deep as the first stratigraphic occurrence of *Thymospora* spp. *(T. pseudothiessenii)* in the 8733.8'/2662m sidewall core sample. However, it is possible that the lower limit of the biozone extends to a stratigraphic break positioned between the 8733.8'/2662m sidewall core sample and the 8800'/2682m cuttings sample.

Clayton *et al.* (1977) also recorded the range base of *Spinosporites spinosus* at the OT biozone lower limit in Western Europe. The first stratigraphic occurrence in 26/27-1b is recorded in a sidewall core sample at 8541'/2603m. Butterworth (1984) recorded the range base of *Cadiospora magna* at the lower limit of the OT Biozone in north-western Europe. The first stratigraphic occurrence is recorded in the 8426'/2568m sidewall core sample. Clayton *et al.* (1977) also indicated that the range tops of *Dictyotriletes bireticulatus* and *Cingulizonates loricatus* mark the lower part of the OT Biozone. In 26/27-1b, the last stratigraphic occurrence of *D. bireticulatus* is recorded at 8800'/2682m. *C. loricatus* is recorded well into the OT Biozone; the last stratigraphic occurrence being recorded at 7890'/2405m.

Clayton *et al.* (1977) additionally recorded the first stratigraphic occurrences of *Polymorphisporites* spp., *Savitrisporites camptotus* and *Candidispora* sp. in the lower part of the OT Biozone. In 26/27-1b, only *S. camptotus* is present, and occurrences are restricted to the 8149'/2484m sidewall core sample. Butterworth (1984) also recorded the range base of *Punctatosporites oculus* at the lower limit of the OT Biozone in north-western Europe. In 26/27-1b, the first stratigraphic occurrence is recorded in the lower part of the OT Biozone at 8314'/2534m.

Stratigraphic break positioned between 8733.8'/2662m SWC and 8800'/2682m samples

A stratigraphic break is positioned between samples 8733.8'/2662m and 8800'/2682m. The break marks the juxtaposition of the OT Biozone recorded at 8733.8'/2662m against the Duckmantian age *Microreticulatisporites nobilis* (NJ) Biozone recorded at 8800'/2682m. An unconformity is tentatively inferred due to the occurrence of reworked taxa including *Savitrisporites concavus* and *Knoxisporites triradiatus* in the 8733.8'/2662m sample.

Microreticulatisporites nobilis – Florinites junior (NJ) Biozone (Duckmantian) 8800'/2682m to 9100'/2774m

The first downhole occurrence of Duckmantian age strata is identified in the 8800'/2682m cuttings sample based on the occurrence of *Lycospora noctuina noctuina.* Butterworth (1984) recorded the range top of the taxon in the middle of the NJ Biozone in north-western Europe. The occurrence of *Camptotriletes bucculentus* at 9014m'/2748m also confirms a Duckmantian age based on range data from Butterworth.

Clayton *et al.* (1977) indicated that the lower limit of the NJ Biozone should be defined by the range bases of the index taxa (figure 2.2). In 26/27-1b, *Microreticulatisporites nobilis* and *Florinites junior* are recorded infrequently at this stratigraphic level. The first stratigraphic occurrences of both taxa are recorded at 9220'/2810m and 8800'/2682m respectively. The lower limit of the biozone is very tentatively positioned at the sole occurrence of *Schulzospora rara* at 9100'/2774m. Clayton *et al.* recorded the range top of the taxon at the lower limit of the NJ Biozone (figure 2.2)

Radiizonates aligerens (RA) Biozone (Langsettian) 9100'/2774m to 9230'/2813m

As indicated above, the RA/NJ Biozone boundary is tentatively positioned at 9100'/2774m based on the sole occurrence of *Schulzospora rara*. The index taxon *Radiizonates aligerens* is only recorded as a single reworked occurrence in the ST

Biozone at 7760'/2365m. Clayton *et al.* (1977) also recorded the last stratigraphic occurrence of *Sinuspores sinuatus* at the RA/NJ Biozone boundary in Western Europe (figure 2.2). Only a single occurrence of *Sinuspores* cf. *sinuatus* is recorded at 9159'/2792m. Overall, there is low confidence in the positioning of the RA/NJ Biozone boundary as it is based entirely on the sole occurrence of *S. rara*. Clayton *et al.* (1977) also recorded occurrences of *Bellispores* spp. and *Westphalensisporites irregularis* in the RA Biozone of Western Europe. However, *Bellispores* spp. is not recorded in 26/27-1b and *W. irregularis* is only present in samples shallower than 9100'/2774m.

Clayton *et al.* (2003) Western European Zonal Scheme

***Thymospora pseudothiessenii* Biozone 7710'/2350m to 8733.8'/2662m SWC**

The lower limit of the *Thymospora pseudothiessenii* Biozone of Clayton *et al.* (2003) is positioned at the first stratigraphic occurrence of the index taxon, recorded in the 8733.8'/2662m sidewall core sample. The interval assigned to the biozone is also characterised by the first stratigraphic occurrences of *Spinosporites spinosus* in the 8541'/2603m sidewall core sample and *Cadiospora magna* in the 8426'/2568m sidewall core sample. Butterworth (1984) recorded the range base of *C. magna* at the lower limit of the equivalent OT Biozone in north-western Europe, although McLean *et al.* (2005) has subsequently recorded occurrences of the taxon in the mid and lower Bolsovian of the North Sea.

McLean *et al.* (2005) recorded the range top of *Dictyotriletes bireticulatus* at the base of the equivalent W7 Biozone of the North Sea (figure 2.5) and Clayton *et al.* (1977) recorded the range top in the lower part of the OT Biozone of Western Europe. The last stratigraphic occurrence of the taxon in 26/27-1b is recorded at 8800'/2682m. The last stratigraphic occurrence of *Cingulizonates loricatus* is recorded well into the OT Biozone, at 7890'/2405m. McLean *et al.* recorded the range top of *C. loricatus* in proximity to the lower limit of the North Sea W7 Biozone and Clayton recorded the range top in the lower part of the OT Biozone. Again it is possible that the lower limit of the biozone extends to a stratigraphic break positioned between the 8733.8'/2662m sidewall core sample and the 8800'/2682m cuttings sample.

Angulisporites splendidus Sub-biozone (Cantabrian) 7710'/2350m to 7760'/2365m SWC

The lower limit of the *Angulisporites splendidus* Sub-biozone of Clayton *et al.* (2003) is defined by the first and only stratigraphic occurrence of the index taxon in the 7760'/2365m sidewall core sample. There is confidence in the positioning of the sub-biozone boundary due to its occurrence in a sidewall core sample.

Torispora verrucosa Sub-biozone (Asturian); 7760'/2365m SWC to 8530'/2600m

The *Torispora verrucosa* sub-biozone cannot be defined based solely on occurrences of the index taxon due to its absence in the well. However, a single occurrence of *Savitrisporites camptotus* in the 8149'/2484m sidewall core sample indicates a biozone no older than the Asturian age *T. verrucosa* Sub-biozone based on range data from the North Sea (McLean *et al.* 2005) (figure 2.5). McLean *et al.* also recorded the range base of *Thymospora obscura* at the lower limit of the Asturian and the range base of *Lundbladispora gigantea* in the lowermost Asturian of the North Sea. In 26/27-1b, the first stratigraphic occurrence of *T. obscura* is recorded in the 8530'/2600m cuttings sample, potentially confirming Asturian age strata at this depth. However, the first stratigraphic occurrence of *Lundbladispora gigantea* is recorded at the lower limit of the *Thymospora pseudothiessenii* Biozone at 8733.8'/2662m. It is noted that Clayton *et al.* (1977) recorded the stratigraphic range of *L. gigantea* extending into the Bolsovian age SL Biozone of Western Europe.

Additional taxa with range tops recorded in the Asturian of the North Sea by McLean *et al.* (2005) are also recorded in the 26/27-1b well. The last stratigraphic occurrences of *Alatisporites hoffmeisterii*, *Cristatisporites solaris*, *Triquitrites tribullatus*, *Florinites junior* and *Vestispora pseudoreticulata* are recorded at 8314'/2534m, 7890'/2405m, 7890'/2405m 7760'/2365m and 7760'/2365m. Range data from Butterworth (1984) suggests the last stratigraphic occurrences of *Lophotriletes microsaetosus* at 8541'/2603m and *Vestispora costata* at 8204'/2501m indicate an age no younger than the top Bolsovian.

Overall, based on the range data from McLean *et al.* (2005) and Butterworth (1984), the lower limit of the Asturian age *Torispora verrucosa* Sub-biozone is very tentatively positioned at the first stratigraphic occurrence of *T. obscura* at

8530'/2600m, constrained by the last stratigraphic occurrence of *L. microsaetosus.* However, due to the inherent risk that the occurrence of *T. obscura* at 8530'/2600m is caved, there is low confidence in the positioning of the sub-biozone lower limit at this depth.

Westphalensisporites irregularis Sub-biozone (Upper Bolsovian) 8530'/2600m to 8733.8'/2662m SWC

The remainder of the interval assigned to the *Thymospora pseudothiessenii* Biozone considered older than the *Torispora verrucosa* Sub-biozone is assigned to the *Westphalensisporite irregularis* Sub-biozone.

Stratigraphic break positioned between 8733.8'/2662m SWC and 8800'/2682m

As indicated above, a stratigraphic break is positioned between samples 8733.8'/2662m SWC and 8800'/2682m. The break marks the juxtaposition of the *Thymospora pseudothiessenii* Biozone assigned to the 8733.8'/2662m sidewall core sample against the *Microreticulatisporites nobilis* Biozone and *Lycospora noctuina noctuina* Sub-biozone recorded at 8800'/2682m (see below). An unconformity is tentatively inferred due to the occurrence of reworked taxa in the 8733.8'/2662m sample.

Microreticulatisporites nobilis Biozone and *Lycospora noctuina noctuina* Sub-biozone (Duckmantian) 8800'/2682m to undefined base

The first downhole occurrence of Duckmantian age strata and the *Lycospora noctuina noctuina* Sub-Biozone of Clayton *et al.* (2003) is identified in the 8800'/2682m sample based on the occurrence of the index taxon. A single shallower occurrence above the unconformity at 8541'/2603m is considered reworked. McLean *et al.* (2005) recorded the range top of the taxon just below the upper limit of the Duckmantian age North Sea W4c Sub-biozone (figure 2.5).

Clayton *et al.* (2003) indicate the lower limit of the Duckmantian age *Microreticulatisporites nobilis* Biozone should be defined by the range base of the index taxon (figure 2.7). However, the first stratigraphic occurrence of the taxon in 26/27-1b is recorded in the 9220'/2810m cuttings sample, below the tentative Langsettian/Duckmantian age Substage boundary (see below). In the North Sea, McLean *et al.* recorded a number of taxa with range tops at a stratigraphic level equivalent to the base of the *M. nobilis* Biozone (figure 2.5). The taxa, including *Sinuspores sinuatus* are not recorded in the 26/27-1b well. A single occurrence of *S.* cf. *sinuatus* is recorded at 9159'/2792m and assigned to the Langsettian. As a result, the lower limit of the *M. nobilis* Biozone cannot be positioned in 26/27-1b.

Sinuspores sinuatus Biozone (lower Duckmantian) undefined top to 9100'/2774m

Clayton *et al.* (2003) indicate the range top of *Schulzospora rara* defines the lower limit of the *Sinuspores sinuatus* Biozone and the Langsettian/Duckmantian Substage boundary (figure 2.7). In 26/27-1b, the biozone boundary is very tentatively positioned at the sole occurrence of *S. rara* at 9100'/2774m. Occurrences of the index taxon should characterise the interval assigned to the *S. sinuatus* Biozone. However, in 26/27-1b, only *S.* cf. *sinuatus* is recorded. The taxon occurs in a single sample at 9159'/2792m which is assigned to the Langsettian age *Schulzospora rara* Biozone.

McLean *et al.* (2005) recorded the range top of *Schulzospora rara* at the lower limit of the equivalent North Sea W4a Sub-biozone in addition to the range tops of a number of additional taxa (figure 2.5). Of these taxa, only *Radiizonates striatus* is recorded in 26/27-1b with occurrences recorded throughout the Duckmantian interval. McLean *et al.* also recorded the range bases of a number of taxa at the W4a Sub-biozone lower limit. In 26/27-1b, occurrences of *Radiizonates tenuis* and *R. faunus* are recorded in cuttings samples assigned to the Langsettian age *S. rara* Biozone. The sole occurrence of *Microreticulatisporites harrisonii* is restricted to a sidewall core sample from 8733.8'/2662m.

Schulzospora rara Biozone (Langsettian) 9100'/2774m to 9230'/2813m

As indicated above, the sole occurrence of *Schulzospora rara* at 9100'/2774m very tentatively positions the boundary between the S. *rara* Biozone and the overlying *Sinuspores sinuatus* Biozone in 26/27-1b. Based on range data in Clayton *et al.* (2003), the range top of *Radiizonates aligerens* should define the lower limit of the *S. rara* Biozone (figure 2.7). As *R. aligerens* is only recorded as a single reworked occurrence at 7760'/2365m, it is assumed that the lower limit of the *S. rara* Biozone has not been encountered.

The last stratigraphic occurrence of *Densosporites intermedius* at 9100'/2774m confirms an age no younger than the Langsettian based on range data from Butterworth (1984). The sole occurrence of *Camptotriletes superbus* at 9159'/2792m also indicates an age no younger than the top Langsettian based on North Sea range data from McLean (1993). *Endosporites globiformis* is recorded in samples assigned to the *S. rara* Biozone including the 9159'/2792m sidewall core sample. McLean *et al.* (2005) recorded the range base of the taxon in the upper Langsettian of the North Sea.

Range data from Butterworth (1984) suggests the occurrences of *Lycospora subtriquetra* at 8800'/2682m and 9159'/2792m should indicate an age no younger than the top Langsettian. Occurrences in 26/27-1b suggest the range offshore western Ireland may extend into the lower Duckmantian.

VII.VIII Well 26/28-1

Revised palynostratigraphic interpretations are based on palynological data from Robeson (1988), Duxbury *et al.* (1979) and the present study (figure 6.8).

Jurassic (Bathonian) 8504'/2592m SWC to 8940'/2725m

Robeson (1988) assigned a Bathonian age to cuttings samples from 8711'/2655m to 8940'/2725m based on occurrences of *Quadraeculina annellaeformis*. The interval is also characterised by occurrences of *Calliasporites trilobatus* and *Cerebropollenites mesozoicus*. Duxbury *et al.* (1979) also recorded the Jurassic age ostracods *Kinkelinella* sp. and *Praeschuleridea trigona/subtrigona* at 8924'/2720m.

Carboniferous 8973'/2735m to 10827'/3300m

Based on the first downhole occurrence of a typical late Westphalian/early Stephanian assemblage at 8973'/2735m and the last downhole occurrence of Jurrassic age miospores at 8940'/2725m, the Carboniferous/Jurassic unconformity is positioned at 8973'/2735m. Carboniferous taxa recorded in samples shallower than 8973'/2735m are considered reworked. The 26/28-1 Geological Completion Report (Simpson 1981) positioned the Carboniferous/Jurassic unconformity at 8973.6'/2735.2m based on microfossil data from Duxbury *et al.* (1979) and wireline log evidence.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Angulisporites splendidus – Latensina trileta (ST) Biozone (upper Barruelian to Stephanian B) 8973'/2735m to 9006'/2745m or 9184'/2799.4m

The ST Biozone lower limit is tentatively positioned at least as deep as the first stratigraphic occurrence of the index taxon *Angulisporites splendidus* in a cuttings sample at 9006'/2745m. An occurrence of *Vestispora fenestrata* at 8973'/2735m confirms a biozone no younger than the ST Biozone. However, it is possible that the lower biozone limit is positioned at 9184'/2799.4m based on a questionable occurrence of *Vittatina* sp. recorded by Duxbury *et al.* (1979) in sidewall core. Clayton *et al.* (1977) indicated that the first stratigraphic appearance of *Vittatina* spp. occurs in the ST Biozone of Western Europe (figure 2.2).

Samples assigned to the biozone are characterised by a miospore assemblage that includes *Latensina trileta*, *Spinosporites spinosus, Lundbladispora gigantea, Crassispora kosankei*, *Vestispora fenestrata* and *Cirratriradites saturni*. However, a number of taxa that characterise the ST Biozone of Clayton *et al.* (1977) are absent in the well, notably *Disaccites non-striatiti, Candidispora* spp., *Cheiledonites* spp. *Polymorphisporites* spp. and *Savitrisporites camptotus.* Occurrences of *Florinites junior* and *Westphalensisporites irregularis* should also characterise the biozone, but occurrences are restricted to samples below the biozone lower limit. As the lower limit is defined either on the first stratigraphic occurrence of *Angulisporites splendidus* in a cuttings sample, or using a questionable occurrence of *Vittatina* spp., there is low confidence in the positioning of the lower limit.

Thymospora obscura – Thymospora thiessenii (OT) Biozone (upper Bolsovian to lower Barruelian) 9006'/2745m or 9184'/2799.4m to 9766'/2976.8m SWC or to fault positioned between 10088'/3075m and 10121'/3085m

Clayton *et al.* (1977) indicate the first stratigraphic occurrence of *Thymospora* spp. and *Spinosporites* spp. define the OT Biozone lower limit (figure 2.2). In 26/28-1, *Spinosporites spinosus* is recorded in a single sample at 9006'/2745m, which is assigned to the ST Biozone. The deepest occurrence of *Thymospora* spp. in sidewall core is recorded at 9183'/2799m. *Thymospora pseudothiessenii* is recorded consistently in cuttings samples down to a fault positioned between 10088'/3075m and 10121'/3085m based on vitrinite reflectance data (Robeson 1988). The taxon is also recorded infrequently below the fault, in cuttings samples assigned to the NJ Biozone (see below). Occurrences of *Thymospora* spp. in cuttings samples cannot be reliably used to define the lower limit of the biozone due to the possibility of caving.

Clayton *et al.* (1977) indicated that the range tops of *Cingulizonates loricatus* and *Dictyotriletes bireticulatus* mark the lower part of the OT Biozone in Western Europe (figure 2.2). *D. bireticulatus* is not recorded in the 26/28-1 well. Occurrences of *C. loricatus* are recorded in samples assigned to the upper OT and ST Biozone. The occurrences are either reworked or represent a younger range top in this locality. If reworked, an occurrence at 9564'/2915m may tentatively represent a non-reworked last stratigraphic occurrence. In addition, there is an absence of a number of taxa whose range bases define the lower part of the biozone in Clayton *et al.* i.e. *Polymorphisporites* spp., *Savitrisporites camptotus* and *Candidispora* spp.

The lower limit of the OT Biozone is positioned at least as deep as 9766'/2976.8m based on the occurrence of *Cadiospora magna* in a sidewall core sample. Butterworth (1984) recorded the range base of the taxon at the lower limit of the OT Biozone in north-western Europe.

Overall, in the absence of taxa with range tops that constrain the lower limit of the OT Biozone, it is possible that the OT Biozone extends to the fault. As a result, there is low confidence in the positioning of the lower biozone boundary.

Fault between samples 10088'/3075m and 10121'/3085m

Robeson (1988) identified a fault between 10088'/3075m and 10121'/3085m based on a jump in vitrinite reflectance values from 0.84%Rr at 10088'/3075m to 1.23%Rr at 10121'/3085m.

Microreticulatisporites nobilis – Florinites junior (NJ) Biozone (Duckmantian) 10121'/3085m to 10827'/3300m

The NJ Biozone is recorded directly below the fault. Range data from Butterworth (1984) suggests the last stratigraphic occurrences of *Ahrensisporites guerickei* at

10121’/3085m in addition to *Cristatisporites connexus* and *Reinschospora triangularis* at 10253’/3125m indicate an age no younger than the top Duckmantian, which corresponds to the upper NJ Biozone. The NJ Biozone index taxa are recorded infrequently in the interval assigned to the biozone. *Florinites junior* is recorded at 10253’/3125m and 10827’/3300m and *Microreticulatisporites nobilis* occurs in a single sample at 10827’/3300m. Clayton *et al.* (1977) indicated that the range bases of the index taxa should define the NJ Biozone lower limit (figure 2.2). Occurrences of *F. junior* and *M. nobilis* in the deepest sample depth and an absence of taxa with range tops that define the lower limit of the biozone (e.g. *Schulzospora rara* and *Sinuspores sinuatus*) suggest the base of the NJ Biozone has not been encountered. Samples assigned to the biozone are also characterized by occurrences of *Cirratriradites saturni* and *Savitrisporites nux* although there is an absence of *Dictyotriletes bireticulatus,* which characterises the NJ Biozone in Clayton *et al.*

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Thymospora pseudothiessenii Biozone (upper Bolsovian to Cantabrian)

8973’/2735m to 9596’/2925m or 9766’/2976.8m

The lower limit of the *Thymospora pseudothiessenii* Biozone should be defined by the range base of the index taxon (figure 2.7). The deepest occurrence in sidewall core is recorded at 9183’/2799m, confirming the biozone at this depth. However, the lower biozone limit cannot be positioned at the first stratigraphic occurrence of the index taxon as occurrences in cuttings samples are recorded to a depth of 10663’/3250m, which is dated as Duckmantian in age (see below).

The biozone lower limit is tentatively positioned as shallow as 9596’/2925m based on the last stratigraphic occurrence of *Raistrickia fulva*. McLean *et al.* (2005) recorded the range top of the taxon just below the lower limit of the equivalent W7 Biozone of the North Sea. However, occurrences of *R. fulva* at this stratigraphic level in 26/28-1 are very infrequent. The additional presence of reworked taxa including *Crassispora maculosa* and *Knoxisporites triradiatus* at this depth may infer that occurrences of *R. fulva* are also reworked. McLean *et al.* also recorded the range top of *Cingulizonates loricatus* in proximity to the North Sea W7 Biozone lower limit. However, in 26/28-1, occurrences of the taxon are recorded in strata assigned to the Cantabrian age

Angulisporites splendidus Sub-biozone (see below). It is possible that the lower limit of the biozone extends to at least the 9766'/2976.8m based on the occurrence of *Cadiospora magna* in sidewall core from this depth. Butterworth (1984) indicated that occurrences of *C. magna* are restricted to the equivalent OT Biozone of north-western Europe. However, as McLean *et al.* (2005) subsequently recorded *C. magna* in the middle and lower Bolsovian of the North Sea, there is uncertainty regarding the use of the taxon to constrain the *T. pseudothiessenii* Biozone lower limit. Overall, there is low confidence in the positioning of the biozone lower limit.

Angulisporites splendidus **Sub-biozone (Cantabrian) 8973'/2735m to 9006'/2745m or 9119'/2779.4m SWC**

The lower limit of the *Angulisporites splendidus* Sub-biozone is tentatively positioned at the first stratigraphic occurrence of the index taxon, recorded in a cuttings sample at 9006'/2745m. However, the biozone lower limit could be positioned as deep as 9119'/2779.4m based on the occurrence of questionable *Vittatina* sp. in sidewall core. Clayton *et al.* (1977) recorded the first stratigraphic occurrence of *Vittatina* sp. in the Stephanian age ST Biozone. Overall, there is low confidence in the positioning of the biozone base.

Torispora verrucosa **Sub-biozone (Asturian) 9119'/2779.4m SWC to 9399'/2865m**

The *Torispora verrucosa* Sub-biozone cannot be identified based on the first stratigraphic occurrence of the index taxon due to its absence in the well. Alternatively it is possible to tentatively position the lower limit of the Asturian Substage at 9399'/2865m based on the occurrences of *Thymospora obscura* and the last stratigraphic occurrences of *Lophotriletes microsaetosus* and *Calamospora* cf. *breviradiata.* McLean *et al.* (2005) recorded the range base of *T. obscura* at the lower limit of the Asturian Substage in the North Sea (figure 2.5). In 26/28-1, *T. obscura* is recorded in cuttings samples at 9170'/2795m and 9399'/2865m with two caved occurrences in cuttings samples at 10121'/3085m and 10663'/3250m, assigned to the Duckmantian Substage (see below). The last stratigraphic occurrences of *L. microsaetosus* and *C.* cf. *breviradiata* tentatively confirm the base Asturian at 9399'/2865m. Butterworth (1984) recorded the range tops of the taxa at the Bolsovian/Asturian Substage boundary in north-western Europe. The last stratigraphic occurrence of *Acanthotriletes echinatus* at 9564'/2915m also indicates an age no younger than the top Bolsovian based on range data from Butterworth (1984)

A number of taxa with range tops recorded in the lower Asturian of the North Sea (McLean *et al.* 2005) help to constrain the base of the Asturian Substage (figure 2.5). The last stratigraphic occurrences of *Florinites junior, Westphalensisporites irregularis* and *Vestispora pseudoreticulata* are recorded at 9285'/2830m, 9170'/2795m and 9285'/2830m respectively. However it is noted that the last stratigraphic occurrences of *Endosporites zonalis*, *Triquitrites tribullatus, Vestispora laevigata* and *Alatisporites hoffmeisterii* are recorded in samples assigned to the *Angulisporites splendidus* Sub-biozone. McLean *et al.* recorded the range tops of the taxa in the Asturian of the North Sea. It is noted that Butterworth (1984) also recorded the range tops of *Granulatisporites granulatus* and *Apiculatasporites spinosaetosus* in the mid Bolsovian of north-western Europe. The last stratigraphic occurrences of the taxa occur at 9399'/2865m and 9564'/2915m respectively in 26/28-1.

***Westphalensisporites irregularis* Sub-biozone (upper Bolsovian) 9399'/2865m to 9596'/2925m or 9766'/2976.8m**

The lower limit of the *Westphalensisporites irregularis* Sub-biozone coincides with the lower limit of the *Thymospora pseudothiessenii* Biozone (figure 2.7). Samples assigned to the sub-biozone in 26/28-1 are characterised by occurrences of the index taxon.

***Vestispora fenestrata* Biozone (Bolsovian) 9596'/2925m or 9766'/2976.8m to fault positioned between 10088'/3075 and 10121'/3085m.**

The interval assigned to the Bolsovian age *Vestispora fenestrata* Biozone is characterised by occurrences of the index taxon which occur in samples that extend to the fault positioned between 10088'/3075m and 10121'/3085m. Clayton *et al.* (2003) indicated that the range base of the index taxon should define the lower limit of the biozone. In 26/28-1, occurrences are also recorded in Duckmantian age cuttings samples below the fault, which are assumed to be caved.

Raistrickia aculeata Sub-biozone (Bolsovian)

The *Raistrickia aculeata* Sub-biozone is deemed to extend to the fault positioned between 10088'/3075m and 10121'/3085m. Rare occurrences of the index taxon define the sub-biozone. Occurrences are recorded in cuttings samples from 10006'/3050m and 10105'/3080m with an additional occurrence just below the fault at 10121'/3085m.

McLean *et al.* (2005) indicated that the lower limit of the equivalent North Sea W6b Sub-biozone is also marked by the range bases of a number of taxa in addition to *Raistrickia aculeata* (figure 2.5). In 26/28-1, only *Latensina trileta* is recorded. The first stratigraphic occurrence is recorded at 9285'/2830m and assigned to the Asturian age *Torispora verrucosa* Sub-biozone. Taxa identified by McLean *et al.* with range tops that define the sub-biozone lower limit are not particularly useful either. *Savitrisporites nux* is recorded in samples assigned to the upper *Vestispora fenestrata* Biozone and *Thymospora pseudothiessenii* Biozone. *Reticulatisporites polygonalis* occurs infrequently in samples assigned to the *T. verrucosa* Sub-biozone and uppermost *V. fenestrata* Biozone.

Microreticulatisporites nobilis Biozone (Duckmantian) 10121'/3085m or 10253'/3125m to 10827'/3300m

McLean *et al.* (2005) recorded the range top of *Ahrensisporites guerickei* in proximity to the Bolsovian/Duckmantian Substage boundary in the North Sea (figure 2.5). The last stratigraphic occurrence of the taxon in 26/28-1 is recorded directly below the fault at 10121'/3085m. McLean *et al.* also recorded the range top of *Cristatisporites connexus* at the substage boundary. In 26/28-1, the last stratigraphic occurrence of *C. connexus* is recorded at 10253'/3125m. Other taxa with range tops that define the Bolsovian/Duckmantian Substage boundary in the North Sea are not recorded in the well. Either the Duckmantian age *Microreticulatisporites nobilis* Biozone of Clayton *et al.* (2003) is assigned to samples immediately below the fault, or the boundary between the *M. nobilis* Biozone and the Bolsovian age *Triquitrites sculptilis* Biozone is positioned at 10253'/3125m. It is likely that the *M. nobilis* Biozone extends to the deepest sample depth at 10827'/3300m based on an absence of taxa with range tops that define the biozone lower limit (i.e. *Sinuspores sinuatus*) or the older Langsettian/Duckmantian Substage boundary (e.g. *Schulzospora rara*). Clayton *et al.*

(2003) indicated that the range base of the index taxon should define the base of the *M. nobilis* Biozone (figure 2.7). In 26/28-1, the index taxon is only recorded in one sample (10827'/3300m) in the interval assigned to the biozone.

The last stratigraphic occurrences of number of taxa with range tops at the Bolsovian/Duckmantian Substage boundary in north-western Europe (Butterworth 1984) are recorded at a range of depths in 26/28-1. The last stratigraphic occurrences of *Mooreisporites fustis* and *Dictyotriletes castaneaeformis* are recorded at 10138'/3090m and 10581'/3225m respectively. The last stratigraphic occurrences of *Secarisporites remotus* and *Simonozonotriletes intortus* are both recorded at 10663'/3250m and the sole occurrence of *Reinschospora triangularis* is recorded at 10253'/3125m. In addition, the last stratigraphic occurrence *Radiizonates* cf. *difformis* at 10761'/3280m indicates an age no younger than the mid Duckmantian, based on range data in Butterworth (1984). Overall, there is some uncertainty in the positioning of the top Duckmantian in 26/28-1.

Vestispora magna **Sub-biozone 10121'/3085m or 10253'/3125m to 10827'/3300m**

The *Vestispora magna* Sub-biozone of Clayton *et al.* (2003) cannot be defined based on occurrences of the index taxon due to its absence in the 26/28-1 well. Most taxa with range tops that define the lower limit of the equivalent W5a Sub-biozone of the North Sea are also absent from the well. *Savitrisporites camptotus* is recorded in the well, but occurs in a single sample at 8809'/2685m, assigned to the Jurassic. The range bases of *Triquitrites sculptilis* and *Punctatosporites granifer* also mark the lower limit of the W5a Sub-biozone (figure 2.5). In 26/28-1, the taxa are recorded in cuttings samples assigned to the Duckmantian with the first stratigraphic occurrences of *T. sculptilis* and *P. granifer* recorded in the deepest sample depth (10827'/3300m) and at 10761'/3280m respectively. This tentatively suggests that the lower limit of the sub-biozone has not been encountered. An absence of *Lycospora noctuina noctuina* also indicates that the older *L. noctuina noctuina* Sub-biozone of Clayton *et al.* (2003) (figure 2.7) is not present in the well.

VII.IX Well 26/28-2

Revised palynostratigraphic interpretations are based on palynological data from Paley and Athersuch (1980), Robeson (1988) and the present study (figure 6.9).

Jurassic 7021'/2140m to 7349'/2240m

Robeson (1988) assigned a Jurassic age to cuttings samples from 7021'/2140m to 7349'/2240m based on occurrences of *Quadraeculina annellaeformis*, *Cerebropollenites mesozoicus* and *Callialasporites trilobatus.* Paley and Athersuch (1980) also assigned a Bathonian age to a sample from 7234'/2205m based on ostracod data. The last downhole occurrence of Jurassic palynomorphs is recorded at 7349'/2240m.

Carboniferous 7447'/2270m to 8825'/2690m

At 7447'/2270m the first downhole occurrence of a typical lower Stephanian age assemblage is recorded, characterised by the first downhole occurrences of *Angulisporites splendidus, Latensina trileta, Endosporites globiformis* and *Vestispora fenestrata*. The boundary with the overlying Jurassic is therefore positioned between the 7349'/2240m and 7447'/2270m cuttings samples. This confirms the positioning of the Carboniferous/Jurassic unconformity at 7431'/2265m, as given in the 26/28-2 Geological Completion Report (Rainey 1980). Rainey positioned the unconformity using the palynological data of Paley and Athersuch (1980) in addition to lithological data. Carboniferous taxa recorded above 7447'/2270m are considered reworked.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Angulisporites splendidus – Latensina trileta (ST) Biozone (upper Barruelian to Stephanian B) 7447'/2270m to 7464'/2275m

Based on range data from Clayton *et al.* (1977), the lower limit of the ST Biozone in 26/28-2 is tentatively positioned at the first stratigraphic occurrence of *Angulisporites splendidus* in a cuttings sample at 7464'/2275m. The interval assigned to the biozone is also characterised by occurrences of *Latensina trileta, Disaccites non-striatiti,* *Polymorphisporites* spp., *Lundbladispora gigantea, Cirratriradites saturni, Vestispora fenestrata* and *Spinosporites spinosus*. Occurrences of *V. fenestrata* and *C. saturni* at 7447'/2270m confirm a biozone no younger than the ST Biozone. However, a number of taxa which characterise the ST Biozone in Clayton *et al.* (1977) are absent, notably *Candidispora* spp., *Vittatina* spp., *Savitrisporites camptotus* and *Cheleidonites* spp. As the biozone lower limit is positioned on the first stratigraphic occurrence of *A. splendidus* in a cuttings sample and not constrained by the last stratigraphic occurrence of a taxon, there is only moderate confidence in its positioning due to the possibility of caving.

Thymospora obscura – Thymospora thiessenii (OT) Biozone (upper Bolsovian to lower Barruelian) 7464'/2275m to 7877'/2401m SWC or 8120'/2475m

Clayton *et al.* (1977) indicate the first stratigraphic occurrences of *Thymospora* spp. and *Spinosporites* spp. define the OT Biozone lower limit in Western Europe (figure 2.2). In 26/28-2, *Spinosporites* spp. is recorded in a single sample at 7464'/2275m, which is assigned to the ST Biozone. The first stratigraphic occurrence of *Thymospora* spp. is recorded in a cuttings sample at 8760'/2670m, assigned to the SL Biozone (see below). The OT Biozone lower limit is positioned at least as deep as the occurrence of *Thymospora obscura* in the 7877'/2401m sidewall core.

Clayton *et al.* (1977) also recorded the range tops of *Cingulizonates loricatus* and *Dictyotriletes bireticulatus* in the lower part of the OT Biozone. In 26/28-2, *C. loricatus* is recorded in samples as shallow as 7628'/2325m. *D. bireticulatus* is recorded in a single cuttings sample at 8120'/2475m. Hence, it may be possible to roughly position the biozone lower limit at 8120'/2475m. The interval 7464'/2275m to 8120'/2475m is also characterised by occurrences of *Thymospora obscura, Thymospora pseudothiessenii, Microreticulatisporites nobilis, Florinites junior, Westphalensisporites irregularis* and *Vestispora fenestrata.* However, a number of taxa that Clayton *et al.* (1977) identified in the OT Biozone are absent, notably *Savitrisporites camptotus* and *Candidispora* spp. The top of the epiboles of *Reticulatisporites reticulatus* and *Vestispora costata – cancellata* should occur at the biozone lower limit, but the last stratigraphic occurrences of the taxa are recorded at 8530'/2600m and 8218'/2505m respectively.

Torispora securis – Torispora laevigata (SL) Biozone (Bolsovian) 7877'/2401m SWC or 8120'/2475m to 8825'/2690m

Clayton *et al.* (1977) recorded the range bases of *Torispora* spp. and *Vestispora fenestrata* at the lower limit of the SL Biozone (figure 2.2). In 26/28-2, both taxa are recorded in the deepest cuttings sample at 8825'/2690m and occurrences also characterise the interval assigned to the SL Biozone. Although the 9 5/8" casing shoe was positioned at 8707'/2654m, it is still possible that occurrences recorded below the casing shoe are caved. Gearhart Geodata Services Ltd. (1980) indicate the well was drilled to 8848'/2697m before the 9 5/8" casing was run. Hence, cuttings samples collected from depths below the casing shoe could still be contaminated with cavings from the borehole above the shoe.

Clayton *et al.* (1977) recorded the range tops of *Grumosisporites maculatus, Raistrickia fulva* and *Grumosisporites varioreticulatus* at the SL Biozone lower limit. In 26/28-2, an absence of *G. maculatus, R. fulva* and a single reworked occurrence of *G. varioreticulatus* in a sample assigned to the *A. splendidus* Biozone tentatively suggests the SL Biozone lower limit has not been encountered. *Punctatisporites granifer* is also recorded at the deepest sample depth. Clayton *et al.* indicate the range base of the taxon occurs just above the SL Biozone lower limit. Clayton *et al.* also recorded the range top of *Savitrisporites nux* just above the lower biozone limit. However in 26/28-2, the taxon is recorded in samples assigned to the *A. splendidus* and *T. pseudothiessenii* Biozones. The first stratigraphic occurrence of *Disaccites striatiti* is also recorded at 8727'/2660m. Clayton *et al.* indicate the range base of the taxon occurs in the SL Biozone of Western Europe.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Thymospora pseudothiessenii Biozone (upper Bolsovian to Cantabrian) 7447'/2270m to 8035'/2449m

In 26/28-2, the lower limit of the *Thymospora pseudothiessenii* Biozone is difficult to position based solely on the first stratigraphic occurrence of the index taxon. The first stratigraphic occurrence is recorded in a sample from 8760'/2670m, which is assigned to the *Vestispora fenestrata* Biozone (see below). All occurrences of the taxon are restricted to cuttings samples.

Alternatively, the biozone lower limit can be tentatively constrained by rare occurrences of *Dictyotriletes bireticulatus* and *Radiizonates faunus*. *D. bireticulatus* is only recorded at 8120'/2475m. In addition to defining the lower part of the OT Biozone of Clayton *et al.* (1977), the range top of the taxon defines the lower limit of the equivalent W7 Biozone of the North Sea (McLean *et al.* 2005) (figure 2.5). McLean *et al.* recorded the range top of *R. faunus* just below the base of the North Sea W7 Biozone. In 26/28-2, the sole occurrence of the taxon is recorded at 8035'/2449m, very tentatively constraining the lower limit of the *Thymospora pseudothiessenii* Biozone. McLean *et al.* also recorded the range top of *Cingulizonates loricatus* in proximity to the base of the W7 Biozone. However, occurrences in 26/28-2 are recorded in samples assigned to the Asturian and Cantabrian Substages. Overall, there is low confidence in the positioning of the sub-biozone lower limit based on the sole occurrence of *R. faunus*.

***Angulisporites splendidus* Sub-Biozone (Cantabrian) 7447'/2270m to 7464'/2275m**

In 26/28-2, the *Angulisporites splendidus* Sub-biozone is identified based on occurrences of the index taxon in cuttings samples at 7447'/2270m and 7464'/2275m. The lower limit is positioned at the first stratigraphic occurrence of the taxon. It is noted that a number of taxa that possess range tops in the Asturian of the North Sea (McLean *et al.* 2005) are also recorded in the interval assigned to the *A. splendidus* Sub-biozone. *Endosporites zonalis, Triquitrites tribullatus* and *Vestispora magna* are recorded at 7447'/2270m. *Schopfites dimorphus* is recorded at 7464'/2275m. As the sub-biozone lower limit in 26/28-2 is positioned solely on the first stratigraphic occurrence of the index taxon in a cuttings sample, there is only moderate confidence in its positioning due to the possibility of caving.

***Torispora verrucosa* Sub-biozone (Asturian) 7464'/2275m to 7877'/2401m or 7956'/2425m**

In 26/28-2, the *Torispora verrucosa* Sub-biozone cannot be identified based on the first stratigraphic occurrence of the index taxon due to its absence in the well. Alternatively, using range data from the North Sea (McLean *et al.* 2005) (figure 2.5), the base of the Asturian is positioned at least as deep as the occurrence of *Thymospora obscura* in the 7877'/2401m sidewall core sample. The lower limit may be positioned as deep as the first stratigraphic occurrence, recorded in a cuttings sample at 7956'/2425m. However, there is an inherent risk that the occurrence is caved.

A number of taxa that possess range tops in the Asturian of the North Sea (McLean *et al.* 2005) are also recorded in the interval assigned to the *Torispora verrucosa* Sub-biozone in 26/28-2. The last stratigraphic occurrences of *Westphalensisporites irregularis*, *Florinites junior* and *Alatisporites hoffmeisterii* are recorded at 7546'/2300m, 7628'/2325m and 7792'/2375m respectively. However, as indicated above, the last stratigraphic occurrences of *Vestispora magna*, *Triquitrites tribullatus* and *Endosporites zonalis* are recorded in the *Angulisporites splendidus* Sub-biozone at 7447'/2270m. In addition, the last stratigraphic occurrences of *Vestispora pseudoreticulata* and *Cristatisporites solaris* are recorded at 8218'/2505m and 8448'/2575m respectively, below the first stratigraphic occurrence of *T. obscura.*

A number of taxa recorded by Butterworth (1984) that possess range tops at the top of the Bolsovian Substage in north-western Europe are also recorded in 26/28-2. The last stratigraphic occurrences of *Granulatisporites microgranifer* and *Raistrickia* cf. *superba* are recorded in proximity to the first stratigraphic occurrence of *T. obscura* at 7956'/2425m and 7792'/2375m respectively. The last stratigraphic occurrence of *Lophotriletes microsaetosus* is possibly reworked at 7464'/2275m, but the next deepest occurrence is recorded at 8120'2475m. An occurrence of *Calamospora* cf. *breviradiata* is recorded at 7447'/2270m but the next deepest occurrence is at 7956'/2425m.

Westphalensisporites irregularis Sub-biozone (upper Bolsovian) 7877'/2401m or 7956'/2425m to 8035m/2449m

The lower limit of the *Westphalensisporites irregularis* Sub-biozone corresponds to the lower limit of the *Thymospora pseudothiessenii* Biozone. Occurrences of *W. irregularis* are recorded in the interval assigned to the sub-biozone.

Vestispora fenestrata Biozone (Bolsovian) 8035m/2449m to 8825'/2690m

The lower limit of the *Vestispora fenestrata* Biozone should be defined by the range base of the index taxon (figure 2.7). In 26/28-2, the taxon is only recorded in cuttings samples and occurs fairly consistently throughout the well including the deepest sample depth of 8825'/2690m. However, it is difficult to determine if occurrences are *in-situ* or caved.

It is unlikely that the lower limit of the biozone has been penetrated by the well. McLean *et al.* (2005) recorded the range tops of *Grumosisporites varioreticulatus* and *Grumosisporites papillosus* at the lower limit of the equivalent North Sea W6 Biozone. In 26/28-2, *G. papillosus* is absent and *G. varioreticulatus* is only recorded in a sample assigned to the *Angulisporites splendidus* Sub-biozone. As noted above, Clayton *et al.* (1977) also recorded the range tops of *Grumosisporites maculatus, Raistrickia fulva* and *G. varioreticulatus* at the lower limit of the equivalent SL Biozone. Both *G. maculatus* and *R. fulva* are absent from the 26/28-2 well.

Sole occurrences of *Lophotriletes* cf. *gibbosus* and *Dictyotriletes castaneformis* are recorded at 8530'/2600m and 8596'/2620m respectively. Butterworth (1984) recorded the range tops of the taxa at the Duckmantian/Bolsovian Substage boundary in north-western Europe. However, it is unlikely that the Duckmantian has been penetrated in 26/28-2 based on an absence of key taxa with range tops that define the Duckmantian/Bolsovian Substage boundary in the North Sea, notably *Cristatisporites connexus*. *Ahrensisporites guerickei* is recorded in the well but is restricted to samples assigned to the *Westphalensisporites irregularis* Sub-biozone and the uppermost *Vestispora fenestrata* Biozone. *Cristatisporites indignabundus* is recorded at 8661'/2640m and 8793'/2680m but is known to extend into the lower Bolsovian of the North Sea. In addition, a number of reworked taxa are encountered at this stratigraphic level including an occurrence of *Radiizonates aligerens* at 8661'/2640m, *Triquitrites* cf. *protentus* at 8202'/2500m, and *Convolutispora florida* at 8793'/2680m. All have range tops in the Langsettian of Western Europe (Butterworth 1984, McLean *et al.* 2005). Hence, it is most likely that Duckmantain age strata has not been penetrated and occurrences of *Lophotriletes* cf. *gibbosus* and *Dictyotriletes castaneaformis* are either reworked or the range tops of the taxa extend into the lower Bolsovian in this locality.

Raistrikia aculeata **Sub-biozone 8035'/2449m to 8596'/2620m**

The *Raistrickia aculeata* Sub-biozone in 26/28-2 cannot be identified based on occurrences of the index taxon as it is only recorded in samples assigned to the

Torispora verrucosa and *Angulisporites splendidus* Sub-biozones. McLean *et al.* (2005) recorded the range bases of a number of additional taxa in proximity to the lower limit of the equivalent North Sea W6b Sub-biozone (figure 2.5). However, only *Latensina trileta* is present in the 26/28-2 well and occurrences are restricted to the upper *Thymospora pseudothiessenii* Biozone. A few taxa are recorded that possess range tops at the lower limit of the North Sea W6b Biozone. The last stratigraphic occurrence of *Vestispora tortuosa* is recorded in a coal sample at 8596'/2620m. *Apiculatasporites spinososaetosus, Alatisporites pustulatus, Reticulatisporites polygonalis, Reticulitriletes reticulocingulum* and *Reticulitriletes mediareticulatus* are absent from the well. *Savitrisporites nux* is recorded in the well, but occurs consistently in samples assigned to the *T. verrucosa* and *Westphalensisporites irregularis* Sub-biozones. As a result, the lower limit of the sub-biozone is tentatively positioned at the last stratigraphic occurrence of *V. tortuosa* at 8596'/2620m.

Torispora securis **Sub-biozone 8596'/2620m to 8825'/2690m**

The *Torispora securis* Sub-biozone extends to the deepest sample depth in 26/28-2. The interval assigned to the sub-biozone is characterised by occurrences of the index taxon.

VII.X Well 26/28-3

Revised palynostratigraphic interpretations are based on palynological data from Athersuch *et al.* (1981), Robeson (1988) and the present study (figure 6.10).

Jurassic (Bathonian) 7349'/2240m to 7856'/2395m

Based on the occurrence of *Lithodinia jurassica,* Athersuch *et al.* (1981) assigned a Middle to Upper Jurassic, late Bajocian to early Oxfordian age to a sidewall core sample at 7792'/2375m. Athersuch *et al.* also recorded the ostracods *Bisulcocypris tenuimarginata* and *Progonocythere* cf. *triquetra* in a cuttings sample at 7349'/2240m, suggesting a Bathonian age for the interval 7349'/2240m to 7792'/2375m. Robeson (1988) dated a cuttings sample at 7841'/2390m as no younger than Bathonian in age based on the occurrence of *Quadraeculina annellaeformis.* The occurrence of *Cerebropollenites mesozoicus* in a cuttings sample at 7856'/2395m also potentially assigns a Jurassic age to this depth. However, occurrences of the Carboniferous age miospores *Lycospora pusilla* and *Cingulizonates loricatus* in cuttings samples from 7808'/2380m and 7858'/2395m results in some uncertainty regarding the age of the sample depths.

Carboniferous 7874'/2400m to 8464'/2580m

As indicated above, there is some uncertainty concerning the age of the interval 7808'/2380m to 7858'/2395m. However, Carboniferous strata can be tentatively identified from 7874'/2400m based on the disappearance downhole of Jurassic age taxa. Occurrences of Carboniferous miospores above this depth are considered reworked. This confirms the positioning of the Carboniferous/Jurassic unconformity at 7861m/2396m given in the 26/28-3 Geological Completion Report (Gidman 1981). The depth was based on microfossil data from Athersuch *et al.* (1981) and dipmeter data.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Thymospora obscura – Thymospora thiessenii (OT) Biozone (upper Bolsovian to lower Barruelian) 7874'/2400m to 8333'/2540m

The OT Biozone is assigned to strata directly below the Carboniferous/Jurassic unconformity. The biozone extends to at least 8235'/2510m based on the occurrence of *Thymospora pseudothiessenii* in sidewall core from this depth. An absence of taxa with range bases that define the younger *Angulisporites splendidus – Latensina trileta* ST Biozone of Clayton *et al.* (1977), i.e. *A. splendidus* and *Cheiledonites* spp. indicates the OT Biozone is the youngest to be recorded in the well. *T. pseudothiessenii* is recorded in cuttings samples to a depth of 8415'/2565m, potentially extending the biozone lower limit to this depth, although occurrences may be caved. Butterworth (1984) also recorded the range bases of *Mooreisporites* cf. *inusitatus* and *Cadiospora magna* at the lower limit of the OT Biozone in north-western Europe. In 26/28-3, the deepest occurrences of *M.* cf. *inusitatus* and *C. magna* are recorded in the 8448'/2575m cuttings sample.

Clayton *et al*. (1977) recorded the range base of *Spinosporite*s spp. at the OT Biozone lower limit (figure 2.2). The authors also recorded the range bases of *Polymorphisporites* spp., *Savitrisporites camptotus,* and *Candidispora* spp. in addition to the range tops of *Dictyotriletes bireticulatus,* and *Cingulizonates loricatus* in the lower part of the biozone. The only taxon recorded in 26/28-3 is *C. loricatus*, which occurs consistently throughout the interval assigned to the OT Biozone. Butterworth (1984) recorded the range tops of *Radiizonates tenuis* and *Verrucosisporites microverrucosus* in the mid Bolsovian, corresponding to the SL Biozone of Clayton *et al*. Occurrences at 8333'/2540m and 8366'/2550m tentatively constrain the OT Biozone lower limit.

Torispora securis – Torispora laevigata (SL) Biozone 8333'/2540m to 8464'/2580m

The interval assigned to the SL Biozone is characterised by occurrences of index taxon *Torispora securis* in addition to *Vestispora fenestrata.* Clayton *et al.* (1977) indicated that the range bases of the taxa should define the biozone lower limit (figure 2.2). The first stratigraphic occurrences of the taxa in 26/28-3 are recorded at 8432'/2570m, just above the deepest sample depth. An absence of taxa with range tops that define the lower biozone limit in Clayton *et al.* i.e. *Grumosisporites varioreticulatus, Grumosisporites maculosa* and *Raistrickia fulva* suggest the lower limit is not encountered in the well. The interval assigned to the biozone in 26/28-3 is also characterised by occurrences of *Punctatosporites granifer* and *Savitrisporites nux.*

Clayton *et al.* (2003) Western European Zonal Scheme

Thymospora pseudothiessenii Biozone 7874'/2400m to 8333'/2540m

The *Thymospora pseudothiessenii* Biozone of Clayton *et al.* (2003) extends from the Jurassic/Carboniferous unconformity to at least 8235'/2510m based on an occurrence of the index taxon in a sidewall core sample from this depth.

McLean *et al.* (2005) recorded the range top of *Dictyotriletes bireticulatus* at the lower limit of the equivalent W7 Biozone of the North Sea, with the range top of *Cingulizonates loricatus* occurring in proximity to the lower limit (figure 2.5). In 26/28-3, *D. bireticulatus* is not recorded and *C. loricatus* is recorded consistently throughout the interval assigned to the *Thymospora pseudothiessenii* Biozone. The occurrences of *Verrucosisporites microverrucosus* at 8333'/2540m, *Radiizonates tenuis* at 8366'/2550m and *Reticulitriletes reticulocingulum* at 8399'/2560m constrain the lower limit of the *T. pseudothiessenii* Biozone based on range data from the North Sea (McLean *et al.* 2005). McLean *et al.* recorded the range tops of the taxa just below the lower limit of the W7 Biozone, which corresponds to the lower limit of the *T. pseudothiessenii* Biozone. Based on this data, the boundary between the *T. pseudothiessenii* Biozone and the *Vestispora fenestrata* Biozone of Clayton *et al.* (2003) is tentatively positioned at 8333'/2540m. Occurrences of *T. pseudothiessenii* in cuttings samples at 8399'/2560m and 8415'/2565m are assumed to be caved.

Angulisporites splendidus Sub-biozone? (Cantabrian)

Athersuch *et al.* (1981) tentatively assigned a Stephanian age to a sidewall core sample from 7877'/2401m based on the occurrence of *Punctatisporites* sp. 2 *sensu* Peppers (1964) and *Falcisporites* sp. aff. *F. mittalensis.* Neither species are recorded in the Carboniferous miospore zonation of the North Sea (McLean *et al.* 2005) or Western Europe (Clayton *et al.* 1977). The assemblage is also unlike any other Stephanian age assemblage recorded offshore western Ireland. Occurrences of *Angulisporites splendidus* or *Cheleidonites* spp. typically define Cantabrian age strata offshore western Ireland. Neither species are recorded in 26/28-3. Overall, it is considered unlikely that Stephanian age strata are present in the well section.

Torispora verrucosa Sub-biozone (Asturian); 7874'/2400m to 8235'/2510m

The *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003) cannot be identified in 26/28-3 based on the first stratigraphic occurrence of the index taxon due to its absence in the well. Based on range data from the North Sea (McLean *et al.* 2005) (figure 2.5), the sole occurrences of *Lundbladispora ?gigantea* in a cuttings sample from 8186'/2495m and *Cirratriradites annulatus* in a sidewall core sample from 8235'/2510m date the samples as no older than lower Asturian in age. The sole occurrence of *Thymospora obscura*, recorded in a cuttings sample at 8382'/2555m, also indicates an Asturian age based on range data from McLean *et al.* However, the occurrences of *Verrucosisporites microverrucosus* at 8333'/2540m and *Radiizonates tenuis* at 8366'/2550m suggest the occurrence of *T. obscura* is caved. As a result, the lower limit of the Asturian is positioned at the sole occurrence of *C. annulatus* at 8235'/2510m.

A number of spores with range tops recorded in the Asturian of the North Sea (McLean *et al.* 2005) are recorded in the well. The last stratigraphic occurrences of *Westphalensisporites irregularis, Acanthotriletes triquetrus* and *Triquitrites tribullatus* are recorded within the interval assigned to the *Torispora verrucosa* Sub-biozone at 8087'/2465m, 7923'/2415m and 7923'/2415m respectively. However, the sole occurrences of *Vestispora laevigata, Cristatisporites solaris* and *Florinites junior* are recorded below the sub-biozone lower limit at 8300'/2530m and 8382'/2555m and 8382'/2555m respectively.

A number of taxa recorded by Butterworth (1984) with range tops assigned to the top Bolsovian in north-western Europe are also recorded in 26/28-3 at a range of depths. The last stratigraphic occurrences of *Calamospora* cf. *breviradiata* and *Granulatisporites microgranifer* are recorded above the occurrence of *Cirratriradites annulatus* at 7989'/2435m and 8038'/2450m respectively. The last stratigraphic occurrences of *Granulatisporites minutus, Granulatisporites adnatoides Calamospora microrugosa Lophotriletes microsaetosus, Raistrickia* cf. *superba* and *Cirratriradites saturni* are recorded at 8300'/2530m 8317'/2535m, 8333'/2540m, 8333'/2540m, 8366'/2550m and 8415'/2565m respectively.

Westphalensisporites irregularis **Sub-biozone (upper Bolsovian) 8235'/2510m to 8333'/2540**

The lower limit of the *Westphalensisporites irregularis* Sub-biozone corresponds to the lower limit of the *Thymospora pseudothiessenii* Biozone (see above). The interval assigned to the sub-biozone should be characterised by occurrences of the index taxon, however, occurrences in 26/28-3 are only recorded above and below the interval.

Vestispora fenestrata **Biozone (Bolsovian) 8333'/2540m to 8464'/2580m**

The interval assigned to the *Vestispora fenestrata* Biozone is characterised by occurrences of the index taxon and *Torispora securis.* McLean *et al.* (2005) indicate the first stratigraphic occurrence of the taxa occur in proximity to the lower limit of the equivalent North Sea W6 Biozone. The first stratigraphic occurrences of both taxa in 26/28-3 are recorded just above the deepest sample at 8432'/2570m. An absence of taxa with range tops that define the lower limit of the North Sea W6 Biozone i.e.

Grumosisporites varioreticulatus and *Grumosisporites papillosus* suggest the lower limit of the *V. fenestrata* Biozone is not encountered in the well.

***Raistrickia aculeata* Sub-biozone (Bolsovian) 8333'/2540m to 8399'/2560m**

***Torispora securis* Sub-biozone (Bolsovian) 8399'/2560m to 8464'/2580m**

The *Raistrickia aculeata* Sub-biozone lower limit should be defined by the first stratigraphic occurrence of the index taxon (figure 2.7). However, the taxon is only recorded in a single sample at 8350'/2545m.

Based on range data from the North Sea (McLean *et al.* 2005), the last stratigraphic occurrence of *Reticulitriletes reticulocingulum* at 8399'/2560m is used to tentatively position the lower limit of the *Raistrickia aculeata* Sub-biozone. The range top of the taxon marks the lower limit of the equivalent North Sea W6b Sub-biozone. McLean *et al.* also recorded the range top of *Savitrisporites nux* in proximity to the W6b Biozone lower limit. In 26/28-3, occurrences of *S. nux* are recorded in samples as shallow as 7890'/2405m. Other taxa with range limits that define or occur in proximity to the North Sea W6b Sub-biozone base are not recorded in the well. As a result there is low confidence in the positioning of the sub-biozone lower limit at 8399'/2560m.

The *Torispora securis* Sub-biozone is deemed to extend from 8399'/2560m to the deepest sample depth at 8464'/2580m. The index taxon is recorded in one sample in the interval assigned to the sub-biozone.

VII.XI Well 26/28-4a

Revised palynostratigraphic interpretations are based on data from Athersuch *et al.* (1982) (figure 6.11).

Jurassic (Bathonian to late Bajocian) 7497'/2285m SWC to 7795'/2376m SWC

Athersuch *et al.* (1982) assigned a Bathonian to late Bajocian age to the 7497'/2285m sidewall core sample based on the occurrence of the dinocyst *Gonyaulacysta* cf. *filapicata*. A mid Jurassic age was also assigned to a sidewall core sample from 7795'/2376m based on the presence of *Cerebropollenites mesozoicus, Callialasporites* *dampieri* and *C. turbatus*. The occurrences of *Callialasporites microvelatus* and *Monosulcites* sp. in the 7612.7'/2320.4m core sample and *C. microvelatus, Densosporites circumundulatus* and *Alisporites lowoodensis* in a core sample from 7618'/2322m confirm a mid Jurassic age.

Reworked Carboniferous miospores are recorded in the interval assigned to the mid Jurassic. These include occurrences of *Vestispora pseudoreticulata* in the 7610.7'/2319.8m core sample, with *Raistrickia saetosa, Raistrickia fulva, Lycospora pusilla, Densosporites sphaerotriangularis, Cyclogranisporites micrograntus, Cirratriradites saturni* and *Radiizonates faunus* occurring in the 7612.7'/2320.4m core sample. *Cristatisporites solaris, Dictyotriletes muricatus* and *Densosporites anulatus* were recorded in a core sample from 7618'/2322m and *Triquitrites bransonii* and *Lophotriletes commissuralis/microsaetosus* occur in the 7795'/2376m sidewall core sample.

Carboniferous 7867'/2398m SWC to 7884'/2403m core sample

The first downhole occurrence of Carboniferous strata is assigned to a sidewall core sample at 7867'/2398m based on the disappearance downhole of Jurassic miospores and the presence of a Carboniferous assemblage including *Cristatisporites solaris, Mooreisporites* cf. *inusitatus, Microreticulatisporites* cf. *nobilis* and *Cadiospora magna.* The 26/28-4a Geological Completion Report (Crawley *et al.* 1981) positioned the Carboniferous/Jurassic unconformity at 7808'/2380m based on the palynological data of Athersuch *et al.* (1982) and log correlation with well 26/28-1 (figure 6.11).

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Thymospora obscura – Thymospora thiessenii (OT) Biozone (upper Bolsovian to lower Barruelian) 7867'/2398m SWC to 7878.8'/2401.5m core sample

The OT Biozone lower limit is tentatively positioned at 7878.8'/2401.5m, defined by the first and only stratigraphic occurrence of *Thymospora* spp. (*Thymospora* sp. aff. *pseudothiessenii*) in a core sample from this depth. Clayton *et al.* (1977) also recorded the range tops of *Dictyotriletes bireticulatus* and *Cingulizonates loricatus* in the lowermost part of the OT Biozone in Western Europe (figure 2.2). In 26/28-4a, the sole occurrences of the taxa are also recorded in the 7878.8'/2401.5m core sample. Occurrences of *Raistrickia fulva* and *Radiizonates faunus* at 7878.8'/2401.5m in addition to *Radiizonates* cf. *tenuis* at 7867'/2398m suggest close very proximity to the lower limit of the OT Biozone. Butterworth (1984) recorded the range tops of the taxa in the mid SL Biozone of Western Europe.

A number of species with range bases that mark the lower part of the OT Biozone in Clayton *et al.* (1977) are absent from well 26/28-4a. Taxa include *Polymorphisporites* spp. *Savitrisporites camptotus* and *Candidispora* spp. (figure 2.2). Occurrences of *Spinosporites* spp., *Florinites junior* and *Westphalensisporites irregularis* should also characterise the biozone but are not recorded in 26/28-4a. The first and only occurrence of *Cadiospora magna* in the 7867'/2398m sidewall core sample confirms the OT Biozone at this depth, based on range data in Butterworth (1984). Overall there is moderate confidence in the positioning of the biozone lower limit at 7878.8'/2401.5m due to the infrequent occurrence of key taxa and poor miospore recovery in deeper samples.

Torispora securis – Torispora laevigata (SL) Biozone (Bolsovian) 7878.8'/2401.5m Core to 7884'/2403m core sample

Miospore recovery below 7878.8'/2401.5m is very poor. Range data from Clayton *et al.* (1977) indicates the SL Biozone lower limit should be defined by the range base of *Torispora* spp. and *Vestispora fenestrata*. However, representatives of the genus *Torispora* are not recorded in the 26/28-4a well and *Vestispora fenestrata* is only recorded in the 7867'/2398m sidewall core sample. Clayton *et al.* also recorded the range bases of *Punctatosporites granifer, Disaccites striatiti* and *Lundbladispora gigantea* in the SL Biozone. However, the taxa are also absent from 26/28-4a. The authors also recorded the range tops of *Raistrickia fulva* and *Savitrisporites nux* in the lower part of the SL Biozone. The last stratigraphic occurrences in 26/28-4a are recorded at 7878.8'/2401.5m and 7867'/2398m respectively.

Clayton *et al.* (2003) Western European Zonal Scheme

Thymospora pseudothiessenii Biozone / *Westphalensisporites irregularis* Sub-Biozone (upper Bolsovian) 7867'/2398m SWC to 7878.8'/2401.5m Core

The lower limit of the *Thymospora pseudothiessenii* Biozone of Clayton *et al.* (2003) is positioned at the first and only stratigraphic occurrence of the index taxon (*T.* sp. aff. *pseudothiessenii*) at 7878.8'/2401.5m.

McLean *et al*. (2005) defined the lower limit of the equivalent North Sea W7 Biozone based on the range top of *Dictyotriletes bireticulatus* and recorded the range top of *Cingulizonates loricatus* in proximity to the biozone lower limit. In 26/28-4a, the sole occurrences of *D. bireticulatus* and *C. loricatus* are also recorded in the 7878.8'/2401.5m core sample, confirming the lower limit of the *Thymospora pseudothiessenii* Biozone. The last stratigraphic occurrences of *Raistrickia fulva* and *Radiizonates faunus* at 7878.8'/2401.5m and *Radiizonates* cf. *tenuis* at 7867'/2398m also confirm very close proximity to the base of the *T. pseudothiessenii* Biozone. McLean *et al.* (2005) recorded the range tops of the taxa just below the lower limit of the W7 Biozone in the North Sea. Overall there is only moderate confidence in the positioning of the biozone lower limit at 7878.8'/2401.5m, mainly due to the rarity of key taxa such as *Thymospora* spp. and *D. bireticulatus*.

Taxa that possess range bases in the Asturian of the North Sea (McLean *et al.* 2005) are absent from 26/28-4a. There is an additional absence of index taxon *Torispora verrucosa*, which defines the Asturian age *T. verrucosa* Sub-biozone of Clayton *et al.* (2003). As a result, the interval 7867'/2398m SWC to 7878.8'/2401.5m is tentatively assigned to the upper Bolsovian age *Westphalensisporites irregularis* Sub-biozone of Clayton *et al.* (2003), even thought the index taxon has not been recorded.

Vestispora fenestrata Biozone (Bolsovian) 7878.8'/2401.5m to 7884'/2403m core sample

The *Vestispora fenestrata* Biozone is only tentatively identified below 7878.8'/2401.5m due to very poor miospore recovery. The biozone cannot be identified based on occurrences of the index taxon, as it is only recorded in the 7867'/2398m sidewall core sample. However, occurrences of *Raistrickia fulva* and *Radiizonates faunus* at 7878.8'/2401.5m in addition to *Radiizonates* cf. *tenuis* at 7867'/2398m indicate very close proximity to the *Thymospora pseudothiessenii*/*Vestispora fenestrata* Biozone boundary based on range data from the North Sea (McLean *et al.* 2005) (figure 2.5). An absence of *Raistrickia aculeata* below 7878.8’/2401.5m means the *V. fenestrata* Biozone cannot be sub-divided into the *R. aculeata* Sub-biozone.

VII.XII Well 26/29-1

Revised palynostratigraphic interpretations are based on palynological data from Athersuch *et al.* (1983) (figure 6.12).

Middle Jurassic (undifferentiated) 5837’/1779m core sample

The majority of sidewall core and core samples from the interval 5487’/1672.5m to 5837’/1779m are barren of palynomorphs. However, Athersuch *et al.* (1983) recorded *Cerebropollenites mesozoicus*, *Callialasporites trilobatus* and *Callialasporites dampieri* in a core sample from 5837’/1779m, dating the sample as Middle Jurassic in age. Reworked Carboniferous spores including *Laevigatsporites* sp. *Lycospora pusilla, Florinites* sp. and *Endosporites globiformis* were recorded in the 5833’/1778m core sample.

Carboniferous 6016.3’/1833.8m core sample to 6027.8’/1837.3m core sample

A Carboniferous age is assigned to the 6016.3’/1833.8m core sample based on the disappearance downhole of Jurassic palynomorphs. Only Carboniferous miospores are recorded in the interval 6016.3’/1833.8m to 6027.8’/1837.3m. Compton (1983) positioned the top Carboniferous at 5873’/1790m based on the palynological data of Athersuch *et al.* (1983) and wireline log data. The present study confirms this as a valid depth for the unconformity (figure 6.12).

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Lowermost *Thymospora obscura – Thymospora thiessenii* (OT) Biozone or *Torispora securis – Torispora laevigata* (SL) Biozone; (Bolsovian) 6016.3’/1833.8m core sample to 6027.8’/1837.3m core sample

The 6016.3’/1833.8m core sample is assigned to a biozone no older than the SL Biozone of Clayton *et al.* (1977) based on the occurrence of *Vestispora fenestrata.*

However, a number of taxa that characterise the SL Biozone in Clayton *et al.* have not been recorded in 26/29-1, including *Torispora* spp.*, Cingulizonates loricatus, Lundbladispora gigantea* and *Disaccites striatiti.* The occurrence of *Cadiospora* cf. *magna* at 6016.3'/1833.8m potentially assigns the sample depth to the OT Biozone of Clayton *et al*. Butterworth (1984) recorded the range base of *C. magna* at the lower limit of the OT Biozone in north-western Europe. However, there is an absence of *Thymospora* spp. and *Spinosporites spinosus;* key taxa that define OT Biozone in Clayton *et al*. Range data from Butterworth (1984) suggests the occurrence of *Cirratriradites saturni* at 6016.3'/1833.8m confirms an age no younger than top Bolsovian, which corresponds to the lowermost part of the OT Biozone. Overall, the limited palynological data suggests the Carboniferous interval in 26/29-1 is assigned to either the lowermost OT Biozone or the SL Biozone.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Vestispora fenestrata Biozone (Bolsovian) 6016.3'/1833.8m core sample to 6027.8'/1837.3m core sample

The 6016.3'/1833.8m core sample is assigned to a biozone no older than the *Vestispora fenestrata* Biozone of Clayton *et al.* (2003) based on the presence of the index taxon. An absence of *Thymospora* spp. in the well section suggests the sample should not be assigned to the younger *Thymospora pseudothiessenii* Biozone.

Cadiospora cf. *magna* is also recorded in the 6016.3'/1833.8m core sample. Butterworth (1984) recorded the range base of *C. magna* at the lower limit of the OT Biozone of Clayton *et al.* (1977); which corresponds to the *Thymospora pseudothiessenii* Biozone lower limit. However, as McLean *et al.* (2005) recorded *C. magna* in mid and early Bolsovian age strata from the North Sea, the taxon is not deemed reliable for defining the lower limit of the equivalent *T. pseudothiessenii* Biozone offshore western Ireland.

The interval cannot be assigned to either the *Raistrickia aculeata* or *Torispora securis* Sub-biozones of Clayton *et al.* (2003) due to an absence of both index taxa. There is an additional absence of taxa with range limits that mark the boundary of the equivalent W6a and W6a Sub-biozones of the North Sea (McLean *et al.* 2005).

VII.XIII Well 26/30-1

Revised palynostratigraphic interpretations are based on palynological data from King *et al.* (1982) (figure 6.13).

Jurassic (Bathonian) 4450'/1356m to 4920'/1500m

King *et al.* (1982) dated a sidewall core from 4450'/1356m as no older than late Toarcian in age based on the occurrence of *Callialasporites dampieri*. A sidewall core sample from 4762'/1451m was additionally dated as no older than Hettangian in age based on the presence of *Cerebropollenites mesozoicus*. King *et al.* also suggested that occurrences of the ostracod *?Ilyocypris P.J.C* (a Palaeoservices species) in the interval 4450'/1356m to 4762'/1451m are characteristic of Callovian/Bathonian age strata from the Porcupine Basin.

Sidewall core samples from 4855'/1480m and 5007m/1526' are devoid of palynomorphs. However, the occurrence of ostracods *Kliana* aff. *bathonica* and *Bisulcocypris* aff. *ancasterensis* in cuttings samples from 4762'/1451m to 4960'/1512m, suggest a Bathonian age. *Callialasporites dampieri* is also recorded in cuttings samples from 4890'/1490m and 4920'/1500m. Rare occurrences of *Lycospora* spp. at 4290'/1308m are deemed to be reworked.

Carboniferous 5090'/1551m to 5590'/1704m

The first downhole evidence for Carboniferous age strata is identified at 5090'/1551m based on first downhole occurrences of *Endosporites globiformis, Cirratriradites saturni, Dictyotriletes bireticulatus, Vestispora costata/cancellata*, *Vestispora fenestrata* and abundant *Lycospora* spp.

The 26/30-1 Final Well Report (1982) positioned the Carboniferous/Jurassic unconformity at 4935'/1504m based on a combination of palynological data from King *et al.* (1982) and wireline log data (figure 6.13).

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Torispora securis – Torispora laevigata (SL) Biozone (Bolsovian) 5090'/1551m to 5590'/1704m

The 5090'/1551m cuttings sample is assigned to a biozone no older than the SL Biozone of Clayton *et al.* (1977) based on the occurrence of *Vestispora fenestrata.* However, a number of taxa that characterise the SL Biozone of Clayton *et al.* have not been recorded in 26/30-1, notably *Torispora* spp., *Cingulizonates loricatus, Lundbladispora gigantea, Punctatosporites granifer* and *Disaccites striatiti.*

An additional absence of taxa with range bases restricted to the *Thymospora obscura – Thymospora thiessenii* OT Biozone of Clayton *et al.* (1977) e.g *Thymospora* spp. suggests the SL Biozone is the youngest to be encountered in the well. Clayton *et al.* also identified a number of taxa with range tops that mark the lower limit or the lowermost part of the SL Biozone, notably *Grumosisporites varioreticulatus, Grumosisporites maculatus, Raistrickia fulva* and *Savitrisporites nux*. An absence of the taxa in the 26/20-1 well indicates the lower limit of the biozone has not been encountered.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Vestispora fenestrata Biozone (Bolsovian) 5090'/1551m to 5590'/1704m

The interval 5090'/1551m to 5590'/1704m is assigned to the *Vestispora fenestrata* Biozone of Clayton *et al.* (2003). The index taxon is only recorded in the 5090'/1551m cuttings sample. Based on range data from the North Sea (McLean *et al.* 2005) (figure 2.5), the presence of *Dictyotriletes bireticulatus* at the same depth confirms a biozone no younger than the *V. fenestrata* Biozone. An absence of taxa with range tops that define the lower limit of the biozone or the equivalent W6 Biozone of the North Sea suggests the *V. fenestrata* Biozone extends to the deepest sample depth above the granitic basement.

VII.XIV Well 27/5-1

Revised palynostratigraphic interpretations are based on palynological data from Millennia (1996) and the present study (figure 6.14).

Mid / Upper Permian 4698'/1432m to 5381'/1640m

Enterprise Oil (1996) assigned a Middle/Upper Permian age to the interval 4698'/1432m to 5381'/1640m based on lithostratigraphy. The 682'/208m of anhydrite and halite is presumed to be Zechstein in age. The interval has not been sampled for biostratigraphy.

Carboniferous 5390'/1643m SWC to 6266'/1910m

Carboniferous strata is confirmed at 5390'/1643m based on the first downhole occurrence of common *Crassipora kosankei* and *Lycospora pusilla* in sidewall core from this depth. The 27/5-1 Geological Completion Report (Enterprise Oil 1996) positioned the Carboniferous/Permian unconformity at 5384'/1641m based on a combination of lithological, wireline log and palynological (Millennia 1996) data.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Angulisporites splendidus – Latensina trileta (ST) (upper Barruelian to Stephanian B) or *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone (upper Stephanian B to Stephanian C) 5390'/1643m SWC to 5426'/1654m SWC

A single occurrence of *Vittatina* sp. in the 5426'/1654m sidewall core sample tentatively assigns the sample to a biozone no older than the *Angulisporites splendidus – Latensina trileta* (ST) Biozone of Clayton *et al*. (1977) (figure 2.2). Occurrences of common *Crassispora kosankei* at 5387'/1642m confirm a biozone no younger than the mid *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone based on range data from Clayton *et al*. The interval 5390'/1643m to 5426'/1654m is also characterised by typical Stephanian age taxa including *Disaccates striatiti* and *Cordaitina* sp. However the interval cannot be definitively assigned to the ST or NBM

Biozones due to an absence of key taxa including *A. splendidus, L. trileta* and *Cheleidonites* spp.

Stratigraphic break between 5426'/1654m and 5446'/1660m

A stratigraphic break is identified between samples 5426'/1654m and 5446'/1660m based on the transition from an interval characterised by Stephanian age taxa to an interval characterised by Duckmantian age taxa.

Microreticulatisporites nobilis – Florinites junior (NJ) Biozone (Duckmantian) 5446'/1660m to 5774'/1760m

The last stratigraphic occurrence of *Radiizonates* cf. *striatus* in the 5446'/1660m coal sample indicates an age no younger than the top Duckmantian and a biozone no younger than the NJ Biozone of Clayton *et al.* (1977) based on range data from north-western Europe (Butterworth 1984). Range data from Butterworth also suggests that the last stratigraphic occurrence of *Lycospora noctuina,* recorded in a cuttings sample from 5446'/1660m by Millennia (1996), indicates an age no younger than the Duckmantian Substage. Occurrences of *Camptotriletes bucculentus* at 5456'/1663m, *Knoxisporites triradiatus* at 5476'/1669m and both *Murospora intorta* and *Ahrensisporites guerickei* at 5485'/1672m confirm an age no younger than the Duckmantian based on range data from Butterworth. There is an additional absence of *Vestispora fenestrata*, *Torispora* spp. and *Thymospora* spp.; key taxa that define the younger SL and OT Biozones of Clayton *et al.* (1977).

Based on range data from Clayton *et al.* (1977) (figure 2.2), the lower limit of the NJ Biozone is positioned at the last stratigraphic occurrence of *Schulzospora rara* at 5774'/1760m. Clayton *et al.* also recorded the range top of *Sinuspores sinuatus* at the base of the NJ Biozone boundary. The taxon is not recorded in the 27/5-1 well, although an occurrence of *S.* cf. *sinuatus* is recorded in a Langsettian age sample from 5869'/1789m. Clayton *et al.* additionally indicated that the range bases of index taxa *Microreticulatisporites nobilis* and *Florinites junior* should define the NJ Biozone lower limit. In 27/5-1, *M. nobilis* is only recorded in the 5695'/1736m sidewall core sample. The first stratigraphic occurrence of *F. junior* is recorded in the 6266'/1910' cuttings sample with the deepest occurrence in sidewall core recorded at 6115'/1864m. Based on range data from Clayton *et al.*, the lower limit of the NJ Biozone should be positioned at least as deep as 6115'/1864m based on the occurrences of *F. junior*. However, from 5774'/1760m, a Langsettian age miospore assemblage is recorded (see below), suggesting the range base of *F. junior* extends into the Langsettian Substage, offshore western Ireland. Due to this conflicting palynological data, there is low confidence in the positioning of the NJ Biozone lower limit in 27/5-1.

Radiizonates aligerens **(RA) Biozone (Langsettian) 5774'/1760m to 6266'/1910m**

As indicated above, the boundary between the RA and NJ Biozones of Clayton *et al*. (1977) and the Langsettian/Duckmantian Substage boundary is positioned at 5774'/1760m based on the last stratigraphic occurrence of *Schulzospora rara*. Occurrences of the taxon in 27/5-1 are very rare. The uppermost part of the RA Biozone in 27/5-1 is also marked by the last stratigraphic occurrence of the index taxon *Radiizonates aligerens* at 5869'/1789m.

Clayton *et al*. (1977) indicated that the range bases of *Westphalensisporites irregularis* and *Disaccites non-striatiti* should mark the uppermost part of the RA Biozone. In 27/5-1, the first stratigraphic occurrence of *D. non-striatiti* is recorded in a sidewall core sample at 5892'/1796m. *W. irregularis* is not recorded in the well. Clayton *et al.* also recorded the range base of the *Punctatosporites* spp. in the RA Biozone and the range top of *Kraeuselisporites ornatus* in the middle of the biozone. The first stratigraphic occurrence of *Punctatosporites* in 27/5-1 is recorded in a cuttings sample at 6234'/1900m with the deepest occurrence in sidewall core at 5892'/1796m. A solitary occurrence of *K. ornatus* is recorded at 5682'/1732m. The interval assigned to the biozone in 27/5-1 is also characterised by occurrences of *Savitrisporites nux, Grumosisporites varioreticulatus, Reticulatisporites reticulatus* and *Endosporites globiformis*.

Clayton *et al.* (1977) also indicated that the range base of *Radiizonates aligerens* should define the lower limit of the RA Biozone (figure 2.2). In 27/5-1, the first stratigraphic occurrence of the index taxon is recorded at 6174'/1882m. However, it is considered unlikely that the lower limit of the biozone has been encountered due to an absence of *Spelaeotriletes triangulus* and *Spelaeotriletes arenaceus*; the range tops of which define the lower limit of the RA Biozone in Clayton *et al.* (1977).

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Stratigraphic break between 5426'/1654m and 5446'/1660m

A stratigraphic break is positioned between samples 5426'/1654m and 5446'/1660m based on the transition from an interval characterised by Stephanian age taxa to an interval characterised by Duckmantian age taxa.

Microreticulatisporites nobilis Biozone (Duckmantian) 5446'/1660m to 5695'/1736m SWC*,* *Lycospora noctuina noctuina* Sub-biozone 5456'/1663m to 5695'/1736m SWC

The last stratigraphic occurrence of *Lycospora noctuina noctuina* at 5456'/1663m assigns the sample to a biozone no younger than the Duckmantian age *Microreticulatisporites nobilis* Biozone and a sub-biozone no younger than the *L. noctuina noctuina* Sub-biozone of Clayton *et al.* (2003). McLean *et al.* (2005) recorded the range top of the taxon just below the upper limit of the North Sea W4c Sub-biozone which corresponds to the uppermost part of the *L. noctuina noctuina* Sub-biozone (figure 2.5). Millennia (1996) also recorded the last stratigraphic occurrence of *Lycospora noctuina* in a cuttings sample from 5446'/1660, potentially confirming the sub-biozone at this depth. The last stratigraphic occurrence of *Punctatisporites minutus* at 5485'/1672m confirms a biozone no younger than the *L. noctuina noctuina* Sub-biozone based on range data from the North Sea. McLean *et al.* recorded the range top of the taxon at the North Sea W4b/W4c Sub-biozone boundary, corresponding to the middle of the *L. noctuina noctuina* Sub-biozone. McLean *et al.* additionally recorded the range top of *Savitrisporites concavu*s at the W4c/W5a Sub-biozone boundary, which corresponds to the top of the *L. noctuina noctuina* Sub-biozone. The last stratigraphic occurrence in 27/5-1 is recorded at 5495'/1675m.

Based on range data in Butterworth (1984), the last stratigraphic occurrences of *Knoxisporites triradiatus* at 5476'/1669m and *Leiotriletes* cf. *priddyi* at 5485'/1672m confirm that the sample depths are no younger than Duckmantian in age. The last stratigraphic occurrence of *Pteroretis primum* at 5476'/1669m also indicates an age no older than Duckmantian based on range data from the North Sea (McLean 1993). The last stratigraphic occurrences of both *Murospora intorta* and *Ahrensisporites guerickei* at 5485'/1672m and *Cristatisporites connexus* at 5584'/1702m confirm an age no younger than the top Duckmantian based on range data from both McLean *et al.* (2005) and Butterworth (1984). McLean (1993) also recorded occurrences of *Krauselisporites pseudoornatus* in the early Duckmantian of the North Sea. A last stratigraphic occurrence in 27/5-1 is recorded at 5594'/1705m.

The *Microreticulatisporite nobilis* Biozone of Clayton *et al.* (2003) should be characterised by occurrences of the index taxon, with the range base defining the biozone lower limit (figure 2.7). However, only a single occurrence of the index taxon is recorded in 27/5-1. The occurrence in a sidewall core sample at 5695'/1736m very tentatively defines the lower limit of the biozone. Clayton *et al.* also indicate that the range top of *Sinuspores sinuatus* should define the lower limit of the biozone. Although the taxon is not recorded in 27/5-1, a single occurrence of *S.* cf. *sinuatus* is recorded at 5869'/1789m and assigned to the Langsettian Substage (see below). Additional taxa recorded by McLean *et al.* (2005) that possess range tops at the equivalent North Sea W4b Sub-biozone lower limit are absent from 27/5-1.

It is noted that Millennia (1996) recorded an occurrence of *Raistrickia aculeata* at 5446'/1660m. The range base of the taxon defines the lower limit of the Bolsovian age *R. aculeata* Sub-biozone of Western Europe (Clayton *et al.* 2003), the lower limit of the equivalent W6b Sub-biozone of the North Sea (McLean *et al.* 2005) and the base of the OT Biozone of north-western Europe (Butterworth 1984). It is possible that the occurrence in the Duckmantian age cuttings sample is due to caving from the overlying Stephanian age interval.

Occurrences of *Lycospora subtriquetra* in the interval assigned to the *L. noctuina noctuina* Sub-biozone suggests the range top of the taxon extends into the lower Duckmantian offshore western Ireland. Butterworth (1984) and Clayton *et al.* (1977) both recorded range tops restricted to the Langsettian in Western Europe.

Sinuspores sinuatus Biozone (lower Duckmantian) 5695'/1736m SWC to 5774'/1760m

As indicated above, the boundary between the *Sinuspores sinuatus* Biozone and the succeeding *Microreticulatisporite nobilis* Biozone is very tentatively positioned at

5695’/1736m based on the first and only stratigraphic occurrence of *M. nobilis*. The lower limit of the *S. sinuatus* Biozone and the Langsettian/Duckmantian Substage boundary is positioned at 5774’/1760m based on the last stratigraphic occurrence of *Schulzospora rara*. Occurrences of the taxon in the 27/5-1 well are very rare and infrequent. The interval in 27/5-1 assigned to the *S. sinuatus* Biozone should also be characterised by occurrences of the index taxon. However occurrences are restricted to the sole appearance of *S*. cf. *sinuatus,* recorded below the lower limit of the biozone at 5869’/1789m.

McLean *et al.* (2005) also recorded the range tops of *Apiculatasporites variocorneus* and *Radiizonates striatus* in proximity to the upper limit of the Langsettian in the North Sea. In 27/5-1, the last stratigraphic occurrences are recorded at 5987’/1825m and 5751’/1753m respectively. Occurrences in the well are infrequent. Butterworth (1984) recorded the range top of *Densosporites intermedius* at the top Langsettian in north-western Europe. The last stratigraphic occurrence of the taxon in 27/5-1 is recorded at 5702’/1738m. Butterworth also recorded the range top of *Florinites pellucidus* at the top Langsettian. In 27/5-1, Millennia (1996) recorded the taxon at 5446’/1660m and 5682’/1732m. A concentration of acritarchs in the 5722’/1744m, 5732’/1747m, 5741’/1750m cuttings samples and 5774’/1760m sidewall core sample may also represent the top Langsettian age Vanderbeckei marine band in 27/5-1.

McLean *et al.* (2005) additionally recorded the range bases of *Radiizonates tenuis* and *Radiizonates faunus* in proximity to the Langsettian/Duckmantian boundary in the North Sea. In 27/5-1, the first stratigraphic occurrences are also recorded in proximity to the Langsettian/Duckmantian boundary; in cuttings samples at 5771’/1759m and 5840’/1780m respectively.

***Schulzospora rara* Biozone (Langsettian) 5774’/1760m to 5869’/1789m**

The last stratigraphic occurrence of *S. rara* at 5774’/1760m marks the boundary between the *S. rara* Biozone and the succeeding *Sinuspores sinuatus* Biozone. Both McLean *et al.* (2005) and Butterworth (1984) recorded the range top of the taxon at the equivalent Langsettian/Duckmantian Substage boundary in the North Sea and north-western Europe. However, occurrences of the index taxon in the interval assigned to the *S. rara* Biozone are very rare and infrequent. The lower limit of the *S. rara*

Biozone in 27/5-1 is positioned at 5869'/1789m, defined by the last stratigraphic occurrence of *Radiizonates aligerens.*

The first stratigraphic occurrence of *Endosporites globiformis* in 27/5-1 is recorded just below the upper limit of the *Schulzospora rara* Biozone at 5840'/1780m. This is at a higher stratigraphic level than in the North Sea, onshore Great Britain and Ireland. In the North Sea, McLean *et al.* (2005) recorded the range base of the taxon in proximity to base of the W2b Biozone, which is roughly equivalent to base of the Langsettian age *Radiizonates aligerens* Biozone of Clayton *et al.* (2003) (see below). In the Duckmanton railway cutting of Great Britain, McLean *et al.* (2004) also recorded *E. globiformis* in samples deeper than the last stratigraphic occurrence of *R. aligerens*. In the Leinster coalfield, onshore Ireland, Higgs & O'Connor (2005) recorded the range base of the taxon in samples assigned to the lower Langsettian age *Triquitrites sinani - Cirratriradites saturni* (SS) Biozone of Clayton *et al.* (1977).

Radiizonates aligerens **Sub-biozone (Langsettian) 5869'/1789m to 6106'/1861m**

The last stratigraphic occurrence of *Radiizonates aligerens* at 5869'/1789m marks the boundary between the *R. aligerens* Biozone and the succeeding *S. rara* Biozone. McLean *et al.* (2005) identified a number of taxa with range tops at the North Sea W2b Sub-biozone lower limit, which roughly approximates to the lower limit of the *R. aligerens* Biozone (figure 2.5). Taxa include *Triquitrites* cf. *protensus*, *Kraeuselisporites ornatus*, *Dictyotriletes probireticulatus* and *Waltzispora polita*. In 27/5-1, a sole occurrence of *K. ornatus* is recorded above the top Langsettian at 5682'/1732m and a single occurrence of *T.* cf. *protensus* is recorded at 5869'/1789m, just below the Langsettian upper limit. A solitary occurrence of *W. polita* recorded at 6106'/1861m may provide a very tentative rough approximation for the *R. aligerens* Biozone lower limit.

The index taxon is recorded moderately infrequently in the interval assigned to the *R. aligerens* Biozone. Occurrences in coal samples from 5928'/1807m and 6017'/1834m suggest the occurrences are not reworked.

Vestispora cancellata Sub-biozone (Langsettian) 6106'/1861m to 6266'/1910m

Based on the zonal scheme of Clayton *et al.* (2003), the interval below the *Radiizonates aligerens* Biozone is assigned to the *Vestispora cancellata* Biozone. The index taxon is not recorded in the well section. It is noted that in similar age samples from the Leinster coalfield, onshore Ireland, Higgs & O'Connor (2005) did not recorded the taxon either.

McLean *et al.* (2005) recorded the range base of *Florinites junior* at the base of the North Sea W2a Biozone, roughly equivalent to the base of the *Vestispora cancellata* Biozone (figure 2.5). The occurrence of *F. junior* in a sidewall core sample at 6115'/1864m confirms a biozone no older than the *V. cancellata* Biozone based on this range data. The taxon is also recorded in cuttings samples as deep as 6266'/1910m, tentatively assigning the biozone to this depth. An absence of *Spelaeotriletes arenaceous* suggests the upper limit of the older *S. arenaceous* Biozone of Clayton *et al.* (2003) has not been encountered (figure 2.7). Overall, the evidence for the *V. cancellata* Sub-biozone being present is limited.

VII.XV Well 34/5-1

Revised palynostratigraphic interpretations are based on palynological data from Church *et al.* (1980), Ducazeaux *et al.* (1981) and Robeson (1988) (figure 6.15).

Palaeogene (Eocene) to Cretaceous 2247'/685m to 2395'/730m

Ducazeaux *et al.* (1981) suggested the presence of small *Nummulites*, *Operculina* spp., *Discocyclina* spp., Bryozoan, Echinoderm and Lamellibranch fragments in cuttings samples from the interval 2247'/685m to 2280'/695m indicate a Paleocene to Eocene age. However, Ducazeaux *et al.* also recorded a mixed assemblage of Tertiary and Cretaceous palynomorphs in a cuttings sample from 2264'/690m including the Cretaceous dinoflagellates *Ovoidinium verrucosum, Dinopterygium cladoides,* and *Exochosphaeridium* sp. Robeson (1988) dated a cuttings sample at 2280'/695m as Eocene in age based on a dinoflagellate assemblage that included *Homotriblium floripes, Wetziella homomorpha* and *Hystrichokolpoma rigaudiae.* Ducazeaux *et al.* further recorded the Cretaceous age miospore *Subtilisphaera* sp. in addition to

Nummulites in a cuttings sample from 2362'/720m. Robeson (1988) assigned a Cretaceous age to a cuttings sample from 2395'/730m based on the occurrence of the miospore taxon *Appendicisporites tricornatus*. Overall it is difficult to precisely date the samples based on the mixed Palaeogene to Cretaceous age microfossil content.

Carboniferous 2411'/735m to 4810'/1466m

The first downhole occurrence of Carboniferous strata is identified in sidewall core from 2411'/735m based on the occurrence of a late Westphalian / lower Stephanian age miospore assemblage that includes *Latensina trileta, Vittatina* sp., *Illinites* sp., *Potoneisporites* spp., *Endosporites globiformis* and *Lycospora* spp. There is an additional absence of Palaeogene/Cretaceous age taxa at this depth. Rare occurrences of Cretaceous taxa in cuttings samples below 2411'/735m are assumed to be caved. Ducazeaux *et al.* (1981) and Church *et al.* (1980) also recorded Carboniferous ostracods in the interval 2526'/770m to 2953'/900m.

An unconformity positioned between samples 2395'/730m and 2411'/735m juxtaposes the Carboniferous age interval against the Palaeogene/Cretaceous interval. In the 34/5-1 Geological Report, Croisilie (1981) positioned the unconformity at 2411'/735m.

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Angulisporites splendidus – Latensina trileta (ST) Biozone (upper Barruelian to Stephanian B) 2411'/735m SWC to 2526'/770m

The first (and only) occurrence of the index taxon *Angulisporites splendidus* in the 2526'/770m cuttings sample tentatively positions the lower limit of the ST Biozone (figure 2.2). The only occurrence of *Vittatina* sp., in a sidewall core sample at 2411'/735m, confirms a biozone no older than the ST Biozone based on range data from Clayton *et al.* (1977). Due to the inherent risk of caving, there is low confidence in the positioning of the lower biozone limit based on the first stratigraphic occurrence of *A. splendidus* in a cuttings sample.

The occurrence of *Vestispora fenestrata* at 2411'/735m confirms a biozone no younger than the ST Biozone based on range data from Clayton *et al.* (1977). The interval assigned to the biozone is characterised by a miospore assemblage comprising the index taxon *Latensina trileta, Westphalensisporites irregularis, Savitrisporites camptotus, Crassispora kosankei, Cirratriradites* aff. *saturni, Vestispora fenestrata* and *Spinosporites spinosus.* However, a number of taxa identified by Clayton *et al.* as characteristic of the ST Biozone are not recorded in the well, notably *Cheleidonites, Lundbladispora gigantea*, *Candidispora* and *Polymorphisporites. Florinites junior* and *Disaccites non-striatiti* should also characterise the biozone but occurrences are restricted to samples deeper than 2526'/770m.

Thymospora obscura – Thymospora thiessenii (OT) Biozone (upper Bolsovian to lower Barruelian) 2526'/770m to 3440'/1048.5m

Clayton *et al.* (1977) indicated that the range bases of *Thymospora* spp. and *Spinosporites spinosus* define the lower limit of the OT Biozone (figure 2.2). In 34/5-1, the first stratigraphic occurrence of *Spinosporites* spp. is recorded in a sidewall core sample at 3440'/1048.5m confirming the OT Biozone at this depth. The deepest occurrence of *Thymospora* spp. in a sidewall core sample is recorded at 2835'/864m. *Thymospora pseudothiessenii* is also recorded in cuttings samples to a depth of 3888'/1185m, although the occurrences below 3440'/1048.5m may be caved.

Clayton *et al.* (1977) also indicate the lower part of the OT Biozone is marked by the range tops of *Dictyotriletes bireticulatus, Cingulizonates loricatus* and the range base of *Savitrisporites camptotus. D. bireticulatus* occurs very infrequently in the 34/5-1 well. The last stratigraphic occurrence, recorded at 3150'/960m, assigns the lower part of the OT Biozone to this depth. *C. loricatus* is consistently recorded in the interval assigned to the OT Biozone, with the last stratigraphic occurrence recorded at 2608'/795m. The first stratigraphic occurrence of *Savitrisporites camptotus* is recorded in a sidewall core sample at 2835'/864m. Overall, as the biozone lower limit is not constrained by the range top of a taxon, there is only moderate confidence in its positioning in 34/5-1.

The interval assigned to the OT Biozone is also characterised by occurrences of *Westphalensisporites irregularis*, *Microreticulatisporites nobilis, Vestispora fenestrata* and *Cirratriradites saturni. Polymorphisporites* spp. and *Candidispora* spp. were identified by Clayton *et al*. (1977) as being characteristic of the OT Biozone, but are not recorded in the 34/5-1 well.

Torispora securis – Torispora laevigata **(SL) Biozone (Bolsovian) 3440'/1048.5m to 4587'/1398m**

Clayton *et al.* (1977) recorded the range bases of *Torispora* spp. and *Vestispora fenestrata* at the lower limit of the SL Biozone (figure 2.2). The first stratigraphic occurrences of the taxa in 34/5-1 are recorded in cuttings samples at 4587'/1398m and 4478'/1365m respectively. Occurrences of the taxa also characterise the interval assigned to the biozone.

Clayton *et al.* (1977) also recorded the range tops of *Grumosisporites varioreticulatus, G. maculatus* and *Raistrickia fulva* at the SL Biozone lower limit. In 34/5-1, the last stratigraphic occurrence of *G. varioreticulatus* is recorded at 4587'/1398m, confirming the lower biozone limit at this depth. However, *R. fulva* occurs fairly consistently up to a depth of 3609'/1100m, with an additional occurrence at 2723'/830m. *G. maculatus* is not recorded in the well. Overall there is moderate confidence in the positioning of the biozone lower limit.

Clayton *et al.* (1977) also recorded the range base of *Punctatosporites granifer* and the range top of *Savitrisporites nux* just above the SL Biozone lower limit. In 34/5-1, the first stratigraphic occurrence of *P. granifer* is recorded in a cuttings sample at 3609'/1100m. *S. nux* is recorded throughout the intervals assigned to the SL and OT Biozones. Clayton *et al.* additionally recorded the first stratigraphic occurrences of *Lundbladispora gigantea* and *Disaccites striatiti* within the SL Biozone. *L. gigantea* is not recorded in the 34/5-1 well, whilst a single occurrence of *D. striatiti* at 2526'/770m is assigned to the ST Biozone.

Microreticulatisporites nobilis – Florinites junior **(NJ) Biozone (Duckmantian to lower Bolsovian) 4587'/1398 to 4810'/1466m**

Clayton *et al.* (1977) indicate the ranges bases of the index taxa define the NJ Biozone lower limit (figure 2.2). In 34/5-1, occurrences of *Florinites junior* are restricted to samples assigned to the SL and OT Biozones. However, the index taxon

Microreticulatisporites nobilis is recorded in the 4810'/1466m cuttings sample, tentatively assigning the deepest sample in well 34/5-1 to the NJ Biozone.

Rare occurrences of taxa with range tops restricted to the Langsettian age RA Biozone of Clayton *et al.* (1977) are recorded in samples assigned to the NJ Biozone. *Bellispores nitidus* is recorded at 4790'/1460m and 4810'/1466m and a solitary occurrence of *R. aligerens* occurs at 4587'/1398m. However, the rarity of the occurrences in addition to the absence of *Schulzospora rara* and *Sinuspores sinuatus* (range tops also define the RA/NJ Biozone boundary) suggests the occurrences are probably reworked.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Thymospora pseudothiessenii Biozone (upper Bolsovian to Cantabrian) 2411'/735m SWC to 3441'/1048.8m

There is low confidence in defining the *Thymospora pseudothiessenii* Biozone based solely on the first stratigraphic occurrence of the index taxon as all occurrences are recorded in cuttings samples. The deepest occurrence of the taxon at 3888'/1185m, is assigned to the older *Vestispora fenestrata* Biozone (see below).

Based on range data from the North Sea (McLean *et al.* 2005) (figure 2.5), the lower biozone limit may be constrained by the last stratigraphic occurrence of *Dictyotriletes bireticulatus* at 3150'/960m. Occurrences of the taxon at this stratigraphic level in 34/5-1 are very infrequent. McLean *et al.* recorded the range top of the taxon at the lower limit of the equivalent W7 Biozone and Clayton *et al.* (1977) recorded occurrences of the taxon in the lower part of the equivalent OT Biozone of Western Europe. McLean *et al.* also recorded the range top of *Cingulizonates loricatus* in proximity to the equivalent W7 Biozone lower limit. However, in 34/5-1, the taxon is recorded consistently in the *T. pseudothiessenii* Biozone, with a last stratigraphic occurrence at 2608'/795m.

The lower limit of the *Thymospora pseudothiessenii* Biozone is positioned at the first stratigraphic occurrence of *Spinosporites* spp. in the 3441'/1048.8m sidewall core sample. The range base of the genus defines the lower limit of the equivalent OT

Biozone of Western Europe (Clayton *et al.* 1977). The taxon is not included in the miospore zonal scheme of the North Sea (McLean *et al.* 2005). Due to the two possible depths for the lower limit of the biozone, there is low confidence in the positioning of the biozone base in 34/5-1.

***Angulisporites splendidus* Sub-biozone (Cantabrian) 2411'/735m SWC to 2526'/770m**

The lower limit of the *Angulisporites splendidus* Sub-biozone is tentatively positioned at 2526'/770m based on the only occurrence of the index taxon in a cuttings sample. The sole occurrence of *Vittatina* sp. in a sidewall core sample at 2411'/735m confirms an age no older than Stephanian based on range data in Clayton *et al*. (1977). Overall, due to the risk of caving, there is low confidence in the positioning of the lower biozone limit based on the first stratigraphic occurrence of *A. splendidus* in a cuttings sample.

***Torispora verrucosa* Sub-biozone (Asturian) 2526'/770m to 3084'/940m or 3182'/970m**

The *Torispora verrucosa* Sub-biozone of Clayton *et al.* (2003) can be confirmed at 2723'/830m based on the first and only occurrence of the index taxon in the well. Using range data from the North Sea (McLean *et al.* 2005) (figure 2.5), the base of the Asturian can be positioned at least as deep as the occurrence of *Thymospora obscura* in the 2835'/864m sidewall core sample. Deeper occurrences are also recorded in cuttings samples at 3182'/970m and 3248'/990m. The first stratigraphic occurrence of *Savitrisporites camptotus* in the 2835'/864m sidewall core and the first stratigraphic occurrence of *Schopfites dimorphus* in the 2964'/903.5m sidewall core sample also confirm an Asturian age based on North Sea range data.

Additional taxa with range tops recorded in the Asturian of the North Sea (McLean *et al.* 2005) also occur in the 34/5-1 well. The last stratigraphic occurrence of *Endosporites zonalis* at 2789'/850m dates the sample as no younger than mid Asturian in age. The last stratigraphic occurrences of *Alatisporites hoffmeisterii*, *Cristatisporites solaris* and *Triquitrites tribullatus* are recorded at 2608'/795m. The last stratigraphic occurrences of *Westphalensisporites irregularis*, *Vestispora pseudoreticulata* and *Florinites junior* are recorded at 2526'/770m, 2493'/760m and

3150’/960m respectively. A sole occurrence of *Vestispora laevigata* is recorded at 3182’/970m.

A number of taxa with range tops recorded at the top of the Bolsovian Substage in north-western Europe by Butterworth (1984) are also recorded in 34/5-1. The last stratigraphic occurrences of *Raistrickia* cf. *superba, Vestispora costata* and *Lophotriletes microsaetosus* are recorded at 3084’/940m, 3150’/960m and 3182’/970m respectively. In combination with the last stratigraphic occurrences of *Florinites junior* and *Vestispora laevigata*, it is possible that the Bolsovian/Asturian boundary is positioned between 3084’/940m and 3182’/970m. Overall, there is uncertainty in the positioning of the base Asturian in the well.

***Westphalensisporites irregularis* Sub-biozone (upper Bolsovian) 3084’/940m or 3182’/970m to 3441’/1048.8m**

The lower limit of the *Westphalensisporites irregularis* Sub-biozone is coincident with the lower limit of the *Thymospora pseudothiessenii* Biozone. The index taxon is recorded once in the interval assigned to the sub-biozone.

***Vestispora fenestrata* Biozone (Bolsovian) 3441’/1048.8m to 4478’/1365m**

The interval assigned to the *Vestispora fenestrata* Biozone in 34/5-1 is characterised by occurrences of the index taxon. The biozone lower limit is tentatively defined by the first stratigraphic occurrence of *V. fenestrata* at 4478’/1365m. It is noted that the first stratigraphic occurrence of *Torispora securis*, which occurs in proximity to the lower limit of the equivalent North Sea W6 Biozone, is recorded in a cuttings sample at 4587’/1398m. As the upper limit of the *Microreticulatisporites nobilis* Biozone and Duckmantian Substage is positioned at 4587’/1398m (see below), it is assumed that the first stratigraphic occurrence of *V. fenestrata* may be more reliable in defining the lower limit of the *V. fenestrata* Biozone.

McLean *et al.* (2005) indicated that the range tops of *Grumosisporites varioreticulatus* and *Grumosisporites papillosus* mark the lower limit of the equivalent North Sea W6 Biozone (figure 2.5). In 34/5-1, the last stratigraphic occurrence of *G. varioreticulatus* is recorded at 4587’/1398m. *G. papillosus* is not recorded in the well. Overall, there is low confidence in the positioning of the biozone lower limit at 4478’/1365m as it is based solely on the first stratigraphic occurrence of *Vestispora fenestrata* in a cuttings sample.

Raistrickia aculeata Sub-biozone (Bolsovian) 3441’/1048.8m to 3609’/1100m.

The *Raistrickia aculeata* Sub-biozone cannot be identified based on occurrences of the index taxon as all occurrences are recorded in samples assigned to the Asturian age *Torispora verrucosa* Sub-biozone.

McLean *et al.* (2005) identified a number of taxa with range tops that mark the base of the equivalent W6b Sub-biozone of the North Sea (figure 2.5). However, in 34/5-1, the last stratigraphic occurrences of the taxa are recorded at a range of depths. The last stratigraphic occurrence of *Apiculatasporites spinososaetosus* is recorded at 3445’/1050m, just 4’/1.2m below the occurrence of *Spinosporites* spp. in sidewall core. The last stratigraphic occurrence of *Alatisporites pustulatus* is recorded at 3609’/1100m. A single occurrence of *Reticulatisporites polygonalis* is recorded at 4810’/1466m and the last stratigraphic occurrences of *Vestispora tortuosa* and *Savitrisporites nux* are both recorded in samples assigned to the *Thymospora pseudothiessenii* Biozone at 3084’/940m and 2526’/770m respectively. The lower biozone limit is very tentatively positioned at the last stratigraphic occurrence of *A. pustulatus*, but due to the range of occurrences of the other taxa, there is very low confidence in the positioning of the sub-biozone limit.

Torispora securis Sub-biozone (Bolsovian) 3609’/1100m to 4478’/1365m

The lower limit of the *Torispora securis* Sub-biozone corresponds to the lower limit of the *Vestispora fenestrata* Biozone. The interval assigned to the sub-biozone is characterised by moderately frequent occurrences of the index taxon in cuttings samples. McLean *et al.* (2005) indicate the range base of the index taxon occurs in proximity to the lower limit of the equivalent W6a Sub-biozone of the North Sea (figure 2.5). In 34/5-1, the first stratigraphic occurrence is recorded in a cuttings sample at 4587’/1398m; 108’/33m deeper than the lower limit of the *V. fenestrata* Biozone.

Triquitrites sculptilis Biozone (lower Bolsovian) 4478'/1365m to 4587'/1398m

The *Triquitrites sculptilis* Biozone is tentatively identified in well 34/5-1. The upper biozone limit is positioned based on the first stratigraphic occurrence of *Vestispora fenestrata* at 4478'/1365m. The biozone lower limit and the top Duckmantian is positioned at the last stratigraphic occurrence of *Cristatisporites connexus* at 4587'/1398m. The range top of the taxon also defines the Duckmantian/Bolsovian Substage boundary in the North Sea (McLean *et al.* 2005). Occurrences of the index taxon are also recorded in the interval assigned to the biozone. Overall, there is confidence in the positioning of the biozone lower limit as it is defined by the range top of a taxon.

McLean *et al*. (2005) additionally recorded the range top of *Radiizonates* cf. *striatus* just above the base of the equivalent North Sea W5b Sub-biozone (figure 2.5). The last stratigraphic occurrence of *R.* cf. *striatus* in 34/5-1 is recorded at 4587'/1398m. Butterworth (1984) recorded the range top of *Lophotriletes granoornatus* at the Duckmantian/Bolsovian Substage boundary in north-western Europe. The last stratigraphic occurrence in 34/5-1 is also recorded at 4587'/1398m. McLean *et al.* also recorded the range top of *Ahrensisporites guerickei* in proximity to the base of the W5b Sub-biozone. The last stratigraphic occurrence in 34/5-1 is recorded at 3445'/1050m and is potentially reworked.

As noted above, the last stratigraphic occurrence of *Grumosisporites varioreticulatus* in 34/5-1 is also recorded at 4587'/1398m. The range top defines the base of the North Sea W6 Biozone, which corresponds to the upper limit of the *Triquitrites sculptilis* Biozone. It is possible that *C. connexus* and *G. varioreticulatus* have similar stratigraphic ranges offshore western Ireland.

Microreticulatisporites nobilis Biozone (Duckmantian) 4587'/1398m to 4810'/1466m

The *Microreticulatisporites nobilis* Biozone is deemed to extend to the deepest sample depth of 4810'/1466m. The index taxon only occurs rarely in the interval assigned to the biozone, the sole occurrence is recorded at 4810'/1466m. However, there is an absence of taxa with range tops that should define the biozone lower limit, i.e *Sinuspores sinuatus*.

Rare occurrences of taxa with range tops restricted to the Langsettian of the North Sea (McLean *et al.* 2005) are recorded in samples assigned to the *M. nobilis* Biozone. Single occurrences of *Radiizonates aligerens* at 4587'/1398m, ?*Kraeuselisporites ornatus* at 4590'/1399m and *Radiizonates striatus* at 4810'/1466m are considered to be reworked.

Vestispora magna Sub-biozone (Duckmantian) 4587'/1398m to 4810'/1466m

The *Vestispora magna* Sub-biozone cannot be identified based solely on the first stratigraphic occurrence of the index taxon. Occurrences of the taxon in well 34/5-1 are restricted to samples assigned to the *Vestispora fenestrata* Biozone.

Alternatively, the presence of *Triquitrites sculptilis* in a cuttings sample at 4790'/1460m, tentatively assigns the sample to the *Vestispora magna* Sub-biozone. The range base of *T. sculptilis* defines the lower limit of the equivalent North Sea W5a Biozone of McLean *et al*. (2005).

VII.XVI Well 34/15-1

Revised palynostratigraphic interpretations are based on palynological data from Roveda *et al.* (1977) (figure 6.16).

Jurassic 11942'/3640m to 12894'/3930m

Cepek *et al.* (1977) assigned the interval 3870-3930m to the Jurassic, based on occurrences of the ostracod *Progonocythere* sp.

Permian (Artinskian to Kasanian) 13320'/4060m to 13697'/4175m or 14239'/4340m

The first downhole occurrences of *Potonieisporites* spp. at 13320'/4060m and *Lueckisporites virkkiae* at 13353'/4070m confirm an age no younger than Permian based on range data from Warrington (1984; 1996) and Traverse (1988). Cepek *et al.* (1977) also confirmed a Permian age for a sidewall core sample at 13697'/4175m based on the occurrence of the ostracod *Suchonellina* sp. Unless caved, the occurrence of *L. virkkiae* in the 13599'/4145m cuttings sample indicates an age no older than the mid Kungurian Stage of the Middle Permian based on range data from Warrington (1984). Warrington (1996) also noted that *Taeniaesporites* spp. first appears at the base of the Middle Permian Kazanian Stage in the Southern Urals. The taxon is recorded in 34/15-1 at 13353'/4070'.

Samples below 13697'/4175m are either assigned to the Permian or to the lower Autunian of the Carboniferous (see below). It is possible that the interval 13697'/4175m to 14239'/4340m is Permian in age. The miospore assemblage from 13353'/4070m to 13599'/4145m has similarities with an assemblage recorded from the Dôme de Barrot, France, assigned to the Zechstein (Middle to Late Permian) by Visscher *et al.* (1974). Visscher *et al.* recorded taxa including *Lueckisporites virkkiae, Klausipollenites schaubergeri, Nuskoisporites dulhuntyi* and rare *Vittatina* spp. Visscher (1971) also assigned strata from the Kingscourt outlier, Ireland to the Zechstein based on occurrences of *L. virkkiae, K. schaubergeri*, *N. dulhuntyi* and *Vittatina* spp. From 13353'/4070m to 13599'/4145m in 34/15-1, *Lueckisporites virkkiae* and *Nuskoisporites* spp. are recorded, although *Vittatina* spp. is absent. Traverse (1988) recorded the last stratigraphic occurrence of *Illinites unicus/polymorphus* in the mid Artinskian Stage of the Permian. As *Complexisporites polymorphus* is synonymous with *I. unicus*, the last stratigraphic occurrence at 14091'/4295m may suggest an age no younger than the mid Artinskian Stage of the Permian.

Carboniferous; 13714'/4180m or 14239'/4340m to 14534'/4430m

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

?*Vittatina costabilis* (VC) Biozone (lower Autunian) 13714'/4180m to 14239'/4340m

It is possible that the interval 13714'/4180m to 14239'/4340m is assigned to the lower Autunian age VC Biozone of Clayton *et al.* (1977). Clayton *et al.* defined the VC Biozone based on the predominance of monosaccate pollen (notably *Potonieisporites* spp. and *Florinites* spp.), a relative abundance of *Vittatina* spp., *Disaccites non-striatiti* and *Cheleidonites* spp. The authors also recorded a marked reduction in *Lycospora* spp., *Laevigatosporites* spp., *Punctatosporites* spp. and *Spinosporties spinosus* at the lower limit of the biozone compared with the older *Potonieisporites novicus-bharadwajii – Cheiledonites major* (NBM) Biozone.

In 34/15-1, the interval 13714'/4180m to 14239'/4340m is dominated by occurrences of *Potoneieisporites* spp. However, *Florinites* spp. is only recorded at the very base of the interval. There is an additional absence of *Vittatina* spp. and *Cheleidonites* spp. in the well. The lower limit of the biozone is positioned at the last stratigraphic occurrence of *Endosporites* sp. *globiformis*, which is not known in strata younger than the Stephanian in Western Europe (Peppers 1985). As a result, the last stratigraphic occurrence of *Lycospora* spp. is recorded below the biozone lower limit. The miospores assemblage shows some similarities with that recorded from shales of the Assise de Muse in Autun, France and assigned to the VC Biozone by Clayton *et al.* (1977). Bouroz and Doubinger (1977) indicated that the shales were dominated by monosaccate pollen with *Potonieisporites* spp. occurring more abundantly than *Florinites* spp. Monolete and trilete spores accounted for just 8% of the assemblage with *Vittatina* comprising just 2% of the assemblage.

***Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone (upper Stephanian B to Stephanian C) 14239'/4340m to 14587.6'/4446.35m**

A limited miospore assemblage is recorded in the interval 14239'/4340m to 14534'/4430m. Almost all occurrences are restricted to cuttings samples. The only productive core sample from 14573'/4442m to 14587.6'/4446.35m contains a single specimen of *Endosporites* sp.

The interval 14239'/4340m to 14587.6'/4446.35m is tentatively assigned to the *Potonieisporites novicus-bharadwajii – Cheleidonites major* (NBM) Biozone of Clayton *et al.* (1977). Peppers (1985) noted that the range top of *Endosporites globiformis* in Western Europe is not recorded in strata younger than Stephanian in age, equating to a biozone no younger than the NBM Biozone. In 34/15-1, Roveda *et al.* (1977) recorded the last stratigraphic occurrence of *E.* sp. *globiformis* at 14239'/4340m, although the authors did report some difficulty in distinguishing between specimens of *E.* sp. *globiformis* and *Nuskiosporites* spp. The last stratigraphic occurrence of *Lycospora* spp. is recorded at 14354'/4375m. Range data from Clayton *et al.* (1977) indicates the last stratigraphic occurrence of rare *Lycospora* spp. marks the upper limit of the Carboniferous System and the *Vittatina costabilis* (VC) Biozone in Western Europe. Clayton *et al.* also indicated that the last stratigraphic occurrence of common *Lycospora* spp. marks the upper limit of the older NBM Biozone. In 34/15-1, the last stratigraphic occurrence of *Lycospora* spp. is recorded by Roveda *et al.* (1977) as a common occurrence. It is possible that the disappearance of *Lycospora* spp may reflect the marked reduction in the number of *Lycospora* spp recorded at the NBM/VC Biozone boundary by Clayton *et al.* (1977).

Occurrences of *Florinites* spp. and *Potonieisporites* spp. recorded in the interval 14239'/4340m to 14534'/4430m are characteristic of both VC and NBM Biozones. However, a number of taxa that characterise the NBM Biozone of Clayton *et al.* (1977) are absent, notably *Laevigatosporites* spp., *Spinosporites spinosus, Thymospora* spp., *Cheleidonites* spp. and *Angulisporites splendidus*. Clayton *et al.* also recorded the range tops of *Crassispora kosankei* and *Westphalensisporites irregularis* in the middle of the NBM Biozone. An absence of the taxa in the 34/15-1 well tentatively suggests that only the upper part of the NBM Biozone is encountered. An absence of *Vestispora fenestrata* also suggests the older *Angulisporites splendidus – Latensina trileta* ST Biozone of Clayton *et al.* (1977) has not been encountered. Clayton *et al.* recorded the range top of the taxon at the upper limit of the biozone.

A late Stephanian assemblage recorded by Jerzykiewicz (1987) in the Intrasudetic Basin, south-western Poland shares some characteristics with the assemblage in 34/15-1. Jerzykiewicz also recorded representatives of *Potonieisporites, Nuskoisporites, Florinites* and *Endosporites globiformis*, although the author does not indicate if *Lycospora* spp. was present or not. An absence of *Vittatina* and *Cheleidonites* was also noted. However, Jerzykiewicz also recorded taxa that are not present in the 34/15-1 interval, including *Laevigatosporites perminutus*, *Spinosporites spinosus, Thymospora thiessenii, Vesicaspora wilsonii* and representatives of *Wilsonites* and *Guthoerlisporites.* Jerzykiewicz also noted the similarity of the Intrasudetic Basin assemblage to that of the NBM Biozone of Clayton *et al.* (1977).

There are also similarities between the assemblage recorded in 34/15-1 and those recorded in the Schistes d'Igornay, from the Autun Basin, France. Bouroz and Doubinger (1977) recorded an upper Stephanian age for the deposits and Clayton *et al.* (1977) assigned them to the NBM Biozone. A shale assemblage was dominated by monolete and trilete spores (87%) with *Vittatina* spp. accounting for just 1% of the content.

VII.XVII 34/19-1

Palynostratigraphic reinterpretations are based on palynological data from the 34/19-1 final well report (1978) (figure 6.17).

Jurassic 9089'/2770.5m - 10332.9'/3149.5m

The 34/19-1 Final Well Report (1978) recorded occurrences of *Klukisporites pseudoreticulatus* and *Contignisporites forteornatus* in core samples from 9629'/2935m and 9633.1'/2936.2m. The authors indicated that the microflora have range bases at the lower limit of the Kimmeridgian Stage in the Upper Jurassic. The final well report authors also recorded Bajocian to Kimmeridgian age nannoplankton in sidewall core and cuttings samples from the 9089'/2770.5m to 9482'/2890m depth interval. The final well report authors additionally recorded rare occurrences of "long-ranging (Jurassic to Lower Cretaceous) microflora" in sidewall core samples from 9839'/2999m, 10332.9'/3149.5m and cuttings samples from 9783'/2982m, 9980'/3042m and 10177'/3102m.

Permian (?Kasanian) 3203.45m to 10517.9'/3205.9m (TD)

A change in the miospore assemblage is recorded in core samples from 10509.9'/3203.45m, 10516.9'/3205.6m and 10517.9'/3205.9m. The occurrence of *Potonieisporites* spp. confirms an age no younger than the top Permian based on range data from Warrington (1984). The assemblage recorded also includes representatives of *Taeniaesporites* spp., *Striatopodocarpites* sp., *Parasaccites* spp. and *Striatites* spp. Warrington (1996) noted that *Taeniaesporites* spp. first appears at the base of the Middle Permian age Kazanian Stage in the Southern Urals. Traverse (1988) also recorded a Kazanian range base for *Lunatisporites* spp. (= *Taeniaesporites*). Warrington additionally noted that in deposits of Western Europe, Israel and the USA, that are equivalent in age to the Kazanian-Tatarian sequences of the Urals, assemblages that include representatives of *Striatopodocarpites* and *Lunatisporites* (= *Taeniaesporites*) are recorded. Based on this limited evidence, it is suggested that the core samples in 34/19-1 are at least Middle Permian in age. Occurrences of *Radiizonates aligerens* and *Endosporites* cf. *globiformis* in the core samples are considered reworked.

VII.XVIII 35/15-1

Palynostratigraphic interpretations of the 35/15-1 well are based on data recorded by Church *et al.* (1981) (figure 6.18).

Early Cretaceous (Albian to ?Barremian) 7370'/2246m to 8260'/2518m

Church *et al.* (1981) assigned an Early Cretaceous age to the interval 7370'/2246m to 8040'/2451m based on occurrences of foraminifera including *Hedbergella washitensis*, *Orbitolina* sp. and *Cribratina* sp. The authors also noted occurrences of the Early Cretaceous age foraminifera *Epistomina caracolla caracolla* and *Trocholina infragranulata* in the 8040'/2451m sidewall core. Ostracods recorded in the interval 8040'/2451m to 8250'/2515m include the Albian restricted species *Cytheris reticulate*.

?Carboniferous 8250'/2515m to 8750'/2518m

In samples from 8250'/2515m to the well TD, maturation levels recorded are high and recovery of *in situ* miospores is very poor. Church *et al.* (1981) recorded a spore colour index of between 9 and 10 for a specimen of *Lycospora pusilla* from 8750'/2667m.

Based entirely on lithostratigraphic data, Church *et al.* (1981) assigned the interval 8250'/2515m to 8750'/2667m to the Carboniferous. Early Cretaceous palynomorphs and microfossils recorded in cuttings samples from the interval are considered caved.

Early Carboniferous (Namurian to Viséan) 8750’/2667m to 12100’/3688m

The first downhole occurrence of *Lycospora pusilla* at 8750’/2667m confirms a Carboniferous age and an age no older than the Chadian Substage based on range data from Clayton *et al.* (1977). The first downhole occurrence of specimens of the genus *Vallatisporites* are recorded at 9140’/2786m. McLean (1993) recorded the range top of the genus in the lower Langsettian of the North Sea. An occurrence of cf. *Discernisporites micromanifestus* at 10950’/3338m may indicate an age no younger than the Yeadonian Substage. Butterworth (1984) recorded a Yeadonian range top for *D. micromanfestus* in north-western Europe. Overall the very limited palynomorphs data suggests the Carboniferous interval in 35/15-1 is potentially Namurian to Viséan in age.

VII.XIX 36/16-1

Revised palynostratigraphic interpretations are based on palynological data from King et al. (1979), Robeson (1988) and the present study (figure 6.19).

Tertiary (Eocene) 3480’/1061m to 3600’/1097m

Robeson (1988) assigned an Eocene age to cuttings samples from 3480’/1061m and 3600’/1097m based on the occurrence of a dinoflagellate assemblage that includes *Samlandia chlamydophora*, *Homotriblium tenuispinosum*, *Eucladopyxis* spp., *Impagidinium* spp. and *Deflandrea* spp. Two reworked Carboniferous taxa were recorded at 3480’/1061m; *Lycospora pusilla* and *Densosporites sphaerotriangularis*.

Cretaceous (Albian) 4160’/1268m to 4280’/1305m

King *et al.* (1979) assigned a late-middle Albian age to cuttings samples from 4230’/1289m to 4250’/1295m based on an assemblage of ostracods that includes *Cythereis* aff. *lamplughi, Veenia florentinensis* and *Bairdia pseudoseptentrionalis*. Samples from 4160’/1268m to 4280’/1305m were confirmed as no younger than Cretaceous in age based on the occurrence of the foraminiferid *Orbitolina* gr. *lenticularis.* Robeson (1988) also assigned a Cretaceous (Albian) age to a cuttings sample from 4200'/1280m based on the occurrence of *Cicatricosisporites australiensis, Cerebropollenites mesozoicus* and *Cyclonephelium distinctum.*

Carboniferous 4316'/1316m SWC to 9000'/2743m

The first downhole occurrence of Carboniferous strata is identified in a sidewall core sample at 4316'/1316m based on the absence of Mesozoic age taxa and the first (non-reworked) downhole occurrence of *Lycospora* spp. *Vestispora fenestrata* is first recorded in a sidewall core sample at 4327'/1319m, with *Endosporites globiformis, Crassispora kosankei* and *Spinosporites spinosus* first recorded at 4330'/1320m.

King *et al*. (1979) positioned the Carboniferous/Cretaceous unconformity at 4300'/1311m based on the transition from Cretaceous limestones to Carboniferous siltstones and claystones (figure 6.19).

Clayton *et al.* (1977) Western European Miospore Zonal Scheme

Angulisporites splendidus – Latensina trileta (ST) Biozone (upper Barruelian to Stephanian B); 4316'/1316m SWC to 4435'/1352m SWC

Clayton *et al.* (1977) indicate the lower limit of the ST Biozone is defined by the range bases of *Angulisporites splendidus* and *Cheleidonites* spp. (figure 2.2). In the absence of *A. splendidus,* the lower limit of the biozone in 36/16-1 is positioned at least as deep as the occurrence of *Cheleidonites* spp. in sidewall core at 4435'/1352m. Occurrences of the taxon in deeper cuttings samples at 4500'/1372m, 4600'/1402m and 4900'/1494m may be caved. Samples assigned to the biozone are characterised by a miospore assemblage including the index taxon *Latensina trileta* in addition to *Spinosporites spinosus, Westphalensisporites irregularis, Lundbladispora gigantea, Cirratriradites saturni* and *Vestispora fenestrata.* However, a number of species that characterise the ST Biozone in Clayton *et al.* are either absent from the well, i.e *Vittatina* spp*., Candidispora* spp., *Polymorphisporites* spp., *Savitrisporites camptotus* and *Florinites junior*, or occur in samples deeper than 4435'/1352m, i.e. *Disaccites non-striatiti.* Overall, there is only moderate confidence in the positioning of the biozone lower limit. Although the occurrence of *Cheleidonites* spp. in sidewall core is used to define the biozone lower limit, the depth is not constrained by the range tops of taxa.

Thymospora obscura – Thymospora thiessenii (OT) Biozone (upper Bolsovian to lower Barruelian) 4435'/1352m SWC to 5000'/1524m

Clayton *et al.* (1977) indicated that the range bases of *Thymospora* spp. and *Spinosporites spinosus* define the lower limit of the OT Biozone (figure 2.2). In 36/16-1, occurrences of *S. spinosus* are restricted to samples assigned to the ST Biozone. The occurrence of index taxon *Thymospora obscura* in a sidewall core sample at 4856'/1480m confirms the OT Biozone at this depth. The lower biozone limit is positioned at a cuttings sample at 5000'/1524m based on the first stratigraphic occurrences of *T. obscura*, *Thymospora pseudothiessenii* and the last stratigraphic occurrence of *Dictyotriletes bireticulatus*. Clayton *et al.* indicate the range top of *D. bireticulatus* marks the lower part of the OT Biozone, although occurrences in 36/16-1 are very infrequent. The last stratigraphic occurrence of *Cingulizonates loricatus* should also define the lower part of the biozone. However, in well 36/16-1, the taxon is recorded throughout the OT Biozone and in samples assigned to the ST Biozone. Samples assigned to the OT Biozone in 36/16-1 are characterised by moderately frequent occurrences of *T. obscura* and *T. pseudothiessenii* in addition to occurrences of *Westphalensisporites irregularis*, *Vestispora fenestrata* and *Cirratriradites saturni.* Clayton *et al.* also recorded the range bases of *Polymorphisporties* spp*.*, *Savitrisporites camptotus* and *Candidispora* spp in the lower part of the OT Biozone. The taxa are not recorded in well 36/16-1. Overall, as the biozone lower limit is defined by the first stratigraphic occurrence of the index taxon and constrained by the range top of *D. bireticulatus*, there is confidence in the positioning of the lower limit.

Torispora securis – Torispora laevigata (SL) Biozone (Bolsovian) 5000'/1524m to 6012'/1832m SWC

The range bases of *Torispora* spp. and *Vestispora fenestrata* define the lower limit of the SL Biozone of Clayton *et al.* (1977) (figure 2.2). The lower biozone limit in 36/16-1 occurs at least as deep as 6012'/1832m based on the presence of *Torispora securis* in sidewall core at this depth. *V. fenestrata* and *T. securis* are both recorded in the interval assigned to the biozone and occurrences are also recorded in cuttings samples below 6012'/1832m. Unfortunately, taxa with range tops that define the SL

Biozone base in Clayton *et al.* (1977) are not useful for constraining the biozone lower limit in 36/16-1. *Grumosisporites varioreticulatus* is only recorded in a single sample at 5400'/1646m and the last stratigraphic occurrence of *Raistrickia fulva* is recorded at 4370'/1332m, assigned to the ST Biozone. The next deepest occurrence is recorded at 5810'/1771m. *Grumosisporites maculatus* is not recorded in the well.

Clayton *et al.* (1977) also recorded the range bases of *Latensina trileta* and *Disaccites striatiti* within the SL Biozone. In 36/16-1 the first stratigraphic occurrence of *D. striatiti* is recorded within the biozone at 5400'/1646m; although the first stratigraphic occurrence of *L. trileta* is recorded in samples assigned to the upper OT Biozone. Clayton *et al.* also recorded the first stratigraphic occurrence of *Punctatosporites granifer* and the last stratigraphic occurrence of *Savitrisporites nux* in the lower part of the SL Biozone. In 36/16-1, the first stratigraphic occurrence of *P. granifer* at 4770'/1454m is restricted to the OT Biozone and *S. nux* is recorded in samples assigned to the upper SL and OT Biozones. Overall, as the lower limit is not constrained by the range tops of taxa, there is only moderate confidence in the positioning of the lower biozone limit.

Microreticulatisporites nobilis – Florinites junior (NJ) Biozone (lowermost Bolsovian to Duckmantian) 6012'/1832m SWC to 7030'/2143m or unconformable contact with Arnsbergian age strata at 8300'/2530m

Clayton *et al.* (1977) indicated that the range bases of the index taxa define the lower limit of the NJ Biozone (figure 2.2). In 36/16-1, index taxon *Microreticulatisporites nobilis* occurs very infrequently with the first stratigraphic occurrence recorded at 6300'/1920m. *Florinites junior* is not recorded in the well.

Clayton *et al.* (1977) indicated that the boundary between the NJ Biozone and the older *Radiizonates aligerens* (RA) Biozone is marked by the range tops of *Schulzospora rara* and *Sinuspores sinuatus*. *S. sinuatus* is not recorded in the 36/16-1 well. *S. rara* occurs very sporadically in 36/16-1, occurring in two samples assigned to the NJ Biozone in addition to occurrences at 7030'/2143m and 8390'/2557m. There is an additional absence of the index taxon *R. aligerens*, which defines the RA Biozone. However, it is possible that the occurrence of *Schulzospora rara* at 7030'/2143m marks the NJ/RA Biozone boundary (see below).

Samples assigned to the NJ Biozone in 36/16-1 are also characterised by occurrences of *Punctatosporites* spp., *Dictyotriletes bireticulatus* and *Vestispora costata/cancellata*. The last stratigraphic occurrence *of Bellispores* spp. should occur in the lower part of the biozone but occurrences are recorded in samples assigned to the SL Biozone

Questionnable *Radiizonates aligerens* (RA) Biozone (Langsettian) 7030'/2143m to unconformable contact with Arnsbergian at 8300'/2530m

Clayton *et al.* (1977) recorded the range top of *Radiizonates aligerens, Schulzospora rara* and *Sinuspores sinuatus* at the RA/NJ Biozone boundary in Western Europe. In 36/16-1, both *R. aligerens* and *S. sinuatus* are absent although *S. rara* is recorded in four samples. The top two occurrences, recorded in samples assigned to the SL Biozone at 5600'/1707m and 6000'/1829m, are reworked. It is possible that the occurrence of *S. rara* at 7030'/2143m defines the boundary between the RA and NJ Biozones. Only one further occurrence of *S. rara* is recorded at 8390'/2557m, in possible Arnsbergian age strata. A solitary occurrence of *Kraeuselisporties ornatus* recorded at 5280'/1609m is also recorded in the SL Biozone. Clayton *et al.* (1977) indicate the range top of the taxon marks the middle of the RA Biozone. Overall, there is very sparse evidence for the RA Biozone in 36/16-1.

Arnsbergian 8300'/2530m to 9000'/2743m (biozone cannot be defined due to lack of index taxa)

Limited miospore assemblages have been recorded below 8190'/2496m due to the high rank (>2.00%Rr). Occurrences of *Schulzospora ocellata* from 8300'/2530m, *Radiizonates cuesta* and *Radiizonates striatus* at 8390'/2557m in addition to a lack of species with ranges restricted to the Westphalian tentatively suggest a Namurian age. *Radiizonates cuesta* is only recorded in Arnsbergian age strata of north-western Europe (Butterworth 1984). McLean *et al.* (2005) and Butterworth (1984) record the range top of *S. ocellata* in the lowermost Kinderscoutian of the North Sea and northwest Europe. Butterworth also recorded a Pendleian range base. Occurrences of *Crassispora kosankei* in a sidewall core at 8850'/2698m confirm an age no older than the base Pendleian based on range data from Owens *et al.* (2004) and Butterworth (1984). Occurrences of *R. striatus* in a cuttings sample at 8850'/2698m also indicate an age no older than Pendleian based on range data from McLean *et al.* (2005). However, an absence of Arnsbergian or Pendleian age index taxa from the Western European miospore zonal schemes of Clayton *et al.* (1977) means the strata cannot be assigned to a biozone.

Clayton *et al.* (2003) Western European Miospore Zonal Scheme

Thymospora pseudothiessenii Biozone (upper Bolsovian to Cantabrian) 4136'/1261m SWC to 5000'/1524m

The *Thymospora pseudothiessenii* Biozone and *Angulisporites splendidus*, *Torispora verrucosa* and *Westphalensisporites irregularis* Sub-biozones of Clayton *et al.* (2003) correspond to the OT Biozone of Clayton *et al.* (1977).

The lower limit of the *T. pseudothiessenii* Biozone can be tentatively defined by the first stratigraphic occurrence of the index taxon in a cuttings sample at 5000'/1524m. The index taxon occurs moderately consistently in samples assigned to the biozone. However, additional taxa are required to constrain the lower limit due to the inherent risk of caving associated with cuttings samples.

The lower biozone limit is constrained by the last stratigraphic occurrence of *Dictyotriletes bireticulatus* at 5000'/1524m. The range top of the taxon defines the lower limit of the equivalent W7 Biozone of the North Sea (McLean *et al.* 2005) (figure 2.5) in addition to marking the lower part of the equivalent OT Biozone of Western Europe (Clayton *et al.* 1977). The lower biozone limit is also constrained by the last stratigraphic occurrence of *Radiizonates tenuis* at 5200'/1585m. McLean *et al.* recorded the range top of the taxon just below the North Sea W7 Biozone lower limit. McLean *et al.* also recorded the range top of *Cingulizonates loricatus* in proximity to the W7 Biozone lower limit. However, in 36/16-1 the taxon is recorded in samples throughout the *T. pseudothiessenii* Biozone, including samples assigned to the Cantabrian age *Angulisporites splendidus* Sub-biozone (see below). Rare occurrences of *Punctatosporites oculus* and *Mooreisporites cf. inusitatus* also occur infrequently in samples assigned to the *T. pseudothiessenii* Biozone in 36/16-1. Butterworth (1984) indicate the range bases of the taxa occur at the lower limit of the OT Biozone in north-western Europe. Overall, as the biozone lower limit is defined by the first stratigraphic occurrence of the index taxon and is constrained by the range top of *D. bireticulatus*, there is confidence in the positioning of the lower limit.

Angulisporites splendidus Sub-biozone (Cantabrian) 4316'/1316m SWC to 4435'/1352m SWC

The *A. splendidus* Sub-biozone cannot be identified in 36/16-1 based on the first stratigraphic occurrence of the index taxon due to its absence from the well. Alternatively, the lower limit of the Cantabrian Substage can be positioned at least as deep as the occurrence of *Cheleidonites* spp. in sidewall core from 4435'/1352m based on range data from Clayton *et al.* (1977). Although the occurrence of *Cheleidonites* spp. in sidewall core is used to define the biozone lower limit, as the depth of the lower limit is not constrained by the range tops of additional taxa, there is only moderate confidence in the positioning of the biozone lower limit.

Torispora verrucosa Sub-biozone (Asturian) 4435'/1352m SWC to 4856'/1480m SWC

In 36/16-1, the first stratigraphic occurrence of the index taxon at 4640'/1414m confirms the presence of the *Torispora verrucosa* sub-biozone at this depth. The index taxon is also recorded in the 4350'/1326m cuttings sample. Using range data from the North Sea, the Asturian lower limit is positioned at least as deep as the occurrence of *Thymospora obscura* in the 4856'/1480m sidewall core sample. McLean *et al.* (2005) recorded the range base of the taxon at the lower limit of the Asturian Substage in the North Sea (figure 2.5). In 36/16-1, the first stratigraphic occurrence is recorded in a cuttings sample at 5000'/1524m and may be caved. The positioning of the base Asturian is roughly constrained by the last stratigraphic occurrences of *Vestispora costata/cancellata* at 4856'/1480m and *Lophotriletes microsaetosus* at 4850'/1478m. McLean *et al.* recorded the range top of *V. cancellata* just above the Asturian lower limit in the North Sea and Butterworth (1984) recorded the range top of *V. costata* and *L. microsaetosus* at the top of the Bolsovian Substage in north-western Europe.

However, it is noted that Butterworth (1984) also recorded the range tops of *Calamospora* cf. *breviradiata* and *Raistrickia* cf. *superba* at the top Bolsovian of north-western Europe. In 36/16-1, the last stratigraphic occurrences of are recorded at 4640'/1414m and 4450'/1356m. A number of taxa with range bases recorded in the

Asturian of the North Sea (McLean *et al.* 2005) are either absent from 36/16-1 or very rare in occurrence. *Schopfites dimorphus, Cirratriradites annulatus* and *Savitrisporites camptotus* are absent and *Lundbladispora gigantea* only occurs in a single sample assigned to the *A. splendidus* Sub-biozone.

A number of taxa with range tops recorded in the Asturian of the North Sea are also recorded in 36/16-1. The last stratigraphic occurrence of *Vestispora pseudoreticulata* at 4500'/1372m is assigned to the upper part of the *Torispora verrucosa* Sub-biozone. However, *Vestispora laevigata, Endosporites zonalis* and *Triquitrites tribullatus* are recorded consistently throughout the sub-biozone and in samples assigned to the Cantabrian age *Angulisporites splendidus* Sub-biozone. In addition, the last stratigraphic occurrences of *Alatisporites hoffmeisterii* and *Cristatisporites solaris* are recorded below the sub-biozone lower limit.

Overall, although the biozone lower limit is defined by occurrences of *T. obscura* in sidewall core and constrained by the range top of *V. costata-cancellata and L. microsaetosus* there is only moderate confidence in the positioning of the lower limit due to the occurrence of *T. obscura* in a deeper cuttings sample and the occurrences of *C.* cf. *breviradiata* and *R.* cf. *superba* in shallower samples.

Westphalensisporites irregularis **Sub-biozone (lower Bolsovian) 4856'/1480m SWC to 5000'/1524m**

The lower limit of the *Westphalensisporites irregularis* Sub-biozone corresponds to the base of the *Thymospora pseudothiessenii* Biozone. Samples assigned to the sub-biozone are characterised by occurrences of the index taxon.

Vestispora fenestrata **Biozone (Bolsovian) 5000'/1524m to 6012'/1832m SWC**

The *Vestispora fenestrata* Biozone, *Raistrickia aculeata* and *Torispora securis* Sub-biozones of Clayton *et al.* (2003) correspond to the SL Biozone of Clayton *et al.* (1977)

The lower limit of the *Vestispora fenestrata* Biozone in 36/16-1 cannot be defined solely on the first stratigraphic occurrence of the index taxon as caved occurrences are recorded in cuttings samples assigned to Duckmantian age biozones (see below).

Alternatively, the lower limit of the biozone limit is positioned at least as deep as 6012'/1832m based on the deepest occurrence of *Torispora securis* in a sidewall core sample (the deepest occurrence of *V. fenestrata* in a sidewall core is at 5630'). The first stratigraphic occurrence of *T. securis* defines the lower limit of the equivalent W6 Biozone of the North Sea (McLean *et al.* 2005) and the SL Biozone of Western Europe (Clayton *et al.* 1977).

The range top of *Grumosisporites varioreticulatus* marks the lower limit of the North Sea W6 Biozone in addition to the SL Biozone of Western Europe. The range top of *Grumosisporites papillosus* is also recorded at the base of the W6 Biozone. However, as noted above, the last of two stratigraphic occurrences of *G. varioreticulatus* in 36/16-1 is recorded in the middle of the *V. fenestrata* Biozone at 5400'/1642m. *G. papillosus* is recorded in two even shallower samples at 4850'/1478m and 5100'/1554m. Without range tops of taxa to constrain the lower biozone limit, the occurrences of *T. securis* and *V. fenestrata* in cuttings samples below the 6012'/1832m sidewall core sample are deemed unreliable for defining the lower limit of the biozone due to the possibility of caving. As the lower limit is not constrained by the range tops of taxa, there is only moderate confidence in the positioning of the lower biozone limit.

***Raistrikia aculeata* Sub-biozone (Bolsovian) 5000'/1524m to 5280'/1609m or 5300'/1615m**

In 36/16-1, the *R. aculeata* Sub-biozone lower limit cannot be identified based on the first stratigraphic occurrence of the index taxon as all occurrences are recorded in samples assigned to the *Torispora verrucosa* and *Angulisporites splendidus* Sub-biozones.

The sub-biozone lower limit is difficult to define using the range tops of taxa that mark the base of the equivalent W6b Sub-biozone of the North Sea (McLean *et al.* 2005). The last stratigraphic occurrences of *Apiculatasporites pustulatus* and *Vestispora tortuosa* are recorded in samples assigned to the *T. verrucosa* Sub-biozone. If the occurrences are deemed to be reworked, the next deepest occurrences at 5280' and 5300' respectively may very tentatively represent the last true stratigraphic occurrences and the sub-biozone lower limit. The range top of *Savitrisporites nux* also marks the base of the W6b Sub-biozone but is consistently recorded in samples assigned to the upper *Vestispora fenestrata* Biozone and the lower *T. pseudothiessenii* Biozone in 36/16-1. McLean *et al.* (2005) also recorded the range base of *Latensina trileta* in proximity to the lower limit of the W6b Sub-biozone. However, in 36/16-1, occurrences are restricted to samples assigned to the *Torispora verrucosa* and *Angulisporites splendidus* Sub-biozones. Overall there is very low confidence in the positioning of the sub-biozone lower limit in 36/16-1.

Torispora securis **Sub-biozone (Bolsovian) 5280'/1609m or 5300'/1615m to 6012'/1832m SWC**

If the *Raistrickia aculeata* Sub-biozone lower limit can be positioned in the 36/16-1 well, the remaining lower part of the *Vestispora fenestrata* Biozone is assigned to the *Torispora securis* Sub-biozone, characterised by moderately frequent occurrences of the index taxon. The lower limit of the sub-biozone corresponds to the lower limit of the *Vestispora fenestrata* Biozone.

Triquitrites sculptilis **Biozone (lowermost Bolsovian) 6012'/1832m SWC to 6200'/1890m**

The *Triquitrites sculptilis* Biozone corresponds to the uppermost part of the NJ Biozone of Clayton *et al.* (1977). There is low confidence in the positioning of the *Triquitrites sculptilis* Biozone lower limit. Almost all taxa with range tops that define the lower biozone limit of the equivalent North Sea W5b Biozone (McLean *et al.* 2005) are absent from the well, e.g *Cristatisporites connexus, Densosporites duriti* and *Camptotriletes bucculentus. Ahrensisporites guerickei* is recorded, but occurrences are restricted to samples assigned to the uppermost *Vestispora fenestrata* Biozone and the *Torispora verrucosa* Sub-biozone.

Alternatively, the biozone lower limit and top Duckmantian are very tentatively positioned at 6200'/1890m based on the last stratigraphic occurrence of *Lophotriletes* cf. *gibbosus.* Butterworth (1984) indicated the range top of the taxa occurs at the top of the Duckmantian Substage in north-western Europe. The index taxon *T. sculptilis* is recorded in the subsequent interval assigned to the biozone. McLean *et al.* also recorded the range top of *Radiizonates* cf. *striatus* just above the top Duckmantian Substage in the North Sea. In 36/16-1, the last stratigraphic occurrence is recorded in samples assigned to the lower *Vestispora fenestrata* Biozone. Overall there is low confidence in the positioning of the biozone lower limit due to the lack of key taxa.

Microreticulatuisporites nobilis **Biozone (Duckmantian) 6200'/1890m to unconformable contact with Arnsbergian at 8300'/2530m**

The *Microreticulatisporites nobilis* Biozone, *Vestispora magna* and *Lycospora noctuina noctuina* Sub-biozones of Clayton *et al.* (2003) correspond to the middle of the NJ Biozone of Clayton *et al.* (1977).

The range base of the index taxon should define the *M. nobilis* Biozone lower limit. However, the taxon occurs very infrequently in the 36/16-1 well with a deepest occurrence of just 6300'/1920m. The range top of *Sinuspores sinuatus* should also define the biozone lower limit. However, the taxon is not recorded in 36/16-1. Evidence below suggests the *Microreticulatisporites nobilis* Biozone extends to an unconformable contact with Arnsbergian age strata at 8390'/2557m.

Vestispora magna **Sub-biozone (Duckmantian) 6200'/1890m to 7348'/2240m SWC**

The *Vestispora magna* Sub-biozone cannot be identified in 36/16-1 based on the first stratigraphic occurrence of the index taxon due to its absence from the well. Alternatively, the lower limit of the sub-biozone is defined by the first stratigraphic occurrence of *Triquitrites sculptilis* recorded in a sidewall core sample at 7348'/2240m. McLean *et al.* (2005) recorded the range base of the taxon at the lower limit of the equivalent North Sea W5a Sub-biozone. McLean *et al.* also recorded the range base of *Punctatosporites granifer* in proximity to the lower limit of the W5a Sub-biozone. However, in 36/16-1 occurrences are restricted to samples assigned to the *Torispora verrucosa* and *Angulisporites spelndidus* Sub-biozones. The range top of *Savitrisporites concavus* is also recorded in proximity to the lower limit of the W5a Sub-biozone. In 36/16-1, the last stratigraphic occurrence at 5280'/1609m is assigned to the upper *Vestispora fenestrata* Biozone. However, the next deepest occurrence at 7360'/2243m is in proximity to the range base of *T. sculptilis*. Other taxa whose range tops define the lower limit of the W5a Sub-biozone are absent from the 36/16-1 well. There is only moderate confidence in the positioning of the lower sub-biozone boundary due to the absence of the index taxon and because the lower limit is not constrained by the range tops of taxa.

Lycospora noctuina noctuina Sub-biozone (Duckmantian) 7348'/2240m SWC to unconformable contact with Arnsbergian at 8300'/2530m

The *Lycospora noctuina noctuina* Sub-biozone cannot be defined in 36/16-1 based on occurrences of the index taxon due to its absence from the well. Alternatively, the sub-biozone is characterised by occurrences of *Cristatisporites solaris.* McLean *et al.* (2005) recorded the range base of the taxon at the top of the W4b Sub-biozone of the North Sea, corresponding to the mid *Lycospora noctuina-noctuina* Sub-biozone. The first stratigraphic occurrence of the taxon in 36/16-1 is recorded in a cuttings sample at 7960'/2426m. The presence of a casing shoe at 7944'/2421m suggests the occurrences are not caved from strata above this depth. The sub-biozone is deemed to extend to the unconformity with Arnsberigan age strata at 8300'/2530m.

Questionnable *Schulzospora rara* Biozone (Langsettian)

The upper limit of the Langsettian age *Schulzopora rara* Biozone of Clayton *et al.* (2003) is marked by the range top of the index taxon. As a result, the top two occurrences of *S. rara* in 36/16-1, in samples assigned to the *Vestispora fenestrata* Biozone, are deemed to be reworked. Based on range data from the North Sea (McLean *et al.* 2005) the first stratigraphic occurrence of *Triquitrites sculptilis* in a sidewall core sample at 7348'/2240m marks the base of the middle Duckmantian age *Vestispora magna* Sub-biozone of Clayton *et al.* (2003). This indicates the occurrence of *S. rara* at 7030'/2143m is also reworked. The deepest occurrence of *S. rara* at 8390'/2557m is tentatively assigned to the Arnsbergian Substage (see below). An absence of *Radiizonates aligerens* in the 36/16-1 well also suggests Langsettian age strata have not been penetrated.

Occurrences of *Apiculatasporites variocorneus* and *Radiizonates striatus* are also recorded at 7300'/2225m and 7130'/2173m respectively. The range tops of the taxa mark the Langsettian/Duckmantian substage boundary in the North Sea (McLean *et al.* 2005). However, both are considered reworked as they occur in samples shallower than the occurrence of *T. sculptilis* in the 7348'/2240m sidewall core sample. It is noted that reworked taxa with range tops no younger than Namurian are also recorded at this stratigraphic level including *Anapiculatisporites globulus* at 7030'/2143m and 7130'/2173m, *Procorona dumosa* at 7130'/2173m and *Radiizonates cuesta* at

7130'/2173m'. However, single occurrences of *Dictyotriletes probireticulatus* and *Waltispora polita* are also recorded at 7510'/2289m at 8190'/2496m. Both have range tops in the mid Langsettian of the North Sea.

Overall, the palynological data from the 36/16-1 suggests the *Schulzospora rara* Biozone and top Langsettian have not been penetrated.

Arnsbergian 8300'/2530m to 9000'/2743m (Biozone cannot be defined due to lack of index taxa

Again, occurrences of *Schulzospora ocellata* from 8300'/2530m, *Radiizonates cuesta* and *Radiizonates striatus* at 8390'/2557m in addition to a lack of species with ranges restricted to the Westphalian tentatively suggest a Namurian age for the interval 8300'/2530m to 9000'/2743m. However, an absence of Arnsbergian or Pendleian age index taxa from the Western European miospore zonal scheme of Clayton *et al*. (2003) means the strata cannot be assigned to a biozone.

APPENDIX VIII

CARBONATE SAMPLE DESCRIPTIONS

36/16-1

Sample 1. Not enough sample for analysis.

Sample 2. 4680-90’
Brown, hard, very finely crystalline limestone (Sample 2A).
Rare calcitic shell fragments (Sample 2B).

Sample 3. 5360-70’
Dark grey/brown/purple, hard, very finely crystalline limestone (Sample 3A).
White crystalline limestone with a sugary texture (Sample 3B).

Sample 4. 7340-50’
White, crystalline, hard with a sugary texture (Sample 4B).
No Group A carbonates present.

26/28-1

Sample 5. Not enough sample for analysis.

Sample 6. 2785m
Brown, very finely crystalline limestone (Sample 6A).
No Group B carbonates present.

Sample 7. 2925m
Purple/brown, very finely crystalline limestone (Sample 7A).
White, sugary textured limestone (Sample 7B).

Sample 8. 2980m
Purple/brown, very finely crystalline limestone (Sample 8A).
White/grey, crystalline limestone with sugary texture (Sample 8B).

Sample 9. 3030m
Brown, soft, very finely crystalline limestone (Sample 9A).
White/grey, hard, crystalline limestone (Sample 9B).

Sample 10. 3180m
Brown, very finely crystalline limestone (Sample 10A).
White, crystalline to sandy limestone (Sample 10B).

26/28-2

Sample 11. 2320m
Purple-brown, moderately hard, very finely crystalline limestone (Sample 11A). White/buff, sandy limestone (Sample 11B).

Sample 12. 2340m
Brown, moderately hard, very finely crystalline limestone (Sample 12A).
White, coarse, sandy limestone (Sample 12B).

Sample 13. 2470m
Brown, moderately hard, very finely crystalline limestone (Sample 13A).
White to pale grey, sandy limestone (Sample 13B).

APPENDIX IX

δ^{18}O AND δ^{13}C ISOTOPE DATA FROM CF-IRMS ANALYSIS

			Initial run		Replicate run					
Sample	**Well**	**Depth**	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{SMOW}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{SMOW}$	$\delta^{13}C_{VPDB}$ Average	$\delta^{18}O_{SMOW}$ Average	$\delta^{13}C_{VPDB}$ Std. Dev.	$\delta^{18}O_{SMOW}$ Std. Dev.
2A	36/16-1	4680-90'	-8.51	-5.56	-8.50	-5.79	-8.51	-5.67	0.00	0.16
3A	36/16-1	5360-70'	-9.66	-8.25	-9.44	-8.28	-9.55	-8.27	0.15	0.02
6A	26/28-1	2785m	-3.98	-2.54	-2.61	-3.19	-3.29	-2.86	0.97	0.46
7A	26/28-1	2925m	-6.82	-4.38	-6.08	-4.24	-6.45	-4.31	0.53	0.10
8A	26/28-1	2980m	-10.30	-9.46	-10.40	-10.49	-10.35	-9.98	0.08	0.73
9A	26/28-1	3030m	-5.49	-4.94	-4.65	-4.64	-5.07	-4.79	0.59	0.21
10A	26/28-1	3180m	-7.41	-5.79	-7.63	-5.51	-7.52	-5.65	0.15	0.20
10A	26/28-1	3180m			-7.83	-5.66				
11A	26/28-2	2320m	-7.83	-4.01	-7.96	-4.26	-7.90	-4.13	0.09	0.17
12A	26/28-2	2340m	-14.59	-2.71	-13.83	-2.46	-14.21	-2.58	0.54	0.17
13A	26/28-2	2470m	-12.44	-5.67	-12.52	-5.61	-12.48	-5.64	0.05	0.04
2B	36/16-1	4680-90'	5.67	-6.55	4.80	-6.21	5.24	-6.38	0.61	0.24
3B	36/16-1	5360-70'	-11.70	-14.82	-11.52	-14.34	-11.61	-14.58	0.12	0.34
4B	36/16-1	7340-50'	2.81	-11.97	2.19	-12.33	2.50	-12.15	0.44	0.25
7B	26/28-1	2925m	-10.28	-11.89	-9.37	-10.57	-9.83	-11.23	0.64	0.93
8B	26/28-1	2980m	-10.80	-10.51	-10.66	-9.97	-10.73	-10.24	0.10	0.38
9B	26/28-1	3030m	-7.42	-5.25	-7.67	-5.29	-7.54	-5.27	0.18	0.04
10B	26/28-1	3180m	-6.99	-11.84	-7.12	-11.18	-7.06	-11.51	0.09	0.47
11B	26/28-2	2320m	-10.45	-12.76	-10.36	-12.35	-10.40	-12.55	0.06	0.29
12B	26/28-2	2340m	-11.73	-10.21	-11.31	-9.63	-11.52	-9.92	0.30	0.41
13B	26/28-2	2470m	-9.49	-7.47	-9.58	-7.94	-9.53	-7.71	0.06	0.33

APPENDIX X
PLATES

Well number, sample depth, slide number and England Finder co-ordinates are provided for each figure. Museum catalogue numbers (prefixed TCD) are provided for specimens curated in the Geological Museum of Trinity College, Dublin, Ireland. All figures are illustrated at x500 magnification unless otherwise specified.

Note; specimen numbers with a single asterisk (*) were first figured by Robeson (1988). These specimens are located in the slide collection of Robeson (1988), curated in the Geological Museum of Trinity College, Dublin, Ireland.

PLATE 1

No.	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.*	*Calamospora microrugosa*	W40/1	34/5-1	1320(3)	1320m	30441
2.	*Calamospora breviradiata*	M39	12/2/1z	R8 ox20mins(2)	4342m	60133
3.	*Calamospora breviradiata*	L26/1	27/5-1	AH11(2)	1675m	60134
4.	*Calamospora mutabilis*	W45/3	26/27-1b	8541(4)	8541’	60135
5.*	*Calamospora* cf. *breviradiata*	H7	26/28-3	2450(4)	2450m	30438
6.	*Calamospora pedata*	L33/4	26/27-1b	8800(2)	8800’	60136
7.	*Calamospora straminea*	U47/4	26/27-1b	8800(2)	8800’	60137
8.	*Calamospora parva*	K35/4	12/2-1z	R15 ox20mins(1)	4384m	60138
9.*	*Leiotriletes sphaerotriangularis*	G11/4	26/28-2	2550(3)	2550m	30432b
10.*	*Leiotriletes tumidus*	R45/1	19/5-1	6100(3)	6100’	30433
11.	*Sinuspores* cf. *sinuatus*	E46	27/5-1	AH49(1)	1789m	60139
12.*	*Sinuspores sinuatus*	R29/4	19/5-1	3880(4)	3880’	30437
13.	*Punctatisporites aerarius*	C44/1	27/5-1	AH20 ox30mins(1)	1702m	60140
14.	*Punctatisporites punctatus*	M22/2	27/5-1	AH12(1)	1678m	60141
15.	*Punctatisporites glaber*	R60/3	27/5-1	AH10 ox15mins(2)	1672m	60142
16.	*Punctatisporites minutus*	D28/3	26/27-1b	9159(2)	9159’	60143
17.*	*Punctatisporites obesus*	H36	34/5-1	770(3)	770m	30436
18.*	*Waltzispora polita*	P26	19/5-1	7320(4)	7320’	30503
19.*	*Anapiculatisporites baccatus*	D13/1	19/5-1	4260(3)	4260’	30510
20.*	*Anapiculatisporites globulus*	U29/1	19/5-1	4020(3)	4020’	30511
21.	*Apiculatasporites aculeatus*	S47/1	27/5-1	AH79 ox5mins(1)	1882m	60144
22.	*Apiculatasporites spinososaetosus*	U29/1	27/5-1	AH79 ox5mins(1)	1882m	60145
23.	*Apiculatasporites variocorneus*	Q49/1	27/5-1	AH85 S&B(1)	1900m	60146

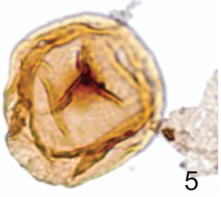
PLATE 1

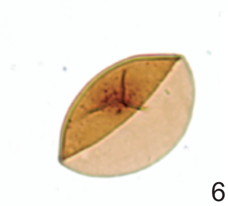

1

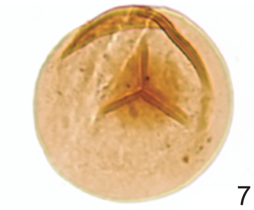

2

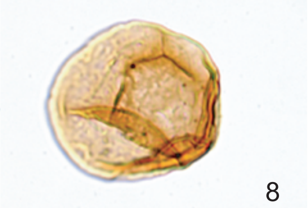

3


4


5

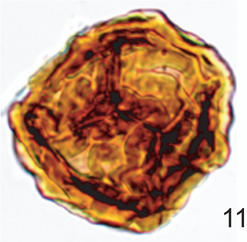

6

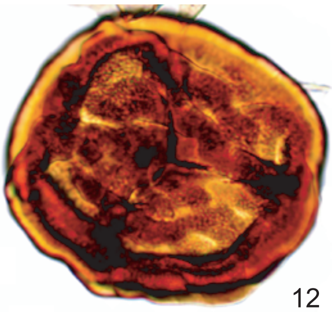

7


8

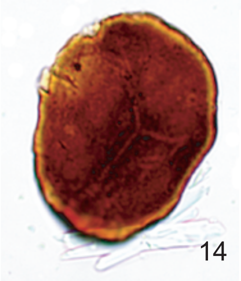

9

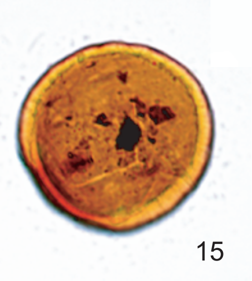

10


11

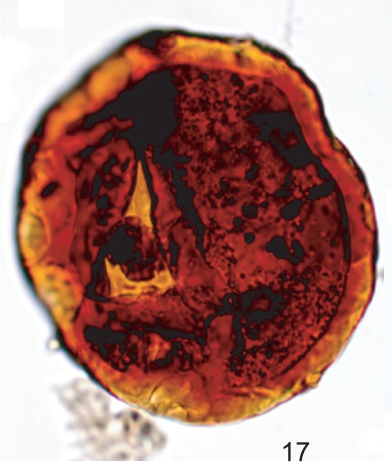

12

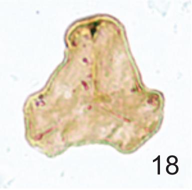

13

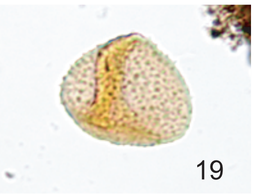

14

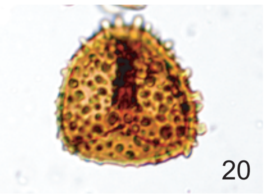

15

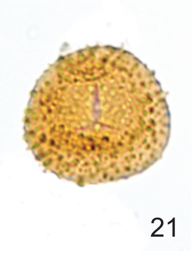

16


17


18


19


20


21


22

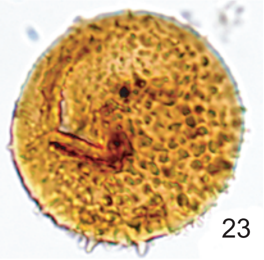
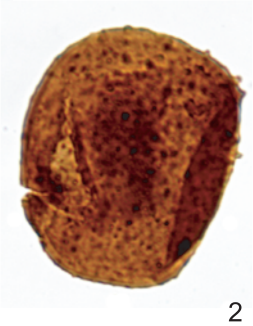

23

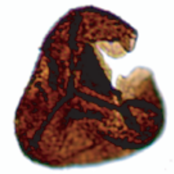
PLATE 2

No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.	*Apiculatasporites spinulistratus*	G43	26/27-1b	8800(3)	8800’	60147
2.	*Apiculatasporites cf. latigranifer*	C33/2	26/27-1b	9159(4)	9159’	60148
3.	*Converrucosisporites cameronii*	N47/4	26/21-1	PE8 noHCL	2105m	60149
4.	*Cadiospora magna*	E56/3	12/2-1z	R18 ox20mins(1)	4408m	60150
5.*	*Cyclogranisporites multigranus*	W33/4	19/5-1	3830(3)	3830’	30462
6.	*Cyclogranisporites aureus*	G58/4	27/5-1	AH10 ox15mins(1)	1672m	60151
7.*	*Cyclogranisporites minutus*	N10/4	19/5-1	3610(3)	3610’	30460
8.	*Granasporites medius*	F52	27/5-1	AH14 ox15mins(1)	1684m	60152
9.	*Granulatisporites microgranifer*	D28/3	26/27-1b	9159(4)	9159’	60153
10.*	*Granulatisporites granulatus*	C20/4	34/5-1	1460(4)	1460m	30451
11.*	*Granulatisporites granulatus*	W12/4	36/16-1	6000(4)	6000’	30450
12.*	*Granulatisporites adnatoides*	R5/2	26/28-1	3250(3)	3250m	30449
13.	*Granulatisporites minutus*	D49	26/28-1	2845m Coal 1hr20min(1)	2845m	60154
14.	*Lophotriletes commisuralis*	G31/2	26/271-b	8541 SWC(4)	8541’	60155
15.	*Lophotriletes commisuralis*	C33/1	26/271-b	8541(3)	8541’	60156
16.*	*Lophotriletes* cf. *gibbosus*	N33/3	19/5-1	3790(3)	3790’	30486
17.	*Lophotriletes granoornatus*	N32	27/5-1	AH72(1)	1861m	60157
18.	*Lophotriletes microsaetosus*	H32	26/27-1b	8541(4)	8541’	60158
19.*	*Lophotriletes* cf. *microsaetosus*	F30/3	26/28-1	3300(3)	3300m	30493
20.*	*Acanthotriletes castanea*	E24/1	19/5-1	4440(3)	4440’	30532
21.*	*Acanthotriletes falcatus*	J12	34/5-1	1100(3)	1100m	30535
22.	*Acanthotriletes echinatus*	Q38	26/27-1b	9000(4)	9000’	60159
23.	*Acanthotriletes triquetrus*	M43/2	26/27-1b	8314(3)	8314’	60160
24.*	*Pustulatisporites papillosus*	C15/3	26/28-3	2520(3)	2520m	30512
25.	*Pustulatisporites pustulatus*	E63/4	27/5-1	AH8 ox15mins(1)	1663m	60161
26.	*Raistrickia fulva*	U60/1	27/5-1	AH62 ox5mins(1)	1828m	60163
27.	*Raistrickia fulva*	Y32	27/5-1	AH41 Coal 1hr45min(3)	1768m	60162

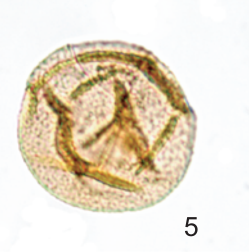
PLATE 2

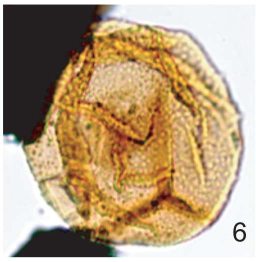

1


2

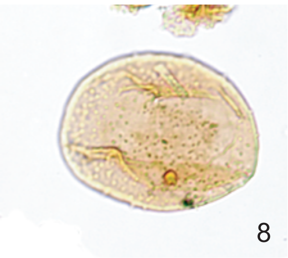

3


4

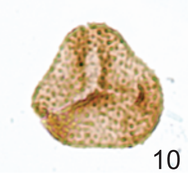

5

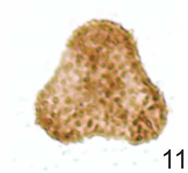

6

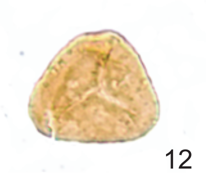

7

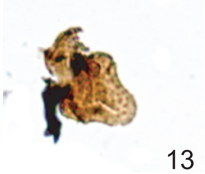

8


9


10

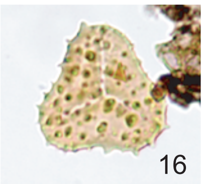

11

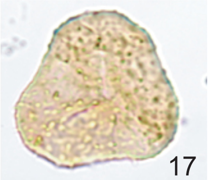

12

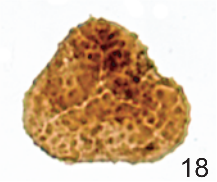

13

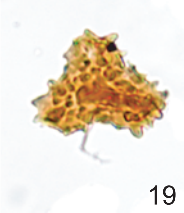

14


15

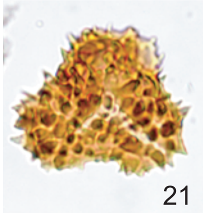

16

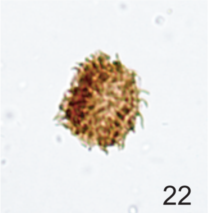

17


18

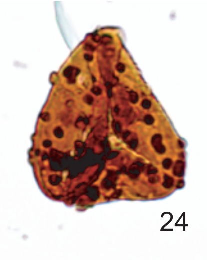

19

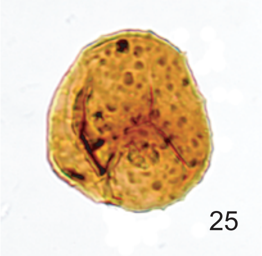

20

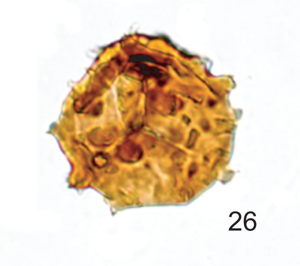

21


22


23


24


25


26

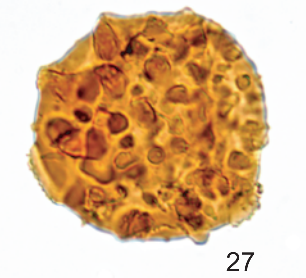
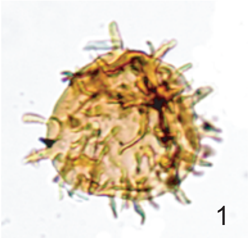
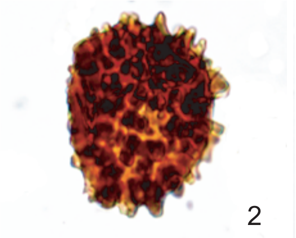

27

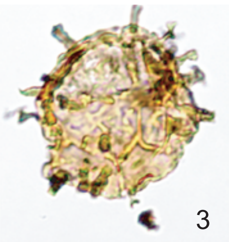
PLATE 3

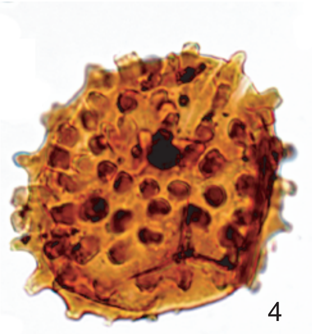
No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.*	*Raistrickia aculeata*	V13/3	26/28-2	2375(4)	2375m	30541
2.*	*Raistrickia abdita*	U24/1	26/28-1	2865(3)	2865m	30515
3.	*Raistrickia* cf. *superba*	P58	27/5-1	AH32 ox40mins(1)	1738m	60164
4.*	*Raistrickia nigra*	J32	19/5-1	5160(3)	5160’	30547
5.	*Raistrickia saetosa*	Q40/3	27/5-1	AH41 Coal 1hr45min(4)	1768m	60165
6.	*Raistrickia saetosa*	O37/2	27/5-1	AH24 ox15mins(1)	1714m	60166
7.*	*Verrucosisporites morulatus*	P19	19/5-1	5500(4)	5500’	30475
8.	*Verrucosisporites donarii*	M28	12/2-1z	R22 ox20mins(2)	4441m	60167
9.	*Verrucosisporites verrucosus*	L32	12/2-1z	R20 ox20mins(1)	4426m	60168
10.	*Verrucosisporites microverrucosus*	T37/3	27/5-1	AH24 ox30mins(1)	1714m	60169
11.	*Verrucosisporites microverrucosus*	E58	27/5-1	AH50(1)	1792m	60170
12.*	*Verrucosisporites microtuberosus*	Q6/4	34/5-1	970(4)	970m	30471
13.	*Camptotriletes bucculentus*	E39/4	27/5-1	AH8(1)	1663m	60171
14.	*Camptotriletes superbus*	M34/1	27/5-1	AH55 ox20mins(1)	1804m	60172
15.*	*Convolutispora jugosa*	P7/2	19/5-1	3900(3)	3900’	30568
16.*	*Convolutispora* sp.	P35	26/28-2	2690(4)	2690m	30569
17.*	*Dictyotriletes probireticulatus*	J42	26/28-3	2465(3)	2465m	30585
18.	*Dictyotriletes bireticulatus*	P32/3	27/5-1	AH41 Coal 1hr45min(3)	1768m	60173

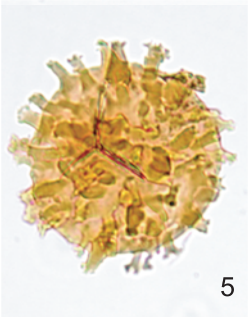
PLATE 3

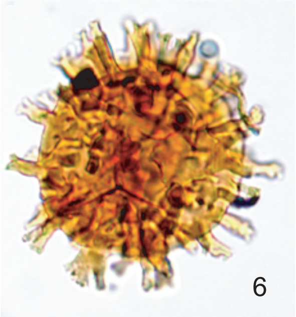

1

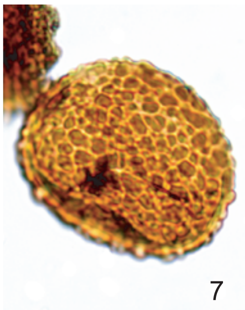

2


3

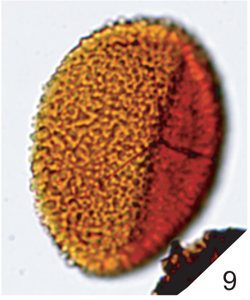

4

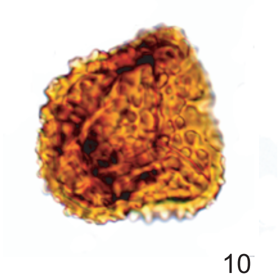

5

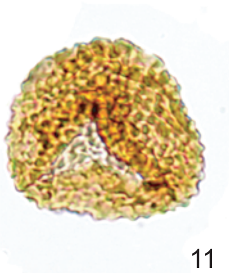

6


7

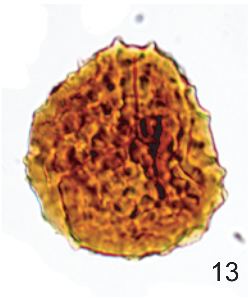

8

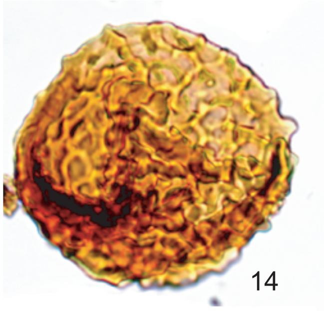

9

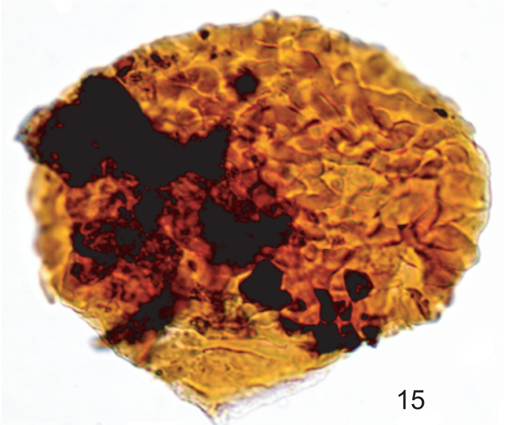

10

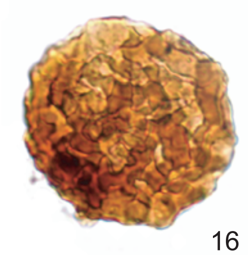

11

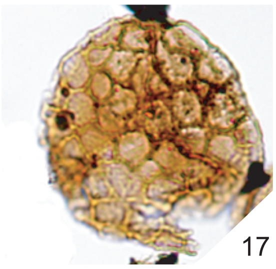

12


13


14


15


16


17

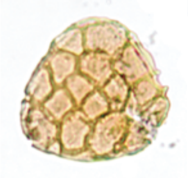
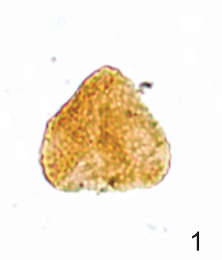
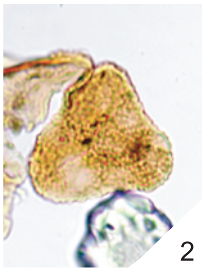

18

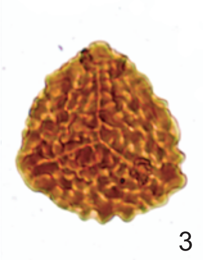
PLATE 4

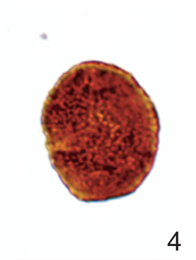
No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.*	*Microreticulatisporites nobilis*	G35/3	34/5-1	1150(3)	1150m	30572
2.*	*Microreticulatisporites concavus*	K18	34/5-1	795(4)	795m	30570
3.	*Microreticulatisporites sulcatus*	Q22/3	26/28-1	2845 Coal 1hr20min(1)	2845m	60174
4.*	*Microreticulatisporites punctatus*	L30/3	26/28-3	2545(3)	2545m	30574
5.*	*Reticulitriletes mediareticulatus*	L27/4	34/5-1	850(4)	850m	30583
6.*	*Reticulitriletes reticulocingulum*	U28	26/28-1	2795(3)	2795m	30587
7.	*Reticulitriletes falsus*	H47/3	26/27-1b	9000(4)	9000’	60175
8.*	*Ahrensisporites guerickei*	S11	19/5-1	4290(4)	4290’	30596
9.*	*Ahrensisporites guerickei*	D29/4	19/5-1	3800(3)	3800’	30597
10.	*Ahrensisporites guerickei*	C50	27/5-1	AH36 ox20mins(3)	1753m	60176
11.*	*Tripartites vetustus*	Q29/4	19/5-1	4140(3)	4140’	30627
12.*	*Tripartites nonguerickei*	H23	19/5-1	6200(4)	6200’	30625
13.*	*Mooreisporites* cf. *inusitatus*	D28/1	26/28-1	2795(3)	2795m	30631
14.*	*Mooreisporites fustis*	V23/1	19/5-1	3850(3)	3850’	30630
15.	*Triquitrites sculptilis*	J49/3	27/5-1	AH49 ox15mins(2)	1789m	60177
16.	*Triquitrites sculptilis*	D47/4	26/27-1b	8314 SWC(2)	8314’	60178
17.	*Triquitrites sculptilis*	C43/2	26/27-1b	8800(2)	8800’	60179
18.	*Triquitrites bransonii*	Y35/1	26/27-1b	8204(1)	8204’	60180
19.	*Triquitrites spinosus*	L29/1	26/28-1	2845 Coal 1hr20min(1)	2845m	60181
20.*	*Triquitrites marginatus*	E25/1	19/5-1	4440(3)	4440’	30601
21.*	*Triquitrites* cf. *protensus*	E38	19/5-1	3710(3)	3710’	30603
22.*	*Triquitrites tribullatus*	K17/4	26/28-2	2300(4)	2300m	30606
23.*	*Bellispores nitidus*	R15	19/5-1	3790(3)	3790’	30663
24.*	*Knoxisporites stephanephorus*	R8/2	26/28-1	2745(4)	2745m	30646
25.	*Knoxisporites stephanephorus*	Y46/1	26/27-1b	8541(3)	8541’	60182
26.	*Knoxisporites triradiatus*	Q50/3	26/27-1b	8733.5(3)	8733.5’	60183
27.	*Knoxisporites triradiatus*	V49/4	26/27-1b	8733.5(3)	8733.5’	60184
28.*	*Rotaspora fracta*	F31/2	19/5-1	5770(2)	5770’	30667
29.*	*Rotaspora knoxi*	O15/1	19/5-1	4290(4)	4290’	30669

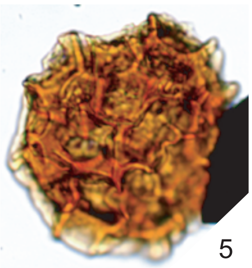
PLATE 4

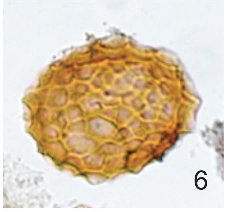

1


2

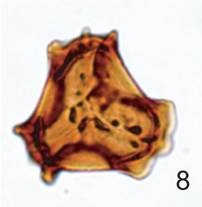

3

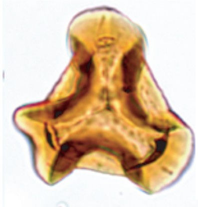

4

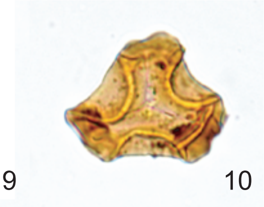

5

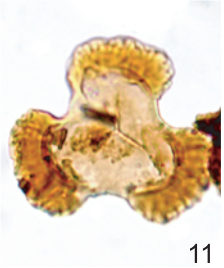

6

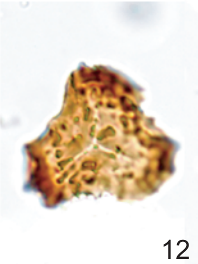

7

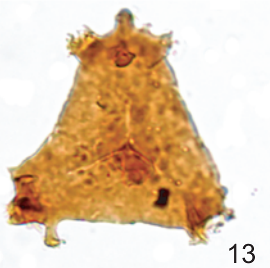

8


9

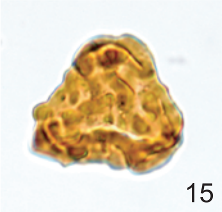

10

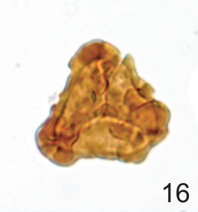

11

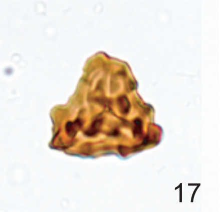

12

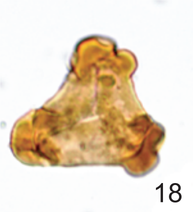

13

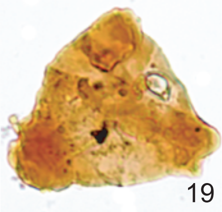

14

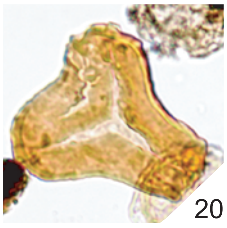

15

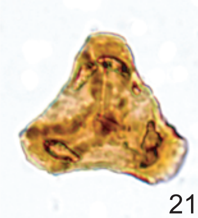

16


17

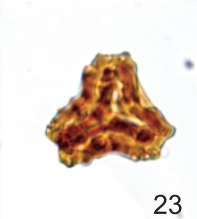

18

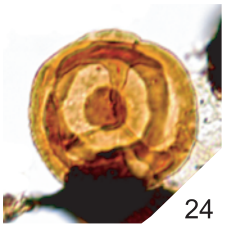

19

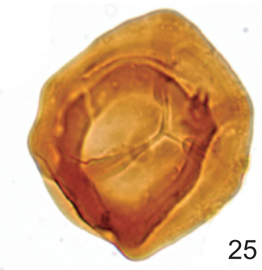

20

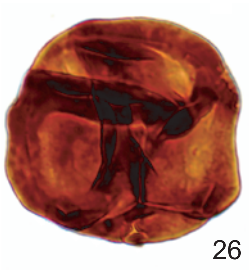

21

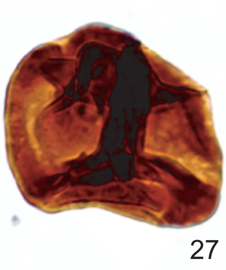

22

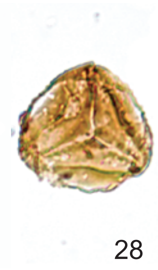

23


24


25


26


27

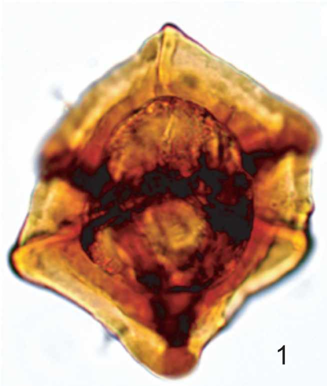

28

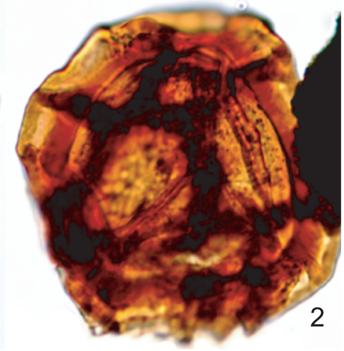

29

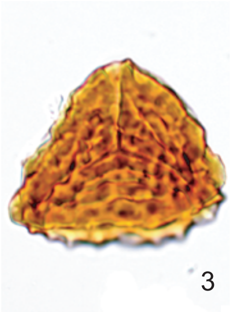
PLATE 5

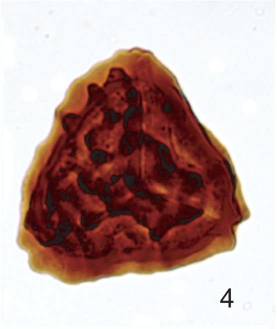
No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.	*Reticulatisporites polygonalis*	S54	27/5-1	AH28 ox15mins(1)	1726m	60185
2.	*Reticulatisporites reticulatus*	E37	19/5-1	3830(3)	3830	30652
3.	*Savitrisporites nux*	G29/4	27/5-1	AH50 ox15mins(3)	1792m	60186
4.	*Savitrisporites nux*	F35/1	26/27-1b	9159(4)	9159'	60187
5.	*Savitrisporites concavus*	H33/2	27/5-1	AH11(2)	1675m	60188
6.	*Savitrisporites concavus*	W51/2	26/27-1b	8733.5(3)	8733.5'	60189
7.	*Stenozonotriletes bracteolus*	O26/1	19/5-1	3280(3)	3280'	30637
8.	*Stenozonotriletes lycosporoides*	V46	19/5-1	3870(3)	3870'	30639
9.	*Secarisporites remotus*	K49	26/27-1b	8900(4)	8900'	60190
10.	*Kraeuselisporites ornatus*	H45/3	26/27-1b	8426(3)	8426'	60191
11.	*Kraeuselisporites* cf. *ornatus*	R53/3	27/5-1	AH72(1)	1861m	60192
12.	*Endosporites zonalis*	F26/4	26/27-1b	8800(3)	8800'	60193
13.	*Endosporites zonalis*	J43/1	27/5-1	AH28 ox15mins(1)	1726m	60194
14.	*Endosporites globiformis*	P25	12/2-1z	R20 ox20mins(1)	4426m	60195
15.	*Endosporites globiformis*	G49	27/5-1	AH45(1)	1780m	60196
16.	*Grumosisporites varioreticulatus*	F35/4	27/5-1	AH55 ox20mins(1)	1804m	60197
17.	*Grumosisporites inaequalis*	E45	26/28-1	3085(1)	3085m	30676
18.	*Grumosisporites varioreticulatus*	K41/1	19/5-1	3800(3)	3800'	30679
19.	*Spelaeotriletes arenaceous/triangulus*	N34/4	19/5-1	5500(4)	5500'	30682
20.	*Ibrahimispores brevispinosus*	N30/1	19/5-1	3850(3)	3850'	30562

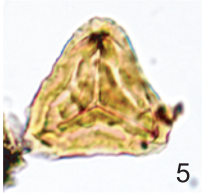
PLATE 5

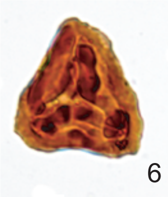

1


2


3

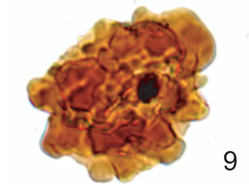

4

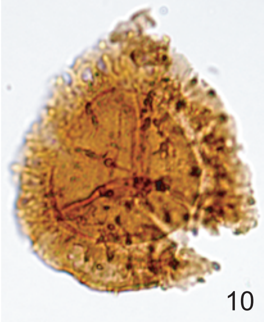

5

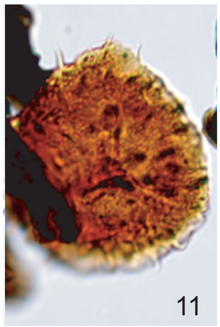

6


7


8

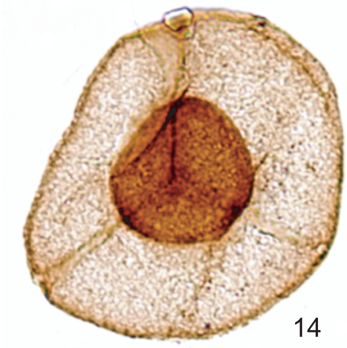

9


10

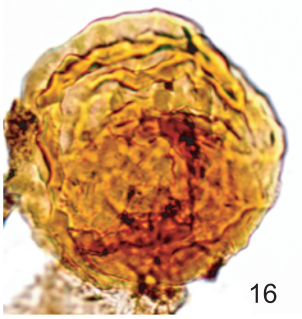

11

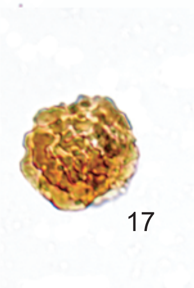

12

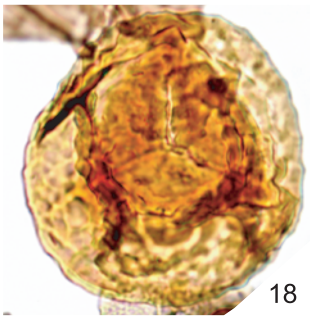

13

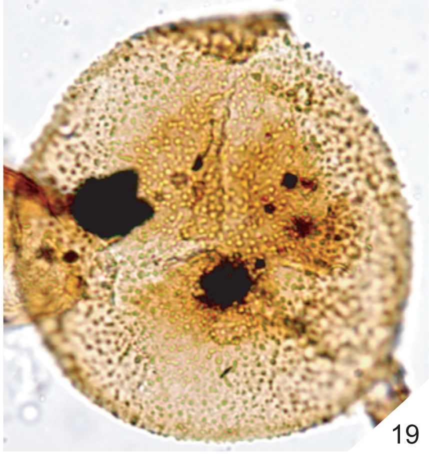

14

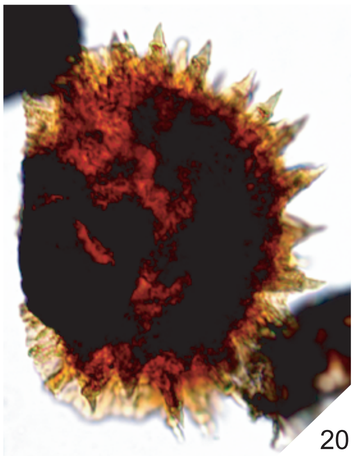

15


16


17


18


19

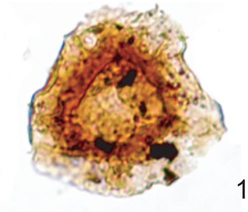

20

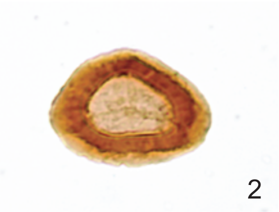
29.	*Lycospora rotunda*	D37/2	26/27-1b	8800(3)	8800’	60216
30.	*Lycospora orbicula*	Q28/4	26/27-1b	7890-900(2)	7890-900’	60217

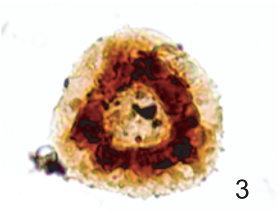
PLATE 6

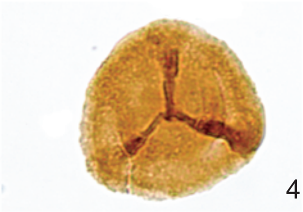
No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.*	*Cingulizonates* cf. *capistratus*	N41/3	19/5-1	4140(3)	4140’	30741
2.	*Cingulizonates loricatus*	F48	26/27-1b	9014 SWC(4)	9014’	60198
3.*	*Cingulizonates bialatus*	W12/3	19/5-1	4649(3)	4649’	30739
4.	*Cirratriradites* cf. *annuliformis*	S45/3	26/27-1b	8204(1)	8204’	60199
5.*	*Cirratriradites saturni*	O14/1	19/5-1	3660(3)	3660’	30732
6.	*Cirratriradites saturni*	G53/1	27/5-1	AH8 ox30mins(4)	1663m	60200
7.*	*Cirratriradites megaspinosus*	Q24/4	26/28-1	2975(4)	2975m	30736
8.*	*Crassispora maculosa*	F11/2	19/5-1	4649(3)	4649’	30698
9.	*Crassispora kosankei*	G42/3	26/27-1b	8800(2)	8800’	60201
10.	*Crassispora aculeata*	G25	26/27-1b	8314(2)	8314’	60202
11.	*Cristatisporites connexus*	H43/1	26/27-1b	9159(4)	9159’	60203
12.	*Cristatisporites connexus*	H41	26/27-1b	9230(2)	9230’	60204
13.*	*Cristatisporites indignabundus*	M22/2	19/5-1	3800(3)	3800’	30725
14.*	*Cristatisporites solaris*	E38/4	19/5-1	3870(4)	3870’	30730
15.	*Cristatisporites solaris*	R28/3	26/27-1b	8733.8 Core(1)	8733.8’	60205
16.	*Densosporites anulatus*	S28/1	26/27-1b	8733.8(1)	8733.8’	60206
17.	*Densosporites gracilis*	E26	26/27-1b	9100(4)	9100’	60207
18.	*Densosporites intermedius*	C47/4	26/27-1b	9230	9230’	60208
19.*	*Densosporites pseudoannulatus*	M15/4	19/5-1	3870(3)	3870’	30711
20.*	*Densosporites sphaerotriangularis*	O16/2	34/5-1	1398(4)	1398m	30708
21.	*Densosporites duriti*	Q52	27/5-1	AH49(1)	1789m	60209
22.	*Densosporites spinifer*	P31	27/5-1	AH45(1)	1780m	60210
23.	*Lycospora pusilla*	S33/1	26/27-1b	7890-900	7890 900’	60211
24.	*Lycospora pusilla*	H41/3	27/5-1	AH83 ox5mins(2)	1894m	60212
25.*	*Lycospora pellucida*	F14/1	26/28-2	2500(4)	2500m	30716
26.	*Lycospora noctuina noctuina*	D36	26/27-1b	9230(2)	9230m	60213
27.	*Lycospora noctuina noctuina*	G28/2	27/5-1	AH8 ox15mins(2)	1663m	60214
28.	*Lycospora rotunda*	T39/1	26/27-1b	9014(4)	9014’	60215

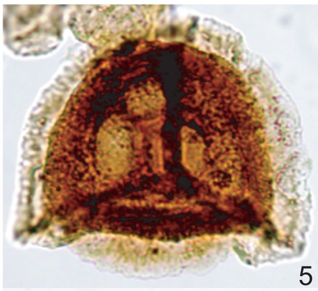
PLATE 6


1

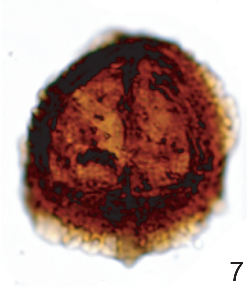

2

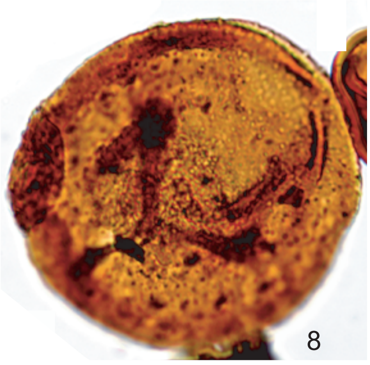

3


4

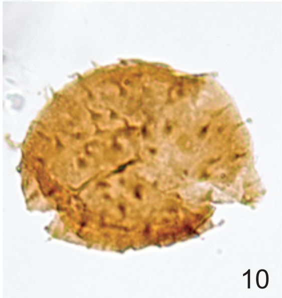

5

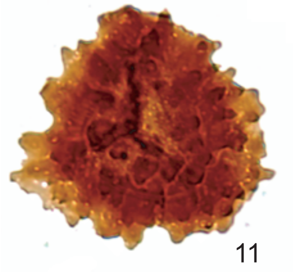

6

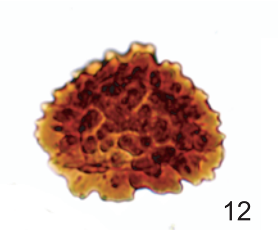

7

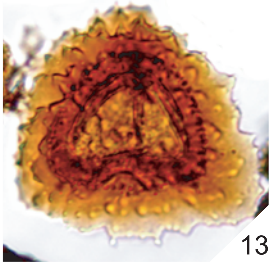

8

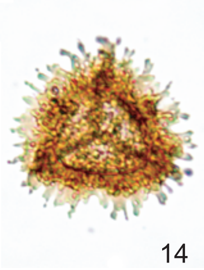

9

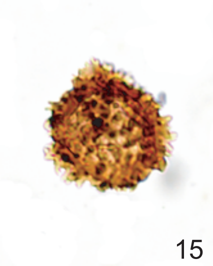

10


11


12

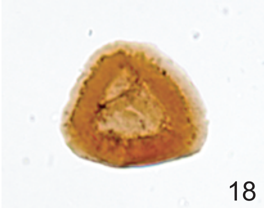

13

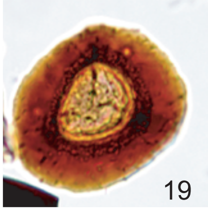

14

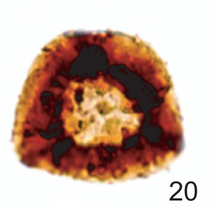

15

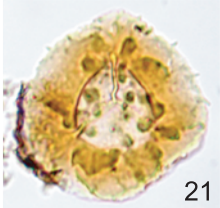

16

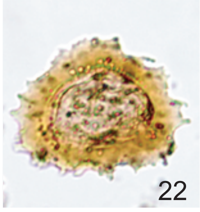

17


18

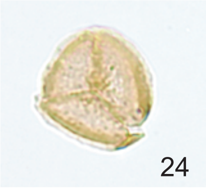

19

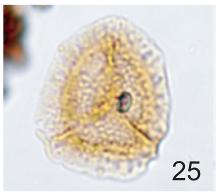

20


21

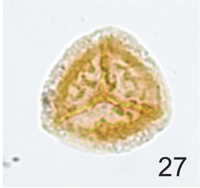

22

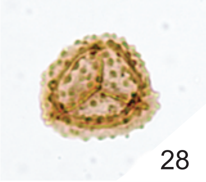

23

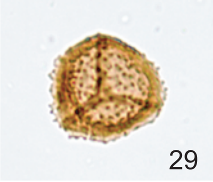

24


25


26


27


28


29

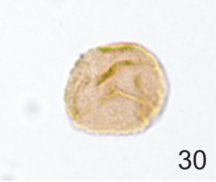
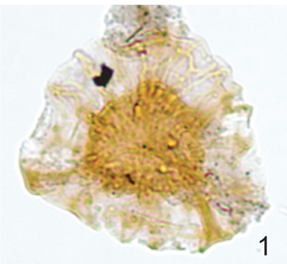
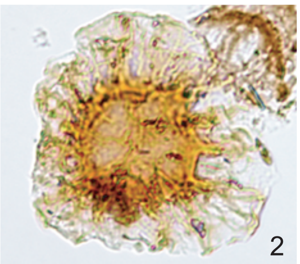

30

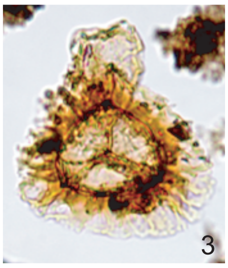
PLATE 7

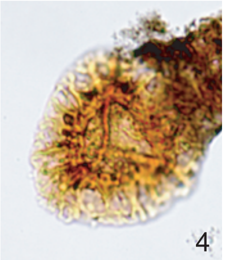
No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.	*Radiizonates aligerens*	L55/4	27/5-1	AH56 Coal 1hr30min sieved(1)	1807m	60218
2.	*Radiizonates aligerens*	K32	27/5-1	AH49 ox15mins(4)	1789m	60219
3.	*Radiizonates tenuis*	T35/3	27/5-1	AH14 ox15mins(1)	1684m	60220
4.	*Radiizonates tenuis*	H46/2	27/5-1	AH28 ox15mins(1)	1726m	60221
5.	*Radiizonates faunus*	L39/3	26/27-1b	8733.8 Core(2)	8733.8	60222
6.	*Radiizonates* cf. *difformis*	Q40/2	27/5-1	AH72 ox15mins(2)	1861m	60223
7.*	*Radiizonates striatus*	R34/2	19/5-1	3860(3)	3860’	30754
8.	*Radiizonates striatus*	M43	27/5-1	AH61 ox15mins(1)	1825m	60224
9.	*Radiizonates* cf. *striatus*	O32	27/5-1	AH72 ox15mins(2)	1861m	60225
10.	*Simozonotriletes intortus*	J32/3	27/5-1	AH50 ox15mins(1)	1792m	60226
11.*	*Alatisporites hoffmeisterii*	G24/4	19/5-1	3850(3)	3850’	30787
12.*	*Alatisporites pustulatus*	M38/1	34/5-1	1100(3)	1100’	30788
13.*	*Schulzospora rara*	Q33/1	19/5-1	6530(3)	6530’	30783
14.	*Schulzospora rara*	C54/2	27/5-1	AH56 Coal 1hr30 sieved(1)	1807m	60227
15.*	*Schulzospora campyloptera*	D38/1	19/5-1	5400(3)	5400’	30776
16.	*Pteroretis primum*	L33/3	27/5-1	AH24 ox15mins(2)	1714m	60228
17.	*Lundbladispora gigantea*	L27/4	26/27-1b	8426(4)	8426’	60229
18.*	*Angulisporites splendidus*	Q13/3	26/28-2	2275(4)	2275m	30872
19.	*Latensina trileta*	G30/1	26/27-1b	7760(2)	7760’	60230
20.	*Laevigatosporites vulgaris*	P31	26/27-1b	9230(2)	9230’	60231
21.	*Laevigatosporites minor*	C37	26/27-1b	9159(4)	9159’	60232
22.	*Laevigatosporites minimus*	D49/2	26/28-1	2845 Coal 1hr20min(1)	2845m	60233
23.	*Latosporites globosus*	B41/3	26/27-1b	8541(4)	8541’	60234

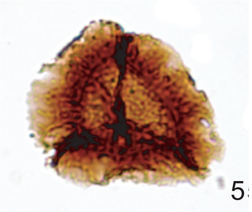
PLATE 7


1

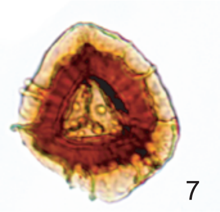

2

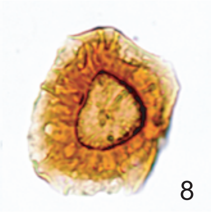

3


4

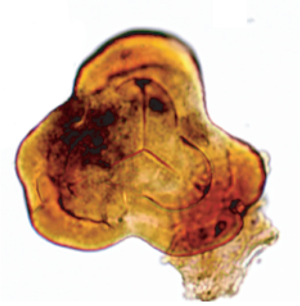

5


6

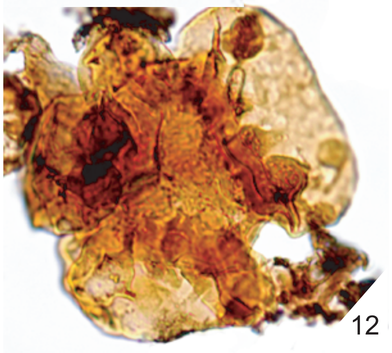

7

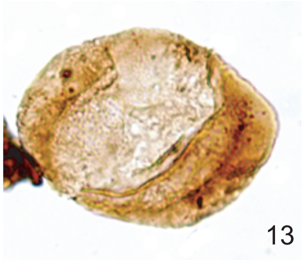

8

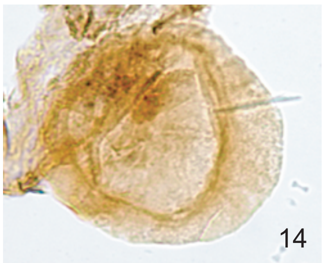

9

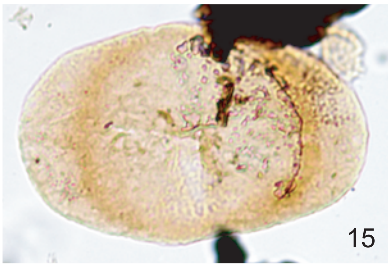

10

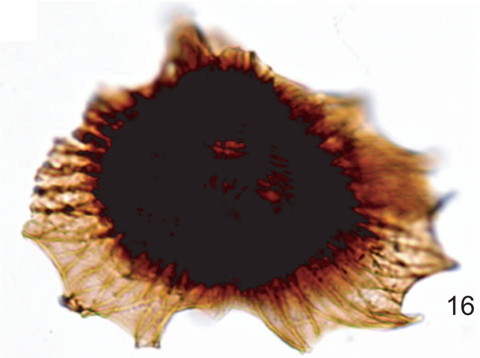

11

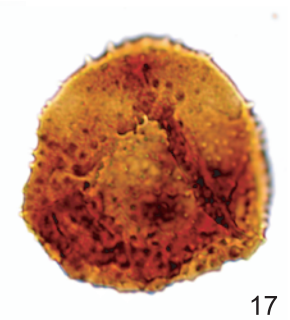

12


13

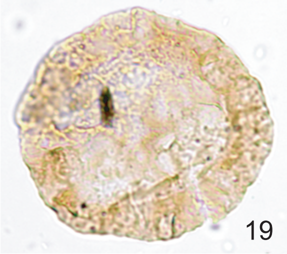

14


15

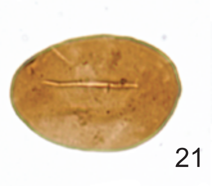

16


17


18


19


20


21


22

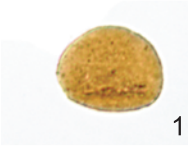

23

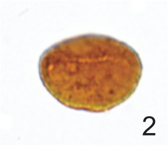
27.	*Florinites junior*	F61/4	27/5-1	AH20 ox15mins(3)	1702m	60257
28.	*Florinites junior*	U26/4	27/5-1	AH28 ox15mins(1)	1726m	60258
29.	*Florinites mediapudens*	X44/2	27/5-1	AH45 ox5mins(1)	1780m	60259
30.	*Florinites mediapudens*	D28	27/5-1	AH14 ox15mins(1)	1684m	60260
31.	*Florinites* cf. *florini*	C37/4	27/5-1	AH60 ox10mins(1)	1819m	60261
32.	*Florinites millotti*	O39/3	27/5-1	AH45(3)	1780m	60262

PLATE 8

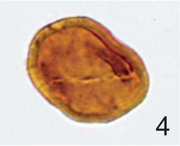
No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.	*Punctatosporites granifer*	S25	26/27-1b	8204(1)	8204’	60235
2.	*Punctatosporites granifer*	F38/1	26/27-1b	8204(1)	8204’	60236
3.	*Punctatosporites minutus*	U24/3	26/28-1	2845 Coal 1hr20min(1)	2845m	60237
4.	*Punctatosporites oculus*	M45	26/27-1b	8314(3)	8314’	60238
5.	*Punctatosporites oculus*	E31/3	26/27-1b	7904(2)	7904’	60239
6.	*Punctatosporites rotundus*	J24/4	12/2-1z	R18 20min(1)	4366m	60240
7.	*Thymospora obscura*	W40/2	26/27-1b	7760(4)	7760’	60241
8.*	*Thymospora obscura*	L15	36/16-1	4350(1)	4350’	30810
9.	*Thymospora obscura*	V27	26/27-1b	8149(2)	8149’	60242
10.	*Thymospora* sp.	N30	26/27-1b	7995(2)	7995’	60243
11.	*Thymospora pseudothiessenii*	S26/2	26/27-1b	7760(4)	7760’	60244
12.*	*Thymospora pseudothiessenii*	O21/4	26/28-2	2275(4)	2275m	30808
13.	*Torispora securis*	E26/4	26/27-1b	7760(4)	7760’	60245
14.	*Torispora securis*	L28/4	26/27-1b	7760(4)	7760’	60246
15.	*Spinosporites spinosus*	L46/2	26/27-1b	7890-900(2)	7890-900’	60247
16.*	*Spinosporites spinosus*	O23/4	26/28-1	2705(4)	2705m	30859
17.	*Columnisporites ovalis*	L42/2	13/3-1	1740 SWC	1740m	60248
18.	*Columnisporites ovalis*	H51	27/5-1	AH9 fine frac	1669m	60249
19.	*Vestispora pseudoreticulata*	D44/1	26/27-1b	8426 SWC	8426’	60250
20.	*Vestispora laevigata*	T27	26/28-1	2845m Coal 1hr20min	2845m	60251
21.	*Vestispora fenestrata*	U24/3	26/28-1	2845m Coal 1hr20min(1)	2845m	60252
22.	*Vestispora costata*	V47/3	27/5-1	AH41 Coal ox1hr45(4)	1768m	60253
23.	*Vestispora costata*	U26	26/27-1b	8541 SWC(4)	8541’	60254
24.	*Vestispora tortuosa*	G40	26/27-1b	8541 SWC(3)	8541m	60255
25.	*V. fenestrata operculum*	U38	26/27-1b	8426(4)	8426’	60256
26.*	*Vestispora magna*	L34	34/5-1	1050(4)	1050m	30829

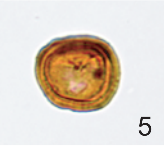
PLATE 8

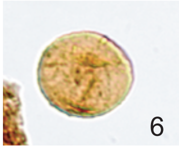

1

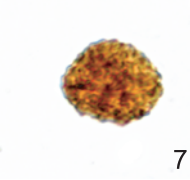

2

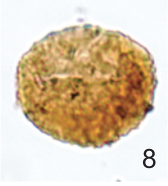

3

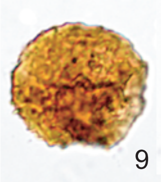

4

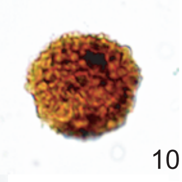

5

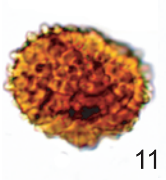

6

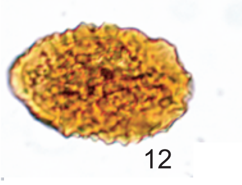

7

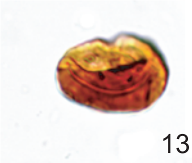

8

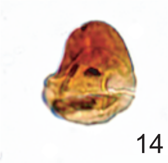

9

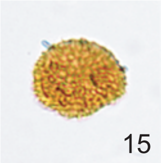

10

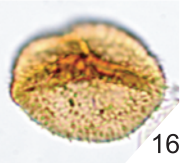

11

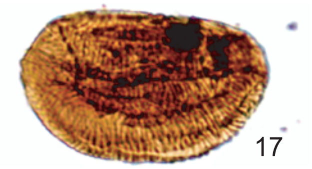

12

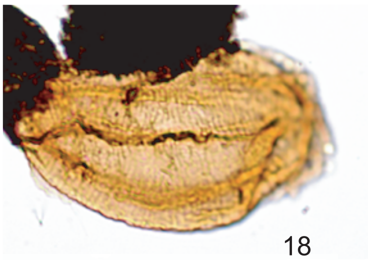

13

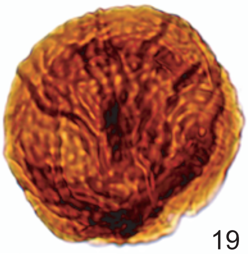

14

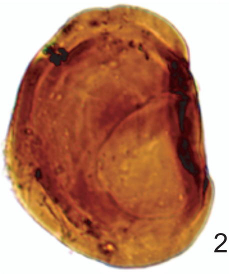

15

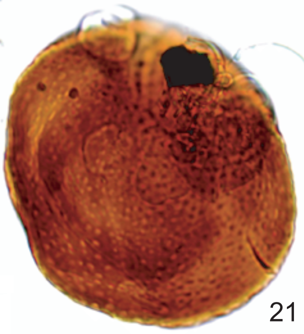

16

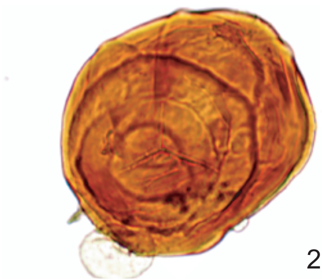

17

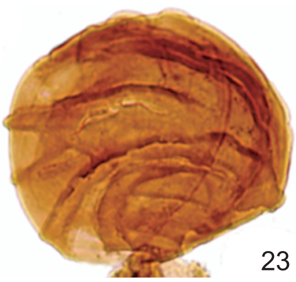

18

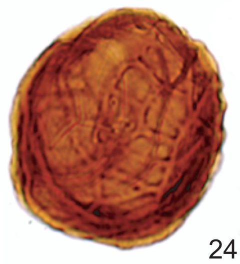

19


20

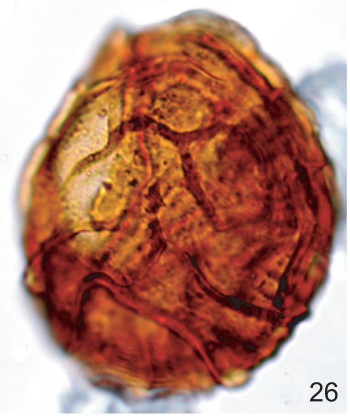

21

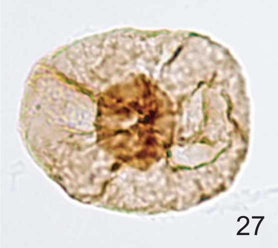

22

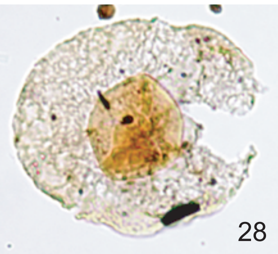

23


24

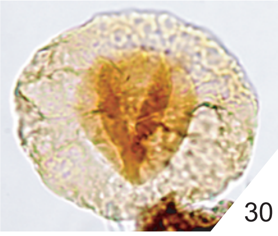

25

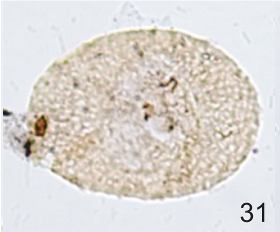

26


27


28


29


30

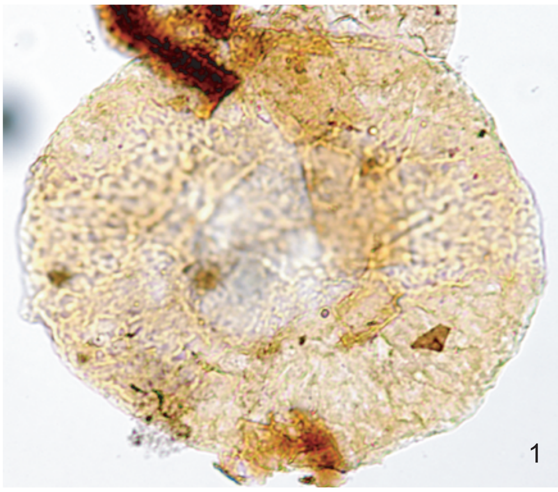

31

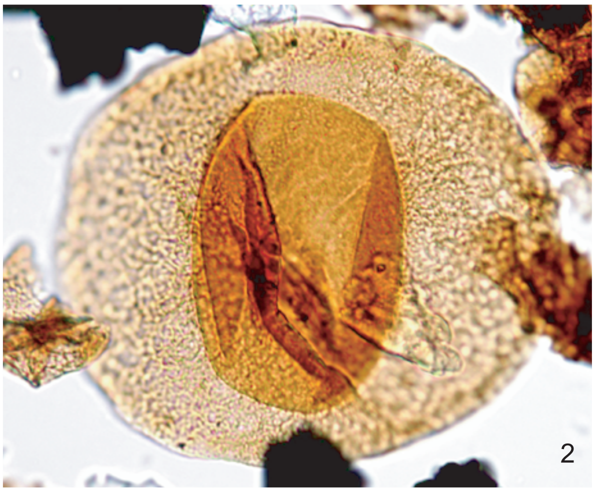

32

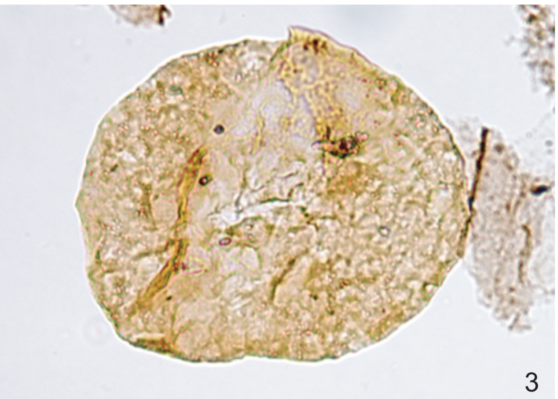
PLATE 9

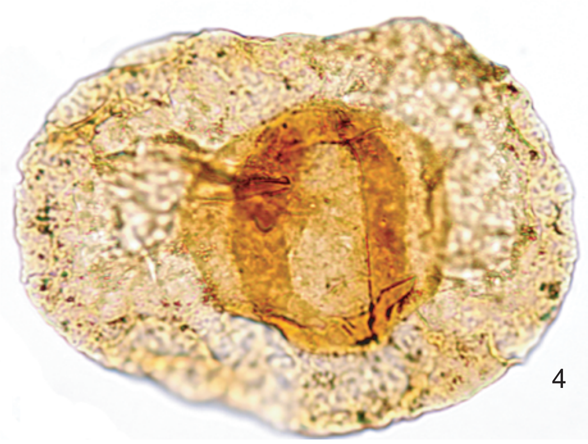
No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.	*Florinites visendus*	F31/3	27/5-1	AH49 ox15mins(1)	1789m	60263
2.	*Florinites similis*	N33/1	19/5-1	3830(3)	3830’	60264
3.	*Florinites pumicosus*	G44/4	27/5-1	AH32 ox40mins(1)	1738m	60265
4.	*Potonieisporites elegans*	O56/3	27/5-1	AH42 ox20mins(1)	1771m	60266
5.*	*Potonieisporites novicus*	F9/3	36/16-1	4450(3)	4450’	30877
6.	*Potonieisporites novicus*	S29	12/2-1z	R17 ox20mins(2)	4396m	60267
7.	*Potonieisporites microsaccus*	F47/1	27/5-1	AH41 Coal 1hr45min(3)	1768m	60268
8.	*Cheleidonites* sp.	G36/1	12/2-1z	R20 ox20mins(2)	4426m	60269
9.	*Vittatina* sp.	W46/3	12/2-1z	R15 ox20mins(1)	4384m	60270
10.	*Corollina* sp.	C64/3	26/21-1	PE10 HCL2	2126m	60271
11.	*Disaccites* sp.	U49/2	26/21-1	PE10 HCL1	2126m	60272

PLATE 9

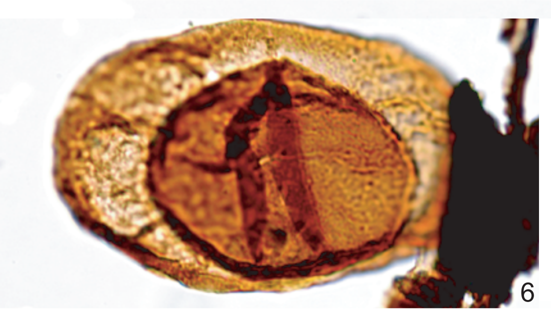

1


2

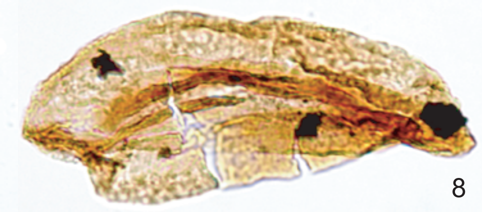

3

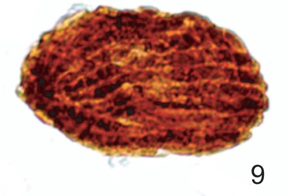

4

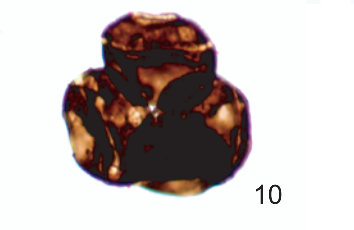

5


6


7


8


9


10

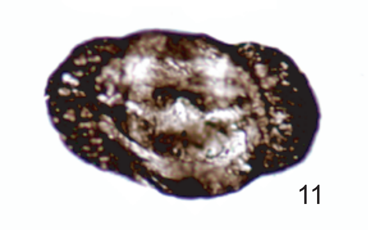
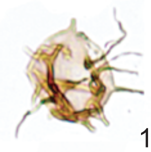

11

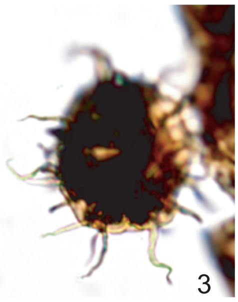
PLATE 10

No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.	*Micrhystridium* sp.	S39/2	13/3-1	1500-20 U2	1500-20’	60273
2.	*Micrhystridium* sp.	W50	13/3-1	1380-1400 U2	1380-1400’	60274
3.	*Micrhystridium* sp.	L40/2	26/28-1	2865 U1	2865m	60275
4.	*Gorgonisphaeridium* sp.	H30	34/5-1	PE20 sieved noHCl(1)	800m	60276
5.	*Baltisphaeridium* sp.	N53/4	34/5-1	PE20 S&B(1)	800m	60277
6.	*Veryhachium* sp.	V52/3	36/16-1	4640-50 U1	4640-50’	60278
7.	Acanthomorphic acritarch	Q58/3	34/5-1	740 U1	740m	60279
8.	*Leiosphaeridia* sp.	J36/3	36/16-1	4640-50	4640-50’	60280
9.	Arthropod cuticle	U35/4	26/28-1	2975 U2	2975m	60281
10.	Arthropod cuticle	D60/2	26/28-1	2975 U2	2975m	60282
11.	Arthropod cuticle	X59/3	26/28-1	2865 U1	2865m	60283
12.	Foraminiferal lining	M34	36/16-1	OST4 noHCl(1)	4570-80’	60284
13.	*Botryococcus*	F60/2	36/16-1	4330-40 U2	4330-40’	60285
14.	*Botryococcus*	F60	26/28-1	2745 U2	2745m	60286
15.	Pyritised *Lycospora*	V45/3	36/16-1	4450-60 U1	4450-60’	60287
16.	?Scolecodont	U55	26/28-1	2765 (U2)	2765m	60288
17.	Epidermal tissue	D36	36/16-1	4330-40 U2	4330-40’	60289
18.	Opaque phytoclast	B41	36/16-1	5000-10 U1	5000-10’	60290
19.	Opaque phytoclast	J65	26/28-1	2765 U1	2765m	60291
20.	Woody tissue	H71/1	36/16-1	5200-10 U1	5200-10’	60292
21.	Woody tissue	M38	13/3-1	1380-1400 U2	1380-1400’	60293
22.	Woody tissue	E52/2	36/16-1	5400-10 U1	5400-10’	60294

PLATE 10


1

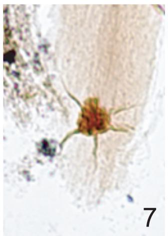

2

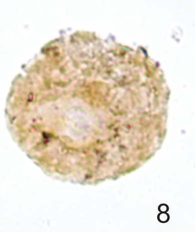

3


4


5


6

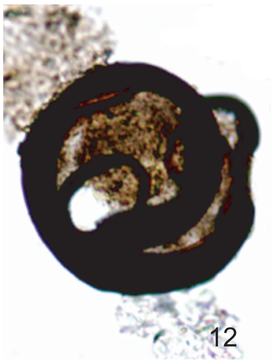

7

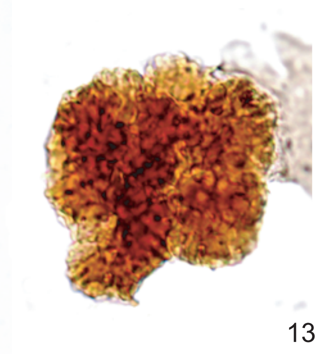

8

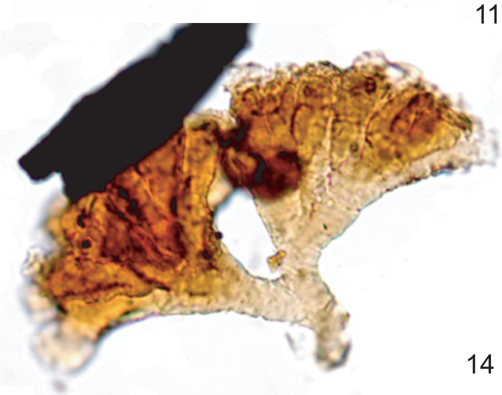

9


10

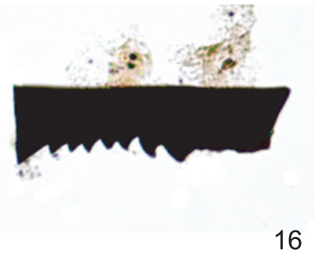

11

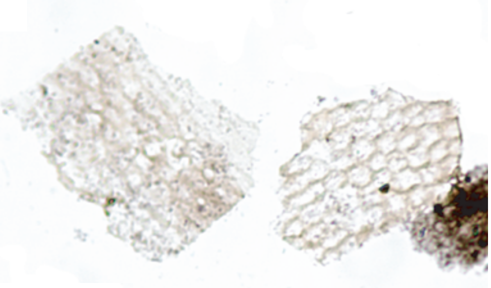

12


13


14


15

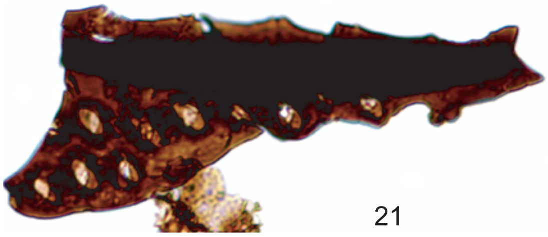

16


17


18


19


20


21

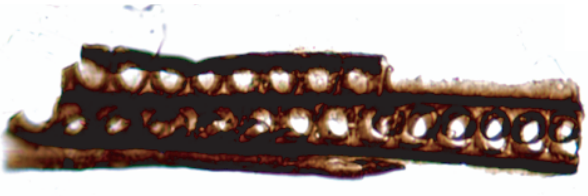
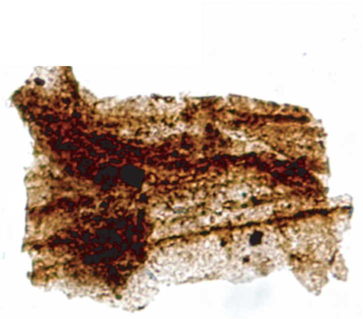

22

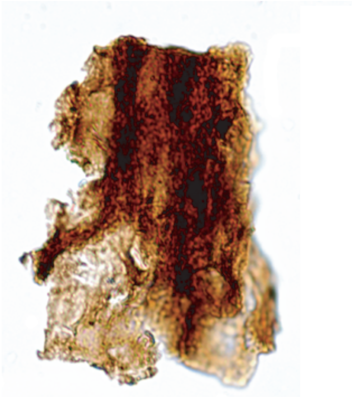
PLATE 11

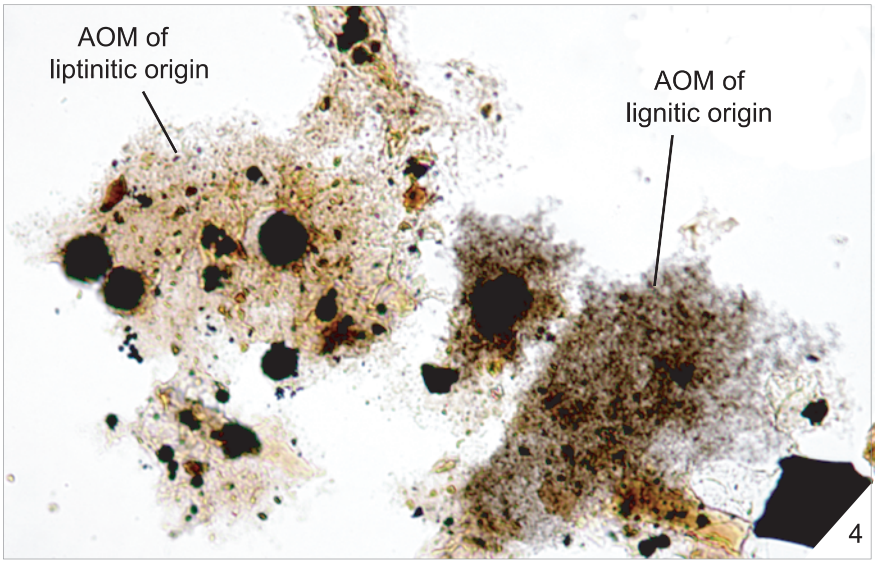
No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.	Non-woody tissue (cortex)	R34	36/16-1	5200-10 U1	5200-10’	60295
2.	Non-woody tissue (cortex)	C33/4	36/16-1	5000-10 U1	5000-10’	60296
3.	Non-woody tissue (cortex)	F52	34/5-1	795 U1	795m	60297
4.	AOM of liptinitic (fluorescent) and lignitic (non-fluorescent) origin	Q55	26/28-1	2765 U2	2765m	60298
5.	AOM (non-fluorescent) dominated sample (x250)	L32/2	36/16-1	OST(1) No HCl	4340-50’	60299

PLATE 11


1


2


3



4

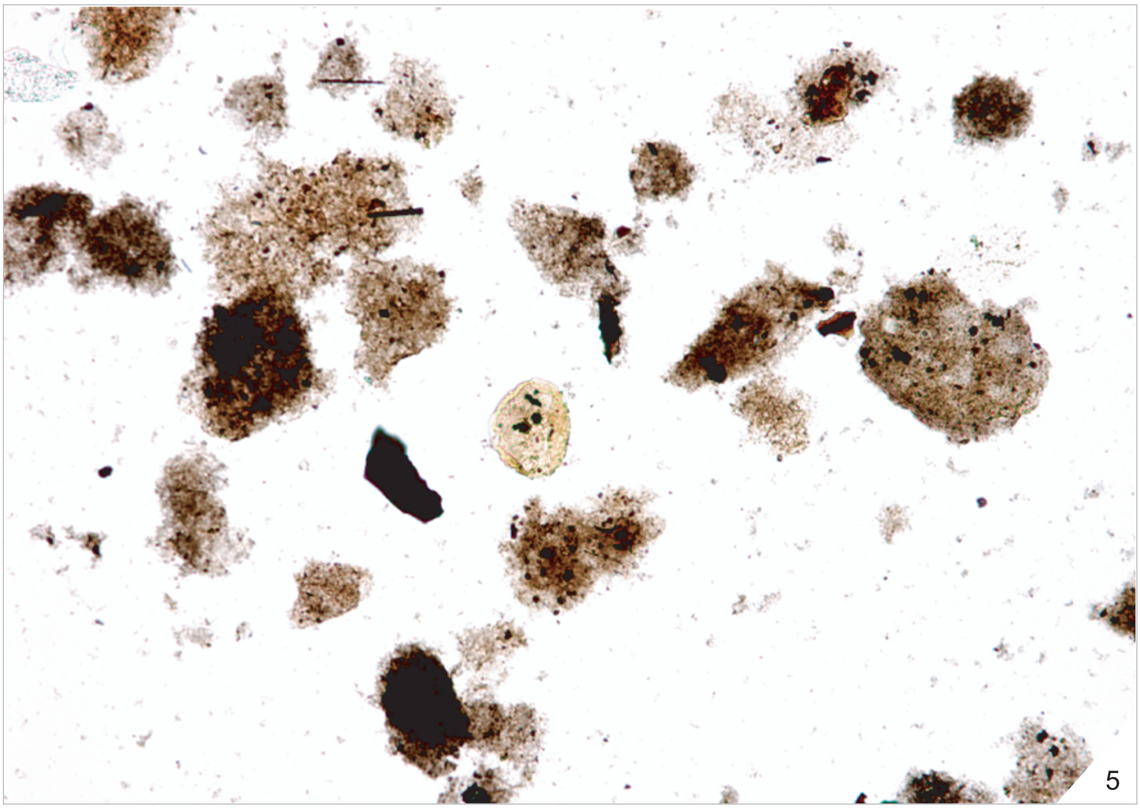
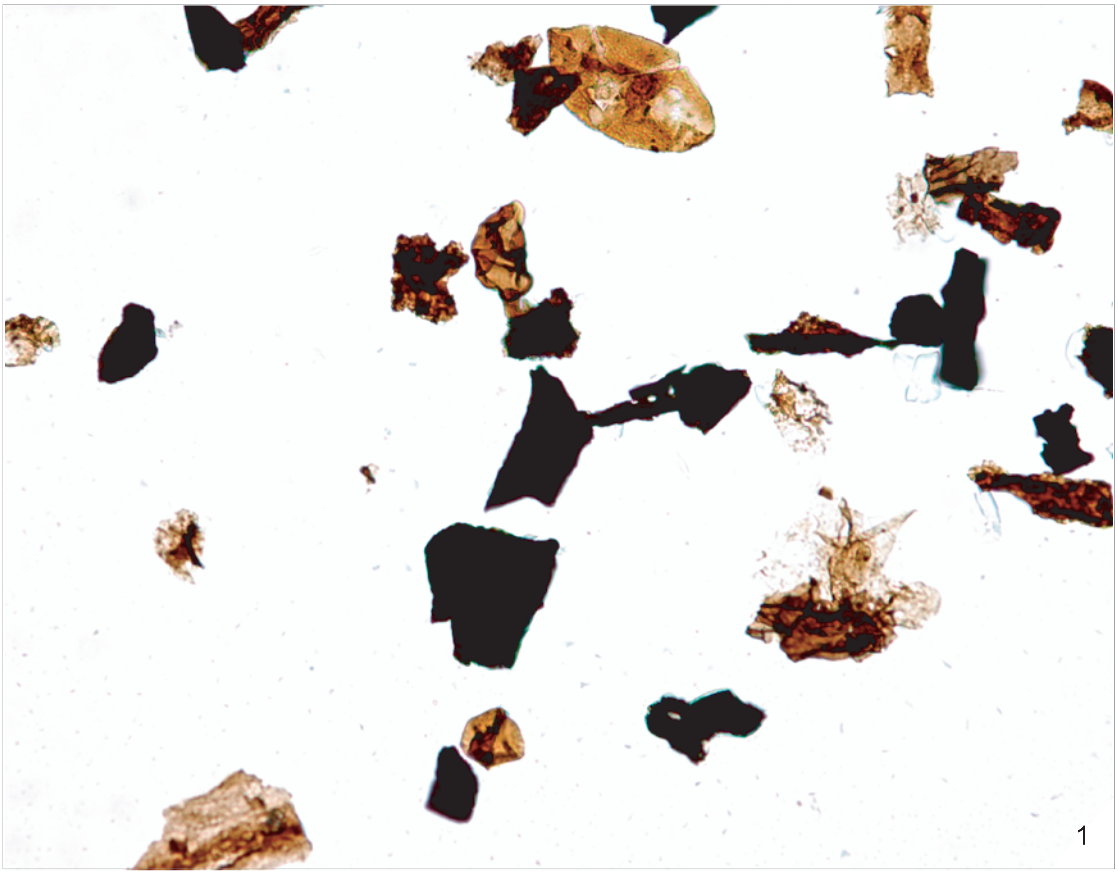
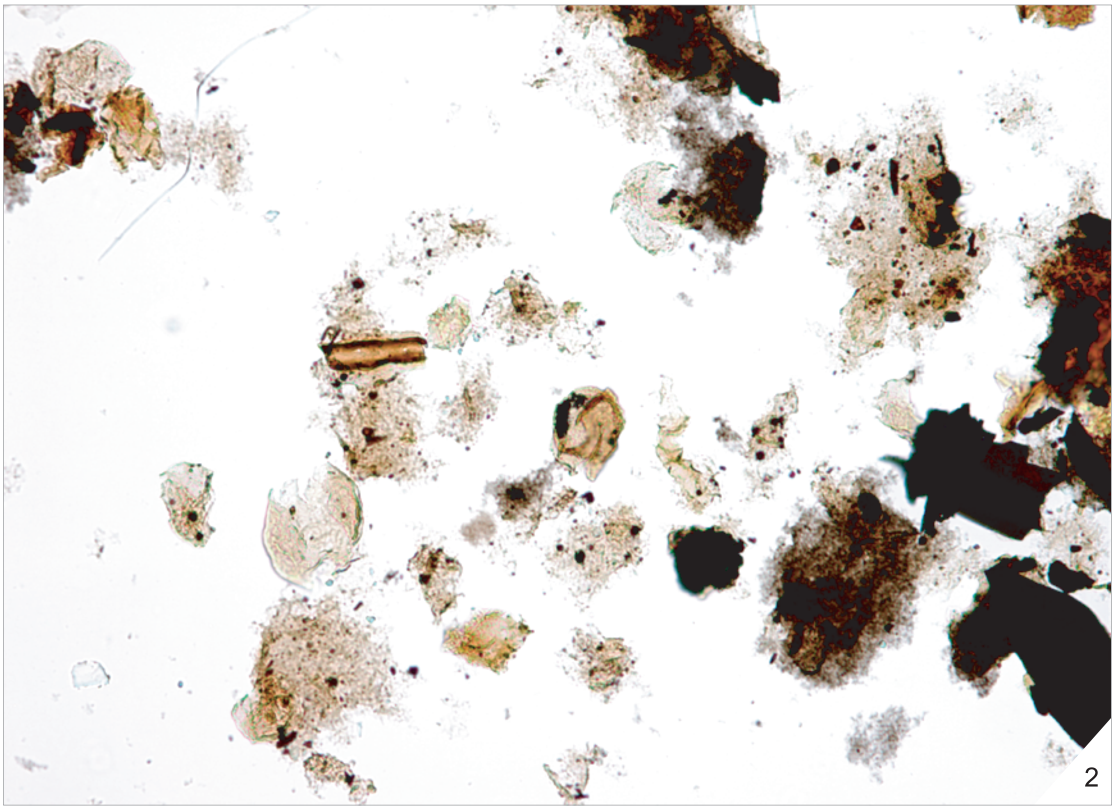

5

PLATE 12

No	Species	England Finder	Well No.	Slide No.	Depth	TCD No.
1.	Phytoclast rich sample (x250)	Y60	13/3-1	1380-1400	1380-1400’	60300
2.	Sample rich in AOM of liptinitic origin (x250)	Q64/3	26/28-1	2765 U1	2765m	60301

PLATE 12


1


2