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PALYNOSTRATIGRAPHY AND PALYNOFACIES ANALYSIS OF UPPER DEVONIAN AND MISSISSIPPIAN STRATA OF EASTERN U.S.A.

By

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

Department of Geology, Trinity College Dublin

March 2009

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Niall W. Paterson

SUMMARY

Well preserved and taxonomically diverse miospore assemblages have been recovered from the uppermost Devonian and lower Mississippian strata of the Appalachian Basin, Eastern USA. Rock samples were collected from 13 localities in the region, including outcrop and borehole cores from four states; Ohio, Kentucky, West Virginia and Pennsylvania. Several of field localities studied have not previously been sampled for palynological analysis. Sampling focused primarily upon on fine grained, organic rich mudrocks, shales and claystones. Samples were processed for palynostratigraphic and palynofacies analysis using standard techniques. Analysis was conducted using transmitted light microscopy.

Miospores encountered in this investigation are systematically described and illustrated. A total of 85 species and 40 genera were recorded. One new species is proposed and two new spore types are described.

The stratigraphic distribution of miospore species was recorded and is presented as a series of range and occurrence charts. Miospore assemblages are closely comparable to those recorded previously from this stratigraphic interval in Eastern Canada and Western Europe. Spore assemblages are assigned to the *Retispora lepidophyta – Verrucosisporites nitidus* (LN), *Vallatisporites vallatus – Retusotriletes incohatus* (VI) and *Spelaeotriletes pretiosus – Raistrickia clavata* (PC) miospore biozones of Western Europe. Recognition of these zones permits correlation at local, regional and intercontinental scales. Notable differences with the European zonation include the absence of assemblages assignable to the *Kraeuselisporites hibernicus – Umbonatisporites distinctus* (HD) and *Spelaeotriletes balteatus – Rugospora polyptycha* (BP) biozones, either due to a cryptic unconformity in the Eastern USA or the absence of the parent plants in the region.

Significant quantities of late Devonian miospores were recorded within Mississippian strata. Quantitative analysis of such assemblages has permitted the recognition of the Devonian/ Carboniferous boundary where reworking precludes its recognition on a purely qualitative basis.

Palynofacies analysis led to the differentiation of four principal 'kerogen assemblages': a distal marine AOM – Tasmanite dominated assemblage in the Ohio Shale, a mixed terrestrial – marine assemblage in the Bedford Shale and Berea Sandstone, a distal marine AOM assemblages in the Sunbury Shale, and a phytoclast – palynomorph assemblage in the upper Price and Burgoon Sandstone formations. Palynofacies data is consistent with inferred depositional environments and palaeogeography of the region during late Devonian – early Mississippian time.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES OF STUDY

The principal objective of this study was to document the stratigraphical ranges of miospore taxa within the uppermost Devonian and lower Mississippian strata of the Appalachian Basin, eastern USA. Historically, the elucidation of the stratigraphy for this interval in the region has been hampered by various factors, including, the complexity and diachronous nature of facies relationships and the general paucity of macrofossil remains. This issue has been further compounded by the application of a complicated system of lithostratigraphic nomenclature, recognising a multitude of formal and informal lithostratigraphic subdivisions for laterally equivalent units. Due to such factors, long-standing stratigraphic problems have emerged. One such issue relates to the placement of the Devonian/ Carboniferous boundary. This problem has been noted in previous palynological studies in the region but until now remained largely unresolved. In this study these problems and others have been resolved by means of a detailed palynological investigation of various upper Devonian and lower Mississippian strata within the Appalachian Basin. Samples were collected from several localities in states of Ohio, Kentucky, West Virginia and Pennsylvania. Miospore ranges were documented and correlation proposed at both local and intercontinental scales. Significant variations in the kerogen composition of the palynological preparations observed during the investigation, led to the incorporation of a detailed palynofacies analysis into the study.

1.2 REVISED CARBONIFEROUS CHRONOSTRATIGRAPHIC NOMENCLATURE

During 1999, the Subcommision on Carboniferous Stratigraphy (SCCS) of the International Commission on Stratigraphy (ICS) reached the decision that the American names Mississippian and Pennsylvanian should be adopted as unambiguous and global chronostratigraphic subdivisions for the Carboniferous system (Heckel & Clayton, 2006). Under these proposals the North American names replaced the more ambiguous terms, 'Lower Carboniferous' and 'Upper Carboniferous', respectively. Under the newly ratified global classification the former European regional subsystem names (Dinantian and

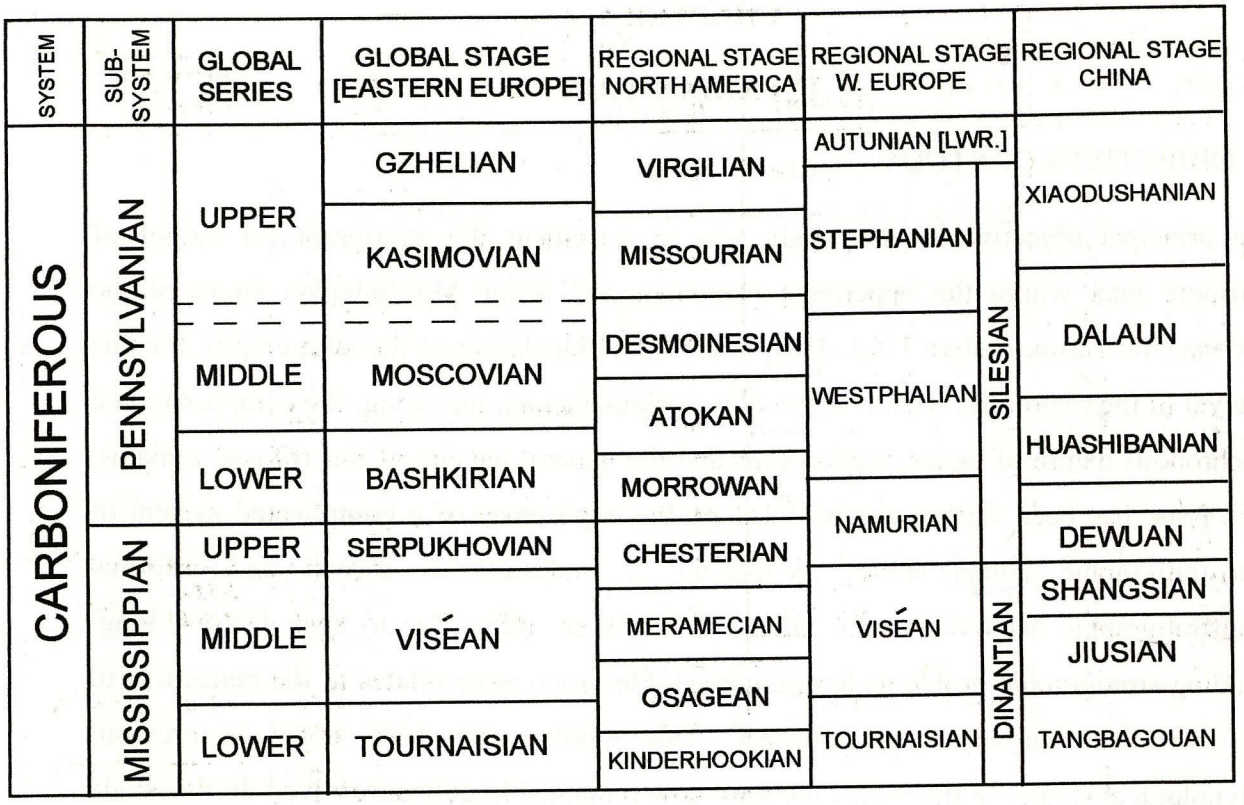


Figure 1.1 Chart showing the ratified global subdivision of Carboniferous System and approximate equivalency of global subdivisions in North America (specifically midcontinent USA), western Europe and China. Regional stages in North America were originally introduced as series of the Mississippian and Pennsylvanian Systems, but have become increasingly regarded as stages. Regional stages indicated for Western Europe have always been regarded as series and were previously grouped into the Dinantian Subsystem (Tournaisian & Visean) and Silesian Subsystem (Namurian, Westphalian & Stephanian), but following Clayton & Heckel (2006) are ranked here as stages because their many component stages have been lowered in rank to substages to keep the scale of subdivisions similar in regional and global classifications for the Carboniferous and adjacent sytems. Correlation of the regional scales and global scale are taken from many sources, summarized by P.L. Brenckle & H.R. Lane in Heckel, ed. (2001) for the Mississippian of North America, by Heckel (2003) for the Pennsylvania of North America and western Europe, and by Wang & Jin (2003) for China. Dashed lines seperating the Moscovian and Kasimovian Stages (and Middle & Upper Pennsylvanian Series) reflect the range of uncertainty of the level at which the event defining the boundary will be chosen (Villa and Task Group, 2004). After Heckel & Clayton, 2006.

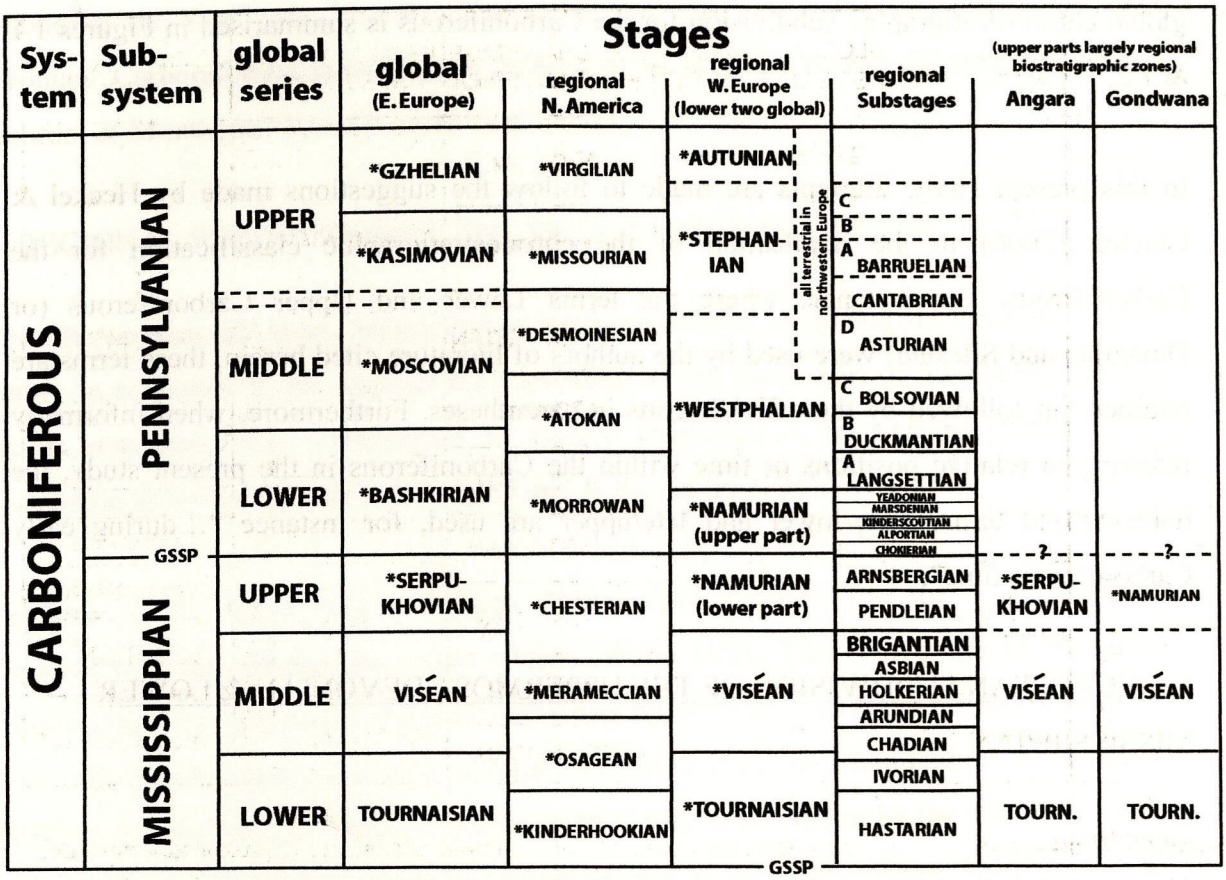


Figure 1.2 Chart showing the ratified global series and stage subdivision of the Carboniferous System, with approximate equivalency of global subdivisions to regional stage subdivisions in North America and to regional stage (formely series) and substage (formely stage) subdivisions in Western Europe. Belgian substage names are shown for Tournaisian and British substage names are shown for the Visean. Relative positions of Mississippian regional stage and substage boundaries were provided by D.M. Work. Dashed lines separating Moscovian and Kasimovian stages (and Middle and Upper Pennsylvanian Series) reflect the range of uncertainty of the level at which the event defining the boundary will be Chosen (Villa and Tasks Group, 2004). Dashed lines in regional columns reflect uncertainty of correlation with global stages. After Clayton & Heckel, 2006.

Silesian) are considered unnecessary and their usage discouraged. The newly ratified global chronostratigraphic subdivision for the Carboniferous is summarised in Figures 1.1 & 1.2.

In this present study, attempts are made to follow the suggestions made by Heckel & Clayton (2006) in the application of the chronostratigraphic classification for the Carboniferous. For instance, where the terms Lower and Upper Carboniferous (or Dinantian and Silesian) were used by the authors of literature cited herein, these terms are retained but followed by the official terms in parentheses. Furthermore, when informally referring to relative positions or time within the Carboniferous in the present study, the uncapitalized terms early/lower and late/upper are used, for instance "...during early Carboniferous time".

1.3. EUROPEAN SUBDIVISION OF THE UPPERMOST DEVONIAN & LOWER MISSISSIPPIAN

Famennian

The term 'Famennian' was first applied by Dumont (1855) in reference to a package of shaley and sandy sedimentary strata originally described by Dumont (1848). The name of the Famennian stage was derived from the historical type area in the Famenne region of southern Belgium. In Belgium the Famennian Stage corresponds to a sedimentary sequence of predominantly siliciclastic shelf sediments, up to 600m thick, bounded by shelf carbonates of upper Devonian (Frasnian) and lower Carboniferous (Tournaisian) on its lower and upper boundaries, respectively (Thorez, Dreesem & Streel, 2006). The GSSP for the Frasnian-Famennian boundary is currently located in a section close to the Upper Coumiac Quarry, in the area southeast of Montagne Noire in Southern France (Klapper *et al.*, 1993). The base of the stage defined by the lower boundary of the Lower *Palmatolepis triangularis* Zone (Thorez, Dreesem & Streel, 2006). The 'Strunian' is the name applied to the uppermost Famennian Substage (Streel *et al.* 2006).

Tournaisian

The name 'Tournaisian' is applied to the lowermost Stage of the Mississippian Subsystem (Carboniferous System). The Tournaisian was first introduced by de Koninck (1842-1844)

who applied the names "calcaire carbonifére de Tournai" (Tournaisian) and "calcaire carbonifere de Visé" (or Viséan). The GSSP for the base of Tournaisian (and the Devonian/ Carboniferous boundary) is defined in an artificial trench (E) near La Serre, southeast of Montagne Noire (Paproth *et al.* 1991).

1.4 REGIONAL SUBDIVISION OF THE MISSISSIPPIAN IN THE USA.

In North America, the term 'Mississippian has been utilised by geologists for more than a century in reference to the interval corresponding to the lower part of the Carboniferous System elsewhere (e.g. Tournaisian to middle Namurian A in western Europe, and Tournaisian to Serpukhovian in Russia) (Lane & Brenckle, 2005).

Winchell (1869) introduced the term 'Mississippi Group' for the Carboniferous Limestones in the Mississippi valley region of the USA. The first usage of the term Mississippian in a time stratigraphical sense was by Williams (1891), who designated it a series. The Mississippian was later promoted to period status by Chamberlain & Salisbury (1907). It was first recognised as a system in 1915 following studies by the USGS (Lane & Brenckle, 2005), and has continued to be recognised as such until recent modifications to the global chronostratigraphic nomenclature for the Carboniferous proposed by Heckel & Clayton (2006). Usage of the Mississippian as a system in North America was further reinforced by Cheney *et al.* (1945) and Weller *et al.* (1948). The stratotype region for the Mississippian in North America consists of a series of outcrops along the Mississippi River, from the area north of Burlington, Iowa to southern Illinois.

Two competing subdivisions for the Mississippian of North America have been proposed, that of the USGS and a second scheme devised by the Illinois and Indiana state surveys (Lane & Brenckle, 2005). The USGS scheme recognises 4 stages, in ascending order, the Kinderhookian, Osagean, Meramecian and Chesterian. The alternative scheme instead recognises 3 stages, the Kinderhookian, Valmeyeran (approximately equivalent to the Osagean and Meramecian) and the Chesterian. The USGS scheme is the one employed in the present study. A brief account of each of these groups is provided here:

Kinderhookian

In North America, the Kinderhookian is equivalent to the European Tournaisian stage (Menning *et al.* 2006). The Kinderhookian was first described by Meek and Worthen (1861) based on exposures near the town of Kinderhook, Pike County, Illinois (Lane & Brenckle, 2005). Lithostratigraphic units assigned to this stage include beds between the latest Devonian age Louisiana Limestone and the earliest Osagean Burlington Limestone. The base of the Carboniferous is placed at the base of the Horton Creek Formation (Glen Park Member of the Hannibal Shale in older literature), and is marked by the first appearance of the conodont taxa *Siphonodella sulcata* and *Protognathodus kuehni* (Collinson, 1961, Sandberg *et al.* 1972). Globally, the first appearance datum of *Siphonodella sulcata* marks the base of the Carboniferous, as defined by the IUGS (Menning *et al.* 2006). The Kinderhookian stage spans seven siphonodellid conodont zones: *sulcata*, Lower *duplicata*, Upper *duplicata*, *sandbergi*, Lower *crenulata*, Upper *crenulata* and *isosticha* (Lane & Brenckle, 2005) (Figure 1.3).

Osagean

The term 'Osagean' was introduced by Williams (1891), who applied the name 'Osage Group' for exposures along the Osage River in St. Clair County in Central Missouri. Within the stratotype region this group includes those lithostratigraphic units between the base of the Fern Glen/ Meppen Limestone Formation to the top of the lower Warsaw Formation (Kammer *et al.* 1990). The last occurrence of Siphonodella spp. is generally considered a useful marker for the Kinderhookian/ Osagean boundary; however other authors have proposed the appearance of *Polygnathodus communis carinus* (Thompson, 1967; Thompson & Fellows, 1970) or the base of the *Gnathodus punctatus* Zone (Lane, 1974; Lane & Brenckle, 2005) as alternative markers for the Kinderhookian/ Osagean boundary. In the Mississippi Valley stratotype region, the Kinderhookian/ Osagean boundary is considered to be absent due to an unconformity which spans the upper part of the Kinderhookian *isosticha* – Upper *crenulata* Zone and the Osagean *punctatus* Zone. However, conodont data from elsewhere, e.g. south-west Missouri, north-east Oklahoma and north Arkansas suggest the boundary is marked by the first appearance of Gnathodus punctatus, and thus the base of the *punctatus* Zone (Lane & Brenckle, 2006). In total, the Osagean stage encompasses eight conodont zones and subzones; *punctatus*, *communis*

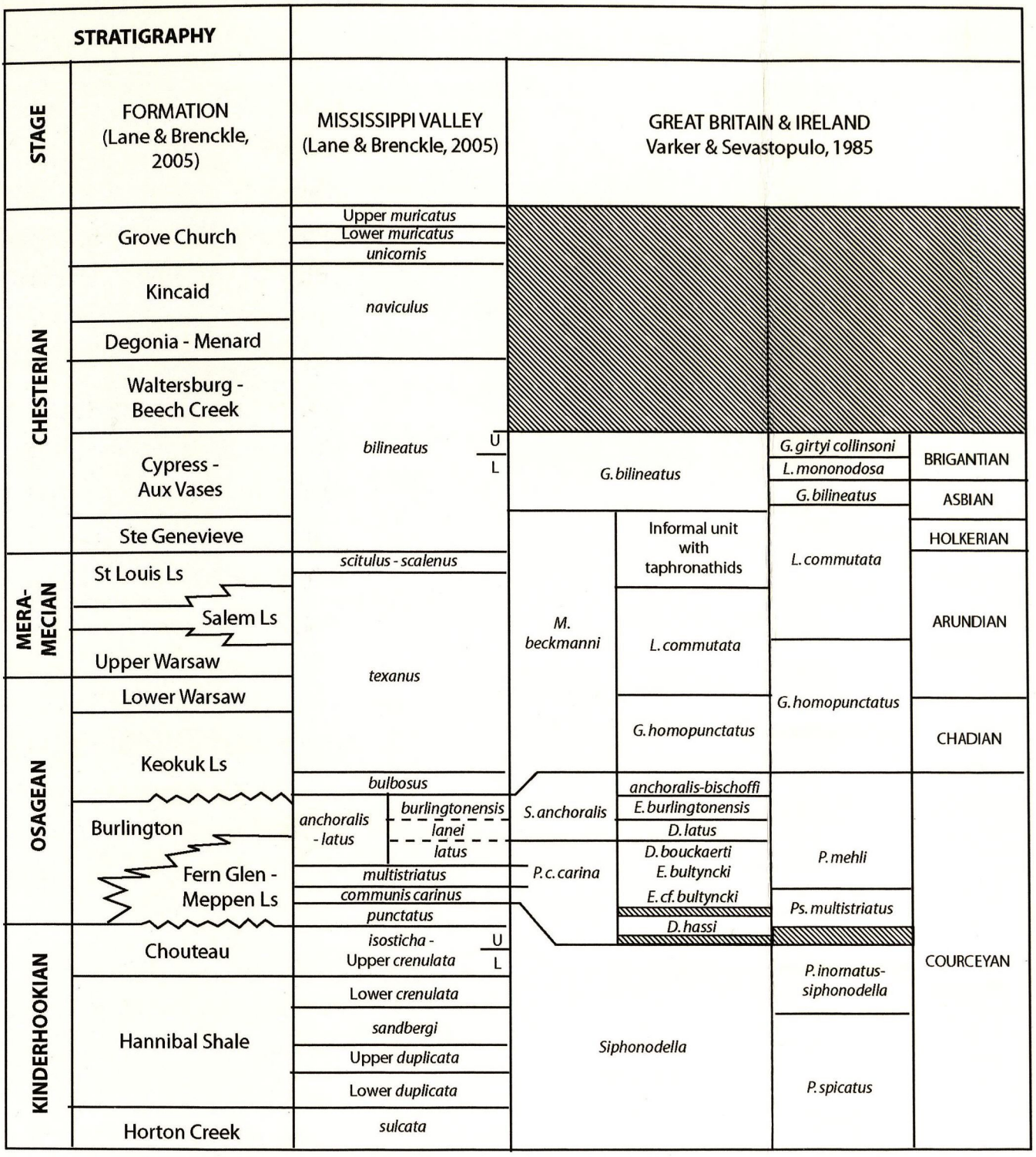


Figure 1.3 Comparison of North American and European conodont biozonation for the Mississippian

carinus, *multistriatus*, *latus*, *lanei*, *burlingtonensis*, *bulbosus* and *texanus* (partial) (Lane & Brenckle, 2005).

Meramecian

The 'Meramec Group' was defined by Ulrich (1904) based upon exposures at the Meramec Highlands Quarry, along the Meramec River southwest of St. Louis, Missouri. It is considered to be equivalent to the Ivorian, Chadian and Arundian substages of Western Europe (Menning *et al.* 2006). The base of the group was placed at the base of Lane & Brenckle's (1977) lithic Unit 24 by Kammer *et al.* (1990). As reported by Lane & Brenckle (2005), this level corresponds to the first appearance of a distinctive group of taxa including brachiopods *Warsawia lateralis*, *Planlvus densa*, *Crossacanthia perlamellosa*, *Setigerites altonensi* and *Tetracamera subcuneata*, the blastoid species *Pentremites conoideus*, and the calcareous foraminifer *Globoendothyra baileyi*.

Chesterian

Worthen (1860) first introduced the Chester Group based on exposures in the vicinity of Chester, southern Illinois. At the stratotype the group includes the lithostratigraphic interval from the base of the Renault Limestone to the top the Kincaid Limestone. The base of the Chesterian is recognised by the first appearance of the asteroarchaediscin foraminifers (*Asteroarchaediscus* and *Neoarchaediscus*) in the basal levels of the Saint Genevieve Limestone (Lane & Brenckle, 2005). This horizon coincides with the base of the Lower *bilineatus* Conodont Zone (Lane & Brenckle, 2005). The Chesterian Stage spans six conodont zones; the Lower *bilineatus*, Upper *bilineatus*, *naviculus*, Lower *muricatus* and Upper *muricatus*.

1.5 GEOLOGICAL SETTING

In the following section a brief review of the geological history and tectonic setting of the Eastern USA is provided. It is obviously beyond the scope of the current study to provide a critical appraisal of all literature concerning the Devonian and Carboniferous geology of the region. However, it is considered necessary that a brief summary is provided here in order to serve as a reference for the non-specialist reader and to place the palynological data discussed in subsequent chapters within a wider sedimentalogical and geographical context. Furthermore, since the lithostratigraphic nomenclature relating to the upper Devonian and Mississippian strata within the region is complicated by the use of local names and informal drillers' terms, it is important that the context in which certain lithostratigraphic names are used is first clarified. As noted by previous authors (e.g. Matchen & Kammer, 1994, p. 30) the usage of such informal terminology within the Appalachian Basin has presented a major obstacle to correlations in the region. Where certain aspects of the lithostratigraphic nomenclatural are considered too complex to be adequately dealt with here, the reader's attention is directed to more comprehensive literature.

This summary consists of two main parts; the first dealing with the structural and tectonic setting of the region, the second section covering the lithostratigraphic subdivision of the latest Devonian and Lower Carboniferous (Mississippian) strata of the Appalachian Basin. Since the lithostratigraphic nomenclature varies considerably between the different states and many units are known by a variety of names depending on their occurrence (i.e. outcrop or subsurface), the lithostratigraphy of each state is discussed in turn. Since this manuscript has been prepared in a European institution metric units are used in preference to imperial units. Where data is cited from American publications the original imperial units are used with metric units noted in parentheses.

1.5.1 STRUCTURAL & TECTONIC CONSTRAINTS ON SEDIMENTATION

The Appalachian Basin is inferred to represent a foreland basin which formed in response to lithospheric flexure accompanying the Taconic, Acadian and Alleghenian orogonies (Quinlan *et al.* 1984). The basin is bounded to the east by the Appalachian Highlands and to the west by the Waverly and Cincinnati arches, structural highs interpreted as foreland

bulges associated the Taconic and Alleghenian orogonies respectively (Root & Onasch, 1999).

Sedimentation within the basin commenced during the mid-Ordovician and continued through the remainder of the Palaeozoic. The Palaeozoic succession within the Appalachian Basin includes several clastic wedges ranging from middle Ordovician to Permian in age. These sedimentary successions are considered to have been deposited during the 'loading-phase' of those respective orogenies (Ettensohn, 2004).

During the late Devonian and Mississippian, a series of deltas are inferred to have prograded into the basin. Ettensohn (1985a) suggests that this period of sedimentation commenced in the late Middle to Late Devonian (late Givetian – Famennian; late Erian – Chautauquan) with the deposition of a clastic wedge which Barrell (1912, 1913, 1914a &b) termed the Catskill Delta (Ettensohn, 2004).

Following the Catskill deposition, siliciclastic sedimentation within the Appalachian Basin recommenced with the 'classic' Bedford-Berea Delta of Pepper *et al.* (1954). These deposits were long considered to represent remnants of an elongate delta system which drained a cratonic source area in what is now Eastern Canada, while the contemporaneous Cussewago Delta was fed by rivers draining an orogenic source area in the Acadian Highlands (Edmunds *et al.* 1979) (Figure 1.4). However, more recent research in this region (e.g. Pashin & Ettensohn, 1995) has suggested that the Bedford- Berea Delta is perhaps best considered part of the Catskill Delta Complex, apparently representing a period of lowstand reworking of the Catskill Delta during the latest Devonian (Ettensohn, 1999).

Where they overlap, deposits of the Catskill and the Bedford – Berea deltas are separated by thick accumulations of black shale (the Ohio Shale Formation and its equivalents) which presumably represent a period of marine transgression 'bracketed' by two lowstand intervals. Similar deposits of black shale, (the Sunbury/ Riddlesburg shales) overlie the deposits of the Bedford-Berea and Cussewago deltas marking a transgression during earliest Mississippian time in south-central parts of the basin (Ettensohn, 1999). This period of basinal, black-shale deposition was immediately followed by the deposition of

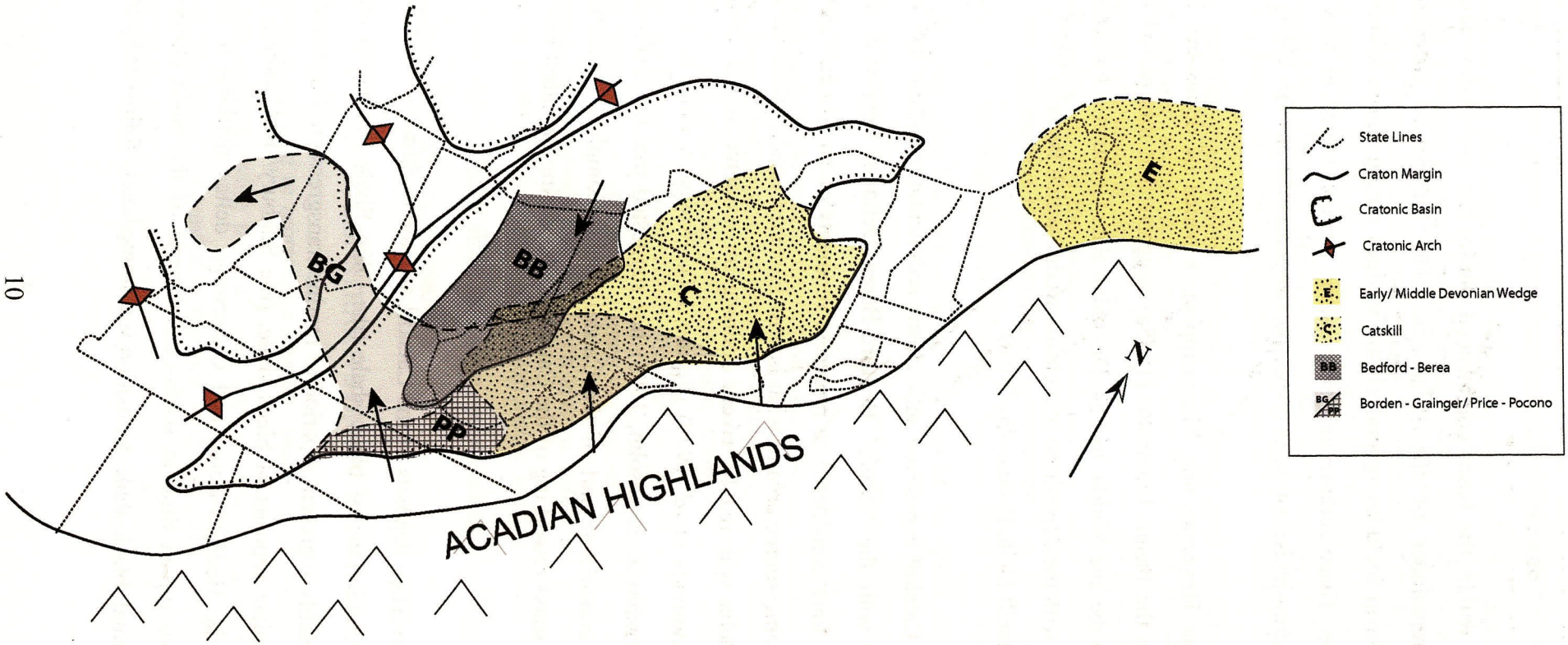


Figure 1.3 Diagram illustrating the distribution of late Devonian and early Mississippian delta systems in the Eastern USA (Modified from Ettensohn, 2004). *Note*: north arrow relates to contemporary north.

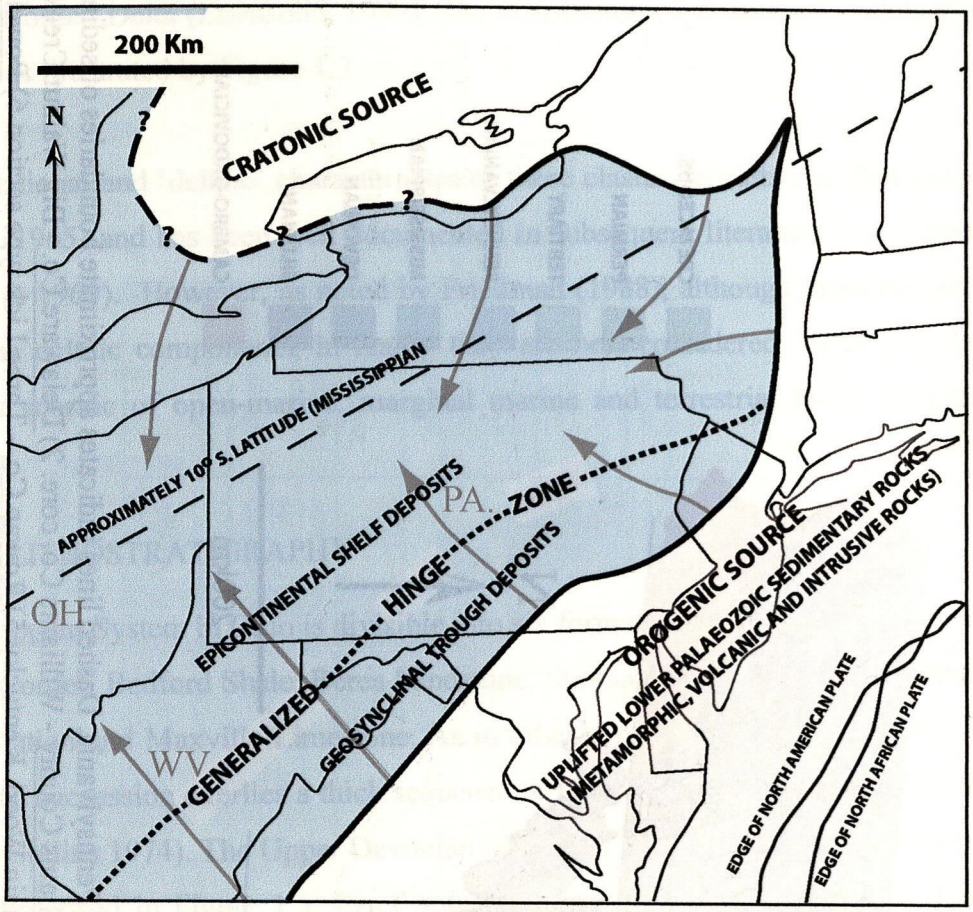


Figure 1.4 Generalised palaeogeography and sediment sources in the Appalachian Basin during late Devonian/ early Mississippian time (Modified from Edmunds *et al.* 1979). *Note*: north arrow relates to contemporary north. OH = Ohio, WV = West Virginia & PA = Pennsylvania.

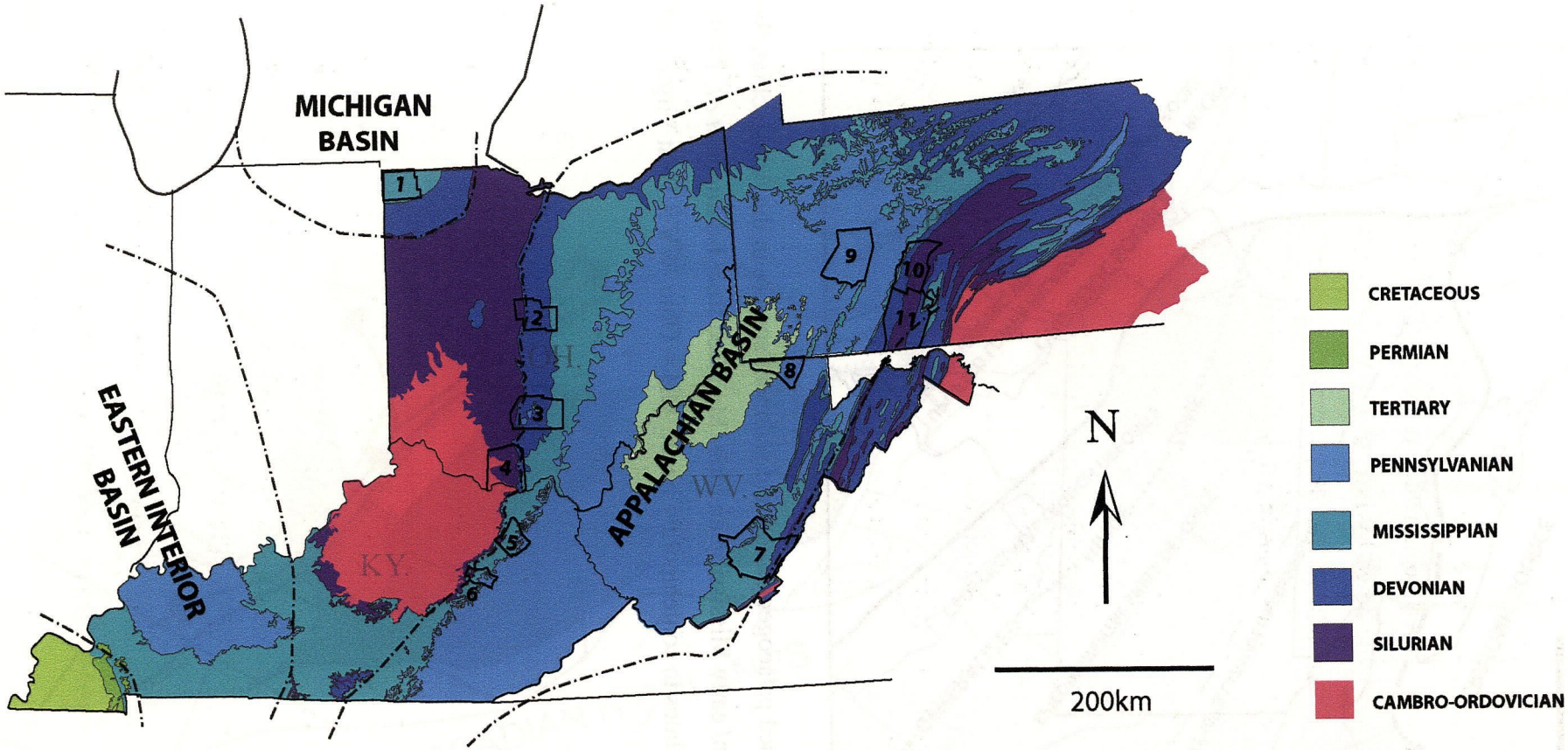


Figure 1.5 Bedrock geology map for Ohio, Kentucky, West Virginia and Pennsylvania. Dashed lines indicates approximate boundaries of sedimentary basins.Counties sampled in the present studyare as follows: Ohio 1) Williams County - Williams Co. core. 2) Delaware Co. - Big Walnut Creek, Sunbury 3) Ross Co. - Three Locks Quarry 4) Adams Co. - Tener Mountain Wood. Kentucky 5) Rowan Co. - Three Lick type section 6) Powell Co. - a. Vanceburg b. Clay City Quarry. West Virginia 7) Greenbrier Co. - a. Caldwell b. Alta 8) Monongalia Co. - Mylan Park core 9) Indiana Co. - Cramer 10) Blair Co. - Altoona 11) Bedford Co. - Warrior's Path State Park.

yet another clastic wedge, known variously in different states as the Price-Pocono, Grainger or Borden Delta (Ettensohn, 1999). The distribution of these clastic wedge/ delta – complexes is illustrated by Figure 1.3.

The progradational and 'deltaic' characteristics of these clastic deposits was first noted by Swan *et al.* (1965) and has been well documented in subsequent literature (e.g. Lineback, 1966, 1968 & 1969). However, as noted by Friedman (1988), although these deposits do contain some deltaic components, in reality they are best considered 'delta complexes' containing a mosaic of open-marine, marginal marine and terrestrial facies (Ettensohn, 1999).

1.5.2 OHIO LITHOSTRATIGRAPHY

The Mississippian System in Ohio is divisible into six formations (Collins, 1974); these are in ascending order, Bedford Shale, Berea Sandstone, Sunbury Shale, Cuyahoga Formation, Logan Formation and Maxville Limestone. As in other states within the region, the lower Mississippian succession overlies a thick sequence of Upper Devonian black shale (Pepper *et al.* 1954; Collins 1974). The Upper Devonian and lower Mississippian succession within Ohio is summarised in Figure 1.5. Brief notes on these formations are provided herein where considered relevant. Palynological data presented in the current study (Chapter 7) and by previous authors (e.g. Winslow, 1962; Eames, 1974; Molyneux *et al.* 1984) would rule out the assignment of the Bedford Shale and Berea Sandstone to the Mississippian System.

Ohio Shale Formation

In Ohio, the Ohio Shale Formation crops out in a wide 'belt', from Cuyahoga County in the north, to the Kentucky Stateline in the south, where it continues southward to Pulaski County, in southern Kentucky. In northern Ohio this unit can be resolved into two distinct members, the Cleveland and the Huron (Pepper *et al.* 1954). The Ohio Shale is thickest in the north of the state, where in places (e.g. Southern Huron County) the thickness of the shale exceeds 500 ft. (152m), it thins southwards towards Kentucky.

Although the two members are noted as both being "...essentially identical in lithological character..." (Pepper *et al.* 1954), a number of differences may be noted between them.

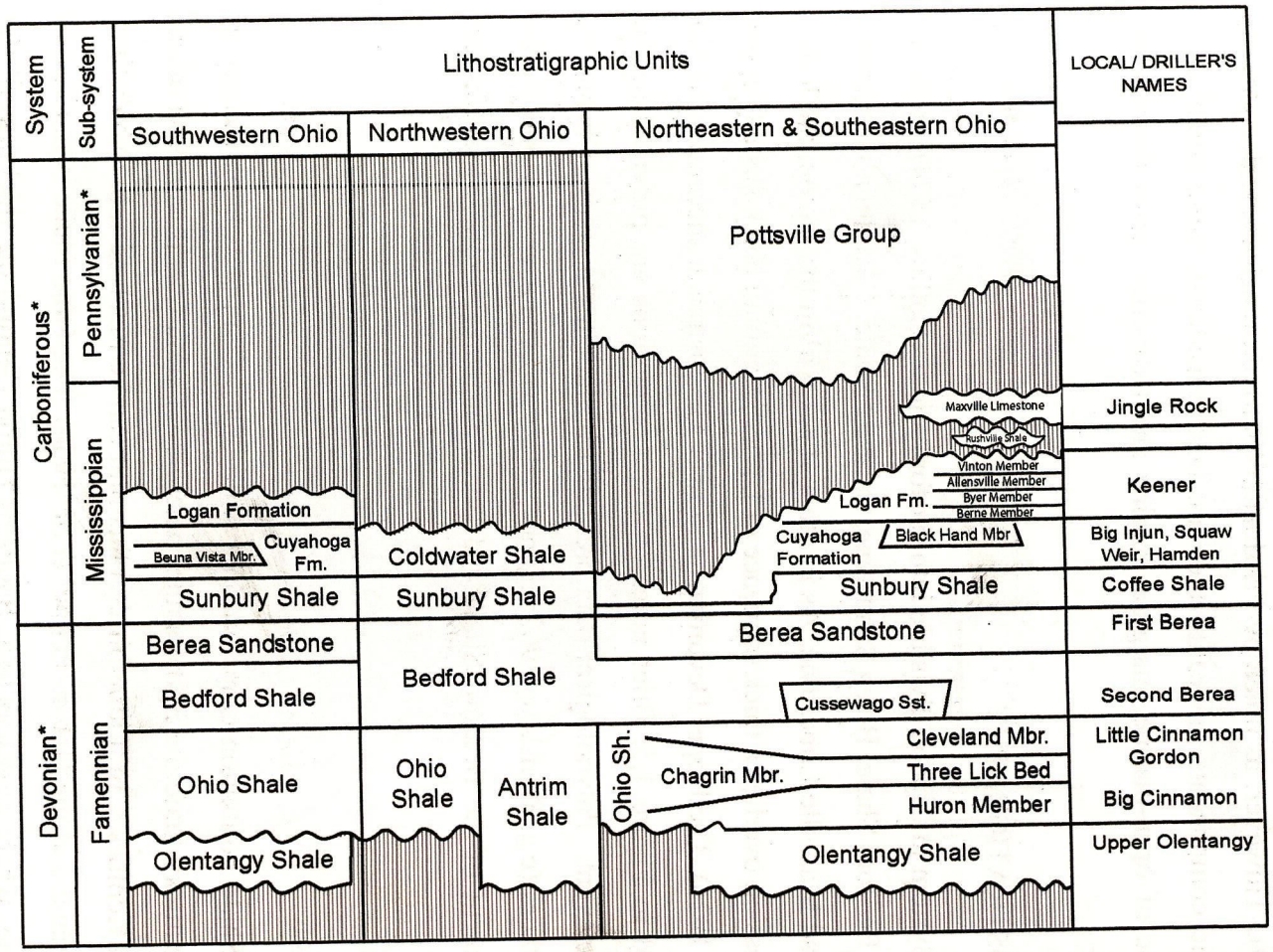


Figure 1.5 Lithostratigraphic nomenclature for the uppermost Devonian, Mississippian and lower Pennsylvanian of Ohio. Modified from Slucher, (2004) after Larsen (2000) and Hull (1990).

* Denotes partial or incomplete.

The Huron Member, named by Newberry (1870b) based on its type locality along the Huron River, typically consists of greyish black shale, with large septarian concretions in its lower levels. The overlying Cleveland Member can be differentiated into a lower and upper part. The lower portion consisting primarily of black shale interbedded with bluish-grey clay, grey-brown siltstones and occasional beds of siliceous limestone. The upper part is comprised of grey/ black shale, which weathers to a rusty brown colour. A more comprehensive description of these members and other local correlatives is provided by Pepper *et al.* (1954).

Bedford Shale Formation

At its type locality in Bedford, Cuyahoga County, the Bedford Shale is approximately 25 metres (82ft.) thick and consists predominantly of soft red clay, grading into a grey shale and grey siltstone at its base. The thickness of this formation is highly variable over Ohio, due to the irregular erosive contact with the overlying Berea Sandstone.

Throughout the state, the Bedford Shale rests directly upon the Ohio Shale Formation, overlying the black bituminous Cleveland Member in central Ohio and penecontemporaneous Chagrin Shale Member in the east (Collins, 1974). The contact between the Bedford Shale and the underlying Ohio Shale is generally distinct, except in the eastern counties, where the Bedford consists predominantly of grey shale and overlies similar grey shales and siltstones of the Chagrin Shale Member (Pepper *et al.* 1954; Collins 1974).

In southern Ohio the Bedford typically consists of bluish-grey sandy shale, grading into sandstone and siltstone in its upper part. Elsewhere in the state, particularly in the central and northern central counties, the Bedford is primarily red to reddish brown in colour and more argillaceous than in the southern Ohio (Collins, 1974). Locally, the Bedford Shale may be divisible into members such as in Cuyahoga County, where two massive siltstone units termed the Sagamore and Euclid siltstones may be recognised (Collins, 1974). Unusual soft sedimentary deformation features have been observed in the Bedford Shale, particularly in central Ohio. These are referred to in the older literature as "turtle-back" stone (Cooper 1943) or 'flow rolls' in more recent publications (e.g. Pepper *et al.* 1954; Molyneux *et al.* 1984).

The Bedford Shale together with the overlying Berea Sandstone Formation, has been interpreted to represent the deposits of an elongate delta system which prograded across Ohio into the Appalachian Basin during latest Devonian – early Mississippian time (Pepper *et al.* 1954). The presence of marine fossils including conodonts (Hass, 1947, De Witt 1970) and brachiopods (Pashin & Ettensohn, 1992) within the Bedford Shale would indicate that at least portions of the Bedford were deposited under fully marine conditions. A comprehensive description of this formation and the overlying Berea Sandstone is provided by Pepper *et al.* (1954).

Berea Sandstone Formation

The Berea Sandstone Formation derives its name from the town of Berea in Cuyahoga County, Ohio. The Berea Sandstone typically consists of a fine to medium grained, pale coloured quartz sandstone. This unit generally overlies the Bedford Shale. However, since it 'thins out' in a southerly direction, grading into light grey coloured sandstone, it is often difficult to distinguish from the underlying Bedford (Pepper *et al.*, 1954). Like the Bedford Shale, the Berea Sandstone is not only of variable thickness across the state but also varies considerably in other lithological characteristics such as grain size, bedding and colouration. In its lower part, the 'Berea' is typically a massive, cross-bedded sandstone, interpreted to represent the infill phase of channels eroded into the Bedford Shale (Pepper *et al.*, 1954). The upper part of the Berea Sandstone is dominated by thinly bedded, oscillation ripple bedforms thought to signify a more transgressive phase of the Bedford-Berea deposition. The symmetrical nature of ripple forms was cited by Cooper (1943) as evidence for deposition under fully marine conditions.

Variability in the thickness of both the Bedford Shale and Berea Sandstone is interpreted to have resulted from a significant period of erosion between the deposition of the two formations (Pepper *et al.* 1954). At a number of localities in Ohio, particularly in Huron County, the Bedford Shale is entirely absent and the Berea Sandstone 'rests' disconformably above the black Ohio Shale (Pepper *et al.* 1954). The Berea has also been observed to fill steep-sided channels eroded into the underlying Bedford Shale (Pepper *et*

al. 1954). However, in central Ohio at least, it appears that sedimentation was continuous across the Bedford – Berea boundary (Coogan *et al.* 1974).

Note: The following formations denoted * have not been sampled in this study; however, a brief summary is provided here due to either to their stratigraphic importance or inclusion in previous palynological studies.

Sunbury Shale Formation *

The Sunbury Shale Formation derives its name from the village of Sunbury in Delaware County, Ohio. The Sunbury Shale was formally introduced as the Sunbury Formation by Hicks (1878). At the type locality it consists of thinly bedded, fissile, carbonaceous black shale. Collins (1981) notes that while the Sunbury is relatively thin in comparison with over and underlying formations (typically about 6 metres), it is remarkably persistent in its geographical extent and can be traced from the Ohio – Kentucky state-line north to Cuyahoga County and eastwards to the Ohio – Pennsylvania line. Although not particularly fossiliferous, the Sunbury Shale has yielded a restricted invertebrate assemblage including brachiopod taxa *Lingula melie* and *Orbiculoidea herzeri* (Pepper *et al.* 1954). Importantly, a *Siphonodella* conodont fauna has also been reported from this formation (Hass, 1947; De Witt 1970), indicating an early Mississippian (Kinderhookian) age.

Cuyahoga Formation *

Collins (1974) describes the Cuyahoga Formation as a thick, complex sequence of shale, sandstone and conglomerate. This formation derives its name from Cuyahoga County where it was first described. As with underlying units, the thickness of the Cuyahoga Formation varies considerably. At its maximum, it is approximately 190 metres (623ft.) thick. The Cuyahoga is divisible into a number of members; these are in ascending stratigraphic order, the Henley Shale, Buena Vista Sandstone, Portsmouth Shale, Black Hand Sandstone (described here in detail) and Berne Conglomerate.

In east central Ohio the Cuyahoga Formation is 129 – 161m (423 – 528ft.) thick, thinning southward towards the Ohio River (Matchen & Kammer, 2006). With the exception of the

Black Hand Sandstone, the unit is considered to be entirely of marine origin, containing rich assemblages of marine invertebrates and trace fossils (Szmuc, 1957 & 1970).

Black Hand Sandstone Member

Hicks (1878) first introduced the term 'Black Hand' for the thick sandstone and conglomerate lithology cropping out in Black Hand Gorge on the Licking River, Ohio. Subsequent authors have included the Black Hand as a member within the Cuyahoga Formation (Collins, 1974). Matchen & Kammer (2006) describe the Black Hand Member as, "...a multi-storey, crossbedded, coarse-grained conglomeratic sandstone..." The contact between the Black Hand Sandstone and the underlying Cuyahoga is sharp and scoured; 'rip-up' clasts of the Cuyahoga are commonly incorporated into the basal layers of the Black Hand (Matchen & Kammer, 2006).

The Black Hand Sandstone has been variously interpreted to represent deltaic (Hyde, 1953), shoreline (Ver Steeg, 1947) and distributary channel (Bork & Malcuit, 1979) deposits. However, recent re-evaluation of the lithofacies and architectural evidence by Matchen & Kammer (2006) would suggest that the Black Hand represents a braided stream deposit. Matchen & Kammer (2006) infer that these deposits infilled a valley previously incised into the underlying Cuyahoga Formation during a glacially driven regression which occurred during the Kinderhookian/ Osagean boundary interval.

Coldwater Shale Formation

The Coldwater Shale Formation was named by Lane (1885) based on isolated exposures along the Coldwater River near Coldwater, Michigan. In Michigan, the Coldwater Shale is one of the thickest of the Mississippian formations, reaching a thickness of approximately 396 metres. This unit has been correlated with the lowermost Borden Group of Illinois and Indiana and also the Cuyahoga Formation of Ohio (Matchen & Kammer, 2006, p. 104) but generally consists of finer grained deposits of grey to bluish grey shale, and obviously represents a more distal facies.

The Coldwater Shale is inferred to extend beneath the recent glacial drift, into the subsurface of north-western Ohio (Ells, 1979). Since one of the sections studied in this present investigation is a borehole core drilled in William's County in north-western Ohio,

it was considered relevant to include brief notes regarding the Coldwater Shale in this introductory section.

In the ODNR Division of Geological Survey Core Record for the Williams County Core (Appendix III), the grey – green shale recorded between the depths of 195.0 and 332.7 feet (60 – 101m) is termed Coldwater Shale. This name is therefore used in the present study to denote the shale overlying the Sunbury Shale in the subsurface of north-western Ohio (specifically in William's County). Meanwhile, the 'Cuyahoga Formation' is used herein to signify the coarser grained deposits of sandstone and conglomerate present elsewhere in Ohio.

Logan Formation *

The Logan Formation is named after the town in Hocking County, Ohio. This formation represents the uppermost clastic portion of the Mississippian succession in Ohio (Collins, 1974). As with underlying units, the Logan is lithogically diverse, including sandstone, conglomerate and sandy shale. Three members are recognised, in ascending order these are the Byer Sandstone, Allensville Conglomerate and Vinton Sandstone. These members are widely recognised in southern parts of the state; however, the Logan thins out northwards and is generally absent in north and north-eastern Ohio. The Logan Formation is particularly fossiliferous and has been divided into two faunal zones based on its marine invertebrate fauna by Fagadau (1952).

1.5.3 KENTUCKY LITHOSTRATIGRAPHY

Kentucky is unique amongst American states since it contains portions of two major sedimentary basins, each containing near complete Mississippian successions (Rice *et al.* (1979). The Eastern Interior or Illinois Basin (Figure 1.6), forms a major negative element of the eastern mid-continent (Sable & Denver, 1990), encompassing much of Illinois and Indiana, parts of Missouri and Tennessee as well as much of Western Kentucky. In Eastern Kentucky the western margin of the much larger Appalachian Basin 'laps' onto the lower Palaeozoic rocks of the Cincinnati Arch, a major positive cratonic element separating the two basins.

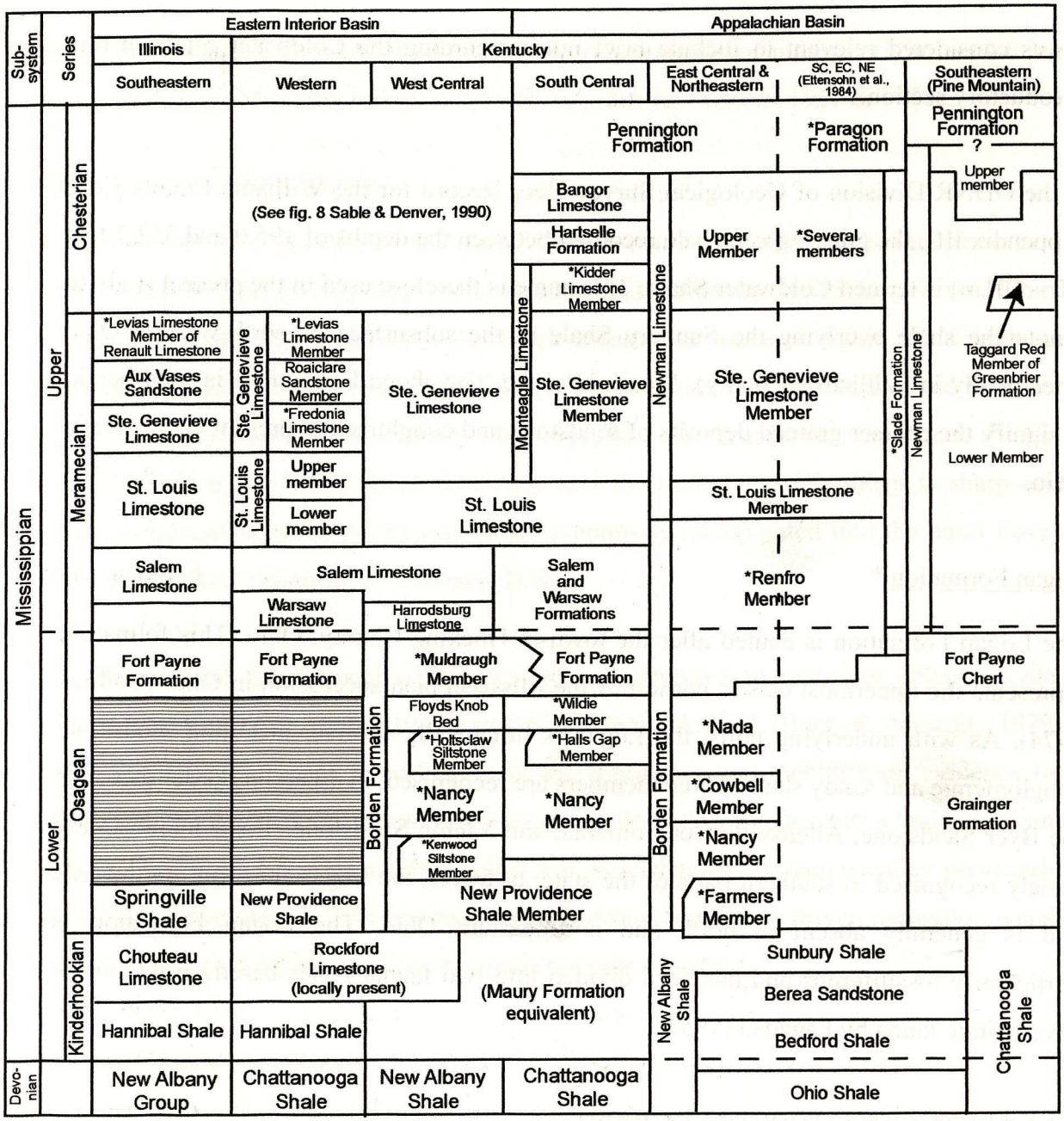


Figure 1.6 Stratigraphic nomenclature of the Mississippian System in Kentuck and Illinois Asterisks (*) indicates type section in Kentucky. Modified from Pryor & Sable (1974), Rice *et al.* (1979) and Sable & Dever (1990).

Mississippian rocks underlie much of Kentucky. However, due to a thick cover of Pennsylvanian strata the majority of the Mississippian strata occur primarily in the subsurface (Sable & Denver, 1990). Outcrop of Mississippian age strata are confined mainly to the margins of the Cincinnati Arch and other positive structures such as the Pascola Arch in Western Kentucky and the Waverly Arch through Lewis, Rowan and Bath Counties. A very narrow band of Mississippian strata also crops out in the southeast of the state, west of Pine Mountain in association with the Pine Mountain Overthrust.

'Late Devonian' Black Shales of Kentucky

As in Ohio, early Mississippian strata in Kentucky are underlain by rocks of mid to late Devonian age. Devonian strata in this region consist principally of black, organic rich, fissile shales and finely bedded siltstones. Three lithostratigraphic names are applied to the Upper Devonian shales of Kentucky, these are the New Albany, Chattanooga and Ohio Shale formations (names extrapolated from Indiana, Tennessee and Ohio respectively). Since these units are interpreted to be essentially time equivalent and laterally continuous, the nomenclatural boundaries between them are mapped arbitrarily to coincide with 7 ½ minute quadrangle boundaries (Sable & Denver, 1990). Generally, the term 'New Albany Shale' is used in central and east central Kentucky, the Chattanooga is recognised in western, south-west, south-west central, south central and south eastern parts of the state; usage of the Ohio Shale is restricted to the exposure belts in north-eastern and east central Kentucky (Figure 1.6). In parts of Kentucky these black shales are subdivided into the Huron Member, the Cleveland Member and the Three Licks Bed, which separates them (Provo *et al.*, 1978; McDowell, 2001). Some brief notes on the later unit are provided here due to its inclusion the current investigation.

Three Lick Bed

The Three Lick Bed was first described by Provo *et al.* (1978) who identified it as a potential marker bed. At its type locality on Interstate Highway 64 in western Rowan County, Kentucky, the Three Lick consists of three greenish-grey shale beds separated by beds of fissile, brownish-black shale. The thickness of the 'bed' ranges from approximately 1.7ft (0.51m) at Creelsboro, Russell County, to approximately 20ft (6.1m) at Copperas Mountain, close to Chillicothe, Ross County, Ohio (Provo *et al.* 1978). Provo *et al.* (*ibid*) noted that the thicknesses of the individual greenish-grey subunits range from less than a

centimetre to approximately 5ft. (1.52m) at those two localities. At the type locality the whole sequence measures approximately 11.5 ft. in thickness (Kepferle & Roen, 1981, p. 287). At the Clay City Quarry section, Powell County, Kentucky, (sampled in the present study) the same interval is 6 ft. thick. The bed separates the Huron and Cleveland members of the Ohio Shale Formation.

Bedford Shale Formation

The Bedford Shale Formation in Kentucky is typically a grey, silty mudstone. This formation is approximately 5.6 metres (~18.4ft) thick at the Morehead locality where it was described by Coleman & Clayton (1987). In Kentucky, the Bedford Shale Formation overlies the Ohio and Chattanooga shales with apparent conformity (Sable & Dever, 1990). However, the Berea Sandstone Formation which overlies the Bedford Shale in Ohio is generally absent in Kentucky or is otherwise unrecognisable due to its lithological similarity to the Bedford.

Sunbury Shale Formation

The Sunbury Shale Formation in Kentucky consists of black, bituminous and often pyritic shale. As in Ohio, the deposits of the Sunbury Shale in Kentucky are thought to represent transgressive marine deposition which marked the re-establishment of basinal, open-marine conditions (Ettensohn, 1979). This lithostratigraphic unit provides an easily recognisable horizon and is extensively used as a structural datum (Sable & Dever, 1990). The Sunbury is typically 10 - 25 feet (3 - 7.6m) thick in north-eastern Kentucky and reaches a thickness of approximately 55 feet (~17m) along Pine Mountain in south-eastern parts of the state (Sable & Dever 1990). Work conducted by Ettensohn (1978) and Ettensohn *et al.* (1979) has demonstrated that the Sunbury is often recognisable on the basis of its radioactivity profile. This has proved particularly useful in southern and western Kentucky where the absence of the intervening Bedford Shale and Berea Sandstone formations makes it difficult to distinguish the Sunbury from underlying lithostratigraphic units. Elam (1981) successfully recognised beds in the upper layers of the Chattanooga and New Albany Shales as Sunbury equivalents by their radioactivity profiles combined with their conodont (*Siphonodella* spp.) faunas.

1.5.4 SOUTHERN- WEST VIRGINIA LITHOSTRATIGRAPHY

Price Formation

This unit was originally defined as the 'Price Sandstone' by Campbell (1894), based upon exposures of "coarse, yellow or green sandstone, and beds of shale or coal", which crop out in the vicinity of Price Mountain, Montgomery County, Virginia. This name was later modified to the Price Formation in reference to the type section designated at Price Mountain by Campbell *et al.* (1925). This type section was later redefined by Bartlett (1974), who suggested that the principal reference section for this formation should instead be designated at Cloyds Mountain, due to poor exposure at the original section. More recently a 256m continuous section exposed along a roadcut through Greenbrier Mountain along Interstate Highway 64 near Caldwell, Greenbrier County, has served as the principal reference section for the formation (Kammer & Bjerstedt, 1986; Bjerstedt, 1987a & b).

Kammer & Bjerstedt (1986a) abandoned the terms 'Pocono Formation' and 'Pocono Group', which had previously been applied to this interval in West Virginia, since 'Pocono' had already been utilised in a chronostratigraphic rather than a lithostratigraphic sense. Kammer & Bjerstedt (*ibid*) reasoned that the rocks of the 'Price' in West Virginia bear a greater lithological similarity to the Price Formation of Virginia than to the Pocono Formation as defined by authors including Sevon (1969) and Berg *et al.* (1980,1983). Authors including Edmunds (1996) have subsequently suggested that the Pocono be reinstated as a formation in the region. However, in the present report the 'Price Formation' is used *sensu* Bjerstedt & Kammer (1988), to include all non-red strata in West Virginia above the non-marine red beds of the marine Greenland Gap Formation, and below the Greenbrier Limestone Group or red beds of the Maccrady Formation.

Cloyd Conglomerate Member

The Cloyd Conglomerate was first defined by Butts (1940) based on exposures on Cloyd Mountain, Pulaski County, Virginia. At the type section, the 'Cloyd' consists of conglomeratic sandstone and conglomerate with minor shale interbeds (Kammer & Bjerstedt, 1986). The Cloyd Conglomerate is rather poorly exposed at Cloyds Mountain (Bjerstedt, 1987b). However, at the new principal reference section for the Price Formation, near Caldwell, Greenbrier County, the Cloyd is well exposed, attaining an

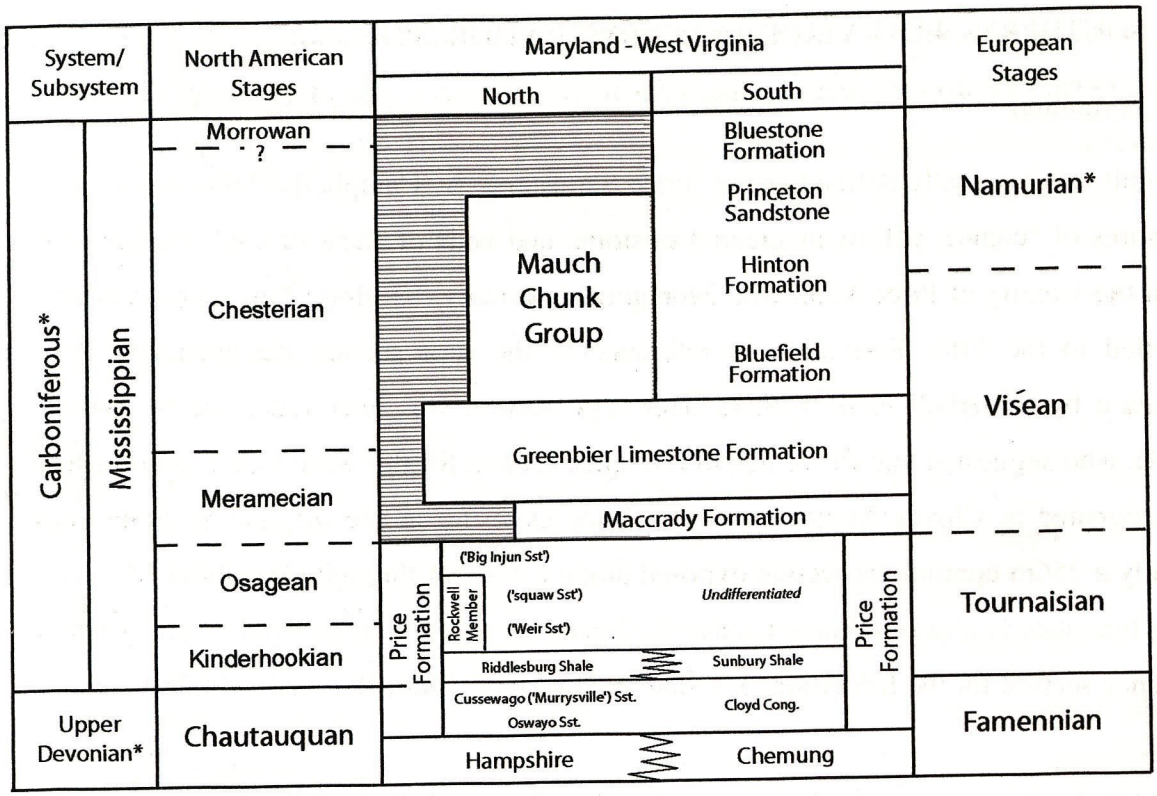


Figure 1.7 Lithostratigraphic nomenclature for the Mississippian in West Virginia and the adjacent state of Maryland and lower Pennsylvanian (Modified from Arkle *et al.*, 1979).

approximate thickness of 48 m (Bjerstedt, 1987b; Bjerstedt & Kammer, 1988). The Cloyd Conglomerate is often utilised in this area to indicate the base of the Price Formation (Brame, 2001).

Based upon subsurface correlations and its brachiopod faunas, the Cloyd Conglomerate is considered to be entirely of latest Devonian age (Bjerstedt & Kammer, 1988; Carter & Kammer, 1990). The Cloyd was likely deposited during a rapid regression followed by a gradual transgression (Bjerstedt & Kammer, 1987) and for this reason has been considered by some authors (e.g. Potter *et al.* 1983) to be synonymous with the Berea Sandstone of Ohio. However, it seems unlikely that the Cloyd is genetically related to the Berea in the subsurface (Bjerstedt & Kammer, 1988).

Riddlesburg/ Sunbury Shale Member

The Sunbury Shale and the Riddlesburg Shale are interpreted to represent laterally equivalent lithostratigraphic units; the former is thought to be indicative of offshore, oxygen-deficient basinal conditions while the latter represents a near-shore equivalent of the Sunbury Shale Formation of Kentucky and Ohio (Kammer & Bjerstedt, 1986; Bjerstedt & Kammer, 1987; Matchen & Kammer, 1994).

The Riddlesburg Shale was defined by Reger (1927) based on exposures on the western edge of the Broad Top Basin, 2.5 km (~1.5 miles) northwest of Riddlesburg, Pennsylvania. In West Virginia, the Riddlesburg is recognised as a member of the Price Formation (Kammer & Bjerstedt, 1986a); however, in Maryland and Pennsylvania it is considered a member of the Rockwell Formation (Edmunds *et al.* 1979; Berg *et al.* 1986). In West Virginia the Riddlesburg is composed of, "a heterolithic package of shales, thin-bedded siltstones and scour-based, fine-grained sandstones, commonly with wave-rippled surfaces and low-angle cross lamination" (Bjerstedt & Kammer, 1987). At Rowlesburg in northern West Virginia, Kammer & Bjerstedt (1986) describe the Riddlesburg Shale as consisting of approximately 18 m of dark grey silty shales and siltstones.

In West Virginia, the Sunbury Shale is considered a member of the Price Formation. The Sunbury Shale was first recognised in West Virginia by Reger & Price (1926), having been previously described in Ohio by Hicks (1878). Only the upper portion of this member in

West Virginia is considered to be equivalent to the basinal Sunbury Shale recognised in Ohio and Kentucky (Bjerstedt & Kammer, 1987). At Caldwell the Sunbury Shale grades into the Riddlesburg Shale (Kammer & Bjerstedt, 1986).

'Upper Un-named Price'

In southern parts of the state, such as at the Caldwell locality, the upper portion of the Price Formation remains unnamed, since its heterolithic character precludes ready subdivision into members (Carter and Kammer, 1990; Matchen & Kammer, 1994). This upper portion is informally referred to herein as the 'upper un-named' Price.

1.5.5 SUBSURFACE LITHOSTRATIGRAPHY OF WEST VIRIGNIA

In addition to the lithostratigraphic units recognised in outcrop within West Virginia, a set of informal names derived from driller's usage have been applied to sandstone intervals within the subsurface (Matchen & Kammer, 1994). A brief review of these sandstones is provided here:

Murrysville Sandstone

The term 'Murrysville Sandstone' was informally introduced by Butts & Leverett (1904) in reference to the producing sandstone encountered in a prolific gas well drilled close to the town of Murrysville, Pennsylvania (Harper & Laughrey, 1989). A number of other terms, especially driller's informal terms, have been used for this unit when encountered in the subsurface, including Butler County, Butler First, Butler Gas, Butler 30-foot and Great Saltwater sandstones (Hughes, 1933).

The Murrysville has traditionally been correlated with the Berea Sandstone of Ohio (e.g. Pepper *et al.* 1954). However, more recent work (e.g. Harper & Laughrey, 1989; Harper *et al.* 1989) has demonstrated that in Alleghany County, PA, the Murrysville splits into two separate sandstone units. Those authors have suggested that the lower of the two sandstones is approximately equivalent to the Cussewago Sandstone, while the upper the unit is likely equivalent to the Berea Sandstone.

Generally the term 'Murrysville' is only applied to the unit when encountered in the subsurface of Pennsylvania. In the present investigation, what is presumably the same

sandstone is encountered in the core drilled near Morgantown, West Virginia. Since this locality is approximately 15km from the WV-PA Stateline the term Murrysville is used.

Weir Sandstones

Like the Murrysville, the 'Weir Sandstone' is an informal driller's term, originally applied to sandstones occurring in the subsurface of West Virginia. Little published data is available concerning the Weir Sandstone; however, some evidence exists to suggest that the Weir in West Virginia is equivalent to the driller's informal 2nd Gas Sand of Pennsylvania (McDaniel, 2006). The 'Weir' sands are generally considered to be entirely of marine origin and discontinuous in the lateral distribution, being named by relative stratigraphic position rather than their lateral lithostratigraphic continuity (Kammer, personal communication).

Squaw Sandstone

The driller's informal 'Squaw' Sandstone is a term applied to sandstones encountered in the subsurface above the Riddlesburg Shale in Allegheny, Washington and Greene Counties (McDaniel, 2006). In the present study the 'Squaw' is used in reference to the sandstone occurring between the depths 1964.78 – 2001.24 ft. (598.6 – 610m), between the 'Weir' and 'Big Injun' sandstones in the Mylan Park core.

Big Injun Sandstone

'Big Injun' is a name first applied to the producing zone in the Mount Morris field, Greene County, Pennsylvania (Overby *et al.* 1963). In the type area in Pennsylvania the 'Big Injun' is a sandstone member positioned at or near the top of the Pocono Formation (Ruley, 1970). However, these authors include the 'Big Injun' and possibly also the 'Squaw' of north-central West Virginia within the Greenbrier Formation. In the present study the term 'Big Injun' is reserved for the sandstone unit encountered within the upper Price Formation in northern West Virginia (1798.44 – 1881.60 ft. depth in the Mylan Park core in the present study), below the Greenbrier Limestone. Used in this more restricted sense, the 'Big Injun' is likely a lateral equivalent of the Burgoon Sandstone of Pennsylvania and Black Hand Sandstone of Ohio, as suggested by Matchen & Kammer (2006 and Kammer & Matchen (2008).

1.5.6 PENNSYLVANIA LITHOSTRATIGRAPHY

Rockwell Formation

The Rockwell Formation was named for exposures near Rockwell Run, Morgan County, West Virginia (Stose & Swartz, 1912; Kammer & Bjerstedt, 1986). The 'type' Rockwell is generally considered to represent nonmarine deposition and consists of sandstones, coaly shales and red mudstones (Kammer & Bjerstedt, 1986). In northern West Virginia the Rockwell constitutes a member of the Price Formation, directly overlying the Riddlesburg Shale Member; in Pennsylvania is upgraded to formation status (Kammer & Bjerstedt, 1986; Bjerstedt & Kammer, 1988; Matchen & Kammer, 2006; Kammer & Matchen, 2008). In southern parts of Pennsylvania the Burgoon Sandstone separates the Rockwell Formation from the overlying Greenbrier Limestone (Bjerstedt, 1986).

Burgoon Sandstone Formation

The Burgoon Sandstone of Pennsylvania ranges from approximately 25 - 90 m in thickness, and commonly "exhibits abundant cross bedding, basal lag deposits, clay galls, plant debris, scour and fill sequences, sole markings and other features typical of fluvial sandstones" (Harper & Laughrey, 1987, p.16). Recently, the Burgoon Sandstone Formation has been correlated with the Big Injun Sandstone in the subsurface of northern West Virginia, the Purslane Sandstone of Maryland and the Black Hand Sandstone Member of the Cuyahoga Formation in central Ohio (Matchen & Kammer, 2006; Kammer & Matchen, 2008).

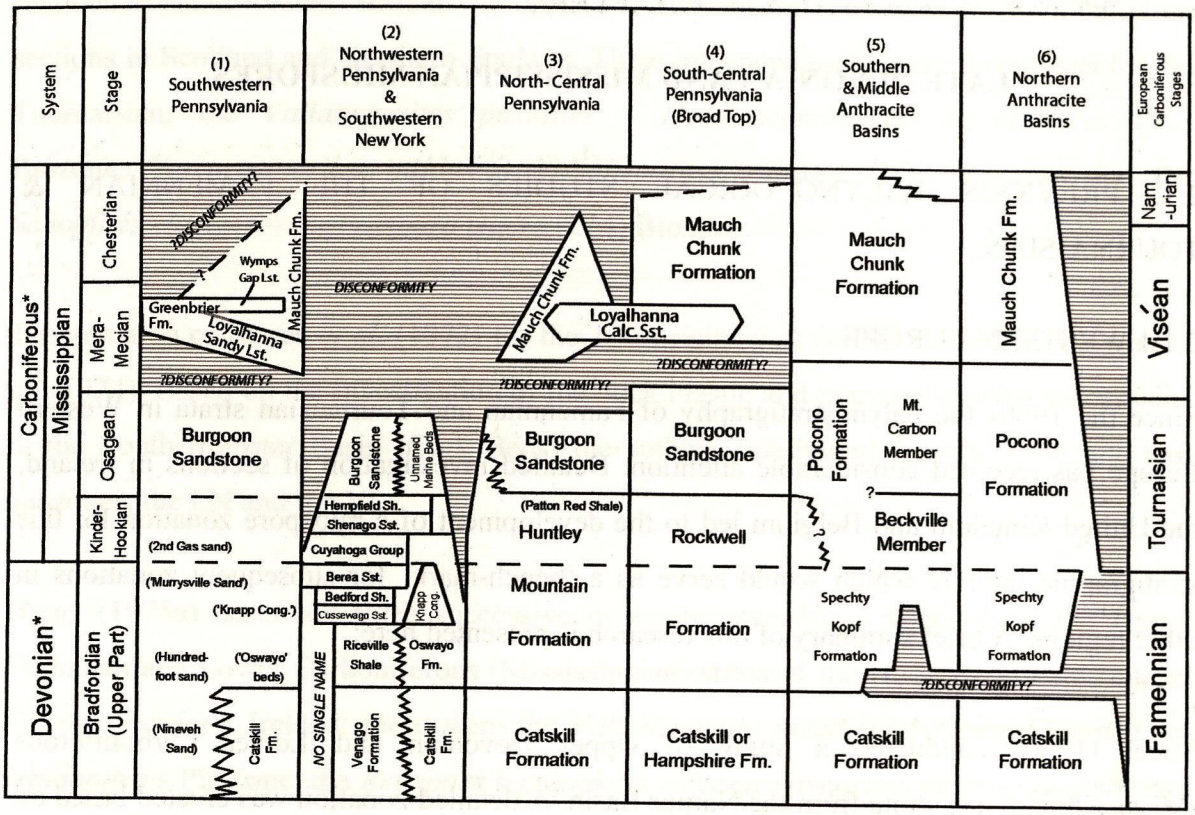


Figure 1.8 Lithostratigraphic nomenclature for the Upper Devonian and Mississippian in Pennsylvania and the adjacent state of Maryland and lower Pennsylvanian (Modified from Arkle *et al.* 1979).

CHAPTER 2

LATE DEVONIAN AND MISSISSIPPIAN MIOSPORES

2.1. PREVIOUS PALYNOLOGICAL STUDIES OF THE FAMENNIAN & TOURNAISIAN.

2.1.1 WESTERN EUROPE

Since the 1960s the palynostratigraphy of Famennian and Tournaisian strata in Western Europe has received considerable attention. Detailed investigation of sections in Ireland, the United Kingdom and Belgium led to the development of a miospore zonation for this stratigraphic interval which would serve as a 'bench-mark' for subsequent zonations in other regions. A brief summary of this research is presented here:

Streel (1966) conducted a study of Upper Devonian and Lower Carboniferous (Mississippian) age strata from the Namur Basin. A detailed zonation was erected based on biometric and morphological changes of key miospore species. This work was further expanded by Streel (1967) who described spore assemblages for the Famennian, Strunian and Tournaisian stratotypes in the Ardenno-Rhenish basins.

Neves & Dolby (1967) described miospore assemblages from the Portishead Beds (Upper Old Red Sandstone) from the Mendip Hills, England. This work was later refined by Neves & Dolby (1970) who conducted a systematic study of the changes in miospore assemblages from the Portishead Beds to the Lower Limestone Shales.

Paproth & Streel (1970) described miospore assemblages from the Upper Famennian and Lower Tournaisian (Fa2c – Tn1b), and from the lower Hangenberg Schicten (upper to VI).

Streel (1972) presented further palynological data relating to the placement of the Devonian – Carboniferous boundary in Western Europe.

Neves *et al.* (1972) erected a miospore zonation for the Lower Carboniferous (Dinantian) of the British Isles. The lower and mid Tournaisian part of the zonation were based on sections in south-western Britain; the upper Tournaisian and Viséan zones were based on

sections in south-western Britain; the upper Tournaisian and Viséan zones were based on sections in Scotland and Northern England. Three miospore zones were recognised for the Tournaisian, the *Vallatisporites pusillites – Hymenozonotriletes lepidophytus* (PL) Biozone, *Verrucosiporites nitidus – Vallatisporites vallatus* (NV) Biozone and the *Schopfites claviger – Auroraspora macra* (CM) Biozone.

The zonation of Neves *et al.* (1972) for the Tournaisian was further refined by Clayton *et al.* (1974). Based on the investigation of the thick clastic and marginal marine successions in the South Munster Basin (Cork Beds) the authors subdivided the NV Zone into two subzones, the LN and the VI.

Higgs (1975a) described three successive miospore assemblage zones from the Upper Devonian and Lower Carboniferous (Mississippian) strata of the Hook Head Peninsula in County Wexford, Ireland; these were the *Vallatisporites pusillites – Hymenozonotriletes lepidophytus* PL Zone, the *Retispora lepidophyta - Verrucosisporites nitidus* LN Zone and the *Vallatisporites vallatus – Spelaeotriletes pretiosus* assemblage.

Based on the investigation of sections in Ireland and Britain Clayton *et al.* (1978) proposed two new subzones of the PL Zone of Neves *et al.* (1972), the LL and LE. Additionally, the PC Biozone was proposed as a new zone above the existing NV Zone. This was correlated with the Middle to Upper Tournaisian (Tn2 – Tn3).

Clayton & Higgs (1979) attempted to reconstruct the palaeogeography of Ireland during the Tournaisian based miospore assemblages from 30 sections in the non marine Upper Red Sandstone, and the overlying marine sediments. The authors demonstrated that much of the Old Red Sandstone in central and northern areas is Carboniferous, not Devonian, in age.

Van Der Zwan (1980) proposed a series of regional phases considered to reflect gradual compositional development of successive palynological assemblages. However, in practice this system was impractical since these zones were poorly defined and recognisable only when certain key species became 'characteristic' within assemblages.

between the PC and CM Zones, conclusively linking the miospore zonations established in South Western Britain and Southern Ireland with those erected in Midland Valley of Scotland and Northern England.

Higgs & Russell (1981) described miospore assemblages from the 'Green Sandstone Formation, the 'Purple Sandstone Group', the 'Transition Group' and the 'Coomhola Series' from sections in Southeast Iveragh, Co. Kerry. Assemblages from the 'Purple Sandstone Group' were assigned to the VU Zone. Those from the 'Transition Group' and the 'Coomhola Series' were assigned to the LE and LN miospore zones respectively, and where thus considered to be latest Strunian in age.

Clayton *et al.* (1982) described assemblages belonging to the LL, LE and LN subzones, from a near complete succession of Devonian and Carboniferous rocks exposed along the coast near the village of Ardmore, Co. Waterford, Ireland. In the study, the base of the Carboniferous VI zone was identified slightly below the base of the Castle Slate Formation.

Higgs & Clayton (1984) described miospore assemblages from the Lower Limestone Shale and lower Black Rock Limestone from Maesbury in the eastern Mendips, England. Assemblages were assigned to VI and PC Biozones, and were compared to those described previously from other regions, particularly southern Ireland.

Clayton (1985) recorded miospore assemblages from the Foulden sequence of Berwickshire, Scotland. The presence of *Convolutispora circumvallata*, *Crassispora trychera* and *Schopfites claviger* (and the absence of *Lycospora pusilla*) led the authors to assign these assemblages to the late Tournaisian (Tn3) *Schopfites claviger – Auroraspora macra* (CM) Biozone.

Clayton (1986) Reported well-preserved miospore assemblages from the Lower Carboniferous (Dinantian) Ballycultra Formation from Co. Down, Northern Ireland. Assemblages were assigned to the Tn3 *Schopfites claviger – Auroraspora macra* (CM) Biozone.

Assemblages were assigned to the Tn3 *Schopfites claviger – Auroraspora macra* (CM) Biozone.

The miospore zonation for the Famennian and Tournaisian was further refined by Higgs *et al.* (1988). The authors proposed two new zones within the Middle Tournaisian – the HD and BP biozones, and the LL and LE subzones of the PL Zone and the LN and VI subzones of the NV Zone were upgraded to full biozonal status.

In recent years attempts have been made to standardise the miospore zonation for the Carboniferous and Uppermost Devonian (e.g. Clayton *et al.*, 2003; Clayton *et al.*, 2008). Under these proposals biozones will be redefined using single taxon events and by the introduction single taxon names for the biozones. The author of this present study acknowledges that such changes to the zonal nomenclature are necessary; however, since these recommendations have only been published as a conference abstract the author of the present study prefers to utilise the zonal nomenclature of Higgs *et al.* (1988) based on the Tournaisian rocks of Ireland.

2.1.2 EASTERN EUROPE

The first palynological study of the Lower Carboniferous (Mississippian) in Eastern Europe was conducted Luber & Waltz (1938) who investigated sections within the former U.S.S.R.

Naumova (1953) studied the Upper Devonian of the Russian Platform documenting a total of 20 miospore zones, 6 in the Givetian, and 10 for the Frasnian and 4 in the Famennian.

Ishchenko (1952, 1956 & 1958) further developed and refined the earlier work conducted by Luber & Waltz (1938) in the Donetz Basin in the Eastern Ukraine. Based on this research Ishchenko was able to delimit 3 microfloral suites characteristic of the Tournaisian, Viséan and Namurian.

Kedo (1955, 1957 & 1963) conducted work primarily concerned with changes in miospore assemblages at the Devonian – Carboniferous boundary and erected a miospore zonation for the upper Famennian and Tournaisian of the Pripyat depression in the former

Turnau (1978) presented miospore assemblages from the uppermost Devonian and Lower Carboniferous (Mississippian) marine strata of western Pomerania. This study defined 4 miospore zones of Oppel zone character.

Avchimovitch *et al.* (1988) attempted to improve stratigraphic correlations and systematic concepts between the European part of the USSR and Western Europe. Several biozonal schemes from the late Famennian and early Tournaisian were compared and correlated by the authors.

2.1.3 USA

Since the mid 1950s there have been a number of previous palynological studies concerning Upper Devonian and Mississippian age rocks in the USA. However, until recently, the scale and scope of these studies has been limited, with most studies focusing on relatively small sections with little or no independent biostratigraphic control. The scope and chronology of these investigations is summarised by Figure 2.1. A brief summary of the aims and results of these studies is provided below:

Hoffmeister *et al.* (1955) documented the occurrence of fossil plant spores from core samples taken from three wells and five outcrop samples from the Hardinsburg Formation (Chesterian) of Kentucky and Illinois. A number of new genera and species where proposed by this study. Unfortunately the original material figured in this study has since subsequently been lost.

Winslow (1962) studied the palynological succession in the Upper Devonian and Lower Carboniferous strata in Ohio and Kentucky. However, since Winslow's study predates the original European miospore zonation of Neves *et al.* (1972) it is difficult to interpret and compare directly with the miospore zonation of Neves *et al.* and subsequent authors.

Felix & Burbridge (1967) studied samples from the Springer Formation from Johnston County, Oklahoma. The principal aim of the study was to use palynology as a means of resolving the debate over the age of the Springer Formation.

Felix & Burbridge (1967) studied samples from the Springer Formation from Johnston County, Oklahoma. The principal aim of the study was to use palynology as a means of resolving the debate over the age of the Springer Formation.

Eames (1968, unpublished M.A. thesis) presented the results of a palynological study of the upper Ohio Shale Formation (Cleveland Shale Member) and of the overlying Bedford Shale from the Tinker Creek locality, Cuyahoga County, northern Ohio.

Von Almen (1970a; 1970b) described uppermost Devonian and lowermost Mississippian miospore and acritarch assemblages from the Woodford Shale Formation, Carter County, Oklahoma.

Urban (1971) conducted a palynological investigation of the Independence Shale (Chesterian) of Iowa.

Warg & Traverse (1973) investigated a section of carbonaceous shales and thin pyritic bituminous 'coal' assigned to the Catskill Formation from a roadcut along Interstate Highway 80 in Centre County, Pennsylvania. Additional samples were collected from the overlying Pocono Formation (presumed Mississippian).

Eames (1974, unpublished PhD thesis) conducted a taxonomic and biostratigraphic study of palynomorphs from the Cuyahoga Group (including the Orangeville Shale, Sharpsville Sandstone, and Meadville Shale) from various sections in Northeastern Ohio. Based on these results Eames assigned the Cleveland and Bedford shales together with the Berea Sandstone to the Upper Devonian, and the overlying Cuyahoga Group to the Lower Mississippian.

Curry (1975) described miospore assemblages from the Greenland Gap Formation (Upper Devonian; Frasnian) from Maryland, West Virginia and Virginia.

Streel & Traverse (1978) conducted a palynological investigation through a section of sandstone and shales assigned to the Catskill and Pocono Formations from the famous Horseshoe Curve section between Altoona and Gallitzin, Pennsylvania. Miospore

Ahmed (1980) conducted a study on the genus *Auroraspora* from the Frasnian and Famennian strata of New York and Pennsylvania. The author noted the first appearance of *Retispora lepidophyta* and *Vallatisporites hystricosus* at the base of the Ellicott Member of the Chadokoin Formation.

Clendening *et al.* (1980) conducted an investigation focusing upon the distribution of *Retusotriletes phillipsii* within Upper Devonian (Famennian) strata in West Virginia, Michigan, Ohio, Kentucky and New York.

Molyneux *et al.* (1984) described well preserved assemblages of miospores and microplankton from 4 samples collected across the boundary between the Bedford Shale and Berea Sandstone formations at the Big Walnut Creek section near Sunbury, Delaware County, Ohio.

Coleman & Clayton (1987) documented well preserved miospore assemblages from a section near Morehead, Kentucky. Samples were collected from the Upper Devonian Bedford Shale, and the Lower Carboniferous (Mississippian) Sunbury Shale and Borden formations. The authors placed the Devonian/ Carboniferous boundary at the base of the Sunbury Shale

Clayton *et al.* (1998) conducted an investigation of samples from two sections through the Logan Formation, near Wooster, Ohio. Samples yielded well preserved miospore assemblages.

Richardson & Ausich (2004) expanding upon work conducted by Coleman & Clayton (1987), reported a highly diverse and abundant miospore flora from north eastern and south-central Kentucky, and from southern Indiana.

Figure 2.1 Previous palynological studies of the uppermost Devonian and Missisippian strata of the Eastern and midcontinental USA.

Richardson (2005) recorded two moderately diverse, moderately abundant miospore assemblages from the lower Mississippian Coldwater Shale and Marshall Sandstone of the Michigan Basin.

Heal & Clayton (2008) reported well preserved miospore assemblages of low diversity from the Hannibal Shale in Missouri. Miospore assemblages were associated with acanthomorph acritarchs, in particular *Micrhystridium stellanum*.

2.1.4 CANADA

Of the palynological investigations conducted in Canada, the majority have focused upon the islands of the Canadian Archipelago and in the region Nova Scotia and New Brunswick; the latter studies are considered particularly relevant due to the geographical proximity of this region to the Eastern United States. A brief review of these is provided here:

Hacquebard (1957) conducted the first study of Mississippian spores in Nova Scotia The author described an abundant and highly varied miospore assemblage from lowermost Mississippian age coals of the Horton Group. The author also noted the occurrence of Upper Devonian miospores in the lowermost Carboniferous.

Playford (1963) documented Mississippian age miospore assemblages from the Horton Group of Eastern Canada. Two distinct miospore assemblages where recognised; one from the Horton Bluff (undifferentiated Horton), and a second from the Chevrie Formation.

McGregor & Owens (1966) illustrated miospore assemblages from Devonian strata of Gaspe Peninsula, southern Ontario, and from the southern District of Mackenzie and the Parry Islands in Northern Canada.

Varma (1969) documented Lower Carboniferous miospores from an equivalent of the Horton Group, the Alberta Oil Shale, from New Brunswick.

McGregor (1970) reported assemblages of spores containing *Retispora lepidophyta* (*Hymenozonotriletes lepidophytus*) from the Horton Group, Nova Scotia; the Kettle Point,

Bedford Shale and overlying formations, Southern Ontario, and from the Imperial Formation, Yukon Territory.

Owens (1971) presented the results of a palynological investigation of the Middle to early Upper Devonian age Weatherall and Griper Bay Formations from western Queen Elizabeth Islands, in the Canadian Arctic Archipelago.

Utting (1980) documented three miospore zones from the Mississippian age Windsor Group from the Shubenacadie Basin, Nova Scotia.

Utting (1987a) investigated the palynology of the Albert Formation of New Brunswick. Miospore assemblages were assigned to the PC Biozone indicating a Tournaisian, late Tn2 – Tn3 age.

Utting (1987b) recognised 3 miospore concurrent range zones in samples from the Windsor Group and boundary beds of the Windsor – Canso Group of Nova Scotia and from lithostratigraphic equivalents in Quebec and New Brunswick

McGregor & McCutcheon (1988) documented miospore assemblages indicative of the Late Devonian from the volcanic Piskahegan Group of New Brunswick.

Utting *et al.* (1989a) reported well preserved and diverse assemblages from the Emma Fjord Formation of the Sverdrup Basin on Devon Island, Canadian Arctic Archipelago; these were interpreted as being indicative a late Viséan (V3) age.

Utting *et al.* (1989b) recognised four informal assemblage zones and two subzones in the Tournaisian (Tn2 and Tn3) strata of Nova Scotia. Assemblages from the lower and middle members of the Horton Bluff Formation and Cheverie formations were assigned to the PC Biozone. Those from the overlying Wilkie Brook and Coldstream sections were considered to be indicative of the late Tn3 CM Biozone. Assemblages from the Lower Windsor Group were interpreted as being characteristic of a Viséan (V2 to early V3) age.

Martel *et al.* (1993) reported late Famennian miospores from the lowermost Horton Group within its type area in Nova Scotia. Based on this study the authors proposed a correlation between the Horton Group and strata previously excluded from the group.

Playford & McGregor (1993) reported diverse and well preserved palynofloras assignable to the Late Famennian LN Biozone from the Bakken Formation from the Williston Basin, southern Saskatchewan.

2.2. FLORAL PROVINCIALISM AND INTERCONTINENTAL CORRELATION

The distribution of Mississippian miospore assemblages are considered to be strongly influenced by floral provincialism, which has resulted in major compositional differences between the various regions (Clayton, 1985). The existence of major compositional differences in Lower Carboniferous (Mississippian) miospore assemblages in different regions was first noted by Sullivan (1965, 1967).

Sullivan described five distinct assemblage types within the Mississippian succession; two within the Tournaisian and three within late Viséan and early Namurian. Assemblages from the eastern United States, eastern Canada, Western Europe, North Africa and north eastern Australia were assigned to the '*Vallatisporites* Suite'. An area which according to Van Hilten's (1962) palaeogeographic reconstructions represented an equatorial belt ranging from approximately 20 ° N to 60 ° S. According to Sullivan (1967) species characteristic of the '*Vallatisporites* Suite' include *Punctatisporites irrasus*, *Retusotriletes incohatus*, *Pustulatisporites pretiosus*, *P. gibberosus*, *Raistrickia clavata* and *Vallatisporites vallatus*. Kinderhookian (Tournaisian) age assemblages from Spitsbergen and western Russia were assigned to the '*Lophozonotriletes* Suite' (renamed the '*Tumulispora* Suite'); these are characterised by *Tripartites incisotrilobus*, *Anulatisporites labiatus*, *Densosporites dentatus*, *D. spitsbergensis*, *Tumulispora rarituberculatus* and *Vallatisporites foveolatus*.

Sullivan described three miospore suites from the Upper Mississippian, the '*Grandispora* Suite', occupying much the same geographical position as the '*Vallatisporites* Suite', the '*Monilospora* Suite' which replaced the '*Tumulispora* Suite', and the 'Kazakhstan Suite'.

However, as was noted by Clayton (1985), many of the assemblages on which Sullivan's 'Upper Mississippian' suites were based were Viséan rather than Namurian in age.

In an attempt to conform to modern botanical classification and floral nomenclature Van der Zwan (1981) renamed Sullivan's Tournaisian suites as 'regions'. Statistical analysis of 14 selected regions using both Jaccard and Simpson correlation coefficients reinforced Sullivan's original conclusions regarding the distribution of distinct floral provinces in the Dinantian (Mississippian).

Clayton (1985) noted that statistical correlation of assemblages from different regions is often complicated by factors including the variable quality of basic data, the application of different taxonomic concepts between different workers, poor preservation of sample material and illustration of material. In the present study the author follows Clayton (1985) in the use of the term 'microflora' rather than 'suite' or 'region', to describe loose sense groupings of miospore assemblages of similar age, with reasonably similar qualitative compositions, and within which some degree of biostratigraphic correlation is possible.

Clayton (1985) was able to distinguish 5 'microfloras' for the mid – Tournaisian – Early Viséan interval (Figure 2.2), these are as follows:

1. Kazakhstan Microflora (Kazakhstan).
2. *Tumulispora* Microflora (North-west Russia, Spitsbergen and Western Canada).
3. *Vallatisporites* Microflora (Eastern Canada, Eastern USA, Western Europe and China).
4. *Aratrisporites balteatus* Microflora (North Africa, Iran).
5. *Granulatisporites frustulentus* Microflora (Australia).

According to Clayton (1985), the distribution of the microfloras during the mid- late Viséan remained more or less constant with only two of the microfloras being replaced during this time interval. The transition from the *Tumulispora* Microflora to the *Monilospora* Microflora is inferred to coincide with the Tournaisian/ Viséan boundary; the *Vallatisporites* Microflora is considered to have been replaced by the *Grandispora* Micro-

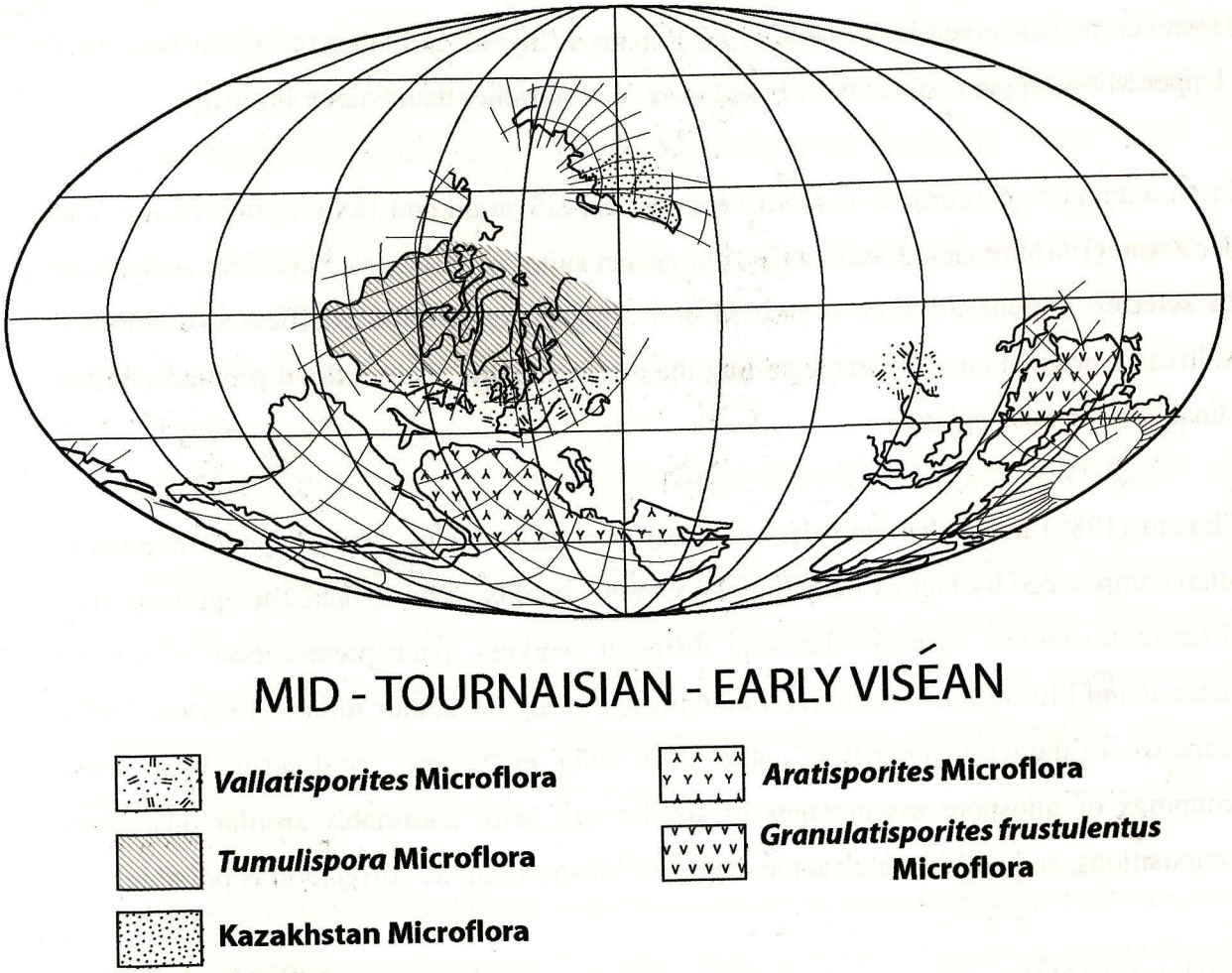


Figure 2.2 Distribution of microfloras in the mid Tournaisian - early Visean (After Clayton 1985).

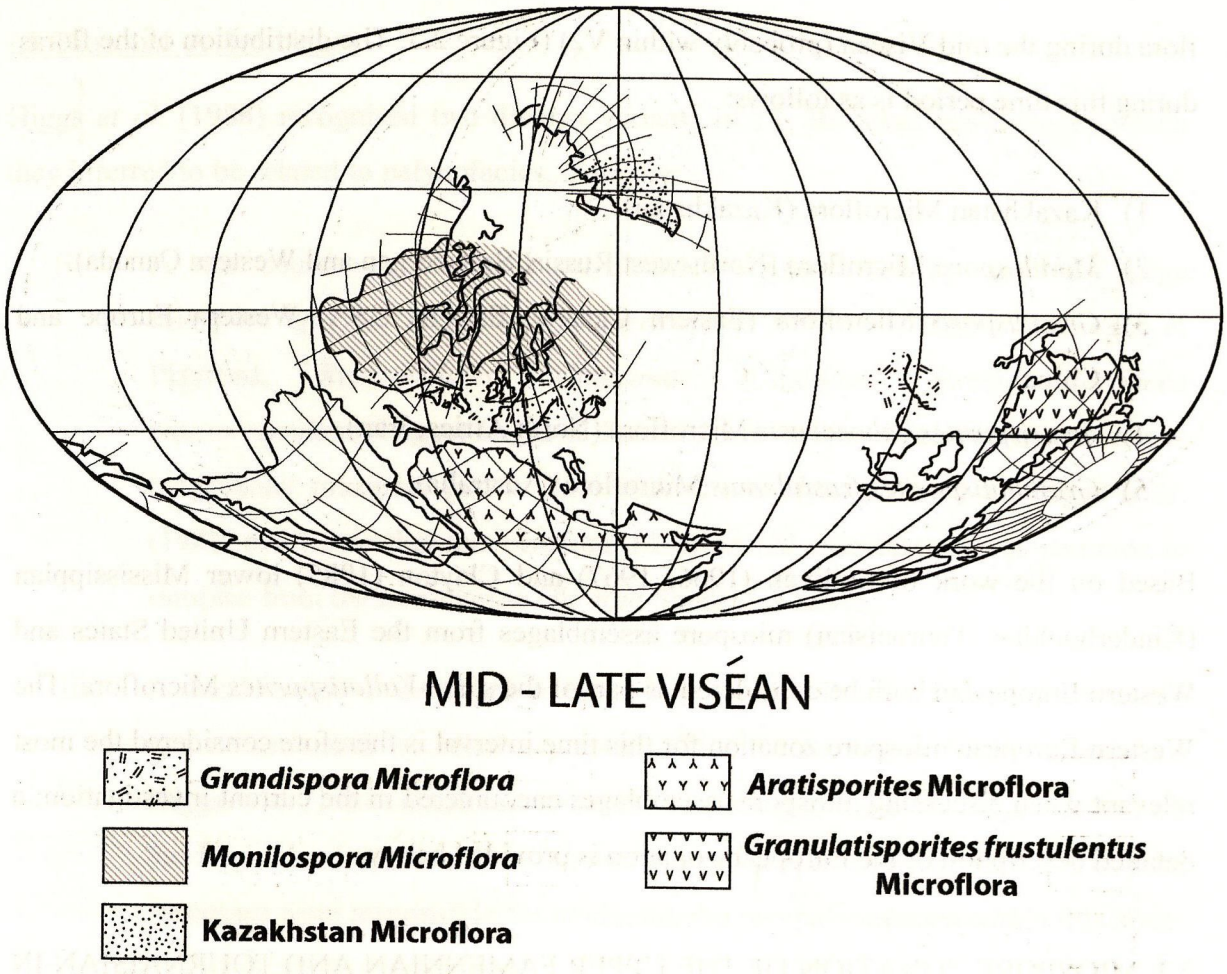


Figure 2.3 Distribution of microfloras in the mid - late Visean (After Clayton 1985).

flora during the mid Viséan (probably within V2) (Figure 2.3. The distribution of the floras during this time period is as follows:

1) Kazakhstan Microflora (Kazakhstan).
2) *Monilospora* Microflora (North-west Russia, Spitsbergen and Western Canada).
3) *Grandispora* Microflora (Eastern Canada, Eastern USA, Western Europe and China).
4) *Aratrisporites saharaensis* Microflora (North Africa, Iran).
5) *Granulatisporites frustulentus* Microflora (Australia).

Based on the work of Sullivan (1966, 1967) and Clayton (1985) lower Mississippian (Kinderhookian; Tournaisian) miospore assemblages from the Eastern United States and Western Europe can both be considered as part of the same *Vallatisporites* Microflora. The Western European miospore zonation for this time interval is therefore considered the most relevant when discussing miospore assemblages encountered in the current investigation; a detailed description of the European zonation is provided below.

2.3. MIOSPORE ZONATION OF THE UPPER FAMENNIAN AND TOURNAISIAN IN WESTERN EUROPE

2.3.1 *Retispora lepidophyta – Knoxisporites literatus* (**LL**) BIOZONE

The LL Biozone is equivalent to the PL Subzone of Clayton *et al.* (1978). This zone was renamed and upgraded to full biozonal status by Higgs *et al.* 1988.

Definition of base

The base of this zone is recognised on the first appearance of the following taxa: *Retispora lepidophyta* (Kedo) Playford, *Vallatisporites pusillites* (Kedo) Dolby & Neves (Jushko) Streel, *Rugospora flexuosa*, *Grandispora echinata* Hacquebard, *Raistrickia variabilis* Dolby & Neves, *Corbulispora cancellata* (Waltz) Bharadwaj & Venkatachala, *Diducites versabilis* (Kedo) Van Veen, *Velamisporites caperatus* (Higgs) Higgs, Clayton & Keegan. Higgs *et al.* (1988, p. 10) noted that while *Knoxisporites literatus* (Waltz) Playford is a distinctive component of LL Zone assemblages, it is a typically inconsistent element of the biozone, particularly in distal marine palynofacies assemblages.

LL Biozonal Assemblages

Higgs *et al.* (1988) recognised two distinct variants of LL Biozonal assemblages which they inferred to be related to palynofacies, these are:

(i) A near-source or proximal palynofacies characterised by relatively large miospore species, including: *Teichertospora torquata* (Higgs) McGregor & Playford, *Retusotriletes witneyanus* (Chaloner) Streel, *Retispora macroreticulata* (Higgs) Higgs & Russell, and various species assigned to the megaspore/ miospore genera *Ancyrospora* and *Hystricosporites*. Higgs *et al.* (1988, p.10) note that this proximal LL Biozonal assemblages was common in samples from the non-marine Old Red Sandstone facies.

(ii) A distal-source or distal palynofacies from marine facies of the South Munster Basin dominated by relatively small (25 – 94μm, mean 54μm) miospores. Higgs *et al.* (1988) noted that miospore assemblages from this palynofacies lack the large sized species listed above. The authors considered that size-sorting processes were responsible for producing the two palynofacies within this zone.

In the present study such size-sorting of miospore taxa is inferred to be responsible for the occurrence of contrasting VI Zone assemblages.

Age of the LL Biozone

The absence of marine faunas within the LL Biozone in southern Ireland precludes age determination for the LL Biozone in this region. Paproth & Streel (1970) demonstrated that distinctive taxa *Retispora lepidophyta* and *Vallatisporites pusillites* range in age from the late Famennian (Fa2d) to Lower Tournaisian (Tn12b). These authors also demonstrated that species including *Grandispora echinata* and *Punctatisporites irrasus* first appear in the upper part of Tn1a in Belgium (Paproth & Streel, 1970, fig. 3). Based on the occurrence of both *G. echinata* and *P. irrasus* in the Irish LL Biozone Higgs et al. (1988, p.10) reasoned that these assemblages must be younger than Fa2d. Streel (in Paproth *et al.*, 1983) considered the LL Biozone to be lowermost Tn1b in age, suggesting an approximate correlation with the Tn1a/ Tn1b boundary in the Dinant Synclinorium. However, Maziane *et al.* 1999 correlated the base of the LL Biozone with the middle or late *expansa* Conodont Biozone, thus indicating a Fa2d age for the zone.

2.3.2. *Retispora lepidophyta – Indotriradites explanatus* (**LE**) BIOZONE

The LE Biozone equates to the LE Subzone of the PL Biozone of Clayton *et al.* (1978). It was upgraded to full biozonal status by Higgs *et al.* (1988).

Definition of base

The base of the LE Biozone is defined by the first appearance of *Indotriradites explanatus* (Luber) Playford.

LE Biozonal Assemblages

LE Biozonal assemblages are characterised by the association with *I. explanatus* and *R. lepidophyta* in conjunction with most of the species typical of the preceding LL Biozone. Higgs *et al.* (1988, p. 11) note that several other distinctive species first appear in this zone but are either rare or too inconsistent to be of zonal value. This includes *Knoxisporites concentricus* (Byvscheva) Playford, *Endoculeospora gradzinskii* Turnau, *Gorgonispora crassa* (Winslow) Higgs, Clayton & Keegan, *Microreticulatisporites araneum* Higgs, Clayton & Keegan, *Knoxisporites* cf. *triradiatus* Hoffmeister, Staplin & Mallow *sensu* Sullivan, and *Dictyotriletes trivialis* Naumova in litt. Kedo. Species with last appearances corresponding with the top of this zone include *Retispora macroreticulata* and *Calyptosporites triangulatus*. Reworking is most likely responsible for the rare occurrence of the latter two species in assemblages assigned to the younger LN and PC biozones in the present investigation

Age of the LE Biozone

No age control is available for the LE Biozone within Irish sections. However, based on work in the eastern Dinant Basin of Belgium, Maziane *et al.* (1999) correlated the LE Biozone with the early to middle *Siphonodella praesulcata* Conodont Zone.

2.3.3 *Retispora lepidophyta – Verrucosisporites nitidus* (**LN**) BIOZONE

The LN Biozone is equivalent to the LN Subzone of the NV Zone in older publications (e.g. Clayton *et al.* 1974). It was given full biozonal status by Higgs *et al.* (1988).

Definition of base

The base of the LN Biozone is recognised by the first appearance of *Verrucosisporites nitidus* (Naumova) Playford. Other species appearing at or close to the base of the biozone may be utilised in the absence of *V. nitidus*, e.g. *Tumulispora malevkensis* (Naumova) Kedo, *Vallatisporites verrucosus* Hacquebard and *Densosporites spitsbergensis* Playford.

LN Biozonal Assemblages

Typical components of LN Biozonal assemblages include *Retispora lepidophyta*, *Rugospora flexuosa*, *R. radiata*, *Vallatisporites hystricosus* and *V. pusillites*. These taxa are characteristically associated with species such as *Indotriradites explanatus* and other longer ranging species from the preceding biozones. Higgs *et al.* (1988) reported that *Verrucosisporites nitidus* is rather sparse in basal LN Biozonal assemblages. Assemblages from the top of the biozone are typically augmented with the appearance of further species, e.g. *Umbonatisporites rarisetosus* (Playford) Clayton, and *Retusotriletes crassus* Clayton. LN Biozonal assemblages were noted as being compositionally diverse since they contain the majority of the species present in preceding biozones as well as taxa which persist into succeeding Carboniferous biozones (Higgs *et al.* 1988)

Age of the LN Biozone

The upper boundary of this biozone appears to correspond closely with the Devonian/ Carboniferous system boundary. LN Biozone assemblages occur below Conodont faunas belonging to the upper *Siphonodella praesulcata* Zone in Germany (Higgs & Streel, 1984). However, the only faunal control of the Irish LN Biozone comes from Late Devonian brachiopods of the genus *Cyrtospirifer* Higgs *et al.* (1988).

2.2.4. *Vallatisporites verrucosus – Retusotriletes incohatus* **(VI)** BIOZONE

The VI Biozone equates to the lower part of the VI Subzone of the NV Zone of Clayton *et al.* (1978).

Definition of base

Unlike other biozones defined on first appearance data, the base of the VI Biozone is recognised by the disappearance of *Retispora lepidophyta* and other taxa characteristic of

plicabilis, *Rugospora flexuosa*, *R. radiata*, *Vallatisporites hystricosus*, *V. pusillites* and *Velamisporites caperatus*.

VI Biozonal Assemblages

The last appearance of the species listed above represents a significant 'turnover' in the microfloral succession associated with the Hangenberg Extinction Event. Miospore assemblages from the VI Biozone are typically very restricted in composition and thus contrast starkly with those from the preceding LN Biozone, which are often compositionally diverse. In Europe, the Devonian/ Carboniferous boundary is perhaps the most easily recognisable Palaeozoic System boundary due to distinctive changes in the composition of the miospore assemblages at this stratigraphic level. VI Biozonal assemblages are commonly described as being dominated by simple laevigate forms such as *Retusotriletes incohatus* and various species of *Punctatisporites*. Some more ornamented forms from the preceding LN Biozone also persist into the VI Biozone e.g. *Emphanisporites* spp., *Indotriradites explanatus*, *Lophozonotriletes malevkensis*, *Spelaeotriletes crustatus*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus*.

As noted previously, the base of the VI Biozone is defined by the last appearance of characteristic Upper Devonian species such as *Retispora lepidophyta* and associated taxa. This means that the recognition of the base of the VI Biozone may potentially be difficult in sections where reworking of older strata has occurred, in such a scenario, older spore assemblages may be mixed with and 'overprint' VI Biozonal assemblages. The occurrence of characteristic Upper Devonian spores within Carboniferous strata has been recorded by numerous authors including, Hacquebard (1957), Playford & McGregor (1993) and Clayton *et al.* (1998). Problems of this nature have been encountered in this present study and in one instance warranted a detailed quantitative and qualitative palynological appraisal of samples. The results of this study are presented in Chapter 9.

In Irish sections, Higgs *et al.* (1988) noted that a number of species first appear a short distance above the base of the biozone. In the South Munster Basin for instance, *Cyrtospora cristifera* (Kedo) is a common component of VI Biozonal assemblages. However, caution must be exercised when utilising the presence of *C. cristifera* as a proxy for this zone since its range has been reported to span the Devonian – Carboniferous

for this zone since its range has been reported to span the Devonian – Carboniferous system boundary in other regions. Further complications arise in the application of the VI Biozone since its assemblages appear to be highly facies dependent with terrestrial assemblages dominated by species such as *Spelaeotriletes obtusus*, *Spelaeotriletes resolutus* and *Corystisporites costatus* whilst assemblages from marine are commonly dominated by *Tumulispora triangulatus* (Higgs *et al.*, 1988). Such facies dependence has been observed in the present investigation and is described in further detail in chapters 7 & 10.

Age of the VI Biozone

The base of the VI Biozone is reported as being approximately equivalent to the Devonian/ Carboniferous boundary (Clayton *et al.* 1974). Higgs & Streel (1984) report VI Biozonal assemblages from strata containing conodonts typical of the basal Carboniferous *Siphonodella sulcata* Conodont Zone from the Northern Rhenish Slate Mountains in Germany.

2.2.5. *Cristatisporites hibernicus – Umbonatisporites distinctus* **(HD)** BIOZONE

The HD Biozone is equivalent to what has been informally referred to as the middle NV Zone in older publications (Higgs *et al.* 1988). The occurrence of the HD Biozone has yet to be convincingly recorded in the USA, perhaps due to palaoebiogeographic control or due to missing intervals in the sedimentary succession. A brief description of the HD Biozone is included in this present account to serve as a reference for the non-specialist reader.

Definition of base

The base of this biozone is recognised by the first appearance of *Cristatisporites hibernicus* Higgs and *Umbonatisporites distinctus* Clayton. Other stratigraphically useful but less abundant species appear at or close to the base of the biozone, e.g. *Schopfites delicatus* Higgs emend, *Baculatisporites fusticulus* Sullivan and *Neoraistrickia cymosa* (Higgs *et al.* 1988).

HD Biozonal Assemblages

The majority of the taxa present in HD Biozone assemblages are longer ranging species from the preceding biozones. This includes taxa such as *Convolutispora* spp., *Dictyotriletes* spp., *Knoxisporites literatus*, *Retusotriletes incohatus* and *Verrucosisporites nitidus*.

Age of the HD Biozone

Palynological investigation of Tournaisian (Hastarian) strata in the Namur Syncline of West Flanders, Belgium, led Higgs *et al.* (1992) to correlate the middle and upper parts of the HD Miospore Biozone with the upper Tn1b – lower Tn2a *Siphonodella sandbergi* and *S. crenulata* Conodont Zones. Absence of diagnostic conodont faunas precluded the precise determination of the relative age of the VI/ HD boundary. However, Higgs *et al.* (1992) suggested a probable age equivalent to the lower part of the *Siphonodella sandbergi* Conodont Zone, or possibly the underlying *S. duplicata* Zone.

2.2.6. *Spelaeotriletes balteatus – Rugospora polyptycha* **(BP)** BIOZONE

The BP Biozone was introduced by Higgs *et al.* (1988) to replace the informal upper VI Biozone in the older literature.

Definition of base

The base of the BP Biozone is defined based on the first appearance of *Spelaeotriletes balteatus* (Playford) Higgs. Other species which appear at or close to the base of the biozone include *Tumulisporas tuberosus* Sullivan, and *Vallatisporites vallatus* Hacquebard. In Irish sections, *Vallatisporites verrucosus* also makes a reappearance after being absent in the HD Biozone Higgs *et al.* (1988).

BP Biozonal Assemblages

Assemblages from the BP Biozone contain most of the species present in the preceding HD Biozone. The morphologically distinctive species *Rugospora polyptycha* Neves & Ioannides is a characteristic component of BP Biozone assemblages although it has been reported to occur infrequently in assemblages from the HD Biozone (Higgs *et al.* 1988).

Assemblages of the BP Biozone are distinguished from those of the succeeding PC Biozone by the absence of *Spelaeotriletes pretiosus* (Playford) Neves & Belt.

Age of the BP Biozone

Age control of the BP Biozone is poor (Higgs *et al.* 1988). Based on its position between the HD and PC biozones, Higgs *et al.* 1988 inferred a mid Tournaisian (Tn2a – Tn2b) age for the zone. BP Biozonal assemblages documented Higgs *et al.* (1992) within the higher part of the lower *Siphonodella crenulata* Conodont Zone from the Namur Syncline of Belgium, indicate an upper Tn2a age for the zone.

2.2.7. *Spelaeotriletes pretiosus – Raistrickia clavata* **(PC)** BIOZONE

The PC Biozone was first described by Clayton *et al.* (1978) as a new biozone above the then existing NV Zone.

Definition of base

The base of the PC Biozone is defined on the first appearance of *Spelaeotriletes pretiosus* (Playford) Neves & Belt. In the absence of *S. pretiosus* other stratigraphically useful taxa may be utilised, e.g. *Raistrickia clavata* Hacquebard emend Playford, *R. condylosa* Higgs, *Kraeuselisporites mitratus* Higgs, *Granulatisporites microgranifer* Ibrahim and *Vallatisporites microspinosus* Higgs. Recent work by Brittain & Higgs (2009) has provided a more precise definition of the base of this zone within southern Ireland.

PC Biozonal Assemblages

Many taxa from the preceding biozone are occur commonly in the PC Zone; this includes *Auroraspora macra*, *Densosporites spitsbergensis*, *Retusotriletes crassus*, *R. incohatus*, *Rugospora polyptycha*, *Spelaeotriletes balteatus*, *Spinozonotriletes uncatus*, *Vallatisporites vallatus* and *V. verrucosus*. *Spelaeotriletes pretiosus* is noted as being rare early in its range and becoming more abundant higher in the biozone (Higgs *et al.* 1988). Upper PC Zone assemblages are characterised by the presence of species such as *Anaplanisporites baccatus*, *A. centrosus*, *Colatisporites denticulatus* and *Crassispora trychera*. However, the occurrence of these species at this level is noted as being sporadic and inconsistent Higgs *et al.* (1988).

Age of the PC Biozone

Higgs *et al.* (1992) reported basal PC Biozone miospore assemblages within the upper *Siphonodella crenulata* Conodont Zone from the West Flanders region of Belgium. An age no older than Tn2b is thus inferred for the base of the PC Miospore Biozone.

Note: * The following two biozones have not been recognised in the present study. Thus only brief details of their assemblages and ages are included here.

2.2.8. *Schopfites claviger – Auroraspora macra* **(CM)** BIOZONE *

This biozone was first described by Neves *et al.* (1972) based on sections from the Midland Valley of Scotland. However, several of the species originally thought to be characteristic of the zone have subsequently been found to range from preceding Tournaisian biozones. This confusion led to the base of the biozone being redefined by Clayton *et al.* (1978).

Definition of base

The base of this biozone is recognised based on the first appearance of the distinctive species *Schopfites claviger* Sullivan, emend.

CM Biozonal Assemblages

Miospore assemblages from the CM Biozone are typified by the association of species such as *Anaplanisporites baccatus*, *Auroraspora macra*, *Colatisporites decorus*, *C. denticulatus*, *Crassispora trychera*, *Retusotriletes incohatus* and *Schopfites claviger*. Higgs *et al.* (1988) reported that large coarsely ornamented forms of *Convolutispora* appear together with rarer forms such as *Radiizonates mirabilis* Clayton, *Anapiculatisporites hystricosus* Playford and *Acanthotriletes hacquebardi* Playford. Assemblages of the CM Biozone are distinguished from those of the succeeding Viséan Pu Biozone by the absence of *Lycospora pusilla* Somers.

Age of the CM Biozone

The CM Biozone is Upper Tournaisian (Tn3c) in age. In Ireland the biozone is associated with conodont faunas of the *Polygnathodus mehli* Conodont Zone. The upper boundary of

the biozone has yet to be precisely dated. On Clare Island in Western Ireland the boundary between the CM and the preceding Pu Biozone is placed close to the base of the of the early Viséan (V1a) limestones. It is therefore interpreted to be of latest Tournaisian age (Phillips & Clayton, 1980).

2.2.9. *Lycospora pusilla* **(Pu)** BIOZONE *

Definition of base

The base of the Pu Biozone is recognised based on the first appearance of *Lycospora pusilla* (Ibrahim) Somers, also coinciding with the first appearance of the Genus *Lycospora* (Clayton *et al.*, 1977).

Pu Biozonal Assemblages

Assemblages from the Pu Biozone are closely comparable to those from the preceding CM Biozone and are characterised long ranging taxa. The two biozones are distinguished only be the occurrence of *Lycospora pusilla.*

Age of the Pu Biozone

The upper boundary of the biozone was placed provisionally at the base of the volcanic sediments within the Cementstones Group in the Midland Valley of Scotland by Neves *et al.* (1973) and Neves & Ioannides (1974). The Pu Zone as defined by these publications encompasses the uppermost portion of the Holkerian regional stages in Britain as proposed by George *et al.* (1976).

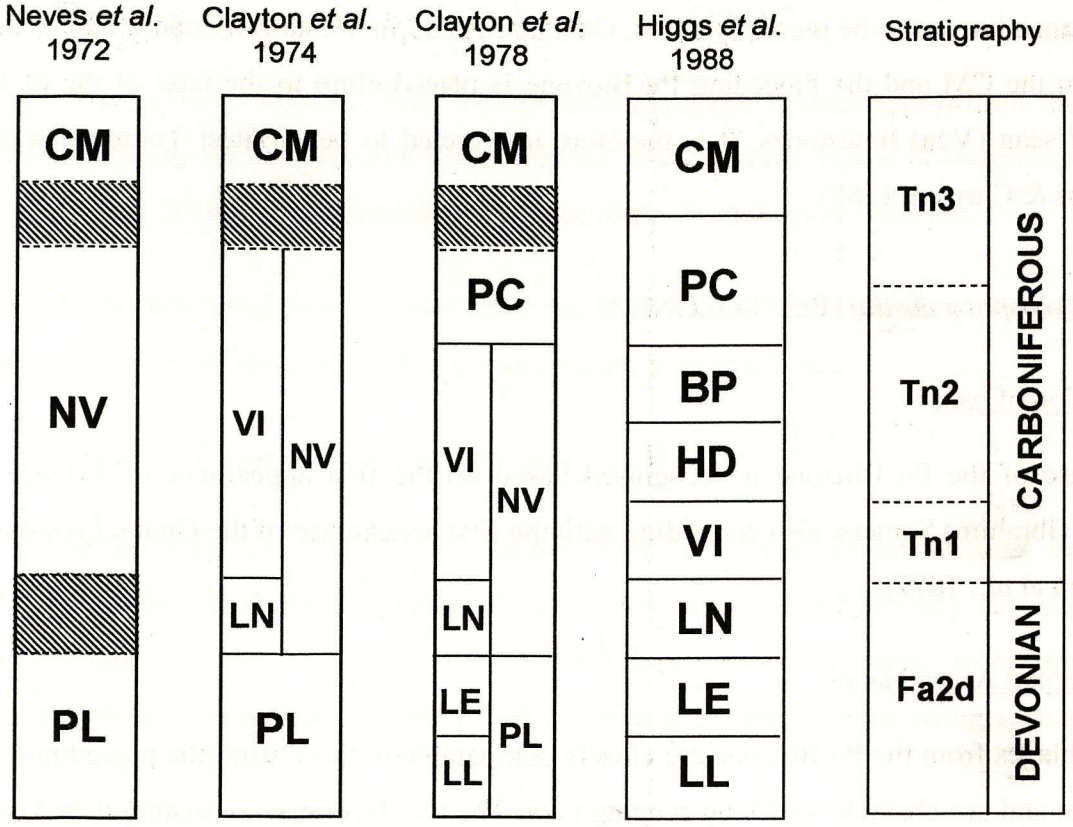


Figure 2.4 The evolution of the miospore zonation for the Tournaisian of Western Europe (Adapted from Higgs *et al.* 1988).

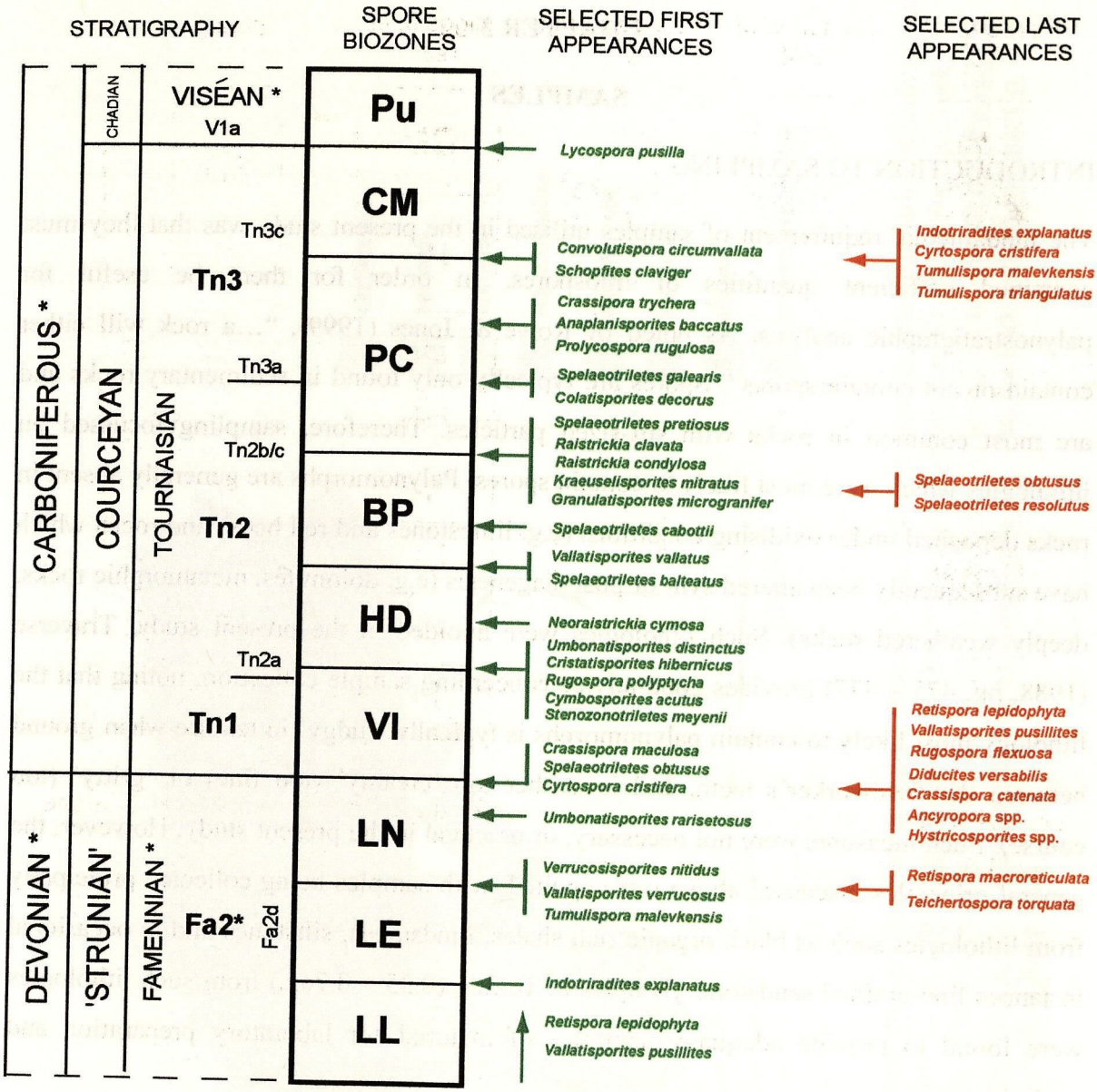


Figure 2.5 Miospore zonation for the Strunian and Tournaisian of Western Europe illustrating first and last appearance data for key taxa. Modified from Higgs *et al.* (1988) with additional data from Higgs *et al.* (1992), Maziane *et al.* (1999) and Brittain & Higgs (2007). *Note* * denotes partial or incomplete.

CHAPTER 3

SAMPLES

INTRODUCTION TO SAMPLING

The fundamental requirement of samples utilised in the present study was that they must contained sufficient quantities of miospores, in order for them be useful for palynostratigraphic analysis. As noted by Rowe & Jones (1999), "...a rock will either contain or not contain spores". Spores are typically only found in sedimentary rocks and are most common in rocks with silt-sized particles. Therefore, sampling focussed on lithologies which were most likely to contain spores. Palynomorphs are generally absent in rocks deposited under oxidising conditions (e.g. limestones and red beds) and rocks which have subsequently been altered syn- or post diagenesis (e.g. dolomites, metamorphic rocks, deeply weathered rocks). Such lithologies were avoided in the present study. Traverse (1988, pp. 475 – 477) provides good advice concerning sample collection, noting that the lithology most likely to contain palynomorphs is typically 'fudgy' in texture when ground between the fieldworker's teeth, and is neither too 'creamy' (too fine) or 'gritty' (too course). Such measures were not necessary, or practical in the present study. However, the general principles discussed above were applied, with samples being collected principally from lithologies such as black organic rich shales, mudstones, siltstones and in occasional instances fine-grained sandstone. Samples of 10-20g (0.35 – 0.7oz.) from such lithologies were found to provide adequate quantities of material for laboratory preparation and analysis.

Rock samples processed in the present study include both outcrop and borehole core material. Plant roots, fungi and contemporary pollen and spores often persist through the sample maceration process, and may occur in abundance on weathered rock surfaces (Wood *et al.*, 1996; Rowe & Jones, 1999). To avoid such sources of contamination, outcrops where 'trenched' to expose a fresh surface, as recommended by authors including Funkhouser (1969) and Traverse (1988). When processing borehole material, the samples were washed thoroughly to all remove traces drilling mud, and the contaminants it may contain. A good account of potential sources of contamination in palynological studies and ways in which it may be minimised is provided by (Wood *et al.*, 1999).

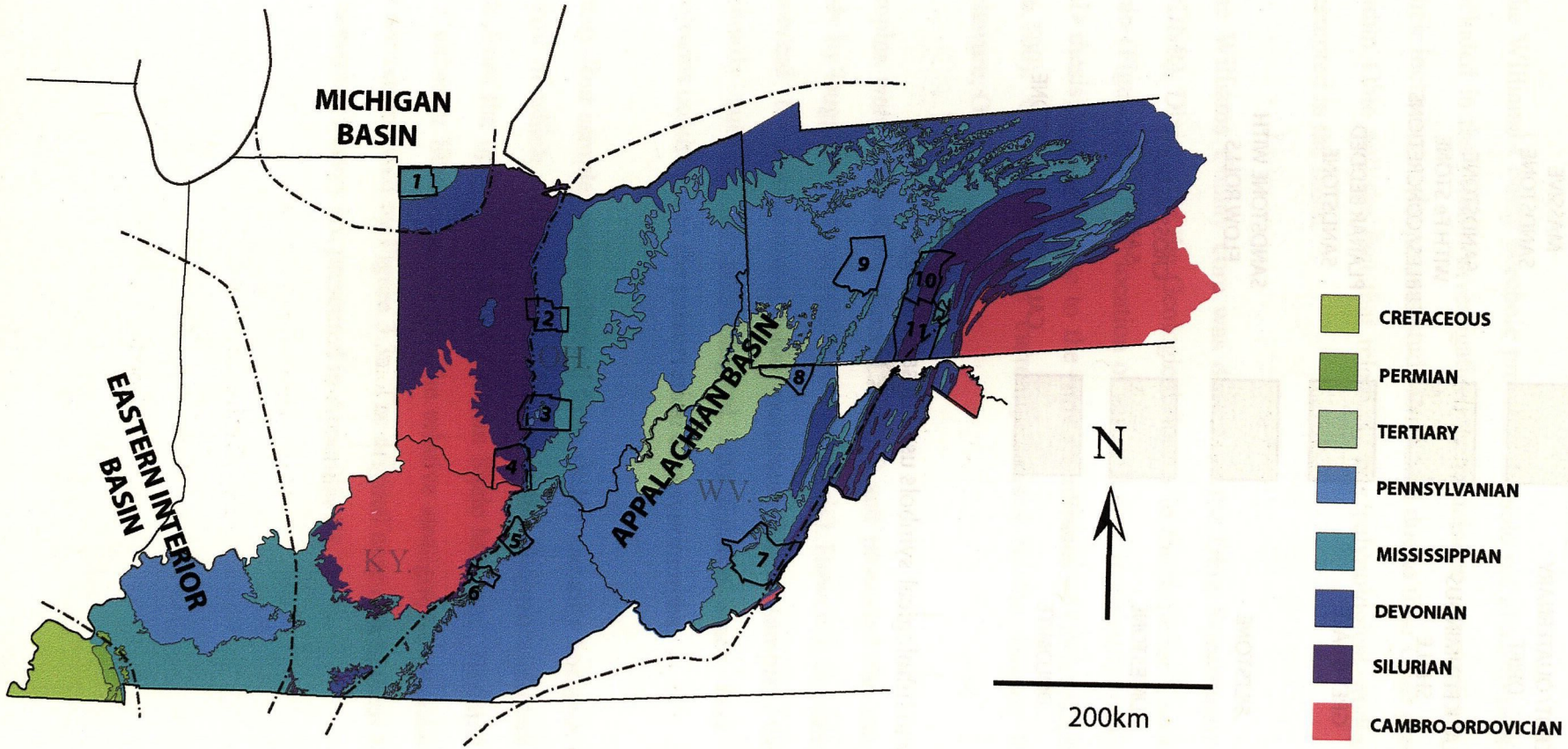


Figure 3.1 Bedrock geology map for Ohio, Kentucky, West Virginia and Pennsylvania. Dashed lines indicates approximate boundaries of sedimentary basins.Counties sampled in the present studyare as follows: Ohio 1) Williams County - Williams Co. core. 2) Delaware Co. - Big Walnut Creek, Sunbury 3) Ross Co. - Three Locks Quarry 4) Adams Co. - Tener Mountain Wood. Kentucky 5) Rowan Co. - Three Lick type section 6) Powell Co. - a. Vanceburg b. Clay City Quarry. West Virginia 7) Greenbrier Co. - a. Caldwell b. Alta 8) Monongalia Co. - Mylan Park core 9) Indiana Co. - Cramer 10) Blair Co. - Altoona 11) Bedford Co. - Warrior's Path State Park.

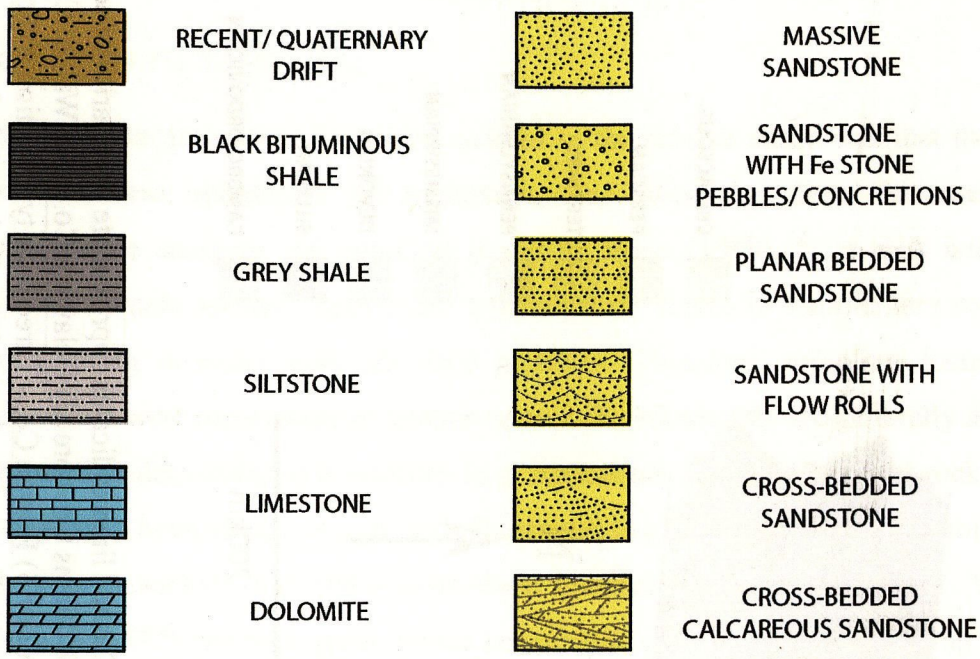


Figure 3.2 Key to lithological symbols used in sample logs.

3.1. OHIO SAMPLES

3.1.1 WILLIAMS COUNTY BOREHOLE CORE

The Williams County borehole provides the sole set of samples from the Michigan Basin included in the present investigation, the remainder coming from the Appalachian Basin. Their inclusion in the present study is merited due to their close proximity to other sections within Ohio and the fact that relatively few palynological studies have previously been attempted in the basin.

The Williams County core was drilled by the Ohio Department of National Resources (ODNR), Division of the Geological Survey in the Superior Township, Williams County, Ohio (Figure 3.3b). The location of the drill core is given by Duggan (2006, unpublished PhD thesis) with reference to the state coordinates of Ohio (North Zone) as (1,409,950/ 696,700). Core material is currently housed in the Horace R. Collins Laboratory, Delaware, Ohio.

Samples were originally collected in 2000 and processed for use in a thermal maturity study by Duggan (2006, unpublished PhD thesis). However, the sample material was never processed for palynostratigraphic purposes. These samples were considered to be eminently suitable for palynological investigation since they were collected from lithologies conducive to the preservation of palynomorphs.

Twenty-four samples were collected from shaley and silty horizons within the core, only a handful of which were processed for use in the Duggan's original study. Samples were taken from the upper Ohio Shale (Antrim Shale Member), Bedford Shale, Sunbury Shale and Coldwater Shale formations. The relative stratigraphic position of samples from the core are summarised by Figure 3.3a. The original core descriptions by the ODNR Division of Geological Survey are presented in Appendix III.

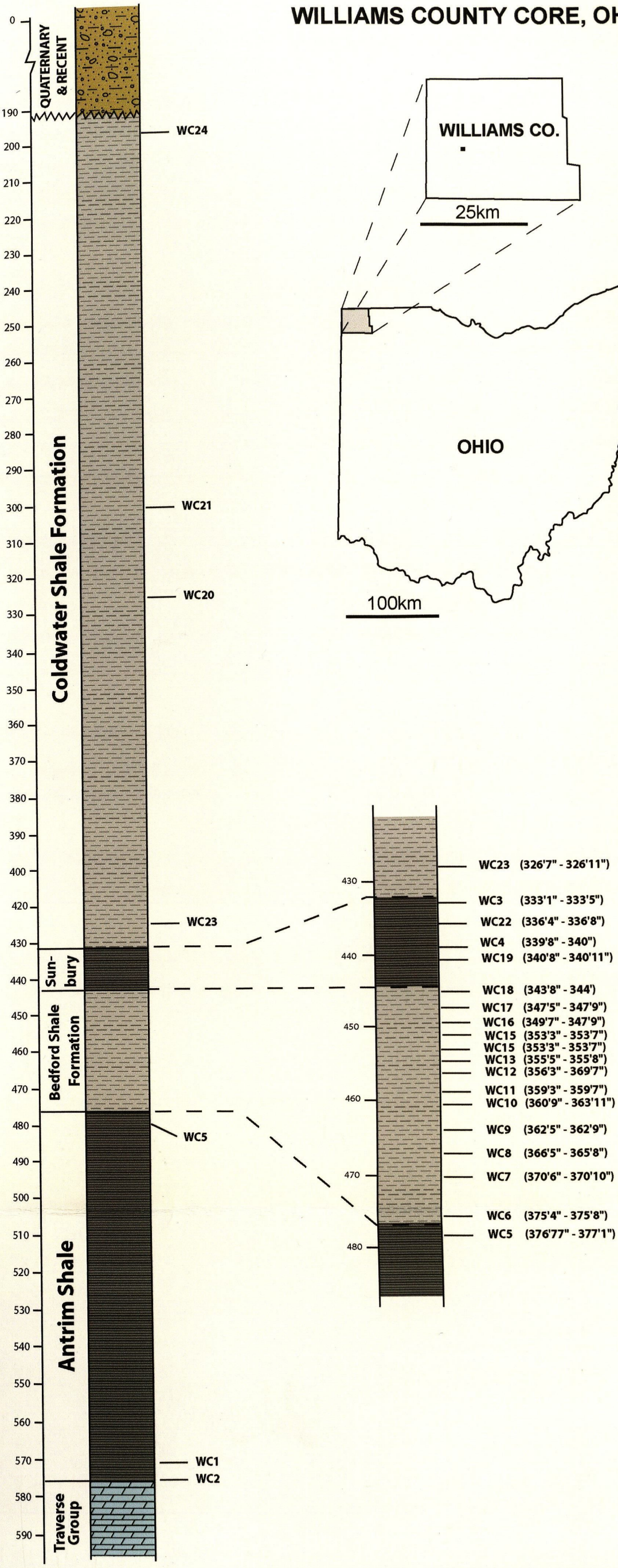


Figure 3.3 a) Stratigraphic log for the Williams County Core, illustrating the position of samples b) Map showing the location of the core in Superior Township, Williams County, Ohio.

3.1.2. BIG WALNUT CREEK

The Big Walnut Creek section is located near Sunbury, Delaware County, Ohio (Figure 3.4). At this locality, a section spanning the boundary of the Bedford Shale and Berea Sandstone is exposed on the west side of the river, immediately downstream from the Hartford Road Bridge (formerly the Croton Road Bridge). This section was the subject of a preliminary palynological investigation by Molyneux *et al.* (1984).

Again these samples were collected for and included in the thermal maturity study conducted by Duggan (2006) but not processed for miospores. At this locality, the Bedford Shale and Berea Sandstone formations crop out on the west side of the river, downstream from the bridge (40°14'46''N, 82°50'60''W). The Bedford Shale is particularly well exposed at this location and reaches a thickness of approximately 90 feet (Stauffer *et al.* 1913). Four samples were processed for inclusion in the present study; samples were collected from the following intervals:

SUN4 TCD 59624. Zone of thin shale within the Berea Sandstone Formation, slightly higher than the Berea sample in the study by Molyneux *et al.* (1984).

SUN3 TCD 59623. Thin Shale within the uppermost layers of the Bedford Shale, immediately below the contact; comparable to sample 2 in Molyneux's study.

SUN2 TCD56752. Zone of silty shale, approximately 1m below the base of the Berea Sandstone, just above the ripple marks; comparable to sample no. #3 in Molyneux *et al.* (1984).

SUN1 TCD56751. Layer of silty shale, 2m below the base of the Berea Sandstone; approximates Molyneux's sample no. #4.

The relative stratigraphic level from which these samples were collected is summarised in Figure 3.4. A detailed description of this locality is provided by Molyneux *et al.* (1984).

BIG WALNUT CREEK, OHIO

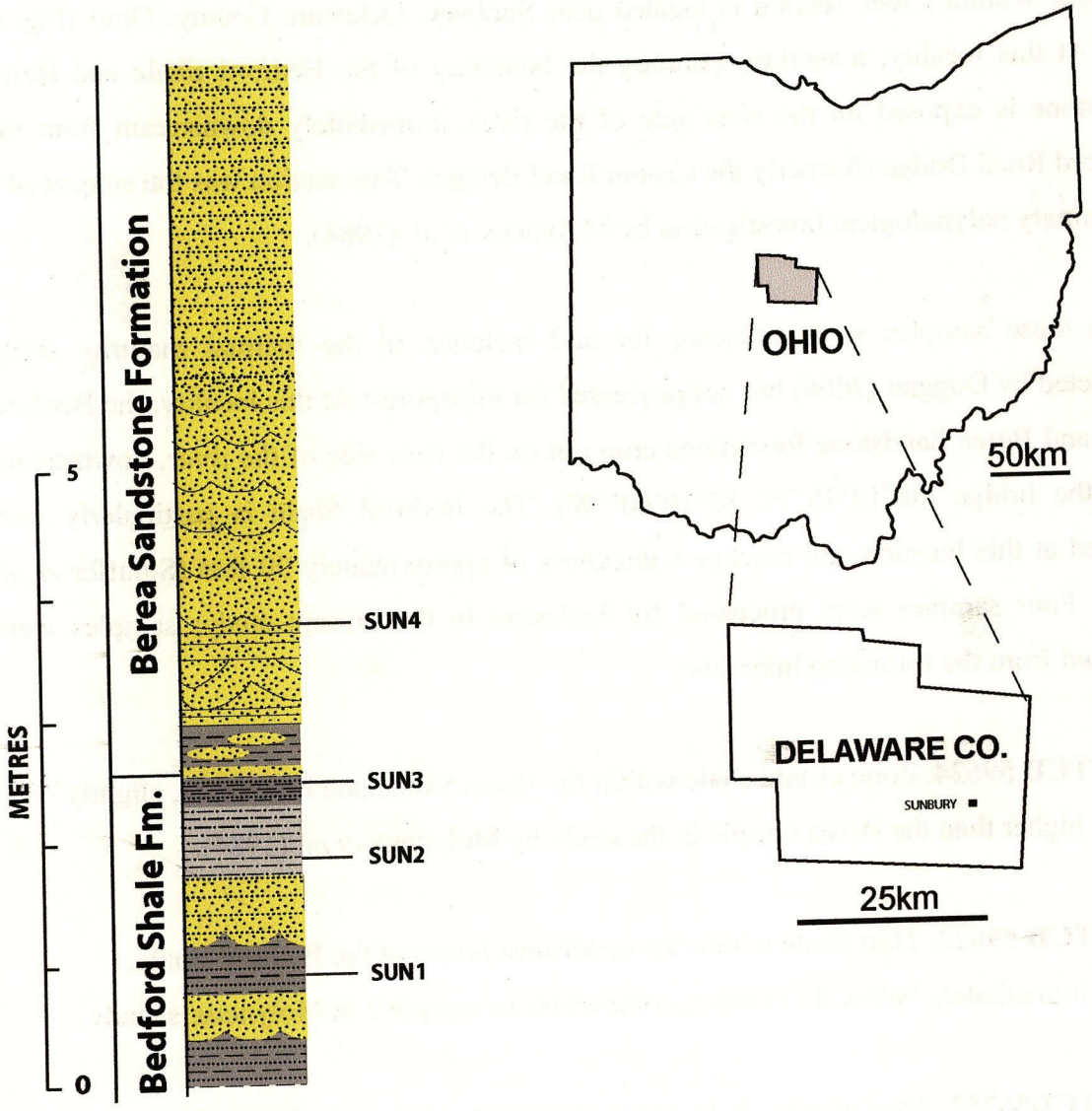


Figure 3.4 a) Stratigraphic log for the Big Walnut Creek section illustrating the position of samples b) Map showing the location of Big Walnut Creek, Sunbury, Delaware Co., Ohio.

3.1.3. THREE LOCKS

The Three Locks Quarry locality provides yet another well exposed section spanning the boundary between the Bedford Shale and Berea Sandstone formations. The now disused quarry is situated close to the town of Chillicothe, Ross County, Ohio (39°17'27.10'' N 82°56'39.70'' W), approximately 100km (~60 miles) south of the Big Walnut Creek section.

Three lithostratigraphic units are exposed at this location; the uppermost Ohio Shale Formation (~7m thickness – exposed in a drainage ditch), the Bedford Shale Formation (~30m thickness), and the lowermost 5m (16ft.) of the Berea Sandstone Formation. A detailed lithostratigraphic description and directions to the locality are provided by Coogan *et al.* (1981). Over much of Ohio the boundary between the Bedford Shale and Berea Sandstone is erosive (Pepper *et al.* 1954), however at Three Locks, sedimentation appears to have been continuous across the 'Bedford – Berea' boundary (Coogan *et al.*, 1981).

Ten samples were collected from this locality by Duggan (2006, unpublished PhD thesis); samples details are as follows:

TL1 TCD56753. From the Bedford Shale at the base of Quarry, immediately above the Ohio Shale Formation.

TL2 TCD56754. Sample taken from the 'Gray Shale' in the basal Bedford described by Coogan *et al.* (1981).

TL3 TCD56755. 'Gray Shale' (as above)

TL4 TCD59615. Below the 'yellow band' (Coogan *et al.*, 1981).

TL5 TCD56756. Sample taken from 6 inches (15cm) below the third sandstone unit.

TL6 TCD59616. From approximately 6 feet (1.82m) below siltstone number 5.

TL7 TCD59617. Sample from the top of siltstone number 7.

TL8 TCD59618. Approximately 3 feet (0.91m) below thick siltstone number 8.

TL9 TCD59619. Sample collected approximately 9 feet (2.7m) above the base of the Berea Sandstone Formation.

TL10 TCD59620. Sample collected 14 foot above the base of the Berea Sandstone.

The relative stratigraphic position of the samples is summarised in Figure 3.5. Field photographs of this section are provided in the Appendix V.

3.1.4. TENER MOUNTAIN WOOD

A near complete section of the Ohio Shale (Huron Member), Bedford Shale, Berea Sandstone and Sunbury Shale is exposed in a series of roadcuts along both sides of Ohio Route 32, over approximately 5 miles (8km) between Union Hill Road and the junction with Ohio Route 73. Kepferle & Roen (1981) give the location of this section as 39°01'12''N 83°16'45''W.

Two samples were collected from the upper Ohio Shale Formation along a side road in Tenor Mountain Wood, Adams County, Ohio (Catherine Duggan pers. comm.). Samples were originally collected by Catherine Duggan but not included in her 2006 PhD thesis (it appears they were never processed). Unfortunately, Duggan didn't record the precise geographical and stratigraphical position of these samples in her fieldnotes; however, it would appear that these samples were taken from either the Huron or Cleveland members of the Ohio Shale. Despite the slight ambiguity concerning the stratigraphic position of these samples, they are included in the present study since they provide biostratigraphic information from a section with no published palynological data. The location of this section is summarised in Figure 3.6; field photos are presented in Appendix V.

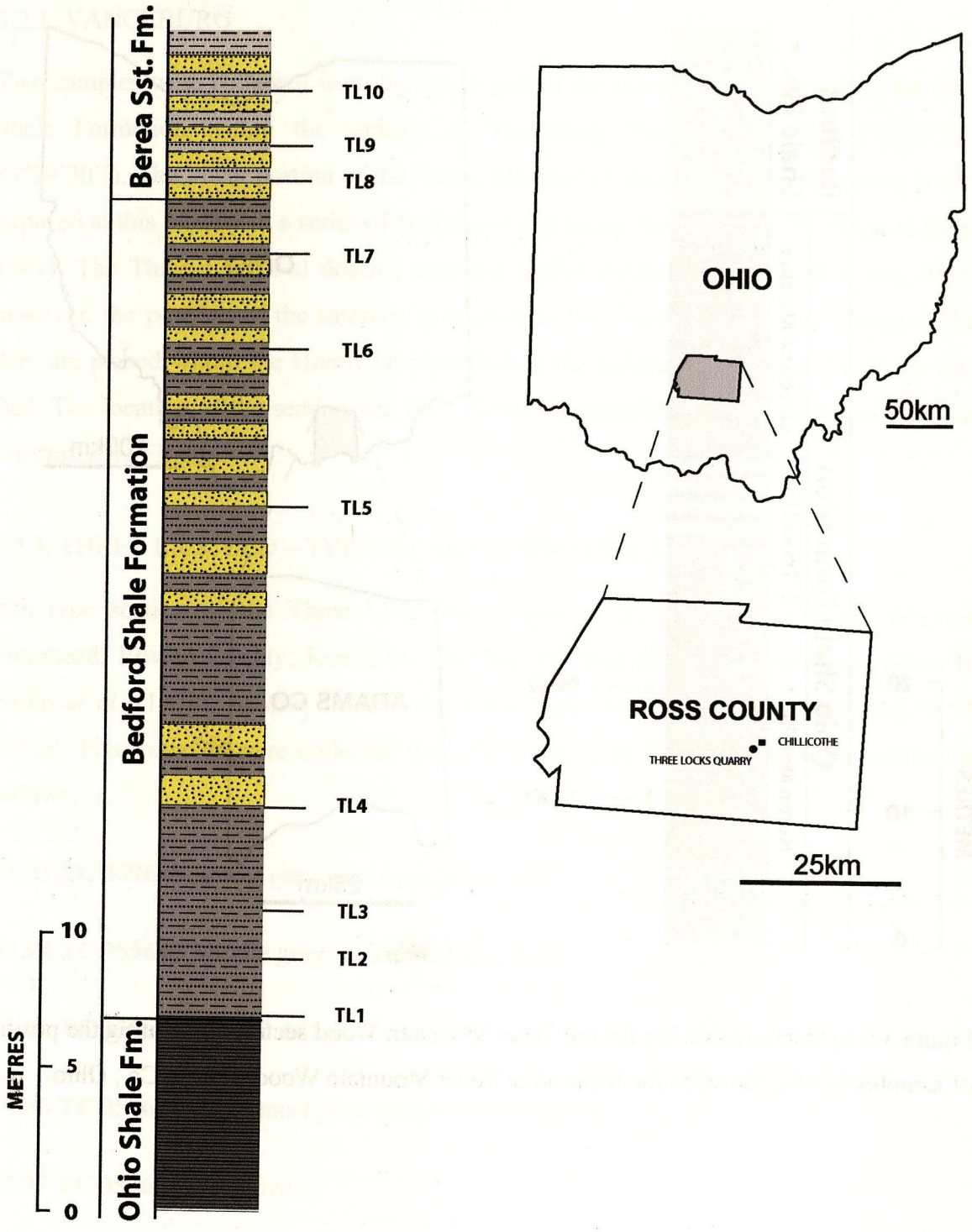


Figure 3.5 a) Stratigraphic log for the Three Locks Quarry section illustrating the position of samples b) Map showing the location of Three Locks, Chillicothe, Ross Co., Ohio.

TENER MOUNTAIN WOOD, OHIO

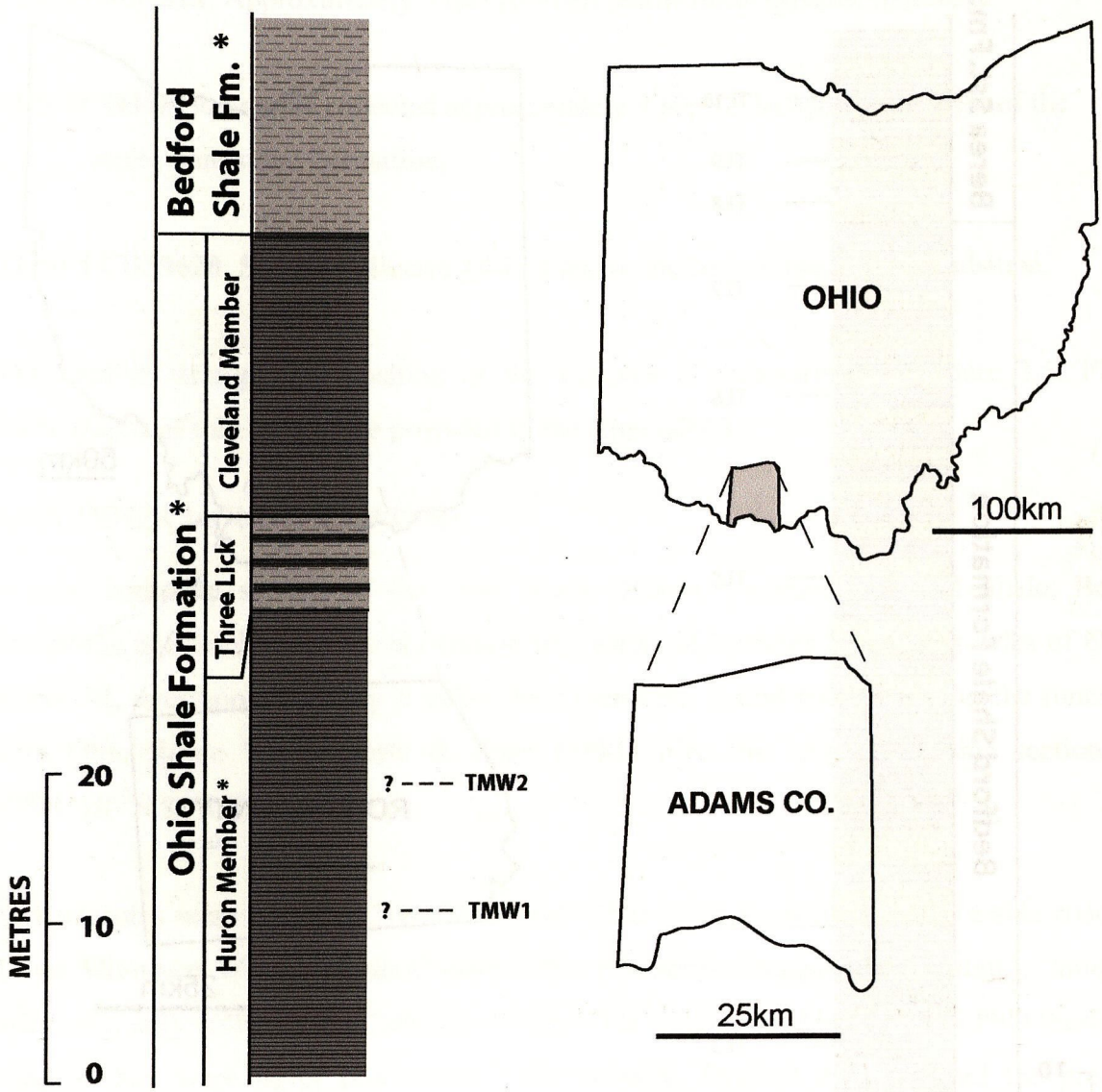


Figure 3.6 a) Stratigraphic log for the Tener Mountain Wood section illustrating the position of samples b) Map showing the location of Tener Mountain Wood, Adams Co., Ohio.

3.2. KENTUCKY SAMPLES

3.2.1. VANCEBURG

Two samples were collected from the lower part of the Huron Shale Member of the Ohio Shale Formation within the vicinity of Vanceburg, Powell Co., Ohio (38°35'53'' 83°19'30''). The lower portion of the Huron Member of the Ohio Shale Formation is well exposed at this locality in a series of cuts above and below the road level Kepferle & Roen, 1981). The Three Lick Bed doesn't crop out at this locality (Kepferle & Roen, 1981); however, the position of the samples in relation to the *Foerstia* Zone would suggest that they are placed within the Huron Member (below the inferred position of the Three Lick Bed. The location of the section and the inferred stratigraphic position of the samples are illustrated by Figure 3.7.

3.2.3. THREE LICK BED – TYPE SECTION, MOREHEAD

The type section of the Three Lick Bed is located on Interstate Highway 64, near Morehead, Rowan County, Kentucky. This locality was designated the type section by Provo *et al.* (1978). At this location the Three Lick Bed reaches a thickness of 11.5ft. (3.5m). Five samples were collected from the Three Lick Bed, the sample details are as follows:

NL93 TCD59648 Lower grey/ green mudstone bed.

NL94 TCD59649 Middle grey/ green mudstone bed.

NL95 TCD59650 Second dark shale bed.

NL96 TCD59651 Uppermost grey/ green mudstone bed.

NL97 TCD59652 *as above.*

The location of this section and the stratigraphic position of the samples are illustrated by Figure 3.7

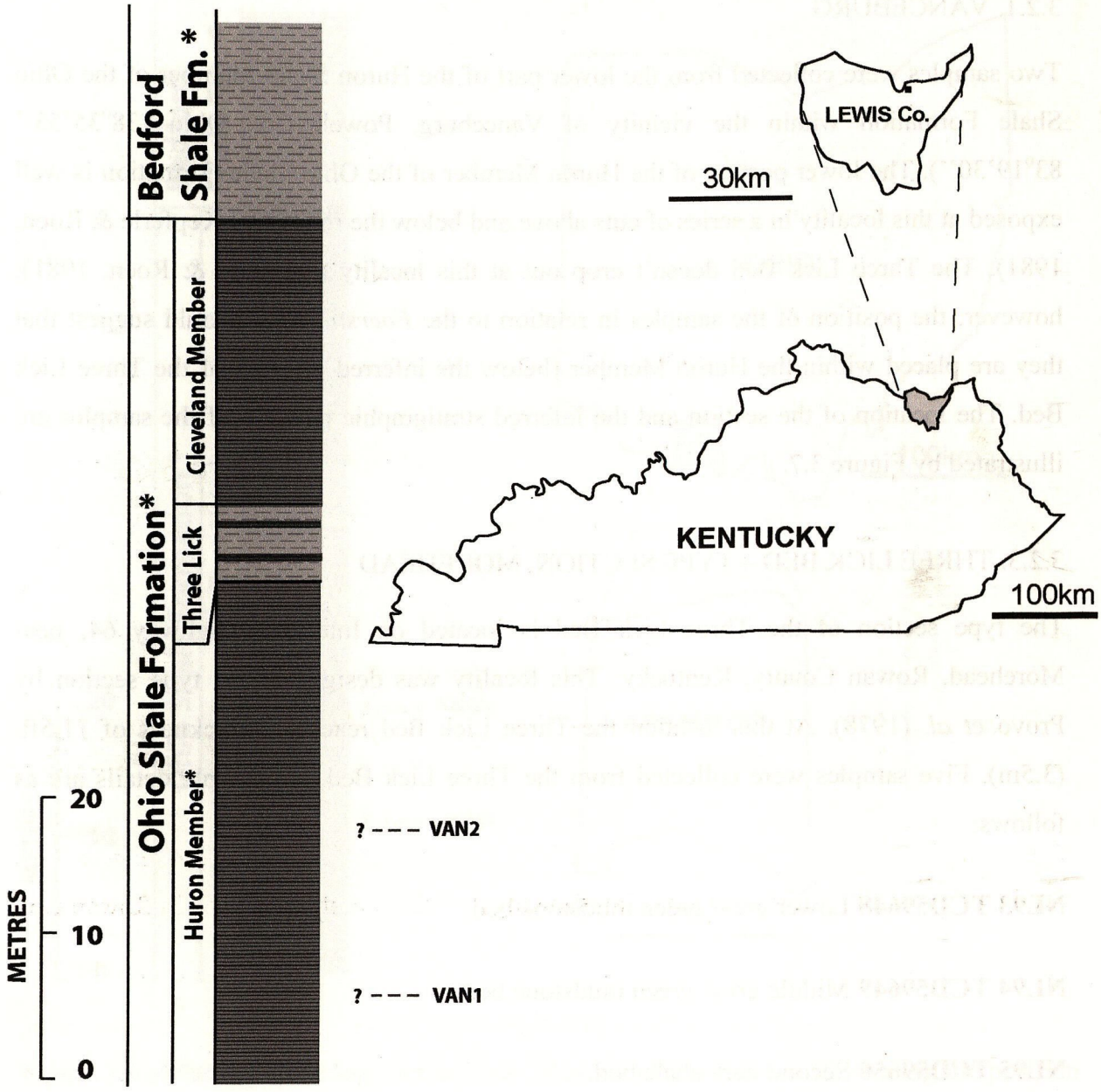


Figure 3.7 a) Stratigraphic log for the Vanceburg setction illustrating the relative stratigraphic position of samples b) Map showing the location of the Vanceburg section in Lewis County.

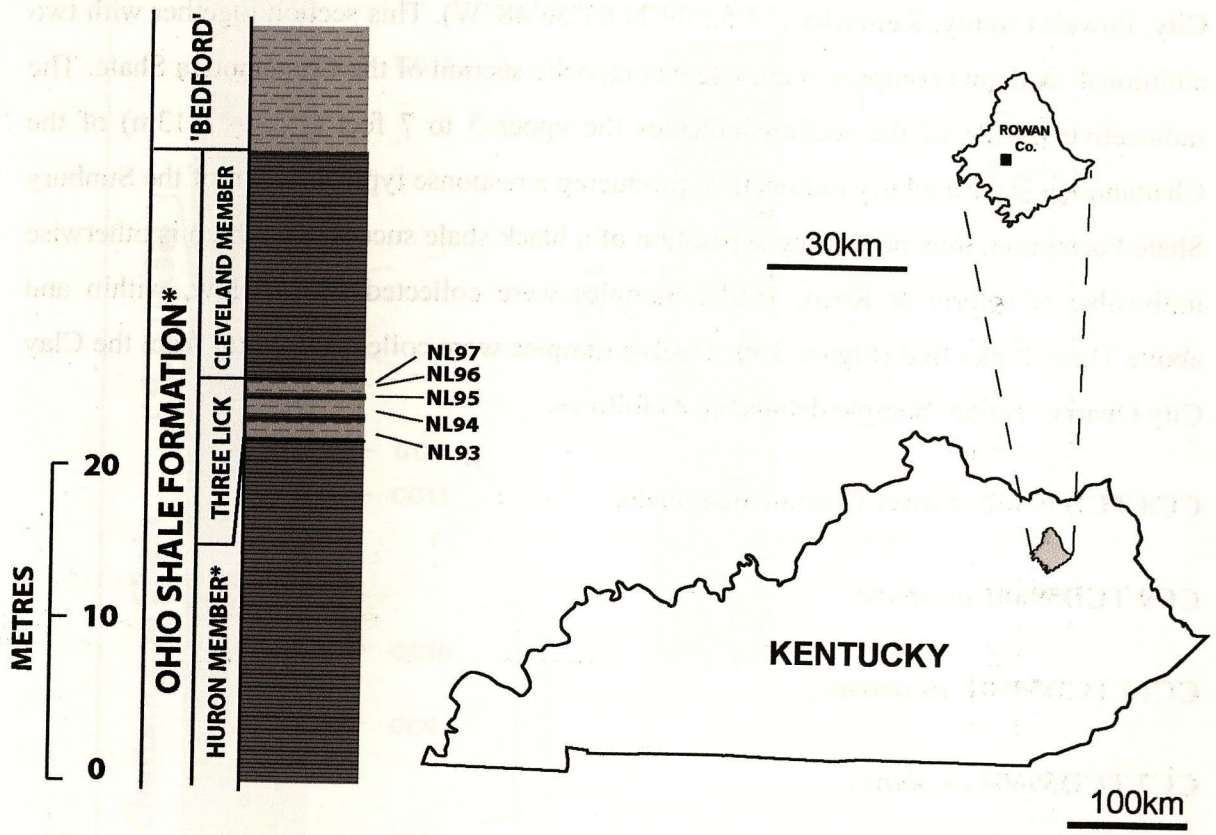


Figure 3.8 a) Stratigraphic log for the Three Lick - type section illustrating the relative stratigraphic position of samples b) Map showing the location of the section in Rowan Co.

3.2.4. CLAY CITY QUARRY

The Clay City Quarry section is located within the vicinity of the Mountain Parkway, Clay City, Powell County, Kentucky (37°52'09"N 83°56'48"W). This section together with two additional road cuts comprise a complete composite section of the Chattanooga Shale. The radioactive profile of the section indicates the upper 5 to 7 feet (1.52 – 2.13m) of the Chattanooga is particularly radioactive, producing a response typical to that of the Sunbury Shale Formation, thus permitting separation of a black shale succession which is otherwise indivisible (Kepferle & Roen, 1981). Samples were collected from below, within and above Three Licks Bed (Figure 3.9). Twelve samples were collected in total from the Clay City Quarry section. Sample details are as follows:

CC8 TCD59602 Lower Chattanooga Shale.

CC9 TCD59601 *as above.*

CC10 TCD59602 *as above.*

CC7 TCD59604 *as above.*

CC6 TCD59605 *as above.*

CC5 TCD59606 Three Lick Bed – lower grey/ green mudstone bed.

CC4 TCD59607 Three Lick Bed – lower black shale bed.

CC3 TCD56761* Three Lick Bed – middle grey/ green mudstone bed.

CC2 TCD59608 Three Lick Bed – upper black shale bed.

CC1 TCD59609 Three Lick Bed –uppermost grey/ green mudstone bed.

CC12 TCD59610 Upper Chattanooga Shale.

The relative stratigraphical position of samples is summarised in Figure 3.9. Field photographs of this section are presented in Appendix V. Directions to this section and a detailed lithological description of each of the Clay City sections are provided by Kepferle & Roen (1981).

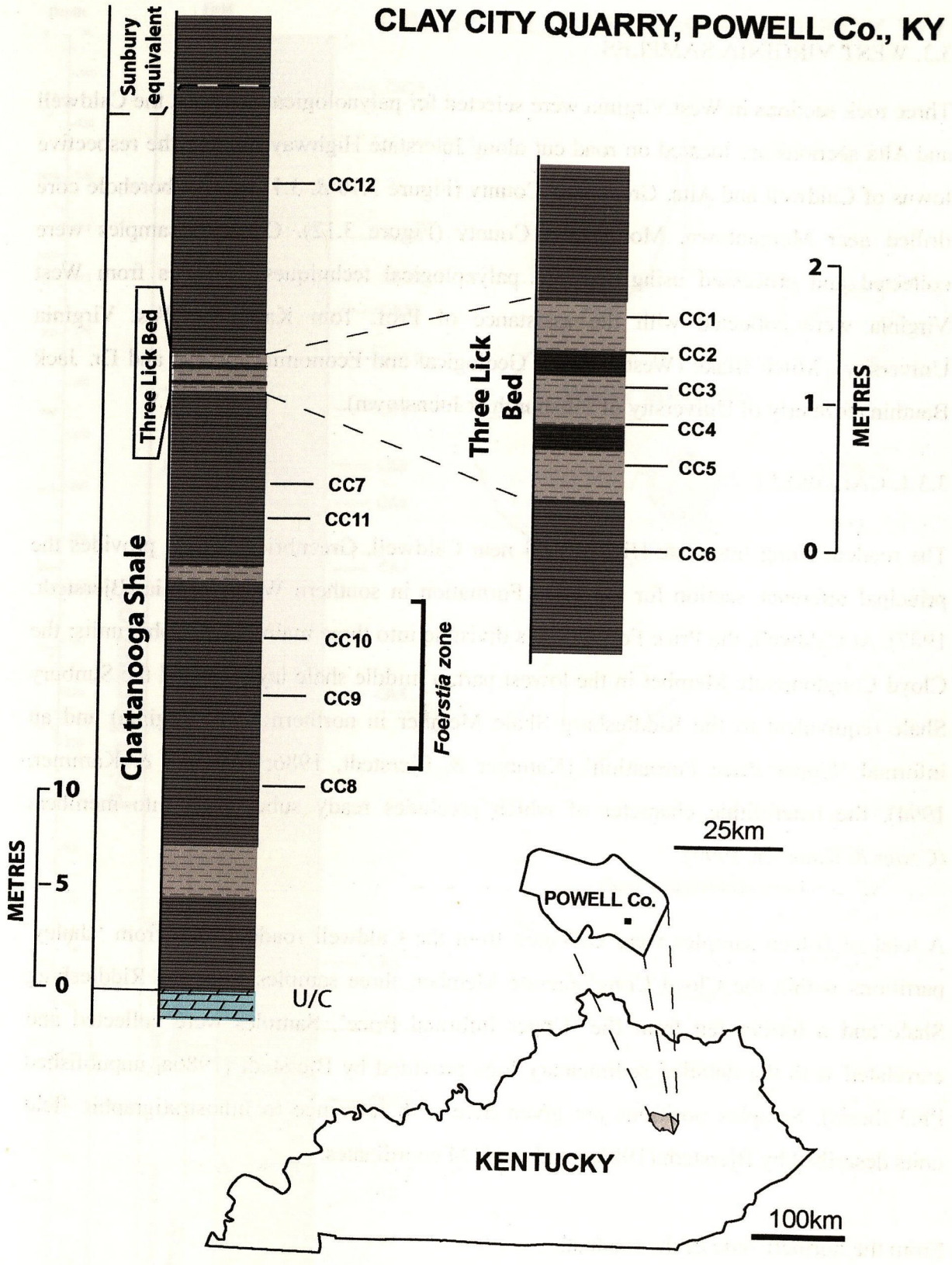


Figure 3.9 a) Stratigraphic log for the Clay City Quarry section illustrating the relative stratigraphic position of samples b) Map showing the location of Clay City Quarry in Powell County.

3.3. WEST VIRGINIA SAMPLES

Three rock sections in West Virginia were selected for palynological analysis; the Caldwell and Alta sections are located on road cut along Interstate Highway 64 near the respective towns of Caldwell and Alta, Greenbrier County (Figure 3.10 & 3.11), and a borehole core drilled near Morgantown, Monongalia County (Figure 3.12). Over 70 samples were collected and processed using standard palynological techniques. Samples from West Virginia were collected with the assistance of Prof. Tom Kammer (West Virginia University), Mitch Blake (West Virginia Geological and Economic Survey) and Dr. Jack Beuthin (formerly of University of Pittsburgh at Johnstown).

3.3.1. CALDWELL

The roadcut along Interstate Highway 64 near Caldwell, Greenbrier County provides the principal reference section for the Price Formation in southern West Virginia (Bjerstedt, 1987). At Caldwell, the Price Formation is divisible into three main stratigraphic units; the Cloyd Conglomerate Member in the lowest part, a middle shale layer termed the Sunbury Shale (equivalent to the Riddlesburg Shale Member in northern West Virginia) and an informal 'Upper Price Formation' (Kammer & Bjerstedt, 1986; Matchen & Kammer, 1994), the heterolithic character of which precludes ready subdivision into members (Carter & Kammer, 1990).

A total of fifteen samples were collected from the Caldwell roadcut; two from 'shaley' partitions within the Cloyd Conglomerate Member, three samples from the Riddlesburg Shale and a further ten from the 'Upper Informal Price'. Samples were collected and correlated with the detailed sedimentary logs provided by Bjerstedt (1986a, unpublished PhD thesis). Samples positions are given here with reference to lithostratigraphic field units described by Bjerstedt (1986a) and to UTM coordinates:

From the northern side of the roadcut;

CA1 TCD59561. Thin siltstone bed within the Cloyd Conglomerate Member (Unit 43) – (17S 0554735, 4180956).

CA2 TCD59562. *As above* – (17S 0554716, 4180945).

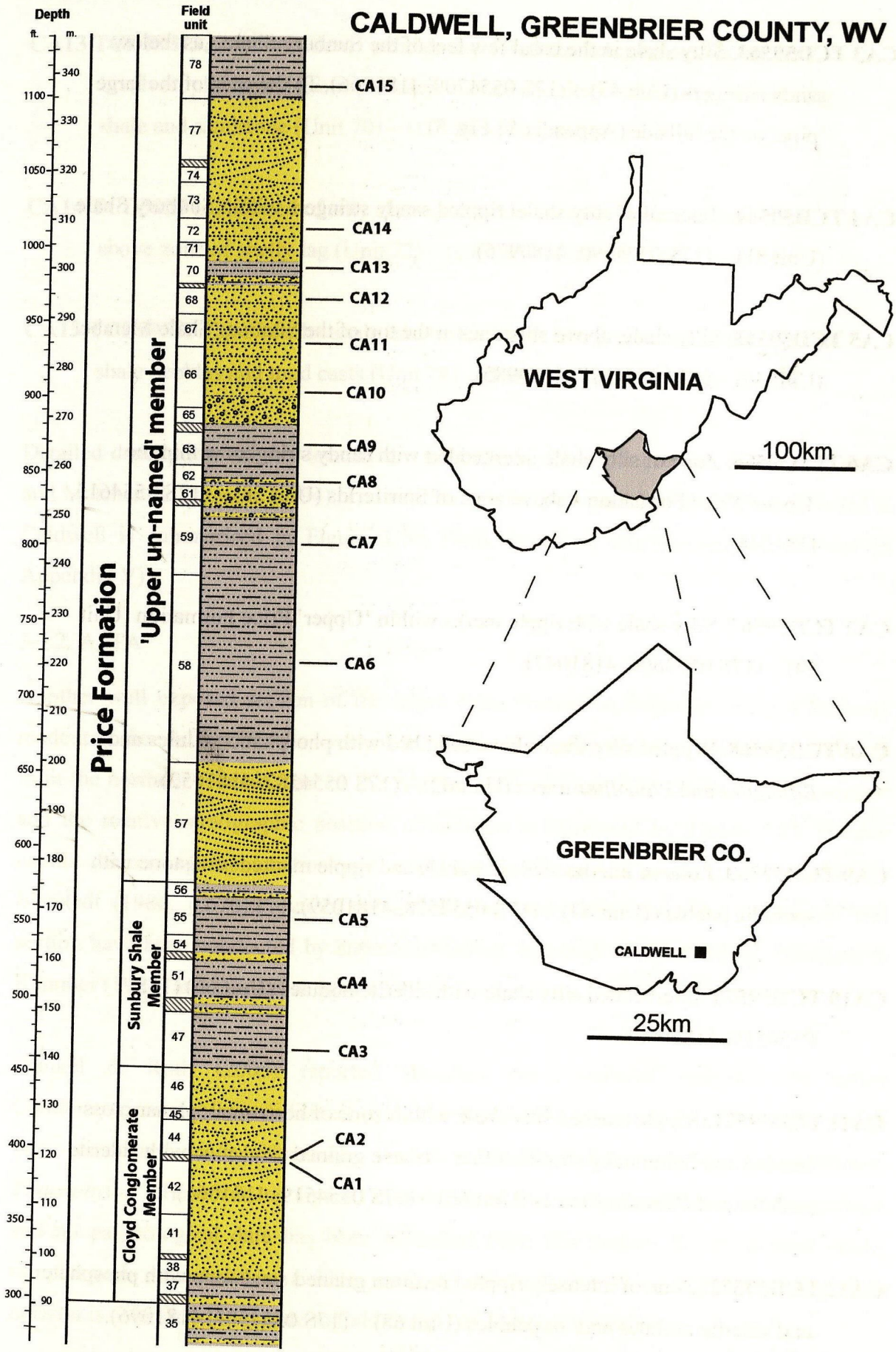


Figure 3.10 Stratigraphic log for the Caldwell roadcut illustrating the position of samples b) Map showing the location of the section in Greenbrier County, West Viginina.

CA3 TCD59563. Silty shale in the basal few feet of the Sunbury Shale, just below sandy stringers (Unit 47) – (17S 0554709, 4180966). To the west of the large 'pipe' on the hillside (Appendix V; Fig. 5)

CA4 TCD59564. Interval of silty shale/ rippled sandy stringers within Sunbury Shale (Unit 51) – (17S 0554690, 4180976).

CA5 TCD59565. Silty shale, above siltstones at the top of the Sunbury Shale Member (Unit 56) – (17S 0554677, 4180985).

CA6 TCD59566. Zone of silty shale interbedded with sandy stringers within the 'Upper' Price Formation - above zone of Spiriferids (Unit 58) – (17S 0554615, 4181044).

CA7 TCD59567. Silty shale with ripple marks within 'Upper' Price Formation (Unit 59) – (17S 0554606, 4181047).

CA8 TCD59568. Rippled silty shale above sand bed with phosphatic nodules and *Bifungites* and *Planolites* traces (Unit 62) – (17S 0554587, 4181052).

CA9 TCD59569. Zone of interbedded silty shale and ripple marked sandstone with sporadic pebbles (Unit 63) – (17S 0554578, 4181059).

CA10 TCD59570. Interbedded silty shale with siderite nodules (Unit 66) (17S 0554519, 4181066).

CA11 TCD59571. Ripple marked silty shale within zone of horizontal, planar cross bedded and hummocky stratified fine – coarse grained sandstone with siderite nodules and *Planolites* traces (Unit 66) – (17S 0554519, 4181066).

CA12 TCD59572. Zone of intensely rippled medium grained sandstone with phosphate and siderite nodules and/ or pebbles (Unit 68) – (17S 0554504, 4181096).

From the southern side of the Interstate Highway 64 roadcut;

CA13 TCD59573. Zone of siderite pebbles and fossil lag (strophomenids, nuclid bivalves, planispiral gastropods and crinoid ossicles) within interbedded silty shale and sandstone (Unit 70) – (17S 0554485, 4181112).

CA14 TCD59574. Thin bed of silty shale within horizontally laminated sandstone, above zone of shelly lag (Unit 72) – (17S 0554478, 4181134).

CA15 TCD59575.Zone of silty shale interbedded with fine grained sandstone and flat shale pebbles and mud casts (Unit 78) – (17S 0554462, 4181174).

Detailed descriptions of this locality are provided by Bjerstedt (1986a) Bjerstedt (1988a) and Matchen & Kammer (1994). The relative stratigraphic position of samples collected at Caldwell is summarised in Figure 3.10; Field photos of this section are provided in Appendix V).

3.3.2. ALTA

Another well exposed section of the upper Price Formation crops-out along a highway roadcut in the vicinity of Alta, west of the Caldwell locality. Four samples were collected from the northern roadcut, east of the Alta exit and on-ramp. The location of this section and the relative stratigraphic position of samples is illustrated by Figure 3.11. Further details concerning the location and stratigraphy of the Alta section are provided by Bjerstedt (1986, p.676).Previous palaeontological and sedimentalogical studies of this section have been conducted by authors including, Bjerstedt (1986 & 1988), Bjerstedt & Kammer (1988) and Frankel & Roth (2005).

Frankel & Roth (2005) reported abundant plant material assigned the taxon *Chlidanophyton dublinensis* Gensel, and described spores recovered from sporangia which they considered to be, "basically similar to those of trimerophytes, *Calamophyton, Rhacophyton*". However, no figured material from this study is available for comparison and no palynological data has been published from this section. In the present study, samples were collected from a shaley interval particularly rich in macroplant remains. This horizon is considered to equate to field unit 23 of Bjerstedt (1986).

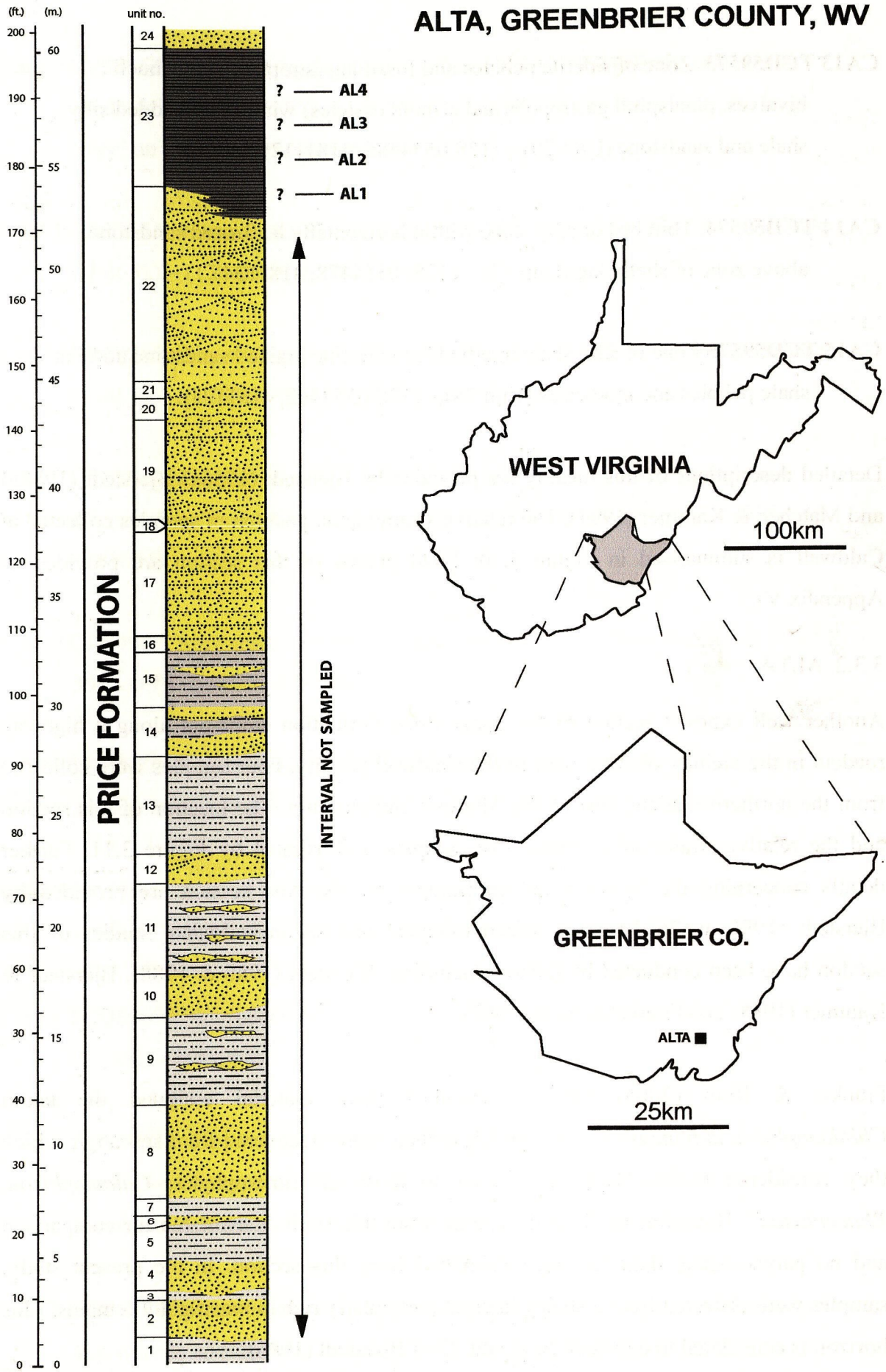


Figure 3.11 Stratigraphic log for the Alta section illustrating the position of samples b) Map showing the location of the section in Greenbrier County, West Viginina.

3.3.2. MYLAN PARK BOREHOLE CORE

The Mylan Park borehole core was drilled in the district of Morgantown, Monongalia County, West Virginia (Figure 3.12). The core was drilled by the US Department of Energy. However, the core material has never been sampled for palynological study prior to the present investigation. In total, 56 samples were collected from the core by Dave Matchen (Athens University, WV.) and Mitch Blake (West Virginia Geological and Economic Survey).

Based on a detailed description of the core (Appendix III) the borehole is inferred to have penetrated the Meramecian (Viséan?) Greenbrier Limestone and 4 informal Driller's Sandstone members of the underlying Price Formation. In descending stratigraphic order, these are the Big Injun, Squaw, Weir and Murrysville sandstones. The subsurface lithostratigraphy of this interval in northern West Virginia and Pennsylvania is discussed in detail in Chapter 1.5.5. The relative stratigraphic level of the Mylan Park samples is summarized in Figure 3.12.

3.4. PENNSYLVANIA SAMPLES

In addition to the samples from Ohio, Kentucky and West Virginia, three sections were selected for study in the state of Pennsylvania. Sampling of these sections focused primarily upon the Burgoon Sandstone Formation with additional samples taken from the uppermost levels of the underlying Rockwell Formation.

3.4.1. CRAMER

The Cramer section consists of a series of well exposed roadcuts along Route 403 (Cramer Pike), near Cramer, Indiana County, Pennsylvania. The location of this section is illustrated by Figure 3.13. The base of the distinctive limestone of the Loyalhanna Formation served as a reference point and samples where collected from the underlying Burgoon Sandstone Formation and uppermost Rockwell Formation.

Six samples were collected along the road cut, 5 from the Burgoon Sandstone Formation with an additional sample taken from a thinly bedded argillaceous sandstone in what is presumed to be the uppermost Rockwell Formation (see below). Sample details with reference to UTM coordinates are as follows:

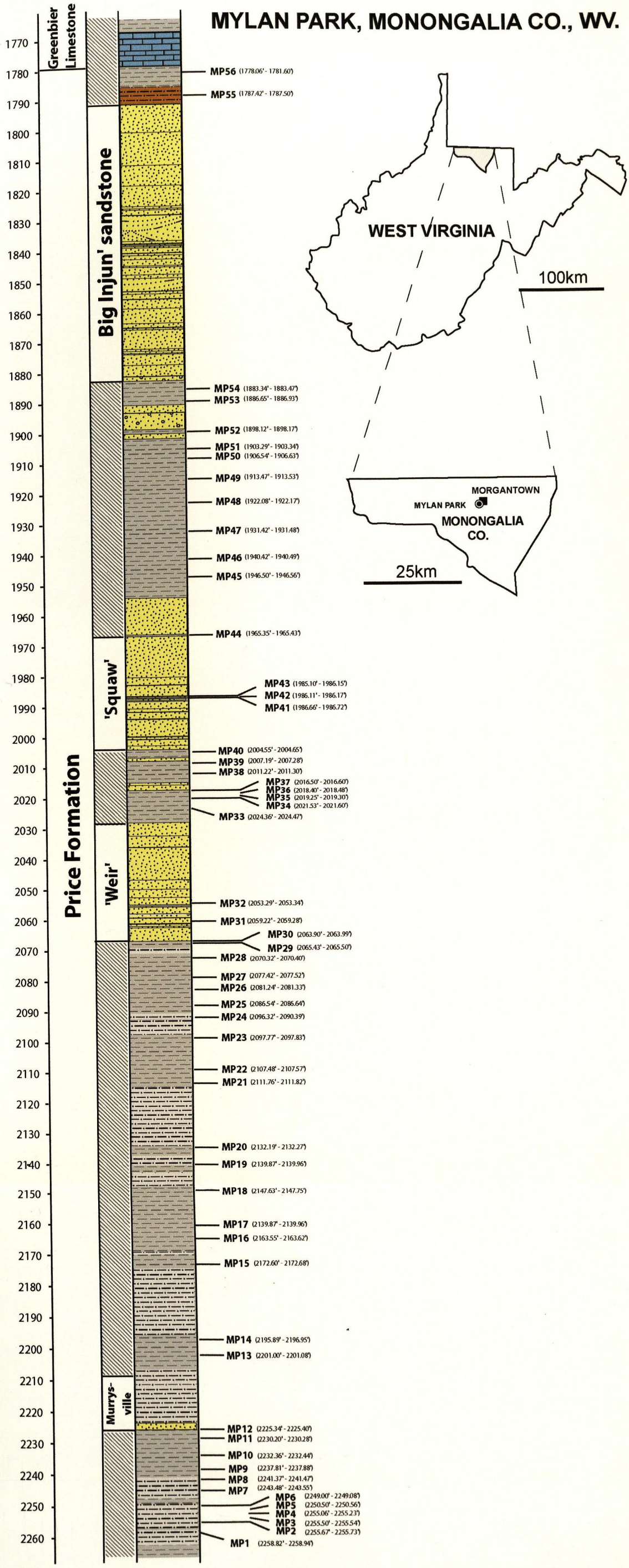


Figure 3.12 a) Stratigraphic log for the Mylan Park core illustrating the position of samples b) Map showing the location of the section in Monongalia County, West Viginina.

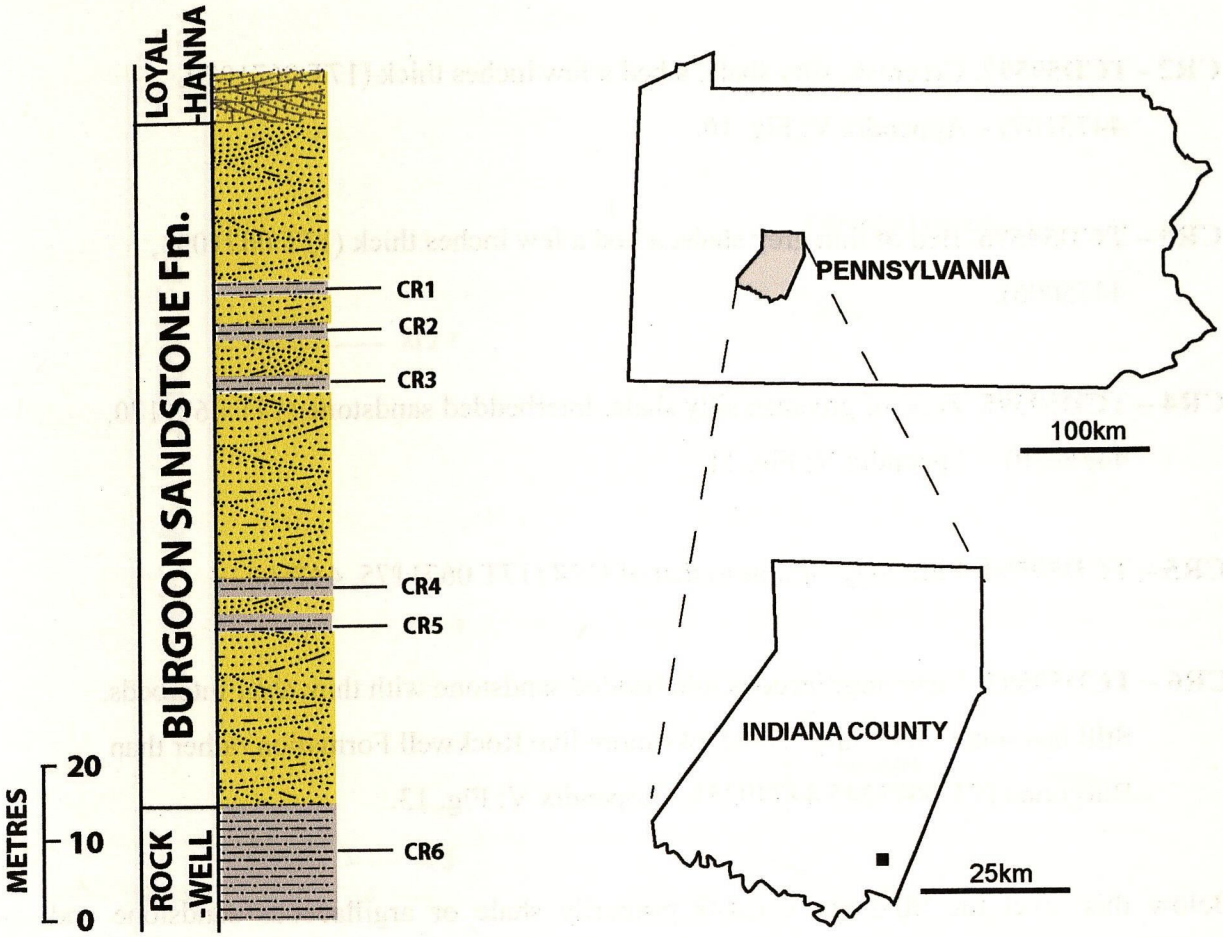


Figure 3.13 a) Stratigraphic log for the roadcut section close to Cramer b) Map showing the location of Cramer, Indiana County, Pennsylvania.

CR1 - TCD59598. Zone of silty, sandy shales with plant macerals in a zone of Burgoon with rip-up clasts (17T 0671073 4475128) – Appendix V; Fig. 9.

CR2 - TCD59597. Greenish, silty shale, a bed a few inches thick (17T 0671070, 4475107) – Appendix V; Fig. 10.

CR3 – TCD59596. Bed of thin grey shale, a bed a few inches thick (17T 0671093, 4475096).

CR4 – TCD59595. Zone of greenish silty shale, interbedded sandstone (17T 0671170, 4475020) – Appendix V; Fig. 11.

CR5 – TCD59594. Lithology similar to that of CR4 (17T 0671175, 4475002).

CR6 – TCD59593. Dirty, argillaceous thin bedded sandstone with thin, shay interbeds. Still has some x-bedding. This looks more like Rockwell Formation rather than Burgoon (17T 0671245 4474925) – Appendix V; Fig. 13.

Below this level the lithology consists primarily shale or argillaceous sandstone and belongs almost certainly to the Rockwell Formation. This interpretation appears to agree with reports of a 91 metre (298.5ft.) thick section of Burgoon reported at Altoona by Inners (1987).

3.4.2. ALTOONA

This section is located close to Altoona, Blair County, Pennsylvania. (Figure 3.13). Samples were collected from a roadcut along Old U.S. Route 22, where the road splits, near the Blair Gap Reservoir. This locality is close to the famous Horseshoe Curve section, sampled for palynology by Streel & Traverse (1978). The Altoona section spans the Burgoon Sandstone, which is 91 metre (298.5ft.) thick (Inners, 1987), and the underlying Rockwell Formation. The Rockwell is reported as consisting of argillaceous sandstone and shale with abundant plant fossils (Kammer personal communication).

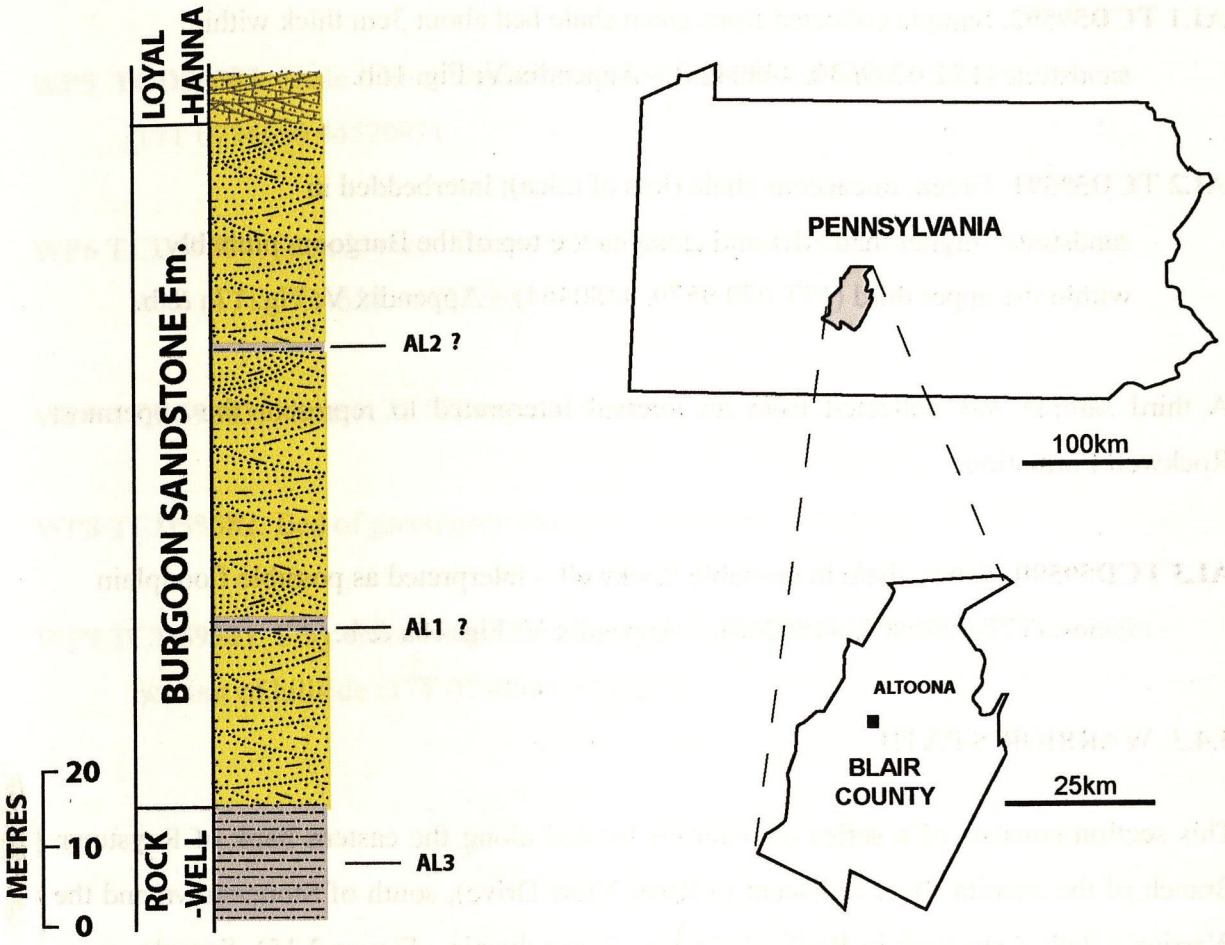


Figure 3.14 a) Stratigraphic log for the roadcut section close to Altoona b) Map showing the location of Altoona, Blair County, Pennsylvania.

Two samples were collected from the Burgoon Sandstone:

AL1 TCD59592. Sample collected from green shale bed about 3cm thick within sandstone (17T 0709630, 4480424) – Appendix V; Fig. 16b.

AL2 TCD59591. Green, micaceous shale (lots of mica); interbedded in sandstone –higher than AL1 and closer to the top of the Burgoon, probably within the upper third (17T 070 9579, 4480464) – Appendix V; Fig. 17a & b.

A third sample was collected from an interval interpreted to represent the uppermost Rockwell Formation:

AL3 TCD59590. Sandy shale in probable Rockwell – interpreted as possible floodplain facies. (17T 0709807, 4480268). – Appendix V; Fig. 18a & b.

3.4.3. WARRIOR'S PATH

This section consists of a series of outcrops located along the eastern bank of Raystown Branch of the Juanita River (adjacent to River View Drive), south of Stonerstown and the Warrior's Path State Park in Bedford County, Pennsylvania. (Figure 3.15). Samples were correlated with the sedimentary log of this locality presented by Beng *et al.* (1986). Eight samples were collected from the Burgoon and one from the underlying Rockwell Formation. Sample details are as follows:

WP1 TCD59589. Interbedded shales in medium bedded sandstone within the Burgoon. Marked on Beng & Dodge section – near top of Burgoon (17T 07346699 4452032).

WP2 TCD59588. Sample collected from a shale, which is 'cooked' (17T 0734703 4452032)"

WP3 TCD59587. Sample from a shale (17T 0734701 4452023). – Appendix V; Fig. 19a & b.

WP4 TCD59586. Shale zone in thick sandstone (17T 0734661 4452093). – Appendix V; Fig. 20.

WP5 TCD59585. Shale in the 'blackcoal shale zone' (avoided coaly matter) (17T 0734650 4452091).

WP6 TCD59584. Sample taken from a bed of shale, several metres below x-bedding WP5 (17T 0734628 4452126).

WP7 TCD59583. Shale (17T 0734616 4452161).

WP8 TCD59582. Bed of green/grey shale (17T 0734592 4452192).

WP9 TCD59581. Silty shale within the uppermost portion of the Rockwell Formation – dug out of hillside (17T 0734544 4452221).

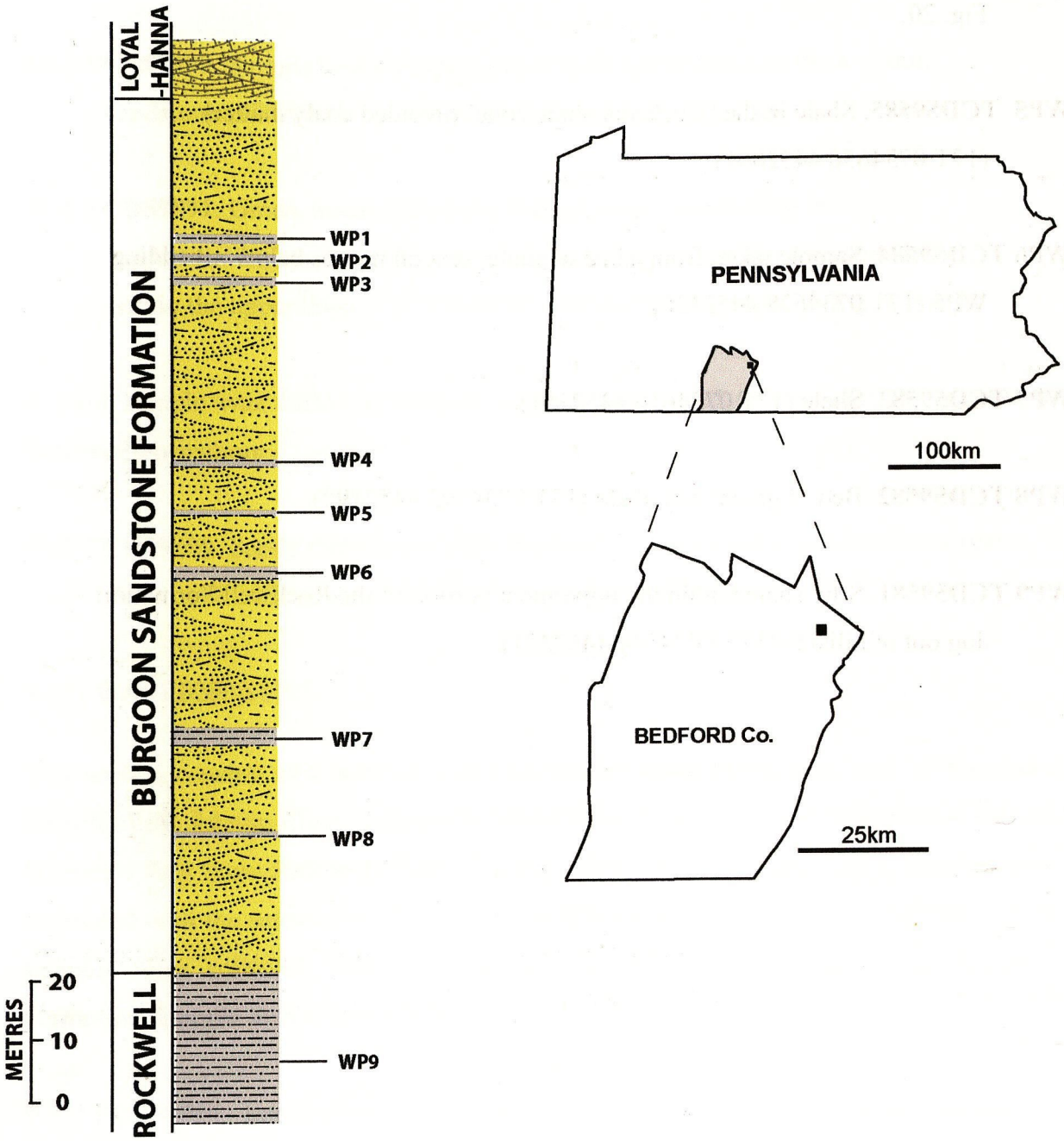


Figure 3.15 a) Stratigraphic log for the Warrior's Path section b) Map showing the location of Warrior's Path, Bedford County, Pennsylvania.

CHAPTER 4

METHODOLOGY

4.1. PROCESSING METHODS

All processing was carried out to comply with British Standard Institution (1981) recommendations; chemicals were handled in accordance to Control of Substances Hazardous to Health regulations (COSHH, 2002) guidelines. All chemical preparation was undertaken in a fume cupboard and protective clothing worn at all times. Samples were processed using standard palynological acid digestion techniques outlined below:

Rock samples were cleaned in distilled water to remove any dirt, dust and other source of potential contaminants. The washed rock was crushed into fragments approximately 5mm (0.2in.) in diameter. This process is typically carried out using a pestle and mortar. However, in some instances in the present study it was found that this technique was both time consuming and unsatisfactory, particularly when dealing with strongly cemented lithologies such as sandstone. These samples were placed in thick polythene sample bags and lightly pounded with a standard geological hammer on an anvil producing sub-centimetre fragments. Each sample was crushed in a fresh sample bag and the anvil and hammer were cleaned with ethanol between samples.

10 - 20g (0.35 – 7oz.) of crushed rock per sample was then transferred from the sample bag into a sterile, 600ml polythene container labelled with the sample number and sample locality.

The crushed sample was rinsed in distilled water to remove fine dust from the container. The removal of dust in the sample container helped reduce the vigorous reaction and effervescence caused when mixed with acid.

Samples which tested positive for carbonate were treated with dilute HCl and left for 24 - 48 hours or until the reaction had ceased. This is a crucial stage since the application of hydrofluoric acid (HF) at this stage can result in a potentially explosive reaction.

The HCl was decanted off and samples were rinsed with water when reaction ceased.

To remove silicates, ~150cl. (5 fl. oz.) of approx. 57% proof hydrofluoric acid (HF) was added to the sample jar, which was placed in water bath for 24 hours, after which a further 150cl HF added.

Samples were stirred twice daily until silicates had dissolved and only black organic residue remained. This usually took between 7 to 14 days depending on the lithology of the sample being processed. During processing it was noted that if samples were not stirred on a regular basis the partially dissolved rock was prone to re-solidify and 'cake' to the base of the sample container. However, it was found that samples could be re-dissolved by replacing the HF in the container with fresh HF.

Samples were deemed to be fully dissolved when the organic residue was 'smooth' when stirred with a polythene rod. Samples which were 'gritty' when stirred were left in HF until totally smooth. When the sample was considered to be fully dissolved the spent HF was decanted off into a waste storage container, and the sample jar filled with distilled water. This process was repeated after 24 hours. Spent HF was safely disposed of by the Chemistry Department, Trinity College.

After the initial two decants, samples were progressively neutralised by decanting water from the jar and refilling with clean water. Samples were decanted eight times to ensure total neutrality.

Neutralised samples were sieved using a 20μm nylon sieve cloth to concentrate palynomorphs and remove any fine un-dissolved mineral grains.

Sieved residue was examined under the microscope for palynomorphs before deciding what further measures were necessary. Barren samples were mounted for record purposes but no further processing was attempted.

Samples with a large quantity of un-dissolved silica were transferred into a small Pyrex beaker and gently heated in HCl over a Bunsen burner. Spent HCl was then decanted off and the sample rinsed.

A small volume (typically 10ml) of sieved residue was treated with cellusize dispersal agent to minimise the 'clumping' of palynomorphs and then mounted onto glass cover slips. Cover slips were allowed to dry before being mounted onto glass slides using elvacite resin. Slides were then let dry for a further 24-48 hours.

To remove pyrite from palynomorphs, residue was treated with Nitric acid (HNO_3). The duration of treatment varied depending on the preservation and maturity of palynomorphs in the sample.

Excess residue was treated with one drop of HCl to inhibit the growth of fungi and bacteria and stored in a glass phial.

4.2. PALYNOFACIES ANALYSIS

To process samples for palynofacies analysis the basic procedure outlined in section 4.1 was utilised. Only un-oxidised samples were selected for palynofacies investigation since oxidising agents such as HNO_3 may alter kerogen content.

Selected slides were photographed at random fields of view using a Nikon camera mounted to a Leitz Wetzlar Orthoplan transmitted light microscope with a x10 objective lens. A 10 x 10 grid was then digitally overlain on the images using Adobe Illustrator ®, and the images printed.

Organic particles present in each field of view were assigned to one of three categories:

1) Phytoclast
2) Palynomorph
3) Amorphous Organic Matter (AOM)

Since acritarchs and other marine prasinophyte algae clearly have a different provenance from miospores, these particles were considered as a subcategory. Once identified, the area % occupied by each of the kerogen type present in each field of view was established by overlaying a smaller 10 x 10 grid (Figure 4.1).

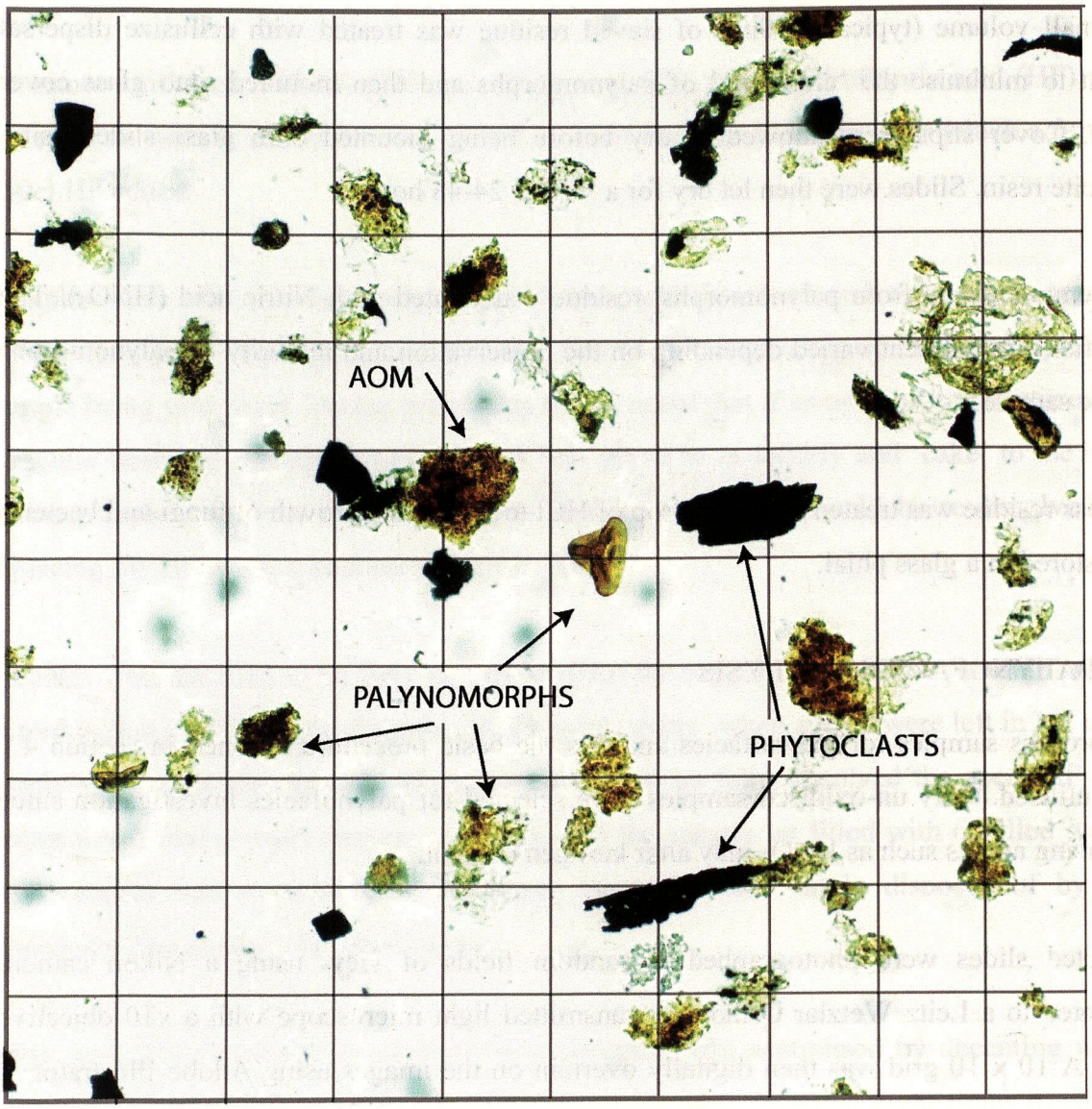


Figure 4.1 Grid used in the visual estimation of kerogen.

4.3 SPORE ABUNDANCE

The present investigation was initially intended to provide a purely qualitative assessment of miospore occurrences. However, during the course of the study it became necessary to acquire quantitative data for selected samples.

In order to provide a quantitative assessment of miospore occurrences, samples were spiked with *Lycopodium* tablets. Known concentrations of *Lycopodium* spores were compared with the number of spores counted. One tablet was used per gram of sample processed. In each case, 20 tablets were added to 20 grams (0.7oz.) of sample. As noted by James (2003 unpublished PhD thesis) since *Lycopodium* tablets effervesce on addition of HCl meant more *Lycopodium* spores were lost during the decant phase relative to palynomorphs present in the sample. Tablets were thus added post - HCl treatment.

The following equation was used to calculate the numbers of spores per gram:

$$\text{no. spores/g} = \frac{\text{no. spores counted x total no. spike added}}{\text{no. spike counted x sample weight}}$$

Equation 4.2. Absolute abundance of particle type per gram sample used.

$$\text{Total \% error} = \pm 100 \sqrt{\left(\left(\frac{S}{X}\right)^2 + \left(\frac{\delta_2}{\beta_2}\right)^2 + \left(\frac{\delta_3}{\beta_3}\right)^2\right)^2}$$

S = ± Error per 20 *Lycopodium* tablets

X = No. of *Lycopodium* spores per 20 tablets

β_2 = No. of particle type

β_3 = No. of *Lycopodium* spores counted

$\delta n \approx \sqrt{\beta_n}$

Equation 4.3 Error in the calculation of the abundance of particle type per gram of sample

Lycopodium samples were manufactured by the University of Lund (Batch no. 938934). Each tablet was determined to contain 10,679 +/- 953 spores (Appendix I).

4.4 MICROSCOPY

All samples were routinely analysed using a Leitz Wetzlar Orthoplan transmitted light microscope (number 968423) equipped $_{x}25$ and $_{x}40$ PL APO objective lenses and a GW $_{x}10$ M binocular eyepiece.

Samples were and photographed and specimens measured using a Nikon Eclipse microscope. Z - stacking software was used to produce focused images of larger spores with coarse ornament. Images were cropped using Adobe Photoshop® version 8.0. Plates were compiled using Adobe Illustrator® version 10.

4.5 CURATION OF SAMPLE MATERIAL

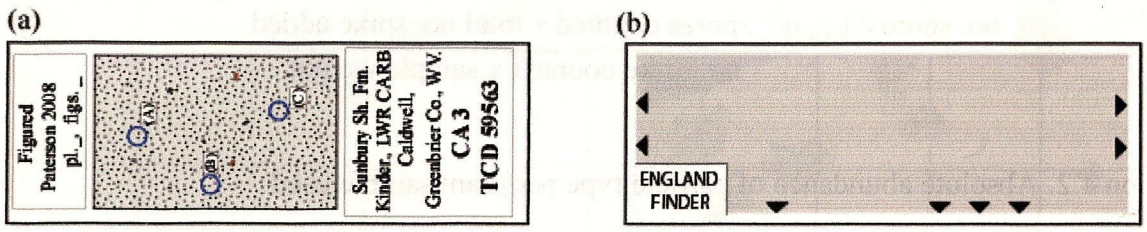


Fig. 4.5 Viewing position of palynological slides with reference to an England Finder slide.

Slides were viewed with the sample label on the right of the slide as illustrated by Figure 4.5a. All material figured in this thesis is housed in the Geological Museum, Dept. of Geology, Trinity College, Dublin. The location of miospores is given with reference to England Finder coordinates (Figure 4.5b). Slides are labelled with a reference number designating the section from which it was collected and its relative position within that section (e.g. CA3 = the 3rd sample collected from the Caldwell section). The exception to this are the samples incorporated from Duggan's (2006) study, where samples were not initially intended for use in stratigraphic study and thus were originally designated with sample numbers which are somewhat arbitrary. All slides utilised in the study are also

labelled with a TCD museum number for curatorial purposes. A complete list of slides used in the present study and their TCD museum numbers is provided in Appendix IV.

CHAPTER 5

TERMINOLOGY AND CLASSIFICATION

5.1. MORPHOGRAPHIC TERMINOLOGY OF MIOSPORES

The morphographic terminology used in the systematic descriptions of miospores in this current study closely follows that utilised by Grebe (1971) and more recently by Punt *et al.* (2007). However, in the current study the following terms are used are used in a different sense to Grebe. These terms are thus defined here in order to avoid confusion.

Ray fold (*sensu* Clayton 1972 unpublished PhD thesis, p.16) "a membranous extension of the exine projecting outwards along the sutura, normally folded. Sometimes the ray fold extends beyond the outer limit of the sutura towards the equator and is often connected radially to the curvatural ridges if these are present. The detailed structure and function of the ray folds are not known". See Figure 5.2.

Cingulum (*sensu* Smith & Butterworth 1967, p. 116) "A thickening of the exine (or exoexine) more or less confined to and encircling the equator, e.g. *Densosporites annulatus* (Loose) Smith & Butterworth. Spores with such a feature are described as cingulate. In cross-section the outer edge of the cingulum may be rounded or cuneiform. Spores with a strongly tapering cingulum which may be membranous near its outer margin are termed cingulizonate. The cingulum may extend some distance towards the poles, at the same time diminishing in thickness". Grebe (1971, p. 16) uses the term cingulum only for equatorial thickenings which are wedge shaped in cross-section, using the term 'equatorial crassitude' for more rounded thickenings. See Figure 5.4.

Biform Element (*sensu* Clayton 1972, p. 16). "An element of ornament which exhibits the combination of two or more distinctly different styles, e.g. baculum surmounted by two or more spinae as in *Umbonatisporites variabilis* Hibbert & Lacey" This term was used in the description of *Dibolisporites* by Richardson (1965, p. 568) but wasn't defined.

Galeae A commonly occurring type of biform element which comprise of well rounded verrucae, surmounted by small spinae. This term was first used by Sullivan (1964b) in the description and diagnosis of *Vallatisporites galearis* Sulluvan.

Mamillae Another form of biform element which are comprised of flat topped verrucae surmounted by spinae as in *Cristatisporites menendezii* Menendez & Azcuy. The bases of mamillae are wider than those of Galeae.

5.2. NOMENCLATURE & CLASSIFICATION OF MIOSPORES

Since the true botanical affinities of the majority of Palaeozoic miospores remains obscure, their classification is based purely on morphology rather than true taxonomic affinity. The nomenclature of the various miospore taxa is subject to the rules of priority and typification stipulated in the International Code of Botanical Nomenclature (1966). However, no classificatory system has been universally accepted at the suprageneric level since these rules do not apply.

Five major systems of suprageneric classification have been proposed for the Anteturma SPORITES of H. Potonié. These are as follows: Naumova (1939), Potonié & Kremp (1955), Dettman (1963), Neves & Owens (1966) and Smith & Butterworth (1967).

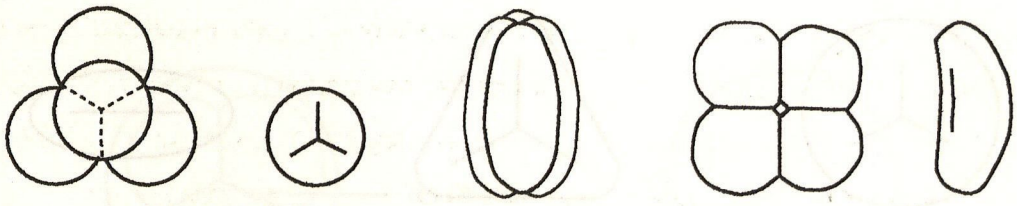
The classification system used in the present study closely follows that proposed by Dettman (1963) (Figure 5.9), with latter emendations by Smith & Butterworth (1967) and Streel in Streel *et al.* (1974). The scheme utilised by Dettman (1963) used the term 'camerate' to describe two-layered miospores. Later work by Neves & Owens rejected the use of the term 'cavate' in this context, since it was originally used by Faegri & Iversen (1950) to describe the separation of the infrareticulate bladder-like 'sac' of gymnosperm pollen from the main pollen body. Neves & Owens (1966) replaced 'cavate' with 'camerate' for two layered spores, naming their two initial suprasubturmas ACAMERATITRILETES and CAMERATITRILETES.

Despite the rejection of the term 'cavate' by Neves & Owens (1966), the term has been accepted by many workers and within the present study it is used to describe two-layered spores. Furthermore, following recent workers the Suprasubturma ACAVATITRILETES is used for one-layered trilete miospores, since the degree of separation of the two layers and the nature of their attachment has not been firmly established for most Lower Carboniferous genera (McPhilemy, 1989).

Trilete miospores with two layers which do not show a wide degree of separation are placed within the suprasubturma LAMINATITRILETES *sensu* Smith & Butterworth (1967, p.228). Further suprageneric subdivisions closely follow Smith & Butterworth (1967) based upon the presence or absence of an equatorial modification of the outermost layer of exoexine. Acamerate, trilete spores, 'in which one whole hemisphere, either proximal or distal, is enclosed in a prominent Exinal thickening', are accommodated in the Infraturma PATINATI sensu Smith & Butterworth.

In the systematics chapter that follows, the original diagnosis is provided for the majority of taxa documented. For clarity reasons, where a diagnosis is quoted from the original paper, quoted text is denoted by quotation marks. New descriptions based on the material examined in the current study are provided only in select instances where a particular species is described for the first time. Within each supra generic subdivision or Infraturma, the genera are listed alphabetically. Species within genera are also listed alphabetically.

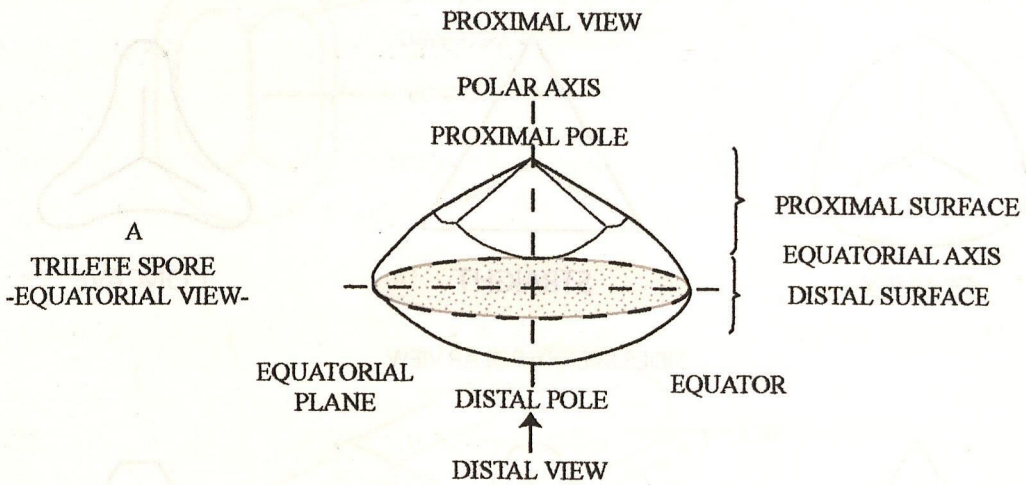
GENERAL TERMS USED IN ORIENTATION & DESCRIPION

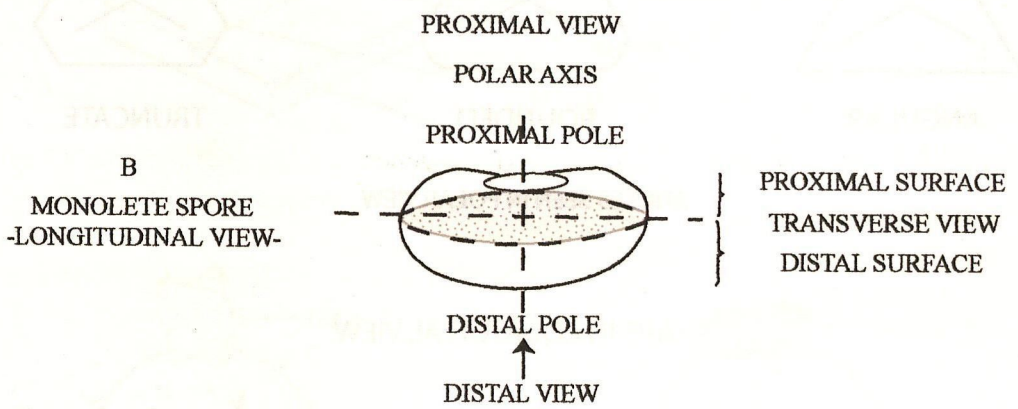


A. TETRAHEDRAL

B. TETRAGONAL

FIG. 1 TETRADS





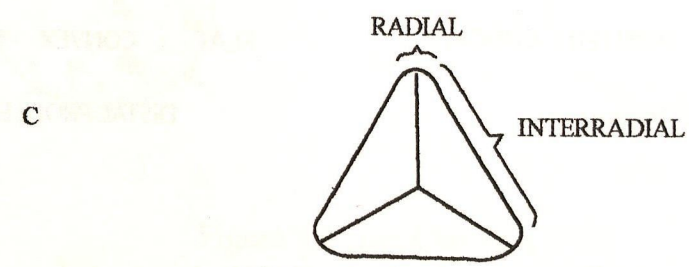


Figure 5.1 Morphographic terminology (after Grebe, 1971).

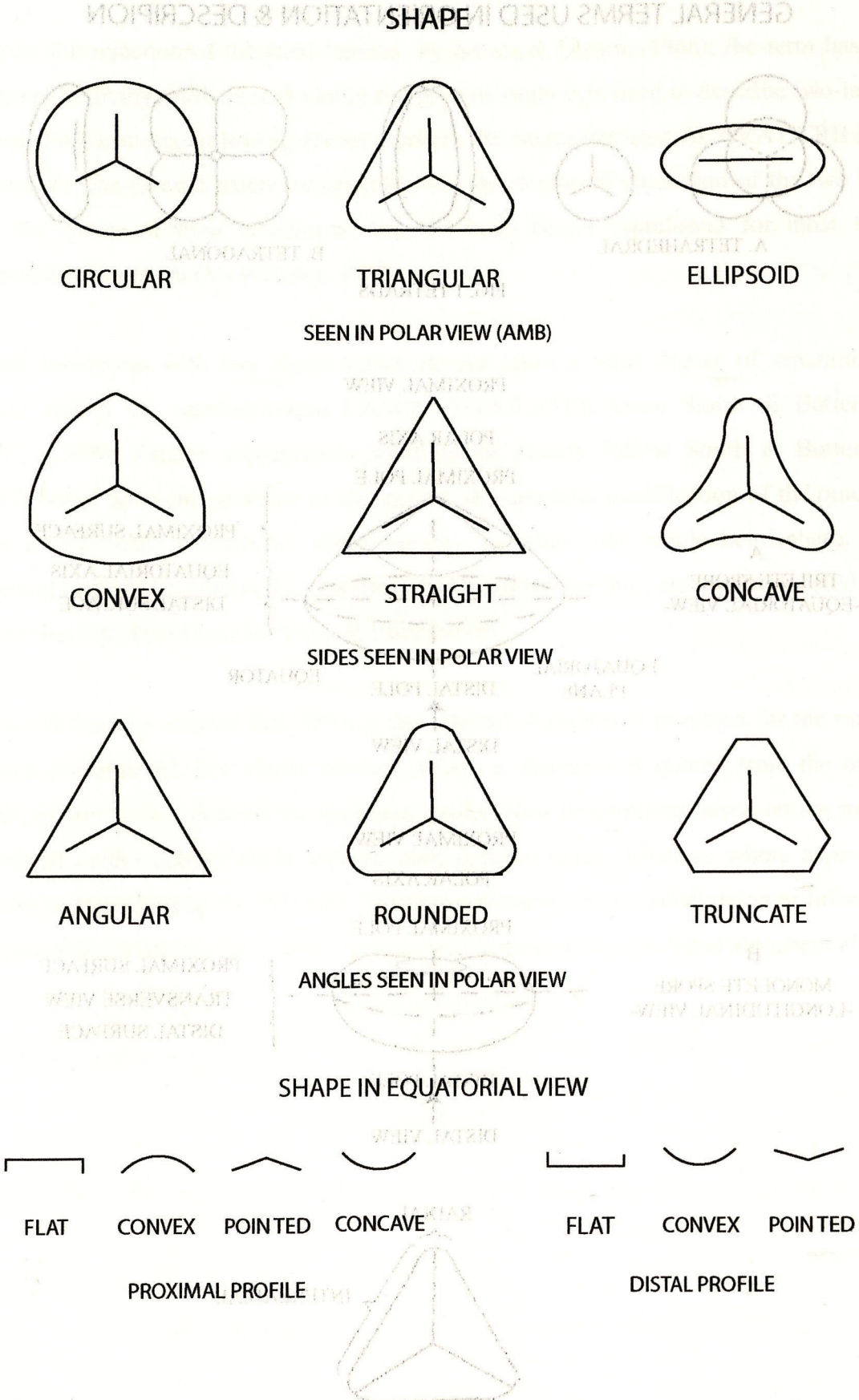


Figure 5.2 after Grebe (1971)

TETRAD MARK & ASSOCIATED FEATURES

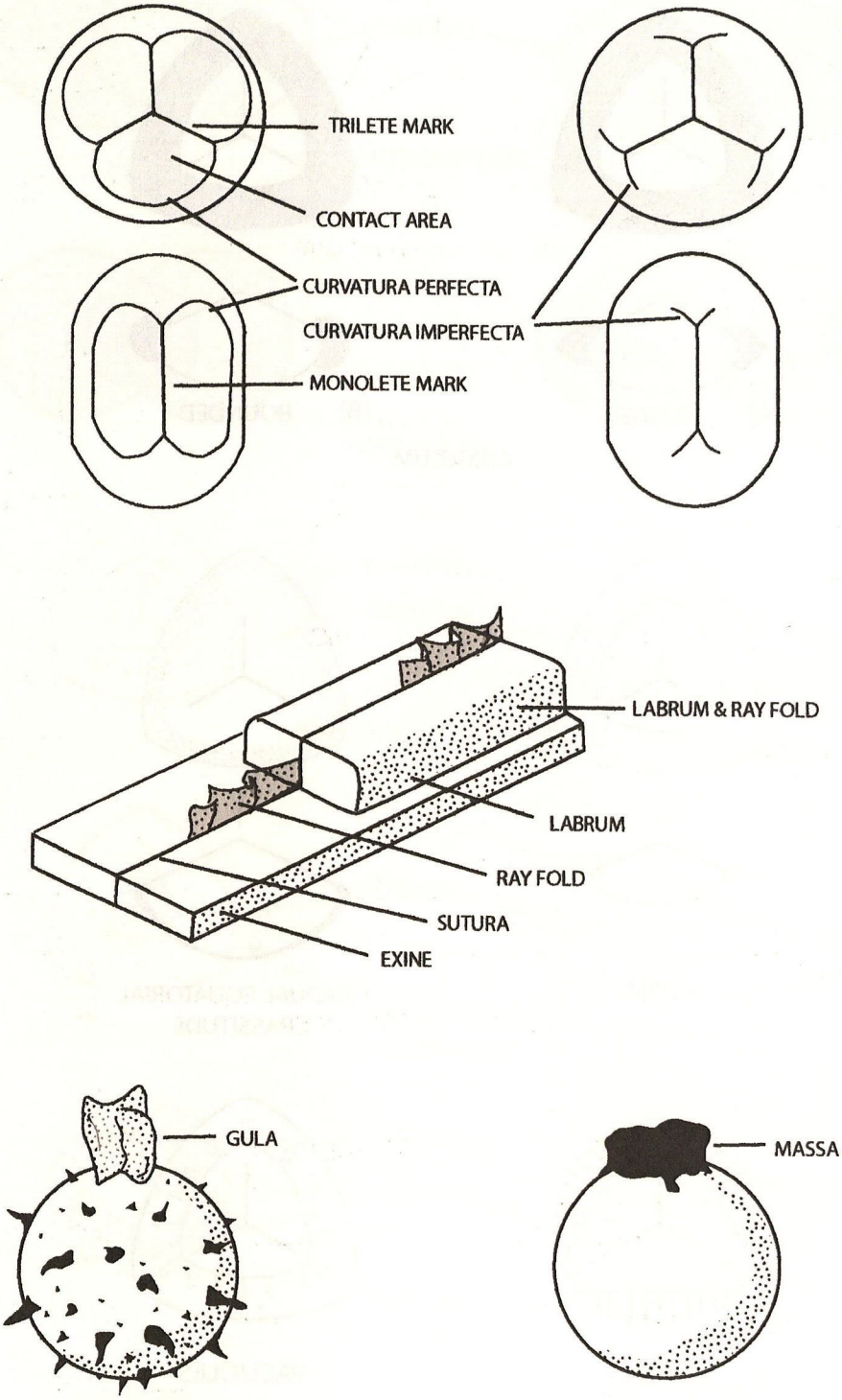


Figure 5.3 after Clayton (1972)

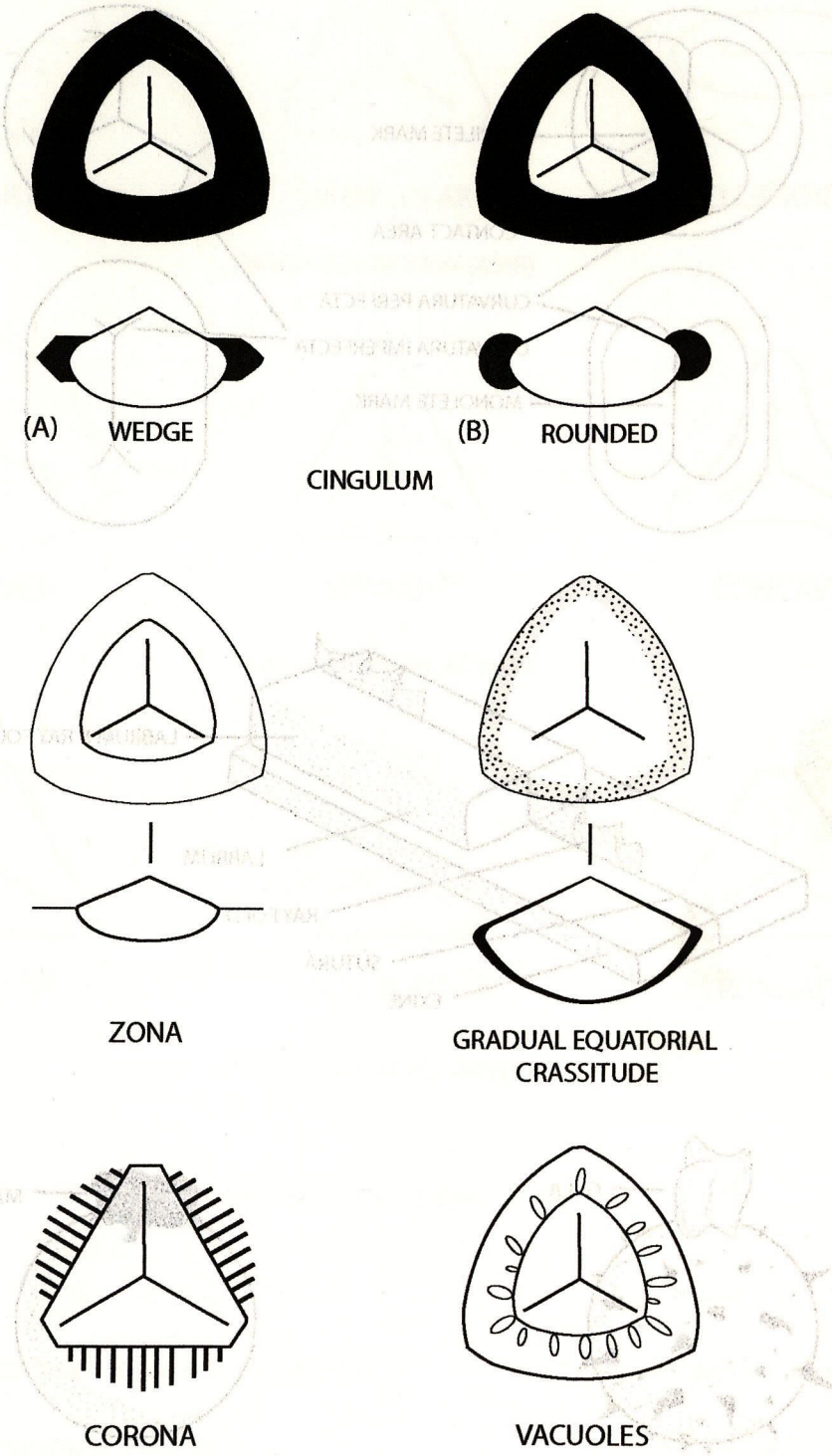


Figure 5.4 after Clayton (1972)

STRUCTUAL FEATURES II

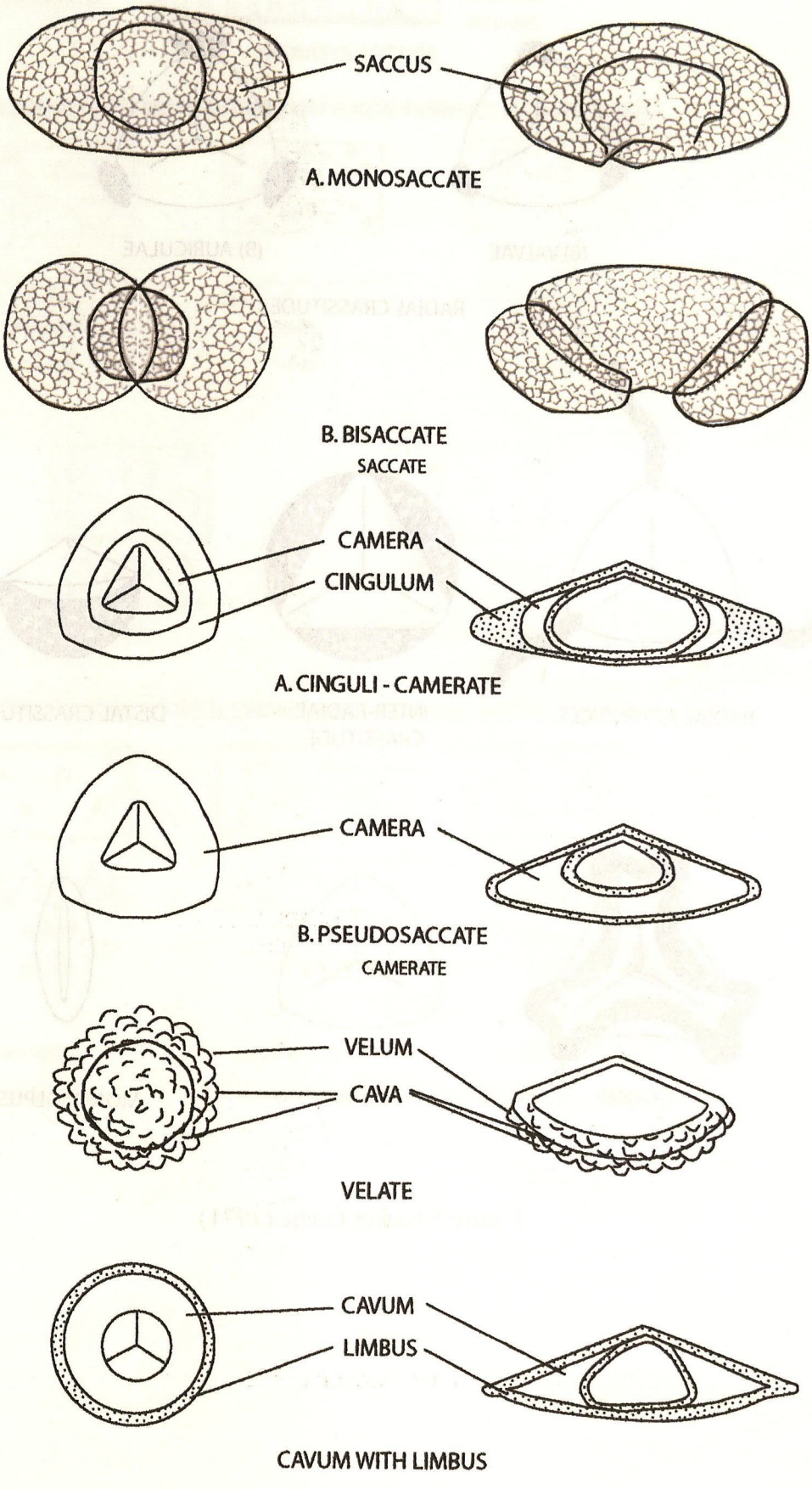


Figure 5.5 after Grebe (1971)

STRUCTURAL FEATURES III

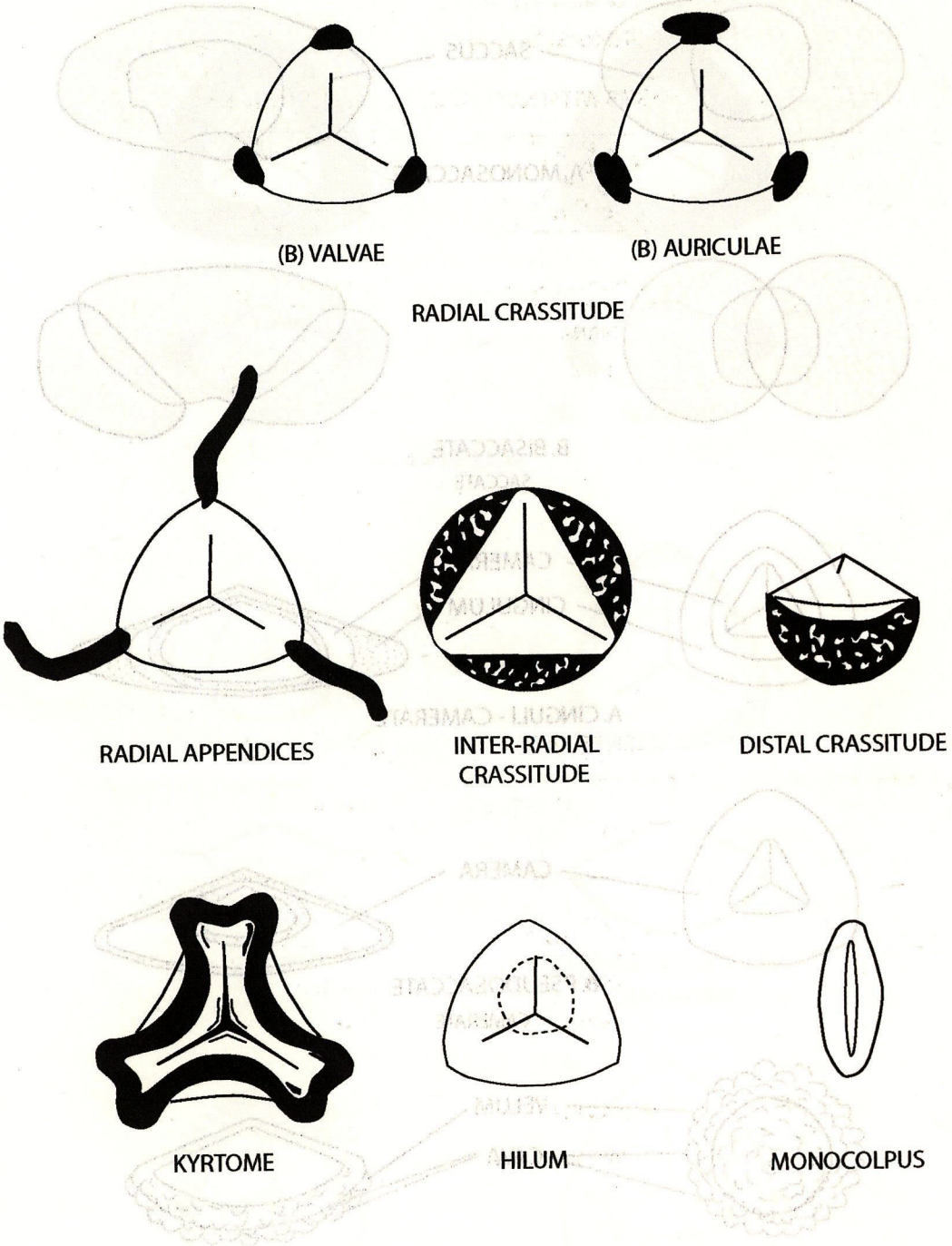
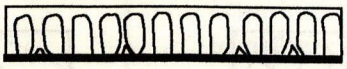


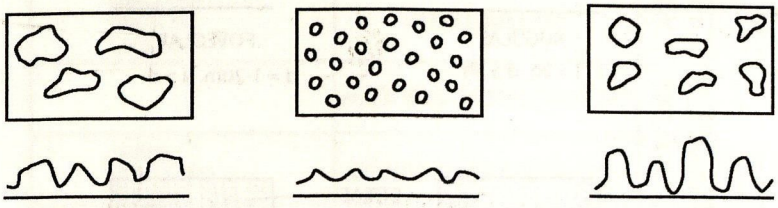
Figure 5.6 after Grebe (1971)

SCULPTURE ELEMENTS AND PATTERNS



INFRASCULPTURE

APICULATE SCULPTURE ELEMENTS WITH NON-POINTED TERMINATIONS



VERRUCAE
$h \leqslant d$

GRANA
$h \leqslant d$

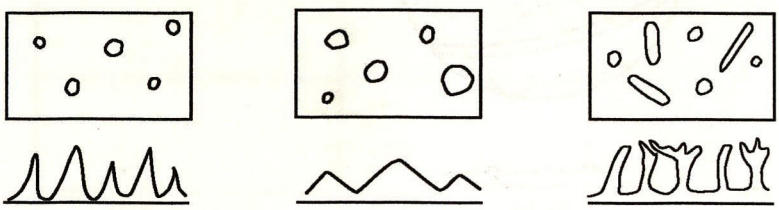
TUBERCULA
$h > d$



PILA

BACULA $h > d$

APICULATE SCULPTURE ELEMENTS WITH POINTED TERMINATIONS



SPINAE
$h \geqslant 2d$

CONI
$h < 2d$

CAPILLI
$h > 2d$

h = HEIGHT
d = DIAMETER
l = LENGTH
b = WIDTH
a = DISTANCE BETWEEN THE ELEMENTS

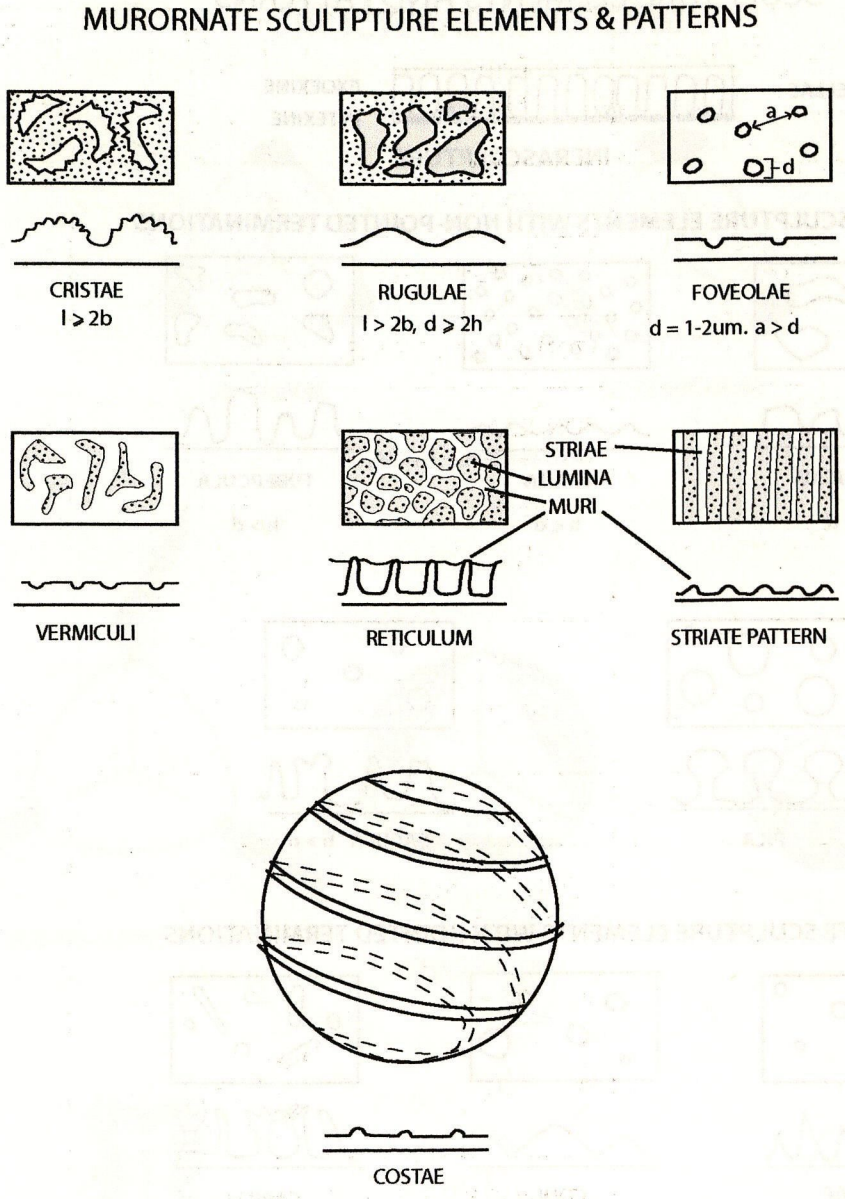


Figure 5.8 after Grebe (1971)

Sculpture / Equatorial thickening and/or extension	Equatorial features	Stratification	Aperture		Diagnositc feature
LAEVIGATI APICULATI MURORNATI GULATI RETUSOTRILETI	AZONOTRILETES	ACAVATI-TRILETES	TRILETES	SPORITES	CATEGORY
AURICULATI CINGULATI TRICRASSATI	ZONOTRILETES				
	AZONOLAMINATITRILETES	LAMINATI-TRILETES			
CRASSITI CINGULICAVATI PATINATI	ZONOLAMINATITRILETES				
POLYPSEUDOSACCITI	PSEUDOSACCI TRILETES	PSEUDOSACCI-TRILETES			
	ACAVATO-MONOLETES	PERINO-TRILETES			
LAEVIGATIMONOLETI	AZONOMONOLETES	ACAVATO-MONOLETES	MONOLETES		
	ZONOMONOLETES				
		CAVATO-MONOLETES			
		ACAVATI-HILATES	HILATES		
EPITYGMATI OPERCULATI	AZONOCAVATIHILATES	CAVATI-HILETES			
	ZONOCAVATIHILATES				
			ALETES		
Infraturma	Subturma	Supra-subturma	Turma	Anteturma	Rank

Figure 5.9. The morphological classification scheme for Carboniferous miospores used in the present study. Adapted from Smith & Butterworth (1967) after Dettman (1963).

CHAPTER 6

SYSTEMATIC PALYNOLOGY

Anteturma PROXIMOGERMINATES R. Potonié, 1970

Turma TRILETES (Reinsch) Dettman 1963

Suprasubturma ACAVTITRILETES Dettman 1963

Subturma AZONOTRILETES (Luber) Dettman 1963

Infraturma LAEVIGATI (Bennie & Kidston) R. Potonié 1956

Genus CALAMOSPORA Schopf, Wilson & Bentall 1944

Type species *Calamospora hartungiana* Schopf
in Schopf, Wilson & Bentall 1944

Calamospora liquida Kosanke 1950
Plate 1, fig 7

1938 Spore type B3 Knox; p.458.
1950 *Calamospora liquida* Kosanke pp.41-42, pl.9, fig.1.

Holotype: Kosanke 1950, pl. 9, fig. 1 (81.6 x 84μm).
Type locality: Scoal Creek Coal, Bond County, Illinois, U.S.A.; Pennsylvania.
Diagnosis: As description in Kosanke 1950, pp. 41-42: "Spores are radial, trilete, spherical, or have numerous placations of the spore coat. The Holotype measures 81.6 x 84μm and the known size range is 76 to 94μm. The plications are numerous and somewhat parallel to the outline of the spore. The trilete rays of the Holotype are distinct and vary in length from 26.2 to 31.5μm. The lips are moderately developed and definitely elevated. The commisure is usually thin but distinct. The area contagion is not present. The spore coat is laevigate and translucent. It is less than 2μm in thickness which probably accounts for the numerous plications".
Size range: 76 to 94μm; Kosanke 1950.
56 - 106μm (based on 39 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.
Present Study: 63 – 99μm (3 specimens)

Range: (i) Top Viséan, Southeast Scotland; Clayton 1972 (unpublished PhD thesis) (ii) LL – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: (i) Bedford Shale Formation, Three Locks, Ohio; (ii) Price Formation, Caldwell roadcut & Mylan Park, West Virginia.

Remarks: This species is distinguished from other Calamospores by its long suturae (greater than half the spore radius) and the presence of narrow labra.

Calamospora microrugosa (Ibrahim)
Schopf, Wilson & Bentall 1944
Plate 1, fig. 3

1932 *Sporonites microrugosus* Ibrahim in Potonié, Ibrahim & Loose p. 447, pl 14, fig 9.

1933 *Laevigato – sporites microrugosus* (Ibrahim) Ibrahim, p. 18, pl 1, fig 9.

1938 *Azonotriletes microrugosus* (Ibrahim) Waltz in Luber and Waltz, p. 10, pl. 12, fig. 9.

1944 *Calamospora microrugosus* (Ibrahim) Schopf, Wilson & Bentall, p. 52.

1952 *Leiotriletes microrugosus* (Ibrahim) Ishchenko, p. 15, pl. 12, fig. 9;

1955 *Calamospora microrugosus* (Ibrahim) Luber, p.36, pl.1, figs.1-3.

1967 *Calamospora microrugosa* (Ibrahim) Schopf, Wilson & Bentall 1944 in Smith & Butterworth, p.133, pl.3, figs. 1-2.

Holotype: Ibrahim 1932, pl. 14, fig. 9, Prep. A42, O6 (1).

Type locality: Ägir Seam, Ruhr Coalfield, Germany. Top Westphalian B.

Diagnosis: As description and diagnosis in Potonié & Kremp, 1955, p.49: "Spores spherical, compressed to polygonal or acutely lenticular outline, generally with several more or less lunate lenticular folds. Trilete rays about one-fourth of spore diameter, sutures distinct and slightly undulating, lips low but definite of from less than one to two microns width on either side of the suture. Arcuate ridges may be regarded as lacking but the pyramic areas are slightly thicker and darker by transmitted light than the rest of the spore coat and slightly coarser surface texture (konstankthof). Spore coat thin, one micron or less, generally yellowish translucent or somewhat red when light is transmitted through numerous thicknesses due to folds or the overlapping of several spores. Spore coat minutely rugose to granular; at low magnification the surface appears quite smooth".

Size range: 72-100μm (based on 35 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: 75 - 81μm (based on 10 specimens).

Range: LL – CM biozones; Higgs *et al.* 1988.

Present study: Price Formation, Mylan Park, West Virginia.

Remarks: Following Smith & Butterworth (1967, p.133), Calamospores of between 70 and 100μm in diameter were assigned to this species.

Calamospora nigrata (Naumova) Allen 1965.

Plate 1, fig. 4

1953 *Leiotriletes nigratus* Naumova pl. 1, fig. 9.

1958 *Leiotriletes nigratus* Ishchenko pl. 1, fig. 5.

1965 *Calamospora nigrata* (Naumova) Allen p. 693.

Holotype: Naumova, pl. 1, fig. 9.

Type locality: Russian Platform; Upper Devonian.

Diagnosis: See Naumova 1953, p. 23.

Size range: (i) 60 – (76) – 80 (based on 26 specimens): Allen 1965.

(ii) 54 - 91μm (based on 6 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 63-(79)-90μm (based on 4 specimens).

Range: LL – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation, Mylan Park, West Virginia.

Remarks: This species is distinguished from others of its genus by its darkened zones around the trilete mark.

Calamospora pallida (Loose) Schopf, Wilson & Bentall 1944

Plate 1, fig. 2

1932 *Sporonites pallidus* Loose *in* Potonié, Ibrahim & Loose p. 449, pl. 18, fig. 31.

1934 *Punctatisporites pallidus* (Loose) p. 146

1944 *Calamospora pallidus* (Loose) Schopf, Wilson & Bentall, p. 52.

1967 *Calamospora pallida* (Loose) Schopf, Wilson & Bentall 1944 in Smith & Butterworth, p.135, pl.3, figs. 5 & 6.

Holotype: Loose 1932, pl. 18, fig. 31. Preparation IV26, d4 (ul).

Type locality: Bismarck Seam, Ruhr Coalfield, Germany, Upper Westphalian B.

Diagnosis: From description and diagnosis in Smith & Butterworth, 1967: Amb circular to oval. Laesurae weakly ridged, straight, up to one-third of radius. Exine about 1µm thick.

Size range: (i) Holotype 58.5µm, Schulze. (ii) 55-70, Schulze (Potonié & Kremp, 1955). (iii) 55 - 68µm (35 specimens); Higgs *et al.* 1988.

Present Study: 56 – (69) – 74µm (based on 13 specimens).

Range: (i) Viséan to Westphalian D, Smith & Butterworth 1967.

(ii) LL – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: (i) Bedford Shale Formation – Williams County core & Three Locks Quarry, Ohio; (ii) Chattanooga Shale Fm (Three Lick Bed) – Clay City Quarry, Kentucky; Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: Following Smith & Butterworth, this species accommodates taxa assigned to *Calamospora* species with a diameter 55 - 75µm.

Calamospora parva Guennel 1958

Plate 1, fig 1

Holotype: Guennel 1958, fig. 16, p.71. Sample 66 sl. 4104.

Type locality: Outcrop Coal, Upper Block b zone, Pottsville Series, Davies County, Indiana, U.S.A.; Lower Pennsylvanian.

Diagnosis: Guennel 1958, p. 70: "Amb circular to elliptical. Laesurae 1/3 of the radius. Exine thicker and darker in contact areas. Folding common".

Size range: 31 – 48µm (based on 9 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 36-(42)-50µm (based on 6 specimens).

Range: LN – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: (i) Bedford Shale/ Berea Sandstone formations, Three Locks Quarry, Ohio. (ii) Three Licks Bed, Clay City Quarry, Kentucky. (iii) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: In the present study *C. parva* is used in the sense of Smith & Butterworth (1967, p.135) and accommodates the smallest taxon assigned to *Calamospora*. *C. parva* has an arbitrary size of less than 55µm.

Calamospora perrugosa (Loose) Schopf,
Wilson & Bentall 1944.
Plate 1, fig. 8

1934 *Laevigati-sporites perrugosus* Loose p. 145, pl. 7, fig. 13.
1944 *Calamospora perrugosus* (Loose) Schopf, Wilson & Bentall, p. 52.
1967 *Calamospora perrugosa* (Loose) Schopf, Wilson & Bentall 1944 in Smith & Butterworth, p.137, pl.3, fig.9.

Holotype: Loose 1934, pl.7, fig.13. Preparation IV9, e4 (1/o1).
Type locality: Bismarck Seam, Ruhr Coalfield, Germany; Upper Westphalian B.
Diagnosis: Expanded diagnosis from Potonié & Kremp 1955, p.51: "Amb oval to round. Laesurae simple, straight, 1/3 of radius or more. Exine relatively thin, markedly folded".
Size range: 110 - 170µm (based on 30 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.
Present Study: 103 – (126) – 155µm (based on5 specimens).
Range: Namurian to Westphalian A; Smith & Butterworth 1967
LL – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.
Present Study: (i) Bedford Shale Formation, Williams County & Three Locks Quarry, Ohio; (ii) Three Licks Bed, Clay City Quarry, Kentucky; (iii) Price Formation, Caldwell & Mylan Park, West Virginia.
Remarks: The arbitrary size range for *C. perrugosa* is 100 - 170µm (Smith & Butterworth 1967, p. 137).

Genus PUNCTATISPORITES Ibrahim emend
Potonié & Kremp 1954

Type species *Punctatisporites punctatus* (Ibrahim)
Ibrahim 1933

Punctatisporites irrasus Hacquebard 1957
Plate 1, fig. 11

1925 Type D Lang, pl.1.
1957 *Punctatisporites irrasus* Hacquebard, p.308, pl.1, figs. 7 & 8.

1970 *Punctatisporites* cf. *irrasus* Dolby & Neves p. 635, pl. 1, fig. 1.

Holotype: Hacquebard 1957, pl.1, fig. 7. M 101, slide 4, (68 x 74 μm)

Type locality: Horton Group, Nova Scotia, West Gore and Blue Beach samples.

Description: Hacquebard, 1957, p. 308: "Spores radial, trilete; form originally spherical; trilete sutures usually narrow but occasionally broad, lips raised, rays not always straight, one-half to two thirds spore radius; surface finely infragranulose (peppery); spore coat 1.5-2 microns thick; arcuate compression folds present and of major proportions; diameter 67-83μm".

Size range: (i) 67-83μm (20 specimens); Hacquebard 1957.

(ii) 50-92μm (60 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 52 – (68) - 80μm (based on 12 specimens).

Range: LL – CM Biozones, Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: (i) Chattanooga Shale Formation/ Three Licks Bed, Clay City Quarry, Kentucky; (ii) Price Formation, Caldwell & Mylan Park, WV.

Remarks: This species is distinguished from others of the genus by gaping labra which are often darkened along the margins.

Punctatisporites minutus Kosanke 1950

Plate 1, figs. 5-6

Holotype: Kosanke 1950, pl. 16, fig. 3 Maceration 584, slide 7.

Type locality: ?Woodbury Coal, Jasper Co., Illinois; USA. McLeansboro Group.

Diagnosis: As Description in Kosanke 1950, p. 15: "Originally spherical in shape with the spore coat variously folded. Laesurae distinct, 2/3 of radius, lips slightly developed. Exine 1 -1.5μm thick and minutely punctuate".

Size range: (i) 22 – (27) - 33μm (18 specimens); UK Coalfields; Smith & Butterworth 1967, p. 126.

(ii) 24 - 36μm (based on 14 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 35 – 36 μm (10 specimens).

Range: (i) Namurian, Smith & Butterworth 1967.

(ii) LL – PC Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation - Mylan Park, West Virginia.

Remarks: *P. minutus* differs from *P. nitidus* Hoffmeister, Staplin & Malloy only on its smaller size.

Punctatisporites planus Hacquebard 1957

Plate 1, figs 9-10.

Holotype: Hacquebard 1957, pl. 1, fig. 12. M 101, Slide 4.

Type locality: Horton Group, Nova Scotia, West Gore and Blue Beach samples.

Description: Hacquebard, 1957, p. 308: "Spores radial, trilete; circular to subcircular in proximal view; trilete simple; two thirds to three fourths spore radius; surface smooth to very slightly infragranulose; spore coat 2µm thick; occasionally one major compression fold".

Size range: (i) 50 – 64µm (12 specimens); Hacquebard 1957.

(ii) 40 – (54) - 68 µm (55 specimens); Higgs *et al.* 1988

Present Study: 38 – (43) - 67 (based on 16 specimens).

Range: LN – CM Biozones, Tournaisian of Ireland, Higgs *et al.* 1988

Present Study: (i) Bedford Shale & Coldwater Shale formations, Williams County, Ohio; (ii) Bedford Shale – Berea Sandstone, Three Locks Quarry, Ohio; (iii) Chattanooga Shale/ Three Lick Bed, Clay City Quarry, Kentucky; (iv) Price Formation, Caldwell & Mylan Park, West Virginia.

Infraturma RETUSOTRILETI Streel 1974

Genus RETUSOTRILETES Naumova emend Streel 1964

Type species *Retusotriletes simplex* Naumova 1953

Retusotriletes crassus Clayton, Johnston,
Sevastopulo & Smith 1980
Plate 1, figs. 12 & 13

1969 *Phyllothecotriletes* sp. No 840 Lanzoni & Magloire, pl. 1, figs. 3, 4.

1975 *Retusotriletes* sp. A. Higgs, p. 395, pl. 1, figs 9, 13.

1980 *Retusotriletes crassus* Clayton, Johnston, Sevastopulo & Smith, p. 97, pl. 3, figs D, G, H.

Holotype: Clayton *et al.* 1980b, p.97, fig.3 D,G & H.

Type locality: Channel sample from depth 200-205', Ballyvergin Shale, Ballyvergin Borehole, County Clare, Ireland; Tournaisian.

Diagnosis: Clayton *et al.* 1980: "Spores radial, trilete, acamerate. Amb circular to oval, or rarely roundly triangular. Suturae rarely seen; straight, simple and approximately ¾ of the spore radius in length. The suturae terminate in curvaturae perfectae which delimit the contact areas. Large thickened sectors are present in the contact areas, separated from each other by radial zones of thin, granulose exine 2 - 8µm wide along the suturae and separated from the curvaturae by a concentric zone of similar width and nature. The equatorial and distal exine is relatively thick and more or less laevigate".

Size range: 43 – (56) - 73µm (25 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 45 – (60) - 85µm (16 specimens).

Range: LN (upper) – CM Biozones; Tournaisian of Ireland, Clayton *et al.* 1980.

Occurrence in E. USA: Sunbury Shale Formation – Borden Formation (Henley and Nancy members); Kentucky, USA, Coleman & Clayton, 1987.

Present Study: (i) Coldwater Shale Formation, Williams County, Ohio; (ii) Three Licks Bed, Clay City Quarry, Kentucky; (iii) Price Formation, Caldwell & Mylan Park, West Virginia; (iv) Burgoon Sandstone Formation, Warrior's Path, Pennsylvania.

Remarks: This species is distinguished from others of the genus by its characteristic dark contact areas.

Retusotriletes famenensis Naumova 1953

Plate 1, figs. 16

Holotype: Naumova 1953, pl. 15, fig. 18.

Type locality: Zadonsk Beds, Russkiy Brod, Orel Province, former USSR.

Diagnosis: See Naumova 1953.

Description: From Higgs *et al.* 1988, p.52: "Trilete acamerate miospores; amb subcircular to convexly triangular. Suturae distinct, straight to slightly sinuous and bordered by prominent labra 4-6µm in overall width. Suturae extend ¾ or more of the spore radius and terminate in curvaturae perfectae. Contact areas normally well defined. Exine laevigate, scabrate or infragranulate and 1.5-3µm in thickness".

Size range: 42 – (49) - 57µm (based on 22 specimens); Higgs *et al.* 1988.

Present Study: 45 – (53) - 60µm (based on 10 specimens).

Range: LL-PC Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: (i) Bedford Shale – Berea Sandstone, Big Walnut Creek, Ohio; (ii) Three Lick Bed, Morehead (Three Lick type section) & Clay City Quarry, Kentucky; (iii) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: *R. famenensis* is distinguished from other representatives of the genus by its prominent labra.

Retusotriletes incohatus Sullivan 1964

Plate 1, figs 14 & 15

1974 *Aneurospora incohata* (Sullivan) Streel *in* Becker *et al.* p.24.

Holotype: Sullivan 1964a, pl. 1, fig. 7.

Type locality: Lower Limestone Series, Forest of Dean, Gloucestershire, S.W. England; Tournaisian.

Diagnosis: Sullivan 1964, pp.1251 & 1252: "Size (100 measured specimens) 35 - 70µm, mean 55µm; amb circular to oval or rounded triangular; exine laevigate to infragranular; contact areas poorly or clearly defined".

Description: Sullivan 1964, pp.1251 & 1252: "Amb circular to oval, occasionally rounded triangular. Exine reddish brown to yellow in colour, wall thickness difficult to determine accurately, but about 2µm. Trilete rays visible to indistinct, usually extend for three

quarters radius of the spore. Tecta straight or sinuous may be bounded by narrow lips with thin membranous folds up to 2μm high. Contact areas shallowly depressed, defined by low complete curvaturae or curvaturae imperfectae. The structure of the exoexine is often more clearly discernible in the contact areas. The exine outside of the contact areas is darker in colour and is characteristically laevigate. Secondary folds rare; sometimes parallel sided folds surround part of the equator".

Size range: 35 – (55) - 70μm (100 specimens)

Present Study: 45 – (55) - 79μm (based on 13 specimens).

Occurrence in E. USA: (i) Samples 10 & 11, Henley Bed, Kentucky (PC Biozone); Coleman & Clayton, 1987.

(ii) Uppermost Cuyahoga and lower Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Bedford Shale & Coldwater Shale formations, Williams County, Ohio; (ii) Bedford Shale – Berea Sandstone, Big Walnut Creek & Three Lock section, Ohio; (iii) Chattanooga Shale/ Three Lick Bed, Morehead (Three Lick type section) & Clay City Quarry, Kentucky; (iv) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: This species is extremely commonly in the present study and is recorded in almost all productive samples. This taxon is distinguished by its thin, simple laesurae which commonly terminate in curvaturae or curvaturae perfectae.

Retusotriletes leptocentrum (Higgs) Higgs, Clayton & Keegan 1988

Plate 1, figs 17 - 19

1970 *Retusotriletes* sp. A. Dolby & Neves p. 636, pl. 1, fig. 4.

1975a *Retusotriletes leptocentrus* Higgs p. 43, pl. 1. fig. 24 – 26.

1988 *Retusotriletes leptocentrum* Higgs, Clayton & Keegan p. 52, pl. 2, figs. 5 -7.

Holotype: Higgs 1975a, pl. 1, fig. 24.

Type locality: Sample H2, Old Red Sandstone, Hook Head, County Wexford, Ireland.

Diagnosis: From Higgs 1975a, p.43: "Trilete acamerate miospores; amb circular to rounded triangular. Suturae distinct, straight to sinuous, often slightly gaping. Length of suturae three-quarters or more of the spore radius, terminating in curvaturae perfectae which are coincident with the equator for half their length. Exine laevigate and 1 -2.5μm in thickness. At the apex of the contact areas, there is a uniformly light coloured area of

thinner exine, which is concavely triangular in shape with its apices along the suturae and extending half to two-thirds the spore radius".

Size range: 45 – (59) - 74μm (based on 41 specimens).

Present Study: 50 - 55 μm (based on 9 specimens).

Range: LN – PC biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation, Mylan Park, West Virginia.

Remarks: This species is distinguished from other taxa by its uniformly thin apical zone. *Retusotriletes phillipsii* Clendening, Eames & Woods 1980 also possesses a thin apical region, however, is distinguished by fine ribs and/ or striae which radiate out from the apex.

Retusotriletes phillipsii Clendening,
Eames & Wood 1980
Plate 1, figs. 22-23

1974 *Retusotriletes* sp. A. Streel *in* Becker *et al.*, p.24; pl. 15, figs 11, 12.

1980 *Retusotriletes phillipsii* Clendening, Eames & Wood p.15 – 20, figs. 1 -9.

Holotype: Clendening *et al.* 1980, pl. 1, fig. 1 (slide 3800 -4, Coordinates 39.4 x 110.9).

Type locality: Road cut on north side of West Virginia State Route 15, 3.2km west of the village of Valley Head, Randolph County, West Virginia, USA.

Diagnosis: Clendening *et al.* 1980, p.17: "Spores radial, trilete, Laesurae straight, distinct, extending 3/5 to ¾ of spore radius; spore outline circular to broadly rounded triangular, 46 - 69μm in diameter (85 specimens measured), 57μm average; exine 1 -3μm thick; proximal surface laevigate to slightly rugulate, with contact area displaying prominent curvaturae perfectae (in the shape of a trifoil); curvaturae arched, concave to the proximal l pole, with the arches often extending completely to the equatorial margin; apical area triangular, ornamented with minute grana, usually lighter in colour due to the thinning of the interradial exine (to ca. 1μm) in this region; within the boundary of the curvaturae perfectae are ribs or striae which radiate outward from the apex; remaining distal surface laevigate; folding of the exine is rare".

Occurrence: 46 – (57) - 69μm in diameter (85 specimens measured); Upper Devonian, West Virginia, Kentucky, Ohio, Michigan, and New York, USA, Clendening *et al.* 1980.

Present Study: 43 – (53) - 67.6μm (based on 4 specimens).

Occurrence: Clendening *et al.* 1980 reported *R. phillipsii* from Upper Devonian (presumably Famennian) strata in the following states in Eastern USA: Hampshire Formation, West Virginia (type locality); upper Canadaway Formation – Chadak Formation, New York State; Three Lick bed (Ohio Shale Formation) Kentucky and Ohio; Ellsworth Shale, Michigan.

Present Study: (i) Bedford Shale Formation, Williams County, Ohio; (ii) Bedford Shale – Berea Sandstone, Three Locks Quarry, Ohio; (iii) Price Formation, Mylan Park, West Virginia.

Remarks: Clendening *et al.* (1980) suggested that this taxon may prove to be a useful marker taxon for the Fa2c interval. However, it would appear that the range of this species is considerably longer than originally thought, being recorded in moderate abundance in Strunian and Mississippian age strata. It is thus likely to be of little biostratigraphic importance in the Eastern USA.

Retusotriletes triangulatus (Streel) Streel 1967

Plate 1, figs. 20-21

1964 *Phyllothecocotriletes triangulatus* Streel, p. 237, pl. 1, figs. 3- 5.

1967 *Retusotriletes triangulatus* (Streel) Streel, pp. 24 – 25.

1976 *Retusotriletes piperatus* Playford, pp. 10 -11, pl. 1, 14 – 17.

Holotype: Streel 1964, pl. 1, fig. 4.

Type locality: Upper Devonian of Belgium.

Diagnosis: See Streel 1964.

Description: From Higgs *et al.* 1988: "Trilete acamerate miospores. Amb subcircular occasionally rounded triangular. Suturae simple, distinct in the apical area, but faintly defined towards the equator. Suturae extend approximately 4/5 of the spore radius and terminate in curvaturae perfectae, which are distinct or more often barely perceptible. Exine thin and laevigate, with darkened zone conformable with amb, with apices coincident with suturae and extending up to ½ the spore radius. Darkened zone uniform or slightly thinner towards the pole. Large compression folds common".

Size range: 36 – (54) - 74μm (40 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 63- (68) - 75μm (10 measured specimens).

Range: LL – PC Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Lower Logan Formation, Wayne County, Ohio (PC Biozone); Clayton et al. 1998.

Present Study: (i) Bedford Shale Formation, Three Locks Quarry, Ohio; (ii) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: This species is very similar in appearance to *Calamospora nigrata* (Naumova) Allen 1965. *R. triangulatus* may be distinguished based on its curvaturae which are absent in *C. nigrata*. Specimens of *R. rotundus* (Streel) emend Lele & Streel 1969 are very similar to *R. triangulatus* but differ due to the presence of an inner light zone within the apical area. Higgs *et al.* (1988) note that the gradual proximal poleward thinning observed in some specimens would indicate a probable morphographic graduation between the two species.

Infraturma APICULATI (Bennie & Kidston) R. Potonié 1954

Subinfraturma BACULATI

Genus NEORAISTRICKIA Potonié 1956

Type species *Neoraistrickia truncatus*

(Cookson) Potonié 1956

Neoraistrickia loganensis (Winslow) Playford & Melo

Plate 2, figs 1-3.

1962 *Granulatisporites logani* Winslow pp. 62 – 63, pl. 22, figs. 10 -11.

1973 Spore 1. Warg & Traverse, p. 40, pl. 1, fig. 9.

1986 *Umbonatisporites baculatus* Coquel & Moreau-Benoit, p. 34, pl 3, figs. 5, 14, 20.

1987 *Neoraistrickia loganii* (Winslow) Coleman & Clayton, pl. 2, fig. 5 -9.

Neoraistrickia loganensis (Winslow) Playford & Melo (*in press*), pl. 1, figs. 1 -12 & pl. 2, figs. 1 – 10.

Holotype: Winslow 1962, pl. 22, fig. 11; upper Cuyahoga and Black Hand formations (undifferentiated), locality 7, maceration 363a, slide 4.

Type locality: Locality 7, Ohio, undifferentiated Cuyahoga/ Black Hand Formation.

Diagnosis: Winslow 1962, p.62: "Spores trilete, subtriangular in outline, generally proximodistally compressed; ranging from 49 to 76μm in diameter, commonly over 60μmm. Inter-radial margins slightly concave to slightly convex; margins at radial extremities broadly rounded.

Trilete suture distinct at apical pole, poorly defined towards spore margin in proximodistal compression; suture margins simple. Proximal pole enclosed by a small, circular, and vaguely defined contact zone with a more granulose surface, darker, but not thicker than remainder of spore coat.

Proximal surface smooth; distal surface sparsely ornamented with blunt to pointed tubercular processes, 1.2 -5μm in diameter and 1.5 - 8μm in length. Tubercles smaller and some more closely set, adjacent to radial extremities. Spore coat ranging in thickness on different specimens from 1-3μm, thickest distally; deep yellow in transmitted light.

Emended diagnosis: Coleman & Clayton 1987, p. 83-84: "Trilete, acamerate miospores. Amb triangular with rounded apices and more or less straight sides. Trilete mark simple; suturae straight, extend almost to the equator. Proximal surface relatively flat; distal surface inflated. Equator, distal surface and proximal surface of apices sparsely ornamented by rounded coni and bacula which are often surmounted by single, small coni or spinae forming biform elements".

Description: Coleman & Clayton 1987, p. 84; "Specimens exhibit considerable variation in ornament. Some specimens are ornamented by simple, blunt bacula; others bear biform elements consisting of bacula 1.5 - 6μm high and 2.5 - 4μm wide surmounted by single coni or spinae 0.5 - 1μm wide. Exine otherwise laevigate, 1 -2μm thick. Lateral and oblique compressions common".

Size range: 49 to 76μm, commonly over 60μm; Winslow 1962.

50 – (75) - 95μm (based on 20 specimens); Coleman & Clayton 1987.

Present Study: 48 – (66) - 84μm (based on 6 specimens).

Range: PC Biozone (rare); Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: (i) Upper Cuyahoga Formation, Black Hand Sandstone and Logan Formation (recorded as *Granulatisporites logani*); Lower Mississippian of Ohio, Winslow 1962.

(ii) Pocono Formation (recorded as spore -1); Lower Mississippian of Pennsylvania.

(iii) Samples 10 -18, Borden Formation (Henley Bed to Cowbell Member) (PC Biozone); Kentucky; Coleman & Clayton 1987.

(iv) Cuyahoga & Logan Formations (PC Biozone), Wayne County, Ohio; Clayton *et al.* 1998.

Present Study: (i) Coldwater Shale Formation, Williams County, Ohio; (ii) Price Formation, Caldwell, West Virginia; (iii) Burgoon Sandstone Formation, Warrior's Path, Pennsylvania.

Remarks: Coleman & Clayton (1987) considered Winslow's assignment of this taxon to the genus *Granulatisporites* inappropriate and transferred it to the genus *Neoraistrickia* based on its triangular shape and baculate ornament. Playford & Melo (in press) noted that Winslow's (1962) naming of this species was non-patronymic, being derived from one its hosting lithostratigraphic units (i.e. The Logan Formation of Ohio, USA). Thus in compliance with Article 60 of the International Code of Botanical Nomenclature, these authors emended the epithet *loganii* to *loganensis*.

Genus PUSTULATISPORITES Potonié & Kremp 1954

Type species *Pustulatisporites pustulatus* Potonié & Kremp 1954

Pustulatisporites dolbii Higgs, Clayton & Keegan 1988

Plate 2, figs. 5-7

1970 *Pustulatisporites* cf. *gibberosus* (Hacquebard) Playford; Combaz & Streel, pl. 3, fig. 2.

1975a Pustulatisporites sp, A, Higgs, pl. 2, fig. 4.

1988 *Pustulatisporites dolbii* Higgs, Clayton & Keegan p.56, pl.4, figs. 6,9 & 10, text fig. 28a.

Holotype: Higgs *et al.* 1988, plate 4, fig. 9.

Type locality: Sample H8, Houseland Sandstone Formation, Hook Head, Co. Wexford.

Diagnosis: Higgs *et al.* 1988, p.56: "Trilete acamerate miospores. Amb subcircular to rounded triangular. Suturae distinct but often gaping, simple or rounded triangular. Suturae distinct but often gaping, simple or occasionally bordered by narrow labra, straight, and extending ¾ or more of spore radius. Exine 1 – 2.5µm in thickness. Distal surface and equatorial region ornamented with verrucae and spinae. Verrucae low with irregular sides and round, flat or irregular tops, 1 -3µm in height, 2 -8µm in basal diameter. Spinae simple, often broken and wide based, up to 4µm in height. Ornament discrete or rarely coalescent, evenly distributed but never crowded and reduced or absent on the proximal surface".

Size range: 45 – (53) - 65µm (based on 53 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 48 – (58) - 63µm (based on 10 specimens).

Range: LL –PC biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Upper Cuyahoga and lower Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: Price Formation, Mylan Park, West Virginia

Remarks: *P. dolbii* compares closely to *Verrucosisporites gibberosus* (Hacquebard) Higgs, Clayton & Keegan 1988; the later differs in possessing a non-apiculate ornament which is typically restricted to the distal surface and equatorial margin. *Dibolisporties uncatus*

(Naumova) McGregor & Camfield 1982 is very similar but possess slightly longer sculptural elements which are essentially biform in character.

Genus RAISTRICKIA Schopf, Wilson & Bentall emend.
R. Potonié & Kremp 1954

Type species *Raistrickia grovensis*
Schopf in Schopf, Wilson & Bentall 1944

Raistrickia clavata Hacquebard emend. Playford 1964
Plate 2, figs. 20-22

1957 *Raistrickia clavata* Hacquebard, p. 310, pl.1, fig. 25.
1957 *Raistrickia pistillata* Hacquebard, pp. 310 – 311, p. 2, fig. 2.
1964 *Raistrickia clavata* Hacquebard; emend Playford, pp. 24-25, pl. 6, figs. 5 - 10

Holotype: Hacquebard 1957, pl. 1, fig. 25 (58 - 62µm).
Type locality: Horton Group, West Gore sample, Windsor, Nova Scotia, Canada; Mississippian.
Diagnosis: As *Description* in Hacquebard 1957: "Spore radial, trilete; subtriangular with convex sides and rounded corners in proximal view; trilete distinct, 2/3 spore radius; ornamentation large club-shaped projections, relatively closely set; projections 7 – 8.8µm long, 3 - 4µm wide at base, 6 -7µm wide at top, where they are thickened; nine projections occur at the equator, spore coat 2µm thick; diameter 58 - 62µm (based on 1 specimen only)".
Emended Diagnosis: Playford 1964, p. 25: "Spores radial, trilete; amb roundly subtriangular, oval, subcircular, or circular. Laesurae usually distinct, simple, more or less straight; length, often unequal on same specimen, ranges from ½ to 9/10 of spore radius. Prominent, comprehensive, pilate sculpture consisting of crowded to loosely distributed, smooth, discrete, club – or mushroom-shaped processes; small, pointed to rounded coni and some verrucae often additionally present in minor proportions. Basal diameter of processes 1 - 6µm, length 2.5 - 12µm, width of (expanded) heads 2.5 - 10µm. Sculptural elements vary in size and shape on any given specimen; sculpture generally coarser and

denser on distal surface and equator than on proximal surface. Eight to twenty-two processes developed at equator. Exine (excluding sculpture) 1.5 – 3μm thick".

Size range: (i) 48-(67)-85μm (140 specimens) (excluding ornament); Playford 1964.

(ii) 55 – (62) - 94μm (based on 54 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 48 – (64) - 72μm (based on 5 specimens).

Range: PC – CM biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: (i) Berea Sandstone Formation, Ohio (?LN Biozone); Eames 1974.

(ii) Samples 11-18, Henley Bed – Cowbell Member (Borden Formation), Kentucky (PC Biozone); Coleman (1991).

(iii) Cuyahoga & Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Coldwater Shale Formation, Williams County, Ohio; (ii) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: The reports of *R. clavata* in the Berea Sandstone Formation by Eames 1974 is somewhat anomalous when compared with the distribution of the species elsewhere.

Raistrickia macrura (Luber) Dolby & Neves 1970

Plate 2, figs. 15-17

1938 *Azonotriletes macrurus* Luber in Luber & Waltz, pl.7, fig. 94.

1952 *Acanthotriletes macrurus* (Luber) Ishchenko, pl. 4, fig. 65.

1970 *Raistrickia macrura* (Luber) Dolby & Neves 1970, p. 637, pl. 1, fig. 7.

Holotype: Dolby & Neves 1970, pl. 1, fig. 7.

Type locality: Portishead Beds, Burrington Combe, the Mendips, England.

Diagnosis: as *Description* Dolby & Neves 1970, p. 637: "Spores radial, trilete and acamerate. Amb circular to oval. Exine laevigate and about 3μm thick. Trilete mark often obscured by ornament, Tecta straight to slightly sinuous and about ½ the spore radius in length. The ornament consists of densely distributed bacula, 8- 10μm high and 4 -5μm wide. They taper gently, broadening again slightly near the tips which are either blunt or slightly bifurcate. Low muri up to 3μm high connect the bases of the bacula forming irregular polygonal lumina, 10-12μm in diameter. About 24 may be counted at the equator".

Size range: 51 - 63μm (based on 8 specimens); Dolby & Neves 1970.

45 - 90μm (based on 29 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 46 – (51) - 60μm (based on 12 specimens).

Range: LL – PC biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation, West Virginia (common).

Raistrickia minor (Kedo) Neves & Dolby 1967

Plate 2, figs. 18-19

1963 *Archaeotriletes minor* Kedo, pl.3, fig.63.

1967 *Raistrickia minor* (Kedo) Dolby & Neves, p.610.

Holotype: Kedo 1963, pl.3, figs.63.

Type locality: Hole 2P, lower phytostratigraphic zone of the Malevka horizon (ml_1), Yelsk district, Gomel province; Byelorussia.

Diagnosis: Kedo 1963: "Spore round. The surface of the spore is covered with close warts and sparse, long spinous processes pointed at the ends. Dehiscence slit trilete, simple. Rays of the slit equal the radius of the spore body".

Description: Higgs *et al.* 1988, p.59: "Trilete acamerate miospores. Amb subcircular to oval. Suturae, often obscured by ornament, simple straight, extending almost to spore margin. Exine 1.5-2μm in thickness, comprehensively ornamented with prominent discrete baculate processes. Elements 6-18μm in height, 2.5μm in width, approximately 14-20 elements project from the equator. Bacula possess rounded pointed, flat (Broken), or multipartite terminations. In some case bacula up to ½ the length of the spore diameter".

Size range: 20-(33)-38μm (20 specimens) (excluding ornament); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: (excluding ornament) 51 - 102 μm (2 specimens).

Range: LL-PC biozones, Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation, Mylan Park, West Virginia.

Remarks: This taxon is distinguished from other species of *Raistrickia* due to its relatively small central body and a comparatively large ornament of bacula.

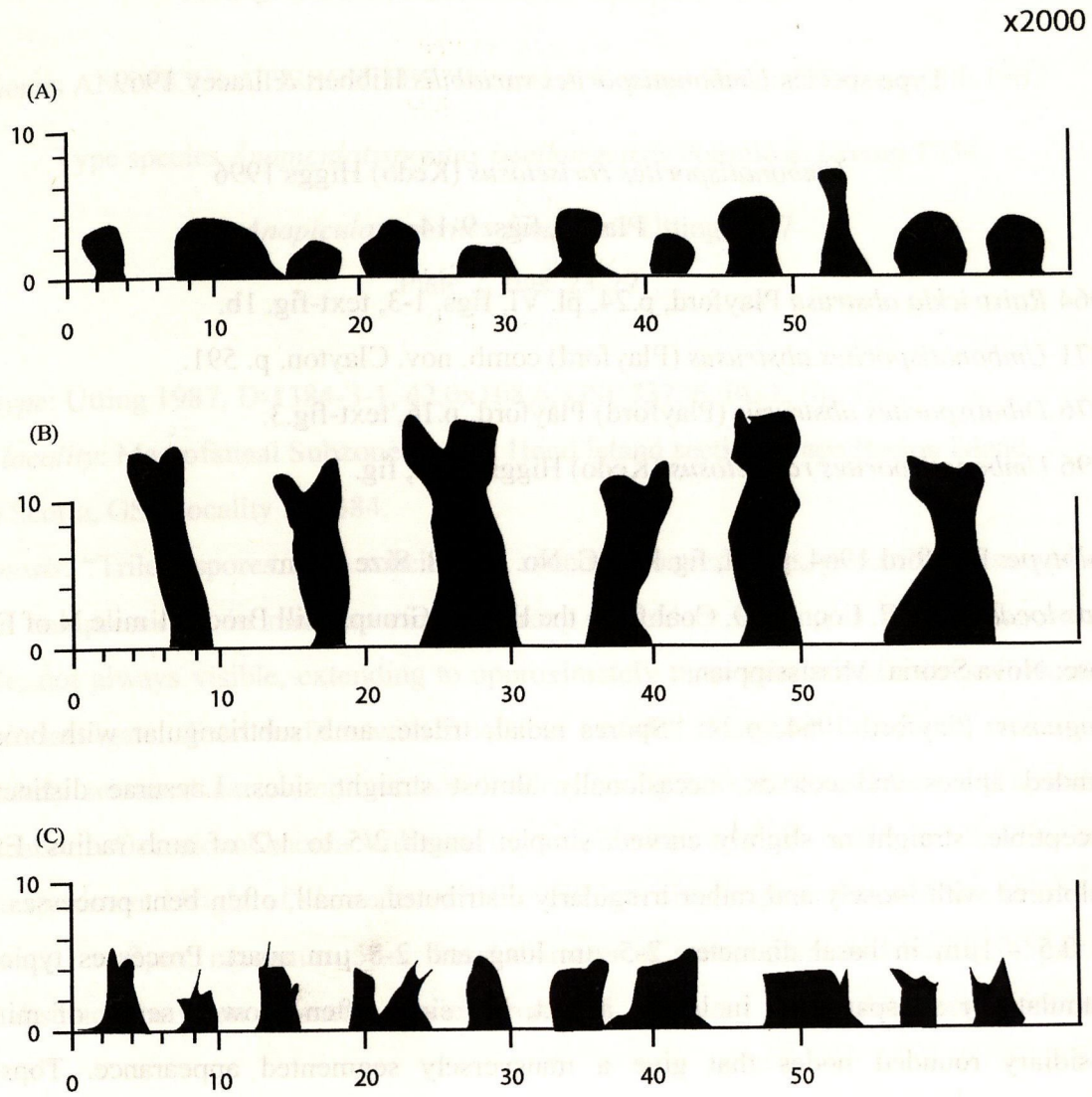


Figure 6.1 Comparison of ornament in three species of *Raistrickia*: A) *R. clavata* B) *R. minor* C) *R. macrura.*

Genus UMBONATISPORITES Hibbert & Lacey 1969

Type species *Umbonatisporites variabilis* Hibbert & Lacey 1969

Umbonatisporites rarisetosus (Kedo) Higgs 1996

Plate 2, figs. 9-14

1964 *Raistrickia abstrusa* Playford, p.24, pl. VI, figs. 1-3, text-fig. 1b.

1971 *Umbonatisporites abstrusus* (Playford) comb. nov. Clayton, p. 591.

1976 *Dibolisporites abstrusus* (Playford) Playford, p.16, text-fig.3.

1996 *Umbonatisporites rarisetosus* (Kedo) Higgs, pl. 2, fig. 1.

Holotype: Playford 1964, pl.VI, fig.1 GSC. No. 13118. Size 64µm

Type locality: GSC. Loc. 6400, Coal from the Horton Group, Mill Brook, 1 mile N of East Gore; Nova Scotia. Mississippian.

Diagnosis: Playford 1964, p.24: "Spores radial, trilete; amb subtriangular with broadly rounded apices and convex, occasionally almost straight sides. Laesurae distinct to perceptible, straight or slightly curved, simple; length 2/5 to 1/2 of amb radius. Exine sculptured with loosely and rather irregularly distributed, small, often bent processes that are 0.5 - 1µm in basal diameter, 2-5 µm long and 2-8 µm apart. Processes typically spathulate or subspathulate in lateral aspect, but sides often show a series of minute subsidiary rounded nodes that give a transversely segmented appearance. Tops of processes diverse-truncate, slightly rounded, sometimes bearing a minute pointed conus or spina. Minute rodlets sometimes additionally present, but in minor proportions. Sculpture often considerably diminished to absent in proximal polar region. Exine otherwise laevigate or very finely and irregularly granulate; thickness 1.5- 2µm. Exinal folding minor or absent".

Size range: (i) 54 – (62) - 69µm (115 specimens); Playford 1964.

(ii) 50 – (55) - 60µm (30 specimens); Tournaisian of Ireland, Higgs et al. 1988.

Present Study: 48 – (53) - 57µm (based on 15 specimens).

Range: LN (Upper) – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Bedford Shale and Berea Sandstone formations – Three Locks Quarry, Ohio; Price Formation – Mylan Park, West Virginia.

Remarks: Rare specimens of this species recorded in the present investigation conform closely with the original diagnosis.

Subinfraturma NODATI Dybová & Jachowicz 1957

Genus ANAPICULATISPORITES (Potonié & Kremp) Smith & Butterworth 1967

Type species *Anapiculatisporites isselburgensis* Potonié & Kremp 1954

Anapiculatisporites fundiensis Utting 1987

Plate 2, figs. 23-27

Holotype: Utting 1987, D-1384-3-1, 42.0x108.6, GSC73736, Pl. 1, fig. 12.

Type locality: Macrofaunal Subzone B, Port Hood Island section, Cape Breton Island, Nova Scotia, GSC locality D-1384.

Diagnosis: "Trilete spores, amb subcircular, rounded convex sides, generally preserved as lateral compressions, in most specimens strong secondary folding is present. Laesurae simple, not always visible, extending to approximately three quarters of radius. Proximal surface laevigate, distal surface with small but variable ornament, consisting mainly of irregularly scattered narrow spinae, which occasionally have bulbous bases and apicular terminations. Occasional bacula with tapering terminations and rare coni may all occur in a single specimen. Height of elements variable within a single specimen; average height of elements 1 to 2μm, maximum 5μm; basal diameter of spinae, coni and bacula 0.5μm or less; distance between elements varies from 0.5 to 3μm. Exine thin, approximately 0.25μm".

Size range: 30 – (40) - 51μm (based on 20 specimens).

Present study: 33 – (42) - 50μm (based on 30 specimens).

Occurrence: Lower Windsor Group macrofaunal Subzones A and B; Upper Windsor Group Subzones C to E; Windsor-Canso Group boundary beds, NS, AT and SM zones.

Present study: Uppermost Price Formation (?upper PC Biozone) – Mylan Park, West Virginia; Uppermost Rockwell & Burgoon Sandstone formations – Crammer & Warrior's Path sections, Pennsylvania (?upper PC Biozone).

Remarks: *Anapiculatisporites fundiensis* Utting 1987 is distinguished from *Raistrickia magdalena* Utting 1987 based upon its ornament of narrow spinae, rare bacula and occasional coni; the later species possesses a stouter ornament consisting mainly of bacula with coni and echini. *Schopfites delicatus* Higgs 1976 differs from *A. fundiensis* in that it has an ornament consisting of closely spaced pila and fine bacula.

Genus SECARISPORITES Neves 1961

Type species *Secarisporites lobatus* Neves 1961

Secarisporites sp. A sensu Higgs, Clayton & Keegan 1988

Plate 3, fig. 5

1980 *Camptotriletes* sp. A Van der Zwan, pl. 7, figs. 5, 6; pl. 8, fig.1.

1988 *Secarisporites* sp. A sensu Higgs, Clayton & Keegan

Description: See Van der Zwan 1980:

Remarks: Higgs *et al.* 1988, p68; "The morphology of the specimens recorded conforms with the description given by Van der Zwan (1980) for *Camptotriletes* sp. A. The specimens are characterized by large globose rugulae on the distal surface and very sinuous rugulae on the proximal surface. The manner in which the globose rugulae modify the equatorial outline is typical of the genus *Secarisporites* Neves 1961".

Size range: 55 – 65µm (7 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: 67µm (based on 1 specimen).

Occurrence: LN – VI Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: Bedford Shale Formation – Big Walnut Creek & Three Locks Quarry sections, Ohio.

Subinfraturma VERRUCATI Dybová and Jachowicz, 1957

Genus VERRUCOSISPORITES Ibrahim emend Smith 1971

Type species *Verrucosisporites verrucosus*

(Ibrahim) Ibrahim 1933

Verrucosisporites nitidus (Naumova) Playford 1964

Plate 3, figs. 1-4

1953 *Lophozonotriletes grumosus*, Naumova p. 57, pl. 7, figs. 14, 15.

1956 *Lophozonotriletes* aff. *grumosus*, (Naumova) Ishchenko, p. 40, pl. 7, fig. 74.

1963 *Verrucosisporites nitidus*, (Naumova) Playford pp. 13-14, pl. 3, figs. 3-6.

1963 *Converrucosisporites parvinodusus*, Playford, p. 15, pl. 3, figs. 7-9.

1964 *Verrucosisporites congestus*, Playford, p. 13, pl. 2, figs. 11-13.

1964a *Verrucosisporites grumosus*, (Naumova) Sullivan pp. 1252-3, pl. 1, figs. 9-15.

1969 *Verrucosisporites congestus* Playford; Varma, p. 306, pl. 1, fig. 13 -14, 18.

Holotype: Naumova 1953, p.57, pl.7, figs. 14-15; holotype not indicated by Naumova, according to Playford 1964.

Hypotypes: Designated by Playford 1964, p.14, pl.III, figs. 3-6.

Type locality: Petino Beds (Upper Frasnian), Petino, Voronezh Region, former USSR.

Diagnosis: Naumova 1953, p.57.

Amplified Diagnosis: Playford 1964, p.14: "Spores radial, trilete; amb circular, subcircular, or rounded subtriangular. Laesurae simple, straight to sinuous, perceptible to obscure (often semi-hidden by sculptute); length ½ to 4/5 of amb radius. Comprehensive, relatively coarse sculpture consisting of numerous, smooth, discrete, non-overlapping verrucae that are rounded in lateral view and possess circular to roundly polygonal basal outlines. Height of verrucae 1- 3µm, greatest basal diameter 2- 12µm (average 5 µm). Verrucae typically closely spaced, thus separated by a more or less regular and continuous negative microreticulum which is usually sharply defined in low focus. Exine thickness (including sculpture) 2 -4µm".

Description: From Higgs *et al.* 1988: "Trilete acamerate miospores; amb subcircular, occasionally convexly triangular. Suturae distinct, often obscured by ornament, simple, straight, length 3/4 to 4/5 of the spore radius. Exine 1.5-5µm thickness, ornamented with

dense to sparsely distributed verrucae. Verrucae discrete, no-overlapping, subcircular to irregularly polygonal in basal outline often forming negative reticulum with rounded to flattened tops; verrucae 2-20μm in height".

Size range: (i) 40 - 64μm; Naumova 1953.

(ii) 30 - 60μm; Ishchenko 1956.

(iii) 28 - 55μm (55 specimens); Playford 1964.

(iv) 37 – 95μm (100 specimens); Tournaisian of Ireland, Higgs *et al.* 1988

Present Study: 35 – (55) - 80μm (15 specimens);

Range: LN-CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in Eastern USA: (i) Bedford Shale and Berea Sandstone formation, Ohio (LN Biozone); Molyneux et al. 1984.

(ii) 1 – 19 Bedford Shale Formation – Cowbell Member (Borden Formation), Kentucky (LN, VI & PC biozones); Coleman 1991.

(iii) Cuyahoga & Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Bedford Shale Formation, Williams County, Ohio; (ii) Bedford Shale – Berea Sandstone, Big Walnut Creek & Three Locks Quarry, Ohio; (iii) Three Lick Bed, Morehead (Three Lick type section) & Clay City Quarry, Kentucky; (iv) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: Higgs *et al.* (1988, p.62) noted a complete morphometric gradation between the species *V. nitidus*, *V. congestus* and *Converrucosisporites parvinodus*.

Verrucosisporites oppressus Higgs *et al.* 1988

Plate 3, fig. 6

1975a *Convolutispora opressa* Higgs p. 297, pl. 3, figs. 3-5.

1988 *Verrucosisporites oppressus* (Higgs) Higgs *et al.*, p. 62, pl.6, figs. 7-8.

Holotype: Higgs *et al.* 1988, pl. 3, figs. 4.

Type locality: Sample 2, Old Red Sandstone facies, East Hook Head, Co. Wexford.

Diagnosis: Higgs 1975a, p.397: "Trilete acamerate miospores; amb rounded to oval and relatively smooth. Suturae distinct, straight, length half to two-thirds of the spore radius, and bordered by thin labra 1-2μm in overall width. Proximal and distal surfaces ornamented with small closely spaced, non-overlapping, rugulae and verrucae. Rugulae

low, smooth, simple or locally expanded 1-2μm in height, 1-2.5μm in width, 2-6μm in length; rugulae anastomose in places, but do not form a reticulum. Verrucae discrete, 1-2.5μm in basal diameter, smooth sided but variable in shape and density. Exine 2μm in thickness; rarely folded".

Size range: (i) 46–(56.5)-68μm (46 specimens); Tournaisian of Ireland, Higgs 1975a.

(ii) 40 - 68μm (50 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 48 – (60) - 72μm (based on 12 specimens).

Range: LL – PC Biozones; Tournaisian of Ireland, Higgs 1975a.

Occurrence in E. USA: Sample 1, Bedford Shale, Kentucky (LN Biozone); Coleman 1991.

Present Study: Bedford Shale Formation, Williams County, Ohio; (ii) Chattanooga Shale Formation, Clay City Quarry, Ohio; (iii) Price Formation, Mylan Park, West Virginia.

Remarks: Assigned to the genus *Verrucosisporites* by Higgs *et al.* 1988 based on the dense ornamentation of verrucae and rugulae 1 -2.5μm in height. The specimens recorded in the current study closely conform to the original diagnosis provided by Higgs (1975a).

Infraturma MURORNATI Potonié& Kremp 1954

Genus CONVOLUTISPORA Hoffmeister,
Staplin & Malloy 1955

Type species *Convolutispora florida* Hoffmeister,
Staplin & Malloy 1955

Convolutispora caliginosa Clayton & Keegan *in*
Clayton *et al.* 1982
Plate 3, figs. 7-9

1967 *Convolutispora* sp. Neves & Dolby pl. 2, fig. 7.
1977 *Convolutispora* sp. Clayton *et al.* pl. 5, figs. 17-18.
1977 *Convolutispora* sp. A p. 548, pl. 2, figs. 6-9.
1982 *Convolutispora caliginosa* Clayton & Keegan, pl. 1, figs. 5, 6, 8 & 9.

Holotype: Clayton & Keegan 1982 Plate 1, fig. 6.
Type locality: Sample P9, Ardmore, County Waterford, Ireland.
Description: Clayton & Keegan 1982, p.522: "Amb circular to subcircular. Trilete mark indistinct; typically obscured by ornament. Suturae straight, simple; length 2/3 – ¾ spore radius. Exine 1.5 - 3µm thick, rarely folded. Ornament on both distal and proximal surfaces consists of flat topped to rounded, anastomosing ridges 3 -6 high, but reduced in the contact areas. Ridges may vary considerably in width on any one specimen within the range 2 -6µm, and enclose irregular, often sinuous lumina. The distance between adjacent ridges is of similar order to their width. Non-polar compressions are common".
Size range: (i) 49 – (61) - 76µm (based on 25 specimens); Tournaisian, County Waterford, Ireland, Clayton & Keegan 1982.
(ii) 46 – (63) - 88µm (65 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.
Present Study: 45 - 75µm (based on 5 specimens).
Range: LL-CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988
Present Study: Bedford Shale Formation, Big Walnut Creek, Ohio.

Convolutispora major (Kedo) Turnau 1978

Plate 3, figs. 10-12

1963 *Dictyotriletes major* Kedo, p.55, pl.4, fig. 97.

1978 *Convolutispora major* (Kedo) Turnau, p.8, pl.2, figs. 18 – 19.

Holotype: Kedo 1963, pl.4, fig.97.

Type locality: Hole 56, lower phytostratigraphic zone of the Malevka horizon (ml_1), Petrikov district, Gomel province; Byelorussia.

Original Diagnosis: Kedo 1963, p.55: "Spores rounded or irregularly multiangular. Exine dense fringed, its surface coarsely reticulate, formed by the interlacing of large dense strands 7μm wide. The loops of the reticulum form 15-20μm. Dehiscence dlit trilete, fringed, frequently open. Rays of the slit ½ the length of the radius of the spore".

Description: Turnau 1978, p.8: "Spores trilete, amb rounded-triangular or subtriangular, margin wavy. Trilete mark distinct, Laesurae accompanied by flat lips each 8μm wide, extending 1/2 to 2/3 radius of spores. Exine 11μm thick (ornament including), homogenous, ornamented all over by dense, irregular, imperfect reticulum of anastomosing, free ending ridges; these are 6-10μm wide, 6μm high, rounded in profile. Lumina usually elongated and branched, 3μm, occasionally 10μm wide. Ridges of proximal spore side may be shorter, occasionally wart-like".

Size range: (i) 69.5 – (95) – 119μm (20 specimens), Turnau 1978.

(ii) 78 – (90) - 105μm (15 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 90 – (104) – 138μm (based on 38 specimens).

Range: (i) Tournaisian deposits of the Pripyat depression; Kedo 1963.

(ii) Oppel zones Ma & Cl (Cl subzone); Tournaisian, Western Pomerania, Turnau 1978.

(iii) VI – PC Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Upper Cuyahoga and Lower Logan formations, Wayne County, Ohio (PC Biozone): Clayton *et al.* 1998.

Present Study: Price Formation (VI & PC biozones) – Mylan Park, West Virginia.

Remarks: The specimens found in this study conform with the original diagnosis for this species.

Convolutispora vermiformis Hughes & Playford 1961

Plate 3, figs. 13-15

1957 *Convolutispora flexuosa* forma *minor* Hacquebard, p. 213, pl. 2, fig. 10.

1961 *Convolutispora vermiformis* Hughes & Playford, p. 30, pl. 1, fig 2.

Holotype: Hughes & Playford 1961, pl. 1, fig. 2. M811/3.

Type locality: Sample B685, Billefjorden Sandstone, Spitzbergen; Lower Carboniferous.

Diagnosis: Hughes & Playford 1961, p. 30: "Spores radial, trilete, originally spherical; amb subcircular. Laesurae straight to slightly sinuous, attain equatorial margin. Exine coarsely lobate to smooth and sinuous; lumina when present rounded to polygonal, 4 - 21μm in diameter. Exine (excluding ridges) 2.5 - 4μm thick".

Size range: (i) Equatorial diameter 57 – (64) - 73μm (based on 25 specimens); Hughes & Playford 1961.

(ii) 45 - 73μm (based on 43 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 48 - 70 μm (based on 8 specimens).

Range: LL – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Uppermost Cuyahoga & lower Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: Price Formation –Mylan Park, West Virginia.

Genus CORDYLOSPORITES Playford & Satterthwait, 1985

Type species *Cordylosporites sepositus* Playford & Satterthwait, 1985

Cordylosporites shawneei sp. nov.

Plate 4, figs. 1-3, 5 & 6

Holotype: Plate 4, fig. 2

Paratypes: Plate 4, figs. 1, 3 -6.

Type locality: Upper Price Formation, Mylan Park core, Monongalia County, West Virginia, USA.

Etymology: The name of this taxon is derived from the Shawnee tribe who inhabited parts of northern West Virginia prior to the arrival of European settlers.

Diagnosis: Miospores trilete, acamerate. Amb circular to subcircular. Trilete mark distinct, straight or slightly sinuous, often imperceptible; bordered by labra ~1μm in width; extend almost to the equatorial margin of the spore. Exine 2- 3μm thick, laevigate, ornamented both proximally and distally with a dense reticulum of muri. Lacaunae irregularly polygonal; 3- 9μm in diameter. Muri typically 3- 4μm at base tapering to 2μm at crest. Mural crests characteristically modified by a variety of projections, including, baculae, papillae and coni/ spinae. Tips of projections roundly pointed, bifurcate or denticulate.

Description: Holotype circular, diameter (excluding ornament) 36μm. Trilete mark obscured by ornament. Exine 3μm thick. Muri 4μm wide at base, interlocking to form a coarse reticulum. Lacunae polygonal; 6- 9μm wid. Murae modified by an ornament consisting primarily of spinae and bacula, which project 7- 10μm from the crests.

Height of muri, and size and style of ornament typically variable, but commonly uniform on an individual specimen. Compression of the muri along the equatorial margin often forms a 'pseudo-flange' around fringe of the spore.

Size range: 18 – (33) - 45μm (based on 47 specimens).

Range: PC Biozone, 'Big Injun' sandstone, upper Price Formation, Mylan Park, West Virginia.

Remarks: This taxon is closely comparable to *Cordylosporites marciae* (Winslow) Playford & Satterthwait 1985, but can be distinguished by its consistently smaller size and longer projections from the crests of the murae.

Cordylosporites marciae (Winslow) Playford & Satterthwait 1985

Plate 4, figs. 8 - 10

1962 *Reticulatisporites? fimbriatus* Winslow, pp. 58-59, pl. 14, figs. 1, 1a, 1b, 2, 2a, 3, 3a; pl.22, fig.21.

1969 *Reticulatisporites* sp. no. 3207 of Lanzoni & Magloire, pl.6, figs. 7, 8 (no description).

1970 *Dictyotriletes* (*Reticulatisporites*?) *fimbriatus* (Winslow) Kaiser, p. 95, pl. 19, figs 4-6 (combination invalid: ICBN, ART. 33.2).

1972 *Dictyotriletes glumaceus* Byvsheva, p.145, pl.1, figs. 8-11.

1974 *Reticulatisporites magloirei* Daemon, p.568, pl. 6, figs. 4,5.

1978 *Dictyotriletes margodentatus* Turnau, p.8, pl.2, fig.15.

1980 *Reticulatisporites glumaceus* (Byvsheva) Byvsheva, p.56 (combination invalid:

ICBN, Art. 33.2).

1985 *Cordylosporites marciae* (Winslow) (sic) Playford & Satterthwait 1985, p.144.

Holotype: Winslow 1962, pl. 14, figs. 1, 1a, 1b, pl. 22, fig. 21; Bedford Shale Formation, locality 1, maceration 40B, slide 16, collection 4–11–1–52.

Type locality: Loc. 1, Bedford Shale, Chippewa Creek Section, Brecksville, Cuyahoga Co., Ohio, U.S.A.

Diagnosis: Winslow 1962: "Spores trilete, prominently reticulate, muri papillate, 69 - 115μm in diameter including reticulate ornamentation, 52 - 80μm in diameter excluding reticulation. Original form somewhat oblate, laterally compressed specimens shorter in axial than transverse dimensions. Spores usually subcircular in outline; showing no preferred orientation upon compression; compressional folding of the spore coat not common.

Trilete rays distinct, 21 - 28μm long, usually partly obscured by flattened muri in compressions. Labial elaboration absent; rays bordered by muri, less delicately fringed than distal muri. Contact areas not delimited.

Reticulation consists of extremely high muri, papillate fringed, that form a distinct rim, slightly proximal to the geometrical equator and muri radiating distally to form a network of 7 to 9 large lacunae as much as 31μm in breadth. Muri also usually extend along the rays and sometimes extend onto interradial surfaces. Muri 8 -21μm high and about 3μm wide (tangential to surface), highest at mural intersections. Muri incised deeply along the top to about half their height, appear fringed; papillate segments 1.6 - 3μm in diameter. Papillae blunt, clavate or slightly taper pointed; often curved on compressed specimens. No perisporal layer is differentiated.

Spore coat ranges from a minimum of 2.1μm – 3.1μm to much thicker along muri. Surface smooth; coat yellow to orange by transmitted light".

Description: Playford & McGregor 1993, pp. 25-26: "Spores radial, trilete. Amb circular to subcircular. Laesurae distinct to perceptible, straight; simple or, more characteristically, bordered by narrow muri that are relatively low but otherwise similar to those of reticulum developed elsewhere on the spore surface; length of laesurae approximately 60 -90% of spore radius. Exine 3-4μm thick, bearing coarse meshed reticulum comprehensively, but tending to be more strongly developed distally and equatorially (producing there a somewhat irregular, fluted-flange appearance) than proximally. Lumina subcircular to irregularly rounded polygonal; diameter usually within 14-38μm range, variable but more

commonly fairly uniform on a given specimen; lumina floors laevigate, scabrate, or finely and irregularly wrinkled (as seen under SEM). Muri 3- 4.5μm broad basally, tapering to narrow crests that are distinctively modified by a range of projections/ indentations giving fimbriate, crenulated or denticulate appearance; depth of incisement or length of projections (verrucae, baculae, papillae, rounded to slightly pointed coni/ spinae) up to about 6μm (usually 1- 3μm)".

Size range: (i) 69 - 115μm in diameter (including ornamentation), 52 - 80μm (excluding reticulation); Winslow 1962.

(ii) 75 – 130μm (based on 10 specimens); Tournaisian of Ireland, Higgs et al. 1988.

(iii) 50 – (61) - 74μm, excluding ornament (number of specimens not specified); Coleman 1991.

(iv) 58 – (80) – 98μm (including muri); Playford & McGregor, 1993, p. 26.

Present Study: 51 – (88) - 120μm (14 specimens).

Range: (i) LL - HD; Tournaisian of Ireland, Higgs *et al.* 1988 (recorded as *Dictyotriletes fimbriatus*).

(ii) Strunian – mid/ late Tournaisian (at least); global distribution, Playford & McGregor (1993, p. 26).

Selected occurrences: (i) Bedford Shale at localities 1 -3, 6 and 9; Berea Sandstone Formation locality 9; Cuyahoga Formation and Black Hand Sandstone (undifferentiated) at locality 7; Lower Mississippian, Ohio, USA, Winslow 1962.

(ii) Bedford Shale to Sunbury Shale formations and uppermost Henley Member (Borden Formation) LN, VI and PC Biozones; Kentucky, USA, Coleman & Clayton 1987.

(iii) Bakken Formation (middle sandstone and upper shale members), Southern Saskatchewan, Canada; Playford & McGregor (1993).

Present Study: (i) Bedford Shale Formation, Three Locks Quarry, Ohio; (ii) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: This species was originally described in detail by Winslow 1962. However, as noted by Playford & Satterthwait (1985, p.144), the epithet she selected in combination with the genus *Reticulatisporites* was illegitimate since it was a homonym of *Reticulatisporites* Knox, 1950. Therefore, Playford & Satterthwait (1985) proposed the new epithet *marciae.* The species was assigned to their newly established genus *Cordylosporites*, which incorporates reticulate miospores with variously modified mural crests.

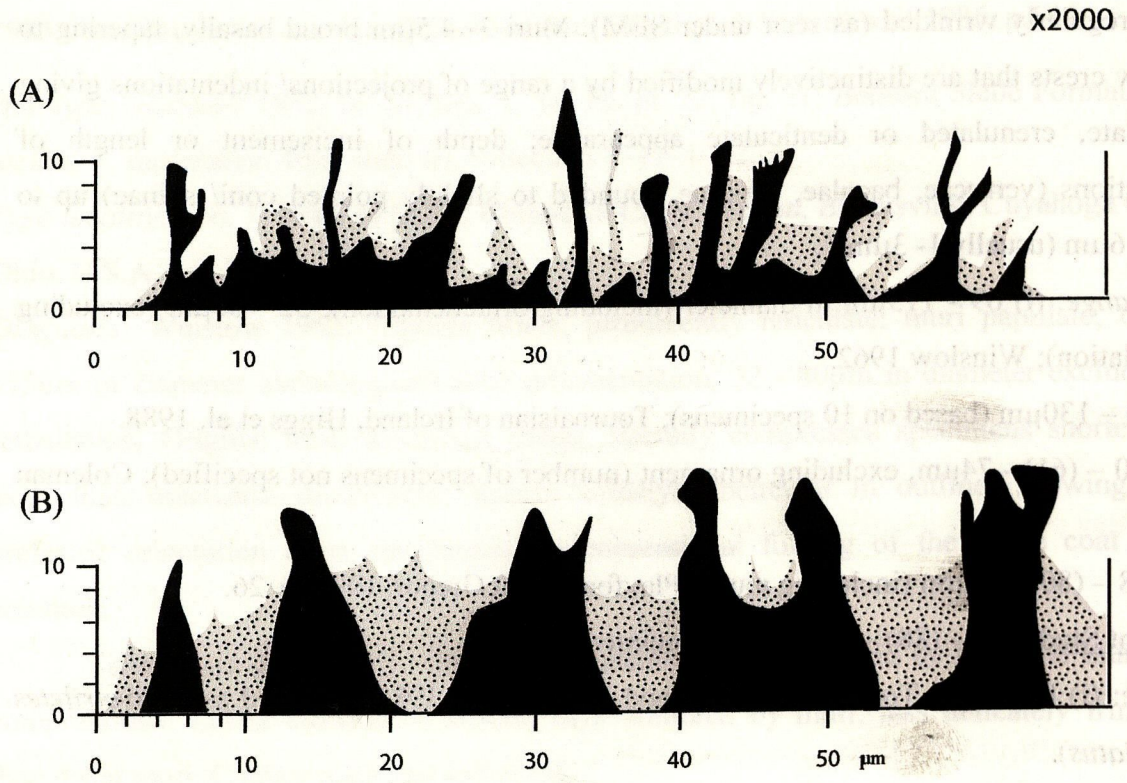


Figure 6.2 Modification of mural crests in A) *Cordylosporites shawneei* sp. nov. & B) *C. marciae*.

Genus DICTYOTRILETES Naumova emend

Smith & Butterworth 1967

Type species *Dictyotriletes bireticulatus* (Ibrahim) Potonié & Kremp 1954

Dictyotriletes flavus Keegan 1977

Plate 4, figs. 11-12

Holotype: Keegan 1977, pl. 2, fig. 3. PC 102 sample 18.

Type locality: Sample 18, Lispatrick Formation, Leap Harbour, County Cork, Republic of Ireland

Diagnosis: Keegan 1977; "Miospores trilete, acamerate. Amb circular to subcircular. Suturae obscure to distinct, sinuous, extending almost to the equator. Exine laevigate to finely granulate and ornamented on the distal and proximal surfaces with irregular muri, 1-3µm wide, 3-8µm high, enclosing polygonal to rectangular lumina, 12 -20µm in greatest diameter. The equator is usually irregular due to slight folding of the exine"

Size range: 39- (48) - 58µm (based on 35 specimens).

Present Study: 36 – (50) - 53µm (6 specimens).

Range: BP – PC Biozones (rare); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation, Mylan Park, West Virginia.

Remarks: This taxon is distinguished from others of its genus by its small size and relatively large lumina.

Dictyotriletes trivialis Naumova in litt. *in* Kedo 1963.

Plate 4, figs. 4-7

Holotype: None designated.

Type locality: Hole 75, middle phytostratigraphic zone of the Cherepet Horizon (ch2) Zhitkovichi district, Gommel province; Byelorussia.

Diagnosis: Kedo 1963 – translated from Russian: "Spore round, exine dense; often with a thickened margin its surface reticulate, formed by close interweaving of quite dense strands. Loops of the reticulum protrude along the margin forming a kind of tubercles. Dehiscence slit trilete, simple. Rays of the slit ½ the radius of the spore".

Description: Higgs *et al.* 1988, p.64: "Trilete acamerate miospores; amb subcircular. Suturae usually indistinct, simple, straight ½ to ¾ of the spore radius in length. Exine bears dense reticulate sculpture of muri, 2-6μm in height and 3-6μm in width, which form subcircular to irregular shaped lumina, 4-10μm in width. Muri protrude at the equatorial margin to give a characteristic undulate outline".

Size range: 55- 90μm (45 specimens); Tournaisian of Ireland, Higgs *et al.*1988.

Present Study: 60 – (72) - 180 μm (10 specimens).

Range: LE – CM Biozones in the Tournaisian of Ireland, Higgs *et al.*1988.

Present Study: Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: The dense and tapering nature of the muri is characteristic of this species.

Genus EMPHANISPORITES McGregor 1960

Type species *Emphanisporites rotatus* (McGregor)

McGregor 1973

Emphanisporites annulatus McGregor 1961

Plate 4, figs. 17-19

1956 Unnamed, Radforth & McGregor, pl.1, fig. 6.

1961 *Emphanisporites annulatus* McGregor, p.3, pl.1, figs.5-6.

1962 *Radiaspora* sp. Balme, p.6, pl.1, fig.13.

1963 *Emphanisporites erraticus* (Eisenack) McGregor, in Chaloner, p.103, fig.1.

1967 *Emphanisporites* cf. *erraticus* McGregor in Daemon et al., p.106, pl.1, fig.10.

1968 *Emphanisporites radiatus* Schultz, p.30.

Holotype: McGregor 1961, pl.1, fig 5.

Type locality: Sextant Formation, Ontario, Canada; Lower Devonian.

Diagnosis: See McGregor 1961, p.3.

Description: Clayton *et al.* 1977b, p.417: "Trilete acamerate miospores; amb subcircular. Suturae distinct, straight; extend almost to the equator, and are bordered by labra 4 -7μm in overall width which taper towards the equator. Exine 3μm thick, ornamented in each interradial sector by 5- 7 radiating ribs. The ribs are up to 5μm wide and 3μm high, and frequently bifurcate towards the equator. Distal surface laevigate except for an annular

thickening approximately 4μm wide which is concentric with the equator with radius approximately 2/3 that of the spore equator".

Size range: 48 - 53μm (based on 4 specimens); Tournaisian of Ireland, Clayton *et al.* 1977b.

Present Study: 60 – (64) – 69 (based on 4 specimens).

Range: LN Biozone; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Bedford Shale, Sunbury Shale and Borden formations (upper Henley Member); Kentucky, USA, Coleman & Clayton, 1987.

Present Study: (i) Bedford Shale Formation, Three Locks Quarry and Big Walnut Creek, Ohio; (ii) Price Formation, Mylan Park, West Virginia.

Remarks: This species of *Emphanisporites* is distinguished from other species in the genus by a distal annular thickening (approximately μm thick in the American specimens). The thickening is concentric with the equator and its radius is approximately 2/3 that of the spore diameter.

Emphanisporites hibernicus Clayton, Higgs & Keegan 1977

Plate 4, fig 20

1987 *Emphanisporites* sp., Azcuy & Ottone, p.28, pl.12, fig. 10.

1977 *Emphanisporites hibernicus* Clayton, Higgs & Keegan, pl. 4, fig 20.

Holotype: Plate 1, fig. 15; Clayton *et al.* 1977b.

Type locality: Grey Shale, 160m above the base of the Old Head Sandstone Formation, South Ringabella, County Cork.

Diagnosis: Clayton *et al.* 1977b: "Trilete, acamerate miospores; amb subcircular to rounded triangular. Suturae distinct, simple or bordered by narrow labra 2- 3μm wide, sometimes gaping; extebd to the spore margin. Exine 1.5- 3 μm thick, distally laevigate to scabrate. Proximal surface ornamented by thin ribs arranged in a chevron pattern along the suturae. Each rib is 1- 1.5μm in width, and 3 or 4 sets of ribs typically intersect each of the suturae. Compression folds are rare".

Size range: 35 – (46) – 55 (25 specimens); Tournaisian of Ireland, Clayton *et al.* 1977b.

Present Study: 39 – (52) - 70μm (based on 4 specimens).

Range: LE - PC Biozone; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: (i) Bedford Shale Formation, Three Locks Quarry, Ohio; (ii) Price Formation, Mylan Park, West Virginia.

Remarks: The species is characterised by a proximal ornamentation of thin ribs, arranged in a typical chevron pattern. McGregor & Camfield (1982) speculated that *E. hibernicus* may represent an end member of a morphological continuum with *E. rotatus* (McGregor) McGregor (1973).

Emphanisporites minutus Allen 1965

Plate 4, figs. 21 & 22

1965 *Emphanisporites minutus* Allen, p. 709, pl. 97, fig. 20.

Holotype: Preparation KA 262/4 56.8 91.5, K908, N276.

Type locality: South Mimerdalen, Central Docksonland, Spitsbergen; Reuterskiøldfjellet Sandstone, Siegenian.

Diagnosis: Allen 1965, p. 709: "Miospores trilete; amb roundly triangular to subcircular. Laesurae straight, length three-quarters to full spore radius, accompanied by smooth, narrow lips, individually less than 1μm wide. Exine 2 -3μm thick, homogeneous to infragranulate; proximal surface with 15 – 30 radially disposed muri, approximately 1μm wide, distal surface laevigate".

Description: Allen 1965, p. 709: "Holotype subtriangular, diameter 26μm. Lips extend almost to the equatorial margin. Exine 2μm thick; proximal surface with 25 radially disposed ribs, 0.5 - 1μm wide".

Size range: 16 – (24) - 27μm (based on 20 specimens); Spitsbergen, Allen 1965.

Present Study: 36 - 45μm (2 specimens)

Range: Fraenkelryggen Division and Reuterskiøldfjellet Sandstone; Gedinnian to Lower Emsian, Spitsbergen, Allen 1965.

Present Study: Bedford Shale Formation (one sample); Three Locks Quarry, Ohio.

Remarks: This species compares very closely to *E. rotatus* McGregor 1961 but can be distinguished by its smaller size. The two specimens assigned to this species in the present investigation are slightly larger than those originally described by Allen 1965, however, they are still significantly smaller than specimens assigned to *E. rotatus*.

Emphanisporites rotatus (McGregor) McGregor 1973

Plate 4, figs. 23-24

? 1952 *Orbiactinotriletes mosoloviensis* Zharkova.

? 1953 *Stenozonotriletes ornatissimus* Naumova, pl.22, fig.111 (nomen nudum).

1954 Spore type E17, Radforth & McGregor, p.611, pl.2, fig.37.

? 1955 "*Radiaspora*" sp., Hoffmeister, Staplin & Malloy, pl.3, fig.7. (nomen nudum).

1959 Unnamed, Radforth & Wilkinson, pl.1, fig.15.

? 1959 *Stenozonotriletes ornatissimus* Naumova, in Chibrikova, p.79, pl.14, fig.2.

1961 *Emphanisporites rotatus* McGregor, p.3, pl.1, fig.1-4.

1961 *Emphanisporites robustus* McGregor, p.4, pl.1, fig.13.

?1962 *Radiaspora* sp. A, Balme, p.6, pl.1, figs. 11 & 12.

1962 *Radforthia radiata* Winslow p.72, pl.16, fig.15, 15a; pl.22, fig.17.

? 1963 *Emphanisporites* Doubinger, pl.3, figs. 18 & 19.

? 1964 *Radiaspora* sp Balme, pl.1, fig.1.

? 1964 *Stenozonotriletes* cf. *ornatissimus* Naumova, in Venozhinskene, pl.1, figs. 13, 14, pl.2, figs. 5 – 13, pl.3, figs. 5 -7.

? 1964 "Grupo TI-st", in Regali, p. 170, figs. 2:3.

1964 *Emphanisporites* sp. aff. *E. rotatus* McGregor, Cousminer, pl.15, fig.36.

? 1965 Stenozonotriletes radiatus 'sp. n.', Nazarenko, pl.1, figs. 24, 25 (nomen nudum).

1965 *Emphanisporites* sp. Herner, p.14, fig.1.

? 1966 *Stenozonotriletes* cf. *ornatissimus* Naumova in Vaitekunience, pl.1, figs. 13, 14.

? 1966b *Stenozonotriletes radialis* Nadler (MSc.), in Nadler, pl.1, fig.18 (nomen nudum).

? 1966b *Stenozonotriletes ornatissimus* Naumova, in Nadler, pl.1, fig.19.

1967 *Emphanisporites* cf. *rotatus* McGregor; in Richardson, pl.2, fig.E.

1967 *Emphanisporites* cf. *robustus* McGregor; in Richardson, pl.2, fig. F.

? 1967 *Emphanisporites* ?sp. Richardson, pl.2, fig.G.

1967 *Emphanisporites* cf. *radiatus* (Winslow) Menendez & Pothe de Baldis, p.165, pl.2, figs. F-H.

1967 *Emphanisporites robustus* McGregor; Beju, pl.1, fig.19.

1968 *Emphanisporites robustus* McGregor; Jardiné and Tapandjian, pl.1, fig. 1-2.

1968 *Emphanisporites robustus* McGregor; Lanninger, p.137, pl.24, fig. 1.

1968 *Emphanisporites robustus* McGregor; Schultz, p.25, pl.3, fig.6-7.

1968 *Emphanisporites radiatus* Schultz, p.30, pl.13, fig.16.

1969 *Emphanisporites* sp. 2514 Lanzoni & Magloire, pl.7, figs. 6-7.

1969 *Emphanisporites* cf. *rotatus* McGregor; Downie & Lister, p.201, pl.1, figs. A-C.

1969 *Emphanisporites robustus* McGregor; Cramer, p.434, pl.1, fig.11.

1972 *Emphanisporites* spp., Kemp, pl.4, figs. 1-3.

1973 *Emphanisporites rotatus* (McGregor) McGregor, pp. 46-47, pl.6, figs. 9-13.

1974 *Emphanisporites* sp. Clayton, Higgs, Gueinn & Van Gelder, pl.6, fig.2.

1976 *Emphanisporites rotatus* McGregor *in* Massa & Moreau-Benoit, pl.1, fig.10.

Lectotype: McGregor 1973, pl. 6, fig. 9-10 (original holotype lost).

Type locality: Battery Point Formation, Douglastown, Eastern Gaspé, Canada; Lower Devonian.

Diagnosis: See McGregor 1973.

Size range: (i) 43 – (56) - 70µm; Mississippian of Kentucky, Coleman (1991)

Present Study: 48 – (69) – 81 (based on 32 specimens).

Range: LE - PC Biozone; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Samples 1-18, Bedford Shale to Nancy/ Cowbell transition, Kentucky (LN, VI & PC biozones); Coleman (1991).

Present Study: (i) Bedford Shale Formation, Williams County, Big Walnut Creek and Three Locks Quarry Ohio; (ii) Chattanooga Shale/ Three Lick Bed, Morehead (Three Lick type section) & Clay City Quarry, Kentucky; (iii) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: This species is characterised by radially aligned ribs on the proximal surface. McGregor and Camfield (1976) noted variation in overall size, wall thickness, and in the dimensions and prominence of the ribs on almost 900 specimens. They concluded that because of complete morphographic integration, taxonomic subdivision of this species was not practical.

Emphanisporites schultzii McGregor 1973

Plate 13, figs. 13-16

1967 *Emphanisporites* sp. McGregor, pl.1, fig.2.

1968 *Emphanisporites macgregori* Schultz, in Lanninger, p.136, pl.23, fig.15.

1970 *E. macgregori* Schultz, in McGregor, Sanford & Norris, pl.II, fig.4.

1970 *Emphanisporites* sp., McGregor, pl. XXXI, fig.2.

1973 *Emphanisporites schultzii*, p.48, pl.6, fig.14.

Non *Emphanisporites mcgregorii* Cramer 1966a, p.263, pl.III, fig. 59.

Hypotype: Slide 7064-1-32.0 x 110.7, Battery Point Formation.

Type locality: York River Formation and Battery Point Formation (Lower Assemblage).

Diagnosis: As description in McGregor 1973, p.48: "Trilete miospores, amb broadly oval to subcircular. Sutures extend from 5/6 to the full distance to the equator, simple or with imperceptibly raised labra 1µm or less wide. Distal hemisphere unornamented. Each interradial area of the proximal hemisphere bears 9 to 14 ridges that radiate from a focus of about 1/3 the way from the pole to the equator, the ridges attaining maximum width of 5µm and 1.5 - 2.5µmthick distally, increasing sharply to 2 – 5.5µm wide (cingulate) in the equatorial zone of the distal hemisphere. Proximal wall, excluding ridges, thinner that distal, but exact thickness not determined".

Size range: 35 – (57) - 81µm (based on 56 specimens); McGregor 1973, p.48.

Present Study: 51 – (61) - 81µm (based on 5 specimens).

Occurrence: York River and Battery Point formations, Lower Devonian (Emsian), Eastern Gaspé, Canada, McGregor (1973).

Present Study: (i) Bedford Shale Formation; Three Locks Quarry, Ohio; (ii) Lower Price Formation, Mylan Park, West Virginia.

Remarks: This species was first described by Schultz (in Lanninger, 1968) as *Emphanisporites macgregori*. However, McGregor (1973, p.48) noted that this name must be rejected because it is a later homonym (orthographic variant) of *E. mcgregorii* Cramer (1966a). Specimens recorded in the present investigation conform closely to those described by McGregor from Canada.

Subturma ZONOTRILETES Waltz 1935

Infraturma AURICULATI (Schopf) Dettman 1963

Genus MOOREISPORITES Neves *1958*

Type species *Mooreisporites fustis* Neves 1958

Mooreisporites streelii Clayton, Manger & Owens 1998

Plate 2, figs. 4-8

1993 cf. *Mooreisporites* sp. Playford & McGregor, pl. 15, fig.1

1998 *Mooreisporites streelii* Clayton, Manger & Owens, pl. 2, figs. 1 -3.

Holotype: Clayton *et al.* 1998, plate 2, fig. 1. Trinity College Dublin Geological Museum, specimen catalogue number TCD 47502, slide 1(3), England Finder co-ordinates E 47/4.

Type locality: Medal Brick and Tile Company Quarry, Wayne County, Ohio, USA. Sample 1, Wooster Member, Cuyahoga Formation.

Diagnosis: Clayton *et al.* 1998, p. 190: "Trilete, acamerate miospores. Amb triangular with convex, straight or slightly concave sides with rounded apices. Trilete mark distinct; suturae straight, simple, extend almost to the equator. Exine moderately thin. Proximal surface laevigate. Apices variably thickened, ornamented by irregular bacula which often coalesce to form irregular projections. Distal surface smooth to ornamented by bacula or irregular ridges".

Description: Clayton *et al.* 1998, p. 190: "Specimens variable in terms of shape of amb and density and distribution of ornament. Exine 1 -2µm thick. Bacula at the apices up to 3µm high and 3µm in basal diameter; flat-topped to rounded in profile, often coalescing to form irregular projections. On a single specimen, the density of ornament may vary greatly between the three apices. Distal ornament also variable, consisting of bacula and ridges similar to those at the apices but generally lower; often concentrated around the distal pole from where it may extend to join with the ornament at one, two or all three of the apices. Non-polar compressions common".

Size Range: 54 – (61) – 75µm (15 specimens) - sample 1 (Medal Brick and Tile Quarry); Clayton *et al.* 1998.

Present study: 66 - 69µm (based on 2 specimens).

Occurrence: Sample 1 (Medal Brick and Tile Quarry); Clayton *et al.* 1998.

Present study: Sample WC24 - uppermost Coldwater Shale Formation, Williams County, Ohio

Remarks: This species is distinguished from others of the genus by its size, shape of amb and the variability of its ornament. Clayton *et al.* (1998, p.190) note that the assignment of this taxon to the genus *Mooreisporites* is somewhat arbitrary since some specimens possess large thickenings at the apices similar to those which characterise the genera *Tripartites* and *Triquitrites*.

Infraturma CINGULATI (Potonié & Klaus) Dettmann, 1963

Genus BASCAUDASPORA Owens 1983

Type species *Bascaudaspora canipa* Owens 1983

Remarks: This genus acts as a repository for variably camerate/ acamerate miospores which have a uniform cingulum and reticulate ornament.

Bascaudaspora submarginata (Playford) Higgs, Clayton & Keegan 1988

Plate 3, figs. 19-22

1964 *Dictyotriletes submarginatus* Playford, pp. 29-30, pl.8, figs. 9-13

1988 *Bascaudispora submarginata* Higgs, Clayton & Keegan, p.65, pl. 7, figs. 19-20

Holotype: See Playford 1964.

Type locality: See Playford 1964.

Diagnosis: See Playford 1964.

Size range: 45 - 67µm (based on 28 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: 48 - 70µm

Occurrence: LL – CM biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: Price Formation – Mylan Park, West Virginia.

Genus GORGONISPORA Urban 1971

Type species *Gorgonispora convoluta* (Butterworth & Spinner) Playford 1976 (senior synonym *G. magna* (Felix & Burbridge) Urban 1971, p.121, pl.29, figs. 8 & 9; the original designated type species)

Gorgonispora crassa (Winslow) Higgs, Clayton & Keegan 1988

Plate 3, figs. 16-18

1962 *Reticulatisporites crassus* Winslow, p.58, pl.14, figs. 8-10, pl.22, fig.23

1970 *Knoxisporites* cf. *literatus* (Waltz) Playford; Combaz & Streel, pl. 3, fig.12

1988 *Gorgonispora crassa* (Winslow) Higgs, Clayton & Keegan, pp. 65-66, pl. 21-22

Holotype: Winslow 1962, pl. 14, fig. 8.

Type locality: Lower Cuyahoga Formation, locality 8, maceration 148, slide 9; Winslow 1962.

Diagnosis: From Winslow 1962, p. 58: "Spores trilete, coarsely reticulate, 94-147μm in diameter including the highly developed muri; body cavity ranges from 69 to 111μm in diameter. Original form somewhat oblate; lateral compressions shorter axially than in transverse diameter. Proximo-distal compressions more numerous than lateral or oblique compressions. Spores generally appear irregularly rounded to oval in outline.

Trilete rays distinct, often split apart (pl.14, fig.9; pl.22, fig.23), 30 - 48μm long, extending to margin of body cavity. Labial elaboration lacking; rays frequently bordered by low muri. Contact areas not delimited.

Reticulation consists of muri forming an irregular ring slightly proximal to the geometrical equator, and usually 5 to 7 muri radiating distally, forming a network of 7 to 9 lacunae 21 - 52μm in breadth. A lacuna may, on some spores, be almost bisected by an attenuate murus. Attenuate muri usually extend proximally, fully or partially (pl.22, fig.23), along each ray, and sometimes intrude into interradial areas. Muri 5 - 19μm high, enlarged at mural intersections; about 6μm wide, usually pressed into the spore wall so that width is distorted. No perisporal layer is differentiated.

Spore coat ranges from a minimum of 2 – 3.5μm to much thicker along muri. Surface smooth; coat yellow to orange brown by transmitted light.

Size range: 70 – 110μm (based on 18 specimens).

Present study: 57 - 80μm (based on 10 specimens).

Range: LE – PC Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in USA: (i) Upper Ohio Shale/ Chagrin Shale formations (rare), Bedford Shale and Berea Sandstone formations, and lower Cuyahoga/ Black Hand formations (undifferentiated); Winslow 1962.

Present study: Price Formation – Mylan Park, West Virginia.

Genus KNOXISPORITES Potonié & Kremp 1954

emend Neves 1961

Type species *Knoxisporites hageni* Potonié & Kremp 1954

Knoxisporites concentricus (Byvscheva) Playford & McGregor 1993

Plate 5, figs. 4,5,7 & 8

1976 *Concentricisporites concentricus* Byvscheva, pp. 83-85, pl. 17, figs. 1-5.

1977 *Lophozonotriletes* sp. Keegan, pl. 3, fig. 9.

1978 *Lophozonotriletes* sp. *in* Sleeman *et al.* table 1, p. 52.

1980 *Lophozonotriletes* sp. *in* Naylor & Higgs, table 1, p. 383

1981 *Tumulispora* sp. Van Veen, pl. 4, figs. 1-2.

1988 *Lophozonotriletes concentricus* (Byvscheva) Higgs *et al.*, p.67, pl.8, figs 7 – 10.

1991 '*Tumulispora concentrica*' (Byvscheva) Coleman, pp.79 – 80, pl.6, fig. 1.

1993 *Knoxisporites concentricus* (Byvscheva) Playford & McGregor, p.28, pl.13, figs. 1-8.

Holotype: Byvscheva 1976, pl.17, figs. 1-5.

Type locality: Eastern Russian Plate, former USSR.

Diagnosis: See Byvscheva 1976, pp. 83-85.

Description: Higgs *et al.* 1988, p.67: "Trilete acamerate miospores, amb subcircular to convexly triangular. Suturae distinct to obscure simple, sometimes gaping, and extending to the inner margin of the cingulum. Proximal surface laevigate. Distal surface ornamented with rugulae and verrucae, up to 8µm in width. Elements arranged in irregular, concentric, spiral bands around the distal pole. Rugulae arcuate to whorl like shape, with smooth, undulate outline and occasionally mammillate tops. Verrucae discrete and subcircular in basal outline. Cingulum smooth, uniform and 4 - 7µm in width".

Size range: (i) 45 – (64) - 75µm (based on 22 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 60 – (70) - 80µm (based on 13 specimens).

Range: LE – PC biozones (rare in PC Biozone); Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Bedford Shale Formation, Kentucky (LN Biozone), Coleman 1991.

Present Study: (i) Three Lick Bed, Clay City Quarry, Kentucky; (ii) Price Formation, Mylan Park, West Virginia.

Remarks: This taxon was transferred to *Tumulispora* by Coleman (1991) in her thesis on the basis of the cingulate nature of the miospore. However, subsequent work by Playford & McGregor (1993) suggested that the rugulate nature of the ornamentation precluded assignment of the species within the genus *Tumulispora*. The authors therefore proposed that the genus Knoxisporites was a more suitable repository for the species based on the emended diagnosis in Neves 1961, which described the sculptural features as 'variable pattern of radial and/ or concentric bands of thickening'. The present study follows Playford & McGregor (1993), since specimens recorded are characterised an ornament of rugulae and coarse verrucae.

Knoxisporites cf. *K. concentricus* (Byvscheva) Playford & McGregor 1993

Plate 5, fig. 10

Description: Trilete, acamerate miospore, amb subcircular to convexly triangular. Suturae indistinct. Proximal surface laevigate. Distal surface ornamented sinuous rugulae, arranged in a vaguely concentric pattern. Cingulum smooth, uniform, 15 µm wide.

Size range: 145µm (based on one specimen).

Occurrence: Sample MP8, lower Price Formation - Mylan Park, West Virginia.

Remarks: The single specimen recorded is closely comparable to *Knoxisporites concentricus* (Byvscheva) Playford & McGregor 1993 but differs from the latter species based only upon its larger size.

Knoxisporites literatus (Waltz) Playford 1963

Plate 5, figs. 1 & 2

1938 *Zonotriletes literatus* Waltz in Luber *in* Luber & Waltz, p. 18, pl. A, fig. 11.

1956 *Euryzonotriletes literatus* (Waltz) Ishenko pp. 52-3, pl. 9, fig. 108

1956 *Anulatisporites literatus* (Waltz) Potonié& Kremp p. 111.

1957 *Cincturasporites literatus* (Waltz) Hacquebard & Barrs, pp. 23-24, pl. 3, figs 2-5.

1963 *Archaeozonotriletes literatus* (Waltz) Kedo, pl. 8, figs. 188-190.

1963 *Knoxisporites literatus* (Waltz) Playford, p. 634, pl. 90, figs. 7-8.

Holotype: Not designated.

Type locality: See Playford 1963, p. 634.

Diagnosis: Playford 1963, p.634. "Spores radial, trilete; amb convexly subtriangular, smooth or may show gentle undulation. Laesurae distinct, straight, length equal to, or slightly less than, spore-body radius; bordered by broad, smooth flat lips which extend approximately 6-10μm on either side of Laesurae. Cingulum broad, usually regular, width 8-19μm; inner margin sometimes darker in colour, possibly indicating poleward extension (3-5μm) over spore body. In some specimens the cingulum is slightly narrower at the apices, so that the amb tends to appear more roundly triangular that the equatorial outline of the spore body. Distal surface has characteristic sculpture of several (usually three or four) smooth, rounded muri, which are rather irregularly disposed and often loosely connected; width of muri 6.5-12μm. Apart from lips and distal muri, spore body and cingulum laevigate".

Size range: (i) 56 – (76) - 102μm (75 specimens); Playford 1963.

(ii) 56 – 111μm (50 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 80 – (96) - 103 μm (based on 6 specimens).

Range: LL -CM Biozone; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: (i) Sample 12, Farmers Member (Borden Formation), Kentucky (PC Biozone); Coleman (1991).

(ii) Cuyahoga & Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Bedford Shale Formation, Williams County, Ohio; (ii) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: *Knoxisporites literatus* is similar to *Knoxisporites hederatus* (Ishchenko) Playford, but can be distinguished from it by having prominent labra.

Knoxisporites triangularis Higgs, Clayton & Keegan 1988

Plate 5, fig. 3

1938 *Zonotriletes literatus* Waltz; Luber, Waltz, pl. 2, fig. 21.

1941 *Stenozonotriletes literatus* (Waltz) Naumova pl. 1, fig. 5.

1958 *Euryzonotriletes literatus* (Waltz) Ishchenko pl. 6, fig. 76.

1963 *Archaeozonotriletes literatus* (Waltz) Naumova var. *triangularis* Kedo, pl. 8, figs, 191-3.

1964a *Knoxisporites hederatus* (Ishchenko) Playford; Sullivan, pp. 1253-4, pl. 2, figs. 1-2.

1971 *Knoxisporites literatus* (Waltz) Playford var. *triangularis* (Kedo) Clayton p. 584, pl. 2, fig. 5.

1976 *Knoxisporites literatus* (Waltz) Playford; Playford pl. 5, fig. 6.

1988 *Knoxisporites triangularis* (Waltz) Higgs *et al.* 1988, p.66, pl.8, figs. 3 & 6.

Holotype: Plate 8, fig. 191, Kedo 1963.

Type locality: Yelsk B/H 23, depth 577.2m, middle phytostratigraphic zone of the Malevka horizon (ml_2), Yelsk district, Gomel province, Byelorussia

Diagnosis: Kedo 1963: "Spore rounded-triangular or rounded multi-angular. Perispore thick, smooth, covered with broad dense, flat strands interlacing the spore in various directions the result of which is that protrusions are formed along the margins of the spore. The spore body round, forms ¾ the size of the perispore. Dehiscence slit trilete, fringed, rays of the slit equal the radius of the spore body".

Description: From Higgs *et al.* 1988: "Trilete acamerate miospores. Amb subcircular to convexly triangular. Suturae distinct, straight, occasionally gaping and extending to the cingulum. Suturae bordered by broad prominent labra up to 20µm in overall width. Equatorial cingulum uniform smooth, and 8-12µm in thickness. Proximal surface laevigate. Distal surface ornamented with three muri arranged in a triangular pattern with the apices of the triangle joining the cingulum in the interradial positions. Muri 8-12µm in thickness often slightly expanded at the cingulum. Remainder of exine laevigate to scabrate".

Size range: 70 – (91) - 121µm (21 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 68 – (93) - 120 µm (based on 4 specimens).

Range: VI – CM biozone; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Bedford Shale Formation, Three Locks Quarry, Ohio.

Remarks: This taxon was described by Kedo 1963 as *Archaeozonotriletes literatus* (Waltz) Naumova var. *triangularis*. Clayton (1971) later transferred this variety to the genus *Knoxisporites*. Higgs *et al.* considered the species distinctive enough to warrant elevation to specific status.

Comparison: This species is distinguished by three radial bars arranged in a triangular pattern on the distal surface with the apices of the triangle connecting to the cingulum at the interradial positions.

Knoxisporites cf. *triradiatus* Hoffmeister,
Staplin & Malloy *sensu* Sullivan 1964a
Plate 5, figs 6 & 9

Description: From Higgs *et al.* 1988, p.66: "Trilete acamerate miospores; amb subcircular to convexly triangular. Suturae bordered by slightly sinuous lab; width of labra variable, up to 8μm and extending to the margin of the cingulum. Distal surface bears three broad muri 8- 12μm in width which radiate from the distal pole to the cingulum in the interradial positions. Cingulum distinct, laevigate and 6-15μm in thickness".

Type locality: Hardinsburg Formation, locality TCO-82

Size range: 75 -112μm (based on 20 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 65 – (82.4) – 100 μm (5 specimens).

Range: LE – PC Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrences in E. USA: (i) Samples 1, 2 & 12, Bedford Shale Formation and Farmers Member (Borden Formation); Kentucky (LN & PC Biozone); Coleman & Clayton, 1987. (ii) Logan Formation, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Bedford Shale Formation, Three Locks Quarry, Ohio; (ii) Three Lick Bed, Clay City Quarry, Kentucky. (iii) Price Formation, Caldwell & Mylan Park, West Virginia.

Remarks: The specimens assigned to this species in the present study are closely comparable to those described as *K.* cf. *triradiatus* by Higgs *et al.* 1988 from the Tournaisian of Ireland and those recorded by Sullivan 1964a from the Lower Limestone Shales of the Forest of Dean, Southwest England. Similar species include *K. triradiatus* Hoffmeister, Staplin & Malloy 1955, which differs in not possessing prominent labra along the suturae and being notably smaller in size.

Genus MUROSPORA Somers 1952

Type species *Murospora kosankei* Somers 1952

Murospora dubitata Higgs 1975a

Plate 6, figs 1 & 4.

1964a *Leiotriletes ornatus* (Ishchenko) Sullivan, p.1251, pl.1, fig.1.

1975a *Murospora dubitata* Higgs; pp. 397 – 398, pl.3, figs. 18 & 19.

Holotype: Higgs 1975a, pl. 3, fig. 18.

Type locality: Sample H6, Houseland Sandstone Member, East Hook Head, Co. Wexford, Ireland; Lower Carboniferous.

Diagnosis: Higgs 1975a, pp. 397- 398: "Trilete acamerate miospores; amb subtriangular with rounded apices and concave to slightly convex sides. Trilete mark straight, accompanied by conspicuous labra which extend to the spore margin. Labra thickened, often partly or totally obscuring the suturae, 5-10µm wide for approximately three-quarters of the spore radius and widening at the radial extremities up to 25µm. Equatorial cingulum distinct to obscure, uniform, smooth sided, 5-13µm in thickness. Exine and cingulum laevigate".

Size range: 43- (59) - 68µm (based on 24 specimens); Higgs 1975a.

Present Study: 54 – (63) - 72µm (based on 4 specimens).

Range: LN – PC Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Samples 1 -3, & 6, Bedford Shale – Sunbury Shale, Kentucky (LN – VI biozones); Coleman (1991).

Present Study: (i) Bedford Shale Formation - Williams County, Big Walnut Creek and Three Locks Quarry, Ohio; (ii) Three Licks Bed, Clay City Quarry, Kentucky; (iii) Price Formation, Mylan Park, West Virginia.

Remarks: The conspicuous labra extending to the spore margin and a cingulum of uniform thickness distinguish this taxon from other species of *Murospora*.

Murospora sp. A

Plate 6, figs. 2 & 3

Description: Trilete, acamerate miospores; amb concavo-triangular, interradial areas concave, apices rounded. Laesurae distinct, simple straight, length extending to the equatorial margin of the spore. Exine 2- 3μm thick, proximal surface laevigate. Distal surface ornamented by 16- 18 ribs which radiate out from the distal pole towards the equator where they fuse with the cingulum Equatorial cingulum well defined, laevigate, 5-7μm in thickness.

Size range: 77- 99μm (based on 3 specimens)

Occurrence: (i) Sample SUN1 - Bedford Shale Formation (LN Biozone) - Big Walnut Creek, Ohio; (ii) lower Price Formation (LN Biozone) – Mylan Park, West Virginia.

Remarks: The distinctive ornamentation of radial ribs on the distal surface of the spores and their relatively large size distinguishes them from other species assigned to *Murospora* in the present study.

Genus TUMULISPORA Staplin & Jansonius 1964

Type species *Tumulispora variverrucata* (Playford) Staplin & Jansonius 1964

Note: Several species of simple, cingulate miospores, possessing a distal verrucate ornament, have been documented in strata spanning the Devonian/ Carboniferous boundary. Many such taxa were originally assigned to the Russian genus *Lophozonotriletes* (Naumova) Potonié. However, subsequent investigation of the type species of this genus (e.g. Turnau, 1975) - led to doubts being raised concerning the cingulate nature of the type species of this genus, a suspicion later confirmed by Avchimovitch *et al.* (1988). As a result, a number of species originally assigned to *Lophozonotriletes* were transferred to the genus *Tumulispora*. Thus, following recent workers, cingulate/ verrucate taxa are assigned to *Tumulispora* in the present investigation.

Tumulispora malevkensis (Kedo) Turnau 1978

Plate 5, figs 16 - 18.

1963 *Lophozonotriletes malevkensis* Naumova in litt. Kedo, p. 87, pl. 10, figs. 240, 241; *non* fig. 242.

1978 *Tumulispora malevkensis* (Kedo) Turnau p. 9. pl.3, fig.8.

Holotype: (Naumova in litt.) Kedo 1963, pl.10, figs. 240-242, non fig. 242.

Type locality: Hole 23, middle phytostratigraphic zone of the Malevkia horizon (ml_2), Yelsk district, Gomel province, Byelorussia.

Diagnosis: (Naumova in litt.) Kedo 1963: "Spore round less frequently rounded-triangular, perispore dense, covered with sparse, quite large tubercules which seldom come to the surface of the fringe. Fringe narrow, thick. Dehiscence slit trilete, simple, now and then thickened. Rays of the slit 2/3 the radius of the spore body".

Description: Higgs 1975b, p.77: "Trilete acamerate cingulate miospores; amb subcircular to convex triangular, with an irregular outline. Suturae distinct, simple, straight, length approximately ¾ of the spore radius. Distal surface ornamented with rounded flat topped verrucae, which are characteristically variable in size, 3-15µm in width and up to 6µm in height. Verrucae subcircular in basal outline, discrete but sometimes fused to give low, smooth, and often sinuous rugulae, up to 22µm in length. Ornament sparsely to densely distributed, absent on the cingulum and proximal surface".

Size range: (i) 32.5 – (42.5) - 52µm (20 specimens) Turnau 1978.

(ii) 35 – (44) - 50µm (54 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 52 – 75µm (5 specimens).

Range: (i) Tournaisian deposits of the Pripyat Depression; Kedo 1963.

(ii) LN – PC biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: (i) Samples 2, 3, 5 & 6, Bedford Shale and Sunbury Shale formations, Kentucky (LN & VI Biozones); Coleman (1991).

(ii) Cuyahoga Formation, Wayne County, Ohio (PC Biozone); Clayton *et al.* (1998).

Present Study: (i) Bedford Shale Formation, Three Locks Quarry, Ohio; (ii) Price Formation, Mylan Park, West Virginia - (LN – PC biozones).

Remarks: Turnau (1978) transferred this species to *Tumulispor*a from *Lophozonotriletes* because of the cingulate nature of the former and the non-cingulate structure of the type species for the latter

Tumulispora ordinaria Staplin & Jansonius 1964

Plate 5, figs 15 & 20.

1964 *Tumulispora ordinaria* Staplin & Jansonius, p.110, pl.20, figs. 20, 24, text-fig. 20.

1975 *Tumulispora obscura* (Staplin & Jansonius) Turnau, pl.3, fig 10.

1978 *Tumulispora obscura* (Staplin & Jansonius) Turnau, pl.3, fig 11.

1988 *Lophozonotriletes ordinarius* (Staplin & Jansonius) Higgs, Clayton & Keegan, p.67, pl. 8, fig.14.

Holotype: See Staplin & Jansonius 1964.

Type locality: See Staplin & Jansonius 1964.

Diagnosis: See Staplin & Jansonius 1964.

Description: From Higgs *et al.* 1988, p67: "Trilete acamerate miospores. Amb subcircular to convexly triangular. Suturae simple, straight, slightly gaping, length to inner margin of cingulum. Cingulum laevigate, 8µm in thickness, uniform to slightly irregular. Distal surface bears large solitary centrally placed verrucus, 20- 24µm in diameter, subcircular in basal outline with smoothly rounded sides. Proximal surface laevigate".

Size range: 50 - 58µm (based on 3 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 45 - 48µm (based on 2 specimens).

Occurence: LN Biozone (Cork Bed facies only); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Lower Price Formation (LN Biozone - rare) – Mylan Park, West Virginia.

Tumulispora tuberosus (Sullivan) Carson 1995

Plate 5, figs. 11 - 14

1964a *Lophozonotriletes tuberosus* Sullivan; p. 1254, pl.2, figs. 6-7.

1975a *Lophozonotriletes* cf. *tuberosus* Sullivan; Higgs, p. 398, pl. 3, fig. 15.

1980 *Lophozonotriletes tuberosus* (Sullivan); Van der Zwan, pl.VI, fig.1.

1995 *Tumulispora tuberosus* (Sullivan) Carson, p. cxi, pl. 10, figs. 16-17.

Holotype: Sullivan 1964a, pl.2, fig.7.

Type locality: Lower Limestone Shales, plump Hill, Forest of Dean, Gloucestershire; England.

Diagnosis: Sullivan 1964a, p.1254: "Amb circular to rounded triangular; proximal surface of spore body laevigate, distal surface ornamented with discrete and coalescent verrucae, 4- 5μm in diameter, 2 - 3μm high. Cingulum about ¼ total radius of the spore".

Description: Sullivan 1964a, p.1254: Sullivan 1964a, p.1254: "Amb circular to subcircular with broadly convex sides and rounded apices. Trilete rays indistinct, tecta straight, simple, extend almost to the margin of the spore body. Cingulum not always clearly differentiated from spore body, usually slightly darker in colour. It maintains a fairly constant fraction of the total radius, approximately ¼. Distal surface of spore body ornamented with verrucae which are circular in basal section and broadly rounded in profile. Verrucae rarely discrete, 4-5μm in diameter and 2-3μm high, frequently occur in pairs and as arcuate or sinuous rugulae up to 12μm in length. Ornament sometimes present on distal surface of cingulum. Proximal hemisphere of spore body laevigate. Outline of cingulum sinuous".

Size range: (i) 36 – (40) - 44μm (16 specimens); Tournaisian of Gloucestershire, Sullivan 1964a.

(ii) 40 – (51) - 58μm; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 30 - 36μm (based on 3 specimens).

Range: BP – PC biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation, Mylan Park, West Virginia.

Remarks: This species was transferred to the genus *Tumulispora* by Carson (1995 thesis) due to its cingulate and verrucate nature

Suprasubturma LAMINATITRILETES Smith & Butterworth 1967

Subturma ZONOLAMINATITRILETES Smith & Butterworth 1967

Infraturma CRASSITI Playford & Dettman 1996

Genus CRASSISPORA Bharadwaj emend Keegan & Penney 1978

Type species *Crassispora kosankei*

Potonié & Kremp emend Bharadwaj 1957

Crassispora maculosa (Knox) Sullivan 1964a

Plate 7, figs. 12

1948b Type 23K Knox, p. 158, fig. 26.

1950 *Verrucoso-sporites maculosus* Knox, p. 318.

1955 *Apiculatisporis maculosus* (Knox) Potonié & Kremp, p. 78.

1964a *Crassispora maculosa* (Knox) Sullivan, p. 376.

Lectotype: Smith & Butterworth, 1967, pl. 18, fig. 8. Note: since Knox did not select a holotype in 1950, a specimen selected by Knox from material studied by Smith & Butterworth was designated as Lectotype. Knox preparation 360A (T83/1 in collection of Coal Survey Laboratory, Sheffield).

Type locality: Dunfermline Splint Seam, Lumphinnans No. 1 Colliery, West Fife Coalfield, Scotland; Namurian A.

Diagnosis: Smith & Butterworth, 1967, p 235: "Amb circular. Laesurae ridged; ridges narrow and flexuosa, 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".

Description: Smith & Butterworth, 1967, p. 236: "Although in well-preserved specimens the amb is circular, most specimens are folded and distorted by compression. In equatorial view, proximal and distal surfaces are pointed and convex respectively. Ridges of Laesurae seldom exceed 4µm in width or height; ridged condition not apparent when commisures are open; rays sometimes accompanied by folds. Crassitudinous thickening is best seen in specimens preserved in off centre compression, when it appears as narrow, darker zone,

sometimes accompanied or concealed by arcuate folds. The pointed apices of coni scarcely project more than 1μm from margin and number about 60 or 70. Exine 2.5 - 3μm thick".

Size range: (i) Lectotype 121 x 113; 100 – 120, Schulze (Knox, 1950).

(ii) 65 - 120μm (based on 55 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 63 - (84) - 118μm (based on 17 specimens).

Range: (i) Assemblages II – IV (Infrequent to frequent); Viséan & Namurian, Scottish and English coalfields, Smith & Butterworth 1967.

(ii) VI – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: (i) Bedford Shale Formation - Big Walnut Creek, Ohio; (ii) Price Formation (LN, VI & PC biozones) - Caldwell & Mylan Park, West Virginia (abundant).

Remarks: *Crassispora kosankei* (Potonié & Kremp) Bharadwaj is similar to *C. maculosa* but differs based on its smaller size, wider equatorial crassitude and denser ornament of coni. Specimens recorded in the present study conform closely to the original diagnosis, however, a number of specimens bear a slightly coarser ornament of coni and spinae, but are comparable in all other respects.

Infraturma CINGULICAVATI Smith & Butterworth 1967

Genus DENSOSPORITES Berry emend

Butterworth, Jansonius, Smith & Staplin 1964

Type species *Densosporites convensis* Berry (1937)

Densosporites spitsbergensis Playford 1962

Plate 7, figs. 8 & 9

Holotype: Playford 1963, preparation P163/3, 22.2, 96.8, L.1146, pl.89, fig.1.

Type locality: Birger Johnsonfjellet (sample G1089), Spitsbergen; Lower Carboniferous.

Diagnosis: Playford 1963: "Spores radial, trilete; amb subtriangular, more or less conformable with body outline. Laesurae perceptible to distinct, straight or slightly sinuous; extending on to cingulum as thickened, elevated ridges which often attain equatorial margin. Spore body convexly subtriangular; exine often poorly preserved or absent. Cingulum robust, darker in colour that body; slight and gradual equatorial decrease in thickness. Prominent spinose sculpture on distal surface of spores (body and cingulum); spines crowded and frequently coalescent around inner margin of cingulum, reduced in size and density in equatorial region; length of spines 1.5 - 5μm, basal diameter 1 – 2.5μm. Proximal surface of spores laevigate to sparsely granulate or spinosa".

Description: Playford 1963: "Holotype convexly subtriangular, 64μm overall; spore-body diameter 28μm; Laesurae distinct, extending to equatorial margin. The species is characterized by its conspicuous distal spinose sculpture, long Laesurae, and well-developed cingulum which shows slight reduction in thickness towards the equator; it is a common microfloral constituent of many of the Spitsbergen samples".

Size range: (i) Overall equatorial diameter 55 – (66) - 80μm; diameter of spore body 23 – (31) - 39μm (100 measured specimens); Playford 1963.

(ii) 51 – (74) - 86μm (based on 53 specimens); Irish Tournaisian, Higgs *et al.* 1988.

Present Study: 50 – (58) - 70μm (based on 3 measured specimens).

Range: LN – CM biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence: Lower Price Formation, Mylan Park, West Virginia (one sample).

Comparison: *Densosporites pannosus* Knox 1950 (p.326, pl.18, fig.267) is distinguished from *D. spitsbergensis* by possessing a more uniform and comprehensively spinose, and by its more prominent labra.

Remarks: Specimens assigned to *D. spitsbergensis* in the present study compares closely to those figured by Higgs *et al.* 1988, by possessing a well-developed, dark cingulum, 10-13μm wide, and spinae 3- 5μm long.

Genus INDOTRIRADITES Tiwari emend Foster 1979

Type species *Indotriradites korbaensis* Tiwari 1964

Indotriradites explanatus (Luber) Playford 1991

Plate 7, figs. 7, 10, 11, 13 & 14

1936 Form 5, Yelovskaya pl.3., figs. 1-2.

1941 *Zonotriletes explanatus* Luber in Luber & Waltz, p.10, pl.1, fig. 4.

1963 *Hymenozonotriletes explanatus* (Luber) Kedo, pl.6, figs. 144-147.

1974 *Hymenozonotriletes tenuicostatus* Kedo, pp. 45-46, pl.11, figs. 8-10.

1977 *Samarisporites* sp. cf. *Hymenozonotriletes explanatus* (Luber) Kedo; Streel, p.404, pl.2, fig.1.

1978 *Hymenozonotriletes explanatus* (Luber) Kedo morphological type ii, Turnaum p.13, pl.5, fig.18.

1988 *Hymenozonotriletes explanatus* (Luber) Kedo, p. 79, pl. 15, figs. 16-18.

1989 *Spinozonotriletes explanatus* (Luber) Moreau-Benoit, p.26, pl.5, fig. 6.

non 1989 *Hymenozonotriletes explanatus* (Luber) Kedo; Ouyang & Chen, pl.4, Fig. 16 (no description).

1991 *Indotriradites explanatus* (Luber) Playford, p.103, pl.3, figs. 17 & 18.

1993 *Indotriradites explanatus* (Luber) Playford & McGregor, p. 32, pl.14, figs. 1,2.

Holotype: Luber in Luber & Waltz, pl.1, fig. 4.

Type locality: Palaeozoic USSR.

Diagnosis: see Luber in Luber & Waltz 1941.

Description: From Higgs *et al.* 1988: "Trilete camerate miospores. Amb convexly to rounded triangular, rarely subcircular. Suturae distinct, straight to slightly sinuous accompanied by labra 3-6μm in height and extending to the spore margin. Intexine

normally distinct but in some cases obscure due to close appression to exoexine. Outline conformable with amb, thin, laevigate and comprising 2/3 or more of the spore diameter. Exoexine is extended equatorially to form a zona; inner margin displays a darkened presumably thickened band, 3 - 7.5μm in width, while the outer margin is lighter coloured 5 - 11μm in width, sometimes fibrous with feint radial structure. The distal and equatorial regions of the exoexine ornamented with wide based coni and spinae and subordinate verrucae and mammillae. Elements 1-5μm in height 1 - 3.5μm in basal diameter. Ornament discrete rarely coalescent, up to 11μm apart, and evenly distributed. Exine scabrate or densely infrastructured. Occasional compression folds present".

Size: (i) 60 - 90μm; Kedo 1963.

(ii) 56–(78) -108μm (23 specimens) type I, 71.5–(80)-93μm (7 specimens); Turnau 1978.

(iii) 60 -71μm (based on 4 specimens) Playford & McGregor 1993.

Present study: Intexine 45 – (65) - 75μm; exoexine 78 – (81) - 105 (based on 12 specimens).

Range: (i) Tournaisian; Kedo 1963.

(ii) LE – PC Biozones in the Tournaisian of Ireland, Higgs *et al.* 1988.

(iii) Latest Devonian (Strunian) – Early Carboniferous (late Tournaisian or early Viséan) interval; Playford & McGregor, 1993, p. 32.

Present study: (i) Bedford Shale Formation – Williams County core & Three Locks Quarry, Ohio; (ii) Price Formation – Caldwell & Mylan Park, West Virginia (common).

Remarks: Playford 1976 proposed that this species can only be tentatively placed within the genus *Hymenozonotriletes* due to the inadequate description and illustration of the "exine layering and sculptural characteristics...". Subsequently, Playford (1991) concluded that the genus *Indotriradites* fulfilled the combination of structural and sculptural characteristics exhibited by this taxon and thus renamed it *Indotriradites explanatus*.

Infraturma PATINATI Butterworth & Williams 1958

Genus CYRTOSPORA Winslow 1962

Type species *Cyrtospora cristifer* (Luber) Van der Zwan 1979

Note: The original type species *Cyrtospora clavigera* Winslow 1962 is regarded a junior synonym of *C. cristifer*.

Cyrtospora cristifera (Luber) emend Van der Zwan 1979

Plate 6, figs. 5-7

1941 *Azonotriletes cristifer* Luber *in* Luber & Waltz, pl. 1, fig. 10.

(?) 1955 *Zonotriletes pelorius* Luber, p.64, pl.4, fig.92.

1957 *Lophozonotriletes cristifer* (Luber) Kedo, p.32, pl. 4, fig. 15.

1960 *Anisozonotriletes fabus* Yushko, p.133, pl.2, fig. 41.

1960 Unidentified specimen, Yushko, pl.2, fig. 42 (no description).

1961b *Torispora*? *tiara* Staplin, p. 1228, text-figs, 1-4.

1962 *Cyrtospora clavigera* Winslow, pl. 22, figs. 18-20.

1966b *Tholisporites cristifer* (Luber) Luber in Pokrovskaya, vol.3, pl.42, fig.9 (no description).

1971 *Anisozonotriletes cristifer* (Luber) emend. van der Zwan, p.3, pl.1, figs. 1-5, pl.2, figs. 1-8, pl. 3, figs. 1-3, pl.5, figs. 1-5.

1976 *Anisozonotriletes cristifer* (Luber) Byvsheva, pl. 13, figs. 3-6, pl. 15, fig. 3.

1985 *Cyrtospora cristifera* (Luber) van der Zwan; Byvsheva, p.126, pl.24, figs. 4-6.

Holotype: Luber & Waltz 1941, pl. 1, fig. 10.

Type locality: See Luber & Waltz

Diagnosis: Winslow 1962, p.67: "Spores trilete, originally asymmetrically subprolate (distally extended), usually compressed obliquely or laterally; ranging from 31 to 49µm (usually more than 38µm) in transverse diameter, from 42 - 59µm in axial length including distal ornamentation (30 specimens measured). Haptotypic structures, ornamentation, and spore coat characteristics are as given for the genus".

Description: From Higgs *et al.* 1988, p.68: "Trilete acamerate miospores. Amb subcircular to convexly triangular. Suturae distinct, simple, straight, length ¾ or more of the spore

radius. Exine 1-2.5μm in thickness. Proximal surface laevigate. Distal surface bears elongated thickening, mainly concentrated on the apical pole; 10-38μm in length and 8-28μm in width. Distal thickening is variable in shape, and is sparsely to densely ornamented with bacula, verrucae and/ or coni; 2 - 6.5μm in height and 1 - 4μm in width. Elements discrete of fused, with convex, concave or parallel sides and rounded or flattened tops. Specimens are often preserved in oblique or lateral compression".

Size range: 45 – (56) - 71μm (based on 56 specimens); Higgs *et al.* 1988.

Present Study: 31 – (53) - 75μm (based on 55 specimens).

Range: (LN) VI- PC Biozones; Tournaisian of Ireland, Higgs *et al.*1988.

Selected occurrences: (i) uppermost Frasnian – mid Tournaisian, North-western Canada; Braman, 1981; van der Zwan & Walton, 1981.

(ii) upper Frasnian to lower Viséan, European former USSR; Raskatova, 1974; Byvsheva, 1985).

(iii) Bedford Shale, Berea Sandstone and Sunbury Shale formations (rare); Cuyahoga, and undifferentiated Cuyahoga and Black Hand formations; Upper Devonian/ Lower Mississippian, Ohio, Winslow 1962.

(iv) Bedford Shale Formation to Farmers Member (Borden Formation); Upper Devonian/ Lower Mississippian, Kentucky, Coleman & Clayton, 1987.

Present Study: (i) Berea Sandstone Formation, Three Locks Quarry, Ohio; (ii) Chattanooga Shale Formation, Clay City Quarry, Kentucky; (iii) Price Formation (above Murrysville Sandstone Member), Mylan Park Borehole, West Virginia.

Remarks: Van der Zwan (1979) and Van der Zwan & Walton (1981) described in detail the *Cyrtospora cristifera* morphon. They established three variants of *Cyrtospora cristifera* (variant A, variant B, and variant *tiara*). While it is a common component of assemblages between VI and PC biozones, *C. cristifera* has been found to range from the upper Devonian in Canada. In the present study, this species ranges from the LN (rare) to PC biozones.

Suprasubturma PSEUDOSACCITITRILETES Richardson 1965

Infraturma MONOPSEUDOSACCITI Smith & Butterworth 1967

Genus *Auroraspora* (Hoffmeister, Staplin & Malloy) Richardson 1960

Type species *Auroraspora solisorta* Hoffmeister, Staplin & Malloy 1955

Remarks: Richardson (1960) emended the generic diagnosis to exclude forms with a limbus.

Auroraspora solisorta Hoffmeister, Staplin & Malloy 1955

Plate 6, figs. 11 & 12

1955 *Auroraspora solisortus* Hoffmeister, Staplin & Malloy, pl. 37, fig.3.

1972 *Auroraspora* cf. *solisortus* (Hoffmeister, Staplin & Malloy) Bertelsen, p.57, pl.23, figs. 7 -8.

1978 *Auroraspora* cf. *solisortus* (Hoffmeister, Staplin & Malloy) Turnau, p. 10-11, pl.4, figs. 17-18.

Holotype: TCO-82, 2071ft., slide 5, ser. 19,471, Hardinsburg Formation; dimensions 61x67µm, central body 21x32µm, width of bladder beyond central body 14-19µm; Hoffmeister *et al.* 1955.

Type locality: Hardinsburg Formation, locality TCO-82; occasional.

Diagnosis: As description in Hoffmeister *et al.* 1955: "Spores radial, Trilete; proximal view subcircular to subtriangular; central body entirely (?) enclosed in thin transparent membrane; central body subtriangular to subcircular, bladder subcircular to weakly subtriangular; central body laevigate, bladder finely granulose and without inner reticulation; Trilete rays moderately well developed. Lips slightly raised and without commisure; length almost equal to radius of central body; central body wall relatively thick, translucent, bladder transparent; extremely thin, and often finely folded; Trilete sutures perhaps influence folding at the three radial corners, where folds are slightly thicker; size range 61 -78 microns, bladder width beyond central body, 13 – 19 microns".

Size range: 50 – (58) - 60µm (10 measured specimens); Higgs *et al.* 1988.

Present Study: Intexine 33 – (40) - 51µm; exoexine 54 – (62) - 75 (based on 4 specimens).

Range: (i) LL – CM biozones; Tournaisian of Ireland, Higgs *et al.* 1988.
(ii) Hardinsburg Formation, Webster County, Kentucky; Hoffmeister *et al.* 1955.
Present Study: Bedford Shale Formation, Three Lock Quarry, Ohio.
Remarks: *Auroraspora macra* is very similar to *A. solisortus* but possesses a strong infrastructure, an equatorial darkening and a larger intexine relative to the exoexine.

Auroraspora macra Sullivan 1968
Plate 6, figs. 8-10

Holotype: Sullivan 1968, pl.27, fig.7, pp.124-5.
Type locality: Cementstone Group, Ayrshire, Scotland (Tournaisian).
Diagnosis: Sullivan 1968, p.124: "Amb subcircular to irregular; exoexine laevigate, intexine laevigate to scabrate; trilete mark exceeds 2/3 radius of spore body".
Description: Sullivan 1968, p.124: "Amb subcircular, frequently irregular due to folding. Intexine 1.5μm thick, laevigate to scabrate. Trilete rays straight, simple, extend 2/3 to 3/4 of the radius of the spore body. Exoexine thin, thickness not determinable, often finely folded in an irregular pattern. Exoexine usually pitted and torn."
Size range: (i) 48 – (58) - 68μm (65 specimens); Sullivan 1968.
(ii) 35 – (51) - 65μm (82 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.
Present Study: Intexine 40 – (41) - 45μm; Exoexine 50 – (57) - 65μm (10 specimens).
Range: Tournaisian; (i) Scotland, Sullivan 1968 & Clayton 1972; (ii) England, Llewellyn et al. 1969, Utting & Neves 1970 and Johnson & Marshall 1971. (iii) LL – CM biozones (common throughout); Tournaisian of Ireland, Higgs *et al* .1988.
Present Study: (LN, VI & PC biozones) (i) Bedford Shale Formation – Williams County, & Big Walnut Creek sections, Ohio; (ii) Three Lick Bed, Clay City Quarry, Kentucky; (ii) Price Formation, Caldwell & Mylan Park, West Virginia.

Genus CALYPTOSPORITES Richardson 1962

Type species *Calyptosporites velatus* (Eisenack) Richardson 1962

Calyptosporites triangulatus Higgs 1975a

Plate 6. fig. 17

Holotype: Plate 7, fig. 5, Higgs 1975a.

Type locality: Sample HK, Old Red Sandstone, Hook Head, County Wexford, Ireland.

Diagnosis: Higgs 1975a, p.88-89: "Trilete camerate miospores; amb triangular, with rounded or pointed apices and convex to almost straight sides. Suturae distinct to obscure, simple, frequently gaping, length on-third to half of the intexine radius, Low sinuous ray folds appear to extend the trilete mark to the spore margin. Distal exoexine and equator bear sparsely and irregularly distributed spinae which taper uniformly from broad bases to pointed or more commonly forked apices; often curved or broken. Height of spinae 3 - 10μm, basal diameter 2 -5μm; bases of spinae often coalescent forming low cristae 2μm in width, which tend to be concentrated at the distal pole. Intexine distinct, subcircular in outline, laevigate and 2-3μm in thickness. The body is centrally placed one-third to two-thirds of the total spore diameter and appears to be attached to the exoexine on the proximal surface only. Exoexine infragranulate; rarely folded".

Size range: Intexine 40 – (69) - 84μm; Exoexine 86- (127) - 154μm (based on 75 specimens); Higgs 1975a.

Present Study: Intexine 103 - 106μm; Exoexine 145 - 155μm (based on 2 specimens).

Range: LL – LE biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Samples MP27 -28, Price Formation – Mylan Park, West Virginia (rare) – PC Biozone (reworked?).

Remarks: This taxon is distinguished from other members of the genus by its constant triangular outline, and circular intexine combined with the ornament of slender simple or bifurcating spines. *Endosporites crassispinosus* Winslow (1962) is similar but differs by possessing prominent labra, simple spinae and a peripheral thickening on the intexine.

Genus DISCERNISPORITES Neves & Owens 1966

Discernisporites micromanifestus (Hacquebard) Neves & Owens 1966

Plate 7, fig. 6

1957 *Endosporites micromanifestus* Hacquebard, p. 317, pl.3, fig. 16.

1958 *Discernisporites concentricus* Neves, p.5, pl.3, fig. 7.

1960 *Auroraspora micromanifestus* (Hacquebard) Richardson, p.51.

1966 *Discernisporites micromanifestus* (Hacquebard) Neves & Owens, pp. 357-8.

non. 1971 *Discernisporites micromanifestus* (Hacquebard) Sabry & Neves, pl.3, fig.11. (= *Discernisporites sullivanii* Higgs & Clayton 1984).

1988 *Discernisporites micromanifestus* (Hacquebard) Sabry & Neves 1971; Higgs et al., pl.14, fig.9.

Holotype: Hacquebard 1957, pl.3, fig.16.

Type locality: Sample 20 miles northeast of Windsor, Horton Group, West Gore, Nova Scotia; Canada, Mississippian.

Diagnosis: As description for Endosporites micromanifestus in Hacquebard 1957, p.317: "Identical with *Endosporites micromanifestus* but smaller, and bladder generally more distinctly infragranulose; width of bladder beyond central body 10 - (18) - 24μm; diameter 58 - 100μm, body 37 - 67μm (14 specimens)".

Size range: 55 – (77) - 110μm (based on 59 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: 50 – (70) - 75μm (based on 7 specimens).

Occurrence: LL – CM biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: Upper Coldwater Shale Formation (PC Biozone) – Williams County, Ohio.

Genus ENDOCULEOSPORA Staplin emend Turnau 1975

Type species *Endoculeospora rarigranulata* Staplin 1960

Emended diagnosis: Turnau, 1975, p. 518: "Trilete, camerate miospores; amb subcircular. Exoexine densely infrapunctate, sculptured, mostly distally, with scattered to dense

prominent granules, minute pila and/ or bacula. Intexine laevigate, relatively large, roughly 2/3 -3/4 total spore diameter".

Remarks: Turnau (1975, p. 518) emended the diagnosis of *Endoculeospora* to include spores of similar appearance but with pilate and baculate ornament.

Endoculeospora gradzinskii Turnau 1975

Plate 8, figs. 7-10

Holotype: Turnau 1975, fig. 1.

Type locality: Babilon 1, depth 2675.3 – 2681.5m; Pomerania, northern Poland; probably early Tournaisian.

Diagnosis: Turnau, 1975, p. 518: "Spores trilete; amb subcircular. Trilete mark distinct, laesurae straight, accompanied by weak lips; extending to intexine margin. Exoexine thin, densely, finely infragranulate, extending at equator in a form of flange 1/10 to 1/3 spore radius wide. Distal surface ornamented with irregularly arranged, scattered to dense prominent granula, minute pila and bacula. Granula c. 1μm in diameter, pila and bacula c. 1μm long, 1 to 5.5μm apart. Intexine conformable with exoexine outline, margin usually clearly defined".

Description: Turnau, 1975, p. 518: "Laesurae often obscured by Exinal folds reaching onto the flange. Distal folds of exoexine were not observed which suggests proximo-distal attachment of exine layers".

Size range: Overall diameter 45.5 – (55.5) - 60μm; Intexine 32.5 – (43.5) - 48μm (mean 43.5μm).

Present Study: 40 – (45) -50μm (based on 10 specimens).

Range: LE - CM; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Sample 1 & 2, Bedford Shale Formation, Kentucky (LN Biozone); Coleman (1991).

Present Study: Price Formation, Mylan Park, West Virginia.

Remarks: *E. rarigranulata* Staplin (1960, p.34, pl.8, figs. 3 -6) is much larger and has granulate ornamentation.

Genus GRANDISPORA Hoffmeister, Staplin & Malloy

emend. Neves & Owens 1966

Type species *Grandispora spinosa* Hoffmeister, Staplin & Malloy 1955

Remarks: The synomony of *Grandispora* and *Spinozonotriletes* Hacquebard 1957 as proposed by Playford (1971) is rejected in the present account and instead *Grandispora* is used in the sense of Neves & Owens (1966).

Grandispora cornuta Higgs 1975a

Plate 8, figs. 15-18

? 1969 *Spinozonotriletes* cf. *uncatus* Streel in Bouckart *et al.*, no description.

? 1973 *Spinozonotriletes* cf. *uncatus* Allen in Gater *et al.*, no description.

1975a *Grandispora cornuta* Higgs, p. 90- 91, pl. 7, fig. 11.

Holotype: Higgs 1975a, pl. 4, fig. 4.

Type locality: Sample K, Old Red Sandstone Facies (LL Biozone), West Hook Head, Co. Wexford, Ireland; Devonian.

Diagnosis: Higgs 1975a, p.90-91: "Trilete camerate miospores; amb rounded to convexly triangular. Suturae distinct, straight to slightly sinuous, simple or with narrow labra, and accompanied by flexuous ray folds up to 6μm in height. Length of suturae three forths or more of spore radius, terminating in curvaturae. Exoexine 1.5 - 2μm in thickness; distal surface and equatorial region ornamented with prominent spinae and galeae. Ornament discrete, sparsely but evenly distributed, with 10 to 20 elements prominent at equator. Bases broad or swollen, 2 - 6μm in diameter, tapering sharply or uniformly to pointed apices, 5 - 16μm in length. Intexine distinct, thin, laevigate, outline almost conformable with amb, diameter approximately four fifths that of Exoexine and attached to it on proximal surface only. Independent sets of concentric and arcuate compression folds commonly developed along outer margin of Intexine only".

Size range: Exoexine 45 – (67) - 84μm; Intexine 36 – (53) - 69μm (based on 33 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Exoexine 63 – (72) - 80μm; Intexine 50 – (58) – 63μm (based on 7 specimens).

Range: LL – PC biozones; Irish Tournaisian, Higgs *et al.* 1988.

Present Study: (i) Bedford Shale Formation - Big Walnut Creek, Ohio; (ii) Three Lick Bed - Clay City Quarry, Kentucky; (iii) Price Formation - Caldwell & Mylan Park, West Virginia.

Remarks: *S. uncatus* Hacquebard 1957 is similar but is distinguished by its equatorial extensions of the exoexine (flange) and more densely distributed spinae.

Grandispora echinata Hacquebard 1957

Plate 8, figs. 11-14

Holotype: Hacquebard 1957, pl. 3, fig. 17, M 101, slide 2.

Type locality: Horton Group, Coal from West Gore, 20 miles north-east of Windsor; Nova Scotia, Canada; Mississippian.

Diagnosis: Hacquebard 1957, p. 317: "Spores radial; trilete; central body enclosed by bladder, both subcircular to broadly roundly triangular in proximal view; trilete generally not distinct, rays simple, extending to body margin; central body fairly thin, margin well defined; bladder thin, folded over body, extending 4 – 9 (12)µm beyond body margin, narrow limbus at equator; body exine probably laevigate; bladder has small cones and spines, 1.5 – 2 (4) µm long and 2 -6µm apart".

Description: Higgs *et al.* 1988, p. 71: "Trilete camerate miospores; amb rounded triangular with convex sides. Suturae distinct to obscure, bordered by flexuous ray folds up to 7µm in height and extending almost to the equator where curvaturae imperfectae and developed. Distal surface and equatorial region of the exoexine ornamented with short spines coni and grana, elements up to 5µm in height, discrete and evenly but not densely distributed. Intexine distinct, laevigate ¾ or more of the overall diameter and appears to be attached to the exoexine on the proximal surface only".

Size range: (i) Overall diameter 62 – 93µm, inner body 47 – 70µm (12 specimens); Canada, Hacquebard 1957.

(ii) 58 – (64) - 75µm (specimens) Higgs *et al.* 1988, Tournaisian of Ireland.

(iii) 56 – (64) - 70µm (number of specimens counted not-reported); Coleman 1991.

Present Study: Exoexine 65 – (74) - 85µm; Intexine 50 – (64) – 70µm (based on 9 specimens).

Range: LL – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrences in USA: (i) Bedford Shale, Sunbury Shale formations and lower Borden Formation (Henley & Farmers members), Kentucky (PC Biozone); Coleman & Clayton 1987.

(ii) Cuyahoga & Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Bedford Shale Formation – Big Walnut Creek & Three Locks Quarry, Ohio; (ii) Price Formation – Caldwell & Mylan Park, West Virginia.

Remarks: Specimens recorded in the present study are larger than those reported by Higgs *et al.* 1988 and Coleman 1991 but compare closely to those originally illustrated by Hacquebard (1957).

Grandispora macrotuberculata (Arkhangelskaya) McGregor 1973

Plate 9, figs. 2 & 4

?1963 *Hymenozonotriletes macrotuberculatus* Arkhangelskaya, p. 26, pl. XII, figs. 1-3.

?1963 *Hymenozonotriletes longus* Arkhangelskaya, p.27, pl.XIII, figs. 1-4.

?1965 *Perotriletes eximus* Allen, p.731, pl.102, figs. 11-13.

?1966 *Hymenozonotriletes longus* (Arkhangelskaya) McGregor & Owens, pl. VII, fig. 4.

1973 *Grandispora macrotuberculata* (Arkhangelskaya) McGregor 1973, pp. 59 -60, pl. 8, figs. 1-5.

1976 *Grandispora macrotuberculata* (Arkhangelskaya) Massa & Moreau-Benoit, pl.3, fig.7, tabl.-fig.5.

1980 *Grandispora macrotuberculata* (Arkhangelskaya) Moreau-Benoit, p. 34-35,

Hypotypes: McGregor 1973; Slides 7102-1-44.4 X 110.3 (pl.8, figs. 1 & 2), 7102-5-33.8 X 110.8 (pl.8, figs. 3 & 5) and 7102-1-60.1 X 119 (pl.8, fig.4).

Type locality: See Arkhangelskaya 1963.

Diagnosis: See Arkhangelskaya 1963.

Description: McGregor 1973, pp. 59-60: "Trilete, camerate miospores, amb of intexine and exoexine broadly subtriangular or irregular. Diameter of inner body (intexine) about ½ to 2/3 total spore diameter. Trilete mark distinct, sutures paralleled and obscured by elevated folds that may extend to the equator of the spore. Intexine apparently unsculptured, darker (? thicker) than exoexine. Proximal surface of exoexine laevigate, distal surface sparsely to

moderately densely ornamented with spines that are 1.5 - 4μm wide at their base, 2 -7μm long, subcircular in plan view.

Spines exhibit considerable variation in profile, being either broad or narrow-based, rounded- or acute-tipped, rarely with a median constriction, and most commonly tapered sharply near the tip and surmounted by a thin, hair-like extension about 1/3 to 1/2 as long as the broader basal part of the spine. Rarely, the small apical spine bears a minute bifurcation at the tip. On some specimens the spines are most densely distributed toward the distal pole. Radially oriented, fold or ridge-like structures about 4μm wide radiate outward from the body on the distal surface of some specimens".

Size range: 95 – (136) - 181μm (based on 44 specimens); Lower & Middle Devonian of Gaspé, Canada, McGregor 1973.

Present Study: Intexine 67μm; Exoexine 165μm (one measured specimen).

Occurrence: Battery Point Formation (Upper Assemblage); Lower & Middle Devonian of Gaspé, Canada, McGregor 1973. = Late Emsian – earliest Eifelian age *douglastownense – eurypterota* Zone of Richardson & McGregor (1986).

Present Study: Bedford Shale Formation – Three Locks Quarry, Ohio; Price Formation - Mylan Park, West Virginia.

Remarks: McGregor (1973) distinguished *G. ?macrotuberculata* and *G. douglastownense* based on the fact the latter taxon possessed longer spines. He noted that *G. douglastownense* always had at least some spines greater than 8μm in length. However, recent work by Wellman & Gensel (2004) would suggest that these two species may in fact represent end members of the same spore complex. Wellman & Gensel differentiate two distinct end members: (i) with spines < 8μm in length; (ii) dominated by large spines up to 17μm in length. However, a number of specimens 'straddle' the critical 8μm and exhibit a variety of spine lengths. The single specimen recorded in the present investigation possesses an ornament which consists primarily of short, broad-based spinae, typically 3 - 11μm long. This specimen is thus more closely comparable to those assigned to *G. ?macrotuberculata* by Wellman & Gensel. The fact that the specimens recorded in the present investigation are found in uppermost Devonian/ lowermost Mississippian strata would suggest that they are reworked from older assemblages.

Grandispora megaformis (Richardson) McGregor 1973

Plate 9, figs. 3

1965 *Samarisporites megaformis* Richardson, p.582, pl.92, fig.6.

1970 *Samarisporites megaformis* (Richardson) McGregor, Sanford & Norris, pl.II, fig.15.

1973 *Grandispora megaformis* (Richardson) McGregor, p.60 -61, pl.8, fig. 6 -7; text-fig. 33.

1976 *Grandispora megaformis* (Richardson) Massa & Moreau-Benoit, tabl.- fig. 5, pl.4, fig.3.

1976 *Grandispora megaformis* (Richardson) McGregor & Camfield, p.24, pl.7, fig.1 & 4.

1978 *Samarisporites megaformis* (Richardson) Donovan, Collins, Rowlands & Archer, p.87.

Holotype: Richardson, 1965, p.582, pl.92, fig.6.

Hypotype: McGregor 1973, slide 53030-C.

Type locality: Basal beds, loc. 11, Middle Devonian, Upper Eifelian, Richardson, 1965.

Diagnosis: Richardson, 1965, p.582: Large spores; ornament consists of rounded and pointed cones and warts on the central area and the zona.

Description: McGregor 1973, pp. 60-61: "Spores with broadly triangular amb. Trilete mark obscured by strong folds that extend to or nearly to the equator of the spore. Body (intexine) unsculptured, darker than equatorial extension (exoexine). Proximal surface of exoexine laevigate; distal and equatorial portions bear verrucae that are subcircular in plan view, rounded in profile, 4 -8μm wide at base, 2.5μm high, and commonly surmounted by an apiculate extension 1 – 1.5μm long and less than 0.5μm wide. Verrucae 2 - 8μm apart, about the same size and spacing all over the distal face. Number of verrucae at equator 25 and 32".

Size range: Diameter (exoexine) 216 & 220μm; body (intexine) 128 & 136μm (2 measured specimens; McGregor 1973.

Present Study: Exoexine 155 - 175μm; Intexine 70 - 85μm (based on 2 specimens).

Occurrence: Malbaie Formation, Gaspé, Canada, McGregor 1973.

Present Study: (i) Bedford Shale Formation, Big Walnut Creek, Ohio (LN Biozone); (ii) Price Formation, Mylan Park, West Virginia (PC Biozone).

Remarks: The two specimens of *Grandispora megaformis* figured by McGregor 1973 are larger than those assigned to *G. ? macrotuberculata*, and possess larger, more rounded verrucae. Specimens figured in the present study are also larger than those of *G. ? macrotuberculata* figured herein, and also possess an ornament of large, rounded verrucae, typically 6- 8μm wide. McGregor (1973, p.61) notes that specimens intermediate between the two species may eventually be found, leading to a combining of the taxa.

Genus RADIIZONATES Staplin & Jansonius 1964

Type species *Radiizonates aligrens* (Knox) Staplin & Jansonius 1964

Radiizonates mirabilis (Knox) Phillips & Clayton 1980

Plate 11, figs. 21 & 22

Diagnosis: As description in Higgs *et al.* 1988: "The thickened margins of the zona are normally 1 - 4μm wide. The radiating ribs on the zona are of similar width and are well-defined. 5 – 20 radiating ribs are typically present, most of which reach the outer thickened zona, but in some specimens, the ribs are discontinuous or absent. In these specimens the ribs die out in the central part of the zona, or are totally absent. The coni and grana on the distal surface and equator of the spore are 0.5 - 3μm high and are discrete, or coalesce to form short cristae".

Size range: 48 – (68) - 97μm (based on 17 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: 50 – (70) - 75μm (based on 10 specimens).

Occurrence: PC – CM biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: Price Formation – Mylan Park, West Virginia.

Genus RETISPORA Staplin 1960

Type species *Retispora florida* Staplin 1960

Remarks: This genus forms a suitable repository for camerate spores with a distal reticulum.

Retispora macroreticulata (Kedo) Byvscheva 1985

Plate 8, figs. 1 & 6

1970 *Hymenozonotriletes* aff. *H. archaelepidophytus* (Kedo) Paproth & Streel, pl.25, figs. 2-3.

1970 *Hymenozonotriletes lepidophytus* (Kedo) Utting & Neves, pl.28, figs 1-2.

1973 *Hymenozonotriletes lepidophytus* (Kedo) Allen, *in* Gayer *et al.* 1973, pl.15, fig, J.

1975a *Spelaeotriletes cassiculus* Higgs p. 100, pl. 9 figs. 1 – 3

1975b *Hymenozonotriletes cassiculus* Higgs p. 399, pl. 5 figs. 1 - 3

1978 *Spelaeotriletes cassiculus* (Higgs) Turnau p .11, pl. 5, fig. 3.

1981 *Retispora cassicula* (Higgs) Higgs & Russell, p. 38.

1985 *Retispora macroreticulata* (Kedo) Byvscheva

1988 *Retispora cassicula* (Higgs) Higgs *et al.*, p. 72, pl. 11, fig. 11.

Holotype: Higgs 1975b, pl.3, fig. 3, sample K.

Type locality: Sample HK, Old Red Sandstone, Hook Head, County Wexford, Ireland.

Diagnosis: Higgs 1975b, p.100: "Trilete camerate miospores; amb subcircular to rounded triangular. Suturae distinct to obscure, sinuous, accompanied by flexuous ray folds 4–15μm in height extending to spore margin and terminating in curvaturae. Exoexine ornamented with low muri 1 - 3μm in width and up to 2μm in height, in many cases bearing small coni and rare spinae, forming a reticulum composed of subcircular, polygonal, and irregular lumina. Equatorial margin of exoexine extended to form a light-coloured, thin zona 4 - 9μm in width. Intexine distinct, 1 - 2.5μm in thickness, laevigate or scabrate, comprising one-half to two thirds of total spore diameter. Outline slightly more circular than amb, in many cases. Outline slightly more circular than amb, in many cases eccentrically placed and attached to exoexine on proximal surface only. Exoexine infragranulate; arcuate compression folds common".

Size range: Exoexine 110 – (154) - 220μm; intexine 80 – (105) - 140μm (based on 37 specimens); Higgs 1975b, p.399.

Present Study: Exoexine 102 – (134) - 165μm; intexine 51 – (67) - 81μm (based on 5 specimens).

Range: LL – LE Biozones (Old Red Sandstone facies only); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Lower Price Formation (LN Biozone – reworked?) - Mylan Park, West Virginia.

Remarks: This species differs from *R. lepidophyta* (Kedo) Playford 1976 by being much larger in overall size and possessing a coarser reticulum.

Retispora lepidophyta (Kedo) Playford 1976

Plate 8, figs. 2-5

1957 *Hymenozonotriletes lepidophytus* Kedo p. 24, pl. 2, fis. 19-21.

1958 *Hymenozonotriletes lepidophytus* Kedo, p. 24, pl. 2, fig. 19-21.

1958 *Hymenozonotriletes molestus* Ishchenko, pl. 7, fig. 82.

1958 *Hymenozonotriletes mentitus* Ishchenko, pl. 7, fig. 83.

1962 *Leiozonotriletes naumovae* Balme & Hassell, p. 18, pl. 4, figs. 10-12

1962 *Endosporites lacunosus* Winslow, p. 44, pl. 16, figs. 1-5.

1962 *Archaeozonotriletes fenestratus* Caro-Moniez, p. 113, pl. 16, fig. 19.

1962 *Archaeozonotriletes microreticulatus* Caro-Moniez, p. 113, pl. 16, fig. 19.

1962 *Hymenozonotriletes reticulatus* Caro-Moniez, p. 114, pl. 17, figs. 9-10.

1963 *Hymenozonotriletes lepidophytus* Kedo var. *tener* Kedo, p. 59, pl. 5, fig. 110.

1964 *Leiozonotriletes* sp. Wray, pl. 1, fig. 25.

1966 *Remysporites lepidophytus* (Kedo) Luber *in* Porkrovskya *et al.*, pl. 40, fig. 14.

1966 *Hymenozonotriletes lepidophytus* Kedo; Owens & Streel, pl. 4, fig. 52, 54.

1969 *Hymenozonotriletes lepidophytus* Kedo; Lanzoni & Magloire, pl. 6, fig. 18-19.

1974 *Spelaeotriletes lepidophytus* (Kedo) Streel *in* Becker et al., p. 26.

1976 *Retispora lepidophyta* (Kedo) Playford, p. 45, pl. 10 figs. 1-15.

Holotype: Kedo 1957, pl. 94, fig. not designated.

Type locality: Upper Famennian/ Lower Tournaisian of Byelorussian S.S.R.

Diagnosis: See Kedo 1957.

Description: From Higgs *et al.* 1988: "Trilete camerate miospores; amb convexly triangular to subcircular. Suturae distinct, straight to slightly sinuous and often accompanied by labra up to 4µm in width. Length of the suturae almost to the spore margin, and terminating in curvaturae imperfectae. Intexine distinct, laevigate to finely granulate, outline conformable with amb. The intexine forms a central body, ½ to ¾ of the total spore diameter, which is sometimes eccentrically positioned and is attached to the

exoexine on the proximal surface only. The exoexine is ornamented with a distal reticulum, which consists of subcircular, polygonal or irregularly shaped lacunae separated by thin muri. The muri are 0.5- 2μm in width and often bear a small ornament of coni and/ or spinae 0.5 - 2μm in height; the muri may break down to form irregular rugulae, coni or small verrucae. The lacunae measure 1 - 4μm in diameter and are often variable in shape and size on one specimen. Exine may bear an equatorial limbus, and taper point compression folds. Three apical papillae are sometimes present".

Size range: 40 – (57) - 92μm (based on 200 specimens); Higgs *et al.* 1988.

Present Study: Intexine 30 – (42) – 68μm; Exoexine 40 – (67) - 92μm (based on 31 specimens).

Range: (i) LL – LN biozones; Tournaisian of Ireland, Higgs *et al.* 1988

(ii) Bedford Shale Formation, Kentucky, USA, Coleman & Clayton 1987.

Present Study: (i) Bedford Shale Formation, Williams County, Ohio; (ii) Bedford Shale – Berea Sandstone – Big Walnut Creek & Three Locks, Ohio; (iii) Three Lick Bed – Morehead (Three Lick type section) & Clay City Quarry, Kentucky; (iv) Price Formation - (Cloyd Conglomerate Member), Caldwell, West Virginia; (v) Price Formation – Mylan Park, West Virginia.

Remarks: The range top of this species is well documented to coincide with the Devonian/ Carboniferous boundary. However, in the present investigation specimens of this taxon are found to occur above the inferred position of the boundary. Based on the numerous other reports of anomalous occurrences of the species, such specimens are considered to be reworked (see Chapter 9).

Genus RUGOSPORA Neves & Owens 1966

Type species *Rugospora corporata* Neves & Owens 1966

Rugospora flexuosa (Jushko) Streel 1974

Plate 9, figs. 5-7

1960 *Trachytriletes flexuosus* Jushko, table 1, fig. 4

1967 *Hymenozonotriletes famenensis* Kedo; Neves & Dolby, pl. 2, fig. 3.

1974 *Rugospora flexuosa* (Jushko) Streel *in* Becker et al., p. 27, pl. 21, figs 8-11.

1976 *Trachytriletes radiatus* Byvscheva, pl. 14, figs. 17-18.

Holotype: Jushko 1960, table 1, fig. 4.

Type locality: Podmoskov Basin, USSR; Upper Tournaisian.

Diagnosis: See Jushko 1960.

Description: Higgs *et al.* 1988: "Trilete camerate miospores; amb convexly triangular. Suturae distinct, straight to slightly sinuous, bordered by labra and extending almost to the spore margin. Exine two layered, although separation of exinal layers is often barely discernible. Exoexine extends 2 -3μm beyond the intexine at the equatorial margin. Intexine conformable with amb, laevigate or with fine folds which terminate at the edge of the body. Exoexine bears dense ornament of rugulae up to 3μm in width; rugulae are radially, irregularly or sinuously arranged often bearing small subcircular thickenings along their length. Exoexine often infragranulate".

Size range: 40 – (62) - 80μm (based on 64 specimens).

Present Study: 51 – (62) - 78μm (based on 25 specimens).

Range: (i) LL – LN Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

(ii) Samples 1-2, Bedford Shale Formation, Kentucky (LN Biozone); Coleman 1991.

Present Study: (i) Bedford Shale Formation – Williams County, Ohio; (ii) Bedford Shale – Berea Sandstone formations – Three Locks Quarry, Ohio; (iii) Three Lick Bed – Clay City Quarry, Kentucky; (v) Price Formation – Caldwell & Mylan Park, West Virginia.

Remarks: This species is characterised by an irregular and often chaotic distal of rugulae on the distal surface; similar spores with radially aligned rugulae are assigned to *Rugospora radiata* (Jushko) Byvscheva. Avchimovitch *et al.* (1988, p.173) note that *R. flexuosa* is often more circular in shape and possesses simple suturae.

Rugospora polptycha Neves & Ioannides 1974.

Plate 8, fig. 8

Holotype: Neves & Ioannides 1974, p.80, pl.2, MPK278.

Type locality: Sample at 2563ft. (781.2m) in the Spilmersford Borehole, East Lothian, Scotland; Lower Carboniferous (Mississippian).

Diagnosis: Neves & Ioannides 1974, p.80: "Spores radial, trilete, camerate; amb subcircular to triangular, suturae usually obscure, thin, sinuous, reaching margin of inner body. Diameter of inner body 33 – 93.5μm, usually eccentric in relation to spore outline; intexine thin and laevigate. Exoexine laevigate to infrapunctate; extends beyond body

margin by up to 12μm; bears an irregular pattern of distinctive folds the crests being bisected by longitudinal grooves; folds up to 6.5μm wide meandering and ramifying".

Description: Neves & Ioannides 1974, p.80: "Amb subcircular. Specimen obliquely compressed; size 94.5 μm; suturae of the trilete mark obscure but associated with folds which run to spore outline. Exoexine overlaps intexine by 12μm where least distorted. Distal surface over central body completely covered by tightly interwoven, anastomosing folds which decrease in intensity toward overlap zone".

Size range: (i) 48 – (76) - 110μm (20 specimens) Neves & Ioannides 1974.

(ii) 48 – (67) - 94μm (40 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 66 - 105μm (3 specimens).

Range: (i) Below the igneous rocks at Spilmersford (Tournaisian & Viséan); Neves & Ioannides 1975.

(ii) HD – CM biozones (rare in HD); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Samples MP23, 27 & 34, Price Formation – Mylan Park, West Virginia (rare).

Remarks: The specimens recorded conform to the original diagnosis.

Rugospora radiata (Jushko) Byvscheva 1985

Plate 9, figs. 9-12

1960 *Camptotriletes radiatus* Juschko, p.128, pl. 2, fig. 26.

1974 *Trachytriletes radiatus* (Juschko) Kedo, p. 7, pl. 1, fig. 1.

1975 *Rugospora famenensis* (Kedo) Higgs, p. 95, pl. 8, figs. 8-9.

1976 *Trachytriletes radiatus* (Juschko) Byvscheva, pl. 14, figs. 17-18.

1985 *Rugospora radiata* (Juschko) Byvscheva, p. 148 – 149, pl .30, fig. 6 -8.

Holotype: Jushko, 1960, p.128, pl. 2, fig. 26.

Type locality: Podmoskov Basin, USSR; Tournaisian.

Diagnosis: See Jushko 1960.

Description: Trilete camerate miospores. Amb subcircular to convexly triangular. Suturae distinct, straight, occasionally slightly sinuous, bordered by labra 2- 3μm wide, extending to the spore margin. Exine two layered, in some cases cameration indiscernible. Exoexine commonly extends 3- 6μm beyond the intexine along the equator margin of the spore, although the cameratation of this taxon often imperceptible. Intexine typically laevigate

and conformable with the amb. Exoexine bears a dense ornament of verrucae and irregularly arranged sinuous rugulae. Exoexine occasionally infragranulate.

Size range: 57 – (65) – 69 (based on 31 specimens).

Range: (present study) (i) Bedford Shale Formation – Williams County core, Big Walnut Creek and Three Locks, Ohio; (ii) Three Lick Bed – Morehead (Three Lick type section) & Clay City Quarry, Kentucky; (iii) Price Formation – Caldwell & Mylan Park, West Virginia.

Remarks: This species is distinguished by possessing a distal ornament consisting of dense rugulae which are arranged in a characteristic radial pattern. As noted by authors including Byvscheva *et al.* (1983) and Avchimovitch *et al.* (1988), this species has been persistently misidentified by western palynologists. Following recommendations by Byvscheva (1985), specimens with radially aligned rugulae are assigned to *R. radiata* (Jushko) Byvscheva in the present study. Those specimens possessing a distal ornament of chaotic and irregular rugulae are assigned to *R. flexuosa* (Jushko) Streel. However, it would appear that both of these species perhaps represent end members of a morphometric continuum.

Genus SPELAEOTRILETES Neves & Owens 1966

Type species *Spelaeotriletes triangulus* Neves & Owens 1966

Spelaeotriletes balteatus (Playford) Higgs 1996

Plate 10, figs. 1-7

? 1962 *Punctatisporites logani* Winslow, p.61, pl.18, figs. 17-19.

1963 *Spinozonotriletes balteatus* Playford p. 657, pl. 94, figs. 4 -6.

1964a *Spinozonotriletes balteatus* (Playford) Sullivan, p.1256, pl.II, figs. 4-6.

1964b *Crassispora balteata* (Playford) Sullivan p. 376.

1970 *Crassispora balteata* (Playford) Kaiser, p.109, pl.24, fig.3.

1971 *Crassispora balteata* (Playford) Johnson & Marshall, pl.23, fig.4.

1971 *Grandispora balteata* (Playford) Playford p. 46.

1975a *Spelaeotriletes balteatus* (Playford) Higgs p. 403, pl. 6, fig 10.

1996 *Spelaeotriletes balteatus* (Playford) Higgs, p.291-292, pl.6, fig.10.

Holotype: Playford 1963, pl. 95, fig. 4, preparation P149A/3 (77µm).

Type locality: Sample G1470, Triungen, Spitsbergen; Lower Carboniferous (Viséan) 'aurita assemblage zone'.

Diagnosis: Playford 1963, pp.657-8. "Spores radial trilete; amb roundly subtriangular to oval. Laesurae obscured by elevated, narrow, membranous, flange-like lips, frequently contorted due to compression and extending to limbare equatorial margin. Intexine indistinct to perceptible, roundly triangular. Distal surface of exoexine densely and uniformly sculptured with small, simple spinae which sometimes coalesce to form a rugulate pattern; spines usually evident at equator, sparsely scattered to absent on proximal surface. Spines have rounded to polygonal bases (diameter 0.5 – 2.5μm); length 1-2μm. Equatorial margin of exoexine marked by well-defined limbus 3.5 -7μm broad in polar view".

Description: Higgs *et al.* 1988, p.73: "Trilete camerate miospores. Amb rounded triangular. Trilete distinct to obscure, often accompanied by narrow sinuous labra Which extend to the equatorial margin and terminate in curvaturae. Proximal surface laevigate, except at the radial extremities. Distal Exoexine densely and uniformly ornamented with small, wide based coni. Ornament discrete and/ or coalesant forming low rugulae and cristae. Intexine perceptible, but often indistinct, conformable with amb. Size of Intexine typically ½ to ¾ the overall spore diameter. Equatorial margin of Exoexine frequently darkened".

Size range: (i) 51 – (73) - 102μm (40 specimens), Playford 1963.

(ii) Exoexine 42 - 92μm; Intexine 30 - 62μm; Tournaisian of Ireland, Higgs *et al.* 1988.

(iii) Exoexine 36 – (71.2) - 109μm; Intexine 20 – (45) - 80μm (based on 45 specimens); Brittain & Higgs 2009.

Present Study: Exoexine 42 – (56) - 78μm; Intexine 25 – (37) - 49μm (based on 36 specimens).

Range: BP – CM; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: (i) Borden Formation (Henley to Cowbell members), Kentucky (PC Biozone); USA, Coleman & Clayton, 1987.

(ii) Cuyahoga and Logan Formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Coldwater Shale Formation – Williams County core, Ohio. (ii) Price Formation (upper un-named Price Fm.) - Caldwell roadcut, West Virginia. (iii) Uppermost Rockwell and Burgoon Sandstone formations, Pennsylvania.

Comparison: *Spelaeotriletes obtusus* Higgs 1975a is similar to *S. balteatus*; the former differs from the latter in possessing non-apiculate ornament. *Spelaeotriletes cabottii* Utting *et al.* is closely comparable to *S. balteatus* but is distinguished based on its coarser ornament of very small verrucae and mammillae. Specimens of *Punctatisporites logani* Winslow 1962 from the Lower Mississippian strata of Ohio appear to be very similar to *S. balteatus*. However, specimens illustrated by Winslow appear to lack a central body, and thus are only tentatively compared with S. balteatus.

Remarks: Specimens of *S. balteatus* recorded in the present study are closely comparable to those illustrated by Brittain & Higgs (2009). However, the specimens described herein are consistently smaller than those described by those authors.

Spelaeotriletes cabottii Utting, Keppie & Giles, 1989

Plate 10, figs. 9-12

1989 *Spelaeotriletes cabottii* Utting, Keppie & Giles, p. 133, pl. 5.3, figs. 8-13 & 15.

Holotype: GSC89954, slide 7, 12.7x94.3, GSC loc. C-146224, pl.5.3, fig.8.

Type locality: Horton Group, Nova Scotia, Eastern Canada.

Diagnosis: Utting *et al.* 1989, p.133: "Trilete, camerate, amb subtriangular with rounded apices and convex to almost straight sides. Outline of intexine poorly defined, almost parallel to amb, intexine very thin. Diameter of inner body approximately 50 to 80 per cent of overall diameter. Trilete rays virtually straight, extending almost to margin of intexine; associated folds up to 2μm in height reach equator, sinuous in outline. Curvaturae imperfectae rarely visible. Exoexine infragranulate, approximately 2μm thick. Ornament on distal surface consisting mainly of closely spaced verrucae, with subordinate coni, spinae and rarely bacula. Verrucae relatively low (1 - 2μm), broadly rounded, bases subcircular basal width (1.5 - 5μm); most verrucae bear a single minute conus or spina approximately 1μm high, with basal diameter 0.25 - 1μm.

Toward the pole, verrucae coalesce to form a regulate pattern in some specimens. Coni, spinae and rare bacula more abundant at equatorial margin than in centre".

Size: (i) Exoexine 49 – (69) - 93μm; Intexine 36 - (46) - 65μm (based on 35 specimens); Eastern Canada, Utting *et al.* 1989.

(ii) Exoexine 40 – (69.1) - 95μm; Intexine 25 – (45.6) - 63μm (based on 64 specimens); Tournaisian of Ireland, Brittain & Higgs 2009.

Present Study: Exoexine 39 – (60) - 75μm; Intexine 24 – (34) - 42μm (based on 13 specimens).

Occurrence: (i) - a) unnamed formation, Lakevale section; b) Rights River Formation (oil shales), Antigonish Basin; c) Horton Bluff Formation (lower, middle & upper members), Windsor Basin, Nova Scotia; d) Albert Formation, New Brunswick; Tournaisian, Eastern Canada, Utting *et al.* 1989.

(ii) Tournaisian of Ireland (upper PC Biozone); Brittain & Higgs (2009).

Present Study: Uppermost Coldwater Shale Formation – Williams County, Ohio (PC Biozone); (ii) Upper Price Formation – Caldwell, West Virginia (PC Biozone).

Comparison: *S. cabottii* is distinguished from *S. balteatus* based primarily on its ornament of verrucae and mammillae. *S. pretiosus* (Playford) Neves & Belt possesses a similar ornament, however, is differentiated from *S. cabottii* based on its larger size and the maximum width of its ornament.

Remarks: Specimens recorded in the present study are consistently smaller than those described by Utting *et al.* (1989) and Brittain & Higgs (2009), however, are closely comparable in all other respects.

Utting *et al.* 1989 correlate the *S. cabottii* Subzone of Nova Scotia with the upper PC Zone of Western Europe. However, Brittain & Higgs (2009) have reported specimens of *S. cabottii* in the upper BP Biozone in South-eastern Ireland.

Spelaeotriletes galearis Brittain & Higgs 2009

Plate 10, figs. 13-16

Holotype: Plate 2I and K, (LBS10aX23), Brittain & Higgs 2009.

Type locality: Lumsdins Bay South, Hook Head, Co. Wexford, Ireland. 1 metre below the top of the Houseland Sandstone Member, Porter's Gate Formation.

Diagnosis: Brittain & Higgs 2009: "Trilete, camerate miospores. Amb rounded to convexly triangular. Trilete distinct to indistinct with sinuous labrae extending to the equatorial margin and terminating in curvaturae. Exine infragranulate, 2-3 μm thick at the equator. Distal surface of exoexine and equatorial margin densely ornamented with regularly distributed galeae; subordinate spinae and coni may also occur. Elements normally discrete and well spaced, but bases may be fused. Ornament basal diameter 1 -10 μm; height 0.5 -5 μm, holotype height 1 -5 μm; basal diameter 1.5 -4 μm. Intexine thin,

laevigate, forming 50 -75 of total spore diameter, but often poorly discernable due to density of ornament".

Description:

Size Range: Exoexine 60 – (81.8) - 104μm, *Holotype* 81μm; Intexine 40 – (53) - 72μm, *Holotype* 51.3μm (based on 17 specimens); Brittain & Higgs 2009.

Present Study: Exoexine 57 – (64) - 78μm; Intexine 27 – (37) - 51μm (based on 13 specimens).

Occurrence: Uppermost Houseland Sandstone & Lyraun Cove Shale members (Portersgate Formation), Hook Head, Co, Wexford, Ireland - Tournaisian (Upper PC Biozone), Brittain & Higgs (2009).

Present Study: Uppermost Coldwater Shale Formation – Williams County, Ohio (PC Biozone); (ii) Upper Price Formation – Caldwell, West Virginia (PC Biozone).

Comparison: Similar species include *S. cabottii* and *S. pretiosus,* however, these species can be distinguished by their predominantly mammilate ornament. *Spelaeotriletes ybertii* (Marques-Toigo) Playford *et al.* 2001 is also similar but can be distinguished by its more diverse ornament of baculae, galeae, coni and occasional spinae.

Remarks: This species is distinguished from other members of the genus by its predominantly galeate ornament.

Spelaeotriletes pretiosus (Playford) Neves & Belt 1970.

Plate 10, figs. 17-24

1964 *Pustulatisporites pretiosus* Playford p. 19, pl. 4, figs. 9-7; pl. 5, fig.1: text fig 1a.

1969 *Pustulatisporites* cf. *pretiosus* Playford in Lanzoni & Magloire, p. 454, pl. 1, figs. 17-19.

1970 *Spelaeotriletes pretiosus* (Playford) Neves & Belt, p.1241.

1987 *Spelaeotriletes pretiosus* var. *pretiosus* (Playford) Neves & Belt) Utting, pp.33-35, pl. 4, figs. 1-8.

Holotype: Playford 1964, pl.IV, fig.6, GSC.no.13109 (156μm).

Type locality: GSC.loc.6407, West shore of Avon River (325ft. South of Blue Beach Fault); Cheverie Formation, Horton Group, Nova Scotia, Mississippian.

Diagnosis: Playford 1964, pp.19-20: "Spores radial, trilete; amb subtriangular with rounded apices and convex to almost straight sides. Laesurae extend to equatorial margin or almost so; often totally obscured by conspicuous, elevated, flexuous lips. Distal surface exhibits diverse sculpture of mainly verrucae, accompanied by subordinate grana and coni and, less frequently, by small spinae. Sculpture usually sparsely and irregularly distributed, often evident at equatorial margin. Verrucae relatively low, broadly rounded, sometimes bearing a single minute conus or spina. Bases of verrucae subcircular, usually discrete but may be fused in groups of up to three individuals. Basal width of verrucae 1.5 - 8μm, height 1 -4μm. Apart from distal sculpturing elements, exine is finely and densely infragranulate, 2 - 3μm thick. Irregular secondary folding common. Mesosporoid occasionally perceptible as an ill-defined, darker, "central body" which is more or less conformable with equator and is roughly ¾ of overall diameter".

Emended diagnosis: Utting 1987, p.34: "Trilete camerate, amb subtriangular with rounded apices and convex to almost straight sides. Outline of intexine or inner body poorly defined, almost parallel to amb outline, intexine very thin. Radius of inner body approximately 50 to 80% of overall diameter. Trilete rays virtually straight extending almost to margin of intexine; associated folds up to 12μm high reach equator, sinuous in outline. Curvaturae imperfectae generally visible. Exoexine infragranulate approximately 2μm thick. Ornament on distal surfaces consisting mainly of verrucae, with subordinate grana and coni and, less frequently, small spinae; elements usually sparsely and irregularly distributed, often evident as equatorial margin. Verrucae relatively low, broadly rounded, sometimes bearing a single minute conus or spina. Bases of verrucae subcircular, usually discrete or fused in groups of up to three individuals. Basal width of verrucae 1.5 to 8μm, height 1 to 5μm. Irregular secondary folding common".

Size range: (i) Exoexinal diameter 98 – (149) - 195μm (115 specimens); Playford 1964.

(ii) Exoexine 68 - 110μm; Intexine 35 - 70μm (27 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

(iii) Exoexine 98 – (103) - 120μm (based on 28 specimens); Tournaisian of Ireland, Brittain & Higgs 2009.

Present Study: Exoexine 69 – (80) - 145μm; Intexine 40 – (47) - 107μm (based on 31 specimens).

Range: PC – CM Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: (i) Borden Formation (Henley to Cowbell members); Kentucky, USA, Coleman & Clayton, 1987.

(ii) Cuyahoga & Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Coldwater Shale Formation, Ohio. (ii) Price Formation (upper un-named Price Fm.); Caldwell roadcut, West Virginia. (iii) Price Formation (upper) Mylan Park Borehole, West Virginia. (iv) Rockwell Formation (uppermost) – Burgoon Sandstone Formation, Pennsylvania.

Remarks: Specimens of *S. pretiosus* recorded in the present investigation are smaller than those recorded by Playford (1964) but are closely comparable to those described from Ireland by Higgs et al, (1988) and Brittain & Higgs (2009).

Spelaeotriletes sp. A

Plate 10, fig. 8

Description: Trilete, camerate miospores. Amb subtriangular. Trilete distinct, bordered by slightly sinuous labra, ~5µm, extending to the edge of intexine. Inner spore body distinct, conformable with amb. Distal spore body and equatorial margin densely ornamented with verrucae, mammillae and occasional coni. Ornament ranges for 4 - 8µm wide and 4 - 6µm in height along the equatorial margin of the spore.

Size range: Exoexine 66µm; intexine 54µm (based on 1 specimen).

Occurrence: Upper Coldwater Shale Formation (Upper PC Biozone) – Williams County, Ohio.

Remarks: This species can be distinguished from *S. pretiosus* based on its smaller size and the density of its ornament.

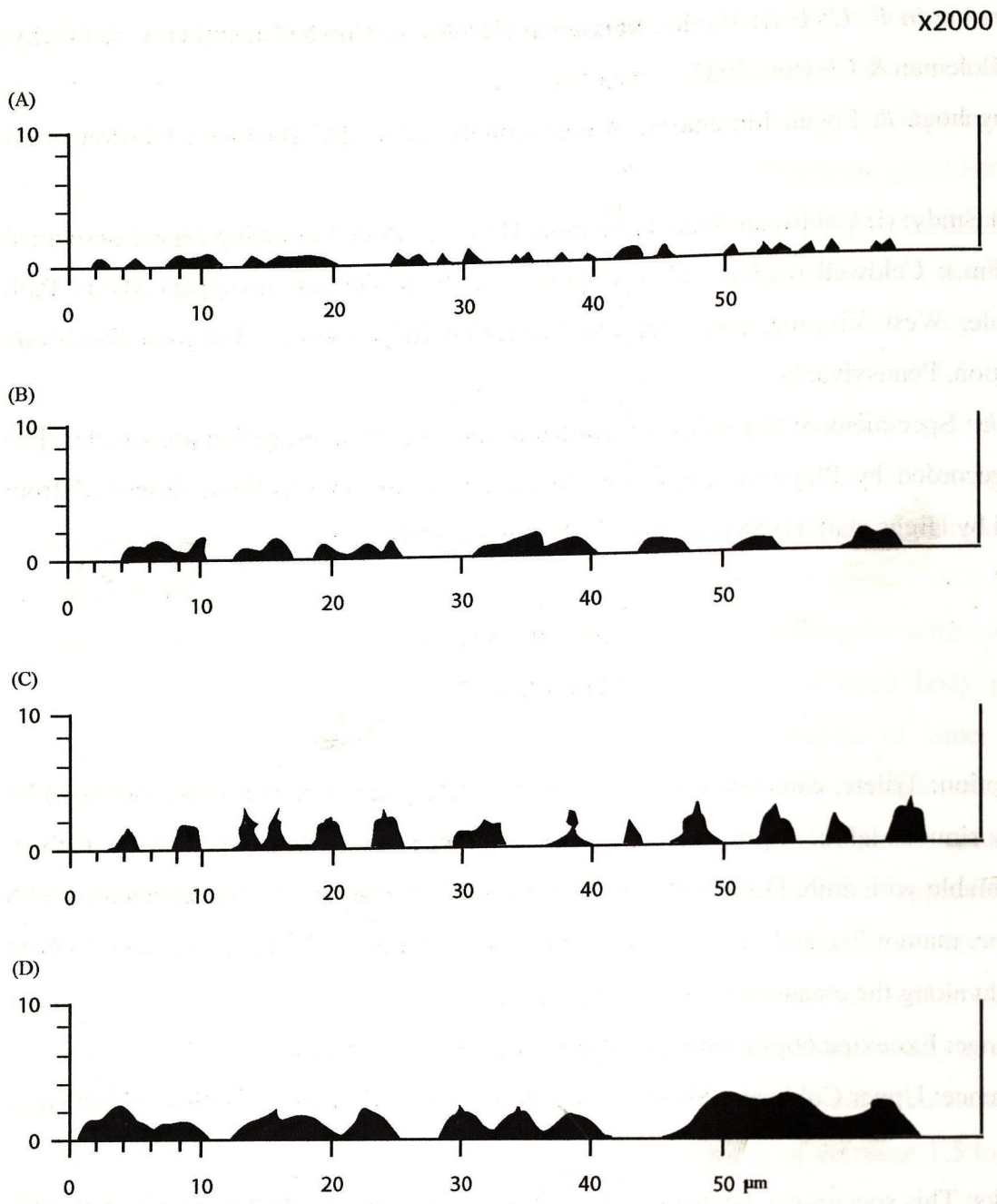


Figure 6.3 Comparison of ornament in four species of *Spelaeotriletes*: A) *S. balteatus* B) *S. cabottii* C) *S. galearis* D) *S. pretiosus.*

Genus SPINOZONOTRILETES Hacquebard emend

Neves & Owens 1966

Type Species *Spinozonotriletes uncatus* Hacquebard 1957

Plate 7, figs. 1-3

Holotype: Hacquebard 1957, plate 3, fig. 8; M 101, Slide 1.

Type locality: Horton Group, Nova Scotia, West Gore and Blue Beach samples.

Diagnosis: As description in Hacquebard 1957, p. 316: "Spores radial; convexly subtriangular in proximal view; trilete distinct, rays flange-like, extending to the equator; central body margin not distinct, fairly dense; perispore thick, forming a dense flange 12 - 25μm wide; perispore surface smooth but carrying stout spines 4-15 (20) μm long, 3 – 6μm wide at base, sharply pointed, tips often bent over; about 21 spines occur at equator".

Size range: (i) Diameter 82 – 148μm (exclusive of spines), body 62 – 103 μm (9 specimens); Hacquebard 1957.

(ii) 70-105μm (based on 20 specimens); Tournaisian of Ireland, Higgs *et al*. 1988.

Present study: 78 – (85) - 105μm (based on 7 specimens).

Range: LL – CM Biozones (Particularly common in the PC Biozone); Tournaisian of Ireland, Higgs *et al*. 1988.

Present study: Price Formation (LN – PC biozones) - Mylan Park, West Virginia.

Remarks: Specimens recorded in the present investigation conform closely to the original diagnosis.

Spinozonotriletes impensus Higgs *et al*. 1988

Plate 7, fig. 4 & 5

1979 *Spinozonotriletes* sp. A. Welsh, pl. 1, fig. 10.

Holotype: Plate 14, fig. 16, Higgs *et al*. 1988.

Type locality: Sample P35, Depth 1378', borehole DM64, Killarecastle, 6.5km northeast of Moate, County Westmeath, Ireland.

Diagnosis: Higgs *et al*. 1988, p. 77: "Miospores trilete, camerate. Amb subcircular to rounded triangular. Suturae indistinct to distinct, straight, bordered by ray folds up to 7μm in height, extending to the equator of the miospore, sometimes gaping, contact areas

occasionally thickened. Exoexine 2-6μm in thickness, bears prominent discrete spinae, which are normally sparsely, but occasionally densely distributed and very reduced on the proximal surface. The processes have broad or more commonly bulbous bases, 1 – 8μm in diameter, 5 - 25μm in length generally in the range 10 -15μm, tapering to a point which may be slightly curved. The remainder of the exoexine is laevigate to granulate with few low verrucae and coni; 1- 5μm wide and 1 to 3 in height. Intexine 1 - 3μm in thickness, distinct laevigate to granulate, outline approximately conformable with amb; diameter ½ to 9/10 of the miospore diameter, attached to the exoexine on both the proximal and distal surfaces. Compression folds uncommon".

Size range: 100 – (154) - 215μm, (based on 28 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Exoexine 120 - 225μm; Intexine 84 - 150μm (based on 2 specimens).

Range: HD – PC Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation - Mylan Park, West Virginia.

Remarks: *Spinozonotriletes impensus* is distinguished from *S. uncatus* by the larger size and smaller number of spinae.

Genus *Teichertospora* Balme 1988

Type species *Teichertospora torquata* (Higgs) McGregor &Playford, 1990

Generic Diagnosis: McGregor & Playford, 1990: "Miospores radial, trilete, cavate. Amb subtriangular to subcircular. Laesurae commonly lipped. Exoexine detached equatorially from intexine to form a saccus – like structure. Outer surface of exoexine laevigate; inner surface finely reticulate. Intexine laevigate, more or less symmetrically positioned with respect to encompassing exoexine; outline circular to broadly rounded subtriangular, characteristically more rounded than amb on given specimen and usually featuring marginal arcuate folds". (Adapted from Balme, 1988a, p. 163)

Teichertospora torquata (Higgs) McGregor & Playford, 1990

Plate 6, figs. 13-16

Auroraspora torquata Higgs, 1975a, p. 398, pl. 4, figs 1 -3.

Teichertospora cuvierica Balme, 1988a, p. 165- 166; pl. 1, figs. 1 -6; text fig. 2.

Teichertospora torquata McGregor & Playford, 1990, p. 12 -14; pl. 1, figs 1 -7, pl. 2, figs 1 -9.

Holotype: Higgs 1975a, pl. 7, fig. 1; specimen no. ML.1102.

Type locality: Sample HK, Old Red Sandstone, Hook Head, Co. Wexford, Ireland.

Diagnosis: McGregor & Playford 1990: "Miospores radial, trilete, cavate. Amb subtriangular with rounded to slightly pointed apices and near straight, convex, or concave sides; rarely subcircular; periphery entire to broadly and often irregularly undulant. Laesurae distinct to perceptible, straight to sinuous, length two thirds of, to almost equal to, radius of inner (intexinal) body; frequently accompanied by slightly to distinctly elevated lips, < 4μm high, 0.6 – 3.5μm in overall width (but both width and height fairly constant on given specimen); lips may extend beyond laesurae as plications that reach or nearly reach equatorial margin. Exoexine 0.6 – 2.0μm thick, detached equatorially from intexine to form marginally inflated and continuous outer body characterised (in well preserved specimens) by internal, finely reticulate structure (endoreticulum) that is more conspicuously developed beyond exoexine contact with intexinal body; muri 0.4 – 1.0μm wide, enclosing rounded polygonal to subcircular lumina 0.2 – 4.5μm in diameter. Exoexine may display coarsely radial plications. Intexine 0.7 – 3.0μm thick, constituting inner body that is normally symmetrically placed within the exoexine but its outline, on a given specimen, tends to be distinctly more rounded in polar view (varying from subcircular to broadly rounded subtriangular). Intexine diameter ca. 50-80% of overall (exoexine) diameter. Intexine margin typically displays coarse, arcuate compression folds; surface may also be modified by fin to fairly coarse wrinkles, but is essentially laevigate".

Size range: (i) Exoexine 80-(123) -143μm; intexine 49-(69) - 88μm, (based on 37 specimens); Hook Head, southeast Ireland (type locality), Higgs 1975.

(ii) Exoexine 85 - (115) - 140μm; intexine 50 – (65) - 81μm, New York State and Pennsylvania, USA, Ahmed 1980.

(iii) Exoexine 72-(98) -129μm; intexine 47- (66) -87μm, (based on 26 specimens); Cape Cuvier No. 1 well, Carnarvon Basin, Western Australia, Balme 1988a.

(iv) Exoexine 95-(115) - 140μm; intexine 46 - (70) - 87μm, (21 specimens); SW New Brunswick, Canada, McGregor & McCutcheon 1988.

Present Study: Exoexine 74 – (88) - 170μm; intexine 42 – (66) - 75μm (based on 7 specimens).

Range: LL – LE Biozones; Strunian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: (i) Lower Sandstone Member, 'Pocono' Formation, Pennsylvania (? LE Biozone); Streel & Traverse 1978.

(ii) Gowanda – Knapp Formation, Pennsylvania & New York (*torquata – gracilis* Biozone – *R. lepidophyta – V. nitidus* LN Biozone); Richardson & Ahmed 1988.

Present Study: (i) Bedford Shale Formation – Big Walnut Creek & Three Locks Quarry, Ohio (LN Biozone); (ii) Price Formation – Caldwell & Mylan Park, West Virginia (LN, VI & PC Biozones).

Remarks: After examining a range of variably preserved specimens, McGregor & Playford (1990) recognised that *Auroraspora torquata* Higgs (1975 and *Teichertospora cuvierica* Balme (1988a) were conspecific and simply represent different preservational modes. The authors considered that this taxon should be more appropriately assigned to the genus *Teichertospora* Balme (1988a) than *Auroraspor*a Hoffmeister et al. 1955, since the latter does not possess an endoreticulate exoexine.

Genus VALLATISPORITES Hacquebard 1957
emend Sullivan 1964

Type Species *Vallatisporites vallatus* Hacquebard 1957

Note: Through much of the 1970's and 1980's there was considerable discussion in the palynological literature concerning the morphological concept of the stratigraphically important taxon *Vallatisporites pusillites*. Of particular interest was the relationship of this species with regard to other related taxa, particularly, *V. vallatus*, *V. verrucosus* and *V. hystricosus*. Discussions summarised by authors including Playford (1976) and Streel & Traverse (1978) focused primarily upon the nature and size of the ornamentation displayed by these species. However, such discussions proved inconclusive until clarification of the precise concept of the Russian taxon *V. pusillites* by Avchimovitch *et al.* (1988, pp. 174-175). Due to the uncertainty that existed prior to this publication, coarsely ornamented forms were commonly miss-assigned to *V. pusillites* (e.g. Dolby & Neves, 1970; Kedo & Golubcov, 1971; Higgs *et al.* 1988). Following clarification of the Russian concept of *V. pusillites* it is now apparent that larger ornamented forms should be assigned to *V. hystricosus*. In the present study, this convention is followed throughout.

Vallatisporites ciliaris (Luber) Sullivan 1964b

Plate 11, figs. 19 & 20

1938 *Zonotriletes ciliaris* Luber *in* Luber & Waltz, pl. 6, fig. 82.

1964b *Vallatisporites ciliaris* (Luber) Sullivan pl. 59, figs. 14 – 15.

Holotype: Luber in Luber & Waltz, 1938, pl.6, fig.82.

Type locality: Lower Carboniferous coals of the Karanga Basin, former USSR.

Diagnosis: Sullivan 1964b, p.370-371: "Size (18 specimens) 50 - 70 μm, mean 62μm. Amb triangular with convex sides and rounded apices, sometimes almost circular. Trilete rays indistinct on the intexine, tecta sinuous, extend to equator of the spore cavity. Exoexine folded above the rays, folds up to 5 μm high at the apex and decrease uniformly in height towards the equator. Folds may terminate at the equator of the spore cavity or continue on to the border. Intexine thin and transparent folded independently of the exoexine, frequently withdrawn from the margin of the spore cavity. Exoexine over proximal surface of the spore cavity is thin and without structure; over the distal surface it is thickened and possesses a well-marked infrapunctation. Ornamentation usually consists of cones with rounded or pointed crests, up to 3 μm high and 3.5 μm wide at the base. These cones are interspersed with other elements which consist of a sharply tapered spine on a broad bulbous base. Their shape is reminiscent of a spiked helmet or 'Pickel-haube' worn by the Prussian Guards and have been termed *galeae*. Elements of a similar shape are characteristic of certain genera of the *Malvaceae*, e.g. *Malvastrum*, *Gossypium*, and *Sida* whose pollen has recently been described and figured by Saad (1960). Galeae differ from mammillate elements by the length of the spine. In certain specimens of this species galeae form the dominant ornamentation. The equatorial portion of two-fifths of the total spore radius. The border appears bizonate: there is an inner light zone and an outer dark one. The boundary between the two is irregularly scalloped and close examination reveals that the light zone is formed by the lateral coalescence of adjacent vacuoles. In some areas the residual still separate the pyriform vacuoles and impart a radially patterned appearance to the light zone. A row of circular pits 0.5μm in diameter lies on the border immediately adjacent to the cuniculus".

Size range: 50 – (62) – 70 (18 specimens); Sullivan 1964b.

Present study: 66 - 70μm (based on 3 specimens).

Range: CM Biozone; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Samples 10 -19 Henley – Cowbell members (Borden Formation), Kentucky (PC Biozone); Coleman, 1991.

Present study: Price Formation – Mylan Park, West Virginia.

Remarks: Coleman (1991, p. 98) notes that there is considerable variation in specimens assigned to this species in Kentucky, with some specimens possessing nearly no ornament and others bearing coarse galeate elements grading towards *Vallatisporites galearis* Sullivan 1964b.

Vallatisporites hystricosus (Winslow)
Byvscheva, 1985
Plate 11, figs. 15 - 18

1962 *Cirratriradites hystricosus* Winslow, p. 40 – 41, pl. 18, fig. 5.

1962 *Cirratriradites* sp. A Winslow, p. 41, pl. 18, fig. 1 -2.

1963 *Hymenozonotriletes pusillites* Kedo; Kedo, pl .6, fig. 141, non fig. 138–140, 142

1970 *Vallatisporites pusillites* (Kedo) Dolby & Neves, pl. 2, fig. 1-2, non fig. 3-4.

1985 *Vallatisporites hystricosus* (Winslow) Byvscheva, p. 136.

1988 *Vallatisporites hystricosus* Avchimovitch, Byvscheva, Higgs, Streel & Umnova. pl.5, fig.14.

Holotype: Plate 18, fig. 5, locality 1, maceration 162, slide 10, collection 17- 2 –6 –53.

Type locality: Bedford Shale Formation, Cuyahoga County, Ohio.

Diagnosis: Winslow 1962, pp. 41- 42: "Spores trilete, 46 – 61μm in diameter, light to dark yellow; flange distinctly subtriangular to triangular to triangular in transverse outline; outline of spore body more rounded. Transverse plane nearly always corresponds to plane of sedimentary compression. Uncompressed spores oblate distally, flattened pyramidal proximally. Trilete rays usually distinct, some what sinuous, extending out onto flange; lips membranous, as much as 4μm in height at proximal pole. Equatorial flange, minutely serrate marginally, ranges from 6 to 16μm in width along the trilete rays and from 4.8 to 10μm in width interradially; often appearing radially plicate, some with thinner rod-shaped areas in denser part adjacent to spore body. Distal spore coat, 1 - 2μm thick. Distal surface of flange bearing sharply pointed spines 2 – 5.2μm long and 1.2 – 4.2μm in diameter basally".

Size range: 46 – 61μm; Upper Devonian & Lower Carboniferous (Mississippian) of Ohio, Winslow 1962.

Present Study: 50 – (65) – 75μm (based on 26 specimens).

Occurrence in E. USA: (i) Bedford Shale Formation at localities 1- 3, 6- 9 and Cuyahoga/ Black Hand (undiff.) at locality 7; Winslow, 1962.

(ii) Samples 1- 3, Bedford Shale Formation, Kentucky (LN Biozone); Coleman 1991.

Present Study: (i) Bedford Shale Formation – Williams County core & Three Locks quarry, Ohio; (ii) Three Lick Bed – Clay City Quarry, Kentucky; (iii) Price Formation – Caldwell & Mylan Park, West Virginia.

Remarks: Following recommendations made by Avchimovitch *et al.* (1988, p.175) specimens of *Vallatisporites* ornamented with spines and galeae, ranging from 3 - 16μm in height, are assigned to this species.

Vallatisporites pusillites (Kedo) Dolby & Neves
emend. Byvscheva 1985
Plate 11, figs. 1 - 4

1957 *Hymenozonotriletes pusillites* Kedo, pl. 22, fig 1. (holotype)

1963 *Hymenozonotriletes pusillites* Kedo; Kedo, p. 66, pl. 6, fig 138 – 140, 142, non fig.141.

1970 *Vallatisporites pusillites* (Kedo) Dolby & Neves, p. 639, pl. 2, fig. 3 – 4, non fig. 1-2

1985 *Vallatisporites pusillites* (Kedo) Dolby & Neves emend. Byvscheva, p. 135 – 136, pl. 27, fig. 1-3.

Holotype: See Kedo 1957 pl. 22, fig 1.

Type locality: See Kedo 1957 pl. 22, fig 1.

Diagnosis: See Kedo 1957.

Size range: 50 – 80μm (based on over 100 specimens); Tournaisian of Ireland, Higgs et al. 1988.

Present Study: 39 – (50) – 80 (based on 18 specimens).

Range: LL – LN Biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: Bedford Shale Formation (LN Biozone); Kentucky, USA, Coleman & Clayton, 1987.

Present Study: (i) Bedford Shale Formation – Williams County core, Ohio; (ii) Bedford Shale – Berea Sandstone – Big Walnut Creek & Three Locks Quarry, Ohio; (iii) Price Formation – Mylan Park, West Virginia.

Remarks: In the present study the name *V. pusillites* is used in the sense of Byvscheva (1985) as apposed to the much broader concept of the species as described by authors such as Dolby & Neves (1970) and Kedo & Golubcov (1971). The specimens described in the present study are typified by an ornament of small (< 3μm), sparsely distributed spines and therefore compare closely to the Russian material. Specimens with spines in excess of 3μm in length have been assigned to *Vallatisporites hystricosus*. However, since there is clearly a complete morphometric transition between both species the division between them is somewhat arbitrary.

Vallatisporites vallatus Hacquebard 1957

Plate 11, figs. 6 - 9

Holotype: Hacquebard 1957, plate 2, fig. 12, M 101, slide 5.

Type locality: Horton Group, Nova Scotia, West Gore and Blue Beach samples.

Diagnosis: Hacquebard 1957, p. 312 – 313: "Spores radial trilete; convexly subtriangular in proximal view; trilete usually distinct, lips slightly raised, extending to the equator or nearly so; central body thin, margin well defined, often folded; in central area, perispore has minute grana and small cones, 1- 2 μm in diameter , 2- 3 μm apart; perisporal extension with rampart-like inner part, up to 8 μm wide, and flange like outer part, 6 – 10μm wide; where the two parts meet, perispore is thickened and contains a single row of pits, visible in high focus; flange like portion has minute cones and small grana, membranous border, and finely toothed outer margin".

Size range: (i) Diameter 60 - 70μm, body 35 – 41 μm (5 specimens); Hacquebard 1957.

(ii) 50-(59)-70μm (based on 38 specimens); Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: 39 – (50) – 60 (based on 8 specimens).

Range: VI – CM Biozone (usually absent in the HD Biozone); Tournaisian of Ireland, Higgs *et al.* 1988.

Occurrence in E. USA: (i) Samples 10 -19, Henley Bed – Cowbell Member, Kentucky (PC Biozone); Coleman, 1991.

(ii) Cuyahoga Formation, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Coldwater Shale Formation – Williams County core, Ohio (PC Biozone); (ii) Bedford Shale/ Berea Sandstone – Big Walnut Creek & Three Locks Quarry, Ohio (LN Biozone); (iii) Price Formation – Caldwell & Mylan Park, West Virginia (VI - PC biozones).

Remarks: *Vallatisporites vallatus* is distinguished from similar species such as *V. pusillites*, based on its ornamentation, which typically consists of small (< 2μm), densely distributed coni, subordinate grana and/or spinae.

Vallatisporites verrucosus Hacquebard 1957

Plate 11, figs. 10 - 12

1957 *Vallatisporites verrucosus* Hacquebard, p.313, pl.2, fig.13.

1957 *Lycospora torulosa* Hacquebard, p.312, pl.2, fig.11.

Holotype: Hacquebard 1957, plate 2, fig. 13, M 101, slide 1.

Type locality: Horton Group, Nova Scotia, West Gore and Blue Beach samples.

Diagnosis: Hacquebard 1957, p. 313: "Spores radial, trilete; convexly subtriangular in proximal view; trilete not always distinct, extending to equator or nearly so; central body thin, margin well defined, often folded; in central area perispore is verrucose, with warts from 2- 4 (5) μm in diameter; perisporal extension with narrow, groove-like inner part; only 1 μm wide, and flange-like outer part 6-10 μm wide; where the two parts meet, perispore is thickened and contains a single row of pits, visible in high focus; flange- like portion is granulose, has membranous border and slightly undulating outer margin".

Size range: Diameter 55- 64μm, body 41 - 47 μm (based on 5 specimens); Hacquebard 1957.

Present Study: 38 – (47) - 65μm (based on 11 specimens).

Range: LN – CM Biozone (usually absent in the HD Biozone); Tournaisian of Ireland, Higgs *et al.* (1988).

Occurrence in E. USA: (i) Bedford Shale, Sunbury Shale and Borden formation, Kentucky (LN, VI & PC biozones); Coleman & Clayton *et al.*, 1987.

(ii) Cuyahoga & Logan formations, Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Bedford Shale & Coldwater Shale formations – Williams County core, Ohio; (ii) Bedford Shale Formation – Big Walnut Creek & Three Locks Quarry, Ohio; (ii) Price Formation – Caldwell & Mylan Park, West Virginia.

Remarks: Following Avchimovitch *et al.* (1988, p. 175), in the present study *V. verrucosus* accommodates forms with a dominantly verrucate ornament, although also accommodates specimens where the verrucae are fused into short 'chains' of rugulae, some of which possessing small spinose tips.

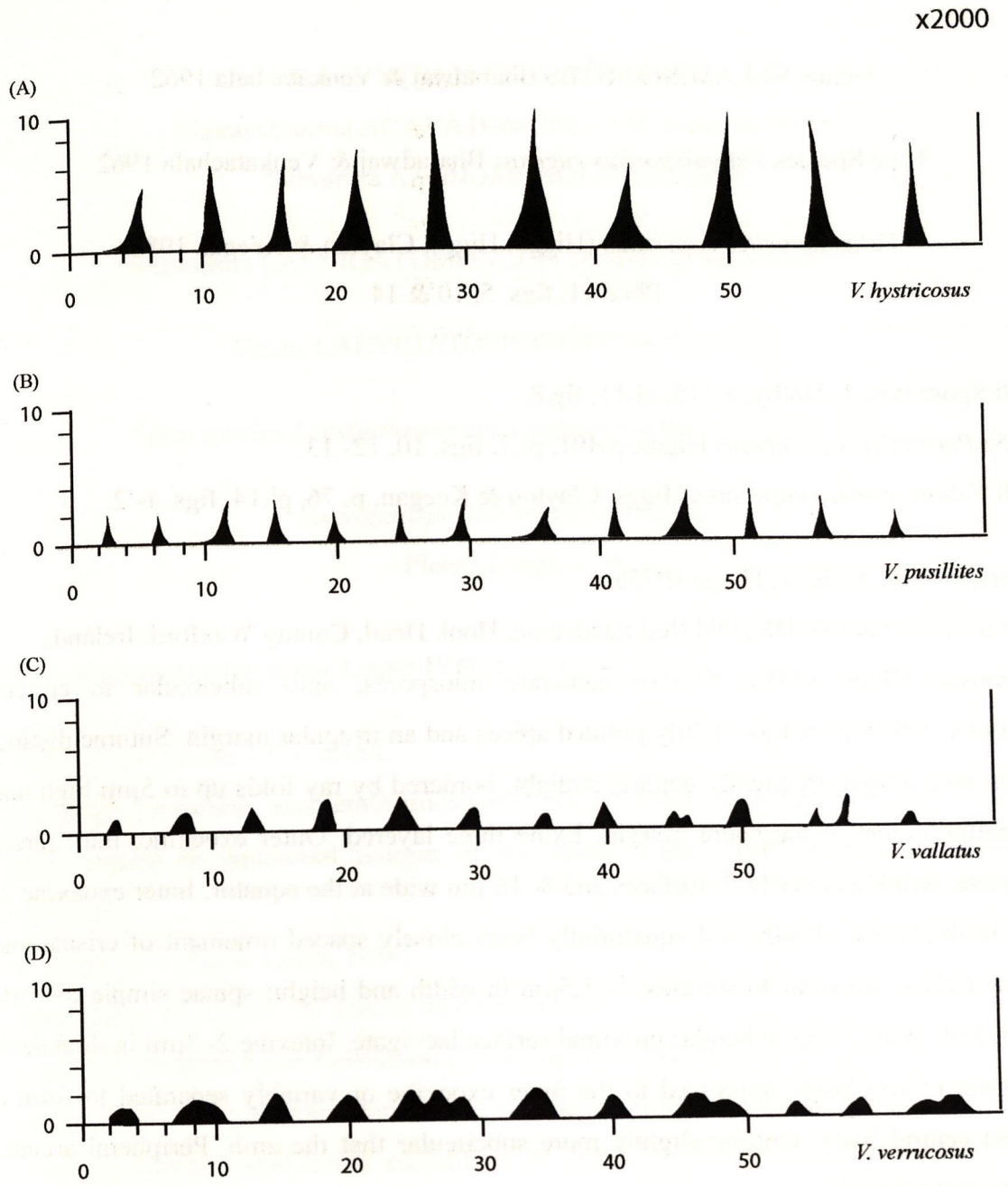


Figure 6.4 Comparison of ornament in four species of *Vallatisporites*: A) *V. hystricosus* B) *V. pusillites* C) *V. vallatus* D) *V. verrucosus.*

Genus VELAMISPORITES Bharadwaj & Venkatachala 1962

Type Species *Velamisporites rugosus* Bharadwaj & Venkatachala 1962

Velamisporites caperatus (Higgs) Higgs, Clayton & Keegan 1988

Plate 11, figs. 5, 10 & 14

1970 Spore type 1, Dolby, p.115, pl.11, fig.8.

1975a *Perotriletes caperatus* Higgs, p.401, pl.7, figs. 10, 12- 13.

1988 *Velamisporites caperatus* Higgs, Clayton & Keegan, p. 76, pl.14, figs. 1- 2.

Holotype: Plate 8, fig. 1, Higgs 1975a.

Type locality: Sample HK, Old Red Sandstone, Hook Head, County Wexford, Ireland.

Diagnosis: Higgs 1975a: "Trilete camerate miospores; amb subcircular to convex triangular with rounded to slightly pointed apices and an irregular margin. Suturae distinct to obscure, simple, frequently gaping, straight, bordered by ray folds up to 5µm high and extending almost to the spore margin. Exine three layered. Outer exoexine, thin, rarely complete, wrinkled over both surfaces and 8- 16 µm wide at the equator. Inner exoexine 2-4µm in thickness, distally and equatorially bears closely spaced ornament of cristae and spinae. Cristae irregular to sinuous, 1- 1.5µm in width and height; spinae simple of wide based, and up to 2.5µm in height; proximal surface laevigate. Intexine 2- 3µm in thickness, laevigate, often closely appressed to the inner exoexine or variably separated to form a distinct central body. Outline slightly more subcircular that the amb. Peripheral arcuate folding uncommon".

Size range: Outer exoexine 69 – (80) - 110µm; intexine 40 – (55) - 75µm (based on 40 specimens).

Present Study: Exoexine 48 – (80) - 96µm; intexine 42 – (78) - 91µm (based on 18 specimens).

Range: LL – LN biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present Study: Price Formation (LN & VI biozones) – Mylan Park, West Virginia.

Turma MONOLETES Ibrahim 1933

Suprasubturma ACAVATOMONLETES Dettman 1963

Subturma AZONOMONOLETES Luber

Infraturma LAEVIGATOMONLETI Dybová & Jachowicz 1957

Genus LAEVIGATOSPORITES Ibrahim 1933

Type species *Laevigatosporites vulgaris* (Ibrahim) Ibrahim 1933

Laevigatosporites minor Loose 1934

Plate 12, figs. 1 - 4

1934 *Laevigatosporites minor* Loose 1934, p. 158, pl.7, fig. 12.

Diagnosis: See Loose 1934, p.158.

Description: Monolete, acamerate miospores. Amb subcircular to oval. Suturae straight, simple, extend to equatorial margin of the spore. Exine, smooth, thin, laevigate or infrapunctate.

Size range: 35 - 64µm; Loose 1934.

Present study: 43 – (52) – 57 (based on 8 specimens).

Occurrence: Bedford Shale Formation (LN Biozone) – Big Walnut Creek, Ohio.

Remarks: Due to the simple often simple structure and ornamentation of taxa assigned to this genus, arbitrary size limits are utilised to define species. See Smith & Butterworth (1967, pp.282- 283) for further details.

Genus LATOSPORITES Potonié & Kremp 1954

Type Species *Latosporites latus* (Kosanke) Potonié & Kremp 1954

Latosporites sp. A sensu Owens 1971

Plate 12, figs. 5 - 8

Description: Monolete, bilateral miospores. Amb subcircular to oval in outline. Spore possesses distinct, simple, straight suturae, which extend approximately 3/5 of the spore radius, terminating in curvaturae perfectae. Exine laevigate.

Size range: (i) 85.8 x 75.0µm (based on 1 specimen); Owens 1971.

(ii) 70 - 100µm (10 specimens); Higgs *et al.* 1988.

Present study: 57 – (79) - 81µm (6 specimens).

Occurrence: LE – CM biozones; Tournaisian of Ireland, Higgs *et al.* 1988.

Present study: (i) Bedford Shale Formation – Big Walnut Creek & Three Locks sections, Ohio; (ii) Three Lick Bed – Clay City Quarry, Kentucky. (iii) Price Formation – Mylan Park, West Virginia.

Suprasubturma CAVATOMONOLETES Oshurkova & Pashkevich 1990

Genus ARATRISPORITES Leschik 1955 emend
Playford & Dettman 1965

Type species *Aratrisporites parvispinosus* Leschik 1955

Aratrisporites saharaensis Loboziak,
Clayton & Owens 1986
Plate 12, figs. 9 -12

1969 Spore monolete zonale no. 2874. – Lanzoni & Magloire, pl. 3, figs. 11 – 13.

1977 *Grandispora balteata* (Playford) Coquel, Loboziak, Stampfli & Stampfli-Vuille, pl. 3, fig. 13.

1980 *Grandispora balteata* (Playford) Massa, Coquel, Loboziak & Taugourdeau-Lantz, pl. 6, figs. 7 – 8.

1980 *Grandispora balteata* (Playford) Attar, Fournier, Candilier & Coquel, pl. 3, figs 8 & 9.

1985 *Spelaeotriletes balteatus* (Playford) Higgs *in* Clayton & Loboziak, pl. 34, figs. 19 & 20.

1986 *Aratrisporites saharaensis* Loboziak, Clayton & Owens, pl. 12, figs. 9 -12.

Holotype: Loboziak, Clayton & Owens 1986, pl. 1, fig. 2.

Type locality: Borehole B1-49, 950.40m depth, Rhadames Basin, Libya.

Diagnosis: From Loboziak *et al.* 1986: "Monolete, camerate, bilaterally symmetrical miospores. Amb oval to reniform, Monolete mark distinct to indistinct. Sutura straight to curved, simple; extends almost to equator where it terminates in a curvatural ridge. Exoexine thin, often folded, laevigate to infrapunctate. Densely ornamented on distal surface and around the equator by various elements including grana, verrucae, coni, spinae, pila and bacula. Intexine thin, laevigate, sometimes indistinct; circular to oval, diameter more or less ½ miospore width".

Size range: (i) Length 49 – (62.3) - 74µm, width 39 – (48.1) – 62µm (50 specimens); Lower Carboniferous Libya, Loboziak *et al.* 1986.

(ii) 49 – (60) - 75µm (equatorial diameter inclusive of ornament – based on 15 specimens); Borden Formation, Kentucky, USA, Coleman & Clayton 1987.

Present Study: 39 – (47) - 69μm (based on 20 specimens).

Range: late Tournaisian to early Namurian (Serpukovian); Loboziak et al. 1986, p.500.

Occurrence: (i) Upper Argiles de Timimoun and Grès d'Ahrlad formations (recorded as Spore monolete zonale no. 2874) – (Zone M4, M5 and early M6 – Viséan), Grand Erg occidental, Algeria; Lanzoni & Magloire, 1969.

(ii) Issendjel and Assekaifal formations (as *Grandispora balteata*), Illizi Basin, Algeria (palynozones III, IV & V = late Tournaisian –early Viséan); Attar, Fournier, Candilier & Coquel, 1980.

(iii) M'Rar and lower Assedjefar formations (as *Grandispora balteata*), Rhadames Basin, Western Libya – (palynozones XII – XV = late Tournaisian -early Namurian); Massa, Coquel, Loboziak & Taugourdeau-Lantz, 1980.

(iv) subsurface un-named formation (as *Spelaeotriletes balteatus*), North-East Libya, Cyrenaica (early Viséan – early Namurian); Clayton & Loboziak, 1985.

(v) Borden Formation (Henley Bed, Farmer, Nancy and Cowbell members) Kentucky, USA; Coleman & Clayton 1987.

(vi) Logan Formation (1 sample), Wayne County, Ohio (PC Biozone); Clayton *et al.* 1998.

Present Study: (i) Uppermost Coldwater Shale Formation (PC Biozone) – Williams County, Ohio; (ii) Uppermost Rockwell & Burgoon Sandstone, Cramer, Pennsylvania, (PC Biozone).

Remarks: As noted previously by Coleman (1991, p.101), some specimens assigned to this taxon in the present study appear to be morphologically intermediates between *A. saharaensis* and the trilete species *Spelaeotriletes balteatus*. Such forms exhibit a typical monolete mark in combination with an incipient 'third-ray', and a more rounded triangular-shaped amb.

CHAPTER 7

STRATIGRAPHIC PALYNOLOGY

INTRODUCTION

In the following chapter, the stratigraphic distribution of miospore species present in the sections investigated is discussed and presented in a series of range and occurrence charts. Brief notes concerning the preservation and taxonomic diversity of miospore assemblages from each of the sections are also provided. In relation to the last point, terms such as, 'high taxonomic diversity' are commonly used when discussing the productivity of individual samples. Please note that such terms are used in a 'semi-quantitative' sense and as such are not meant to signify any precise numerical value. When miospore assemblages are described as being of high or low diversity, it is in relation, primarily, to other assemblages recovered from that section, this is apparent when the text is read in conjunction with the range charts. In some instances, assemblages from one section are described as being of high diversity relative to assemblages from another section. Once more this point becomes apparent when the reader consults the range charts. For instance, compare the range and occurrence data for the Mylan Park and Three Locks sections – both of which are described as yielding highly diverse miospore assemblages, however, when one consults the range charts it is clear that the former possesses the more diverse assemblages.

7.1. OHIO

7.1.1. Williams County Core

Miospore assemblages recorded from the Williams County Core samples range from poor to well preserved, and from high taxonomic diversity to being entirely barren. The range and occurrence of selected miospore taxa is summarised in Figure 7.1.

Ohio Shale Formation (Antrim Shale Member)

Samples collected from the Antrim Shale Member proved to be largely barren. Miospores are rare and preservation at this level is typically poor; spores are commonly pyritised and obscured by AOM which dominates the sample. Due to the poor preservation miospores from the Antrim Shale are unidentifiable in most instances and thus these assemblages

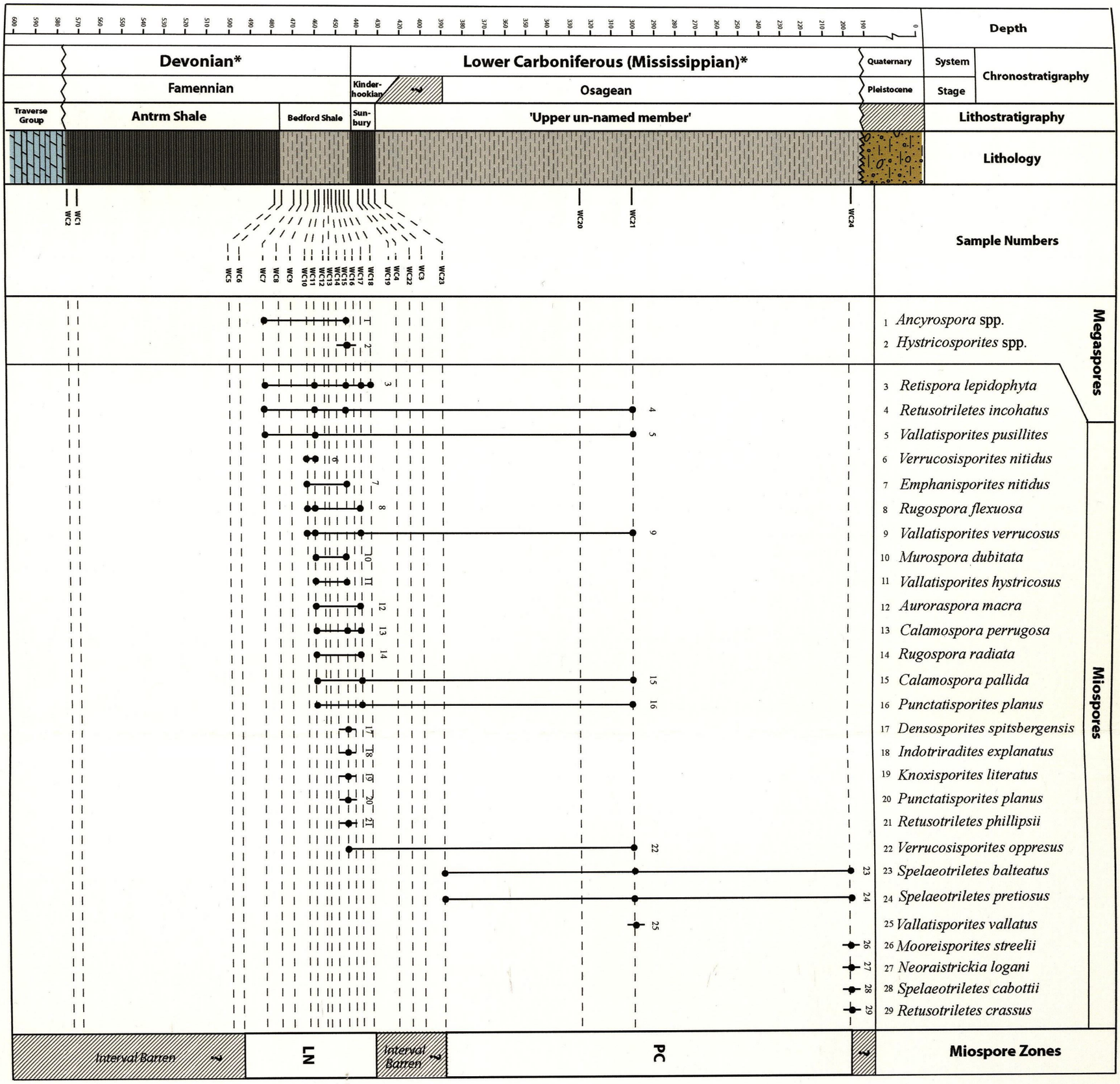


Figure 7.1 Range chart for the Williams County core displaying occurence data for selected miospore and megaspore taxa. Strat. column based on Ohio Geological Survey core desription (see Appendix III). * *denotes partial or incomplete.*

cannot be assigned to a specific biozone. *Tasmanites* and Leiospheres are both relatively common in these samples.

Bedford Shale Formation

The lowermost samples from the Bedford Shale (WC7 – 10) contain low diversity assemblages with relatively few identifiable specimens. Species recorded in these samples include: *Emphanisporites rotatus*, *Punctatisporites planus*, *Retispora lepidophyta*, *Retusotriletes incohatus*, *Rugospora flexuosa*, *Vallatisporites pusillites*, *V. verrucosus* and *Verrucosiporites nitidus*. Megaspores such as *Hystricosporites* spp. are present but rare in these samples.

Samples taken from higher levels in the Bedford Shale (WC11 – 15) contain assemblages of greater taxonomic diversity; in addition to the taxa listed above, samples also contain species including: *Calamospora* spp., *Indotriradites explanatus*, *Knoxisporites literatus*, *Murospora dubitata*, *Punctatisporites minutus*, *Retusotriletes famenensis*, *Retusotriletes phillipsii*, *Rugospora radiata* and *Vallatisporites hystricosus*. Acritarchs and *Tasmanites* are both present and relatively abundant through the upper portion of the Bedford Shale.

Assemblages recorded in samples from the Bedford Shale are assigned to the LN Biozone based on the occurrence of *Retispora lepidophyta* and *Verrucosisporites nitidus*; this assignment is supported by the presence of associated taxa such as *Rugospora flexuosa*, *R. radiata*, *Vallatisporites hystricosus* and *V. pusillites*. Based on this evidence the miospore assemblages recorded from the Bedford Shale Formation in the Williams County Core are exclusively latest Devonian in age.

Sunbury Shale Formation

The palynofacies of the Sunbury Shale compares very closely to that recorded in samples from the Antrim Shale Member of Ohio Shale Formation (see Chapter 8) and obviously signifies a similar depositional environment. The five samples analysed from this level are dominated by relatively large particles of brown AOM; palynomorphs are rare in this interval. Samples contain rare acritarchs; no Tasmanites were recorded in the Sunbury Shale. Due to the scarcity of miospores, assemblages from the Sunbury Shale samples cannot be assigned to a specific biozone with any certainty. However, palynological

analysis of this lithostratigraphic unit in previous studies (e.g. Coleman & Clayton, 1987; Heal & Clayton, 2009) would suggest probable assignment to the earliest Carboniferous *V. vallatus – R. incohatus* (VI) Biozone.

Coldwater Shale Formation

Three miospore assemblages from the Coldwater Shale Formation (WC23, 20, 21 & 24) are relatively well preserved but of moderately low diversity. Assemblages from this interval include the following species: *Calamospora pallida*, *Mooreisporites streelii*, *Neoraistrickia loganensis*, *Punctatisporites planus*, *Raistrickia clavata*, *Retusotriletes incohatus*, *Retusotriletes crassus*, *Spelaeotriletes balteatus*, *S. cabottii*, *S. pretiosus*, *Vallatisporites vallatus* and *Verrucosisporites oppressus*. The occurrence of *S. pretiosus* in conjunction with *R. clavata* would indicate that assemblages from the Coldwater Shale are assignable to the mid Tournaisian (Tn2- Tn3) *S. pretiosus – R. clavata* (PC) Biozone. Rare specimens of *Vallatisporites pusillites* recorded in these assemblages are most likely reworked.

7.1.2. Big Walnut Creek - Sunbury

Assemblages recorded from the Big Walnut Creek section are well preserved and moderately diverse. The overall character of these assemblages is closely comparable to those reported from the same locality by Molyneux *et al.* (1984), and also to those recorded in the present investigation from the Bedford Shale in the Williams County samples. The range and occurrence of selected miospore taxa at Big Walnut Creek is summarised by Figure 7.2. Assemblages recorded from the Bedford Shale and the lower part of the Berea Sandstone Formations at Big Walnut Creek are characterised by the following association of taxa:

Auroraspora macra, *Calamospora* spp., *Convolutispora* spp., *Cordylosporites marciae*, *Emphanisporites rotatus*, *Grandispora echinata*, *Indotriradites explanatus*, *Knoxisporites* cf. *triradiatus*, *Murospora dubitata*, *Punctatisporites* spp., *Retispora lepidophyta*, *Retusotriletes crassus*, *R. incohatus*, *Rugospora flexuosa*, *R. radiata*, *Teichertospora torquata*, *Vallatisporites hystricosus*, *V. pusillites*, *V. vallatus*, *V. verrucosus* and *Verrucosiporites nitidus*. Megaspores assignable to *Ancyrospora* spp. and *Hystricosporites* spp. are also present in samples from the Bedford Shale and Berea Sandstone.

Figure 7.2 Range chart for Big Walnut. Occurence data for selected miospore and megaspore taxa.

Miospore assemblages recovered from the Bedford Shale and Berea Sandstone at the Big Walnut Creek locality are assigned to the LN Biozone based on the occurrence of *Retispora lepidophyta* in samples also containing *Verrucosisporites nitidus*; the occurrence of associated taxa such as *Rugospora flexuosa*, *R. radiata*, *Vallatisporites hystricosus* and *V. pusillites* are also indicative of such an age assignment.

7.1.3. Three Locks Quarry

Ten samples from Three Locks Quarry yielded miospore assemblages which were both taxonomically diverse and well preserved. Quantitatively, assemblages are dominated by *Retispora lepidophyta,* which is present in all productive samples. Like assemblages from the Big Walnut Creek locality, there is no discernable difference between assemblages recorded from the Bedford Shale and the lower Berea Sandstone formations. Miospore assemblages recorded from this locality include the following taxa:

Auroraspora macra, *Calamospora* spp., *Convolutispora* spp., *Cyrtospora cristifera*, *Cordylosporites marciae*, *Emphanisporites rotatus*, *E. schultzii*, *Grandispora echinata*, *Indotriradites explanatus*, *Knoxisporites* cf. *triradiatus*, *Murospora dubitata*, *Punctatisporites* spp., *Retispora lepidophyta*, *Retusotriletes crassus*, *R. incohatus*, *R. phillipsii*, *Rugospora flexuosa*, *R. radiata*, *Teichertospora torquata*, *Vallatisporites pusillites*, *V. vallatus*, *V. verrucosus* and *Verrucosisporites nitidus*.

Assemblages are assigned to the latest Devonian LN Biozone based on the occurrence of *Retispora lepidophyta*, *Verrucosisporites nitidus* and associated taxa (e.g. *Rugospora flexuosa*, *R. radiata*, *Vallatisporites hystricosus* and *V. pusillites*). The range and occurrence of selected miospore taxa at Three Locks is summarised by Figure 7.3.

7.1.4. Tener Mountain Wood

The two poorly constrained samples collected from the Ohio Shale at the Tener Mountain Wood section both yielded well preserved miospore assemblages of relatively low taxonomic diversity and abundance. Species recorded from this section include: *Auroraspora macra*, *Knoxisporites literatus*, *Laevigatosporites minor*, *Punctatisporites irrasus*, *P. planus*, *Retusotriletes incohatus*, *R. minor*, *Rugospora flexuosa* and *Vallatisporites hystricosus*. Samples also contain rare specimens *Retispora lepidophyta*.

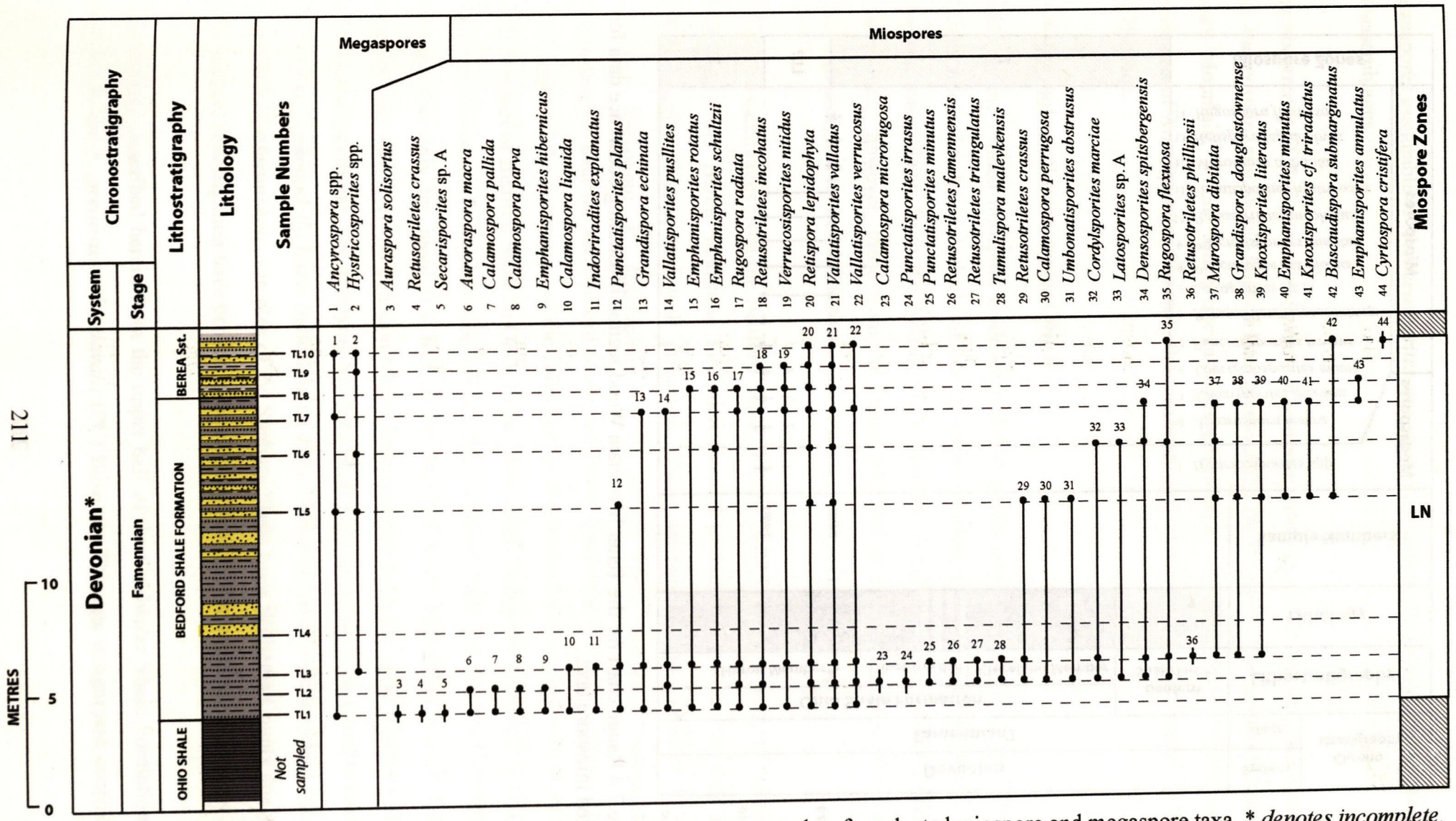


Figure 7.3 Range chart for Three Locks Quarry section displaying occurence data for selected miospore and megaspore taxa. * *denotes incomplete*.

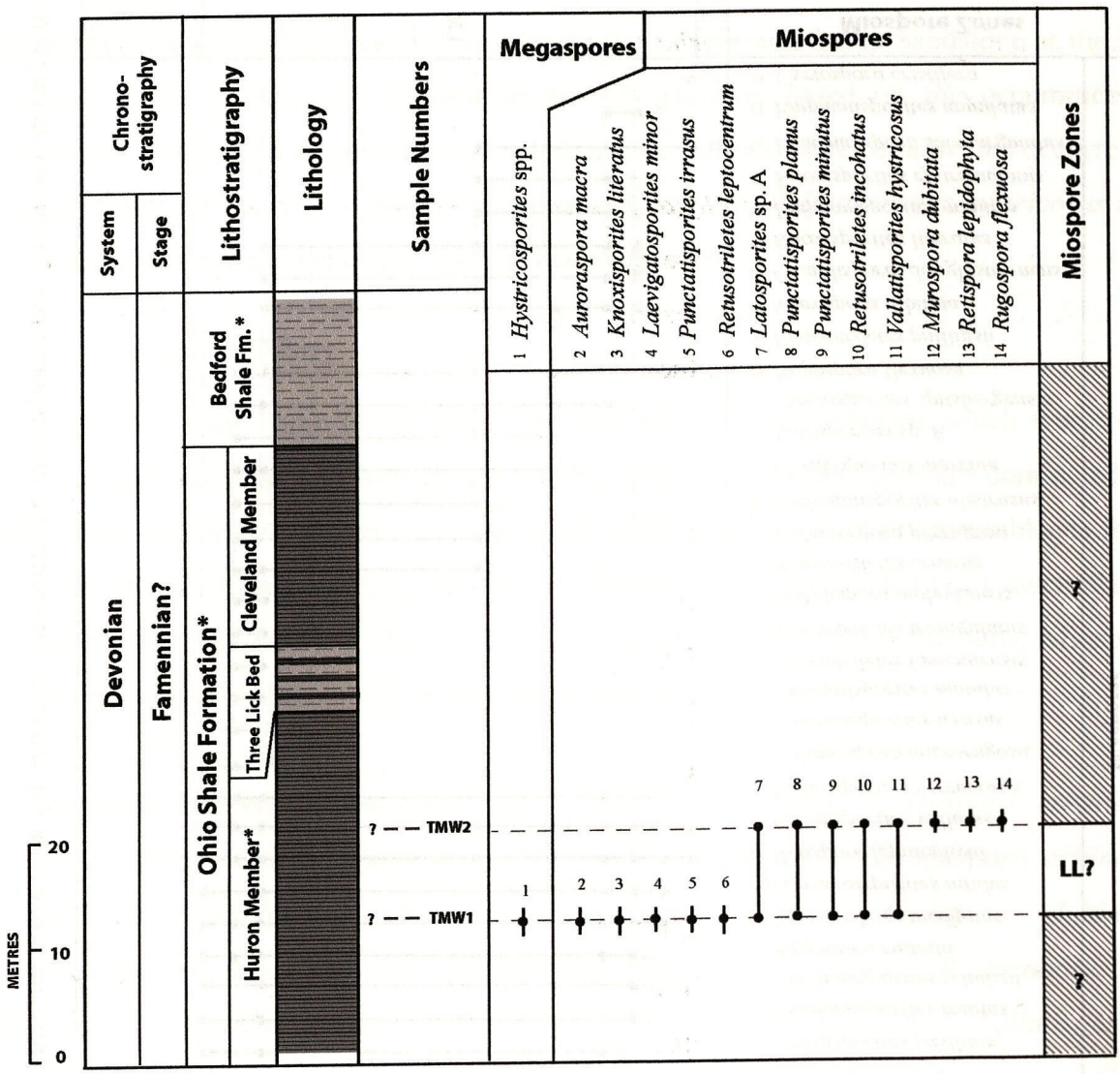


Figure 7.4 Range chart for the Tener Mountain Wood section illustrating occurence data for selected miospore taxa..

Megaspores assignable to *Hystricosporites* spp. are also a relatively common component of the assemblages.

The occurrence of *Retispora lepidophyta*, *Rugospora flexuosa*, *Vallatisporites hystricosus* and *Ancyrospora* spp. would imply a late Devonian age for the assemblages documented at Tener Mountain Wood. Since one assemblage (sample TMW1), also contains rare specimens of *Knoxisporites literatus*, the maximum age of this assemblage equates to the LL Biozone.

7.1.5. *Palynological summary for Ohio*

Based on the limited miospore evidence gathered in the present study, the upper Ohio Shale is inferred to be exclusively of late Devonian (Famennian) age. Age assignment of miospore assemblages from the Antrim Shale Member in the Williams County Core is indeterminate; however, those from the Huron Member at Tener Mountain Wood are tentatively assigned to the LL Biozone.

Miospore assemblages from the Bedford Shale, in north-west Ohio, and from the Bedford Shale and lower Berea Sandstone formation interval in central parts of the state are compositionally diverse, and well preserved. These assemblages are assigned to the uppermost Devonian *R. lepidophyta – V. nitidus* (LN) Biozone. Independent biostratigraphic data for the Bedford Shale and Berea Sandstone in Ohio is scarce. Haas (1947) reported the occurrence of the conodont *Spathognathodus anteposecornis* from the lower few feet of Bedford Shale in Ohio. In the Mississippi Valley this species is typical of the latest Devonian *Protognathodus* fauna. This evidence later led De Witt (1970) to conclude that only the basal few feet of the Bedford Shale Formation was of Latest Devonian age. However, no conodonts have been reported from the upper Bedford Shale or the Berea Sandstone. The overlying Sunbury Shale Formation has been found to contain an abundant *Siphonodella* fauna indicating an early Mississippian (Kinderhookian) age (de Witt, 1974). Unfortunately, samples of the Sunbury Shale from Williams County analysed in the present investigation have proved to be entirely devoid of miospores.

Assemblages described herein from the upper half of the Coldwater Shale Formation are assigned to the *S. pretiosus – R. clavata* (PC) Biozone. This age assignment contradicts

Richardson (2006), who assigned miospore assemblages from the Coldwater Shale formation of Michigan to the BP Biozone. However, as noted in Chapter 10.2, p.314-315, Richardson's age determination is suspect based upon the specimens of key zonal taxa figured in that study. Independent biostratigraphic control in the form of foraminifera (Conkin, 1954) and cephalopods (Miller & Garner, 1953 & 1955) would suggest an Osagean or Kinderhookian/ Osagean age for this formation respectively. A Kinderhookian/ Osagean age is entirely consistent with other PC Zone assemblages previously described in the USA (e.g. Coleman & Clayton, 1988; Clayton *et al.* 1998).

7.2. KENTUCKY

Samples collected from the upper Ohio Shale Formation and equivalents in Kentucky yielded miospore assemblages which are typically well preserved and of moderately high taxonomic diversity. The abundance of acritarchs, tasmanites and leiospheres within these samples would indicate marine deposition for this interval (see Chapter 8).

7.2.1. Vanceburg

Two samples (VAN 1 & 2) were collected from the Huron Member (Ohio Shale Formation) at the Vanceburg locality. The lowermost sample proved to be barren; however, the upper sample (VAN2) yielded a highly restricted assemblage dominated by simple, laevigate taxa including: *Auroraspora macra*, *Calamospora pallida*, *C. parva*, *Laevigatosporites minor*, *Latosporites* sp. A, *Punctatisporites irrasus*, *Retusotriletes incohatus*, *Rugospora radiata*, *Vallatisporites hystricosus*, *Verrucosisporites oppresus*. This assemblage is comparable to that documented from the Tener Mountain Wood section. Since this assemblage lacks zonal taxa such as *Retispora lepidophyta* and *Knoxisporites literatus*, age assignment is indeterminate. However, since sample VAN2 contains *V. hystricosus* an age no older than the late Devonian VH Biozone is inferred.

7.2.2. I- 64 Roadcut, Morehead – Three Lick Type Section

Samples from the Three Licks Bed at its type section along Interstate 64 yielded moderately diverse and generally well preserved miospore assemblages. Most assemblages are dominated by simple, laevigate taxa, including: *Calamospora parva*, *Laevigatosporites minor*, *Latosporites* sp. and *Punctatisporites* spp. Other species recorded include: *Auroraspora macra*, *Cyrtospora cristifera*, *Knoxisporites literatus*, *Murospora dubitata*,

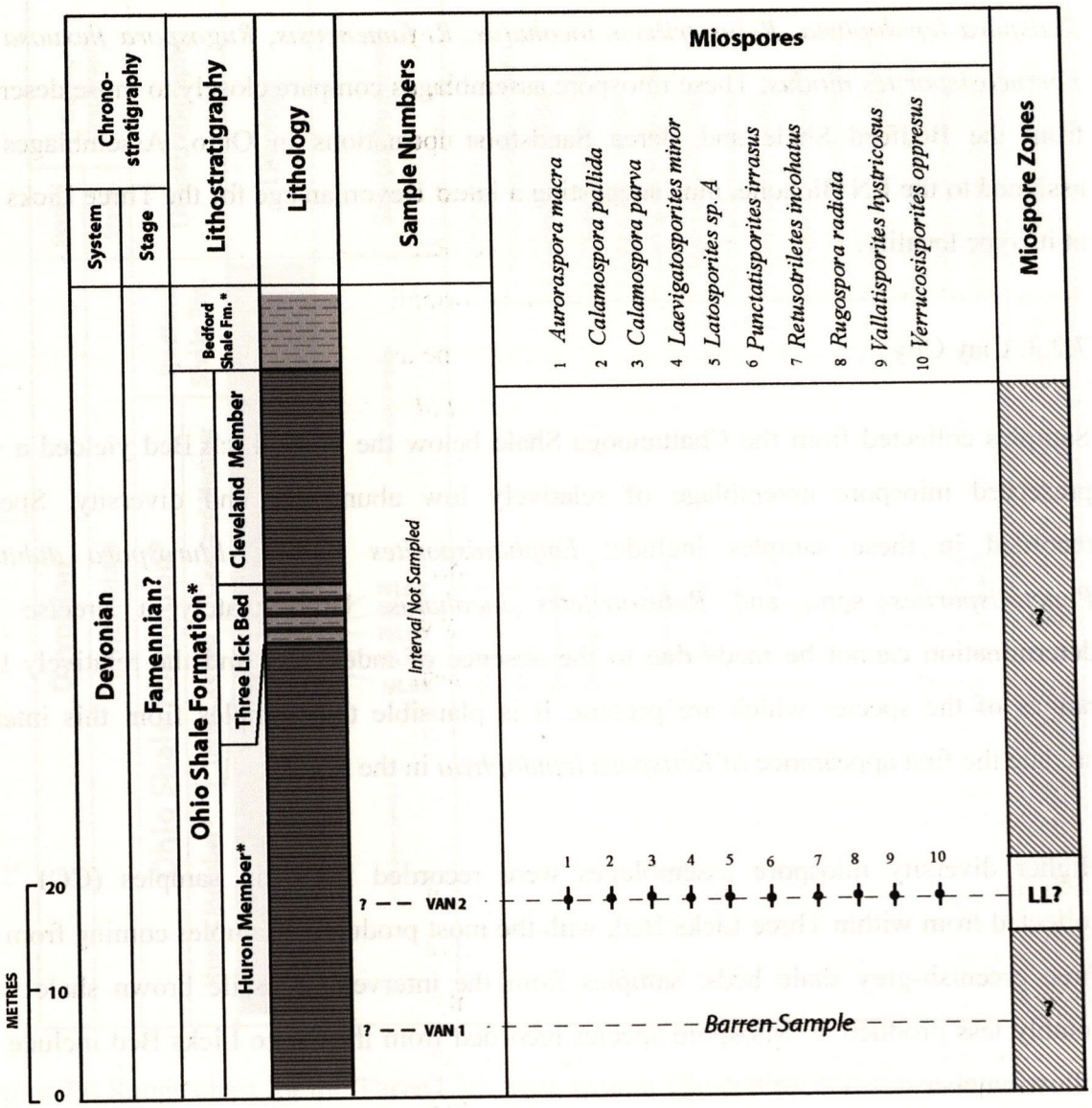


Figure 7.5 Range chart for the Vanceburg section illustrating occurence data for selected miospore taxa..

Retispora lepidophyta, *Retusotriletes incohatus*, *R. famenensis*, *Rugospora flexuosa* and *Verrucosisporites nitidus*. These miospore assemblages compare closely to those described from the Bedford Shale and Berea Sandstone formations in Ohio. Assemblages are assigned to the LN Biozone, thus suggesting a latest Devonian age for the Three Licks Bed at its type locality.

7.2.3. Clay City

Samples collected from the Chattanooga Shale below the Three Lick Bed yielded a well preserved miospore assemblage of relatively low abundance and diversity. Species recorded in these samples include: *Emphanisporites rotatus*, *Murospora dubitata*, *Punctatisporites* spp., and *Retusotriletes incohatus*. Unfortunately a precise age determination cannot be made due to the absence of index taxa and the relatively long ranges of the species which are present. It is plausible that samples from this interval predate the first appearance of *Retispora lepidophyta* in the region.

Higher diversity miospore assemblages were recorded from six samples (CC1 – 6) collected from within Three Licks Bed, with the most productive samples coming from the three greenish-grey shale beds; samples from the intervening fissile brown shale were notably less productive. Miospore species recorded from the Three Licks Bed include the following taxa:

Auroraspora macra, *Calamospora* spp., *Convolutispora* spp., *Cyrtospora cristifera*, *Densosporites spitsbergensis*, *Indotriradites explanatus*, *Knoxisporites* cf. *triradiatus*, *Laevigatosporites* sp., *Latosporites* sp., *Murospora dubitata*, *Punctatisporites* spp., *Retispora lepidophyta*, *Retusotriletes crassus*, *R. incohatus*, *R. famenensis*, *Rugospora flexuosa*, *R. radiata*, *Knoxisporites concentricus*, *Vallatisporites hystricosus*, *V. pusillites* and *Verrucosisporites nitidus*.

The assemblages recorded from the Three Licks Bed at Clay City are assigned to the LN Biozone based on the occurrence of *Retispora lepidophyta*, *Verrucosisporites nitidus* and associated taxa. An approximate correlation with the Bedford Shale and Berea Sandstone formations of Ohio is thus inferred, together with the Three Lick Bed at its type section.

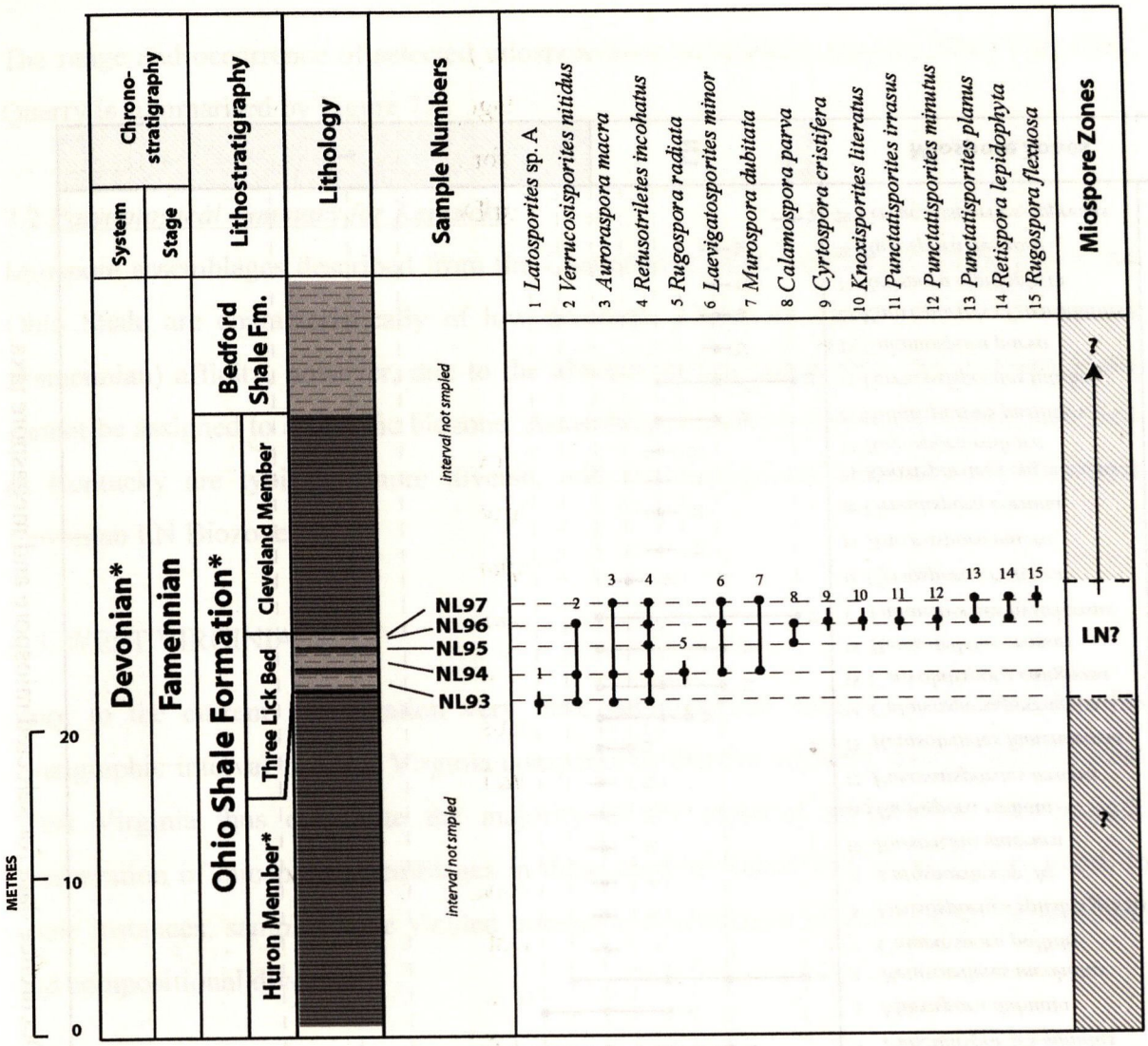


Figure 7.6 Range chart for the Three Lick 'type section' illustrating occurence data for selected miospore and megaspore taxa..

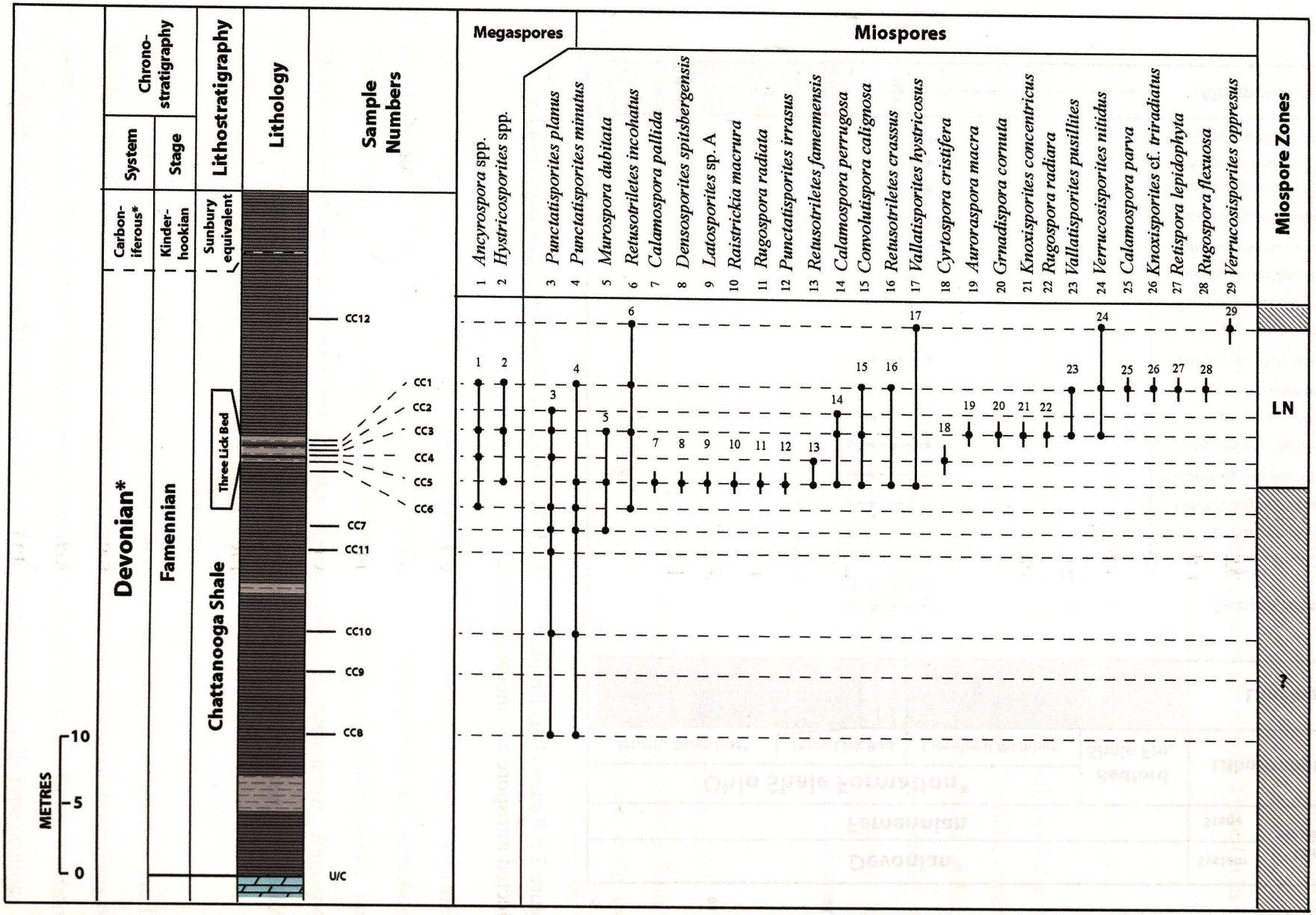


Figure 7.7 Range chart for the Clay City Quarry section. Occurence data for selected miospore and megaspore taxa.

The range and occurrence of selected miospore taxa recorded in samples from Clay City Quarry is summarised by Figure 7.4.

7.2 *Palynological summary for Kentucky*

Miospore assemblages described from the Chattanooga Shale and Huron Members of the Ohio Shale are characteristically of low diversity. These are clearly of late Devonian (Famennian) affinity, however, due to the absence of key index taxa, these assemblages cannot be assigned to a specific biozone. Assemblages recovered from the Three Lick Bed in Kentucky are typically more diverse, and contain species indicative of the latest Devonian LN Biozone.

7.3. WEST VIRGINIA

Prior to the current investigation very little palynological data was available for this stratigraphic interval in West Virginia compared to that for adjacent states. Samples from West Virginia thus constitute the majority of the material analysed in this project. Preservation of miospore assemblages in these samples varies very poor to very good. In some instances, samples have yielded miospore assemblages of exceptional preservation and compositional diversity.

7.3.1. Caldwell

Cloyd Conglomerate Member

Two samples (CA1 -2) were collected from the Cloyd Conglomerate Member (Unit 43; Bjerstedt, 1986a) at the Caldwell roadcut locality. These samples yielded rather poorly preserved miospore assemblages of moderately low taxonomic diversity. Assemblages from this interval include the following species: *Auroraspora macra*, *Cordylosporites marciae*, *Cyrtospora cristifera*, *Emphanisporites rotatus*, *Retispora lepidophyta*, *Rugospora flexuosa*, *R. radiata*, *Retusotriletes crassus*, *Vallatisporites hystricosus*, *V. pusillites*, *V. verrucosus* and *Verrucosisporites nitidus*.

Assemblages from the Cloyd Conglomerate are assigned to the uppermost Devonian LN Biozone based on the occurrence of *Retispora lepidophyta* and *Verrucosisporites nitidus*. This age determination is consistent with reports of brachiopods of the Late Famennian

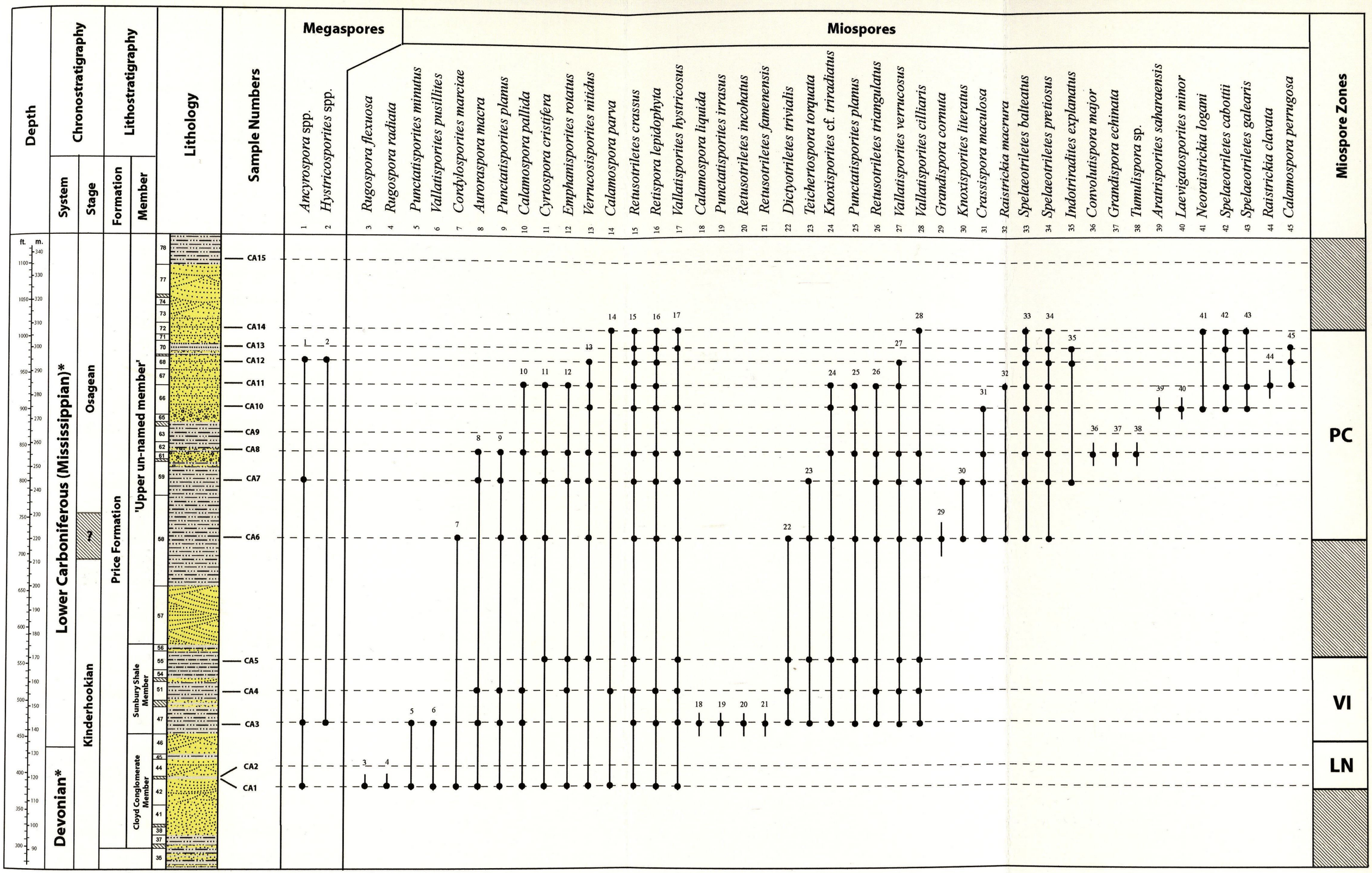


Figure 7.8 Range chart for the Caldwell section displaying occurence data for selected miospore and megaspore taxa. Field units after Bjerstedt 1986. * *denotes partial or incomplete.*

genus *Cyrtospirifer* sp. from the Cloyd Conglomerate at this locality (Carter & Kammer, 1990).

Sunbury Shale Member

The samples from the Sunbury Shale (CA3 - CA5) have yielded miospore assemblages of moderately low taxonomic diversity and poor preservation. Taxa recorded from this interval include: *Calamospora liquida*, *Convolutispora* spp., *Crassispora maculosa*, *Dictyotriletes trivialis*, *Knoxisporites* cf. *triradiatus*, *Retusotriletes crassus*, *R. incohatus*, *R. famennensis*, *Teichertospora torquata*, *Punctatisporites irrasus*, *Vallatisporites hystricosus* and *V. verrucosus*.

Assemblages from the Sunbury Shale at Caldwell are tentatively assigned to the lowermost Carboniferous VI Biozone based on the absence of *Retispora lepidophyta* and associated taxa. However, the occurrence of *Vallatisporites hystricosus* at this level is somewhat anomalous and perhaps can be explained by reworking. A more obvious example of reworking is indicated by the occurrence of *Teichertospora torquata*, the range of species is typically restricted between the late Frasnian to latest Strunian (McGregor & Playford, 1990). However, it entirely is possible that this species has an extended stratigraphical range in the Eastern USA.

'Upper' Price Formation

Samples collected from the undifferentiated 'upper' Price Formation yielded miospore assemblages ranging from poorly preserved low diversity assemblages to assemblages that are well preserved and taxonomically rich. Samples from this lower portion of this interval (samples CA6 – CA9) typically contain rather poorly preserved 'pyritised' miospore assemblages. The age assignment for these is indeterminate due to the absence of key index taxa. On this basis, these assemblages are tentatively assigned to the VI Biozone.

The upper samples (CA10 – CA14) from the 'Upper' Price Formation (Unit 66; Bjerstedt, 1986a) generally contain better preserved assemblages. Species recorded from the upper Price Formation include: *Auroraspora macra*, *Calamospora* spp., *Crassispora maculosa*, *Cyrtospora cristifera*, *Cordylosporites marciae*, *Grandispora echinata*, *Indotriradites explanatus*, *Knoxisporites literatus*, *Retusotriletes crassus*, *Spelaeotriletes balteatus*, *S.*

pretiosus, *Teichertospora torquata*, *Vallatisporites vallatus*, *V. verrucosus* and *Verrucosisporites nitidus*. Rare specimens of *Retispora macroreticulata*, *R. lepidophyta* and *Rugospora radiata* also occur at this level and are presumably reworked. The uppermost samples also contain *Aratrisporites saharaensis*, *Neoraistrickia loganensis*, *Raistrickia clavata*, *S. cabottii*, and *S. microgalearis*. These assemblages are assigned to the PC Biozone.

7.3.2. Alta

Samples from the Alta section yielded moderately well preserved assemblages of low to moderate diversity. Assemblages from these samples include species such as: *Aratrisporites saharaensis*, *Cyrtospora cristifera*, *Emphanisporites rotatus*, *Latosporites* sp. A, *Neoraistrickia loganensis*, *Radiizonates mirabilis*, *Retusotriletes crassus*, *R. triangulatus*, *Spelaeotriletes balteatus*, *S. cabottii*, *S. galearis*, *S, pretiosus*, *Vallatisporites cilliaris* and *V. pusillites*. These assemblages are assigned to the PC Biozone. This interval has previously been correlated with the uppermost Price Formation at the Caldwell section by Bjerstedt 1986 based on the inferred position of the transgression surface termed T4. The miospore evidence would support such a correlation.

7.3.2. Mylan Park

Samples collected from the Mylan Park Core yielded miospore assemblages which are highly diverse and well preserved. The range and occurrence of selected miospore taxa recorded in Mylan Park samples is summarised by Enclosure I. Samples from this section also contain rare marine indicators such as acritarchs and scolecodonts; no *Tasmanites* were recorded within the samples. However, since such marine indicators are relatively rare they may represent specimens reworked from underlying strata.

Samples MP2 – MP12 collected from the stratigraphic interval below the Murrysville Sandstone yielded particularly rich miospore assemblages, species recorded include: *Auroraspora macra*, *Calamospora* spp., *Crassispora maculosa*, *Emphanisporites rotatus*, *E. schultzii*, *Grandispora cornuta*, *G. echinata*, *Knoxisporites concentricus*, *K. literatus*, *K.* cf. *triradiatus*, *Punctatisporites* spp., *Retispora macroreticulata*, *R. lepidophyta*, *Retusotriletes crassus*, *R. incohatus*, *Rugospora flexuosa*, *R. radiata*, *Vallatisporites hystricosus*, *V. pusillites*, *V. verrucosus* and *Verrucosisporites nitidus*. Megaspores assignable to *Ancyrospora* spp. and *Hystricosporites* spp. are also particularly common and

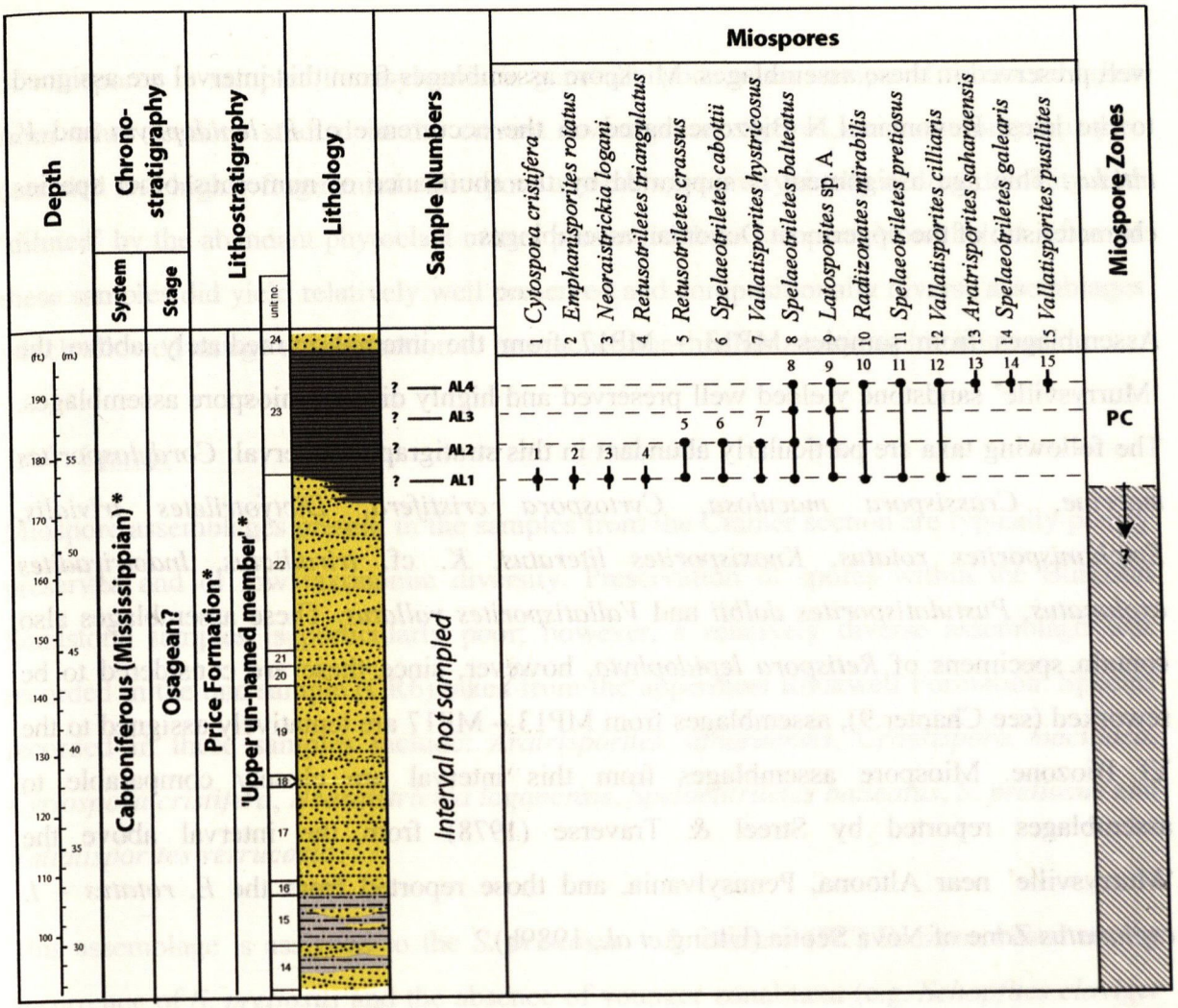


Figure 7.9 Range chart for the Alta section illustrating occurence data for selected miospore taxa. Field units after Bjerstedt (1986). * *denotes incomplete or partial.*

well preserved in these assemblages. Miospore assemblages from this interval are assigned to the latest Devonian LN Biozone based on the occurrence of *R. lepidophyta* and *V. nitidus*. This age assignment is supported by the abundance of numerous other species characteristic of the uppermost Devonian assemblages.

Assemblages from samples MP13 – MP17 from the interval immediately above the 'Murrysville' sandstone yielded well preserved and highly diverse miospore assemblages. The following taxa are particularly abundant in this stratigraphic interval: *Cordylosporites marciae*, *Crassispora maculosa*, *Cyrtospora cristifera*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Knoxisporites literatus*, *K.* cf. *triradiatus*, *Indotriradites explanatus*, *Pustulatisporites dolbii* and *Vallatisporites vallatus*. These assemblages also contain specimens of *Retispora lepidophyta*, however, since these are considered to be reworked (see Chapter 9), assemblages from MP13 – MP17 are tentatively assigned to the VI Biozone. Miospore assemblages from this interval are closely comparable to assemblages reported by Streel & Traverse (1978) from the interval above the 'Murrysville' near Altoona, Pennsylvania, and those reported from the *E. rotatus – I. explanatus* Zone of Nova Scotia (Utting *et al.*, 1989b).

Samples MP18 – MP55 yielded moderately well preserved and moderately diverse miospore assemblages. Species recorded from this interval include: *Convolutispora major*, *Crassispora* cf. *maculosa*, *Cyrtospora cristifera*, *Raistrickia clavata*, *Spelaeotriletes balteatus*, *S. cabottii*, *S. pretiosus* and *Vallatisporites vallatus*. Although relatively rare in the lower samples in this interval, the occurrence of *S. pretiosus* is diagnostic of the PC Biozone. All assemblages from samples MP18 – MP55 are assigned to the PC Biozone. The first appearance of the *Cordylosporites shawneei* sp. nov. within samples from the interval immediately below the Big Injun Sandstone (MP53 – MP54) may prove to be of stratigraphic importance if recognised in future studies of other sections.

7.4. PENNSYLVANIA

Like West Virginia, relatively little palynological data is available for the lower Mississippian succession in Pennsylvania. In the present investigation, samples spanning the boundary between the Rockwell Formation and Burgoon Sandstone Formation were collected from three road-cut sections in the south-central region of the state. Preservation

of miospores in samples Pennsylvania is generally poor when compared to assemblages from other sections studied in the current investigation. Spores are commonly opaque, corroded and highly fragmented. Miospore assemblages are typically of low diversity and 'diluted' by the abundant phytoclast matter present in these samples. Nonetheless a few of these samples did yield relatively well preserved and compositionally diverse assemblages which allowed an age determination to be reached for this lithostratigraphic interval.

7.4.1. Cramer

Miospore assemblages present in the samples from the Cramer section are typically poorly preserved and of low taxonomic diversity. Preservation of spores within the Burgoon Sandstone samples is particularly poor; however, a relatively diverse assemblage was recorded in the one sample (CR6) taken from the uppermost Rockwell Formation. Species recorded in these samples include: *Aratrisporites saharaensis*, *Crassispora maculosa*, *Cyrtospora cristifera*, *Neoraistrickia loganensis*, *Spelaeotriletes balteatus*, *S. pretiosus* and *Vallatisporites verrucosus*.

This assemblage is assigned to the *S. pretiosus – R. clavata* (PC) Biozone based on the occurrence of *S. pretiosus* and the absence of younger zonal taxa (e.g. *Schopfites claviger* and *Lycospora pusilla*). The miospore evidence would thus indicate a mid Tournaisian (Tn2 – Tn3) age for the uppermost Rockwell Formation at this locality, and presumably also too for the overlying Burgoon Sandstone Formation. Since the upper samples are barren, the absence of *S. pretiosus* in the latter formation is assumed to be a function of poor preservation of miospores rather than due to its stratigraphic range.

7.4.2. Altoona

Samples from the Altoona section yielded miospore assemblages which were so poorly preserved that most specimens were unidentifiable. The only identifiable specimens recorded from this section are assigned to long ranging, acamerate, laevigate taxa such as *Calamospora* spp., *Punctatisporites* spp. and *Retusotriletes* spp.

7.4.3. Warrior's Path State Park

Miospore assemblages present in the samples from the Warrior's Path section are of limited diversity (Figure 7.10) and relatively poor preservation. Species recorded include:

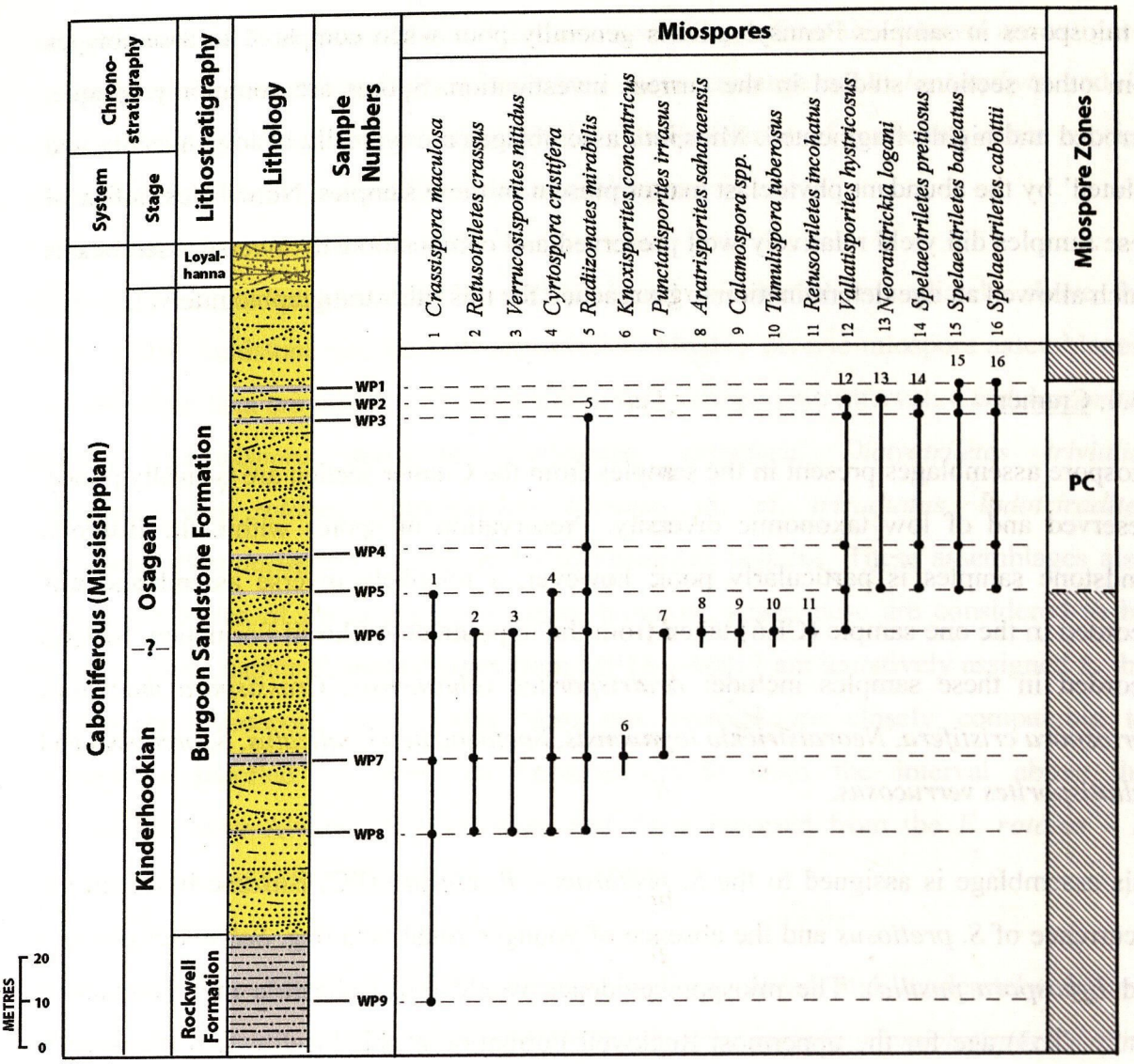


Figure 7.10 Range chart for the Warrior's Path section. Occurence data for selected miospores.

Aratrisporites saharaensis, *Crassispora maculosa*, *Calamospora* spp., *Neoraistrickia loganensis*, *Punctatisporites* spp., *Retusotriletes crassus*, *Spelaeotriletes balteatus*, *S. pretiosus*, *Tumulispora ordinarius* and *Vallatisporites* spp. Miospore assemblages from the upper part of the Burgoon Sandstone Formation samples are assigned to the *S. pretiosus – R. clavata* (PC) Biozone based on the occurrence of *S. pretiosus* thus a mid Tournaisian (Tn2 – Tn3) age for the uppermost Burgoon Sandstone at this locality is inferred.

7.4.4. *Palynostratigraphic summary for Pennsylvania*

Samples from the uppermost Rockwell and Burgoon Sandstone formations in Pennsylvania yielded miospore assemblages which are assigned to the mid Tournaisian (Tn2 – Tn3) *S. pretiosus – R. clavata* (PC) Biozone, based upon the occurrence of *S. pretiosus*. The absence of *Schopfites claviger* and/ or *Lycospora* spp. in these assemblages would negate the assignment of the assemblages to a younger miospore biozone. The character of assemblages from the more productive samples are closely comparable to others assigned to the PC Biozone, both in the present investigation and previous studies in the region (e.g. Coleman & Clayton, 1987; Clayton *et al.* 1998). These samples are characterised by the occurrence of species including *Aratrisporites saharaensis*, *Crassispora maculosa*, *Cyrtospora cristifera*, *Neoraistrickia loganensis*, *Spelaeotriletes balteatus*, *S. pretiosus* and *Vallatisporites* spp.

7.5. Palynostratigraphic summary

R. lepidophyta – V. nitidus (LN) Biozone

Miospore assemblages assigned to the LN Zone in the present study are closely comparable to those assigned to the zone in Western Europe and in previous studies conducted in the Eastern USA. In the present investigation the composition and diversity of these assemblages vary slightly between different localities as well as vertically within particular sections. However, in general terms LN Zone assemblages are characterised by an association of the following miospore and megaspore species: *Ancyrospora* spp., *Calamospora* spp., *Hystricosporites* spp., *Indotriradites explanatus*, *Knoxisporites concentricus*, *K. literatus*, *K.* cf. *triradiatus*, *Murospora dubitata*, *Punctatisporites* spp., *Retispora lepidophyta*, *Retusotriletes crassus*, *R. incohatus*, *R. famenensis*, *R. phillipsii*,

Rugospora flexuosa, *R. radiata*, *Vallatisporites hystricosus*, *V. pusillites*, *V. verrucosus* and *Verrucosisporites nitidus*.

All of the species listed above are common components of the LN Zone in Western Europe. In the present study, specimens of *Cyrtospora cristifera* first appear within the uppermost part of this zone. Coleman & Clayton (1987) also reported specimens of *C. cristifera* in the uppermost Devonian of Kentucky. In this respect, the American assemblages differ from those of Western Europe, where *C. cristifera* typically appears at the base of the Carboniferous and only very rarely in the Upper Devonian. The early first appearance of this species is also been reported at lower levels in the Upper Devonian strata of Canada (McGregor & Owens, 1966) and the former USSR (Kedo, 1963).

V. vallatus – R. incohatus (VI) Biozone

In this study, miospore assemblages from the interval immediately above the Murrysville Sandstone in the Mylan Park samples are assigned to the VI Zone. With the exception of a number of species thought to be reworked from upper Devonian strata (see Chapter 9) these assemblages are characterised by the association of a number of relative long ranging taxa, these include: *Cordylosporites marciae*, *Cyrtospora cristifera*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Knoxisporites concentricus*, *K. literatus*, *K.* cf. *triradiatus*, *Punctatisporites* spp., *Pustulatisporites dolbii*, *Retusotriletes crassus*, *R. incohatus* and *Vallatisporites vallatus*.

In the USA, assemblages assigned to the VI Biozone by previous authors (e.g. Coleman & Clayton, 1987; Heal & Clayton, 2008) have been noted as being of restricted compositional diversity, and being dominated by simple, acamerate and laevigate taxa such as *Retusotriletes* spp. and *Punctatisporites* spp. Whilst species assignable to both these genera are common in 'VI' Zone assemblages in the present study, the overall character of the assemblages is typically more diverse. These VI assemblages typically contain larger more ornate species such as *Cordylosporites marciae*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Knoxisporites* spp. and *Vallatisporites* spp. being particularly abundant. In this respect, these assemblages compare more closely to those characteristic of the *E. rotatus – I. explanatus* Assemblage Zone described from Nova Scotia by Utting *et al.* (1989b). The authors of that study correlated the zone with the

Cristatisporites hibernicus - *Umbonatisporites distinctus* (HD) Biozone of Western Europe. However, neither *C. hibernicus* nor *Umbonatisporites distinctus* have been recorded in any assemblage documented in the current investigation. In Canada, the *E. rotatus – I. explanatus* Zone 'sits' directly above assemblages assigned to the LN Biozone, as do those assigned to the VI Zone in the present study.

Warg & Traverse (1973) and Streel & Traverse (1978) both documented similar miospore assemblages from the lower Mississippian 'Pocono Formation' from Pennsylvania. Based on various palaeogeographic reconstructions for this time period, both Pennsylvania and West Virginia were considerably closer to the principal sediment source, the Acadian Highlands, than the location of sections studied in Kentucky (Coleman & Clayton, 1987) and Missouri (Heal & Clayton, 2008). Judging by the palynofacies data presented by authors of those studies, and the reported occurrence of acritarchs and scolecodonts, both the sections appear to have been sites of normal marine deposition.

In the current investigation, samples taken from the interval directly above Murrysville Sandstone in the Mylan Park core contain rare acritarchs. However, terrestrially derived phytoclast material and miospores dominate the palynofacies indicating a far more proximal sedimentary environment (see Chapter 8). The abundance of plant fragments in the sections studied by Warg & Traverse (1973) and Streel & Traverse (1978) would suggest a similar depositional environment during earliest Mississippian times in Pennsylvania. Given the distal nature of sections studied by Coleman & Clayton (1987) and Heal & Clayton (2008), it is entirely plausible that the low diversity of miospore assemblages and the abundance of small, smooth walled spores in samples from those sections was the result of sedimentary transport and sorting. It is equally plausible that the greater diversity of miospores within assemblages assigned to the VI Zone in the present study is the related to the more proximal depositional environment.

S. pretiosus – R. clavata (PC) Biozone

Miospore assemblages assigned to the PC Biozone are closely comparable to those assigned to this zone in Western Europe. Species common within this zone include: *Aratrisporites saharaensis*, *Crassispora maculosa*, *Cyrtospora cristifera*, *Mooreisporites streelii*, *Neoraistrickia loganensis*, *Spelaeotriletes balteatus*, *S. cabottii*, *S. pretiosus* and

Vallatisporites spp. Previous palynological studies in the Eastern USA have recorded PC Zone assemblages from the Borden Formation in Kentucky (Coleman & Clayton, 1987) and the Black Hand Sandstone (Cuyahoga/ Logan formation boundary) in Ohio (Clayton *et al.* 1998). Based on the available palynological evidence these lithostratigraphic units are correlated with the upper Price Formation (including the Big Injun Sandstone) in West Virginia, the Rockwell/ Burgoon Sandstone interval in Pennsylvania and the Coldwater Shale Formation in Ohio.

CHAPTER 8

PALYNOFACIES ANALYSIS

8.1 INTRODUCTION

The term palynofacies was first introduced by Combaz (1964) to include the "total complement of acid resistant organic matter recovered from a sediment or sedimentary rock by acid processing techniques using HCl and HF" (Durand, 1980, after Combaz, 1964). The principal aim of the present palynofacies study was to investigate the depositional environment represented by the lithologies from which samples utilised in the palynostratigraphic study were collected. Particular emphasis is given to determining whether such lithologies represent marine or fresh water (fluvial) deposition and to changes in the relative sea-level and/ or proximity to terrestrial kerogen sources as indicated by the kerogen content of the samples. By achieving a better understanding of the depositional history of the sedimentary basins in question through palynofacies analysis, it was hoped that more accurate interpretations of the miospore record can be made, and that in some instances, distinct changes in the kerogen content of samples may be linked to changes in the miospore succession.

In the following chapter, important terms are defined, the kerogen classification scheme utilised herein is summarised and the methodology of the study discussed. Important details are also provided concerning previous palynofacies studies of Upper Devonian and Mississippian (Lower Carboniferous) strata in the region and how the results of these studies compare to those of the present investigation.

8.2. DEFINITIONS

Palynofacies: The term palynofacies was defined by Powell *et al.* (1990) as a distinct assemblage of hydrochloric (HCl) and hydrofluoric (HF) acid insoluble particulate organic matter, whose composition reflects a particular sedimentary environment. In other studies the term has been used to describe a facies based solely upon palynomorph distribution (e.g. Richardson & Ahmed, 1988). However, in the current investigation the term is employed in the former sense, as an indication of a set of parameters which characterise a particular lithology, as apposed to a definitive method of identification.

Palynofacies analysis: This term is defined as the identification of characteristics of rock facies through the palynological investigation of their contained organic matter (Combaz, 1964; Powell, 1990; Tyson, 1995; Batten, 1999). Based on this definition, all HCl and HF resistant organic matter recovered in palynological preparations are included in the analysis, not just palynomorphs.

8.3. CLASSIFICATION

Different interests in kerogen and various methods of analysis have led to the creation of a multitude of competing kerogen classification schemes by a number of authors, including: Combaz (1964), Correira (1971), Burgess (1974), Raynauld & Robert (1976), Bujak *et al.* (1977), Scott & Collinson (1978), Robert (1979), Combaz (1980), Durand (1980), Parry *et al.* (1981), Fischer (1980), Masran & Pocock (1981), Pocock (1982), Tissott & Welte (1982), Walton (1983), Hart (1986) and Tyson (1995). A number of these schemes are summarised in Table 8.1.

Palynology based studies (including the present investigation) rely primarily upon the use transmitted light for the identification of kerogen types. Such studies are concerned with the composition and distribution of the kerogen in palynological preparations from which attempts are made to interpret the depositional environment and digenetic history of the samples in question.

The system of kerogen classification utilised in the present investigation (see Table 8.2) is primarily based upon that originally proposed by Tyson (1995), which itself closely follows the classification scheme of Combaz (1964). In both of these classifications the authors recognise three main groups of palynological organic matter: the palynomorph, phytoclast and amorphous groups. Each of these groups are defined below (see Section 8.4). A fourth and essentially subordinate group, the zooclast group, is also recognised in Tyson's scheme. This group acts as repository for all fragmentary non-palynomorph material of definite animal derivation, including arthropod exoskeletal and graptolite debris. However, if foraminiferal material can be identified as such it is instead assigned to the palynomorph group (zoomorph subgroup) since it is not strictly a zooclast Tyson (1995, p. 27).

I.C.C.P. (1963)	COMBAZ (1964)	ALPERN (1970)	BOSTICK (1971; 1972)	CORREIA (1971)	RAYNAUD & ROBERT (1976)	BUJAK *et al.* (1977)	TEICHMULLER & OTTENJAHN (1977)	ALPERN & CHEYMOL (1978)	HABIB (1979)	HUNT (1979)
EXINITE/ LIPTINITE: SPORONITE, CUTINITE, ALGINITE, RESINITE, LIPTODENDRITE etc	MICROFOSSILS	ORGANISMES AUTONOMES ZOOPLANKTON & ZOOBENTHOS	LIPTINITE (-EXINITE), SPORES, POLLEN, CUTICLES; RESIN; ALGAL BODIES	VEGETALE	STRUCTURED MATERIAL	PHYROGEN	LIPTINITE: SPORONITE, CUTINITE, SUBERINITE, FLUORINITE, RESINITE, CHLOROPHYLLINITE, LIPIDODETRINITE			
VITRINITE: COLLINITE, TELINITE	DEBRIS VEGETAUX	FUNGI; PHYTO-TERRESTRES	'HIGH-GRAY VITRINITE' & FUSINITE; 'LOW-GRAY VITRINITE'; PHYTOCLAST	LIGNEUSE		HYLOGEN	HUMITIE/ VITRINITE: TELLINITE, COLLINITE, VITRODETRINITE, CORPOCOLLINITE	INERTINITE: SPORES, POLLEN, CUTICLES, SUBERINS, MICROARNELLES (SHEETS)		
INERTINITE				TRACHEIDES		MELANOGEN	INERTINITE: FUSINITE, SEMIFUSINITE, SCLEROTINITE, MACRINITE, INERTODETRINITE, MICRINITE	INERTINITE: VITRINITE, GELS, GELLIFIED TISSUE, CELLULOSIC GELS; FUSINISED TISSUE	TRACHEIDS; CUTICLE	COALY
MATIERE ORGANIQUE AMORPHE		BITUMES; BACTERIES	FLOCCULES & GROUNDMASS ("COLLOALGINITE") SORBOMIXINITE; SOLID BITUMIN	COLLOIDALE	AMORPHOUS	AMORPHOGEN	ALGINITE: BITUMINITE; EXSUDATINITE (OIL EXPULSIONS); FAUNAL RELICS; MINERAL-BITUMINOUS GROUND MASS (MATRIX BITUMINITE)	ALGUES: BLACK-RED SHEETS; BLACK-RED BITUMINITE	DINOFLAGELLATES: GLOBULAR DEBRIS; COMMINUTED DEBRIS; SHREDDED DEBRIS	ALGAL: AMORPHOUS

ROBERT (1979)	ALPERN (1980a)	COMBAZ (1980)	DURAND (1980)	FISHER (1980)	HUTTON *et al.* (1980)	PARRY *et al.* (1980)	MASRAN & POCOCK (1981)	DAVIES *et al.* (1991)	*TYSON (1995)
INERTINITE: FUSINITE, SCLEROTNITE	GELITEXTITE; GELITE; DETRITE	GELIFIED ORGANIC MATTER	LIGNEOUS COALY HUMIC OR TERRESTRIAL	INERTINITE	INERTINITE: INERTODETRINITE	BLACK WOOD	CHARCOAL	MELANOGEN	PHYTOCLAST: MACROPHYTE DEBRIS: CHARCOAL; WOODY TISSUE; CUTICLE
HUMITIE/ VITRINITE: TELLINITE, COLLINITE	FUSITEXTITE; SCLEROTES	VEGETATION FRAGMENTS		VITRINITE: STRUCTURED; UNSTRUCTURED; CUTICLE	VITRINITE: CORPOHUMINITE; DESMOCOLINITE	BROWN WOOD; CORTEX & RESIN; CUTICLE	FUNGI: TERRESTRIAL (STRUCTURED)	HYLOGEN: NON-WOODY TISSUE; TUBES; WOODY PLANT DEBRIS	FUNGAL DEBRIS: FUNGAL HYPHAE
EXINITE: SPORONITE, CUTINITE, FLUORINITE, RESINITE, TERPENITE	SPORITES; EPIDERMS; INCLUSIONS	MICROFOSSILS	RECOGNISABLE BIOLOGICAL FRAGMENTS	PALYNOMORPHS	EXINITE: SPORONITE, CUTINITE, LIPTODETRINITE	PALYNOMORPHS	STRUCTURED AQUEOUS; SPORES & POLLEN	SPORES; ORGANIC WALLED MICROPLANKTON; SCOLECODONTS	PALYNOMORPH: SPOROMORPH: SPORES, POLLEN; ORGANIC WALLED MICROPLANKTON: ACRITARCHS, DINOFLAGELLATES; ZOOMORPH: FORAMINIFERAL LININGS, SCOLECODONTS; ZOOCLAST: GRAPTOLITE FRAGMENTS, ARTHROPOD FRAGMENTS
ALGINITE BITUMINITE I; BITUMINIES, EXSUDAUNITE, OIL (MICRINITE) II; FLUORESCING MATRIX (HUMIC) (SAPROPELIC)	ALGAL & BACTERIAL GELS (SAPROPELITE); MIGRABITUMEN; ZOOPLANKTON ZOOBENTHOS	GRANULOSE SPONGY, COLLODIALORGANICMATTER	COLLODIAL, ALGAL SAPROPELIC OMARINE	AMORPHOUS	ALGANITE A: ALGINITE B, BITUMITE OR RNE LAMELLAR ALGINITE; BITUMEN OIL STAINS	AMORPHOUS	RESINS; BIODEGRADED AQUEOUS; BIODEGRADED TERRESTRIAL		AMORPHOUS ORGANIC MATTER: RESINS, GELS, AOM
PLANKTONIC ALGAE: ALGAL & BACTERIAL GELS (SAPROPELITE); MIGRABITUMEN; ZOOPLANKTON ZOOBENTHOS	ALGUES: ALGINITE BITUMINITE I; BITUMINIES, EXSUDAUNITE, OIL (MICRINITE) II; FLUORESCING MATRIX (HUMIC) (SAPROPELIC)								

Table 8.1. Comparison of selected kerogen classification schemes. * denotes the scheme utilised in the present investigation.

	ZOOCLAST					Marine Zooplankton
						Insect Remains
						Other Arthropod Remains
	ZOOMORPH					Foraminiferal Test Linings
						Scolecodonts
						Chitinozoa
	PALYNOMORPH	Phytoplankton	Dinoflagellate Cysts			Peridinoid cysts
						Gonyaulacoid cysts
						Proximate & proximochorate morphotypes
						Chorate morphotypes
						Holocavate & circumcavate morphotypes
			Prasinophytes			Tasmanitids
						Crassosphaerids
						Leiospherids
						Pterospermellids
						Cymatiospherids
			Acritarchs	Acanthomorphitae		Short processes
						Long processes
						Polygonomorphitae
						Nectomorphitae
			Cyanobacteria			Chroococcales
						Rivulariacae
						Oscillatoriales
			Chlorococcale			*Botryococcus*
						Pediastrum
						Rhodophyte spores
		Sporomorph	Pteridophyte	Microspores (<200µm)		Isospores
						Smooth & thin walled
						Thick & strongly ornanmented
						Saccate
						Megaspores (>200µm)
			Gymnosperm pollen & prepollen			Bissacate
						Simple, small, sphaeromorph
						Angiosperm pollen
						Fungal spores
						Fungal sclerotia
		Translucent	No definitive biostructure	Non-cellular		Membranes
				Square, elongate, lath	Non-fibrous	Tissue without pits
					Fibrous	Marine macrophyte (seagrass)
				Massive, angular		Highly gelified woody tissue
				Irregular degraded		Degraded macrophyte tissue
				Residual trace of structure		Pseudo-amorphous phytoclast
			Definitive biostructure	Cellular	2D mass	Cuticle
					3D mass	Cortex
						Suberinized phellem tissue
						Melanized fungal hyphae
						Wood tracheid
		Opaque				Equidimensional (l:w < 3)
						Lath-shaped (l:w > 3)
STRUCTURELESS	AMORPHOUS MATTER					A.O.M.
						Humic Gel
						Resin

STRUCTURED

PHYTOCLAST

Table 8.2. Tyson's palynofacies classification scheme. Adapted from 'Sedimentary Organic Matter: Organic Facies & palynofacies' (Tyson, 1995).

8.4 KEROGEN TYPES

8.4.1 PHYTOCLAST GROUP (ORIGIN AND CLASSIFICATION) Fig. 10.3

The term phytoclast was first introduced by Bostick (1971, p.84) in reference to dispersed clay to fine sized particles of altered plant matter apparently derived originally from land plants. Bostick (1974) includes "grains of clastic organic matter similar to coal", as phytoclasts "because many of them have relict plant structures' (*ibid.*, p.1) and which "consist of plant spores and pollen, leaf cuticles and fragments that have bordered pits, ribs, fibres, or cellular structure" (*ibid.*, p.3). Bostick (1971, p.85) also lists probable algal debris ('floccules') under the heading of phytoclast. Thus, Bostick's definition apparently includes all plant derived kerogen under the term 'phytoclast'.

Tyson (1995, p.27) notes that there seems to be little value in such a wide ranging term, instead advocating the usage of the term in a stricter context. In the present study, the term phytoclast is used *sensu* Tyson (*ibid*) and is restricted to particles which are literally 'clasts' (from the original Greek *klastos* = broken in pieces). Usage of the term in this context thus excludes palynomorphs and amorphous/ structureless kerogen from the group. The phytoclast group can be further sub-divided into three main categories:

8.4.2 WOODY TISSUES

The majority of dispersed fossilizing phytoclasts are derived from the lingo-cellulosic tissues of terrestrial macrophytes (Tyson, 1995, p.151). This majority most likely represent fragmentary remains of strongly lignified mechanical support and vascular tissues of the secondary xylem ('wood') of arborescent gymnosperms and angiosperms, including analogous tissues in tree ferns and extinct vascular plants that exhibited secondary growth. Such material typically has a high preservation potential due to the resistant and stable nature of the lignin it contains. Lignin contents for arborescent wood are typically 25-30 wt % and are generally higher in gymnosperms than in angiosperms.

Woody tissue typically exhibit lath-shaped, equidimensional, or 'needle-like' morphologies and may be tabular, pitted or banded; most fragments have an angular outline (see Figure 8.3). Among the most commonly occurring lignified structures observed in the present study are fragments derived from 'xylem elements', which most likely represent tracheids and vessels (Tyson, 1995, p.151). Tracheids are characterised by

their bordered, scalariform or other types of 'pits', pores by which the elements communicate with adjacent cells (Tyson, 1995). In palynological preparations these particles are generally brown, dark-brown or entirely opaque. In modern wood tracheids are up to 1500-5000um in length, and 15-80um in diameter (Wilson & White, 1986; Eaton & Hale, 1993, pp 11-12); they are approximately 'tubular', elongate spindle shapes, but often have hexagonal or polygonal cross section. Each tracheid may have 50-300 pits (Fahn, 1982, p. 314), mostly located on the radial walls, and arranged in single or multiple rows (uniseriate, biseriate or multiseriate).

8.4.3. CUTICLE (EPIDERMAL TISSUES)

The cuticular layer represents the outermost part of the epidermis of higher plants which do not show secondary growth (Tyson, 1995, p.156). The majority of cuticular fragments are derived from leaves (because these are also produced and shed in great numbers and their surface area is very large). In modern forests annual forest litter production consists of about 65-75 wt% leaf material (Bray & Gorman, 1964; Hayes, 1979, pp. 28-9). Under transmitted light, cuticle appears as very fine, pale yellow to colourless material. In the present investigation, material is only identified as cuticle where remnants of the original cell structure are observed (see Figure 8.3) Cuticle material is a common component in palynofacies assemblages from the Mylan Park samples.

In modern settings, cuticle tends to be associated hydrodynamically with the sand-silt fraction of sediments. Cuticle material is commonly found in abundance in delta top, prodelta and proximal siliciclastic submarine fan facies.

8.4.4. OPAQUE AND SEMI- OPAQUE PHYTOCLASTS

Tyson (1995, p.159) notes that there is a complex continuum of variously charred or oxidized plant tissues in palynological preparations. This poses a considerable problem when attempting to classify mixed materials when relying solely upon transmitted light microscopy. Opaque and semi-opaque phytoclasts are the most dominant kerogen type in samples from Pennsylvania analysed in the present study.

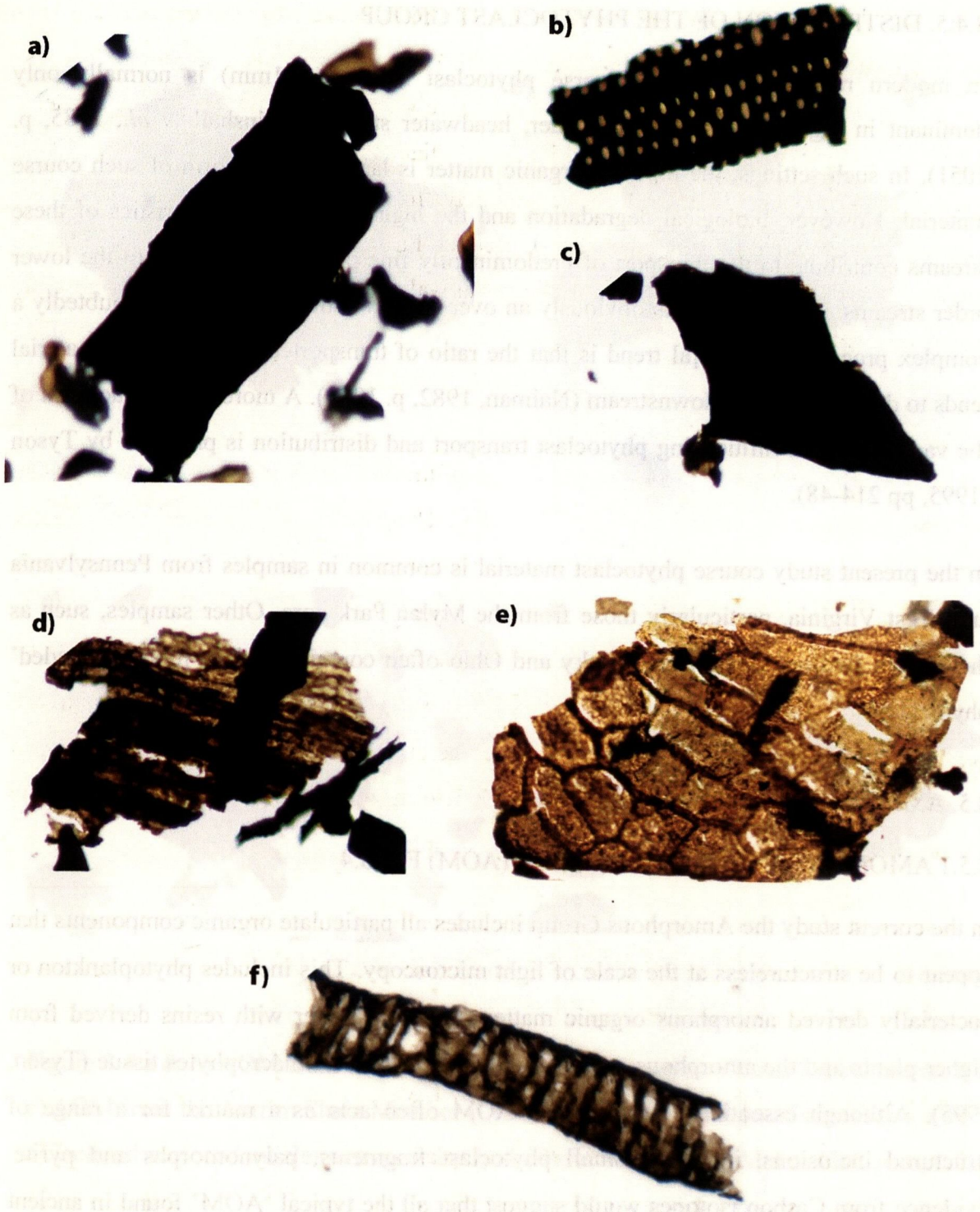


Figure 8.3. Opaque and semi- opaque phytoclast particles. a) Opaque lath shaped phytoclast. b) Opaque phytoclast - pittied structure characteristic of tracheid tissue. c) Opaque phytoclast. d) Semi-opaque phytoclast with remnant scalariform pitting. e) Semi-opaque phytoclast - polygonal cell outlines characteristic of cuticle tissue. f) Semi-opaque phytoclast - tracheid - note the helical thickening of the secondary wall.

8.4.5. DISTRIBUTION OF THE PHYTOCLAST GROUP

In modern rivers and streams, coarse phytoclast material (>1mm) is normally only dominant in high, first and second order, headwater streams (Minshall *et al.*, 1985, p. 1051). In such settings, the input of organic matter is largely in the form of such course material. However, biological degradation and the high retention characteristics of these streams contribute to the transport of predominantly fine phytoclast material to the lower order streams. Although this is obviously an over simplification of what is undoubtedly a complex process, the general trend is that the ratio of transported coarse to fine material tends to decrease rapidly downstream (Naiman, 1982, p. 1078). A more detailed account of the various factors influencing phytoclast transport and distribution is provided by Tyson (1995, pp 214-48).

In the present study course phytoclast material is common in samples from Pennsylvania and West Virginia, particularly those from the Mylan Park core. Other samples, such as those from Bedford Shale in Kentucky and Ohio often contain smaller, more 'degraded' phytoclasts.

8.5. AMORPHOUS GROUP

8.5.1 AMORPHOUS ORGANIC MATTER (AOM) Fig. 8.4

In the current study the Amorphous Group includes all particulate organic components that appear to be structureless at the scale of light microscopy. This includes phytoplankton or bacterially derived amorphous organic matter (AOM) together with resins derived from higher plants and the amorphous products of the diagenesis of macrophytes tissue (Tyson, 1995). Although essentially structureless, AOM often acts as a matrix for a range of structured inclusions, including small phytoclast fragments, palynomorphs and pyrite. Evidence from Carbon isotopes would suggest that all the typical 'AOM' found in ancient marine basinal fine-grained sediments is ultimately derived from phytoplankton or bacteria (Lewan, 1986). Thus in mass terms, nearly all fossilised marine organic matter is represented by AOM since marine biomass is dominated by unicellular algae. However, since complications arise over the definition of what is 'amorphous' (structureless), palynologists typically apply the term amorphous in a purely descriptive sense and as such

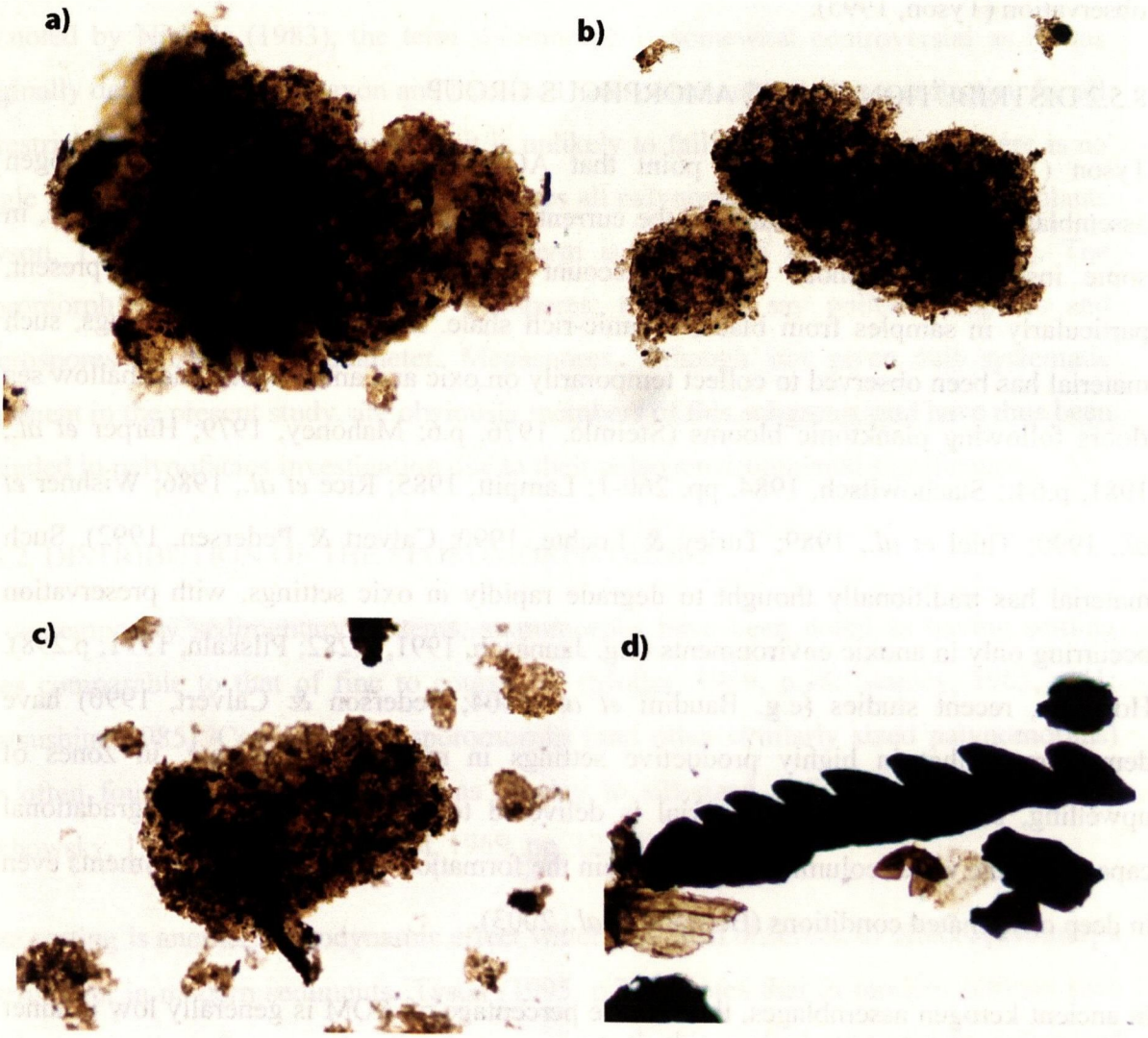


Figure 8.4 a & b) AOM from the Chattanooga Shale Formation - Three Licks Quarry, KY.
c) AOM from the Antrim Shale Member (Ohio Shale Fm.) - Williams County core. OH.
d) Isolated scolecodont element recorded in the Price Formation - Mylan Park core, WV.

is not intended to imply a precise physico-chemical condition at all possible scales of observation (Tyson, 1995).

8.5.2 DISTRIBUTION OF THE AMORPHOUS GROUP

Tyson (1995, p249) makes the point that AOM frequently dominates the kerogen assemblages in which it is found. In the current investigation this is certainly the case, in some instances amorphous organics account for 90-100% of the kerogen present, particularly in samples from black, organic-rich shale. In modern marine settings, such material has been observed to collect temporarily on oxic and anoxic deep and shallow sea floors following planktonic blooms (Steimle, 1976, p.6; Mahoney, 1979; Harper *et al.*, 1981, p.64;; Stachowitsch, 1984, pp. 260-1; Lampitt, 1985; Rice *et al.*, 1986; Wishner *et al.*, 1990; Thiel *et al.*, 1989; Turley & Lochte, 1990; Calvert & Pedersen, 1992). Such material has traditionally thought to degrade rapidly in oxic settings, with preservation occurring only in anoxic environments (e.g. Jannasch, 1991, p.282; Pilskaln, 1991, p.298). However, recent studies (e.g. Baudini *et al.* 2004; Pederson & Calvert, 1990) have demonstrated that in highly productive settings in modern oceans, e.g. in zones of upwelling, sufficient organic material is delivered to: (i) outbalance the degradational capacity of the water column, and (ii) sustain the formation of organic rich sediments even in deep oxygenated conditions (Bertrand *et al.*, 2003).

In ancient kerogen assemblages, the relative percentage of AOM is generally low in inner (shallow) shelf facies but tend to increase in more offshore, dark, organic-rich basinal sediments (Dow & Pearson, 1975, pp. 87-8; Bujak *et al.*, 1977a, p.200).

8.6. PALYNOMORPHS

The term palynomorph was first introduced by Tschudy (1961) to denote all discrete HCl and HF-resistant, organic-walled (either unicellular, multicellular, or colonial) microfossils that may be present in palynological preparations. In the present investigation, the term palynomorph is used in the same sense. Three major groups of palynomorphs are distinguished in this present work: sporomorphs (spores, pollen and fungal spores), phytoplankton (e.g. acritarchs, dinoflagellates) and 'zoomorphs' (animal derived palynomorphs, e.g. scolecodonts, chitinozoans and foraminiferal linings). Each of these sub-groups is defined below.

8.6.1 SPOROMORPH SUBGROUP

As noted by Nichols (1983), the term sporomorph is somewhat controversial as it was originally defined as a form taxon and has since been commonly used as a collective for all terrestrial spores and pollen. However, it is unlikely to fall into disuse because there is no single term collective term which that embraces all palynomorphs produced by land plants (Tyson, 1995). In this current study, the term is applied in its collective sense. The sporomorph group is dominated by miospores; that is to say pollen, isospores and microspores < 200µm in diameter. Megaspores, although not given full systematic treatment in the present study, are obviously members of this subgroup, and have thus been included in palynofacies investigation due to their palaeoenvironmental significance.

8.6.2. DISTRIBUTION OF THE SPOROMORPH GROUP

In contemporary sedimentary systems, sporomorphs have been noted as having settling rates comparable to that of fine to course silt (Muller, 1959, p.28; Stanley, 1965, p.31; Matsushita, 1985). Consequently, sporomorphs (and other similarly sized palynomorphs) are often found in high concentrations in clay to silt-sized sediments, i.e. <63µm (de Jekhowsky, 1958, p.1394; Rossignol, 1969, pp. 122-3).

Size sorting is another hydrodynamic effect which has been observed to effect sporomorph distribution in modern sediments. Tyson (1995, p.264) notes that in modern settings such sorting typically influences the distribution of small, thin-walled, non-saccate pollen and other larger, or more dense, non-saccate sporomorphs. On the basis of modern samples from the Atlantic and Gulf of Mexico, Hoffmeister (1954) suggested that ratios of large to small sporomorphs may be applied to infer proximity to shorelines (Traverse, 1988, p.397; Tyson, 1995, p.264). Such size sorting has also been demonstrated to occur in late Devonian and Mississippian sediments (e.g. Higgs *et al.* 1988, p. 10; Jaeger, 2004). Based upon the results of the present investigation, and data reported by previous authors (e.g. Coleman & Clayton, 1987; Heal & Clayton, 2009), it is inferred that such size sorting has influenced the distribution of palynomorphs assemblages assigned to the VI Biozone in the Eastern USA (see Chapter 12).

8.6.3. MARINE PHYTOPLANKTON

Three distinct groups of marine microplankton are distinguished in the current study: acritarchs, leiospheres and tasmanites. A description of each and brief notes concerning their environmental significance are provided below:

Acritarchs Pl. 13

Strother (1996, p.81) defines acritarchs as "fossilized, organic-walled cysts of unicellular protists that cannot be assigned to known groups of organisms". The term was first introduced by Evitt (1963b) as an informal holding category for all non-sporomorph and non-dinocyst palynomorphs (in particular those belonging to the non-dinocyst 'hystricospheres') that were of uncertain affinity or awaiting reclassification. Based on their mode of occurrence, it is the general consensus that the vast majority of, if not all, acritarchs represent the fossilised resting cysts of marine plankton (Tappan, 1980, p. 199; Strother, 1996, p.81).

Since the current thesis is primarily concerned with the miospore biostratigraphy, acritarchs are not given full systematic treatment. Where tentative identifications are made it is almost exclusively to the generic level. However, due to their obvious palaeoenvironmental significance, the occurrence of acritarchs in palynological preparations is incorporated into this palynofacies investigation. Samples from the Ohio Shale and Bedford Shale formations were found to contain particularly diverse and abundant acritarchs assemblages. In contrast, acritarch occurrence in overlying lithostratigraphic units was found to be somewhat sporadic. Coleman & Clayton (1987) report a similar stratigraphic distribution of acritarchs in Eastern Kentucky. Despite being the most diverse and abundant of the three microplankton subgroups recognised in the present study, due to their small size, they are likely to be the least significant in volumetric terms.

Leiospheres Pl. 13

Leiospheres are smooth, thin-walled, spherically shaped palynomorphs, thought to be characteristic of inshore-shallow water facies (Tyson, 1995, p.319-320). Although the true taxonomic affinity of leiospheres is uncertain, they are generally considered to represent the fossilised resting cysts of prasinophytic algae. However, they could equally represent

the vegetative stages of the algal life cycle. Authors including (Wall, 1962) suggest that the affinities of *Leiosphaeridia* lie with the *Halosphaera*, a modern planktonic green alga. In the present study leiospheres were found to be relatively common in samples from the Ohio Shale Formation, however, were most abundant in the samples of grey mudstone from the Three Licks Bed in Kentucky, occurring in association with Tasmanites and various species of acanthomorph acritarchs.

Tasmanites Pl. 13

Tasmanites are simple, punctuate, thick-walled, spherical palynomorphs. The name was originally given by Newton (1875) in reference to microfossils he described from the Tasmanite marine 'coal' of Tasmania. The Family *Tasmanitacea* is included in the Division *Prasinophyta* of the Green Algae.

The occurrence of tasmanites in upper Devonian sections in Eastern and the Midwest USA is well documented by previous investigations. Reinsch (1884) described specimens of tasmanites from the Ohio Shale in the Chicago area. In the same year, Johnson & Thomas (1884) reported the occurrence of tasmanites within quaternary glacial deposits and the water supply in the same area, presumably reworked from the Ohio Shale. More recently, Winslow (1962) recorded several genera of *Tasmanites* sp. from the Upper Devonian Olentangy, Ohio and Bedford Shale formations in Ohio.

Coleman (1991, unpub. PhD thesis, p. 150) noted that *Tasmanites sinuosus* is particularly common within the lower Bedford Shale in Kentucky. However, this species becomes rare higher in the unit, and is entirely absent in the Sunbury Shale and overlying formations. Similarly, in the present investigation, *T. sinuosus* is particularly abundant in samples of the Ohio Shale from localities in Ohio and Kentucky, yet no specimens have been observed in lithostratigraphic units herein assigned in to the Mississippian. Coleman (*ibid.*) notes that it is somewhat surprising that there are no Tasmanites present in the black Sunbury Shale, since it is so similar in lithology to the Ohio Shale, where Tasmanites occur in abundance. Like acritarchs, in the present study, Tasmanites are recorded primarily for palaeoenvironmental purposes. Thus, discussion relating to the stratigraphic range of *Tasmanites* sp. is beyond the scope of this account. However, it does appear from the data gathered in this investigation and that previously reported by Winslow (1962) and Coleman (1991) that species including *Tasmanites sinuosus* may become extinct close to

the inferred position of the Devonian – Carboniferous boundary, thus coinciding with the extinction of several distinctive miospore species.

8.7 SCOLECODONTS (ZOOMORPH GROUP)

Scolecodonts are defined by Tyson (1995, p.205) as, "the part-calcified and scleroproteinaceous ('chitinous') mouth parts ('pharyngeal jaws') of benthic polycheate annelid worms". Most scolecodonts occur as detached elements of compound jaw apparatuses originally composed of several morphologically varied pairs of dorsal maxillae and one pair of ventral mandibles (Szaniawski, 1996). Since the muscular and cuticular tissues holding the elements together presumably decay rapidly post-mortem, the majority of scolecodonts are recorded as dispersed elements, and articulated jaws are rarely preserved (Tyson, 1995).

The oldest scolecodonts have been recovered from Lower Ordovician (Arenig) age strata, ranging to recent sediments. However, they appear to have reached their acme during the Upper Ordovician, Silurian and Devonian (Traverse, 1988, p.140; Tyson, 1995, p.205; Szaniawski, 1996, p.337). Scolecodonts have been recorded in many types of marine sediments but are noted as being particularly common in shallow water lithologies, including marly limestones and shales. They are often found in association with other microfossils including graptolites, chitinozoans, spores and acritarchs (Szaniawski, 1996, p.337). Since they occur almost entirely in marine sedimentary rocks (Traverse, 1988, p.140), they serve as useful palaeoenvironmental indicators.

Due to their acid- resistant organic composition, scolecodonts are commonly found in palynological preparations. Tyson (1995, p.339) notes that while palynological reports of scolecodonts are common they are mostly incidental. Little use has been made of scolecodonts for biostratigraphic purposes, a situation Szaniawski (1996, p.350) attributes to our insufficient knowledge concerning their taxonomy and stratigraphic range. Sporadic occurrences of scolecodonts recorded in the present investigation are used primarily as indicators of marine deposition. However, as is the case with most microfossils, scolecodonts are prone to reworking. As highlighted by Tyson (1995, p.349), it cannot be assumed that all scolecodonts necessarily represent *in situ* autochthonous remains. Furthermore, the low abundance of scolecodonts may result in too much importance being attached to rare, sporadic and potentially redeposited scolecodonts. Thus, in the present

study, scolecodonts are only used as marine indicators when found in association with other marine microfossils (e.g. acritarchs, tasmanites and leiospheres) or macrofossils (e.g. marine bivalves, brachiopods).

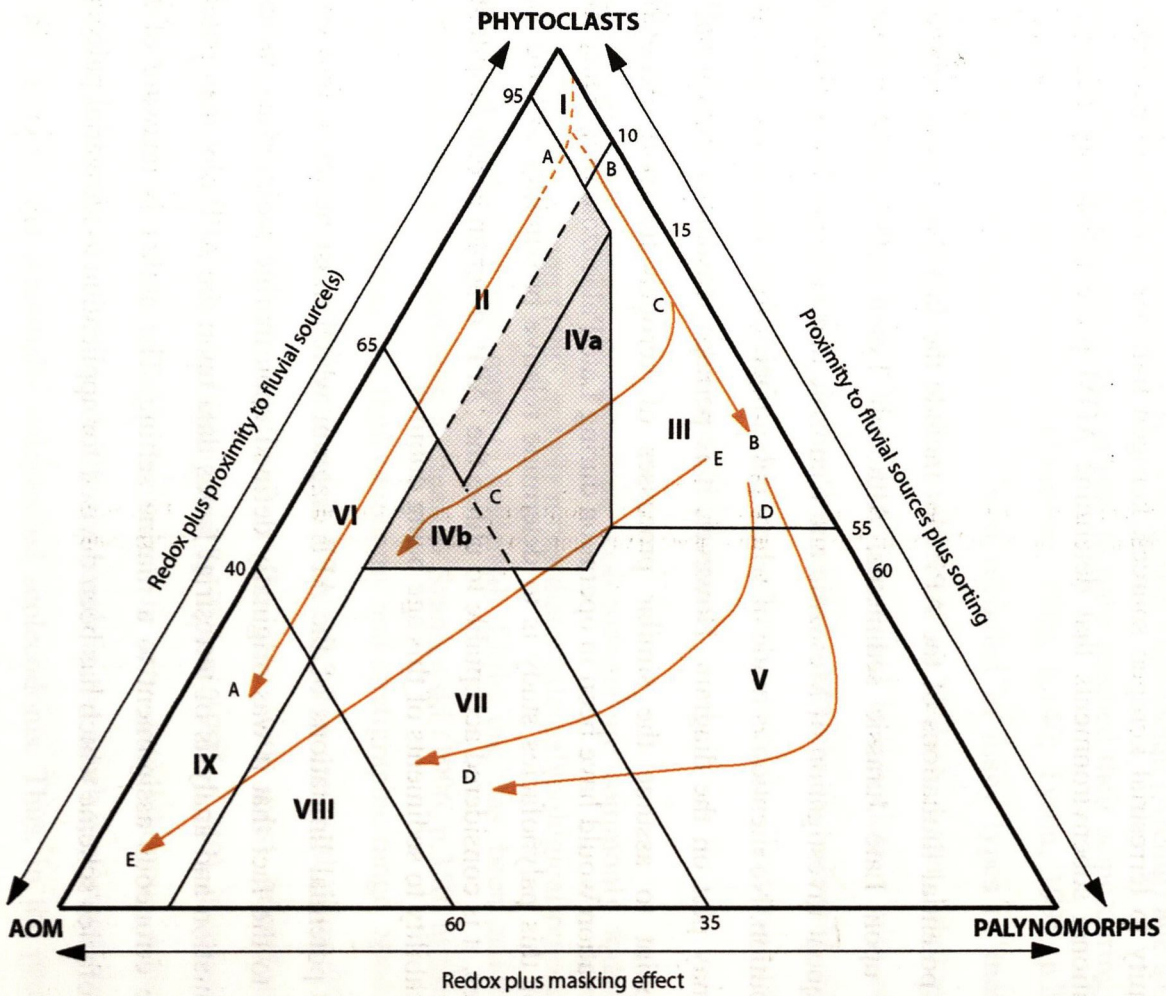
8.8 GRAPHIC PRESENTATION OF PALYNOFACIES DATA

In the present investigation, palynofacies data are presented primarily in the format of ternary ('triangular') diagrams. Such diagrams are a particularly useful means of presenting percentage data for populations with three components. The main advantage of ternary diagrams is that the data plots with a spatial separation which is useful for grouping samples into empirically defined associations or assemblages (Tyson, 1995, p.441). In this thesis the particular ternary diagram used to present data and characterise kerogen assemblages is the 'AOM' – phytoclast – palynomorph ('APP') plot (after Tyson, 1985, p.573; 1989, p.162; 1993; 1995, p.443). This plot can 'pick out' differences in relative proximity to terrestrial kerogen sources, kerogen transport paths and the redox status of depositional subenvironments that determine AOM preservation (see Figure 8.5; Table 8.6).

Some potential limitations of the APP plot include the fact that it was originally defined based upon Late Jurassic sediments. Although Tyson (1995, p.443) notes that the subsequent investigation of Mesozoic and Cenozoic marine facies has yielded similar plot distribution. No mention is made of where palynofacies from Devonian and Carboniferous data may plot on the diagram. However, it is perhaps reasonable from a uniformitarian standpoint to assume the similar processes of kerogen transport, deposition and/or preservation would have been in operation during Late Palaeozoic time. Since the principal aim of this palynofacies study is to determine relative proximities to terrestrial kerogen sources, it is considered acceptable to utilise the 'APP' diagram herein despite its potential applicability to sediments of this age being dubious.

Other potential limitations of the APP diagram which must be taken into consideration relate to the fact that it was originally defined upon marine sedimentary facies. Thus the presentation and analysis of terrestrial facies data upon the APP plot may potentially lead to the erroneous assignment to a marine setting. The author is unaware of any similar palynofacies scheme which has been devised for application to terrestrial paleoenviron-

Figure 8.5. Ternary 'AOM' - phytoclast - palynomorph kerogen plot (after Tyson, 1985, 1989, 1993).



Key to palynofacies fields & environments

- **I** Highly proximal shelf or basin
- **II** Marginal dysoxic - anoxic basin
- **III** Heterolithic oxic shelf ('proximal shelf)
- **IV** Shelf to basin transition
  IVa dysoxic- suboxic IVb suboxic - anoxic
- **V** Mud dominated oxic shelf ('distal shelf)
- **VI** Proximal suboxic - anoxic shelf
- **VII** Proximal dysoxic - anoxic shelf
- **VIII** Distal dysoxic - oxic shelf
- **IX** Distal suboxic - anoxic basin

Shaded region overlaps with adjacent fields

Shelf - basin transport paths A -E

Table 8.6. Key to marine palynofacies fields distinguished on ternary APP diagram in Fig X. (from Tyson, 1993, after Tyson, 1989, p. 163)

Palynofacies field and Environment		*Comments*	*Spores: Bisaccates*	*Mircoplankton*	*Kerogen Type*
I	Highly proximal shelf or basin	High phytoclast supply dilutes all other components	usually high	very low	III, gas prone
II	Marginal dysoxic-anoxic basin	AOM diluted by high phytoclast input, but AOM preservation moderate to good. Amount of marine TOC dependent on basin redox state and dilution	high	very low	III, gas prone
III	Heterolithic oxic shelf ('proximal shelf)	Generally low AOM preservation; absolute phytoclast abundance dependent on actual proximity to fluvio-deltaic source. Oxidation and reworking common.	high	common to abundant Dinocysts dominant	III or IV, gas prone
IV	Shelf to basin transition	Passage from shelf to basin in time (e.g. increased subsidence/ water depth) or space (e.g. basin slope).Absolute phytoclast abundance depends on proximity to source and degree of redeposition. Amount of marine TOC depends on basin redox state. IVa dysoxic- suboxic IVb suboxic - anoxic	moderate to high	very low - low	III or II, mainly gas prone
V	Mud dominated oxic shelf ('distal shelf)	Low to moderate AOM (usually degraded). Palynomorphs abundant, Light coloured bioturbated, calcareous mudstones are typical.	usually low	common to abundant Dinocysts dominant	III > IV, gas prone
VI	Proximal suboxic-anoxic shelf	High AOM preservation due to reducing basin conditions. Absolute phytoclast content may be moderate to high due to turbiditic input and/ or general proximity to source.	variable, low to moderate	low to common Dinocysts dominant	II, oil prone
VII	Proximal dysoxic-anoxic shelf	Moderate to good AOM preservation, low to moderate palynomorphs. Dark coloured slightly bioturbated mudstones are typical.	low	moderate to common Dinocysts dominant	II, oil prone
VIII	Distal dysoxic-oxic shelf	AOM dominated assemblages, excellent AOM preservation. Low to moderate palynomorphs (partly due to masking). Typical of organic-rich shales deposited under stratified shelf sea conditions	low	low to moderate Dinocysts dominant, % prasinophytes increasing	II >> I, oil prone
IX	Distal subsoxic-anoxic basin	AOM dominated assemblage. Low abundance of palynomorphs partly due to masking. Frequently alginite-rich. Deep basin or stratified shelf sea deposits, especially sediment starved basins.	low	generally low Prasinophytes often dominant	II > I, highly oil prone

mental settings. For this reason, palynofacies data presented in this chapter are also displayed as plots of kerogen relative to stratigraphic depth. Although the presentation of data in this way may also lead to misinterpretations (see Tyson, 1995, p.441), it is considered that such plots give a good indication of the ratio of terrestrial vs. marine derived kerogen present in samples, and thus also to the sedimentary setting.

8.9. METHODOLOGY

The samples used for palynofacies analysis were prepared using a similar methodology to that described in Chapter 4. Since samples were initially processed for palynostratigraphy, sample preparation was optimised for miospore preparation rather than palynofacies analysis. Processing techniques such as sieving and boiling in HCl are likely to have altered the quantitative composition of the organic residues, primarily by removal of small (<20μm) particles of organic matter. However, since all samples were processed in this way, it is considered that the overall effects upon that data recorded will be negligible. Other processing techniques, such as the use of oxidising agents such as HNO_3, were considered too destructive to be used upon samples designated for palynofacies analysis; such techniques were reserved for use upon samples included in the palynostratigraphic study.

Some previous palynofacies investigations (e.g. Coleman, 1991) have made estimates of the total kerogen present by performing counts of the individual kerogen particles present in slides. However, in the present study this method was considered unsuitable since problems may arise in circumstances when one kerogen group is consistently smaller in size than yet numerically superior to another, e.g. spores to phytoclasts. Thus in the present study a different approach was taken. To estimate the quantity of the various kerogen components present in the samples, photographs were taken of a number of random fields of view under the microscope; it was found that 10x magnification was optimal for such purposes. Images were imported to Adobe Illustrator ® 10 where they were 'overlain' with a 10 x 10 grid. The kerogen present in each sample was then assigned to one of three categories discussed earlier in this chapter: the phytoclast, palynomorphs (sporomorph/ microplankton subgroups) or AOM groups. Once all of the kerogen had been identified, counts were made for each group using the grid, and a smaller 10 x 10 grid. Since the concentration of organic matter present in each samples varied, counts were normalised so

that the total kerogen counted = 100%, and the relative percentage of each of the three kerogen components determined.

8.10. PREVIOUS PALYNOFACIES STUDIES OF UPPER DEVONIAN & LOWER MISSISSIPPIAN STRATA IN THE EASTERN USA.

The majority of palynological investigations of Upper Devonian and Lower Mississippian strata in the Eastern USA have dealt exclusively with palynostratigraphy. However, a few studies also concerning palynofacies have been published by previous authors:

Richardson & Ahmed (1988) studied the palynofacies of the Upper Devonian strata from Western New York State Pennsylvania, including the Canadaway, Conneaut and Conewango Groups, and the Knapp Formation. These authors recognised five palaeoenvironments in their study.

Coleman & Clayton (1987) conducted a palynofacies investigation of the Bedford Shale, Sunbury Shale and Borden Formations of Eastern Kentucky. They recognised three distinct palynofacies types within the section, in ascending order; i) tasmanitid – amorphogen palynofacies (Bedford Shale), ii) amorphogen palynofacies (Sunbury Shale) and iii) melanogen palynofacies (Henley Bed, Farmers Member, Nancy Member and Cowbell Member).

Heal & Clayton (2009) conducted an investigation of the palynofacies of the Hannibal Shale Formation from two sections in northeastern Missouri, an outcrop section at Hannibal and a borehole core drilled at Clarence Dam. The presence of acritarchs and scolecodonts within the Hannibal Shale was interpreted by the authors as confirmation of a marine depositional environment for this lithostratigraphic unit.

A detailed discussion concerning the results of these palynofacies studies are discussed in relation to the results of the present investigation in section 8.12.

8.11 RESULTS OF PALYNOFACIES ANALYSIS

8.11.1 WILLIAMS COUNTY CORE Figs. 8.7 & 8.8.

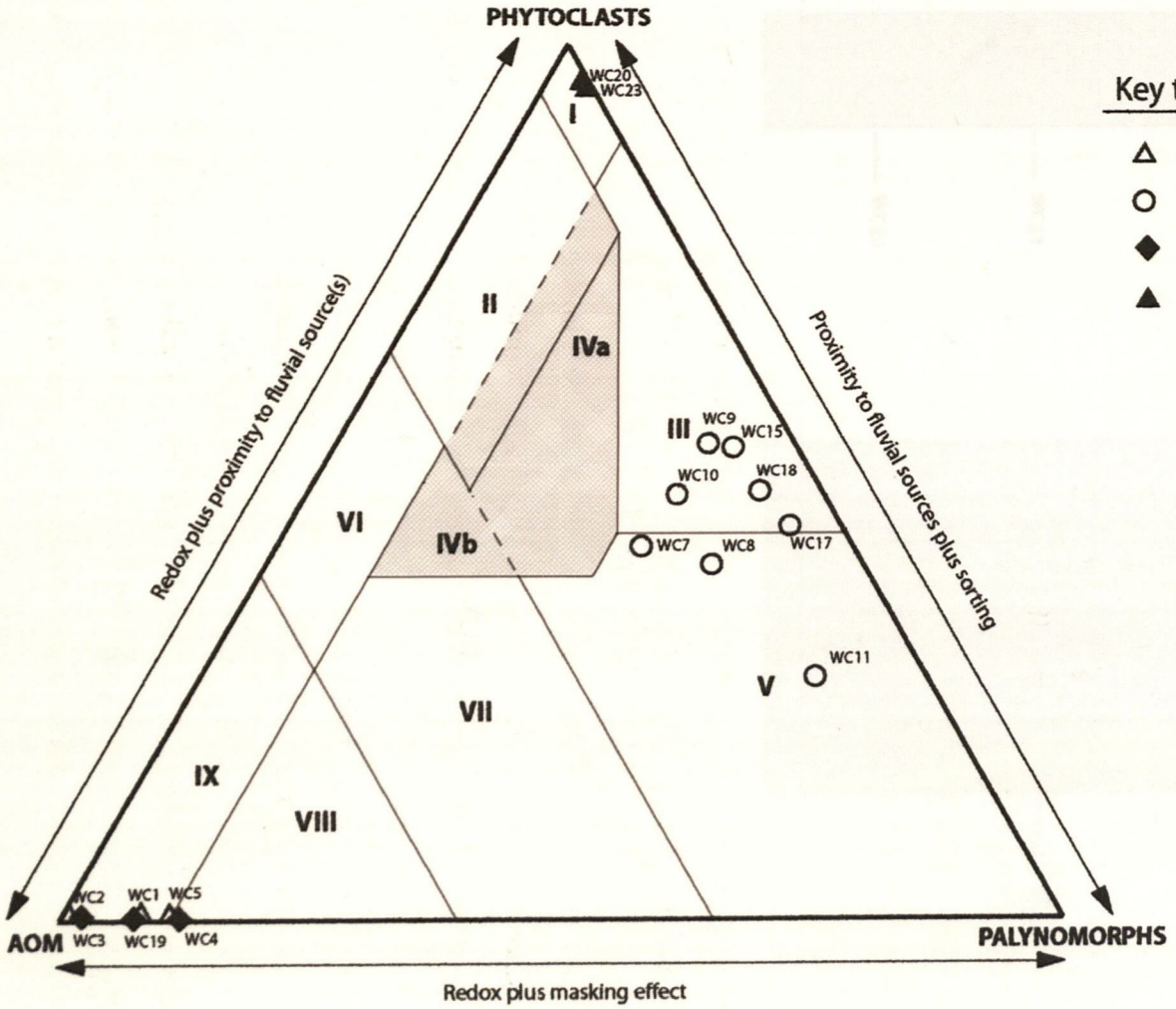
Samples from the Antrim Shale (WC2, WC1 and WC5) are dominated by AOM, which accounts for 98-100% of the kerogen present in these samples. Sample WC1 from the lower Antrim Shale is totally devoid of miospores. However, it contains a small quantity of tasmanites (2%). In the uppermost Antrim Shale (WC5) both miospores and tasmanites are present, accounting for 2% and 3% of the total kerogen content respectively. Phytoclasts are entirely absent within the Antrim Shale samples.

The palynofacies of the Antrim Shale appears to be indicative of deposition in a distal marine setting. The scarcity or absence of terrestrially derived kerogen (miospores and phytoclasts) within this stratigraphic interval supports this interpretation. Tyson plots for the palynofacies data from the Antrim Shale plot with field IX indicating deposition in a distal suboxic – anoxic basin environment.

The kerogen content of samples from the Bedford Shale Formation is more variable than that present in the underlying Antrim Shale. Generally, phytoclast material is the dominant kerogen component within this interval, representing between 33-57% of the palynofacies. The abundance of miospores within this interval also contrasts with that of the Antrim Shale. Miospores are present in all samples from the Bedford Shale, accounting for 18-32% of the total kerogen content. All samples analysed from this interval also contain tasmanites and leiospheres (6- 35%), and AOM (5 -19%).

Palynofacies assemblages of the Bedford Shale samples clearly differ from that of the underlying Antrim Shale. The Bedford Shale contains a relatively large proportion of terrestrially derived kerogen, indicating a close proximity to the coast-line. However, these samples also contain a significant quantity of organic matter derived from the marine realm, including tasmanites, leiospheres, acritarchs (rare), scolecodonts and AOM. The overall character of the palynofacies assemblages in these samples would therefore indicate a considerable degree of mixing between land derived material and that more typical of a marine setting. 'APP' plots for the Bedford Shale Formation (see Figure 8.7) can be interpreted as being indicative of deposition partially within a heterolithic oxic ('proximal') shelf environment, and partially upon a mud dominated oxic ('distal') shelf.

Figure 8.7. Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Williams County Core samples.



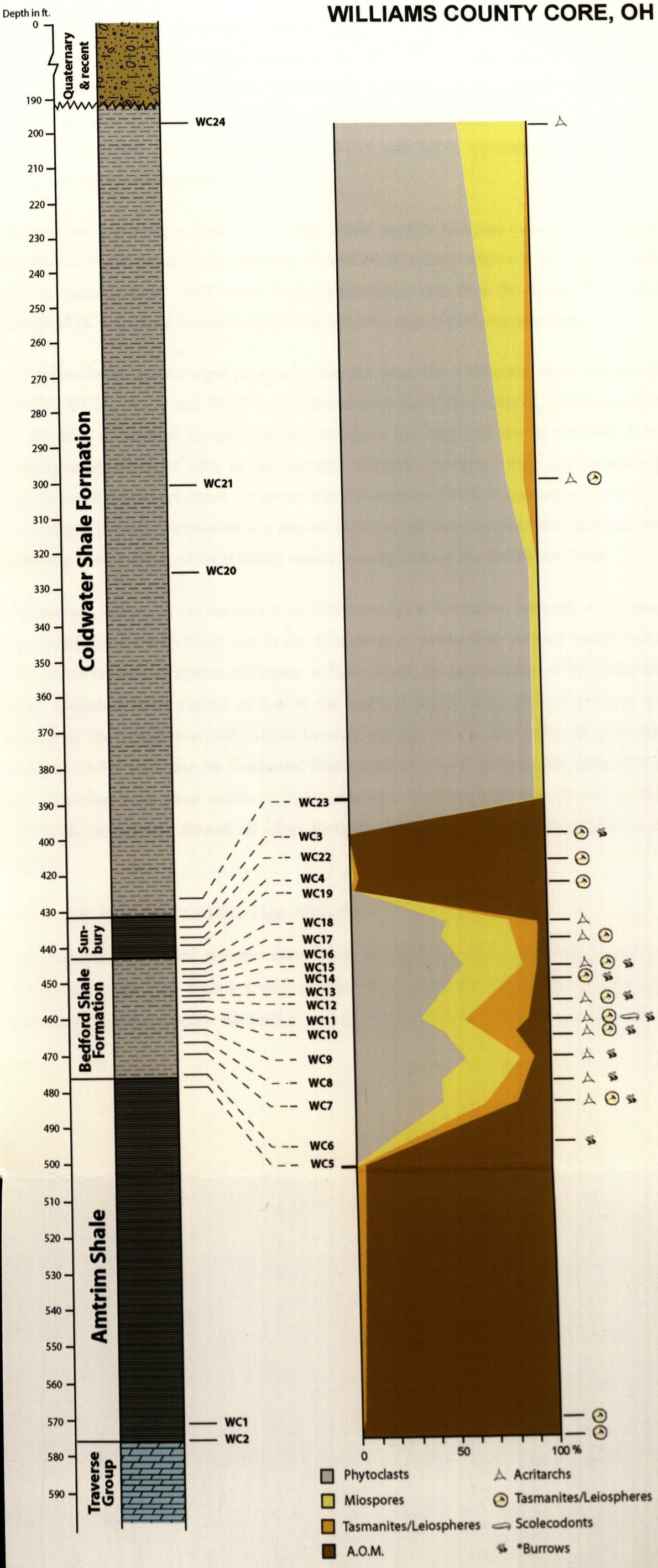


Figure 8.8 a) Stratigraphic log for the Williams County Core section illustrating the relative proportion of the main organic constituents present in the samples. *Reported in Ohio State Geological Survey core description (Appendix III)

Samples from the Sunbury Shale Formation (WC19, WC4 and WC3) contain relatively large quantities of AOM, which represents 95-100% of the total kerogen. Phytoclast material is entirely absent within the Antrim Shale samples. Miospores are relatively rare within this interval, accounting for ~2% of the total kerogen content of a single sample (WC4). Tasmanites are present in samples WC19 and WC4, representing 2-3% of the kerogen present in those samples.

Palynofacies assemblages from the Sunbury Shale samples compare closely to that from the Antrim Shale, presumably indicating deposition in a distal marine environment, with little terrigenous input. 'APP' plots for the palynofacies data from the Antrim Shale plot with field IX indicating deposition in a distal suboxic- anoxic basin environment.

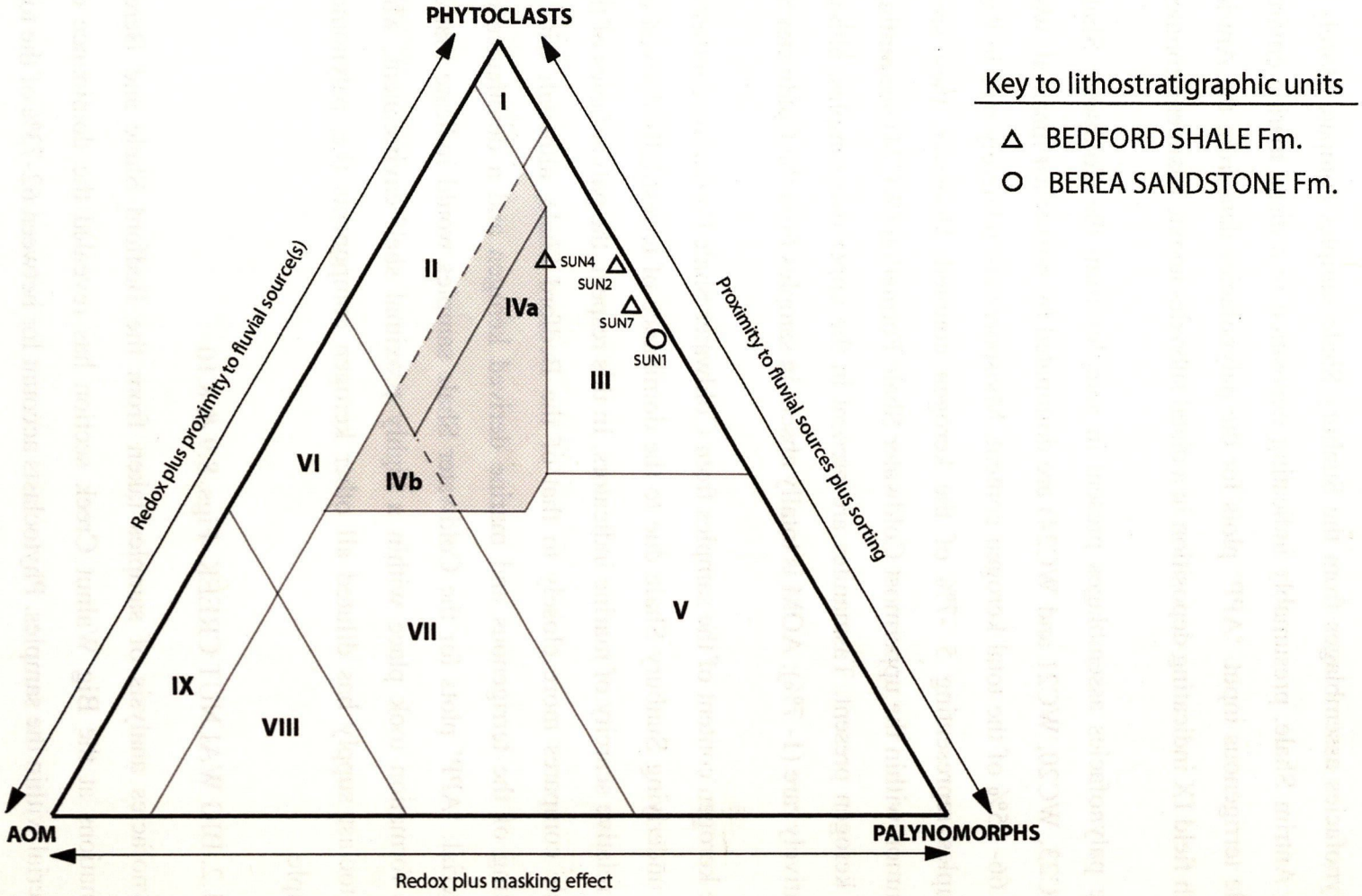
The palynofacies assemblages present in samples from the Coldwater Shale Formation (WC23, WC20, WC21 and WC24) are dominated by phytoclast material, which accounts for 66- 95% of the total kerogen content. Miospores are relatively rare in the lower three samples representing 5 -7% of the kerogen counted. However, they are particularly common within the uppermost Coldwater Shale Formation (WC24) accounting for 33% of the kerogen present. Tasmanites are present in the upper two samples, although they are relatively rare (1- 7%); AOM is totally absent in samples from the Coldwater Shale.

The kerogen content of the samples from Coldwater Shale Formation contrasts with that of the underlying Sunbury Shale due to the dominance of terrestrially derived matter and to the relative scarcity of marine indicators. In this respect, the palynofacies of the Coldwater Shale compares more closely to that of the Bedford Shale, although with perhaps less mixing of the terrigenous and marine derived kerogen and a dominance of phytoclast material. 'APP' plots for the Coldwater Shale samples would indicate that deposition of this formation took place within a highly proximal shelf environment, where the high phytoclast supply has diluted all other kerogen components (i.e. palynomorphs) in the sample.

8.11.2. BIG WALNUT CREEK Figs. 8.9 & 8.10

Palynofacies analysis of samples taken from the Bedford Shale and Berea Sandstone formations at the Big Walnut Creek section has revealed the dominance of phytoclast material within the samples. Phytoclasts account for between 62-73% of the total kerogen

Figure 8.9. Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Big Walnut Creek section.



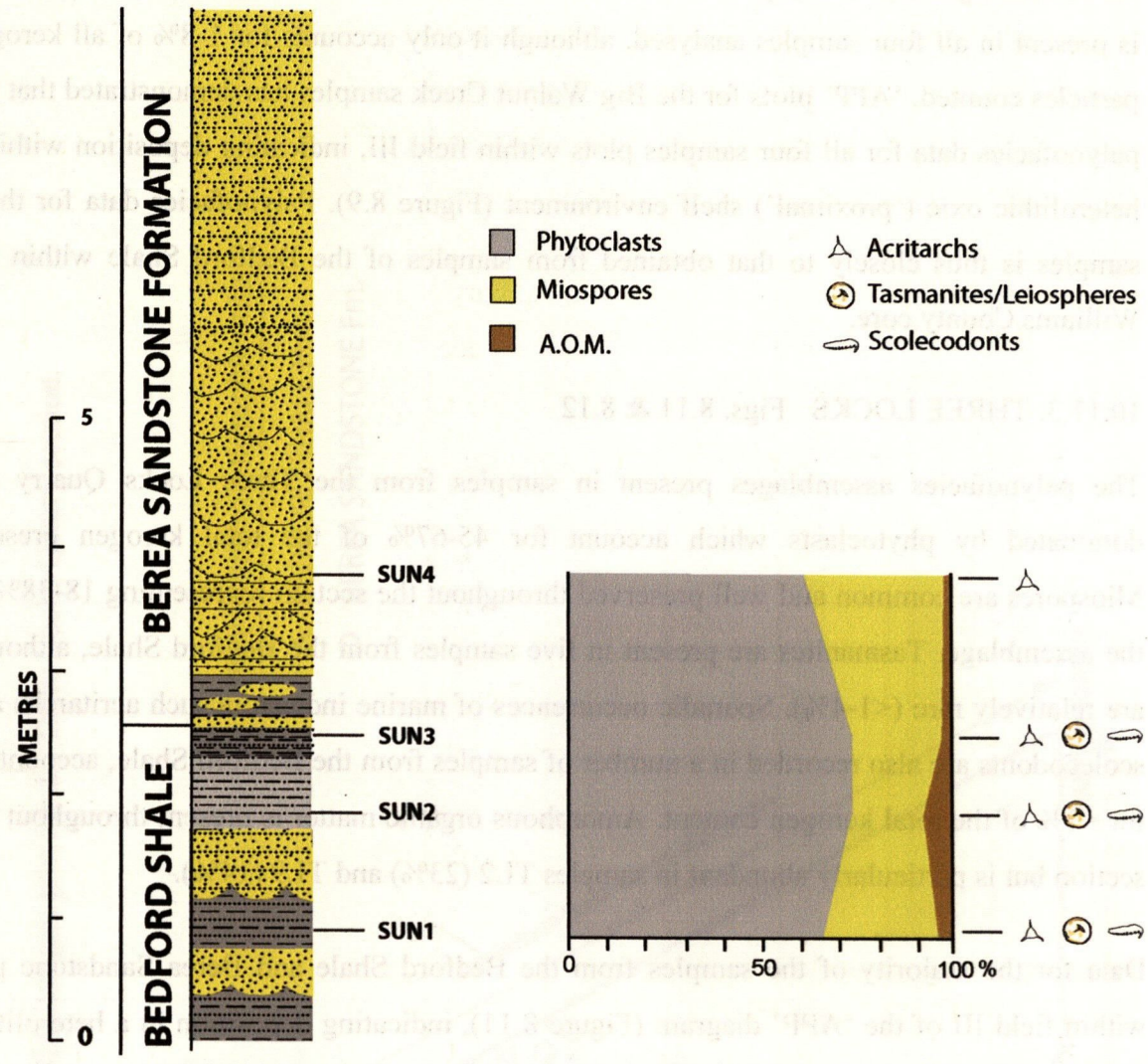


Figure 8.10. Stratigraphic log for the Big Walnut Creek section illustrating the relative proportion of the main organic constituents present in the samples.

present within the samples analysed. Miospores are the next most abundant component of the assemblages representing 18-37% of the material present. Amorphous organic material is present in all four samples analysed, although it only accounts for 1-8% of all kerogen particles counted. 'APP' plots for the Big Walnut Creek samples has demonstrated that the palynofacies data for all four samples plots within field III, indicating deposition within a heterolithic oxic ('proximal') shelf environment (Figure 8.9). Palynofacies data for these samples is thus closely to that obtained from samples of the Bedford Shale within the Williams County core.

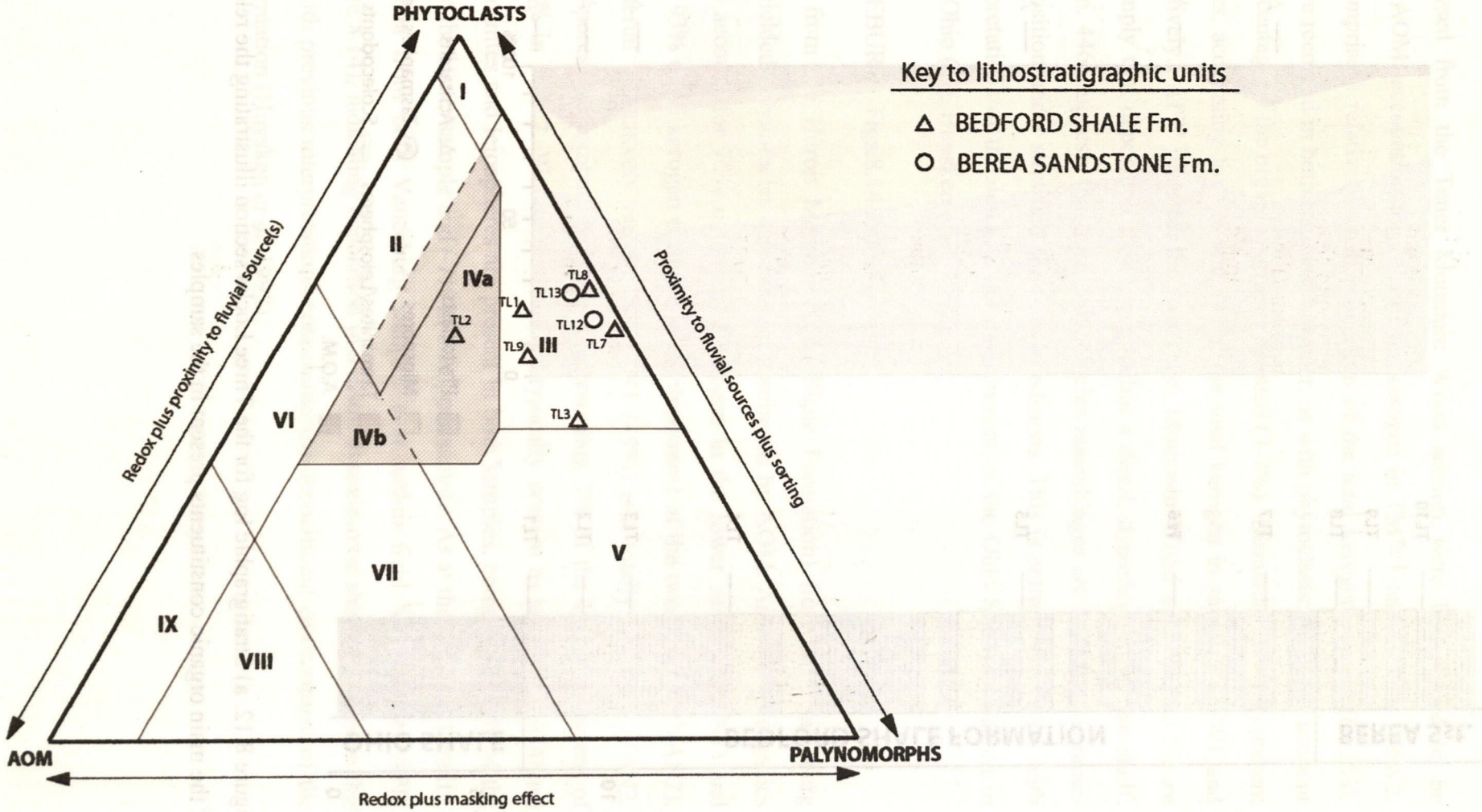
10.11.3. THREE LOCKS Figs. 8.11 & 8.12

The palynofacies assemblages present in samples from the Three Locks Quarry are dominated by phytoclasts which account for 45-67% of the total kerogen present. Miospores are common and well preserved throughout the section representing 18-38% of the assemblage. Tasmanites are present in five samples from the Bedford Shale, although are relatively rare (<1-4%). Sporadic occurrences of marine indicators such acritarchs and scolecodonts are also recorded in a number of samples from the Bedford Shale, accounting for <1% of the total kerogen content. Amorphous organic matter is present throughout the section but is particularly abundant in samples TL2 (23%) and TL9 (14%).

Data for the majority of the samples from the Bedford Shale and Berea Sandstone plot within field III of the 'APP' diagram (Figure 8.11), indicating deposition in a heterolithic (proximal) shelf environment. Sample TL2 from the lower Bedford Shale contains more AOM and thus plots in field IVa. This may be interpreted as being indicative of deposition within a dysoxic-suboxic shelf to basin transition.

The contact between the Ohio Shale and Bedford Shale in Central and Southern Ohio and Northern Kentucky is marked by the Bedford fauna, a combination of inarticulate phosphatic brachiopods and rhipidomellid brachiopods (Coogan *et al.*, 1981), and is thus indicative of a marine setting. Palynofacies analysis of samples from this interval at this locality and the Big Walnut Creek section are consistent with this interpretation.

Figure 8.11. Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Three Locks Quarry section.



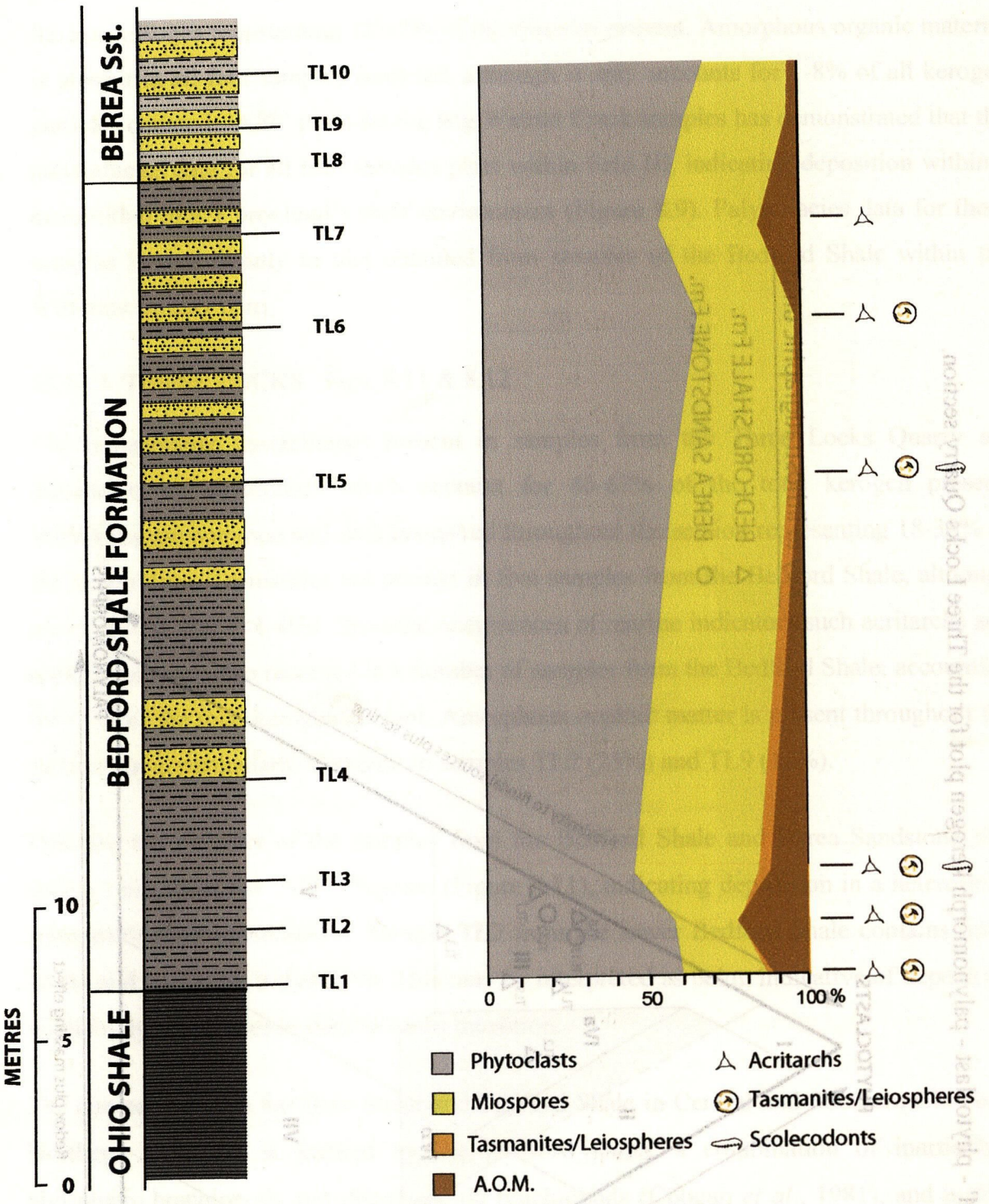


Figure 8.12. a) Stratigraphic log for the Three Locks section illustrating the relative proportion of the main organic constituents present in the samples.

8.11.4. TENER MOUNTAIN WOOD Figs. 8.13 & 8.14

Samples analysed from the Tener Mountain Wood section were both found to be dominated by AOM; accounting for 74% of the kerogen in TMW1 and 80% in TMW2. Phytoclasts comprise a relatively small proportion of the total kerogen present (6-12%). Miospores were recorded in both samples, however, as with phytoclasts; they only account for a small percentage of the organic particles counted (3-7%). Tasmanites are also present in both samples, accounting for 9% and 7% of the total kerogen in samples TMW1 and TMW2 respectively. 'APP' plots for the two Tener Mountain Wood samples (see Figure 8.14) would imply that deposition took place within a distal, dysoxic-oxic marine shelf. Tyson (1993, p. 446) suggests that such palynofacies assemblages are typical of organic-rich shale deposition under stratified shelf sea conditions. This is entirely consistent with previous interpretations of the depositional environment of the Ohio Shale Formation in Kentucky and Ohio (e.g. Huysken *et al.* 1992).

8.11.5. VANCEBURG Figs.8.14 & 8.15

Two samples from the Huron Member (Ohio Shale Formation) from the Vanceburg locality have yielded palynofacies assemblages dominated by AOM. Amorphous organics were found to account for 70% of the total kerogen in the lower sample (VAN1) and approximately 93% of all kerogen particles in the uppermost of the two samples (VAN2). Phytoclast material is relatively rare in the VAN1 (~9%) and totally absent in VAN2. Likewise, miospores are comparatively rare, representing 3% of the kerogen content of VAN1 and <1% in VAN2. Woody particles are typically present as small (<50-100μm) macerals. Tasmanites and leiospheres are present in both samples, comprising 15% of the total kerogen in the lower sample and ~7% in the upper sample. As at the previous locality, palynofacies data from both Vanceburg samples plot within field VIII in the 'APP' diagram (Figure 8.14), indicating deposition in a distal dysoxic-oxic shelf. Once more this is consistent with previous interpretations concerning the depositional environment of the Ohio Shale Formation (Huysken *et al.* 1992).

TENER MOUNTAIN WOOD, OH

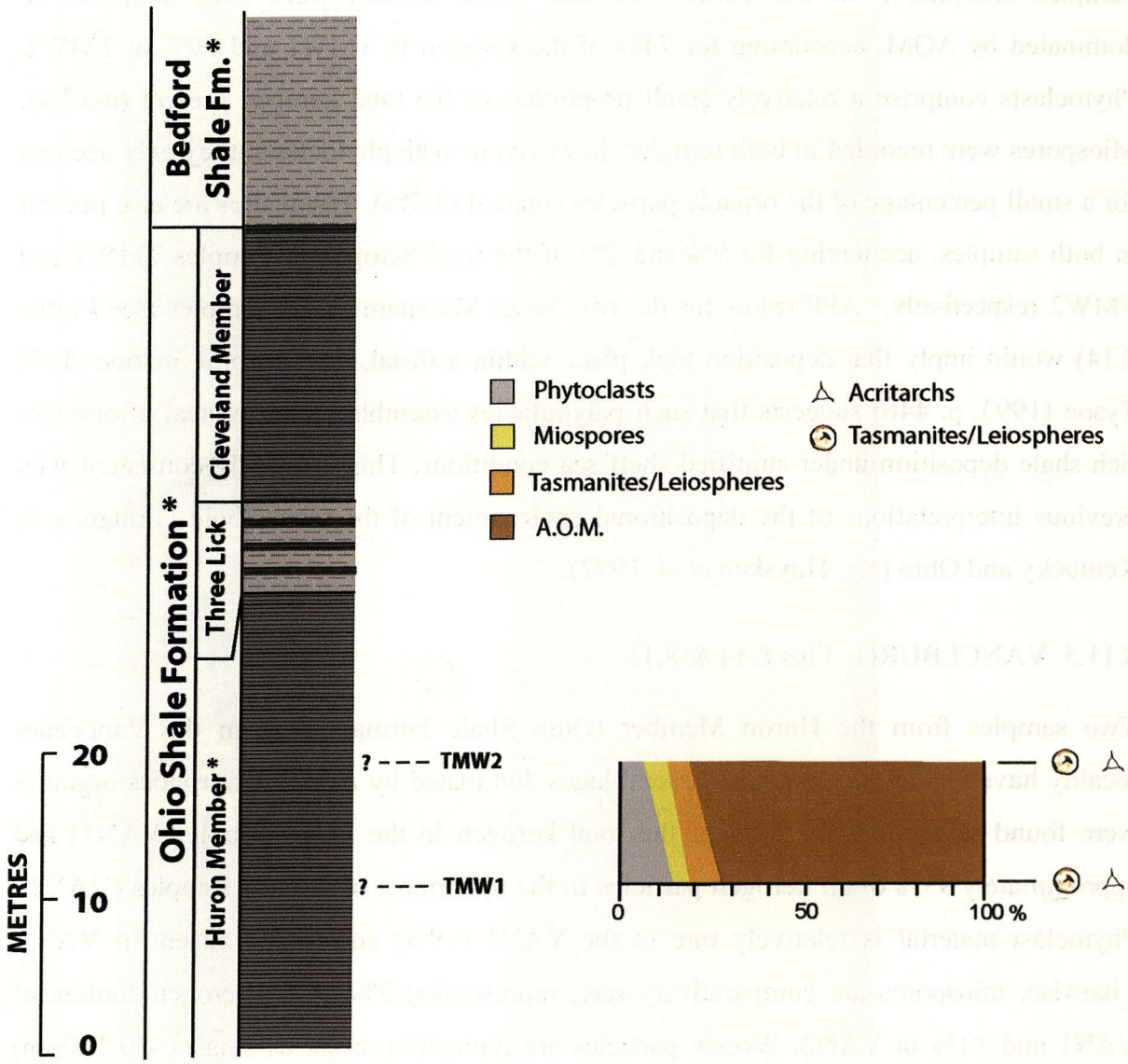
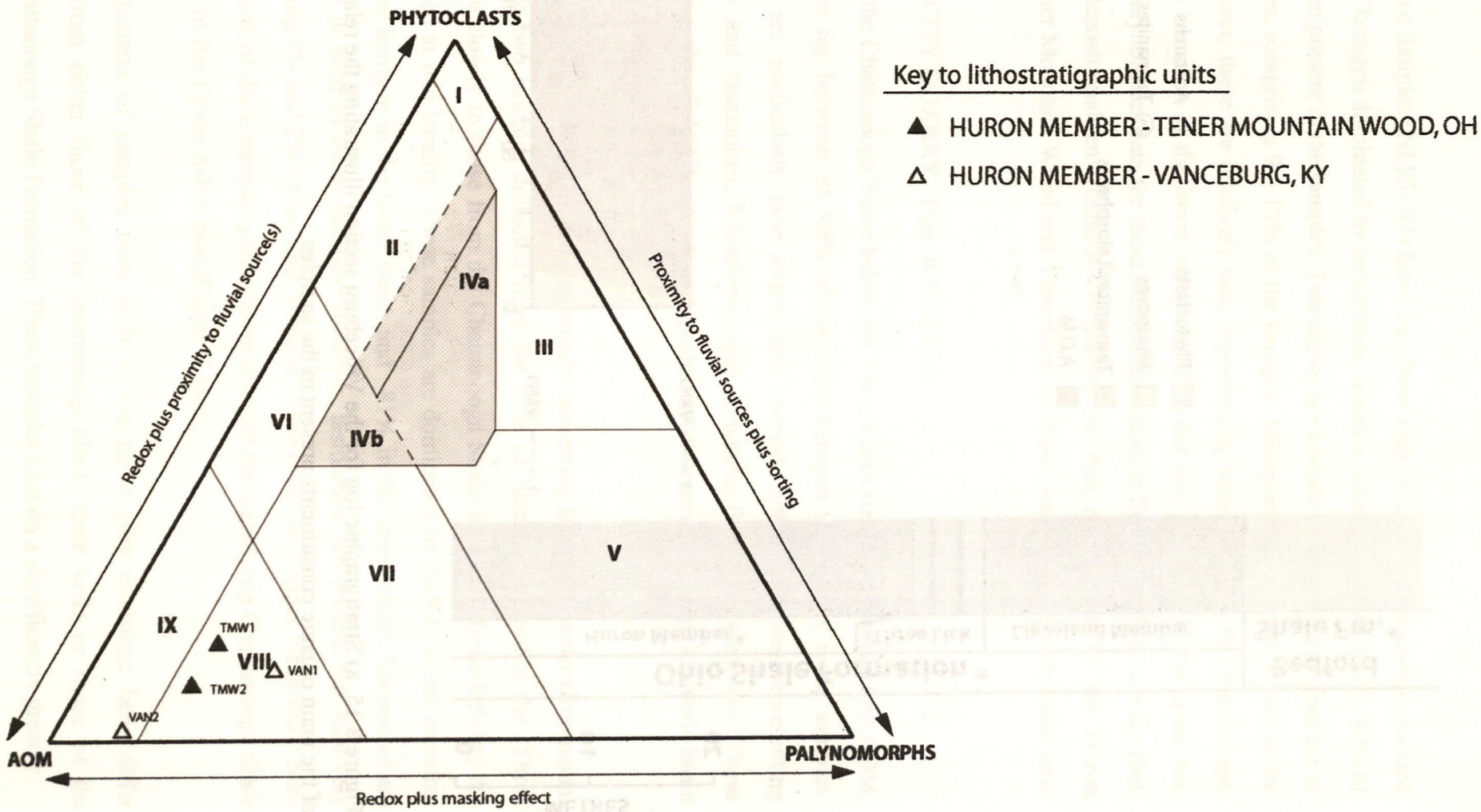


Figure 8.13. Stratigraphic log for the Tener Mountain Wood section illustrating the relative proportion of the main organic constituents present in the samples.

Figure 8.14. Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Tener Mountain Wood & Vanceburg sections.



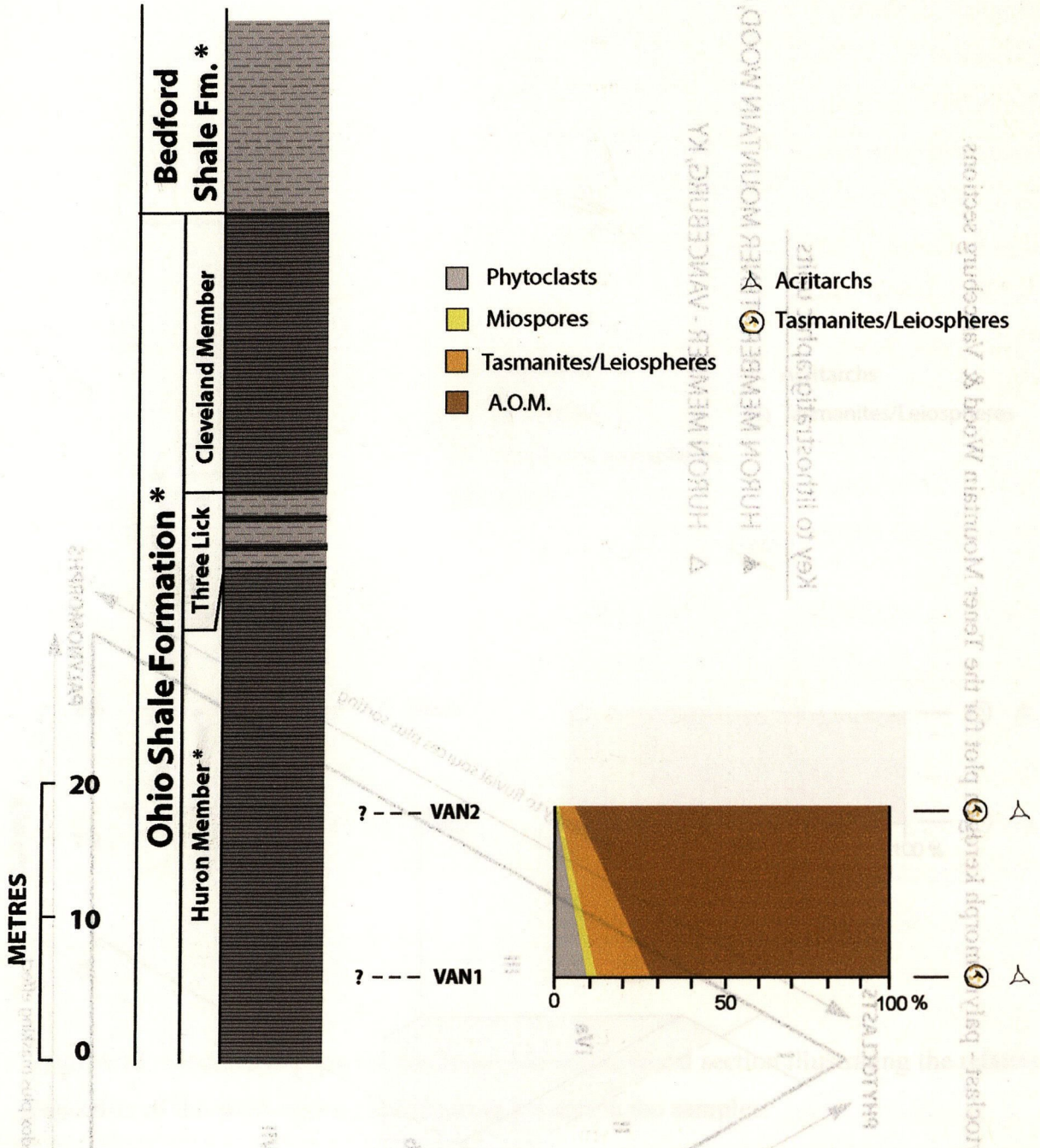


Figure 8.15. a) Stratigraphic log for the Vanceburg section illustrating the relative proportion of the main organic constituents present in the samples.

8.11.6. THREE LICKS TYPE SECTION, I-64 ROADCUT - MOREHEAD Figs. 8.16 & 8.17

Three productive samples (NL95- 97) from the Three Lick Bed at its type section yielded assemblages of kerogen dominated by amorphous organics, which accounts for 65- 80% of the total kerogen present in the samples. Tasmanites are a relatively common component of the palynofacies, comprising 9 – 13% of the kerogen. Miospores are present in two of the samples. However, these are relatively rare, representing only 2- 4% of the assemblage. Phytoclasts are common in the lower samples (22%) but less abundant in the upper two samples. The palynofacies data for these assemblages plots in field VIII of the ternary plot, indicating a depositional environment comparable to that represented by the Huron Member at Tener Mountain Wood and Vanceburg localities, such as a distal dysoxic/ oxic shelf.

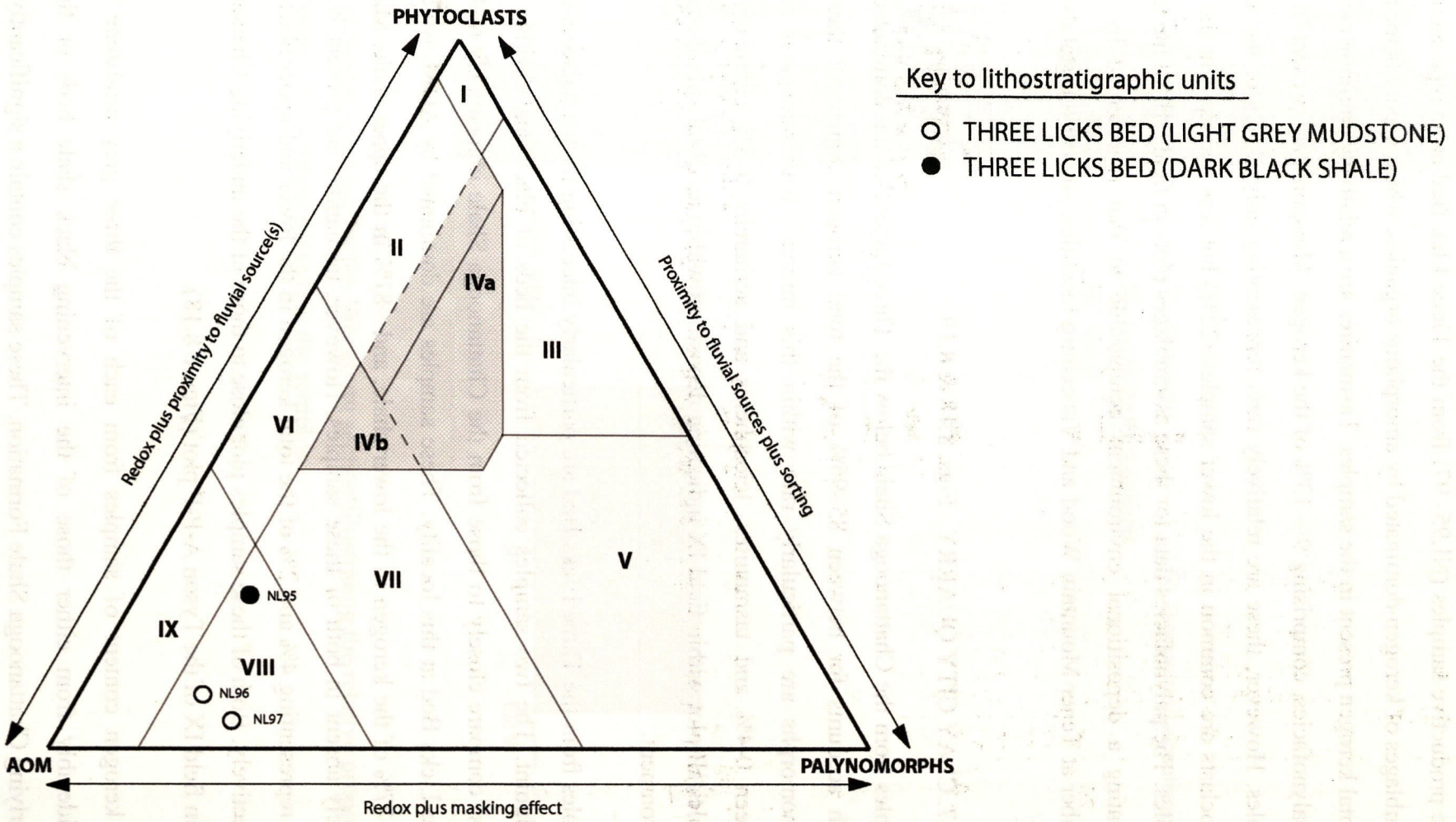
8.11.7. CLAY CITY QUARRY Figs. 8.18 & 8.19

Samples from the Chattanooga Shale below the Three Licks Bed are dominated by AOM, which accounts for between 85–96% of the total kerogen content of these samples. Palynomorphs are particularly rare within this interval, with miospores representing between 0-4% and tasmanites, leiospheres and acritarchs 0–8% cumulatively. These samples all plot within field IX indicating deposition within an distal suboxic-anoxic basin environment.

Samples from the Three Licks Bed are particularly interesting from a palaeoenvironmental standpoint. The two samples collected from the beds of black shale within the 'Three Licks' compare closely to those from the Chattanooga Shale immediately underlying the Three Licks Bed at this locality. These samples are dominated by AOM, which accounts for ~77% of the kerogen in the lower shale, and ~81% in the upper shale. Miospores are entirely absent in both of these samples. However, tasmanites are present but relatively rare, representing 4% and 2% of the total kerogen in the lower and upper black shale beds respectively. Both of these samples plot close to those of the underlying Chattanooga Shale within field IX of the Tyson A-P-P plot (Figure 8.18).

The kerogen content of samples from each of the three grey mudstone beds differ considerably from either those of the intervening black shale beds or those of the underlying Chattanooga Shale Formation. These samples contain a significantly greater

Figure 8.16. Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Three Licks Bed type section.



THREE LICK TYPE SECTION, MOREHEAD - KENTUCKY

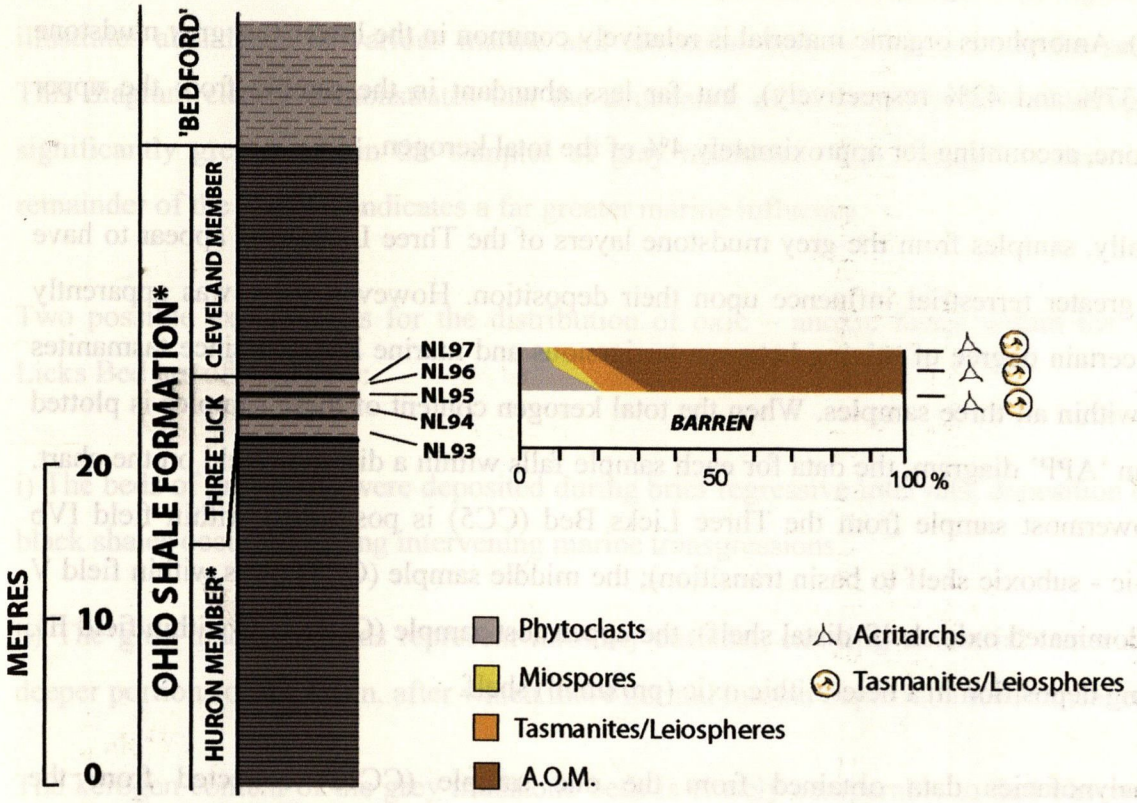


Figure 8.17. Stratigraphic log for the Three Lick type-section illustrating the relative proportion of the main organic constituents present in the samples. * de-notes incomplete.

proportion of terrigenous derived kerogen, particularly phytoclast material, accounting for 37–67% of the kerogen present; miospores are present in these beds but are relatively rare (4-6%). Amorphous organic material is relatively common in the lower two grey mudstone beds (37% and 42% respectively), but far less abundant in the sample from the upper mudstone, accounting for approximately 4% of the total kerogen.

Generally, samples from the grey mudstone layers of the Three Licks Bed appear to have had a greater terrestrial influence upon their deposition. However, there was apparently still a certain degree of mixing between terrigenous and marine kerogen since tasmanites occur within all three samples. When the total kerogen content of these samples is plotted upon an 'APP' diagram, the data for each sample falls within a different field on the chart. The lowermost sample from the Three Licks Bed (CC5) is positioned within field IVb (dysoxic - suboxic shelf to basin transition); the middle sample (CC3) plots within field V (mud dominated oxic shelf/ distal shelf); the uppermost sample (CC1) falls within field III, implying deposition in a heterolithic oxic (proximal) shelf.

The palynofacies data obtained from the one sample (CC12) collected from the Chattanooga Shale above Three Licks Bed is closely comparable to that yielded by samples from the samples below the Three Licks and those of the black shale within the unit. Like those samples, CC12 is dominated by AOM, which accounts for 60% of the total kerogen. Tasmanites and miospores are both present within this sample, totalling 8% and 6% respectively. The only notable difference between the kerogen content of this sample and those of the Chattanooga below the Three Licks is the slightly greater proportion of phytoclast material present in CC12 (approximately 30%). Based on the kerogen content, CC12 was perhaps deposited an environment intermediary to that of the lower Chattanooga Shale and that represented by the grey mudstone of the Three Licks Bed. The 'APP' diagram for this sample (Figure 8.18) would support such an interpretation, since data plots within field VII, suggesting and deposition within a proximal dysoxic – anoxic shelf environment.

Based upon the palynofacies data outlined above, the depositional environment/s represented by the black mudstone beds of the Three Licks Bed at the Clay City Quarry locality, differ significant from those of grey mudstone beds. The latter samples have yielded data indicative of a more proximal setting with higher supply of terrestrially

derived phytoclast material. Yet each of the three mudstone beds is immediately overlain by black shale more conducive to deposition in a distal, anoxic marine setting. Figure 8.19 illustrates abundance of various marine and terrestrial indicators present in the section. This diagram clearly demonstrates that the abundance of terrestrially derived kerogen is significantly greater within the samples of grey mudstone. The kerogen content in the remainder of the samples indicates a far greater marine influence.

Two possible explanations for the distribution of oxic – anoxic facies within the Three Licks Bed are offered here:

i) The beds of grey shale were deposited during brief regressive intervals, deposition of the black shales occurred during intervening marine transgressions.

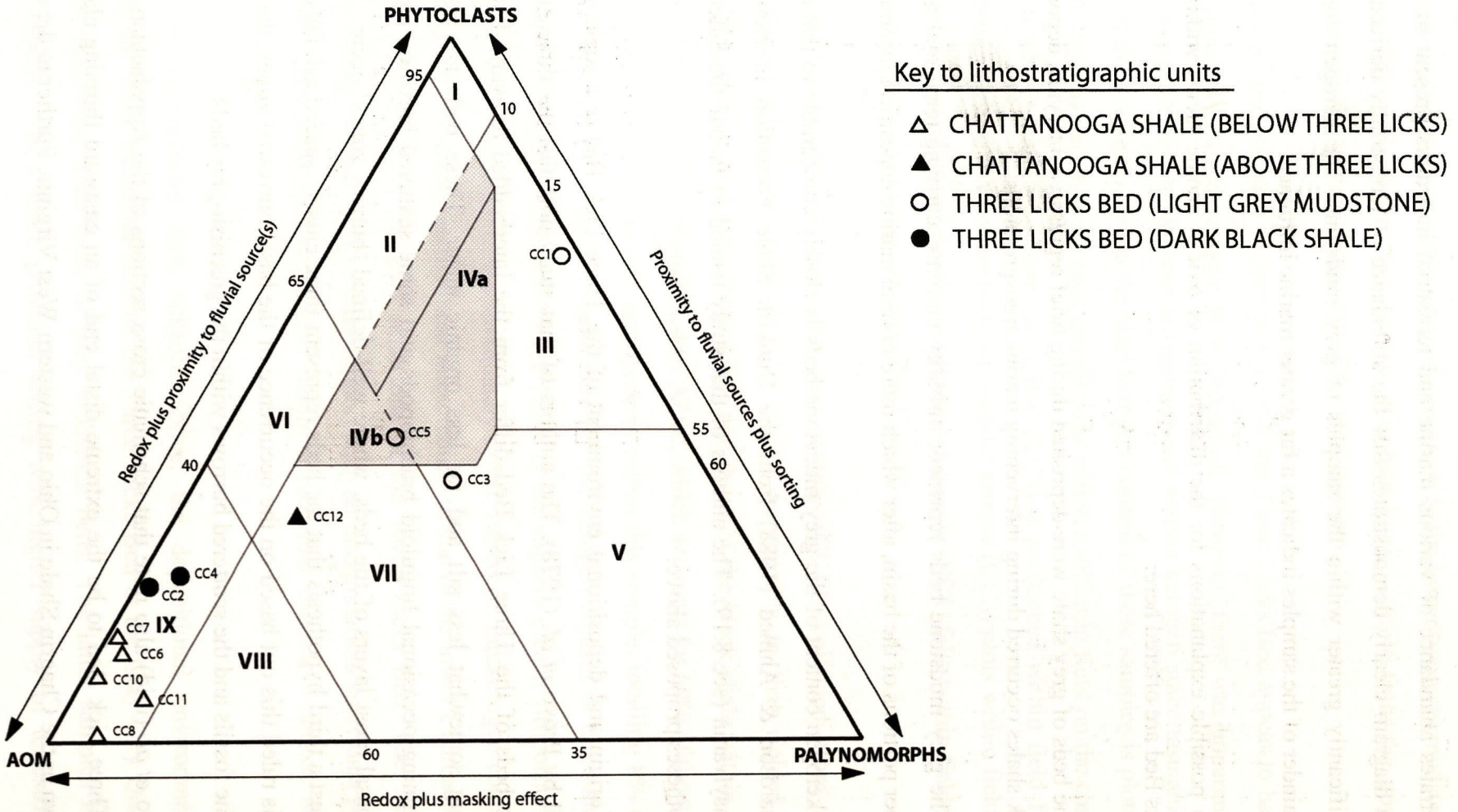
ii) The grey mudstone beds represent turbidity currents, carrying terrestrial material into deeper portions of the basin, after which more normal marine deposition recommenced.

The kerogen content of the grey mudstone beds is closely comparable to that observed by Richardson & Ahmed (1988) from the Dunkirk Shale Formation in New York and Pennsylvania (see 8.19). The authors of that study tended to favour the latter of the two hypotheses proposed above.

The origin and depositional environment of the Three Lick Bed is a topic discussed in detail by Provo *et al.* (1978). The authors of that study note that the three greenish-grey shale beds of the Three Lick Bed differ from the interbedded brownish-black shale in having somewhat less silt and far less organic mater. These beds are also noted as containing occasional linguloid brachiopods and some scattered burrows, particularly in the basal most layers of the beds, where well-defined 'burrow zones' occur. Provo *et al.* suggest a third hypothesis that the beds represent three closely spaced ash falls. However, this is ruled this out based on the occurrence of the basal burrowed zones, the presence of marine fossils and the scattered burrows within the greenish-grey beds.

Provo *et al.* (ibid) also note that schematic cross sections of the Appalachian Basin show the Three Lick Bed to be the extreme distal end of an eastward thinning clastic wedge, known as the Chagrin Shale in Ohio and western West Virginia. Further to the east, the

Figure 8.18. Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Clay City Quarry section.



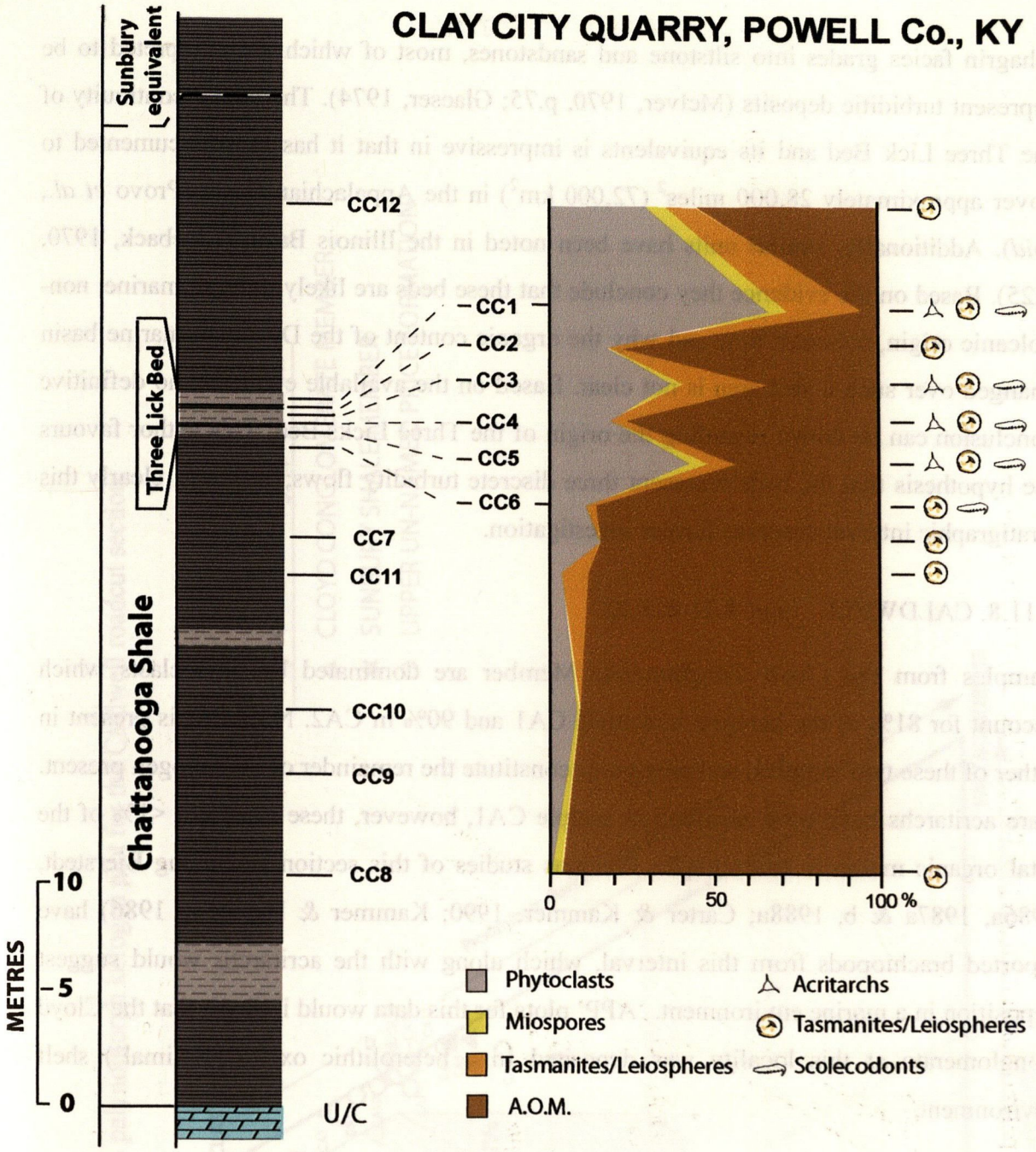


Figure 8.19 Stratigraphic log for the Clay City Quarry section illustrating the relative proportion of the main organic constituents present in the samples.

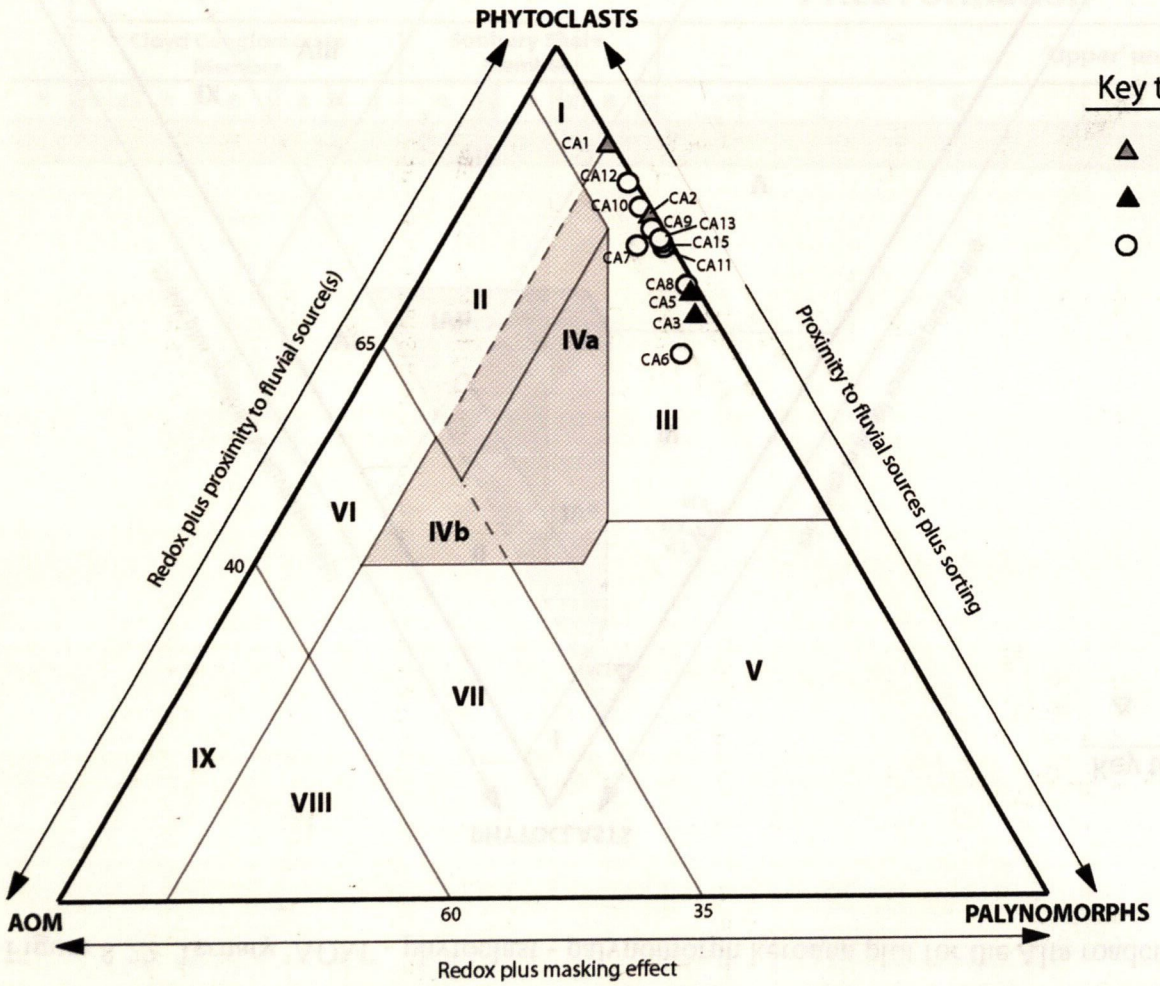
Chagrin facies grades into siltstone and sandstones, most of which are interpreted to be represent turbiditic deposits (McIver, 1970, p.75; Glaeser, 1974). The lateral continuity of the Three Lick Bed and its equivalents is impressive in that it has been documented to cover approximately 28,000 miles^2 (72,000 km^2) in the Appalachian Basin (Provo *et al.*, *ibid*). Additionally, similar units have been noted in the Illinois Basin (Lineback, 1970, p.25). Based on the evidence they conclude that these beds are likely to be of marine, non-volcanic origin, although how and why the organic content of the Devonian marine basin changed over such a vast area is not clear. Based on the available evidence, no definitive conclusion can be drawn regarding the origin of the Three Licks Bed. This author favours the hypothesis that the beds represent three discrete turbidity flows; however, clearly this stratigraphic interval deserves further investigation.

8.11.8. CALDWELL Figs. 8.21 & 8.22

Samples from the Cloyd Conglomerate Member are dominated by phytoclasts which account for 81% of the kerogen in sample CA1 and 90% in CA2. No AOM is present in either of these two samples, and miospores constitute the remainder of the kerogen present. Rare acritarchs have been recorded in sample CA1, however, these represent <1% of the total organic matter in this sample. Previous studies of this section (including Bjerstedt, 1986a, 1987a & b, 1988a; Carter & Kammer, 1990; Kammer & Bjerstedt, 1986) have reported brachiopods from this interval, which along with the acritarchs would suggest deposition in a marine environment. 'APP' plots for this data would indicate that the Cloyd Conglomerate at this locality was deposited in a heterolithic oxic ('proximal') shelf environment.

Samples CA3 and CA5 from the overlying Sunbury Shale Member contain a slightly lower proportion of phytoclast material when compared to samples from the Cloyd Conglomerate. However, woody phytoclast matter still constitutes approximately 70% of total kerogen in both the samples analysed from this interval. The percentage of miospores present is also consistent between the two samples, accounting for ~ 28% of the kerogen in both CA3 and CA5. The lower sample contains a relatively small proportion of AOM (~2%) and amorphous organics are entirely absent in the upper of the two samples. Palynofacies data for the Sunbury Shale samples at Caldwell plot within field III of the

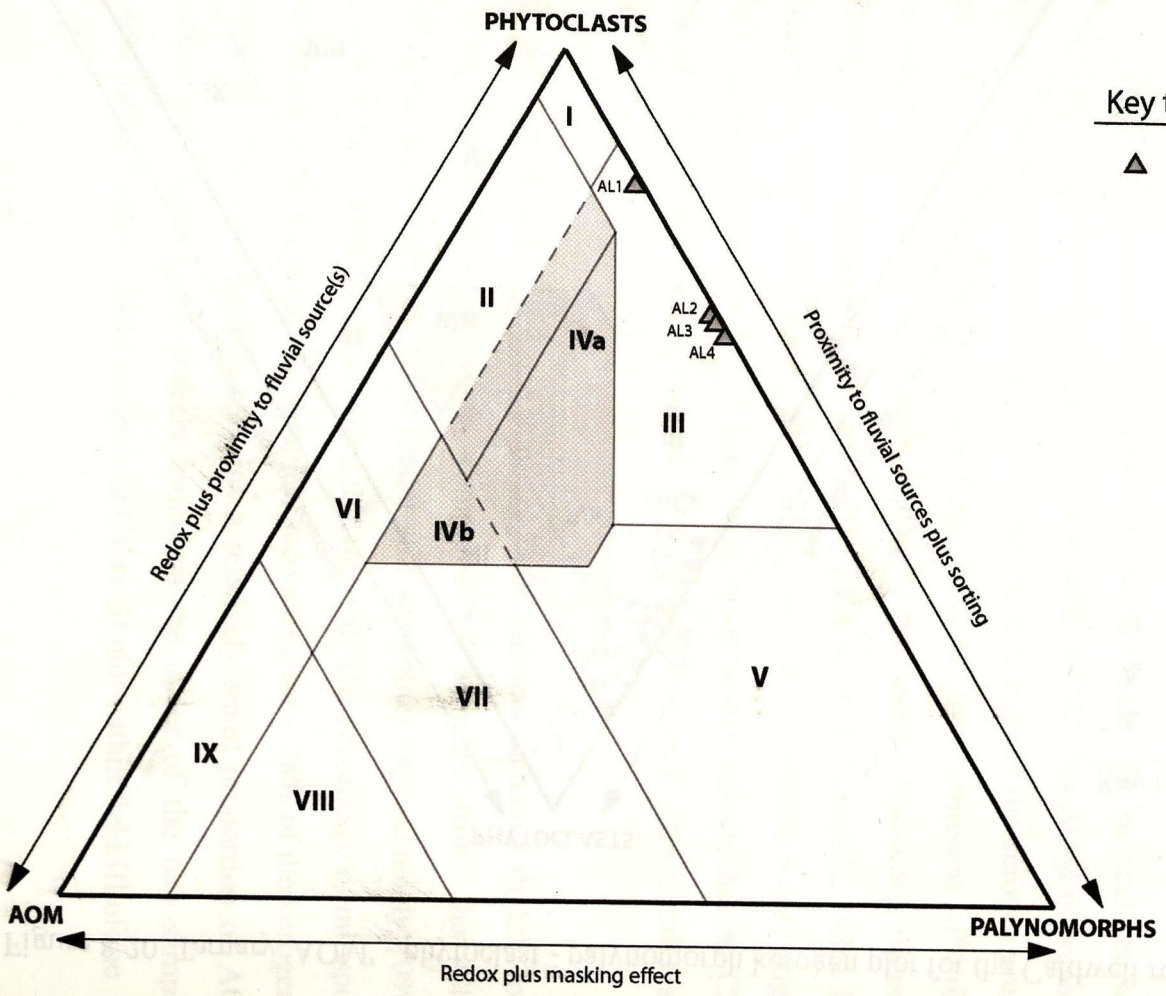
Figure 8.20. Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Caldwell roadcut section.



Key to lithostratigraphic units

- ▲ CLOYD CONGLOMERATE MEMBER
- ▲ SUNBURY SHALE MEMBER
- O UPPER UN-NAMED PRICE FORMATION

Figure 8.22. Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Alta roadcut section.



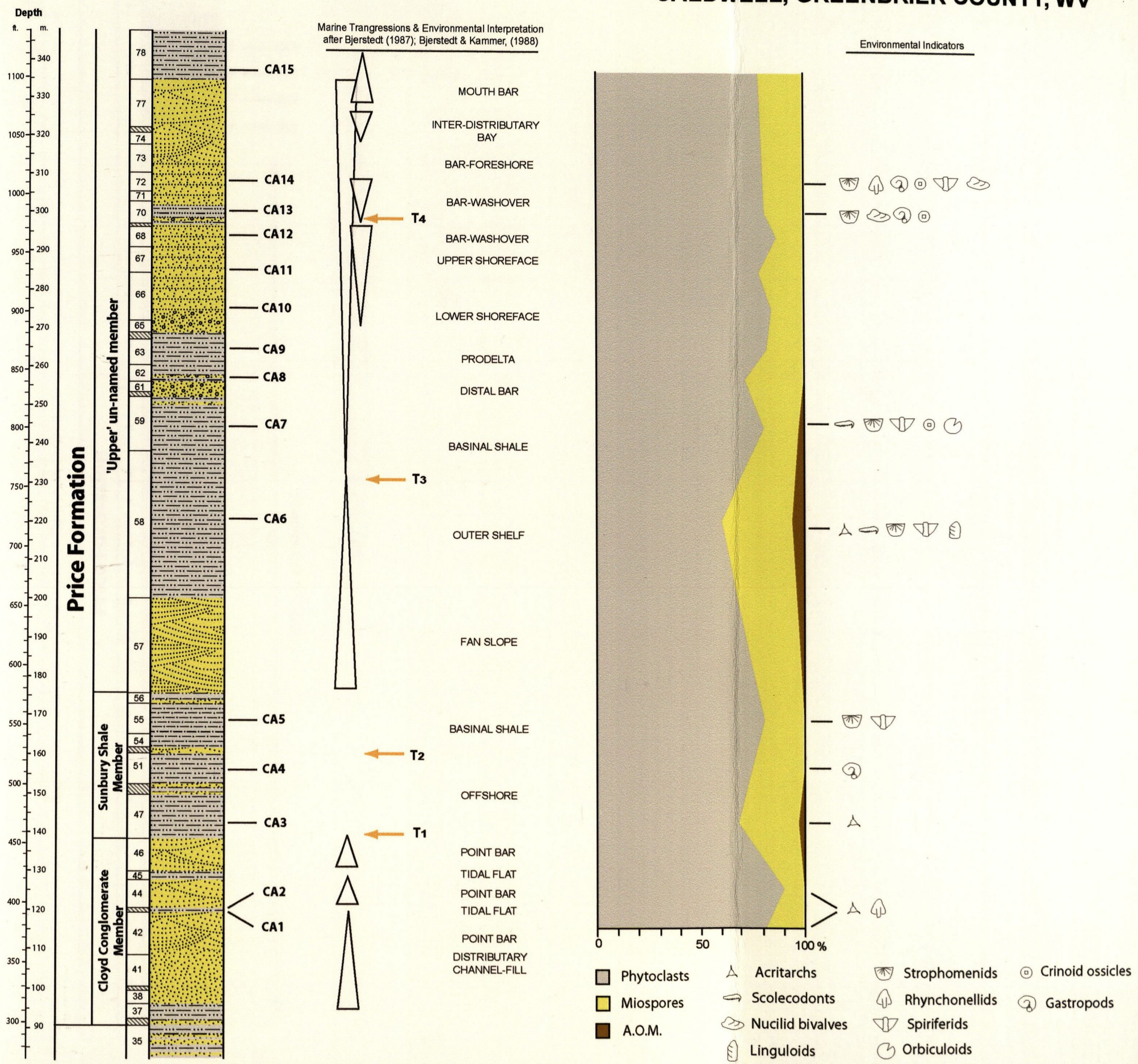


Figure 8.21 a) Stratigraphic log for the Caldwell roadcut section illustrating the relative proportion of the main organic constituents present in the samples.

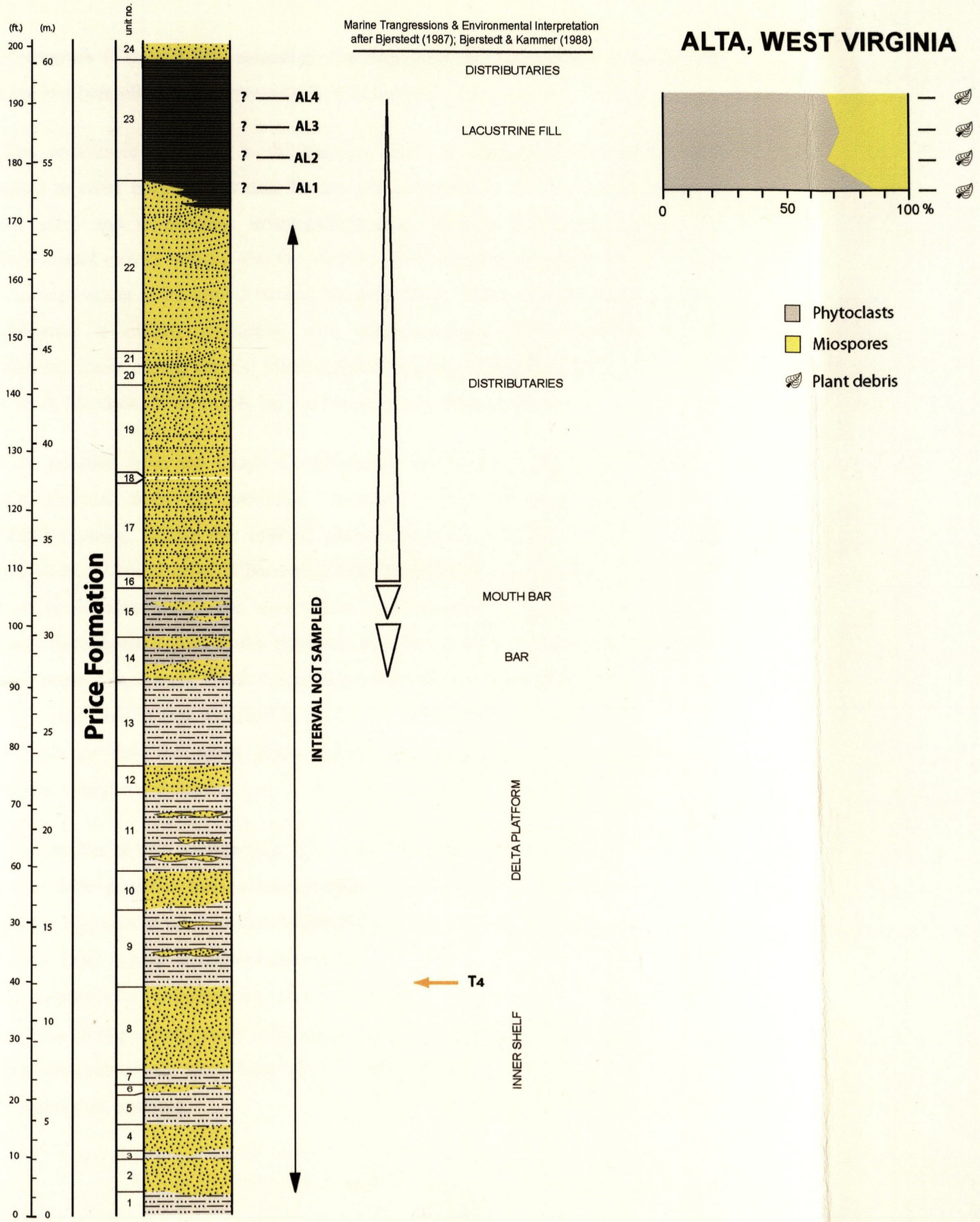


Figure 8.23. a) Stratigraphic log for the Alta roadcut section illustrating the relative proportion of the main organic constituents present in the samples.

'APP' diagram (Figure 8.20), indicating that deposition of this member probably also occurred in a heterolithic oxic ('proximal') shelf setting.

The low abundance of AOM in the Sunbury Shale at Caldwell is anomalous when compared to other palynofacies data for the unit presented in this study (e.g. Williams County core) and in previous investigations (e.g. Coleman & Clayton, 1987). This evidence would clearly indicate that the Sunbury Shale Member at Caldwell is a far more proximal equivalent of the typical basinal 'Sunbury Shale' of Kentucky and Ohio. Such an interpretation is entirely consistent with palaeogeographic reconstructions for the Appalachian Basin during earliest Mississippian time (e.g. Ettensohn, 2004, p.666, fig 7, Kammer & Matchen, 2008, p.268, fig. 3a; Pepper *et al.*, 1954, pl. 13I).

As with samples from the Cloyd Conglomerate and Sunbury Shale members, those samples analysed from the overlying, 'un-named' Price member, are dominated by phytoclast material. Within this interval, phytoclasts account for 62-84% of all kerogen present, with the broad trend of becoming more abundant up section. Miospores are also particularly abundant within the 'upper Price', comprising 14-33% of all organic matter counted. Amorphous organic matter is present in only two samples, representing 6% of the kerogen present in sample CA6. Palynofacies data for the 'un-named' Price member is closely comparable to that recorded in the lower two members. Tyson plots for this data would indicate that the upper Price member was deposited in a heterolithic oxic ('proximal') shelf environment.

Previous studies of this section (e.g. Bjerstedt, 1988; Bjerstedt & Kammer, 1994) have identified four possible marine transgression events. With the possible exception of Kammer's T1 event at the boundary between the Cloyd Conglomerate and Sunbury Shale members, these marine transgressions cannot be recognised based on the results of the current palynofacies investigation,. This is perhaps due to the relatively wide spacing of the samples in the current study (15 samples over approximately 250m), or the fact that samples were selectively taken from 'shaley' horizons which looked to be most promising for palynological analysis.

8.11.9 ALTA Figs. 8.22 & 8.23

Samples from the Alta locality have yielded palynofacies assemblages closely comparable to those recorded at the nearby Caldwell section. These samples contain an abundance of phytoclast material, which accounts for 67- 85% of the total kerogen. The remainder of the organic matter present in these samples is comprised of miospores. The APP plot constructed for this section (Figs. 8.22) would indicate that deposition occurred in a heterolithic (proximal) shelf environment. However, since no marine indicators were recorded in any of these samples, it is more likely that deposition occurred entirely within a terrestrial setting. This latter interpretation is more consistent with previous palaeoenvironmental environmental interpretation of this section by Bjerstedt (1987) and Bjerstedt & Kammer (1988) who concluded that the upper part of the exposure represented lacustrine deposition.

8.11.10. MYLAN PARK CORE Figs. 8.24 -8.31

Samples from the Mylan Park core represent the single largest data set incorporated in the present investigation. A total of 56 samples were collected from the core; 37 of these were selected for palynofacies analysis. Based on the West Virginia Geological Survey core report (see Appendix II), the borehole is inferred to have penetrated the Meramecian (Viséan?) age Greenbrier Limestone Formation and four informal Driller's Sandstone members of the underlying Price Formation. In descending stratigraphic order these are the Big Injun, Squaw, Weir and Murrysville sandstones. For reasons of clarity, samples are grouped here into seven subsets, representing either the shaley layers within the thicker sandstone units or the dominantly shaley intervals between the sandstones.

Sub-Murrysville Sandstone Fig. 8.24

The kerogen content of samples from the interval immediately below the Murrysville Sandstone is dominated primarily by phytoclasts (56-62%) and miospores (38-44%). Amorphous organic matter is present in two lowermost samples, accounting for <1 -2% of the kerogen present in those samples. Marine indicators such as acritarchs and scolecodonts are recorded in the majority of samples from this interval; however, *Tasmanites* are absent. The core description provided by West Virginia Geological Survey (Appendix II) notes that the stratigraphic interval below the Murrysville Sandstone contains macroplant fossils, pelecypods (bivalves) and burrows. These data combined with

the occurrence of acritarchs and scolecodonts in the samples analysed would indicate deposition in a proximal marine environment. 'APP' plots for the palynofacies data from these samples data would suggest sedimentation occurred in a heterolithic oxic ('proximal') shelf setting.

Sub-Weir Sandstone Fig. 8.25

Samples from the stratigraphic interval between the top of Murrysville Sandstone and the base of the Weir Sandstone compare closely to those from below the Murrysville in terms of total kerogen content. The majority of the samples from this interval are dominated primarily by phytoclast material, which accounts for 57-85% of the kerogen. Miospores are common in these samples, comprising 15-43% of the organic content. The ratio of phytoclast material to miospores increases up-section. Amorphous organic matter is present in a number of samples, although it is relatively rare, accounting for <1-4% of the total kerogen. Scolecodonts and acritarchs are present in a number of samples within this stratigraphic interval, indicating deposition within a marine environment. This interpretation is consistent with the occurrence of other marine indicators such as brachiopods, burrows, crinoids and pelecypods (see Figure 8.31.; Appendix II). The palynofacies data for the samples analysed from this stratigraphic interval all plot consistently within field III of the 'APP' diagram (Figure 8.25), thus indicating depositional within a proximal heterolithic shelf setting.

Weir Sandstone Fig. 8.26

Samples MP31 and MP33 both plot within field III of the Tyson diagram (Fig. 8.26). Palynofacies data for the intervening sample, MP32, plots within the region of the chart bordering fields II and IVa. This would indicate deposition within a marginal dysoxic-anoxic basin or a dysoxic-suboxic shelf to basin transition. Further evidence for marine deposition at this level includes the occurrence of acritarchs, recorded in samples MP31 and MP32 and brachiopods reported in the core description close to level from which MP33 was taken.

Sub-Squaw Sandstone Fig. 8.27

Samples MP35 – 39 from the interval below the Squaw Sandstone plot within field III of the APP plot (Fig. 8.27). The palynofacies assemblages of these samples are closely

comparable to those from the underlying units, and are dominated by phytoclast material which accounts of 62- 69% of the total kerogen, the remainder of which is comprised of miospores and relatively rare particles of AOM. The palynofacies data indicates that deposition occurred in proximal marine setting. This interpretation is consistent with the sporadic occurrence of marine indicators including, acritarchs, scolecodonts and brachiopods, combined with evidence of terrestrially derived plant debris.

Squaw Sandstone Fig. 8.28

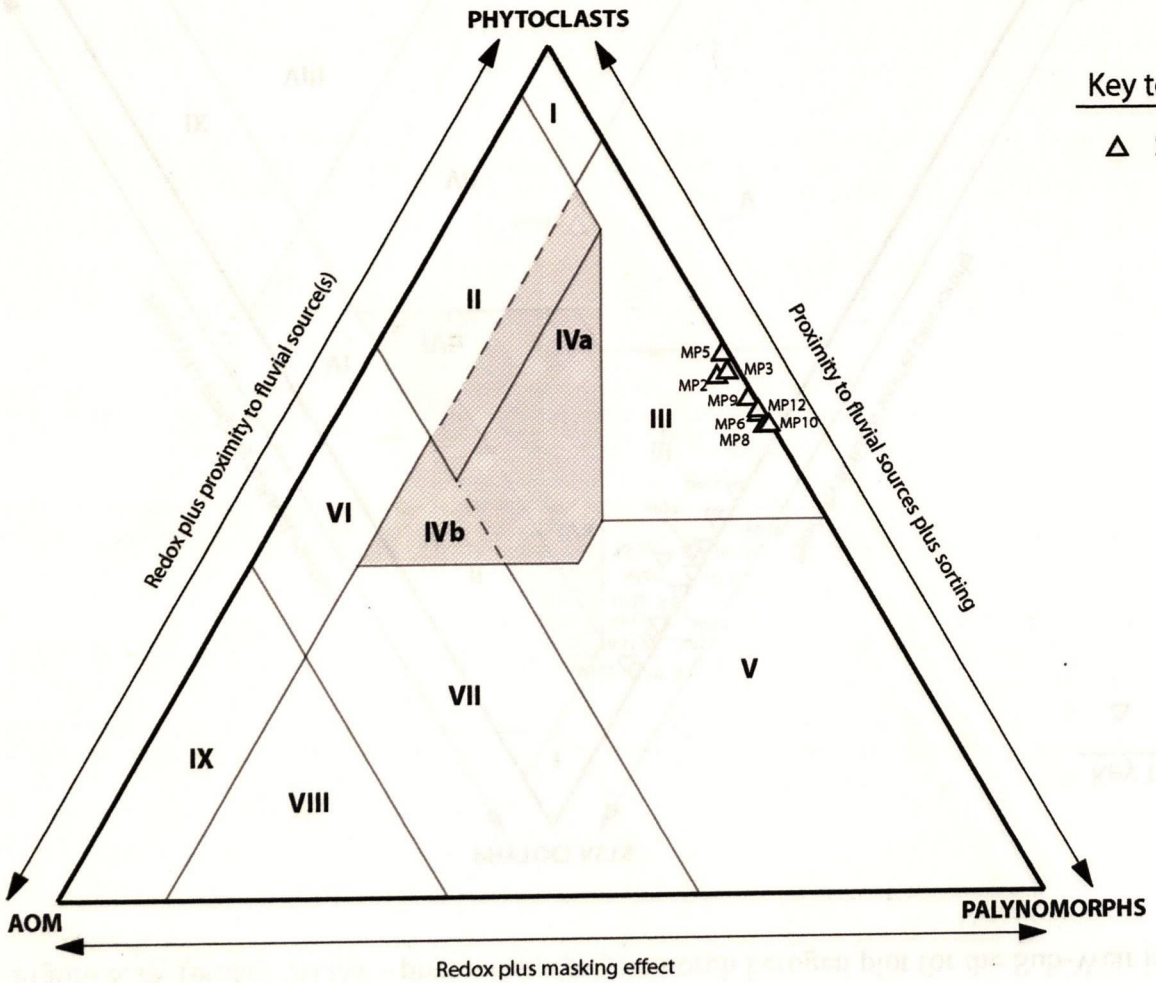
Samples MP40, 43 and 45 from the Squaw Sandstone yielded palynofacies assemblages consistent with those recorded in underlying units. These samples contain an abundance of terrestrially derived kerogen, including phytoclast material (50- 86%) and miospores (13- 45%). Data for these samples plots within field III of the APP chart and suggests that deposition took place in a proximal shelf setting. This interpretation is once more consistent with the occurrence of environmental indicators such as brachiopods and macroplant debris.

In contrast, the kerogen content of sample 41 is dominated entirely by amorphous organic material, which accounts for 100% of the organic particles counted from this sample. Palynofacies data for this sample plots within field IX of the APP, indicating deposition within a distal suboxic/ anoxic basin. Clearly the kerogen content of this sample anomalous when compared to that recorded in the samples immediately above and below this interval. One possible explanation for the dominance of AOM within this interval is that it was deposited during a brief deepening event in basin or during a short-lived transgression.

Sub-Big Injun Sandstone Fig. 8.29

Samples from the stratigraphic interval below the Big Injun Sandstone have yielded palynofacies assemblages closely comparable to the majority recorded from this locality. Once more the dominant kerogen types are phytoclast fragments (78- 86%) and miospores (13- 19%). Palynofacies data for these samples indicates that deposition occurred in a proximal heterolithic basin, which is consistent with the occurrence of burrows, acritarchs

Figure 8.24 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Sub-Murrysville interval in the Mylan Park core.



Key to lithostratigraphic units

△ SUB-MURRYSVILLE SANDSTONE INTERVAL

Figure 8.25 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Sub-Weir interval in the Mylan Park core.

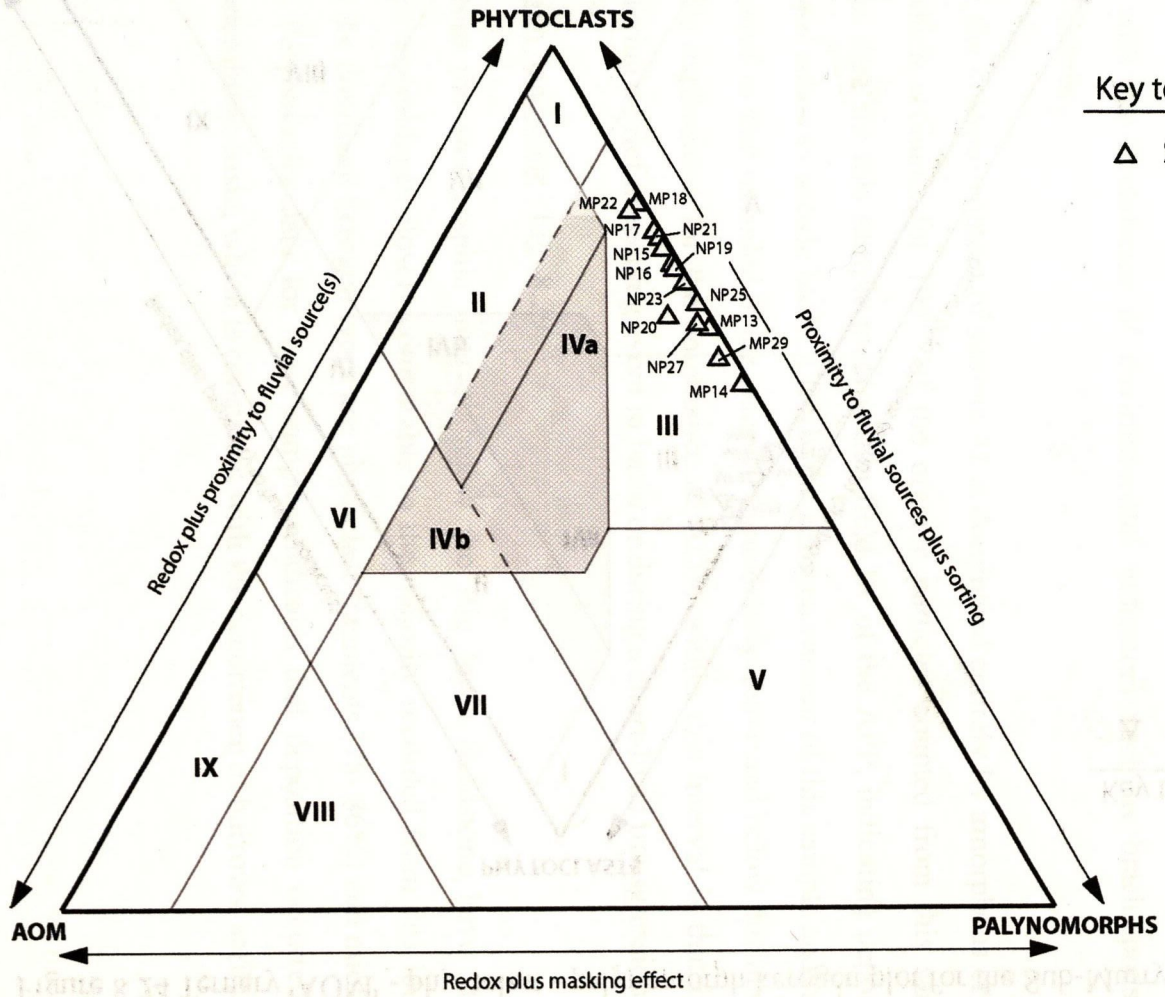


Figure 8.26 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Weir interval in the Mylan Park core.

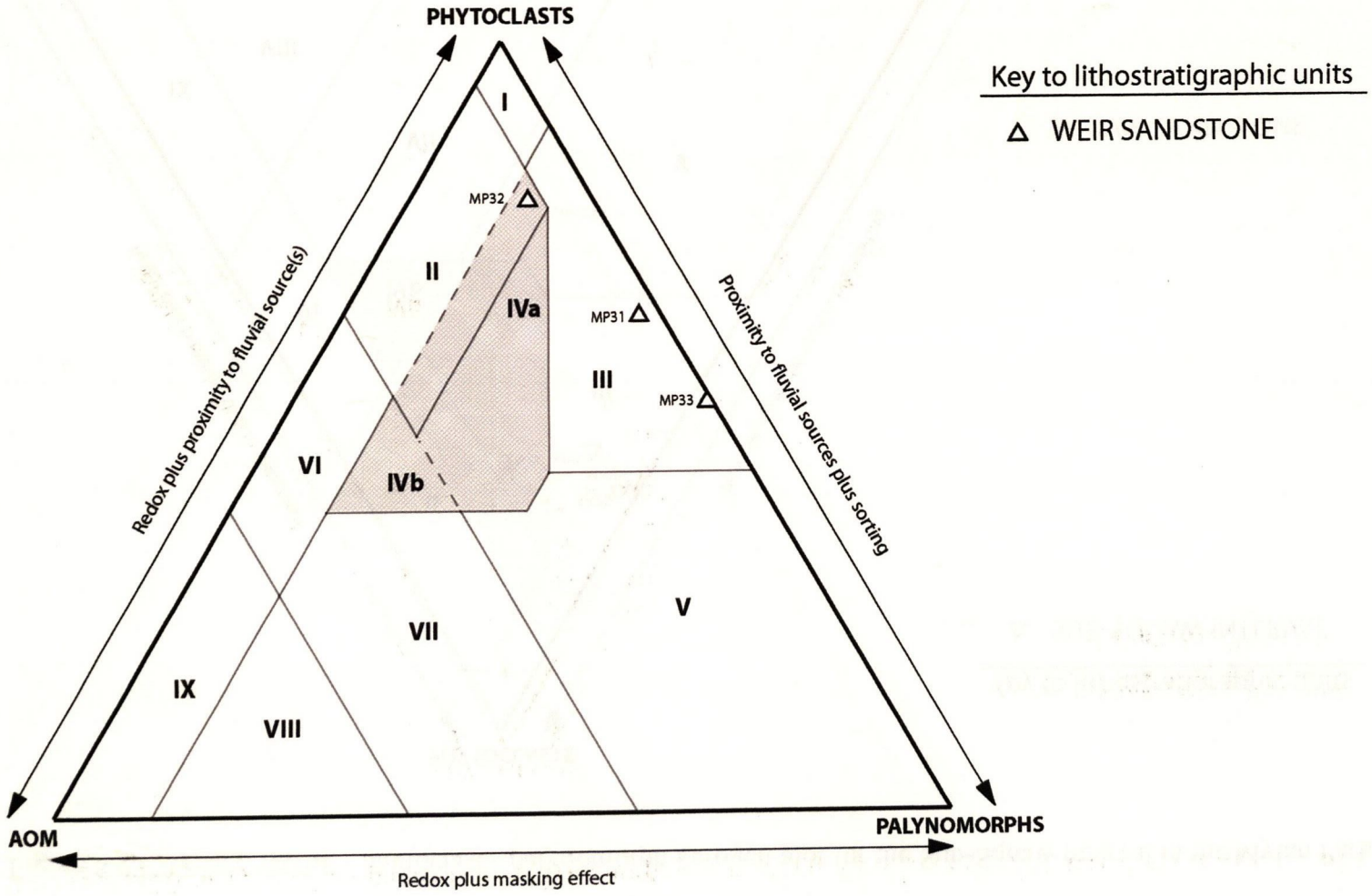


Figure 8.27 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Sub-Squaw interval in the Mylan Park core.

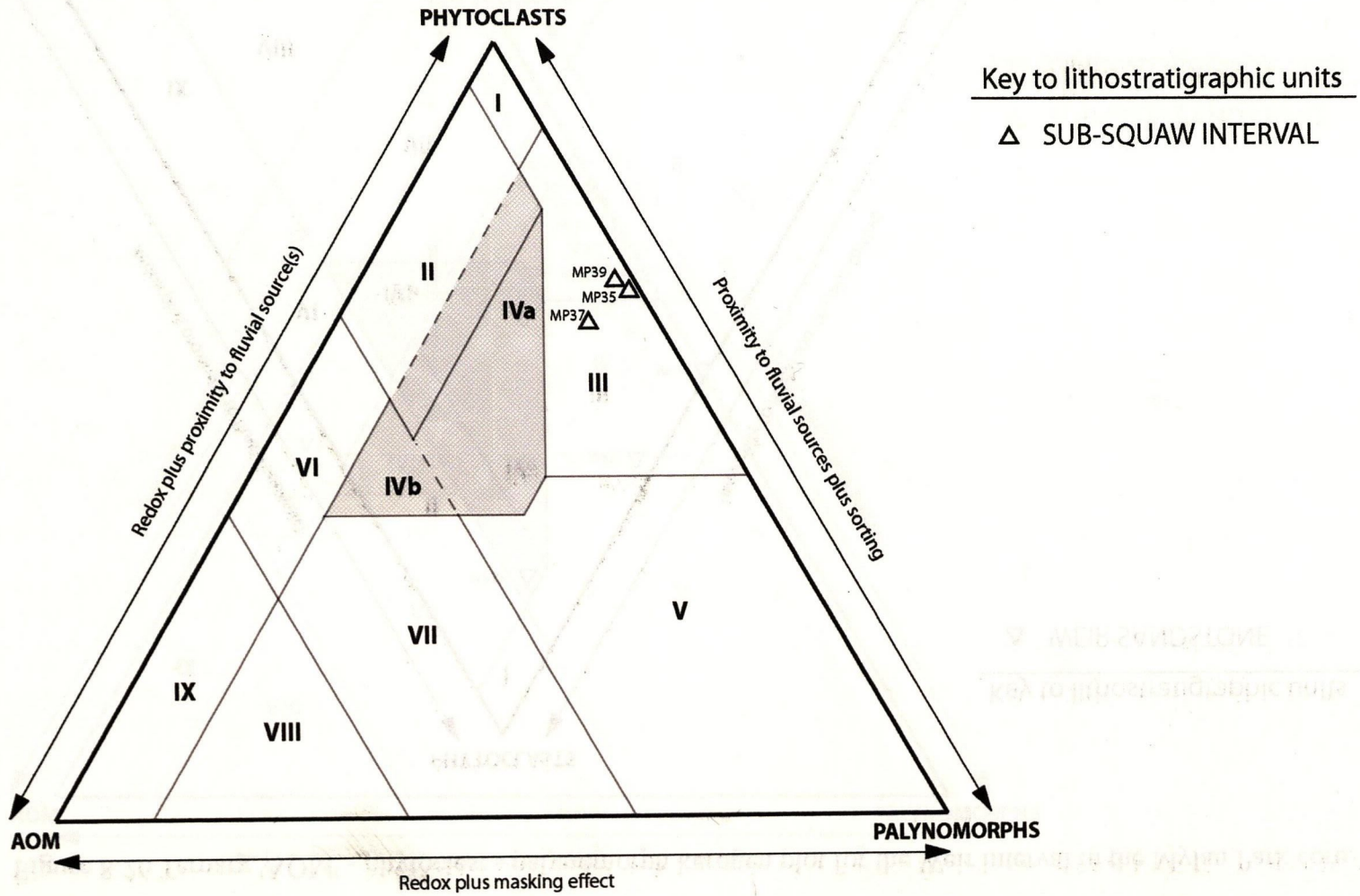


Figure 8.28 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Squaw Sandstone interval in the Mylan Park core.

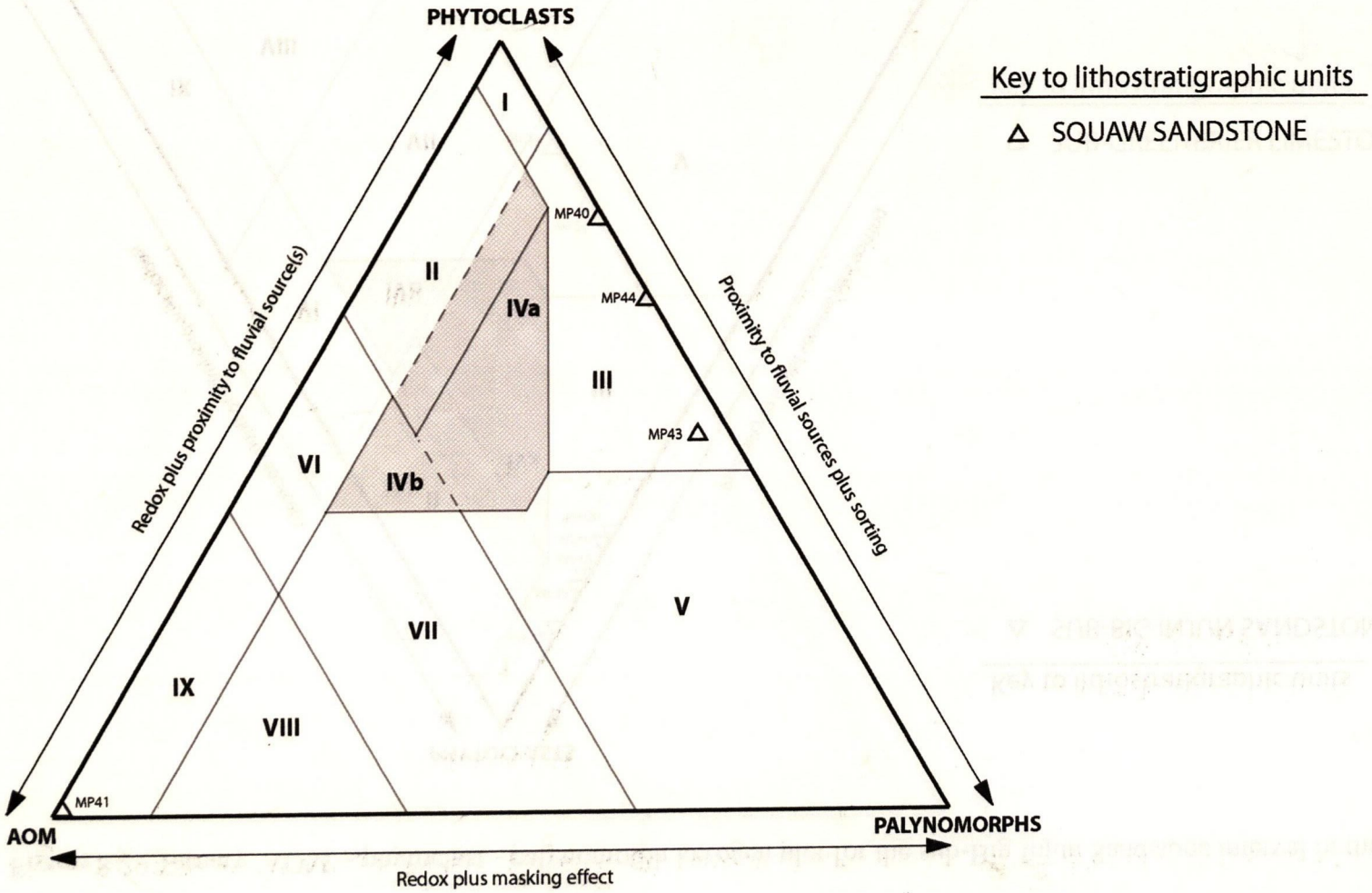


Figure 8.29 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the sub-Big Injun Sandstone interval in the Mylan Park core.

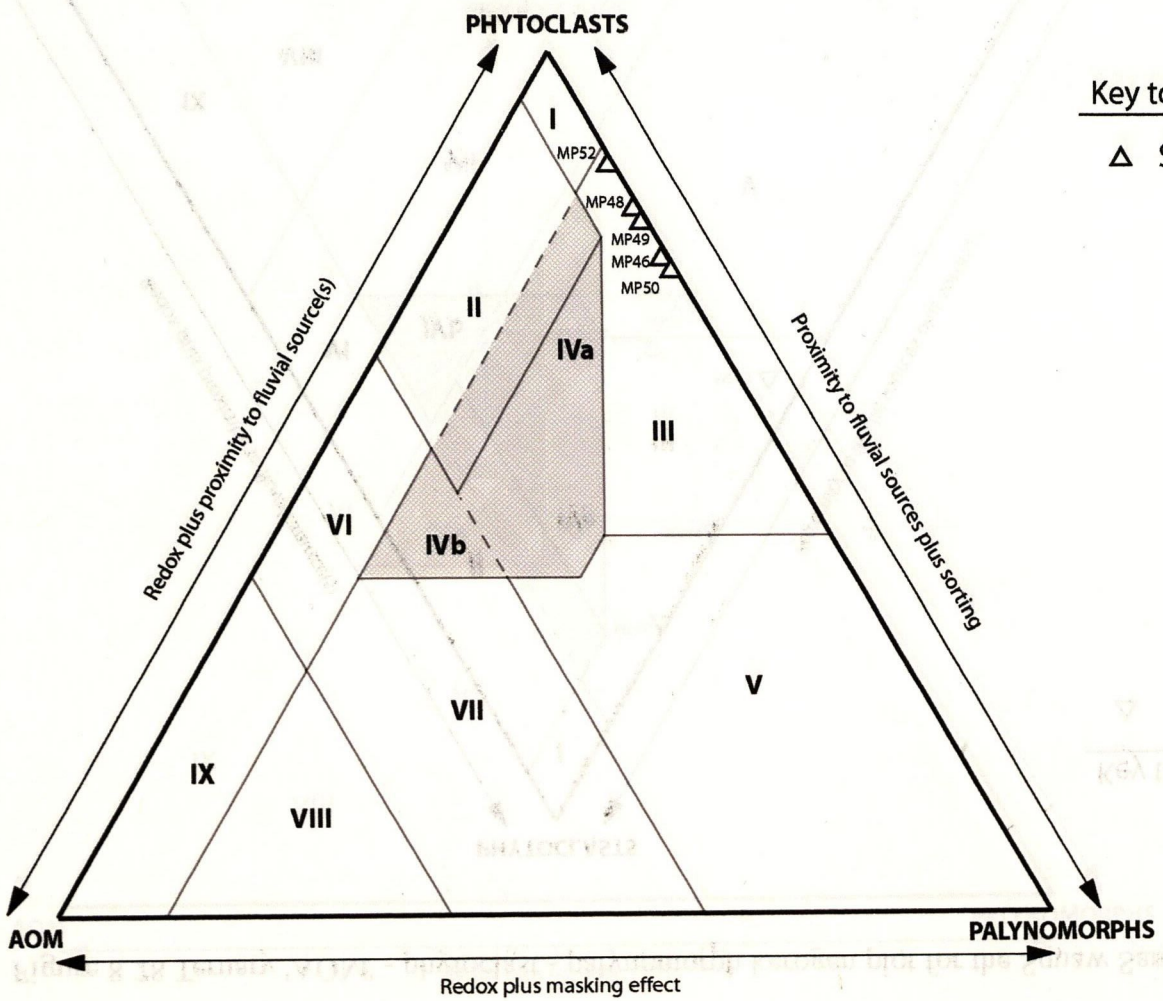
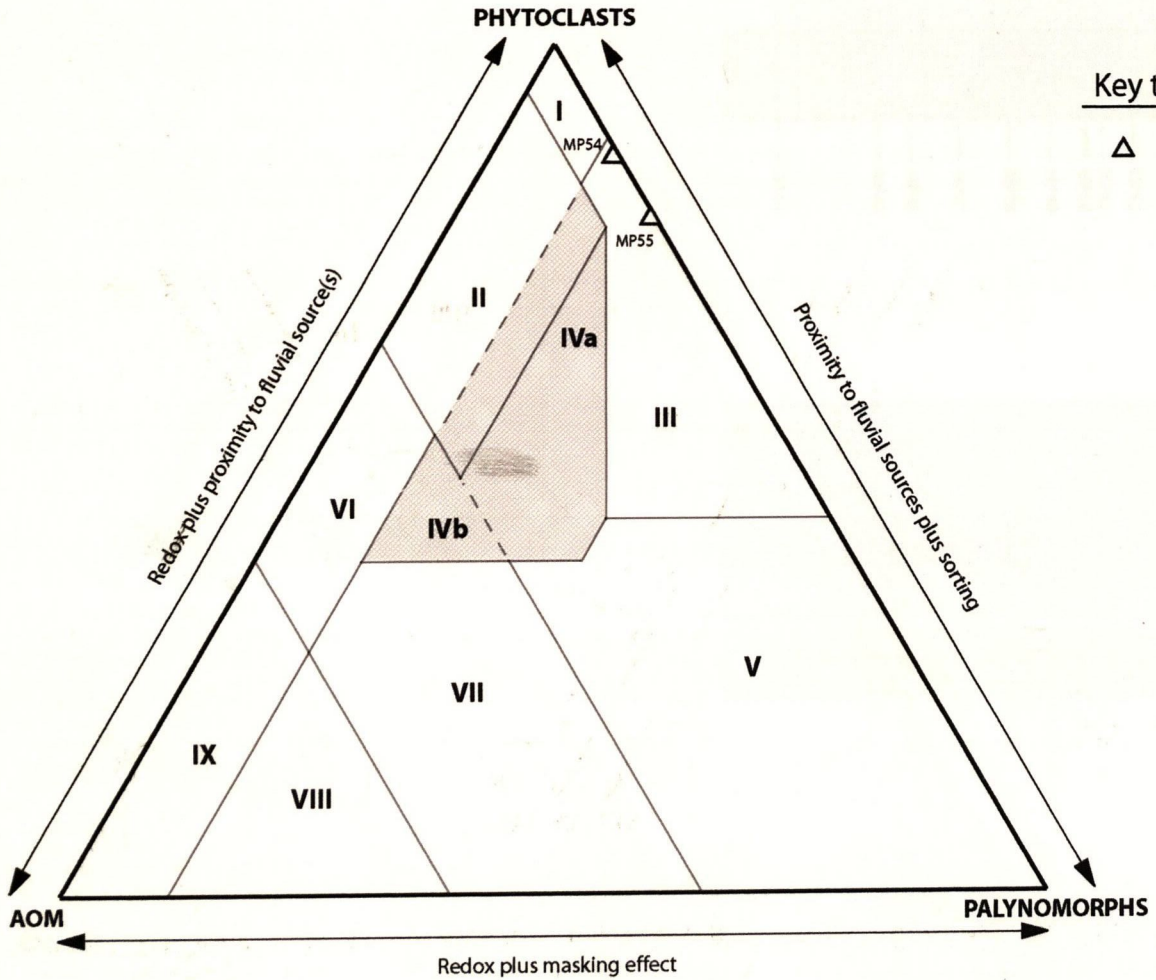


Figure 8.30 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the sub-Greenbrier Limestone interval in the Mylan Park core.



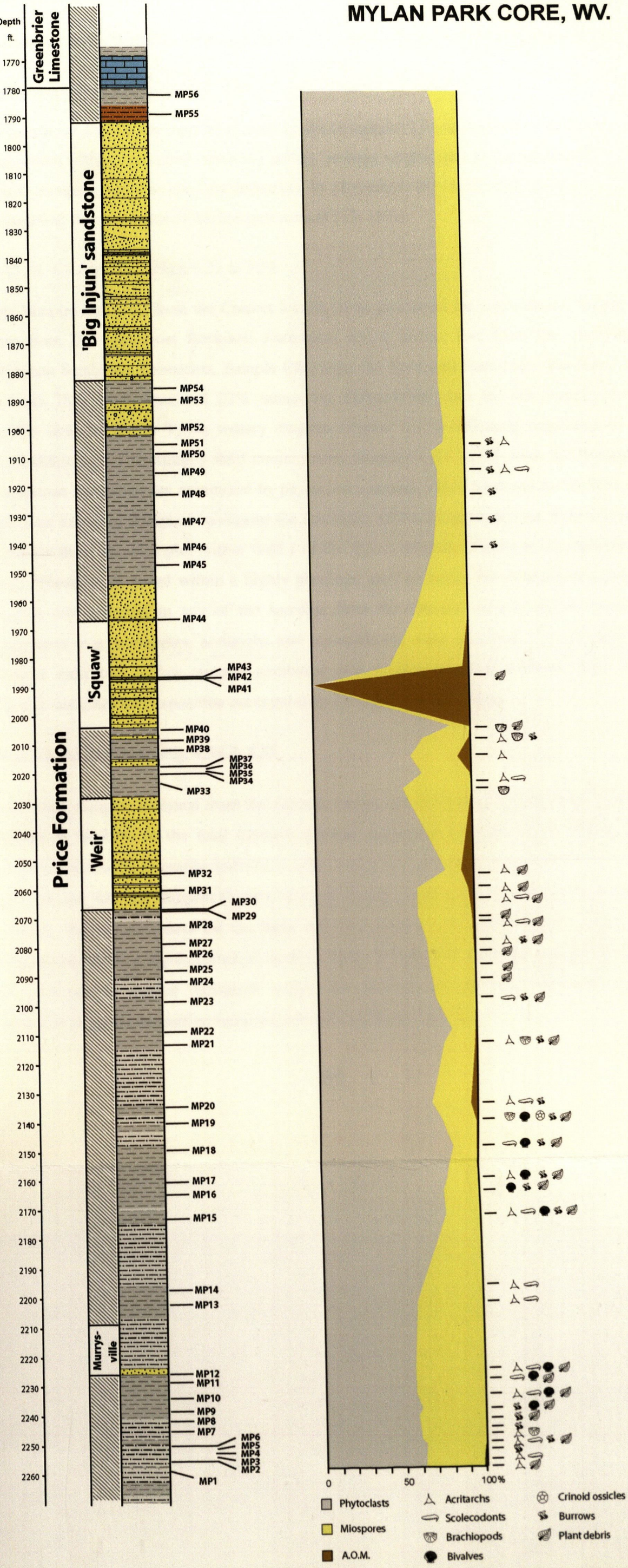


Figure 8.31 Stratigraphic log for the Mylan Park core section illustrating the relative proportion of the main organic constituents present in the samples.

and scolecodonts from this same interval.

Sub-Greenbrier Limestone Fig. 8.30

Palynofacies data for the interval underlying the Greenbrier Limestone further indicates deposition within a proximal oxic shelf setting, perhaps verging on a highly proximal basin. Samples from this level are dominated by phytoclasts (81- 86%) with miospores accounting the remainder of the kerogen present (13- 19%).

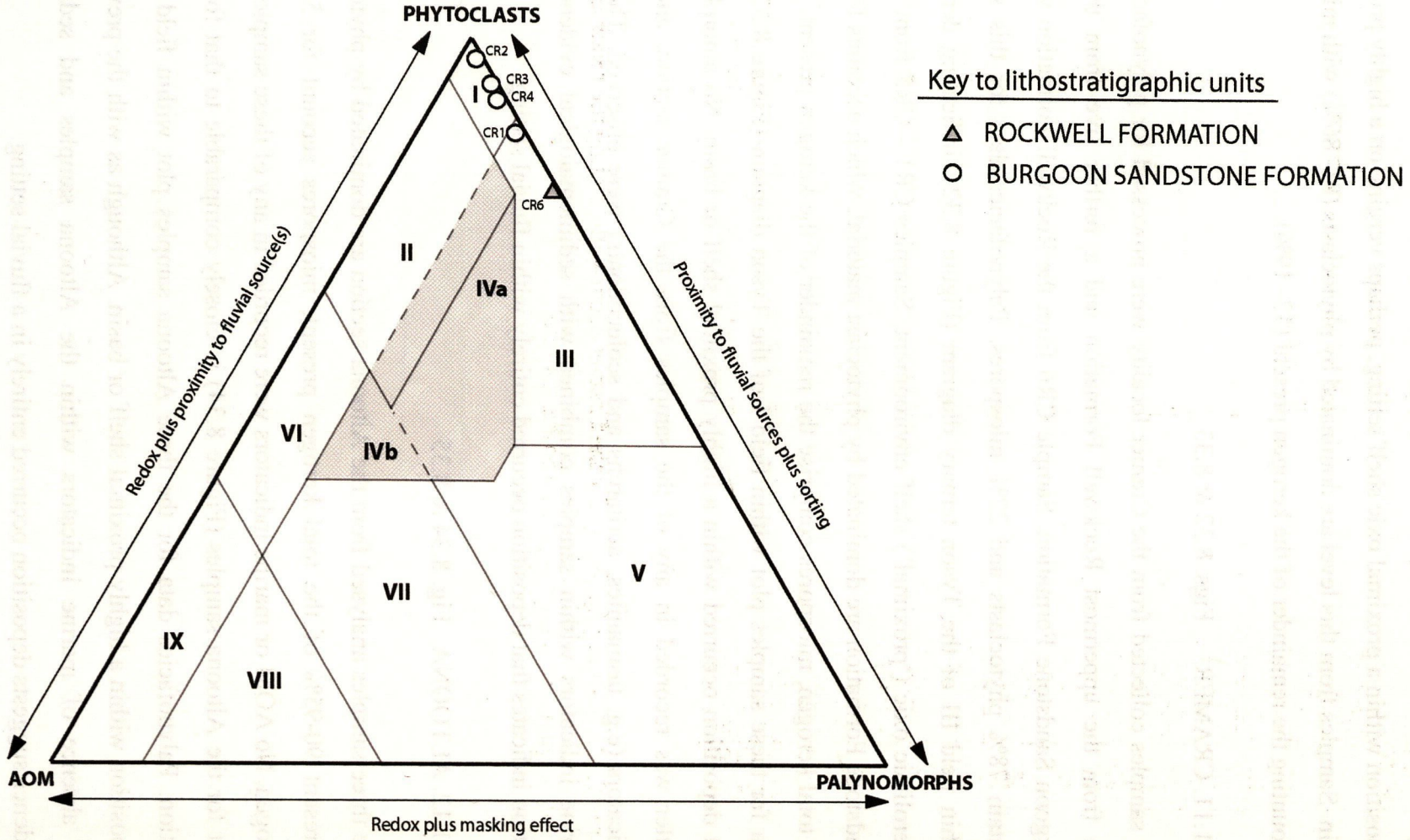
8.11.11. CRAMER Figs. 8.32 & 8.33

Six samples collected from the Cramer locality were processed for palynofacies analysis; one from the uppermost Rockwell Formation and a further five from the overlying Burgoon Sandstone Formation. Sample CR6 from the Rockwell Formation was found to contain 78% phytoclasts and 22% miospores. Palynofacies data for this sample plots within field III of the Tyson ternary diagram (Figure 8.32), indicating deposition in a heterolithic oxic ('proximal') shelf environment. Samples CR1 - CR5 from the Burgoon Sandstone Formation are dominated by phytoclast material, which accounts for 90-98% of the total kerogen, miospores comprise the remainder of the kerogen present. Palynofacies data for these samples plot within field I of the Tyson diagram (Figure 8.32), indicating that deposition occurred within a highly proximal shelf or basin. No amorphous organic matter was recorded in any of the samples from the Cramer section, and no marine indicators (e.g. tasmanites, acritarchs and scolecodonts) were observed. The absence of marine indicators within samples combined with sedimentalogical evidence from this section indicates that deposition occurred entirely within fluvial setting.

8.11.12. ALTOONA Fig. 8.34 & 8.35

The three samples analysed from the Altoona section are dominated by phytoclasts which represent 90-95% of the total kerogen present, miospores account for 5-10% of the kerogen. No AOM or marine indicators were recorded in any of these samples. The 'APP' plot for the Altoona samples (Figure 8.34) is closely comparable to that for the Cramer section. Palynofacies data for the three Altoona samples plot within field I, indicating deposition within a highly proximal shelf or basin. Although as with the previous section, the absence of marine indicators within the Altoona samples and sedimentalogical evidence suggests deposition occurred entirely in a fluvial setting.

Figure 8.32 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Crammer section.



CRAMER, INDIANA COUNTY, PENNSYLVANIA

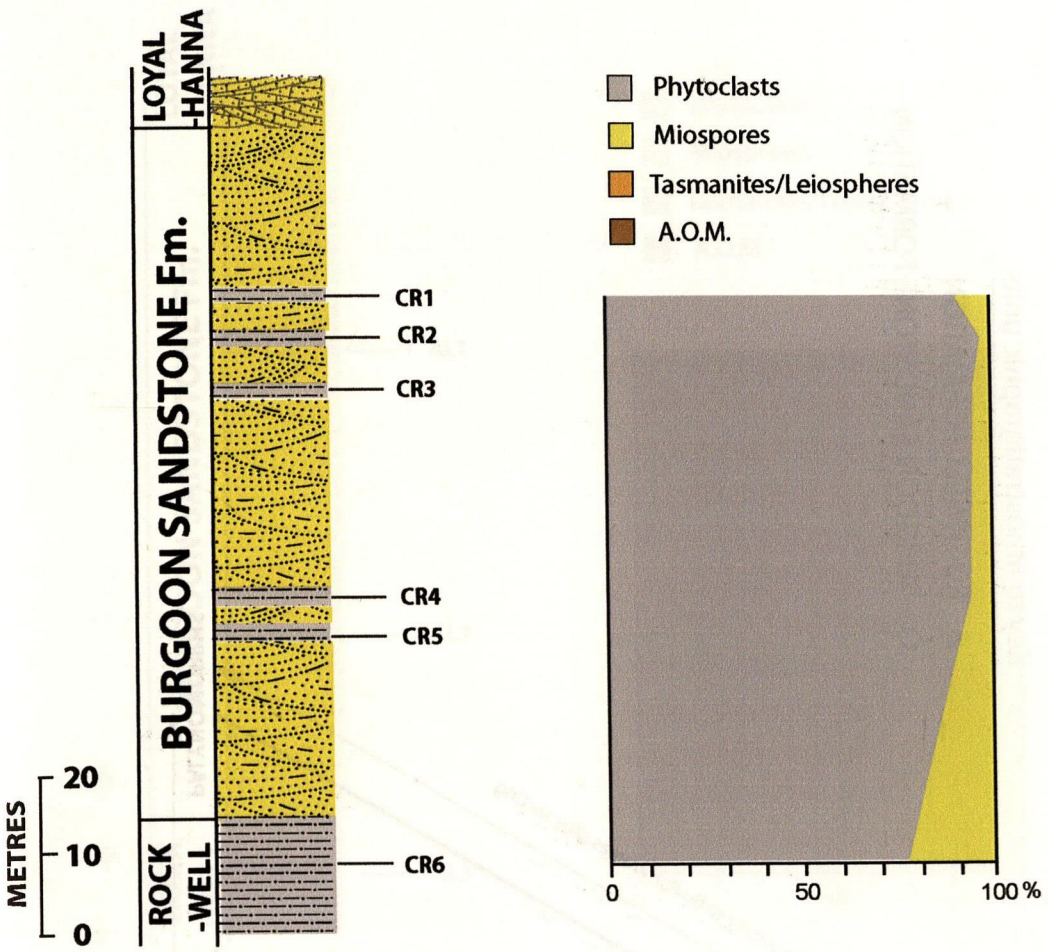
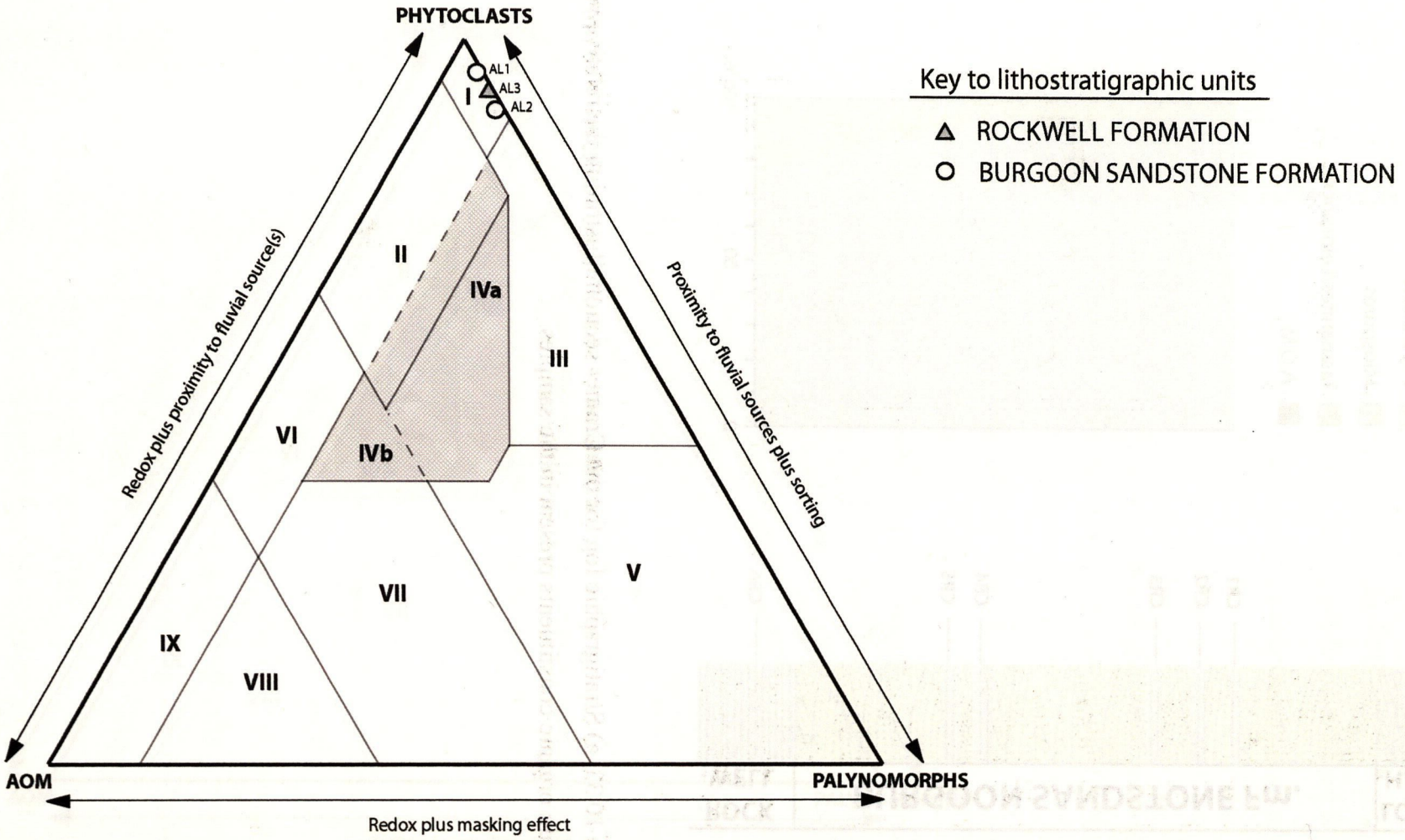


Figure 10.33. a) Stratigraphic log for the Cramer section illustrating the relative proportion of the main organic constituents present in the samples.

Figure 8.34 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Altoona section.



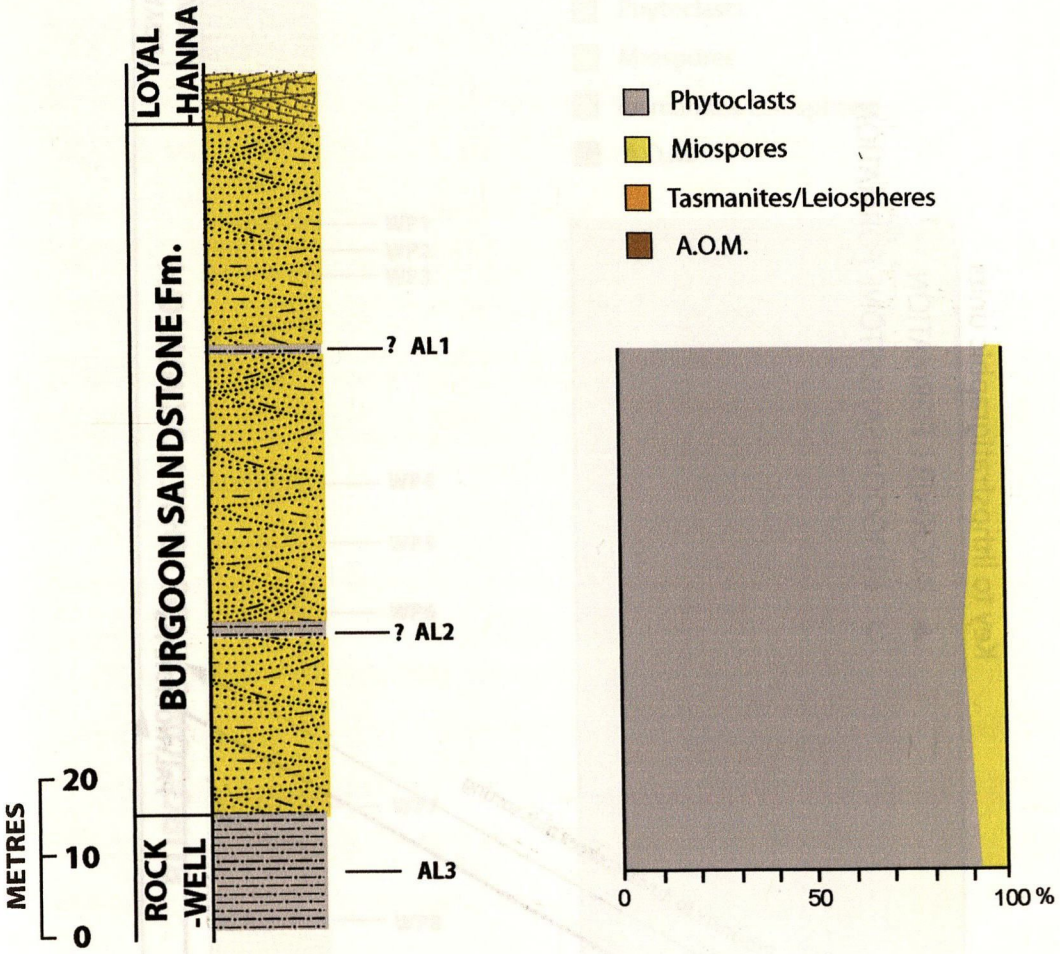
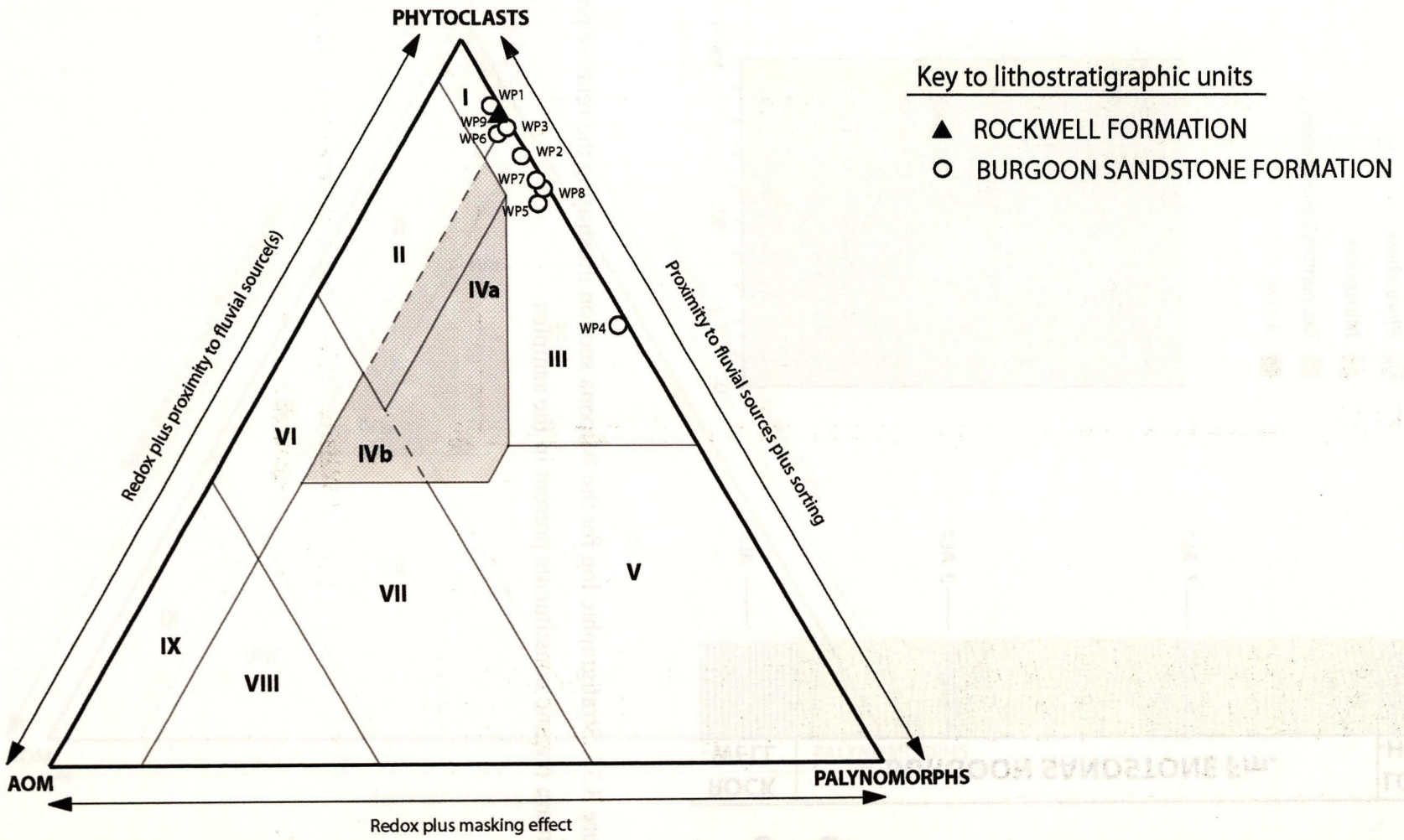


Figure 8.35. Stratigraphic log for the Altoona section illustrating the relative proportion of the main organic constituents present in the samples.

Figure 10.36 Ternary 'AOM' - phytoclast - palynomorph kerogen plot for the Warrior's Path section.



WARRIOR'S PATH STATE PARK, BEDFORD Co., PENNSYLVANIA

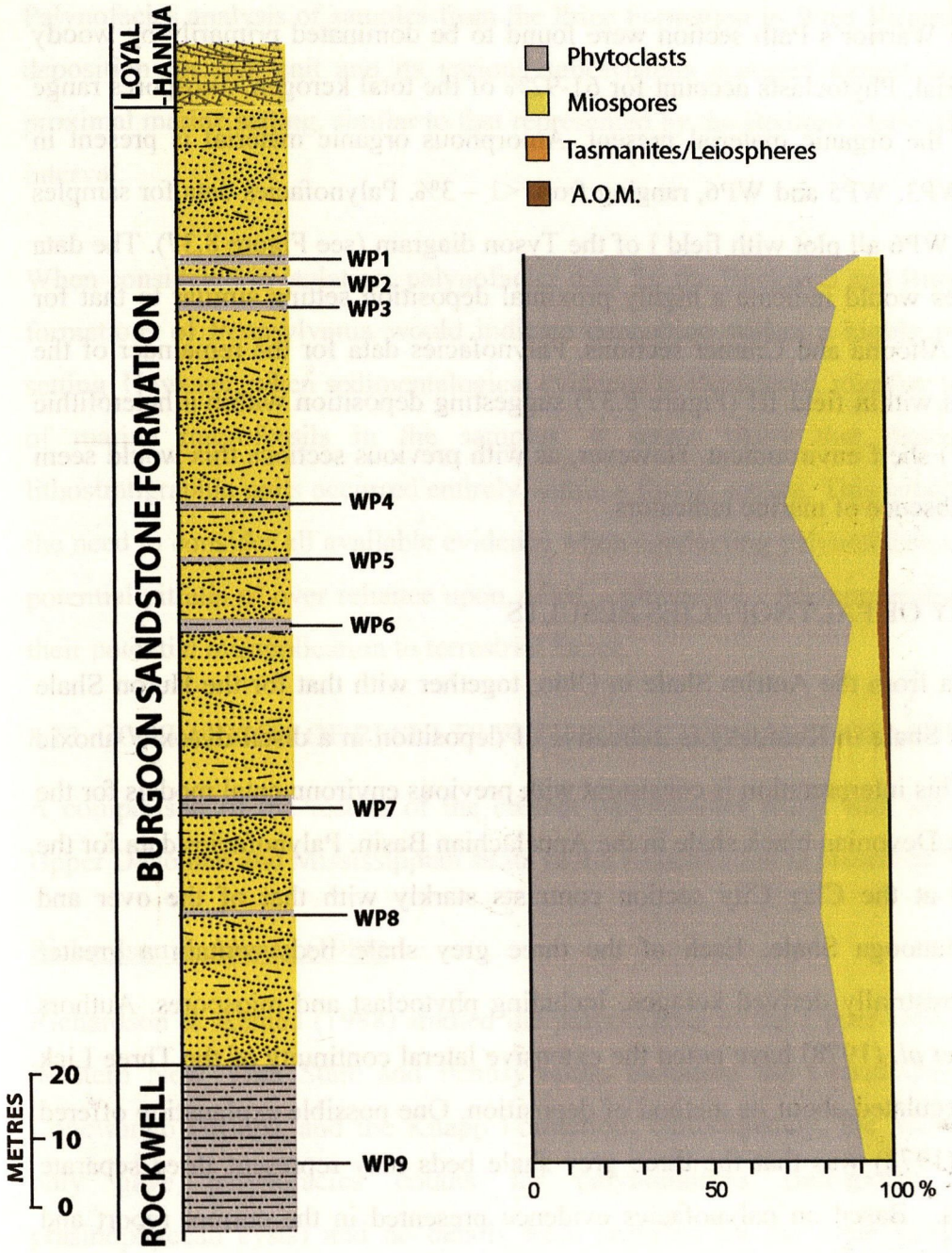


Figure 8.37 Stratigraphic log for the Warrior's Path section illustrating the relative proportion of the main organic constituents present in the samples.

8.11.13. WARRIOR'S PATH Fig. 8.37 & 8.38

Samples for the Warrior's Path section were found to be dominated primarily by woody phytoclast material. Phytoclasts account for 61-92% of the total kerogen, miospores range from 8-39% of the organic material present. Amorphous organic material is present in three samples, WP3, WP5 and WP6, ranging from <1 – 3%. Palynofacies data for samples WP1, WP9 and WP6 all plot with field I of the Tyson diagram (see Figure 8.37). The data for these samples would indicate a highly proximal deposition setting similar to that for inferred for the Altoona and Cramer sections. Palynofacies data for the remainder of the samples all plots within field III (Figure 8.37) suggesting deposition within a heterolithic oxic ('proximal') shelf environment. However, as with previous sections this would seem unlikely due to absence of marine indicators.

8.12. SUMMARY OF PALYNOFACIES RESULTS

Palynofacies data from the Antrim Shale in Ohio, together with that for the Huron Shale and Chattanooga Shale in Kentucky is indicative of deposition in a distal-dysoxic/ anoxic marine setting. This interpretation is consistent with previous environmental models for the deposition of late Devonian black shale in the Appalachian Basin. Palynofacies data for the Three Lick Bed at the Clay City section contrasts starkly with that of the over and underlying Chattanooga Shale. Each of the three grey shale beds contain a greater proportion of terrestrially derived kerogen, including phytoclast and miospores. Authors including Provo *et al.* (1978) have noted the extensive lateral continuity of the Three Lick Bed and have speculated about its method of deposition. One possible explanation offered by Provo *et al.* (1978) was that the three grey shale beds may represent three separate volcanic ash falls. Based on palynofacies evidence presented in the current report and available sedimentalogical it is proposed that the deposition of the grey beds occurred as three discrete turbidity flows which carried terrestrial kerogen into deeper, anoxic parts of the basin.

Palynofacies data from the Bedford Shale/ Berea Sandstone interval at various sections in Ohio and Kentucky indicates that deposition most likely occurred within a heterolithic oxic shelf environment, where considerable mixing between terrestrially and marine derived kerogen occurred. Deposition within such a setting is consistent with previous

interpretations concerning the depositional environment for these lithostratigraphic units. Palynofacies analysis of samples from the Price Formation in West Virginia indicates that deposition for this unit and its various subdivisions occurred almost entirely within a proximal marine setting, similar to that represented by the Bedford Shale/ Berea Sandstone interval.

When considered in isolation, palynofacies data for the Rockwell and Burgoon Sandstone formations of Pennsylvania would indicate deposition within a highly proximal marine setting. However, when sedimentalogical evidence is considered, together with the absence of marine microfossils in the samples, it seems likely that deposition of these lithostratigraphic units occurred entirely within a fluvial setting. This conclusion highlights the need to consider all available evidence when conducting palynofacies analysis, and the potential pitfalls of over reliance upon AOM – phytoclast - palynomorph (APP) plots and their potential misapplication to terrestrial facies.

8.13. COMPARISON OF RESULTS WITH SELECTED PALYNOFACIES STUDIES

A comparison of the results of the current palynofacies study with previous studies of Upper Devonian and Mississippian strata in the Eastern USA is presented below:

Richardson & Ahmed (1988)

Richardson & Ahmed (1988) studied the palynofacies of the Upper Devonian strata from Western New York State and Pennsylvania, including the Canadaway, Conneaut and Conewango Groups, and the Knapp Formation. Unfortunately, the authors of that study only gave palynofacies counts for palynomorphs (miospores, acritarchs and prasinophycean cysts) and no details were provided for the other kerogen components present in the samples (e.g. phytoclasts, AOM). Since they do not include a complete quantitative analysis of the kerogen it is difficult to compare directly with the results of this investigation or other previous studies. However, it is possible to make some rudimentary comparisons with palynofacies assemblages discussed in the present study. Richardson & Ahmed recognised five palaeoenvironments:

i) Distal Basin; Dominated by prasinophycean cysts, acritarchs rare, spores relatively abundant though poorly preserved, organic matter unstructured. Richardson & Ahmed

(1988) interpret that these sediments were deposited some distance from land and sedimentation occurred in a deep water setting, which was at times anoxic. The authors assign the Angola Shale, Pipe Creek Shale and Hanover Shale formations (upper West Falls Group), and the Dunkirk Shale Member of the overlying Canadaway Formation to this palynofacies. The Dunkirk Shales are noted as being dominantly black but include intercalations of grey shale which are described as containing abundant miospores. Due to the contrast in spore abundance and the preservation of organic matter, Richardson & Ahmed infer that the grey shales were deposited in a distal environment by density currents.

Richardson & Ahmed's 'Distal Basin' palynofacies is closely comparable to palynofacies assemblages described in the present study from the Ohio Shale Formation, which contain abundant AOM, very few spores and abundant Tasmanites. The intercalations of grey shale within the 'Dunkirk Shales' are noted as containing abundant miospores. As noted previously (see 8.11.7), palynofacies assemblages from the grey shale beds are similar to those described in the present study from beds of grey mudstone within the Three Lick Bed of Kentucky. Since Richardson & Ahmed assign the Dunkirk Shale to the *torquata – gracilis* Zone, and the Three Licks Bed is assigned to the LN Zone (this study) it is clear that these two lithostratigraphic units represent non-age equivalent strata. However, the similarity in the palynofacies assemblages would perhaps infer a common depositional environment, at different times.

ii) Proximal Basin and Slope; Richardson & Ahmed (*ibid*) assigned the following members of the Canadaway Group to this palynofacies: South Wales Shale, Gowanda Shale, Laona Siltstone, Westfield Shale, Shumla Siltstone and Northeast Shale members. Two distinct palynofacies are recorded by the authors in these units:

(a) The siltstones are noted as containing land-derived plant material, structured wood and cuticle, and structured spores dominate this palynofacies. This material was considered by the authors to have been derived from the continental shelf and carried by density currents into deeper water.

(b) In contrast, the interbedded shales contain abundant prasinophycean cysts, acritarchs and unstructured organic matter. Palynofacies assemblages from these

units were inferred by the authors to be representative of a proximal basin or slope environment intermittently invaded by density currents.

The palynofacies assemblages from the siltstones seem to be comparable to those described in the present study from the Bedford Shale Formation (and also perhaps the grey mudstones of the Three Licks Member). The kerogen content of interbedded shales from this interval appears to be similar to that recorded from the Ohio Shale Formation due to the abundance of AOM and prasinophycean cysts.

iii) Open Shelf; Deposits of shales, siltstones and fine to medium sandstones. Palynofacies characterised by common acritarchs, prasinophycean cysts, relatively abundant spores and frequent structured, land-derived plant fragments. Palynofacies assemblages of this type occur in the upper part of the Northeast Shale Formation (Canadaway Group) and the Dexterville and Ellicott Formations (Conneaut Group).

The 'Open Shelf Palynofacies' most closely compares to the kerogen assemblages recorded in the present study from the Bedford Shale Formation in Ohio and from the interval below the Murrysville Sandstone in the Mylan Park core, both of which are dominated with terrestrially derived kerogen; One notable difference is that the Mylan Park samples lack prasinophycean cysts which are reportedly common in this palynofacies in Richardson & Ahmed's study. However, as noted elsewhere in this thesis (e.g. 8.6.3) no prasinophytes are recorded above the Devonian/ Carboniferous boundary.

iv) Nearshore shelf/ marine influenced alluvial plain;
Spores are noted as dominating this palynological assemblage; acritarchs are said to be diverse and abundant at some horizons. Lithostratigraphic units assigned to this palynofacies include: the Venango, Cattaraugus and Oswayo formations, the Conewango Group and the Knapp Formations.

Like the previous palynofacies, the kerogen content of Richardson & Ahmed's 'Nearshore shelf/ marine influenced alluvial plain' is dominated primarily by terrestrially derived kerogen. The most closely comparable palynofacies assemblages identified in the present study come from the interval below the Murrysville Sandstone in the Mylan Park core.

v) Continental flood plain; Units assigned to this palynofacies include the Upper Cattaraugus Formation, Conewango Group. The palynofacies is composed almost entirely of miospores, megaspores and are frequently associated with abundant structured plant material. The authors noted that palynological preparations from some sections in the uppermost Cattaraugus Formation contain only fragmentary plant remains.

In the present study, no palynofacies assemblages are described in which miospores and megaspores account for more than ~45% of the total kerogen. However, a number of palynofacies assemblages consisting almost entirely of phytoclast have been documented. Such assemblages are common in samples of the Rockwell and Burgoon Sandstone formations from the Altoona, Cramer and Warrior's Path localities in Pennsylvania, and also from samples of the Upper Price Formation at the Caldwell section in West Virginia.

Coleman & Clayton (1987)

Coleman & Clayton (1987) conducted a palynofacies investigation of the Bedford Shale, Sunbury Shale and Borden Formations of Eastern Kentucky. The authors of this study utilised the kerogen classification scheme originally proposed by Bujak, Barss & Williams (1977). This scheme differs slightly from that of Tyson (1995, after Combaz, 1964) used in the current investigation, instead recognising four distinct categories:

I) Amorphogen; comprises all un-organised structureless organic matter, which is either finely disseminated or coagulated fluffy masses; termed AOM in the present study.

II) Hylogen; all non-opaque, fibrous plant material of woody origin. Approximates vitrinite in older studies and non-opaque phytoclast in the present investigation.

III) Melanogen; includes all opaque organic matter.

IV) Phyrogen; non-opaque, recognisable plant matter which is not of woody origin, including plant cuticles, spores and dinoflagellates cysts.

Using this kerogen classification scheme, Coleman & Clayton (*ibid*) recognised three distinct palynofacies types within the section, in ascending order; i) tasmanitid – amorphogen palynofacies (Bedford Shale), ii) amorphogen palynofacies (Sunbury Shale) and iii) melanogen palynofacies (Henley Bed, Farmers Member, Nancy Member and Cowbell Member).The results of this study are summarised by Figure 8.39.

i) Tasmanitid – Amorphogen Palynofacies

Coleman & Clayton assigned samples 1-3 from the Bedford Shale to this palynofacies, which is characterised by the occurrence of amorphogen (4.5-64%), phyrogen (15-39%), hylogen (5-19%) and melanogen (17-46%). Palynomorphs are noted as being particularly diverse within this 'palynofacies zone'; tasmanites are relatively common, accounting for between 0.5–4% of the assemblage, leiospheres (0.2–2%) and acritarchs (1–1.5%) are both present and miospores are particularly abundant (9-37%).

The authors considered the palynofacies of the Bedford Shale to be consistent with its interpretation as a prodelta environment, and suggested the high proportion of amorphogen in these samples as perhaps being indicative of limited input of inorganic sediment into the basin during this time. The relative abundance of tasmanitids is interpreted as an indication of stratification in the basin, with brackish surface waters produced by an influx of fresh water from the Bedford Delta to the north.

ii) Amorphogen Palynofacies

Samples 4-6 from the Sunbury Shale Formation in Coleman & Clayton (*ibid*) are assigned to this palynofacies. Amorphogen is reported as being the dominant kerogen type within these samples, accounting for 81-89%. Leiospheres (1-5%) are noted as being the most common of the palynomorphs present, spores and acritarchs are rare, and tasmanites are absent. Hylogen (0-2.5%) and melanogen (7-9.5%) together comprise less than 12% of the total kerogen content. The amorphogen palynofacies is interpreted by the authors of the study as being indicative of normal salinities with low terrigenous input. Such an interpretation is thought to be consistent with the inferred re-establishment of quiet, basinal conditions. This is comparable to results from analysis of the Sunbury Shale Formation in Ohio but not those from the Caldwell section.

iii) Melanogen Palynofacies

Coleman & Clayton assigned samples 10-19 from the Henley Bed, Farmers Member, Nancy Member and basal most Cowbell Member to the melanogen palynofacies. Melanogen is the most dominant kerogen type present in these samples, accounting for 52-92%; hylogen is subordinate, representing 4-16% of the total kerogen present. Leiospheres and tasmanitids are present in these samples, although rare, and amorphogen is almost entirely absent. The authors report that the proportions of miospores (0.4-38%) and

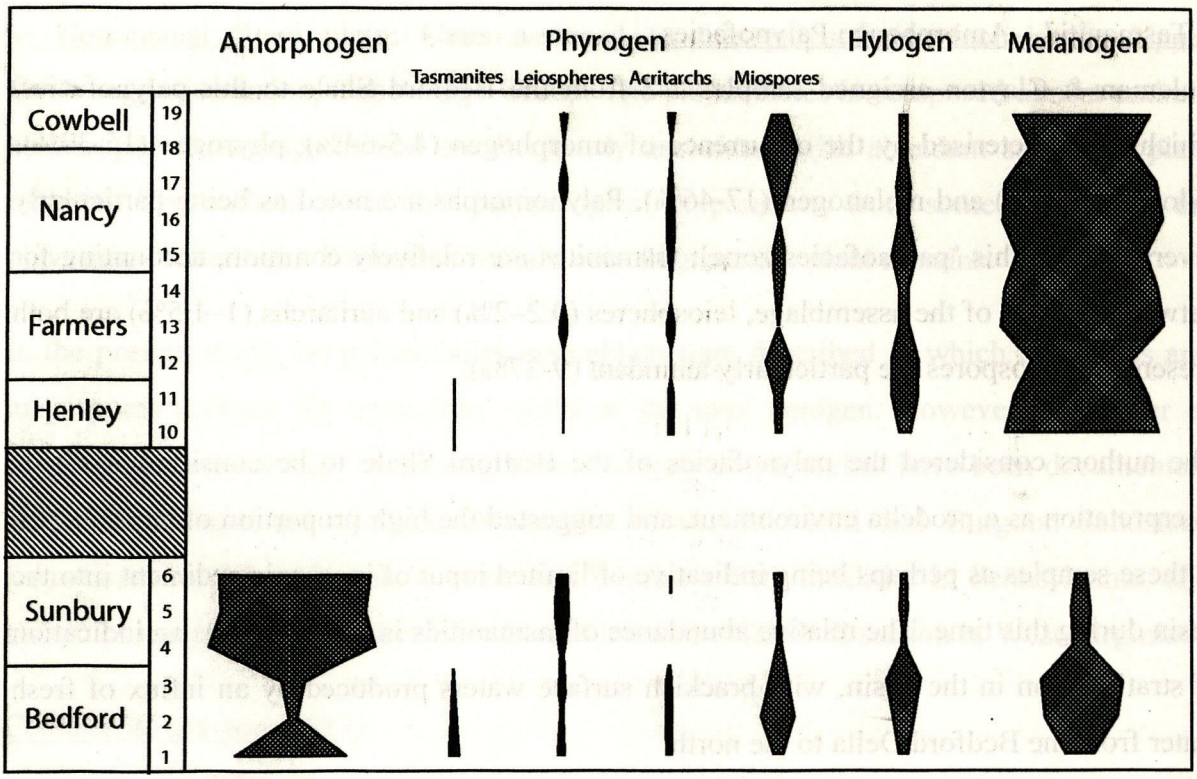


Figure 8.38 Proportions of kerogen/ palynomorph types in the Kentucky samples. Gap in occurences is related to barren samples (7-9) in lower part of the Henley Bed. After Coleman & Clayton (1987).

acritarchs (0.5-5%) are variable within this interval however, acritarchs are generally most abundant in the Henley Bed and in the Nancy Member. Scolecodonts were reported from both the Henley Bed and Cowbell Member.

Coleman & Clayton (1987) report that the mean organic particle size increases upward from the Bedford Shale to the base of the Cowbell Member, with miospore tetrads and megaspore fragments becoming more common towards the upper portion of the section. This was interpreted by the authors as being consistent with the prograding nature of the Borden Delta. Coleman & Clayton's melanogen palynofacies appears to contrast strongly with the preceding palynofacies due to the dominance of terrestrially derived kerogen. These results are comparable to those from the upper Price Formation samples in the present study.

Heal & Clayton (2009)

Heal & Clayton (2009) conducted an investigation of the palynofacies of the Hannibal Shale Formation from two sections in northeastern Missouri, an outcrop section at Hannibal and a borehole core drilled at Clarence Dam. The presence of acritarchs and scolecodonts within the Hannibal Shale is interpreted by the authors as confirmation of a marine depositional environment for this unit. The abundance of acritarchs in relation to land derived kerogen (miospores and phytoclasts) is cited as evidence of deposition in a distal marine setting. Two samples from the section at Hannibal (S47 and S54) and four samples from the Clarence Dam core (CC1, CC2, CC3 and CC4) are reported as being relatively rich in AOM.

Amorphogen – Palynomorph – Phytoclast plots were constructed by Heal & Clayton in order to interpret the palynofacies of these samples. Palynofacies data from the Hannibal samples plot in fields III, IV and V, which is interpreted by the authors as being indicative of deposition in an oxic proximal shelf, distal shelf and shelf basin transition environment respectively. The authors also noted that this interpretation is consistent with the inferred palaeogeographic position of the Hannibal area during the early Carboniferous, approximately 480km (~300 miles) west of the Borden Delta front. Within the Clarence Dam core samples, the authors reported a 'palynofacies shift' from fields VII, VIII and IX to field V. This was suggested as being indicative of a change in depositional environment

from an anoxic basin/ distal shelf depositional in the lower part of the section to an oxic distal shelf environment in the mid-upper portion.

CHAPTER 9

QUANTITATIVE ANALYSIS OF MIOSPORE ASSEMBLAGES

9.1 THE 'ANOMALOUS' OCCURRENCES OF DEVONIAN MIOSPORES

The occurrence of miospore taxa supposedly restricted to Devonian strata in assemblages recovered from younger rocks is a phenomenon which has been widely documented by previous authors who have studied the Mississippian succession in the USA (e.g. Winslow 1962; Eames 1974; Coleman & Clayton, 1987; Clayton *et al.* 1998). This trend has been observed in studies of strata of various ages in other regions, including Canada (Hacquebard, 1957; McGregor, 1970; Playford & McGregor, 1993), South America (Pasquo & Azcuy, 1997; de Souza *et al.* 1999), Western Europe (Bless & Streel, 1976; Collinson *et al.* 1985); and the Middle East (Eshet *et al.* 1988). However, this is a topic which has rarely been discussed in any detail.

Previous authors who have reported the anomalous occurrence of upper Devonian miospores within Carboniferous strata have offered a number of possible explanations. For example, Clayton *et al.* (1998) in a study of the Cuyahoga and Logan formations of Ohio noted the association of Latest Devonian 'Strunian' taxa (e.g. *R. lepidophyta*, *Rugospora radiata* and *V. pusillites*) with species indicative of the mid – Tournaisian *Spelaeotriletes pretiosus – Raistrickia clavata* (PC) Biozone (e.g. *Granulatisporites microgranifer*, *Raistrickia clavata* and *Spelaeotriletes pretiosus*). Clayton *et al.* (1998) offered three possible explanations for this anomaly:

1) The early (latest Devonian) first appearance in Ohio of the parent plants of *Convolutispora major*, *G. microgranifer*, *Neoraistrickia cymosa*, *Raistrickia clavata*, *Spelaeotriletes balteatus* and *S. pretiosus*.
2) The late (mid-Tournaisian) extinction of the parent plants of *Retispora lepidophyta*, *Rugospora radiata* and *Vallatisporites pusillites* in Ohio.
3) Reworking of significant numbers of latest Devonian miospores into mid – Tournaisian (PC Biozone) assemblages.

Clayton *et al.* (1998) discounted the first hypothesis due to 'a total lack of evidence'. The second explanation was regarded as 'plausible' in light of the anomalous occurrence of *Retispora lepidophyta* in numerous sections in North America. However, in light of circumstantial evidence, the authors concluded that the latter hypothesis was the most probable. The author of the present study agrees with Clayton *et al.* (1998), and acknowledges that the second hypothesis is entirely plausible. However, since several other species characteristic of upper Devonian spore assemblages (e.g. *Ancyrospora* spp., *Hystricosporites* spp., *Rugospora flexuosa*, *R. radiata*, *Vallatisporites hystricosus* and *V. pusillites*) have anomalous ranges in North America, this hypothesis may be considered less likely if not discounted entirely. Nevertheless, as highlighted by Playford & McGregor (1993) and Clayton *et al.* (1998), there is obviously a certain degree of circularity in the argument when attempts are made to correlate the extinction of *R. lepidophyta* with the Devonian/ Carboniferous boundary in sections lacking independent faunal control.

In the Eastern USA, the placement of the Devonian/ Carboniferous boundary USA has long been a matter of controversy (Pepper *et al.* 1954). Based on palynological data, the Devonian/ Carboniferous boundary is generally considered to be the most easily recognisable Palaeozoic System boundary. The extinction of several distinctive miospore species (including *Retispora lepidophyta*, *Rugospora radiata*, *Vallatisporites hystricosus* and *V. pusillites*) is well documented in the literature and appears to be more or less coincident with the boundary, independent of facies and an event which may be recognised globally. The base of the lowermost miospore biozone of the Carboniferous, the VI Biozone, is recognised by this extinction event and the last appearance of *R. lepidophyta*. Since no new species appear at the base of this zone, its recognition may potentially be hindered due to the reworking of the species listed above.

During the analysis of the Mylan Park samples in the present investigation, *R. lepidophyta* was found to be present in every productive sample analysed, occurring in assemblages with species whose stratigraphical ranges are generally considered to be incompatible (e.g. *Spelaeotriletes balteatus* and *S. pretiosus*). If the specimens of *R. lepidophyta* and other Upper Devonian taxa recorded above the Murrysville Sandstone in the core are reworked, then it may be reasonably assumed that these species should be significantly less abundant above their last level of in-situ occurrence (i.e. the Devonian/ Carboniferous boundary).

Therefore by determining the absolute abundance of 'Upper Devonian' taxa in the samples it was considered possible to delineate the boundary by quantitative means.

Unfortunately, no independent biostratigraphic evidence is available for this core. However, Carter & Kammer (1990) have reported a well developed brachiopod fauna from the Oswayo and Cussewago sandstones from localities in northern West Virginia, as well as in adjacent Maryland and Pennsylvania. Species recorded include: *Centrorhynchus* spp., *Chonetes* sp., *Cyrtospirifer* spp., *Rhipidomella* sp., *Schuchertella bowdenensis* and *Syringothyris angulata*. These taxa are indicative of a Famennian age for the Oswayo and Cussewago Sandstones. Since the overlying Riddlesburg Shale Member contains brachiopod taxa diagnostic of a Kinderhookian age (e.g. *Schuchertella macensis* and *Verkhotomia nascens*) Carter & Kammer, (1990) inferred that the Devonian/ Carboniferous boundary is positioned between the Cussewago Sandstone and the overlying Riddlesburg Shale. Since the 'lower' Murrysville Sandstone in the subsurface is considered to be approximately equivalent to Cussewago Sandstone in outcrop (see Chapter 1.55 for a full lithostratigraphic discussion), the inferred position of the Devonian/ Carboniferous boundary in the Mylan Park core is either within or above the Murrysville Sandstone.

9.2. METHODOLOGY

In order to determine if 'upper Devonian taxa' recorded above the Murrysville Sandstone represented genuine in-situ occurrence or reworking a quantitative evaluation of miospore assemblages was attempted. In order to undertake the analysis, a number of weighed samples were selected from above and below the level of the Murrysville Sandstone (the inferred position of the Devonian/ Carboniferous boundary). Selected samples were 'spiked' with *Lycopodium* tablets using the method outlined in Chapter 4. Samples were analysed and counts were made of the 'upper Devonian' taxa (*Ancyrospora* spp., *Hystricosporites* spp, *Retispora lepidophyta*, *Rugospora flexuosa*, *R. radiata*, *Vallatisporites hystricosus* and *V. pusillites*), longer ranging species (e.g. *Calamospora* spp., *Dictyotriletes* spp., *Emphanisporites* spp., *Punctatisporites* spp., *Retusotriletes* spp. etc) and the number of *Lycopodium* spores present in each of the selected samples. The absolute abundance of each of the species was then determined using the equations presented in Chapter 5.

9.3. RESULTS OF QUANTITATIVE ANALYSIS

The absolute abundance of spores assignable to 'upper Devonian' species was found to be significantly higher in samples selected from below the Murrysville Sandstone. In the samples from above the level of the Murrysville Sandstone the same species were found to constitute a much smaller percentage of the assemblages. For instance, in samples MP2-TCD59502 and MP5-TCD59505 taken from in the interval below the Murrysville Sandstone, 'Upper Devonian species' constitute 37% and 33% of the total assemblages respectively.

The lowest figure recorded for any of the samples collected below the Murrysville is for sample MP10-TCD59510 where upper Devonian taxa comprise 28% of the total assemblage. In the highest sample collected from the stratigraphical interval below the Murrysville Sandstone, sample MP12-TCD59512 (approximately 2 ft. below the base of the Murrysville) 30% of the spores recorded in the assemblage could be assigned to an upper Devonian taxon. In contrast, samples from above the Murrysville Sandstone contained far fewer upper Devonian spores. Sample MP13-TCD59513 was found to contain an assemblage of which 11% of all spores represented upper Devonian forms and in sample MP15-TCD59514 the same species account for only 6% of the total assemblage. The abundance of upper Devonian species in selected samples from the Mylan Park core is summarised by Figure 9.1.

9.4. CHAPTER SUMMARY

Obviously the application of quantitative techniques to miospore assemblages of anomalous composition does not provide conclusive proof that the occurrence of late Devonian species in such assemblages is the result of reworking. The author acknowledges that the quantitative analysis of miospore assemblages is undoubtedly less favourable than the correlation of independent biostratigraphic markers. However, the results of this preliminary investigation are clearly encouraging enough to suggest that the technique has the potential be utilised to delineate the position of the Devonian/ Carboniferous boundary in other sections where independent faunal control is unavailable and where reworking is suspected to have occurred. Further work is necessary, such as the quantitative analysis of miospore assemblages in well correlated and dated sections with good independent biostratigraphic control.

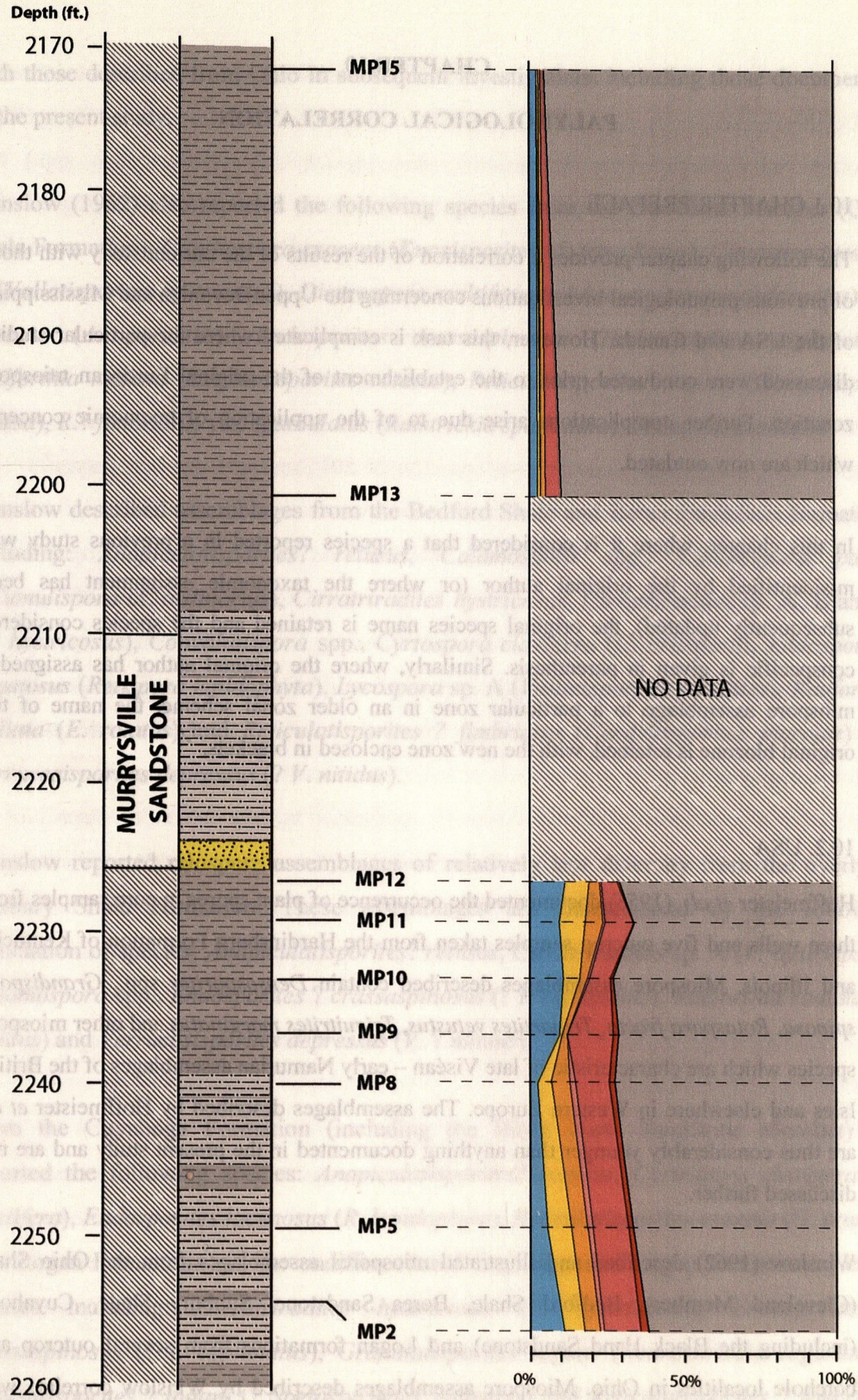


Figure 9.1. The abundace of miospore taxa in selected samples form the Mylan Park core:

Retispora lepidophyta; *Rugospora flexuosa*; *R. radiata*; *Vallatisporites pusillites*; *V. hystricosus*; *Ancyrospora*/ *Hystricosporites* spp.; 'Longer ranging' taxa.

CHAPTER 10

PALYNOLOGICAL CORRELATION

10.1 CHAPTER PREFACE

The following chapter provides a correlation of the results of the current study with those of previous palynological investigations concerning the Upper Devonian and Mississippian of the USA and Canada. However, this task is complicated where the particular studies discussed were conducted prior to the establishment of the original European miospore zonation. Further complications arise due to of the application of taxonomic concepts which are now outdated.

In this chapter, where it is considered that a species reported in a previous study was misidentified by the original author (or where the taxonomic assignment has been subsequently updated), the original species name is retained and the species considered conspecific is given in parenthesis. Similarly, where the original author has assigned a miospore assemblage to a particular zone in an older zonal scheme, the name of the original biozone is retained, with the new zone enclosed in brackets.

10.2. USA

Hoffmeister *et al.* (1955) documented the occurrence of plant spores in core samples from three wells and five outcrop samples taken from the Hardinsburg Formation of Kentucky and Illinois. Miospore assemblages described contain *Densosporites* spp., *Grandispora spinosa*, *Rotaspora fracta*, *Tripartites vetustus*, *Triquitrites marginatus* and other miospore species which are characteristic of late Viséan – early Namurian assemblages of the British Isles and elsewhere in Western Europe. The assemblages described by Hoffmeister *et al.* are thus considerably younger than anything documented in the present study and are not discussed further.

Winslow (1962) described and illustrated miospores assemblages from the Ohio Shale (Cleveland Member), Bedford Shale, Berea Sandstone, Sunbury Shale, Cuyahoga (including the Black Hand Sandstone) and Logan formations from several outcrop and borehole localities in Ohio. Miospore assemblages described by Winslow correlate well

with those described from Ohio in subsequent investigations including those documented in the present study.

Winslow (1962) also reported the following species from the Cleveland Member (Ohio Shale Formation): *Canthospora cracens* (*Knoxisporites* cf. *triradiatus*), *Cirratriradites* sp. A (*Vallatisporites hystricosus*), *Dicyrospora multifurcata* (*Ancyrospora multifurcatus*), *D. porcata* (*A. porcatus*), *Endosporites crassaspinosus* (?*Indotriradites explanatus*), *Radforthia radiata* (*Emphanisporites rotatus*), *Reticulatisporites crassus* (*Gorgonispora crassa*), *R.? fimbriatus* var. *spathulatus* (*Raistrickia spathulata*), *Triletes catenulatus*.

Winslow described assemblages from the Bedford Shale and Berea Sandstone formations including: *Anapiculatisporites? retusus*, *Calamospora* spp., *Canthospora patula* (?*Tumulispora* cf. *ordinarius*), *Cirratriradites hystricosus*, *Cirratriradites* sp. A, B and C (*V. hystricosus*), *Convolutispora* spp., *Cyrtospora clavigera* (*C. cristifera*), *Endosporites lacunosus* (*Retispora lepidophyta*), *Lycospora* sp. A (*Vallatisporites pusillites*), *Radforthia radiata* (*E. rotatus*) and *Reticulatisporites ? fimbriatus* (*Cordylosporites marciae*) and *Verrucosisporites depressus* (? *V. nitidus*).

Winslow reported miospore assemblages of relatively low diversity from the overlying Sunbury Shale Formation. These assemblages are characterised by the following association of species: *Anapiculatisporites? retusus*, *Cirratriradites* sp. A (*V. hystricosus*), *Calamospora* spp., *Endosporites* ? *crassaspinosus* (? *I. explanatus*), *Radforthia radiata* (*E. rotatus*) and *Verrucosisporites depressus* (*V.* ? *nitidus*).

From the Cuyahoga Formation (including the Black Hand Sandstone Member) she reported the following species: *Anapiculatisporites? retusus*, *Cyrtospora clavigera* (*C. cristifera*), *Endosporites lacunosus* (*R. lepidophyta*), *Reticulatisporites crassus* (*G. crassa*). The Logan Formation and the undifferentiated Cuyahoga and Logan formations yielded species including: *Cirratriradites hystricosus* (*V. hystricosus*), *Endosporites* ? *crassaspinosus* (? *I. explanatus*), *Granulatisporites logani* (*Neoraistrickia loganensis*), *Punctatisporites* ? *logani* (? *Spelaeotriletes balteatus*) and *Reticulatisporites* ? *fimbriatus* (*Cordylosporites marciae*).

Assemblages described by Winslow from the Cleveland Shale Member are considered to be Upper Devonian in age based upon the occurrence of *Vallatisporites hystricosus* (recorded as *Cirratriradites hystricosus*), *Ancyrospora* spp. (*Dicyrospora* spp.) and *Emphanisporites rotatus* (*Radforthia radiata*). However, they cannot be assigned to a particular biozone due to the absence of key zonal taxa. As observed in the present study, assemblages reported by Winslow from the Ohio Shale are of relatively low diversity, probably due to the distal nature of the sedimentary environment. It is possible that these assemblages are age equivalent to other assemblages herein assigned to the LN Zone, however, since *R. lepidophyta* and *V. nitidus* are absent in the Ohio Shale in Winslow's account, these assemblages cannot be assigned to the LN Zone with any certainty.

Assemblages described from the Bedford Shale and the Berea Sandstone formations by Winslow are typical of the LN Biozone in Western Europe. These assemblages are characterised by the association of the following taxa: *Retispora lepidophyta*, *Vallatisporites hystricosus*, *Verrucosisporites nitidus* and *Cordylosporites marciae*. These assemblages closely comparable to those recorded from this stratigraphic level in the current investigation.

Winslow's assemblages from the Sunbury Shale Formation compare closely with those from the European VI Biozone. These assemblages are typically of restricted composition and are dominated primarily by species ranging from the preceding biozones, including taxa such as *Cyrtospora cristifera*, *Emphanisporites rotatus* and *Verrucosisporites nitidus*. According to Winslow's record no 'new' taxa appear in the Sunbury Shale, another feature characteristic of the VI Biozone.

From the overlying Cuyahoga Formation Winslow reported *Retispora lepidophyta* (as *Endosporites lacunosus*) and other taxa abundant lower in the stratigraphy. The occurrence of *R. lepidophyta* in the Cuyahoga Formation is somewhat anomalous when compared to its occurrence in Europe and elsewhere, where the uppermost limit of its range closely approximates the Devonian/ Carboniferous boundary. For this reason and the absence of the species in the Sunbury Shale, specimens of *R. lepidophyta* recorded in the Cuyahoga Formation are considered to be reworked. A detailed description of the anomalous

occurrence of Devonian miospore taxa within Mississippian strata in the USA is provided in Chapter 9.

Other stratigraphically useful taxa reported by Winslow (1962) include *Cyrtospora cristifera* (described as *Cyrtospora clavigera*) and *Spelaeotriletes balteatus* (*?Punctatisporites logani*). According to Winslow, the latter of these two species first appears in the Logan Formation. This has been interpreted by subsequent authors (e.g. Coleman, 1991) as evidence that the base of the BP Biozone lies within the Logan Formation. However, since Clayton *et al.* (1998) have since reported PC Biozone assemblages from lower stratigraphical levels, assignment of these assemblages to the BP Biozone is discounted. No spores indicative of biozones younger the BP Biozone were recorded by Winslow.

In his unpublished M.A. thesis, Eames (1968) presented results of a palynological study of the upper Ohio Shale Formation (Cleveland Shale Member) and of the overlying Bedford Shale from the Tinker Creek locality, Cuyahoga County, northern Ohio. In this study, Eames reported a number of species recorded in the present study. From the Cleveland Shale Eames recorded species including: *Hymenozonotriletes famenensis* (*Rugospora radiata*), *Hymenozonotriletes lepidophytus* (*Retispora lepidophyta*), *Retusotriletes incohatus, Vallatisporites pusillites* and *Vallatisporites* sp. B (*V. hystricosus*), *Vallatisporites verrucosus* and *Verrucosisporites nitidus*.

From the overlying Bedford Shale Formation, Eames recorded taxa including: *Cordylosporites fimbriatus*, *Emphanisporites rotatus*, *Hymenozonotriletes explanatus*, *(Indotriradites explanatus*), *Knoxisporites literatus* (*K.* cf. *triradiatus*), *Laevigatosporites* sp., *Lophozonotriletes cristifer* (*Cyrtospora cristifera*), *Punctatisporites irrasus*. Eames (1968) also reported taxa present in the Cleveland Shale at this level, including the stratigraphically useful *H. lepidophytus* (*R. lepidophyta*) and *V. nitidus*. These results suggest a late Devonian, LN Zone age for the Bedford Shale Formation in northern Ohio.

Von Almen (1970a & b) presented the results of a palynological study of Woodford Shale Formation, from Carter County, central Oklahoma. The abundance of microplankton (>90%) in some samples led Von Almen to conclude that deposition occurred entirely in a

marine environment. In the uppermost 25 feet (7.6m) of the Woodford Formation, Von Almen reported a miospore assemblage including species such as: *Archaeozonotriletes luteolus*, *Discernisporites concentricus*, *D. irregularis*, *Lophozonotriletes dentatus*, *Murospora subtera*, *Perotriletes evanidus*, *P. luteolus*, *P. perinatus* and *Pustulatisporites gibberosus*.

Von Almen concluded that the upper 25 feet of the Woodford Shale in Carter County is of Mississippian (Tournaisian: Kinderhookian) age. The results of Von Almen's study are difficult to reconcile with the results of other studies, including those of the current investigation. None of the species listed above are recorded in the present investigation, nor do they feature in the Upper Devonian – Carboniferous miospore zonation of Western Europe.

In the middle portion of the Woodford Shale, the only identifiable miospores are assigned by the author to *Anapiculatisporites* cf. *ampullacus*. Von Almen noted apparent absence of distinctive miospore species such as *Dicyrospora multifurcata* (*Ancyrospora multifurcatus*), *Hymenozonotriletes lepidophytus* (*Retispora lepidophyta*), *Lophozonotriletes rarituberculatus* (*Tumulispora triangulatus*), and *Vallatisporites vallatus* in the middle and upper Woodford Shale. This is somewhat anomalous when compared with assemblages reported from the equivalent stratigraphic interval further east both in previous studies (e.g. Winslow 1962) and in the present investigation. Von Almen suggests this disparity may be due to, "the effect of the locus of deposition or the lack of 'foot-by-foot' sampling and analysis". An alternative explanation offered here is that the absence of these species may be due to palaeobiogeographic control and the absence of the parent plants of these species in this region.

Eames (1974) continued the work of his previous study with an investigation focusing on the Berea Sandstone and Cuyahoga formations (Orangeville Shale, Sharpsville Sandstone and the Meadville Shale members), of northern Ohio. From the Berea Sandstone Formation Eames documented miospore assemblages including:

Auroraspora macra, *Hymenozonotriletes explanatus*, (*I. explanatus*), *H. famenensis* (*Rugospora radiata*), *H. lepidophytus* (*Retispora lepidophyta*), *Punctatisporites planus*,

Raistrickia clavata, *R. corynoges*, *Vallatisporites* sp. A (*V. hystricosus*), *Vallatisporites* sp. B (*V. hystricosus*), *Vallatisporites* sp. C (*V. pusillites*), *V. vallatus* (*V. hystricosus*), *Verrucosisporites nitidus*. Additionally, megaspores assigned to the genera, *Ancyrospora* spp. and *Hystricosporites* spp were reported from the Berea Sandstone in association with the miospore taxa listed above.

From the overlying Cuyahoga Formation Eames (*ibid*) recorded taxa which include: Orangeville Shale Member; *Crassispora* sp. (? *Spelaeotriletes pretiosus*), *Dictyotriletes cheveriensis*, *Emphanisporites annulatus*, *Endosporites minutus*, *Lophozonotriletes malevkensis* (*Tumulispora malevkensis*), *L. rarituberculatus* (*T. triangulatus*), *Pustulatisporites* sp. A., *Secarisporites* sp. A, *Umbonatisporites distinctus* and *Vallatisporites splendens*. From the Sharpsville Sandstone Member; *Convolutispora vermiformis*, *Dictyotriletes cancellatus*, *Dictyotriletes* cf. *trivialis*, *Punctatisporites fissus* and *Reticulatisporites papillatus*.

Based on these results, Eames (1974) was able to differentiate three miospore assemblages; 'Upper Devonian', 'Lower Mississippian' and 'Transitional'. The Devonian assemblage was reported from the Berea Sandstone Formation. The Lower Mississippian assemblages were described from the Cuyahoga Formation. As noted by Eames (1974), taxa comprising the transitional assemblage, "do not appear to be particularly important for distinguishing between the Devonian and Mississippian ages. These taxa are not restricted to nor do they have consistently higher frequency of abundance in either the Berea or Cuyahoga Group".

Reinterpretation of these results suggests that Eames was indeed correct in the assignment of assemblages from the Berea Sandstone to the Upper Devonian. The occurrence of *Retispora lepidophyta* together with *Verrucosisporites nitidus* in these samples indicates an affinity with the uppermost Devonian LN Biozone. As subsequently noted by Coleman (1991), the occurrence of *Spelaeotriletes pretiosus* (recorded as *Crassispora* sp.) and *Raistrickia clavata* suggests that Eame's 'Lower Mississippian' assemblage can be assigned to the PC Biozone. However, it may be regarded as slightly anomalous that Eames reports the occurrence of the mid- late Tournaisian species *Raistrickia clavata* in the 'Upper Devonian' assemblages, and yet other stratigraphically useful taxa including

Spelaeotriletes balteatus and *Neoraistrickia loganensis* are totally absent within the 'Lower Mississippian' assemblage.

As in the current investigation, Eames reported a number of species which are inferred to be reworked; this includes *Hymenozonotriletes lepidophytus* (*R. lepidophyta)*, which occurs in a low relative frequency (generally less than 1%) as high as in the section as the lower Meadville Shale. Other taxa generally restricted to the Devonian were also reported from Mississippian strata, e.g. *Vallatisporites pusillites* (*V. hystricosus*) from the Orangeville Shale (Sharpsville and Meadville members), and from the Sharpsville Member, *Ancyrospora* spp., *Hystricosporites* spp., *Hymenozonotriletes famenensis* (*Rugospora flexuosa*) and *Vallatisporites* sp. A (*Vallatisporites hystricosus*).

Warg & Traverse (1973) investigated a section of carbonaceous shales and thin pyritic bituminous 'coal' assigned to the Catskill Formation, from a roadcut along Interstate Highway 80, Centre County, Pennsylvania. Samples collected from the Catskill Formation yielded assemblages containing *Hymenozonotriletes lepidophytus* (*R. lepidophyta*), *H. famenensis* (*Rugospora radiata*), *H. pusillites* (*Vallatisporites pusillites* and *V. hystricosus*). On the basis of the evidence presented by the authors, the assemblages from these samples can be tentatively assigned to the uppermost Devonian based on the occurrence of *Retispora lepidophyta.* The apparent absence of species such as *Knoxisporites literatus*, *Indotriradites explanatus* or *Verrucosisporites nitidus* preclude precise age determination of these assemblages, however, a maximum age equivalent to the LL Biozone is inferred.

In samples collected from the overlying 'Pocono' Formation, Warg & Traverse noted that, "*H. lepidophytus* was no longer found in the spore assemblage". This is taken as an indication of the lowermost Carboniferous (Mississippian - VI Biozone) age for the 'Pocono' Formation. The occurrence of *Neoraistrickia loganensis* (recorded as Spore -1) is perhaps also indicative of such an age assignment.

Further palynological investigation of the Catskill and Pocono formations in Pennsylvania was conducted by Streel & Traverse (1978). These authors studied a succession of sandstone and shales cropping out along the famous Horseshoe Curve section between

Altoona and Gallitzin. Miospore assemblages compare closely to those previously described by Warg & Traverse (1973) from Centre County.

Two major assemblages were identified by the authors: the lower one dominated by *Cirratriradites hystricosus* (*Vallatisporites hystricosus*) and *Spelaeotriletes lepidophytus* (*Retispora lepidophyta*), the higher assemblage, containing *Hymenozonotriletes explanatus* (*Indotriradites explanatus*) and *Vallatisporites vallatus.*

As with the study conducted by Warg & Traverse (1973), the assemblages containing *Retispora lepidophyta* can presumably be assigned to the upper Devonian. However, since the authors did not report *Verrucosisporites nitidus*, it is unclear if these assemblages belong to the LN Biozone. The occurrence of *Knoxisporites literatus* in these samples suggests that the assemblages may belong to the *Retispora lepidophyta – Knoxisporites literatus* (LL) Biozone.

The higher assemblage meanwhile, most likely signifies a Mississippian age. The overall character of this assemblage compares very closely to that of assemblages recorded in the present study from above the Murrysville Sandstone in the Mylan Park core. In the present investigation, samples from this lithostratigraphic interval yielded assemblages containing significant quantities of *Indotriradites explanatus* and *Vallatisporites vallatus*. These assemblages are herein assigned to the lowermost Carboniferous VI Biozone. Presumably the 'higher assemblage' described by Streel & Traverse (1978) is also assignable to this zone.

At the Horseshoe Curve section, Read (1955) reported a well developed *Adiantites* flora of early Mississippian age from the lower part of the Pocono Formation. The 'Murrysville sand' of Bayles (1949) occurs within this interval of sub-Burgoon strata, and can be traced laterally westwards into North-eastern Ohio where it is overlain by the Berea Sandstone. Making reference to the palaeobotanical evidence presented by Read (1955), De Witt (1970) reasoned that the remainder of Bedford Shale and the Berea Sandstone must be of early Mississippian age since they overlay the sub-Burgoon strata containing the Mississippian plant fossils. However, as was noted Streel & Traverse (1978) it seems likely that the position of Bayle's (1949) 'Murrysville sand' actually lies below the level of

the *Adiantites* flora at Horseshoe Curve. No such floral evidence has been observed in either the Bedford Shale or Berea Sandstone formations in Ohio.

Ahmed (1980) conducted a study on the genus *Auroraspora* from Frasnian and Famennian strata of New York and Pennsylvania. Although this investigation focused primarily upon the occurrence and systematics of *Auroraspora* spp., the author noted the first appearance of *Retispora lepidophyta* and *Vallatisporites hystricosus* at the base of the Ellicott Member of the Chadokoin Formation. Assemblages from this level can be tentatively assigned to the LL Biozone based on the first appearance of these species. Unfortunately, Ahmed didn't mention whether *Knoxisporites literatus* was also present in these assemblages. However, subsequent investigation of the Frasnian & Famennian sections of New York and Pennsylvania was conducted by Richardson & Ahmed (1988). These authors note that *R. lepidophyta* and *K. literatus* both first appear in the mid Cattaraugus Formation, with *Indotriradites explanatus* and *Verrucosisporites nitidus* first appearing in the basal Oswayo Formation and Knapp formations respectively.

Clendening *et al.* (1980) conducted an investigation focusing upon the distribution of *Retusotriletes phillipsii* within Upper Devonian (Famennian) strata in West Virginia, Michigan, Ohio, Kentucky and New York. It was suggested that *R. phillipsii* may prove to be a potentially useful marker taxon. However, in the present study this species has been found to have a significantly longer stratigraphic range.

Molyneux *et al.* (1984) described well preserved assemblages of miospores and microplankton from four samples collected across the boundary between the Bedford Shale and Berea Sandstone formations at the Big Walnut Creek section near Sunbury, Delaware Co., Ohio. The authors reported the occurrence of *Spelaeotriletes lepidophytus* (*R. lepidophyta*) and *V. nitidus* from both the Bedford Shale and the overlying Berea Sandstone. Making comparisons between this miospore association and that in the Ardennes- Rhine region, Molyneux *et al.* (1984) assigned the miospore assemblages to the latest Devonian LN Subzone (later given full zonal status by Higgs *et al.* 1988)

This section has also been sampled in the present investigation. There are no notable differences between the assemblages reported by Molyneux *et al.* (1984) and those

presented in the current study. However, since sample 4 (this study) is higher than theirs, the position of the Devonian/Carboniferous can perhaps be extended to a slightly higher level.

Coleman & Clayton (1987) documented well preserved miospore assemblages from a section near Morehead, Kentucky. Samples were collected from the Upper Devonian Bedford Shale, and the Lower Carboniferous Sunbury Shale and Borden formations. The following taxa were found by Coleman & Clayton (1987) to occur exclusively in the Bedford Shale at Morehead: *Ancyrospora* sp., *Apiculiretusispora* cf. *fructicosa*, *Grandispora cornuta*, *G.* cf. *echinata*, *Knoxisporites triradiatus*, *L. concentricus* (*Knoxisporites concentricus*), *Retispora lepidophyta*, *Rugospora flexuosa* and *Vallatisporites pusillites*.

Coleman & Clayton (1987) also reported the occurrence of longer ranging taxa including: *Auroraspora macra*, *A. minor*, *Cristatisporites menendezii*, *Cyrtospora cristifera*, *Emphanisporites rotatus*, *Leiotriletes turgidus*, *L. triangulatus*, *Murospora dubitata*, *Dictyotriletes fimbriatus* (*Cordylosporites marciae*), *Punctatisporites planus*, *Retusotriletes communis*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus*.

From the Sunbury Shale Formation Coleman & Clayton (1987) recorded species including: *Auroraspora minor*, *Cyrtospora cristifera*, *Lophozonotriletes triangulatus* (*Tumulispora triangulatus*), *Punctatisporites planus*, *Retusotriletes communis*, *R. crassus*, *R. incohatus*, *R. famennensis*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus*. The overlying Borden Formation yielded miospore taxa including: *Aratrisporites saharaensis*, *Auroraspora* sp. A, *Cristatisporites menendezii*, *Cyrtospora cristifera*, *Neoraistrickia loganensis*, *Vallatisporites* cf. *cilliaris*, *Spinozonotriletes uncatus*, *Umbonatisporites distinctus*, *Vallatisporites vallatus*, *V. verrucosus*. *Spelaeotriletes balteatus* and *S. pretiosus* were also noted as being particularly abundant within these assemblages.

These authors assigned assemblages from the Bedford Shale to the LN Biozone based on the occurrence of *Verrucosisporites nitidus* in assemblages also containing *Retispora lepidophyta*. A single specimen of *R. lepidophyta* encountered by Coleman & Clayton (1987) within the bioturbated Bedford/ Sunbury transition was interpreted by the authors as

being, "...probably reworked". Assemblages from the Sunbury Shale were assigned to the VI Biozone due to their low taxonomic diversity, absence of *R. lepidophyta* and the dominance of acamerate, laevigate forms. It is interesting to note that while Coleman & Clayton (1987) report VI assemblages of low diversity, more diverse assemblages have also been reported from level, both in the present investigation and in previous studies such as that of Streel & Traverse (1978). Assemblages from the overlying Borden Formation were assigned exclusively to PC Biozone. Coleman & Clayton (1987) attribute the absence of the intervening HD and BP to a condensed interval in the basal Henley Bed.

In her unpublished PhD thesis, Coleman (1991), presented the results of her study in Kentucky previously reported in Coleman & Clayton (1987) together with the unpublished data from an investigation of a borehole spanning the Borden Formation in Harrison County, Indiana. Coleman stated that, "At this stratigraphic level no European Biozone can be recognised". However, she was able to differentiate the miospores encountered into 3 assemblages; the *Schopfites claviger* Assemblage, the *Tumulispora* sp. B Assemblage and the *Tricidarisporites* sp. A – *Dictyotriletes* sp. B Assemblage. From the occurrence of *S. claviger* in the basal New Providence Shale, Coleman inferred that this is at least as young as the *S. claviger – Auroraspora macra* (CM) Biozone (Tn3c, uppermost Tournaisian), and is thus clearly younger than assemblages recorded in the present study.

Clayton *et al.* (1998) conducted a study of samples collected from the upper Cuyahoga Formation (type Wooster Member), and the overlying Logan Formation (Byer Member) from two localities near Wooster, Ohio. The assemblages reported by the authors were described as being relatively diverse, but generally similar in composition being dominated numerically by *Vallatisporites* spp. and *Spelaeotriletes* spp.

Species recorded include: *Auroraspora macra, Convolutispora major, Cyrtospora cristifera, Discernisporites micromanifestus, Knoxisporites literatus, Neoraistrickia loganensis Spelaeotriletes balteatus, S. pretiosus, Tumulispora malevkensis* and *Verrucosisporites nitidus*. These assemblages were assigned by the authors to the mid Tournaisian (late 'Tn2' – early 'Tn3') PC Biozone. The association of taxa in reported by Clayton *et al.* is closely comparable to that recorded in the present study from the upper

portion of the Price Formation at Caldwell and in the Mylan Park section, which are assigned to the PC Biozone herein.

In addition to species with a mid Tournaisian affinity, Clayton *et al.* also noted the occurrence of the taxa with stratigraphic ranges which are restricted to the latest Devonian 'Strunian', including *Retispora lepidophyta*, *Rugospora flexuosa* and *Vallatisporites hystricosus*.

Clayton *et al.* proposed three possible explanations for the anomalous occurrence of latest Devonian miospores:

1) An early first appearance of *Raistrickia clavata*, *Spelaeotriletes balteatus* and *S. pretiosus* in Ohio.
2) The late extinction of the parent plants of *Retispora lepidophyta* and associated species in Ohio.
3) Reworking of significant numbers of latest Devonian miospores into the mid-Tournaisian (PC Zone) assemblages.

As in the present investigation, Clayton *et al.* favoured the later hypothesis as the most probable explanation.

Richardson & Ausich (2004) described miospore assemblages from the Borden Formation in Kentucky. The results of this study compare closely to those reported by Coleman & Clayton (1987). Based on their results, Richardson & Ausich assigned the majority of the Borden Formation to the PC Biozone. The authors also reported sporadic occurrences of *Schopfites claviger* from the upper Nancy Member, which was interpreted as evidence for the base of the CM Biozone and an inferred Tn3c age. However, this age assignment is dubious since the specimen of *Schopfites claviger* figured by Richardson & Ausich (2004) is uncharacteristic of miospores typically assigned to this taxon. Specimens of *Lycospora pusilla* from the Floyds Knob Bed in Indiana were cited as evidence of the Pu Biozone. However, once again the assignment of the figured specimen to this taxon is perhaps questionable.

Richardson (2005) recorded two moderately diverse, moderately abundant miospore assemblages from the Lower Mississippian Coldwater Shale and Marshall Sandstone of the Michigan Basin. The assemblage described from the Coldwater Shale was considered by the Richardson to be assignable to the *Spelaeotriletes balteatus–Rugospora polyptycha* (BP) Biozone of Western Europe. Assemblages from the overlying Marshall Sandstone were considered by Richardson (2005) to be representative of the oldest Osagean *Spelaeotriletes pretiosus–Raistrickia clavata* (PC) Biozone of Western Europe. Based on the evidence Richardson placed the Kinderhookian – Osagean boundary within or between these two formations. However, miospore evidence presented in this present study suggests a slightly younger, PC Biozone age for the Coldwater Shale Formation, in north-western Ohio at least (see Chapter 9). Furthermore, the specimens of *Spelaeotriletes balteatus* and *S. pretiosus* figured but Richardson (2005, pl. 1, figs. 12 & 14) appear somewhat atypical of miospores normally assigned to these species, and are almost certainly misidentified.

Heal & Clayton (2008) reported well preserved miospore assemblages from the Hannibal Shale in Missouri. The authors described miospore assemblages which closely resembled those of the VI Miospore Biozone of Western Europe. Miospore assemblages described in that study are dominated by simple round, laevigate spores, such as: *Calamospora* spp., *Converrucosisporites vermiformis*, *Geminospora* spp., *Leiotriletes trivialis*, *Punctatisporites* spp., *Retusotriletes* spp. and *Verrucosisporites nitidus*.

Miospore assemblages reported by Heal & Clayton compare closely to assemblages previously assigned to the VI Zone in the USA, such as those described from the Sunbury Shale in Ohio (Winslow, 1962; Eames 1974) and Kentucky (Coleman & Clayton, 1987; Coleman 1991). However, they appear to differ from assemblages assigned to the VI Biozone in the present study (Mylan Park section, West Virginia) and in previous studies from Pennsylvania (Warg & Traverse 1973: Streel & Traverse, 1978). These differences appear to be related to facies and relative proximity to the land mass.

10.3. CANADA

Hacquebard (1957) conducted the first study of Mississippian miospores in Canada. The author described an abundant and taxonomically diverse miospore assemblage from lowermost Mississippian age coals of the Horton Group of Nova Scotia. The Horton Group

was differentiated into the older Horton Bluff Formation and the overlying Cheverie Formation. Two samples were collected, the lowermost 'Blue Beach' sample from a layer of coaly shale from the type section of the Horton Bluff Formation; the upper 'West Gore' sample was taken from an outcrop of fine grained sandstone and shale with interbedded layers of coal. The precise stratigraphical position of the latter sample was uncertain at the time; Hacquebard considered it to be part of the Horton Bluff Formation.

Hacquebard recorded nineteen genera and fifty species, of which four genera, thirty species and fourteen types were proposed as new. No major differences between the composition of the two miospore assemblages were recognised, species recorded include: *Grandispora echinata*, *Spinozonotriletes uncatus*, *Raistrickia clavata*, *Vallatisporites vallatus* and *V. verrucosus*. Hacquebard noted that species assignable to the genus *Punctatisporites* dominate the assemblages, in particular *P. irrasus*, which accounted for approximately one-third of the assemblage. In this regard these assemblages are closely comparable to VI assemblages described elsewhere. No precise age determination was possible at the time of the study since little palynological data with good independent biostratigraphic control was available from other Carboniferous localities. However, the occurrence of *R. clavata* as recorded by Hacquebard would be indicative of a Tn2 – Tn3 age. The author also noted the occurrence of Upper Devonian miospores in the lowermost Carboniferous.

Playford (1964) described a well preserved and taxonomically diverse miospore flora from the Horton Group (Horton Bluff and Cheverie formations) from Nova Scotia and New Brunswick. The author differentiated two distinct miospore assemblages; one from the Horton Bluff (undiff. Horton) and a second from the Chevrie Formation. Playford recognised a total of fifty –three species; twenty –one were described as new. A number of species including *Spelaeotriletes pretiosus* and *Dictyotriletes cheveriensis* were restricted from the younger Cheverie Formation. However, like Hacquebard, Playford was unable to make any precise age determinations because of the lack of comparative palynological data.

Varma (1969) documented Mississippian miospores from the Alberta Oil Shale (Horton Group equivalent) from New Brunswick. Samples were processed from the Dawson Settlement, Frederick Brook and Hiram Brook members. Varma noted that the three

members could be demarcated by the frequencies of the dominant spores and spore groups. From the Dawson Settlement Member the dominant spore groups were designated as the *Punctatisporites – Punctatasporites – Verrucosisporites* complex. The Frederick Brook Member was noted by Varma as being characterised by a highly diverse and abundant miospore flora. The dominant microfloral groups designated the *Punctatisporites – Punctatasporites – Verrucosisporites – Perotrilites* complex. From the Hiram Brook Member Varma recognised an assemblage characterised as the *Pustulatisporites – Verrucosisporites – Punctatisporites – Cyclogranisporites – Punctatasporites* complex.

Varma described 38 species from the Albert Formation, of which seven were new species and one a new combination. Twenty species from the Albert Formation assemblage had previously been reported from the Horton Group by Hacquebard (1957) and Playford (1964). Based on the palynological evidence, Varma correlated the Albert Oil Shales with Horton Group of Nova Scotia. The reported occurrence of *Raistrickia clavata* and *Spelaeotriletes pretiosus* (recorded as *Pustulatisporites pretiosus*) within the Frederick Brook and Hiram Brook Members would suggest a direct correlation with the undifferentiated Horton Group and Cheverie Formation and a mid –Tournaisian (Tn2 – Tn3) age when correlated with the well established stratigraphy in Western Europe.

McGregor (1970) reported assemblages of spores containing *Retispora lepidophyta* (recorded as *Hymenozonotriletes lepidophytus*) from the Horton Group, Nova Scotia; the Kettle Point, Bedford Shale and overlying formations, Southern Ontario, and from the Imperial Formation, Yukon Territory. The author noted that several species associated with *R. lepidophyta* in Europe (e.g. *Ancyrospora multifurcata*, *Vallatisporites pusillites* and *Tumulispora rarituberculatus*), also occur with *R. lepidophyta* in Canada. McGregor concluded that these species are probably of stratigraphical significance, even if there ranges should prove not to coincide in every instance with the ranges in Europe. The reported occurrence of these species within the Bedford Shale and Berea Sandstone formation in Ontario is closely comparable to the assemblages described from these formations in the present study. In the current investigation such assemblages are assigned to the uppermost Devonian LN Biozone.

Barss & Hacquebard (in Hacquebard 1972, fig. 4) provided a summary of the palynological data from the Horton Bluff and Cheverie Formation assigning the assemblages from these two formations to "Spore Zone G". This zone contains *Vallatisporites vallatus* and *Spelaeotriletes pretiosus*. The authors suggested that "Spore Zone G" straddles the Tournaisian – Viséan boundary.

Utting (1987a) conducted an investigation focusing upon the Albert Formation of south-eastern New Brunswick. The author reported moderately diverse miospore assemblages with preservation varying from very good to very poor. No significant qualitative taxonomic variations were discernible in the palynofloras vertically through the formation. Quantitatively, the majority of the samples were dominated by *Punctatisporites irrasus* and *Punctatisporites planus*, thus comparing closely to assemblages described by Hacquebard (1957) from the Horton Group in Nova Scotia. Utting noted that *Spelaeotriletes pretiosus* is particularly abundant in samples taken from the Hiram Brook Member. Comparison with miospore assemblages recorded from the Horton Group of Nova Scotia favours a correlation with the Horton Bluff Formation. Utting correlates the miospore assemblages to the PC Biozone indicating a Tournaisian, late Tn2 – Tn3 age.

McGregor & McCutcheon (1988) documented miospore assemblages from the volcanic Piskahegan Group of New Brunswick. Based on its relative stratigraphic position the group had generally been considered Early Carboniferous in age. However, miospore assemblages reported by McGregor & McCutcheon from the Carrow Formation (upper Piskahegan Group) would indicate most, if not all, of the group is Late Devonian (Famennian) rather than Carboniferous. Miospore assemblages are reported as being poorly to well preserved and relatively diverse; stratigraphically significant species recorded include: *Ancyrospora* sp., *Teichertospora torquata* (recorded as *Auroraspora torquata*), *Hystricosporites* spp., *Grandispora echinata*, *Retispora macroreticulata*, *R. lepidophyta* ?, *Retusotriletes crassus* and *Vallatisporites pusillites*. In the present study all of these species are recorded in abundance in assemblages assigned to the latest Devonian LN Biozone. The only notable difference between the composition of assemblages from the Piskahegan Group and those recorded in the present investigation from the USA is the absence of species including: *Cyrtospora cristifera*, *Cordylosporites fimbriatus*,

Indotriradites explanatus, *Knoxisporites literatus*, *Tumulispora* spp. and *Verrucosiporites* spp., all of which are moderately abundant in assemblages from the Eastern USA.

Utting *et al.* (1989b) conducted a detailed investigation of the type section of the Horton Group in the Windsor Basin with further investigation of sections in the Musquodoboit, Shubenacadie, Cumberland and Antigonish basins in Nova Scotia. Miospore assemblages were described from the lower and middle members of the Horton Bluff Formation and Cheverie formations.

The authors extended the Horton Group to include the Wilkie Brook Formation and recognised four informal assemblage zones and two subzones for the group in Nova Scotia (Figure 10.1):

I. *Emphanisporites rotatus – Hymenozonotriletes explanatus* Assemblage Zone from the unnamed formation (except the uppermost part).
II. *Vallatisporites vallatus* Assemblage Zone from the Horton Bluff Formation.
IIa. *Umbonatisporites abstrusus* (*U. rarisetosus) – Umbonatisporites distinctus* Assemblage Subzone from the lower member and lower part of the middle member of the Horton Bluff Formation
IIb. *Spelaeotriletes cabottii* Assemblage Subzone from the upper middle member and upper member of the Horton Bluff Formation.
III. *Spelaeotriletes pretiosus* var. *pretiosus* Assemblage Zone recognised in the Wilkie Brook and Goldstream Formations
IV. *Colatisporites decorus – Schopfites claviger* Assemblage Zone of the Wilkie Brook and Goldstream Formations.

Emphanisporites rotatus – Hymenozonotriletes explanatus Assemblage Zone

This zone is characterised by the association of species including: *Emphanisporites rotatus*, *Indotriradites explanatus*, *Knoxisporites literatus*, *Latosporites* sp., *Raistrickia corynoges*, *Retusotriletes incohatus*, *R. triangulatus*, *R. crassus*, *Tumulispora malevkensis*, *Umbonatisporites rarisetosus*, *U. distinctus* and *Verrucosisporites nitidus*.

Utting *et al.* (1989b) correlated the *E. rotatus – H. explanatus* Assemblage Zone with the Western European HD Biozone. The HD Zone is generally absent in the USA, however, previous authors (e.g. Coleman 1987 & 1991) have suggested that the HD Biozone may be represented by the upper part of the Sunbury Shale and the lower part of the Henley Bed in Kentucky. The character of Utting's (1989b) *E. rotatus – H. explanatus* Zone compares closely to that of assemblages recorded in the present study from above the Murrysville in the Mylan Park core, and, from the lower 'Pocono' Formation in Pennsylvania (Warg & Traverse, 1973; Streel & Traverse, 1978).

Vallatisporites vallatus Assemblage Zone

a. *Umbonatisporites rarisetosus – Umbonatisporites distinctus* Assemblage Subzone

Some species present in the underlying zone persist, however, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Retusotriletes crassus* and *Tumulispora malevkensis* are generally absent. Species present include: *Auroraspora macra*, *Dictyotriletes trivialis*, *Punctatisporites irrasus*, *Raistrickia clavata*, *Retusotriletes incohatus*, *R. triangulatus*, *Rugospora polyptycha*, *Spelaeotriletes cabottii*, *Spelaeotriletes echinatus*, *Umbonatisporites rarisetosus*, *U. distinctus*, *Vallatisporites vallatus*, *V. verrucosus* and *Verrucosisporites nitidus*. Rare specimens of *Spelaeotriletes pretiosus* var. *pretiosus* are also present.

The occurrence of *Umbonatisporites rarisetosus* and/ or *U. distinctus* is noted by Utting *et al.* (1989b) as being of possible value in regional correlation of Atlantic Canada, although in Western Europe *U. distinctus* has been recorded in assemblages ranging from the HD Zone through to the *Lycospora pusilla* (Pu) Zone of Viséan age (Clayton *et al.* 1978; Clayton, 1985). However, *U. distinctus* has been recorded in association with *Retispora lepidophyta* in the late Devonian rocks of the Banff Formation in Western Canada, and also those of the Bakken Formation in Saskatchewan (Utting *et al.*, 1989b). The sporadic occurrence of *Spelaeotriletes pretiosus* var. *pretiosus* together the more consistent occurrence of *Vallatisporites vallatus* and *Raistrickia clavata* throughout the zone is indicative of an age no older than the late Tn2 to early Tn3 *Spelaeotriletes pretiosus – Raistrickia clavata* PC Zone of Western Europe.

Coleman (1991 unpublished PhD thesis) correlated the *U. rarisetosus – U. distinctus* Assemblage Subzone of Utting *et al.* with the PC Biozonal assemblages she recorded in samples from the Henley Bed to the base of the Cowbell Member in Kentucky. Assemblages from the upper Price Formation of West Virginia, assigned to the PC Zone in the present investigation, are also closely comparable to those of the *U. rarisetosus – U. distinctus* Assemblage Subzone.

b. *Spelaeotriletes cabottii* Assemblage Subzone

Most of the species present in the preceding also occur in *S. cabottii* Subzone, however, *Umbonatisporites rarisetosus* and *U. distinctus* are noted by Utting *et al.* (1989b) as being absent. *Spelaeotriletes cabottii* and *Vallatisporites vallatus* are both common to abundant in the subzone. Rare specimens of *Crassispora trychera* and *Schopfites claviger* are present within the subzone. In Western Europe, the first appearance of the *S. claviger* defines the base of the *S. claviger – A. macra* CM Biozone. Utting *et al.* (1989b) suggest the occurrence of *S. claviger* is perhaps indicative of a position close to the PC/ CM biozonal boundary and an early Tn3 age.

In American sections, *Schopfites claviger* has been recorded in the basal New Providence Shale of Indiana by Coleman (1991 unpublished PhD thesis) together with questionable occurrence in the Nancy Member (Borden Formation) of Kentucky by Richardson & Ausich (2004). However, Coleman notes the absence of *Raistrickia clavata*, *Spelaeotriletes pretiosus* and *Vallatisporites vallatus*. *Schopfites claviger* has not been recorded in the present investigation suggesting all assemblages documented in this study are older than both the *Spelaeotriletes cabottii* Assemblage Subzone of Eastern Canada and the *S. claviger – A. macra* CM Biozone of Western Europe.

Spelaeotriletes pretiosus var. *pretiosus* Assemblage Zone

In qualitative terms, the *S. pretiosus* var. *pretiosus* Zone has many features in common with the underlying zone, although *Vallatisporites vallatus* is absent. Quantitatively, the spore assemblage differs from the *Vallatisporites vallatus – Spelaeotriletes cabottii* assemblage by the dominance of *S. pretiosus* var. *pretiosus*. As with the preceding biozone, Utting *et al.* (1989b) suggested a position close to the PC/ CM biozonal boundary

and a Tournaisian (mid Tn3) age. The *S. pretiosus* var. *pretiosus* Biozone is thus younger than the zones documented in the current investigation.

Colatisporites decorus – Schopfites claviger Assemblage Zone

Assemblages from this biozone contain many species present in the preceding biozone but may be distinguished quantitatively by the abundance of *Auroraspora macra*, *Crassispora trychera* and *Colatisporites decorus*. Other species present include *Schopfites claviger*, *Spelaeotriletes pretiosus* var. *bellii*, *S. windsorensis* and *Verrucosisporites nitidus*; *Spelaeotriletes cabottii* and *S. pretiosus* var. *pretiosus* are both absent. Utting *et al.* (1989b) suggested that this zone may be correlated with the late Tournaisian (Tn3) Western European CM Biozone. The absence of *Lycospora* spp. indicates that the assemblage is older than *Lycospora pusilla* (Pu) Zone. Nonetheless, the *Colatisporites decorus – Schopfites claviger* Zone is younger than any of the zones documented in the current investigation.

Martel *et al.* (1993) reported miospore assemblages from the lowermost Horton Group in its type area in the Windsor Sub-basin in Nova Scotia. The authors reported late Famennian miospores from the lowermost 7.3m (24ft.) of the Harding Brook Member, 2.5m (8.2ft.) above the top of the Meguma Group. This miospore assemblage is noted as being taxonomically diverse; however, many specimens are unidentifiable due to carbonization. Species recorded include: cf. *Apiculiretusispora cancellata*, *Cordylosporites marciae*, *Diaphanospora perplexa*, *Grandispora upensis*, cf. *Hystricosporites crystus*, ?*Hystricosporites multifurcatus*, *Indotriradites explanatus*, *Knoxisporites literatus*, *Knoxisporites concentricus* (recorded as *Lophozonotriletes concentricus*), *Punctatisporites irrasus*, *Retispora lepidophyta*, *Rugospora flexuosa*, *Vallatisporites banffensis*, *V. vallatus*, *V. verrucosus*, *Verrucosisporites nitidus* and *V. scurrus*. The authors correlated this assemblage with the uppermost Famennian *R. lepidophyta – V. nitidus* (LN) Biozone of western Europe. Based on this evidence, the lowermost Harding Brook Member of the Horton Bluff Formation appears to be time equivalent to the Bedford Shale and Berea Sandstone in Ohio, the Cloyd Conglomerate Member of the Price Formation in southern West Virginia and the interval below the Murrysville Sandstone in the subsurface of northern West Virginia.

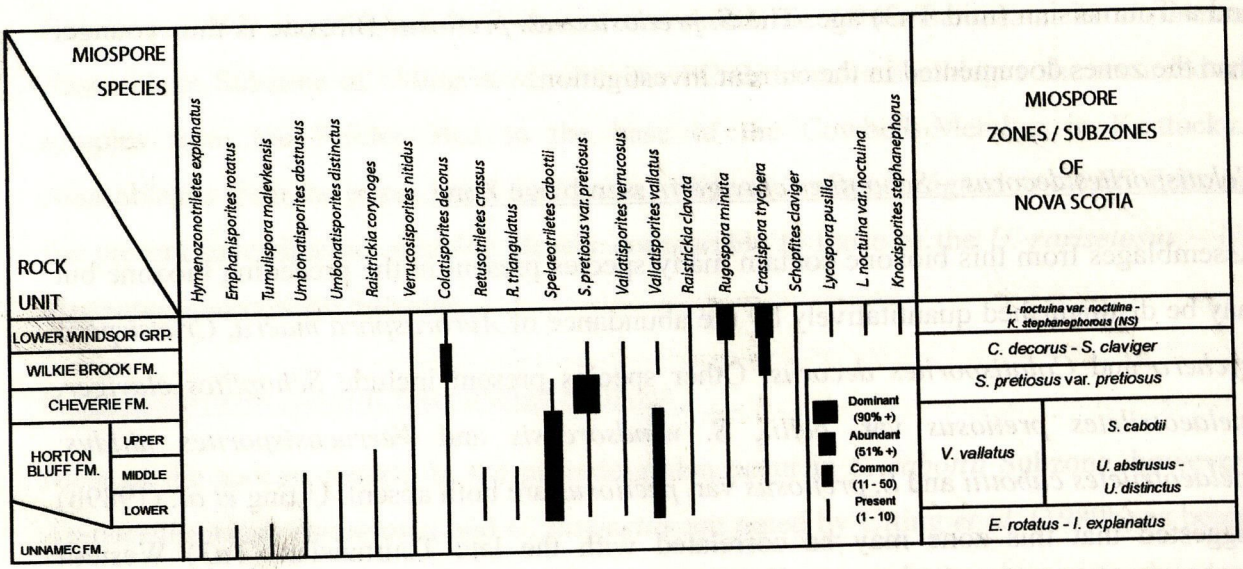


Figure 10.1 a. Vertical qualitative and quantitative distribution of stratigraphically important taxa from units in Nova and probable palynostratigraphic correlation with the spore zones of Western Europe (After Utting *et al.* 1989b).

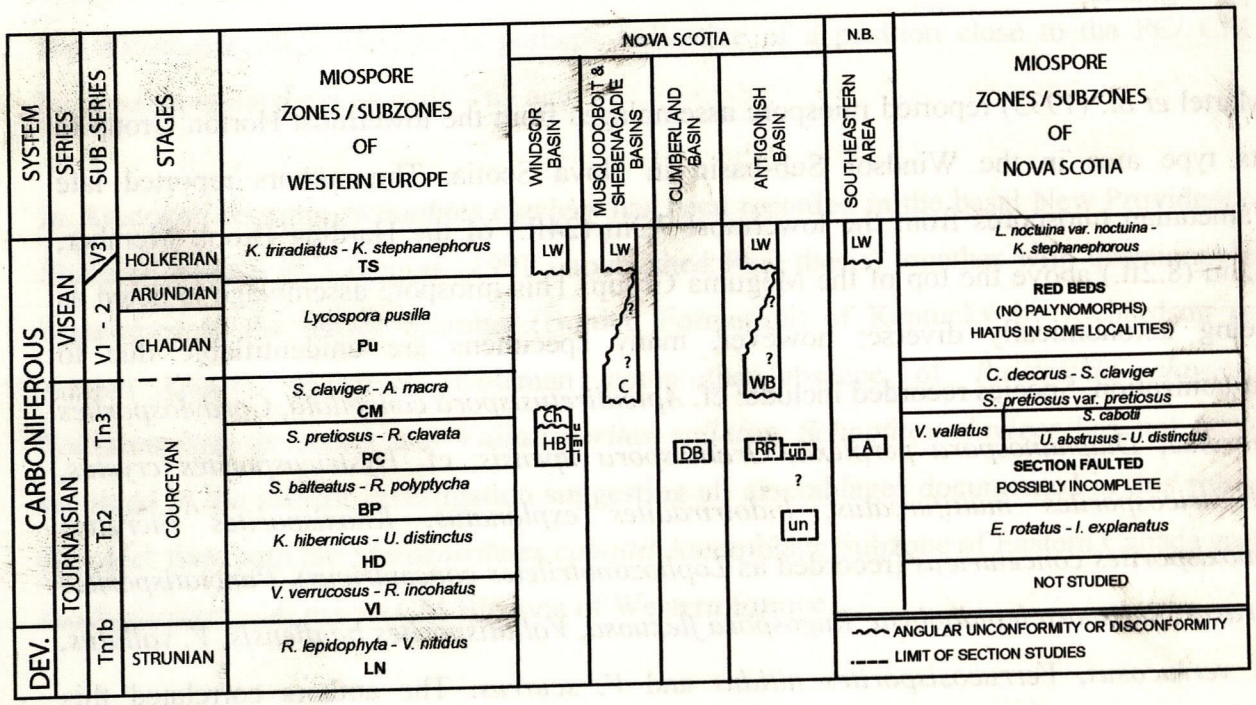


Figure 10.1 b Comparison of age determinations for formations studied from the Windsor, Musquodoboit, Snubenacadie, Cumberland and Antigonish basins of Nova Scotia, and for those of southeastern New Brunswick, Palnostratigraphic correlation made with the spore zones of Western Europe, as defined by Clayton *et al.*, 1977 & 1978, & Clayton, 1985; probable ages in terms of British and Belgian stages are given. (After Utting *et al.* 1989b).

LW= Lower Windsor Group; C = Coldstream Formation; WB = Wilkie Brook Formation; Cheverie Formation; HB = Horton Bluff Formation; DE = Diamond Brook Ormation; RR = Rights River Formation; un. = unnamed formation

Samples collected from the interval 14.5 – 53.3 metres (47.6 – 175ft.) above the top of the Meguma Group yielded miospore assemblages considered by Martel *et al.* (1993) to signify an early Tournaisian age. Miospore assemblages from these samples contained species including: *Camptotriletes verrucosus*, *Converrucosisporites parvinodosus*, *Convolutispora flexuosa*, *C. vermiformis*, *Cyclogranisporites commodus*, *Cymbosporites acutus*, *Cyrtospora cristifera*, *Endosporites micromanifestus*, *Indotriradites explanatus*, *Knoxisporites literatus*, *Leiotriletes inermis*, *Tumulispora malevkensis*, *Punctatisporites irrasus*, *Retusotriletes crassus*, *Spelaeotriletes echinatus*, *Umbonatisporites rarisetosus*, *Verrucosisporites gibberosus* and *V. papulosus*. Martel *et al.* assigned these assemblages to the *E. rotatus – I. explanatus* Zone of Tournaisian Tn2 age, and suggested a correlation with the *C. hibernicus – U. distinctus* (HD) Biozone of Western Europe.

Assemblages assigned to *E. rotatus – I. explanatus* Zone by Martel *et al.* are closely comparable to those described in the present study from the interval immediately above the Murrysville Sandstone in the subsurface of northern West Virginia, and by previous authors (e.g. Warg & Traverse, 1973; Streel & Traverse, 1978) from the lower 'Pocono' in Pennsylvania. In the current investigation, these assemblages are dominated by species including: *Cordylosporites marciae*, *Crassispora maculosa*, *Cyrtospora cristifera*, *Dictyotriletes* spp., *Emphanisporites rotatus*, *Knoxisporites literatus*, *K.* cf. *triradiatus*, *Vallatisporites vallatus* and *Verrucosisporites nitidus*. In this thesis these assemblages are found directly above assemblages assigned to the LN Biozone, and are thus assigned to the lowermost Carboniferous VI Biozone. Martel *et al* (Fig. 3) also illustrate that *E. rotatus – I. explanatus* Zone assemblages directly overlie those assigned to the LN Biozone. For this reason the current author prefers to correlate the *E. rotatus – I. explanatus* Zone of Eastern Canada with the VI zone of Western Europe, rather than the HD Zone, which has yet to be recognised in the USA.

Playford & McGregor (1993) conducted a palynological study of the Bakken Formation from the Williston Basin, in southern Saskatchewan, Canada. They reported diverse and well preserved assemblages of miospores and acritarchs. Miospore taxa reported by Playford & McGregor include:

Cordylosporites marciae, *Cyrtospora cristifera*, *Emphanisporites* spp., *Grandispora echinata*, *G. saurota*, *Indotriradites explanatus*, *Knoxisporites concentricus*, *Punctatisporites* spp., *Pustulatisporites dolbii*, *Retispora lepidophyta*, *Spelaeotriletes crustatus*, *Tumulispora rarituberculata* (*T. triangulatus*), *Vallatisporites* spp. and *Verrucosisporites nitidus*. Megaspores assigned to the genera *Ancyrospora* spp. and *Hystricosporites* spp. are also reported in to occur in association with the miospore taxa listed above.

The miospore assemblages described by Playford & McGregor from the Lower Shale and Middle Sandstone members of the Bakken Formation can be assigned to the uppermost Devonian LN Biozone based on the occurrence of *R. lepidophyta* and *V. nitidus*. This stratigraphical interval therefore appears to correlate with the Bedford Shale and Berea Sandstone of Ohio (and their lateral equivalents in adjacent states). Miospore assemblages reported from the Upper Shale Member of the Bakken Formation also would appear to belong to the LN Zone. However, since the upper shale has been previously attributed to the early Carboniferous (Tournaisian) *Siphonodella crenulata* Conodont Zone, the occurrence of *R. lepidophyta* at this level is somewhat anomalous. Playford & McGregor suggest two possible explanations for this discrepancy: either the specimens of *R. lepidophyta* present in the Upper Bakken are reworked, or they represent genuine *in situ* occurrences. The topic of reworking vs. in situ occurrence is a topic discussed in detail in Chapter 9 of the present report.

CHAPTER 11

GEOLOGICAL IMPLICATIONS

11.1 LATE DEVONIAN - FAMENNIAN

The late Devonian in eastern USA commenced with a period characterised by offshore, basinal deposition. Deposits of black shale from this time period (Ohio Shale and Chattanooga Shale) contain miospore assemblages of relatively low diversity and abundance. These assemblages are dominated by simple, rounded, laevigate taxa. The kerogen content of such samples is typified by an abundance of AOM and prasinophyte algae. Based on the low abundance miospores and the absence of phytoclasts a highly distal, marine depositional setting is indicated. Miospore assemblages for this interval are most likely assignable to either the LL, LE or LN biozones, but certainly no older than the VH Biozone based on the occurrence of *Vallatisporites hystricosus*. However, the low diversity and abundance of miospores from this interval precludes more precise age determination.

Miospore assemblages recovered from the Bedford Shale/ Berea Sandstone in Ohio, the Three Licks Bed and Bedford Shale in Kentucky, and the Cloyd Conglomerate and Murrysville Sandstone in West Virginia are all assigned to the LN Biozone and are thus interpreted to be of latest Devonian (Famennian age). LN Biozone assemblages reported herein are typically well preserved, compositionally diverse and consistent between the various sections investigated. Independent biostratigraphic evidence including conodonts from the Bedford Shale (Hass, 1947) and late Devonian brachiopods from the Cloyd Conglomerate Member (Carter & Kammer, 1990) confirm this age assignment.

Sedimentation during this time period was characterised primarily by nearshore siliciclastic deposition as typified by the Bedford Shale and Berea Sandstone formations in Ohio and Kentucky, the Cussewago/ Murrysville in Pennsylvania and northern West Virginia, and the Cloyd Conglomerate in southern West Virginia. Palynofacies data indicates that sedimentation in Ohio and Kentucky occurred in a highly proximal marine setting due to the mixture of both terrestrial (phytoclasts, miospores, megaspores) and marine kerogen (acritarchs, prasinophyte algae, scolecodonts, AOM). Penecontemporaneous deposition in Pennsylvania and West Virginia occurred in a more proximal environmental with

occasional marine incursions. This environmental interpretation is consistent with palaeogeographic reconstructions of eastern USA for latest Devonian time (Figure 11.1).

11.2 LOWER MISSISSIPPIAN - KINDERHOOKIAN

In terms of miospore biostratigraphy, the base of the Carboniferous System (Mississippian Subsystem) coincides with the last in-situ occurrence of the following miospore and megaspore taxa: *Ancyrospora* spp., *Hystricosporites* spp., *Retispora lepidophyta*, *Rugospora flexuosa*, *R. radiata* and *Vallatisporites hystricosus*. In the present investigation all of these species were recorded with consistency from lithostratigraphic units which are exclusively and unequivocally Mississippian in age. Quantitative analysis of such samples has revealed that these taxa are considerably less abundant above the inferred position of the Devonian/ Carboniferous boundary and thus their anomalous distribution is considered to be the result of reworking (Chapter 9).

The Sunbury Shale Formation of Kentucky and Ohio is considered to be lowermost Mississippian in age based on its conodont (Haas, 1947; De Witt 1974) and miospore (Coleman & Clayton, 1987) content, with its base corresponding to the approximate position of the Devonian/ Carboniferous boundary. Deposition of this unit is generally considered to have occurred in an offshore, deep marine setting, similar to that of the Ohio Shale and its equivalents. The Riddlesburg Shale Member of the Price Formation in West Virginia is thought to be a near-shore equivalent of the Sunbury Shale (Bjerstedt & Kammer, 1986; Bjerstedt & Kammer, 1987; Matchen & Kammer, 1994). Palynofacies analysis of this unit would confirm these interpretations. Samples of the Sunbury Shale are dominated by AOM but are devoid of miospores. The kerogen content of the Riddlesburg Shale at Caldwell indicates a greater terrestrial influence upon its deposition.

Coleman & Clayton (1987) described low diversity assemblages dominated by simple, round, laevigate, acamerate taxa from the Sunbury Shale at Morehead, Kentucky. The authors assigned these assemblages to the lowermost Carboniferous VI Biozone. Similarly, Heal & Clayton (2008) assigned assemblages of simple rounded miospore taxa from the Hannibal Shale Formation of Missouri to the VI Zone. In both studies the restricted composition of assemblages was considered to represent 'survival taxa' following the end Hangenberg Extinction Event. However, in the present study compositionally diverse

miospore assemblages assigned to this zone have been recovered from more proximal settings in West Virginia and Pennsylvania. It is thus inferred that the low diversity of VI Zone assemblages reported by Coleman & Clayton (1987) and Heal & Clayton (2008) reflects sedimentary sorting and is related to the distal depositional setting of these localities, rather than due to the extinction of parent plant taxa in the region. The possible existence of two facies dependent variants of this biozone is consistent with the palaeogeographic reconstruction of eastern USA for the lowermost Mississippian (Figure 11.2).

11.3 MID- KINDERHOOKIAN

The European HD and BP biozones are generally absent in the USA. Coleman & Clayton (1987) concluded that the absence of these zones in the USA was the result of sediment starvation and that these zones were represented by a condensed interval at the base of the Henley Bed. Leslie *et al.* (1996) and Richardson & Ausich (2004) estimated that this condensed interval would represent a period of approximately 17 million years, spanning the entire Kinderhookian and part of the Osagean. However, neither of these zones have been demonstrated to occur elsewhere in the USA. Richardson (2006) tentatively assigned miospore assemblages from the Coldwater Shale of Michigan to the BP Zone. However, as noted elsewhere in this thesis (Chapter 10) this assignment is suspect based upon the specimen of *Spelaeotriletes balteatus* figured by Richardson (2006, p. 69, pl. I, fig. 12). Furthermore miospore assemblages from the Coldwater Shale Formation described in the present study contain abundant specimens of *Spelaeotriletes pretiosus*, together with associated taxa such as *Raistrickia clavata*, *Neoraistrickia loganensis* and *Mooreisporites streelii*. These assemblages are assigned to the PC Biozone.

In Western Europe, the range tops of the HD Zone index taxa, *Cristatisporites hibernicus* and *Umbonatisporites distinctus*, correspond with the CM Zone (Higgs *et al.*, 1988). However, both of these taxa are generally absent in PC Zone assemblages in the USA. Thus the absence of the HD Zone in the USA may relate to the absence of the parent plants of the zonal taxa in the region rather than sediment starvation. In the present study, samples collected from more proximal sections such as Caldwell, Mylan Park and Warrior's Path lack assemblages assignable to either the BP or PC zone. Furthermore,

neither *Cristatisporites hibernicus* nor *Umbonatisporites distinctus* are recorded in any of these samples. Rare specimens of *Spelaeotriletes balteatus* are recorded but only occur in assemblages also containing *S. pretiosus*. In the Eastern Canadian miospore zonation (Figure 10.1a & b), both the HD and BP zones are absent. Instead, assemblages containing *Spelaeotriletes pretiosus* directly overlie assemblages dominated by *Dictyotriletes trivialis* and *Indotriradites explanatus*. This corresponds closely to observations made herein, where such assemblages are considered to represent nearshore equivalents of the VI Zone (11.2).

11.4 KINDERHOOKIAN - OSAGEAN

PC Zone assemblages are recorded from the upper Rockwell and Burgoon Sandstone Formations (Pennsylvania), the upper Price Formation (West Virginia) and the Coldwater Shale Formation (Ohio). Previous authors have described similar PC Zone assemblages from the Borden Formation in Kentucky (Coleman & Clayton, 1987) and the Black Hand Sandstone in Ohio (Clayton *et al.*, 1998). Matchen & Kammer (2006) and Kammer & Matchen (2008) proposed that the Burgoon Sandstone, the Big Injun Sandstone and the Black Hand Sandstone represent laterally equivalent sandstone bodies deposited during a glacially induced regression spanning the Kinderhookian/ Osagean boundary. Miospore evidence presented herein confirms that these units are indeed time equivalent and where available, independent biostratigraphic evidence indicates a Kinderhookian/ Osagean age for PC Biozone in the USA.

Palynofacies analysis of the upper Price Formation (including the 'Big Injun') in West Virginia and the Rockwell/ Burgoon Sandstone formations in Pennsylvania indicates terrestrial or highly proximal marine deposition during this time period. Samples from this interval are dominated by terrestrially derived kerogen including phytoclasts and miospores, and are devoid of marine kerogen and palynomorphs. These data are in concurrence with the palaeogeographic reconstruction of eastern USA for the Kinderhookian/ Osagean interval (Figure 11.3). The abundance of reworked uppermost Devonian spores at this level is consistent with the significant down-cutting which would have presumably occurred in response to a marine regression at this time.

Recent work focusing on well dated sections in southern Ireland (Brittain & Higgs, 2009) suggest that the PC Zone may be subdivided based on the occurrence of *Spelaeotriletes galearis* Brittain & Higgs, which first appears in the upper part of the zone. This species is recorded in the present study but its occurrence is sporadic. However, the first appearance of *Cordylosporites shawneensis* sp. nov. and *Anapiculatisporites fundiensis* within the upper PC Zone in West Virginia may be of stratigraphic value in the future.

1 * Von Almen (1970) - Woodford Shale Formation, central Oklahoma

2 Bedford Shale Formation - Williams County core, Williams Co., OH

3 * Eames (1974) Bedford Shale & Berea Sandstone formations, Lorain Co. & Cuyhoga Co., OH

4 * Warg & Traverse (1974) - Catskill Fm, Centre Co., PA

5 * Streel & Traverse (1978) - Catskill Fm, Altoona, Blair Co., PA

6 sub- Murrysville interval, Mylan Park, Monongalia Co, WV.

7 Bedford Shale & Berea Sandstone formations - Big Walnut Creek, Delaware Co, OH

8 Bedford Shale & Berea Sandstone formations - Three Locks Quarry, Ross Co, OH

9 a Three Lick Bed - Morehead, Rowan Co. KY

b* Coleman & Clayton (1987) - Bedford Shale Formation - Morehead, Rowan Co. KY

10 Three Lick Bed - Clay City Quarry, Powell Co., KY

11 Cloyd Conglomerate Member (Price Fm) - Caldwell, Greenbrier Co., WV

- Sample locality
- Acritarchs/ Tasmanites
- Plant fossils
- Black Shale
- Siltstone
- Sandstone
- Statelines
- Coastline
- Palaeo-current
- Tectonic highs
  - W.V.D - West Virginia Dome
  - C.A. - Cincinnati Arch
- Acadian Highlands

C.C.C - Cabin Creek Channel

G.F.C. - Gay Fink Channel

C.I. - Cincinnatia

B.B.D. - Bedford- Berea Delta

V.C.D. - Virginia - Carolina Delta

C.M.D - Cussewago/Murrysville Delta

Figure 11.1 Palaeogeographic reconstruction of Eastern and midcontinental USA for latest Devonian time. Sample localities for LN Biozonal assemblages. Palaeo-coastlines after Ron Blakey & Pepper *et al.* (1954). Palaeo-current data after Matchen & Kammer (2006)



1 * Von Almen (1970) - Woodford Shale Formation, central Oklahoma

2 * Heal & Clayton (2008) - Hannibal Shale Fm., Missouri

3 Bedford Shale Formation - Williams County core, Williams Co., OH

4 * Eames (1974) Bedford Shale & Berea Sandstone formations, Cuyahoga Co., OH

5 * Warg & Traverse (1973) - 'Pocono' Fm., Centre Co., PA

6 * Streel & Traverse (1978) - 'Pocono' Fm., Altoona, Blair Co., PA

7 Riddlesburg Shale, Mylan Park, Monongalia Co., WV.

8 Sunbury Shale Member (Price Fm) - Caldwell, Greenbrier Co., WV

9 * Coleman & Clayton (1987) - Bedford Shale Formation - Morehead, Rowan Co., KY

Sample locality

Acritarchs/ Tasmanites

Plant fossils

Black Shale

Siltstone

Sandstone

Statelines

Coastline

Palaeo-current

Tectonic highs

Acadian Highlands

C.C.C - Cabin Creek Channel

C.I. - Cincinnatia

G.F.C. - Gay Fink Channel

V.C.D. - Virginia - Carolina Delta

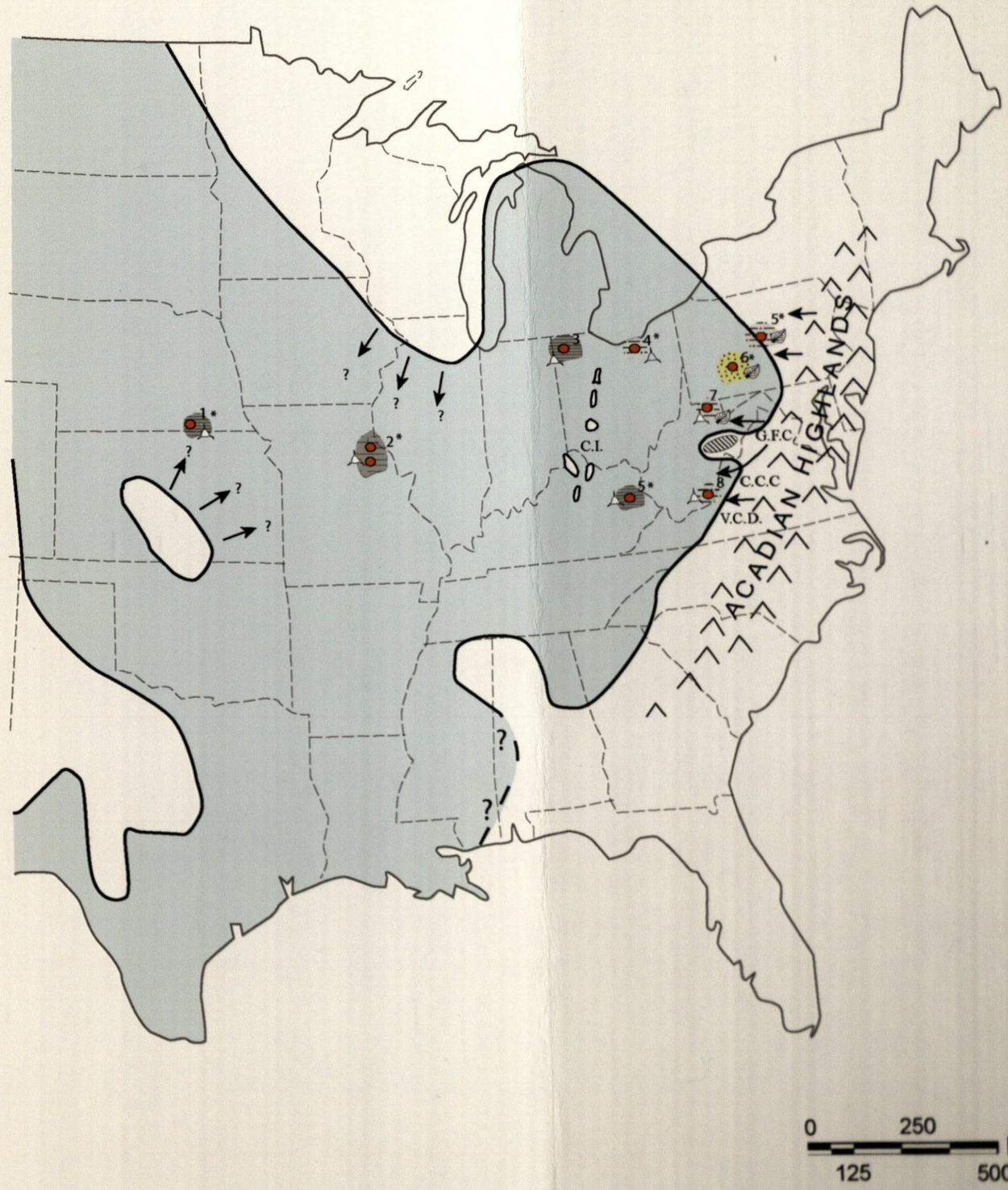


Figure 11.2. Palaeogeographic reconstruction of Eastern and midcontinental USA for earliest Mississippian time. Sample localities for VI Biozonal assemblages. Palaeo-coastlines after Kammer & Matchen (2006).

1 Coldwater Shale Fm. - Williams County core, Williams Co., OH

2 * Black Hand Sandstone (Cuyahoga Fm.), Wooster, Wayne Co., OH

3 * Coleman & Clayton (1987) - Borden Formation - Morehead, Rowan Co. KY

4 a upper Price Formation - Caldwell, Greenbrier Co., OH

b upper Price Formation - Alta, Greenbrier Co., OH

5 upper Price Fm. (incl. Big Injun Sst.), Mylan Park, Monongalia Co, WV.

6 Rockwell & Burgoon Sst. formations, Cramer, Indiana Co., PA

7 Rockwell & Burgoon Sst. formations, Altoona, Blair Co., PA

8 Rockwell & Burgoon Sst. formations, Warrior's Path, Bedford Co., PA

Sample locality

Acritarchs/ Tasmanites

Plant fossils

Black Shale

Siltstone

Sandstone

Statelines

Coastline

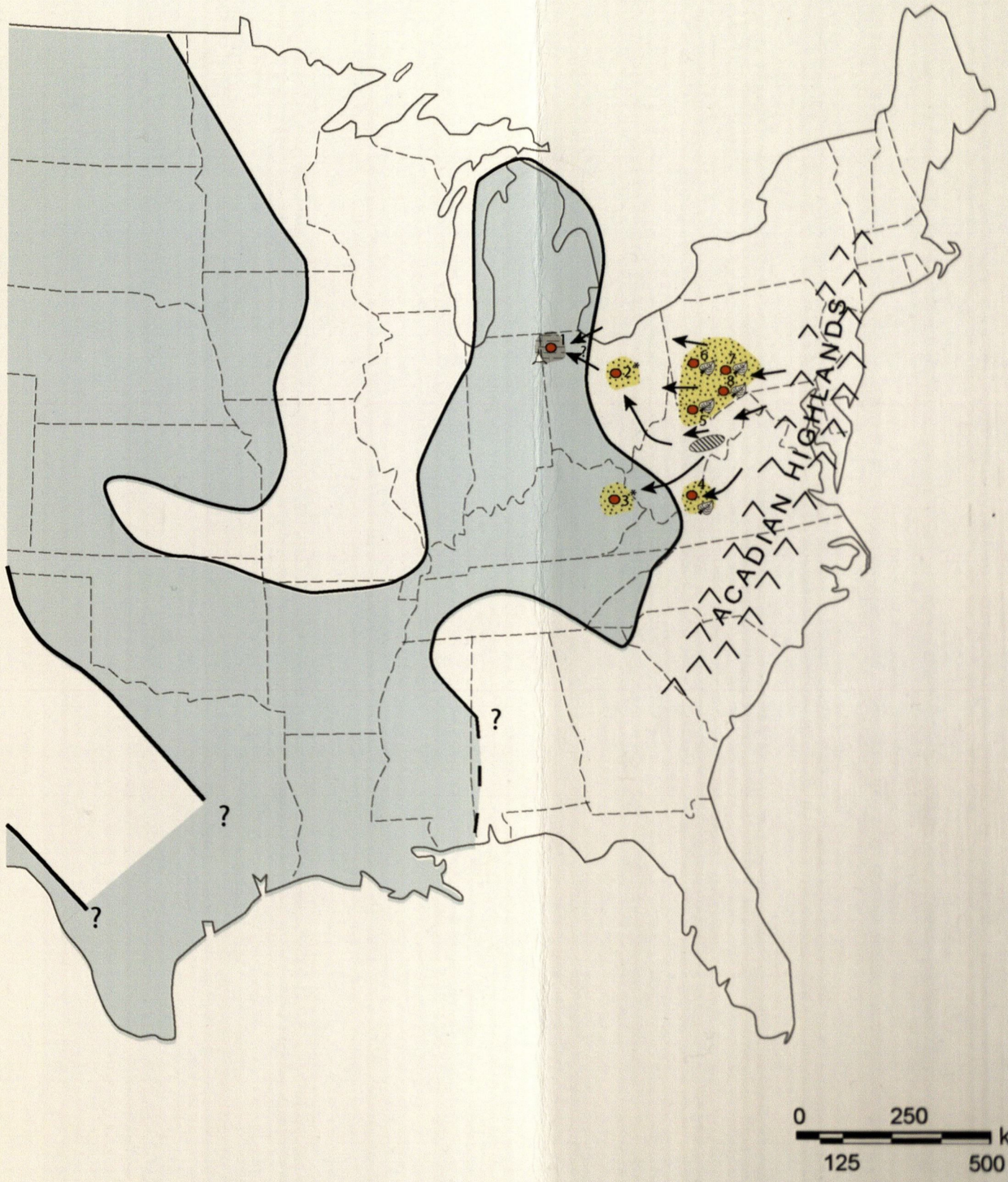
Palaeo-current

Tectonic highs

Acadian Highlands

Figure 11.3. Palaeogeographic reconstruction of Eastern and midcontinental USA for earliest Mississippian time. Sample localities for VI Biozonal assemblages. Palaeo-coastlines after Kammer & Matchen (2006).

TOURNAISIAN/ OSAGEAN - PRICE/ BURGOON/ BIG-INJUN/ BORDEN/ BLACK HAND - PC ZONAL ASSEMBLAGES



CHAPTER 12

CONCLUSIONS

1) Well–preserved miospore assemblages were recovered from the uppermost Devonian and lower Mississippian strata of four states in the Eastern USA: Ohio, Kentucky, West Virginia and Pennsylvania. The taxonomic diversity of assemblages was variable, but overall, rich assemblages were recorded in the study.

Palynostratigraphic analysis has facilitated the recognition of three Western European miospore biozones:

a. *Retispora lepidophyta – Verrucosisporites nitidus* (LN) Zone.
b. *Vallatisporites verrucosus – Retusotriletes incohatus* (VI) Zone.
c. *Spelaeotriletes pretiosus – Raistrickia clavata* (PC) Zone.

The *Cristatisporites hibernicus – Umbonatisporites distinctus* (HD) and *Spelaeotriletes balteatus – Rugospora polptycha* (BP) zones of Western Europe were not recognised in the present investigation, perhaps either due to palaeobiogeographic control or the presence of a previously unrecognised regional unconformity.

2) Miospore evidence suggests the correlation and approximate time-equivalency of the following lithostratigraphic units:

a) Bedford Shale/ Berea Sandstone (Ohio & Kentucky), Three Lick Bed (Kentucky), Cloyd Conglomerate (southern West Virginia), and the sub-Murrysville Sandstone interval (sub-surface northern West Virginia).
b) Sunbury Shale Formation (Ohio & Kentucky) – Sunbury/ Riddlesburg Shale members (West Virginia).
c) Coldwater Shale Formation (Ohio), upper Price Formation (West Virginia), and the uppermost Rockwell/ Burgoon Sandstone (Pennsylvania).

Based on miospore evidence presented in previous studies, the latter units are also considered to be time-equivalent to the Black Hand Sandstone of central Ohio and the Borden Formation of Kentucky. Independent biostratigraphic evidence would indicate all of these units span the Kinderhookian/ Osagean boundary.

3) Qualitative assessment of miospore assemblages indicates that the Devonian/ Carboniferous boundary closely approximates the base of the Sunbury Shale Formation in Ohio and Kentucky, and the base of the Sunbury/ Riddlesburg Shale members in West Virginia. Such a placement is consistent with all available independent biostratigraphic evidence from the Sunbury Shale and underlying units.

4) Considerable quantities of upper Devonian miospores are present within the lower Mississippian strata investigated. Quantitative analysis of miospore assemblages from above and below the inferred position of the Devonian/ Mississippian boundary would suggest these spores are reworked.

5) Palynofacies data suggests the following:

a) The Ohio Shale was deposited in a distal, deep water, anoxic setting.
b) The Bedford Shale/ Berea Sandstone were deposited in a proximal marine environment. The penecontemporaneous Three Lick Bed was most likely deposited by turbidity currents in a distal marine setting.
c) The Sunbury Shale Formation was deposited in a distal, anoxic marine setting in Ohio and Kentucky. Deposition of the Sunbury Shale/ Riddlesburg Shale members in West Virginia occurred in a more proximal marine setting.
d) The Price Formation of West Virginia and the Rockwell/ Burgoon Sandstone formations of Pennsylvania were deposited in fluvial terrestrial environments. The Coldwater Shale Formation of northwest Ohio is consistent with deposition in a proximal marine setting.

NP

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PLATE 1

Fig. 1 *Calamospora parva* Guennel 1958

TL3 (1) TCD56755 – **O35**

Fig. 2 *Calamospora pallida* (Loose) Schopf, Wilson & Bentall 1944

TL1 (XI) TCD56753 – **P54**

Fig. 3 *Calamospora microrugosa* (Ibrahim) Schopf, Wilson & Bentall 1944

TL2 (3) TCD56754 – **E40-1**

Fig. 4 *Calamospora nigrata* (Naumova) Allen 1965.

MP5 no ox. (A) TCD 59505 – **F67-1**

Fig. 5- 6 *Punctatisporites minutus* Kosanke 1950

5. MP7 no ox. (X) TCD 59507 **N40-1**

6. WC9 no ox. (A) TCD59631 – **W62- 1**

Fig. 7 *Calamospora liquida* Kosanke 1950

MP10 no ox. (B) TCD 59510 – **S30**

Fig. 8 *Calamospora perrugosa* (Loose) Schopf,

MP9 no ox. (B) TCD 59509 **C64-1**

Fig. 9- 10 *Punctatisporites planus* Hacquebard 1957

MP15 30min ox. (A) TCD 59515 – **S34-3**

Figs. 11 *Punctatisporites irrasus* Hacquebard 1957

MP7 no ox. (X) TCD 59507 – **D47-2**

Figs. 12 & 13 *Retusotriletes crassus* Clayton, Johnston, Sevastopulo & Smith 1980

12. WC24 (C) TCD59645 – **T54-4**

13. MP27 30 min. ox. (A) TCD 59527 – **K62**

Figs. 14 & 15 *Retusotriletes incohatus* Sullivan 1964

14. TL1 (XI) TCD56753 – **U65-3**

15. MP49 no ox. (A) TCD 59549 – **F66-2**

Fig. 16 *Retusotriletes famenensis* Naumova 1953

- MP10 no ox. (A) TCD59510 – **C34**

Figs. 17 - 19 *Retusotriletes leptocentrum* (Higgs) Higgs, Clayton & Keegan 1988

17. MP10 no ox. (A) TCD 59510 – **R48-4**

18. MP10 15 min. ox. (A) TCD 59510 – **H36-1**

19. MP10 15 min. ox. (A) TCD 59510 – **X68-2**

Fig. 20 & 21 *Retusotriletes triangulatus* (Streel) Streel 1967

20. MP49 no ox (A) TCD 59549 – **S51**

21. MP10 no ox (B) TCD 59510 – **M57-3**

Figs. 22 & 23 *Retusotriletes phillipsii* Clendening, Eames & Wood 1980

22. TL8 (0) TL8 (0) TCD59616 – **E43**

23. TL3(1) TCD56755 – **S57-4**

Plate 1

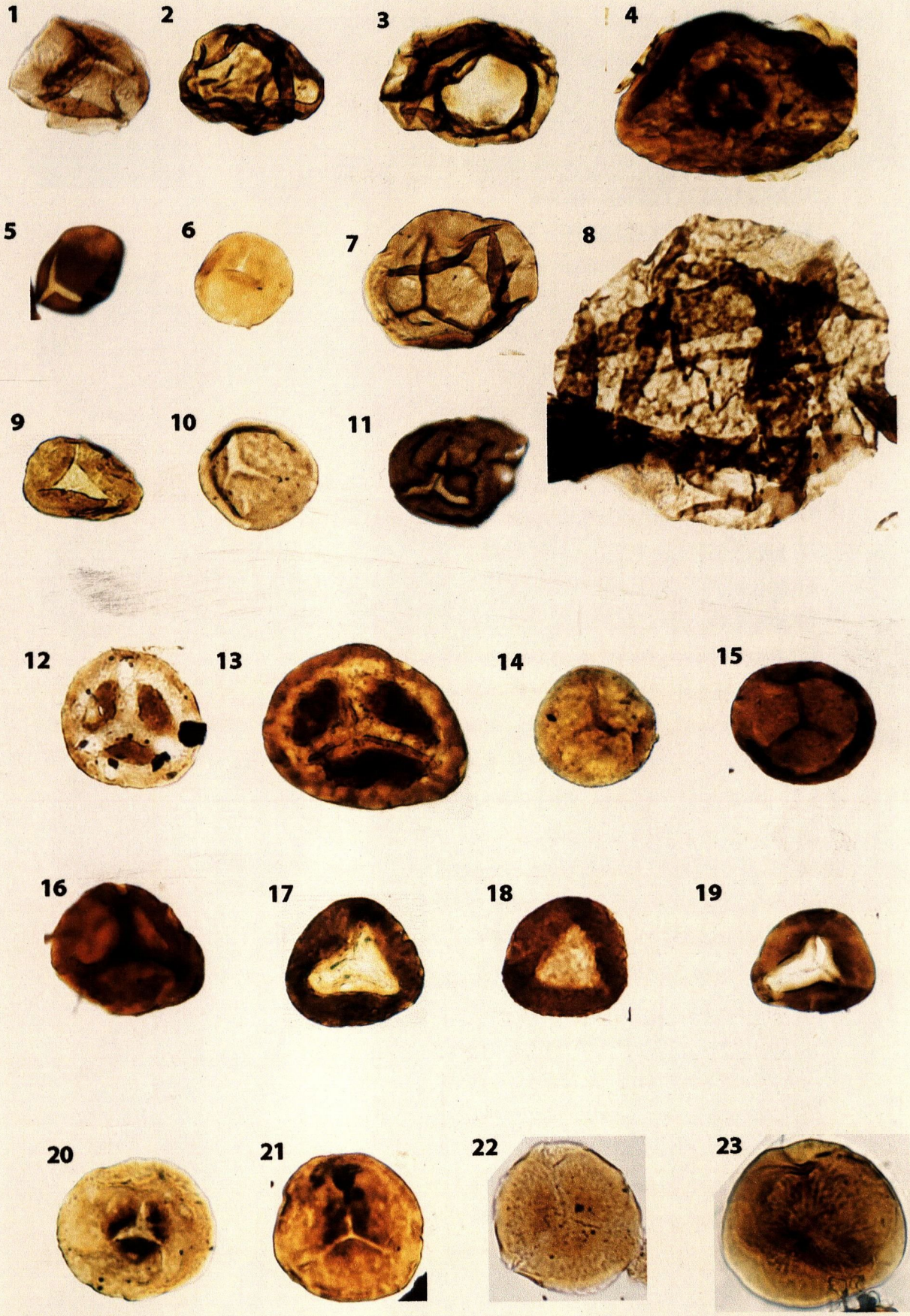


PLATE 2

Figs. 1 - 3 *Neoraistrickia loganensis* (Winslow) Playford & Melo (in press)

1. WC24 (C) TCD59645 – **Q55**
2. WC24 (B) TCD59645 – **L61-2**
3. WC24 (C) TCD59645 – **K37-3**

Figs. 4 & 8 *Mooreisporites streelii* Clayton, Manger & Owens 1998

4. WC24 (A) TCD59645 – **Q34-1**
8. WC24 no ox (B) TCD59645 – **V36-2**

Figs. 5 - 7 *Pustulatisporites dolbii* Higgs, Clayton & Keegan 1988

5. NP43 no ox (A) TCD 59543 –**T46-2**
6. TL8 (0) TL8 (0) TCD59616 – **Y38-3**
7. WC 9 no ox (A) TCD59631 –**T33-4**

Figs. 9 - 14 *Umbonatisporites rarisetosus* (Kedo) Higgs 1996

9. MP10 no ox (A) TCD 59510 – **N43-4**
10. MP32 1 hour ox. (B) TCD 59532 – **E62-3**
11. MP28 no ox (B) TCD 59528 – **Q28-2**
12. MP28 no ox (A) TCD 59528 – **B44-1**
13. MP28 no ox (A) TCD 59528 – **B49**
14. MP28 no ox (A) TCD 59528 – **B49** *Detail of ornament* x1000

Figs. 15 - 17 *Raistrickia macrura* (Luber) Dolby & Neves 1970

15. MP49 45 min ox (B) TCD 59549 – **N39-4**
16. MP49 45 min ox (B) TCD 59549 – **U46-2**
17. MP49 45 min ox (B) TCD 59549 – **U48-2**

Figs. 18 & 19 *Raistrickia minor* (Kedo) Neves & Dolby 1967

18. MP12 30min. ox. (C) TCD 59512 – **E28-1**
19. MP34 no ox. (A) TCD 59534 – **E55**

Figs. 20 - 22 *Raistrickia clavata* Hacquebard emend. Playford 1964

20. WC24 no ox. (C) TCD59645 – **E65-4**
21. MP27 no ox. (A) TCD 59527 – **K48-1**
22. MP27 no ox. (A) TCD 59527 – **K48-1** x1000

Fig. 23 - 27 *Anapiculatisporites fundiensis* Utting 1987

23. NP53 45min ox (D) TCD 59553 – **W51-2**
24. NP53 45min ox (D) TCD 59553 – **V48-4**
25. MP53 45min ox (D) TCD 59553 – **G42-1**
26. MP53 45min ox (D) TCD 59553 – **Q53-3**
27. MP53 45min ox (D) TCD 59553 –**W51-1**

Plate 2

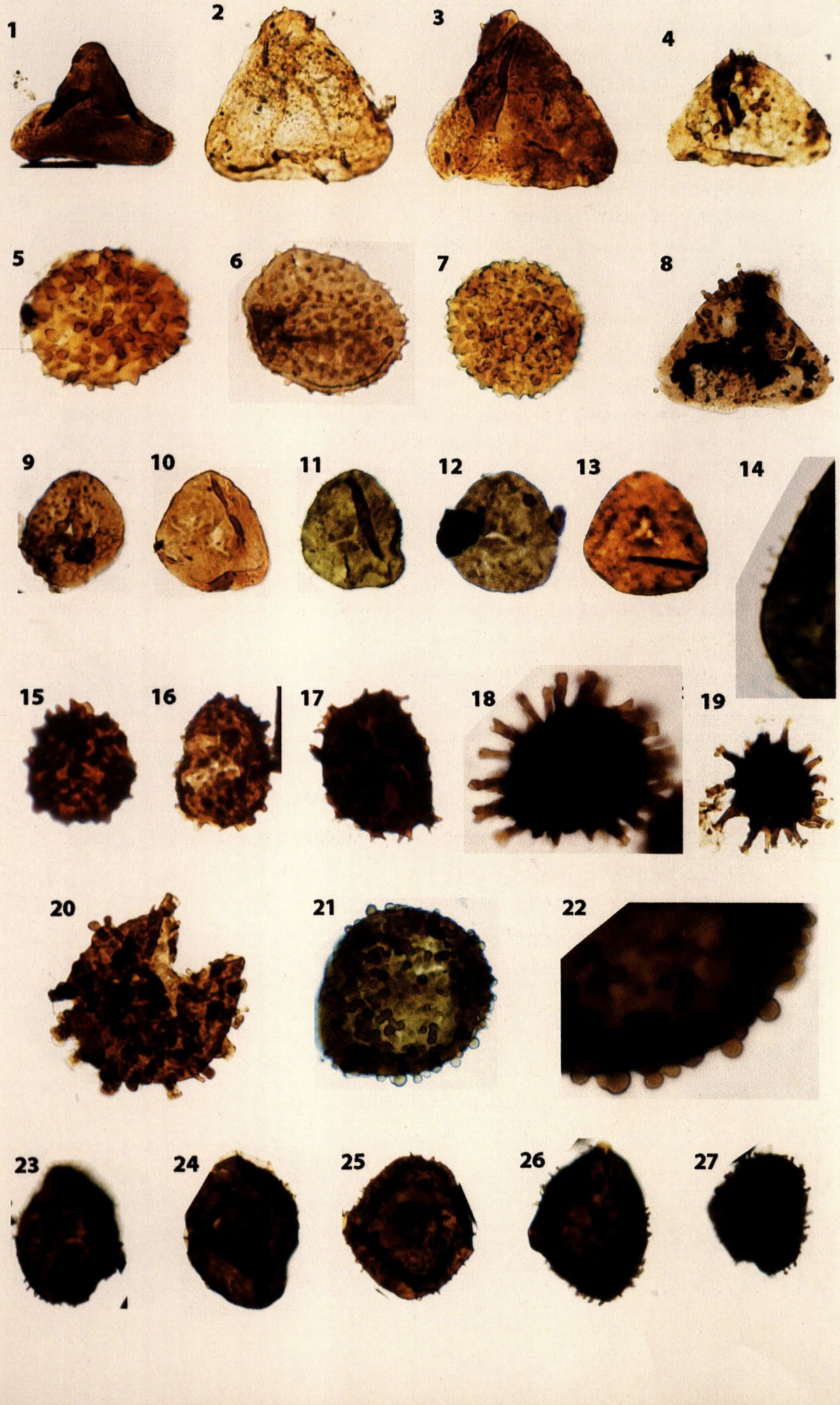


PLATE 3

Figs. 1 - 4 *Verrucosisporites nitidus* (Naumova) Playford 1964

1. MP11 no ox (X) TCD 59511 – **H38-1**
2. MP28 no ox (B) TCD 59528 – **F51-4**
3. MP14 no ox (A) TCD 59514 – **Q32-2**
4. SUN1 (Boiled) TCD56751 – **H73-3**

Fig. 5 *Secarisporites* sp. A *sensu* Higgs, Clayton & Keegan 1988

TL1 (XI) TCD56753 – **T72-3**

Fig. 6 *Verrucosisporites oppresus* Higgs *et al.* 1988

MP28 no ox (C) TCD 59528 – **U44**

Fig. 7 - 9 *Convolutispora caliginosa* Clayton & Keegan *in* Clayton *et al.* 1982

7. MP15 30 min. ox. (B) TCD 59515 – **M31-4**
8. MP15 30 min. ox. (B) TCD 59515 – **C37**
9. MP15 30 min. ox. (B) TCD 59515 – **D55-3**

Figs. 10 - 12 *Convolutispora major* (Kedo) Turnau 1978

10. MP15 45 min. ox. (B) TCD 59515 – **U44-4**
11. MP15 45 min. ox. (A) TCD 59515 – **E48-3**
12. MP15 30 min. ox. (B) TCD 59515 – **U59-1**

Figs. 13 – 15 *Convolutispora vermiformis* Hughes & Playford 1961

13. MP15 30 min. ox. (B) TCD 59515 – **V65-2**
14. MP9 30 no ox. (A) TCD 59509 – **G60**
15. MP15 30 min. ox. (B) TCD 59515 – **X61**

Figs. 16 – 18 *Gorgonispora crassa* (Winslow) Higgs, Clayton & Keegan 1988

16. MP10 no ox. (B) TCD 59510 – **S48**
17. MP12 30 min. ox. (C) TCD 59512 – **J34-2**
18. MP12 30 min. ox. (C) TCD 59512 – **A36-2**

Figs. 19 – 22 *Bascaudispora submarginatus* (Playford) Higgs, Clayton & Keegan 1988

19. MP10 no ox (A) TCD 59510 –**C36-4**
20. MP10 no ox (B) TCD 59510 – **T36-4**
21. MP10 no ox (B) TCD 59510 –**D44-2**
22. MP10 no ox (B) TCD 59510 – **P55**

Plate 3

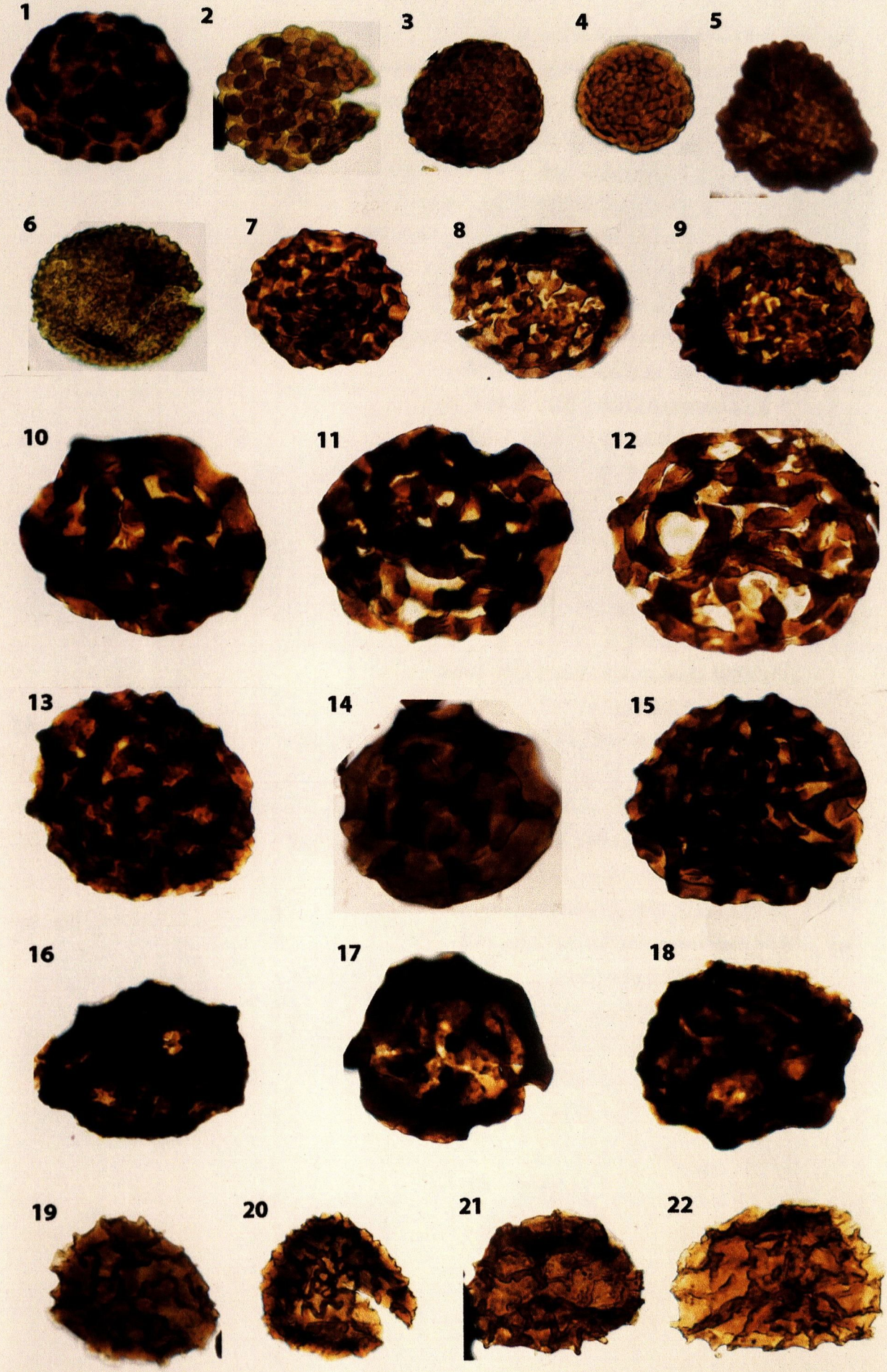


PLATE 4

Figs. 1- 3, 5- 6 *Cordylosporites shawneei* sp. nov.

1. MP54 no ox. (B) TCD 59554 – **G46-3** - *Paratype*
2. MP54 1 hour ox. (A) TCD 59554 – **H43-3** – *Type specimen*
3. MP54 no ox. (A)TCD 59554 – **Y39-1** - *Paratype*
5. MP54 no ox (A) TCD 59554 – **Y39-1** - *Paratype*
6. MP54 no ox (B) TCD 59554 – **T37** - *Paratype*

Figs. 4 & 7 *Dictyotriletes trivialis* Naumova in litt. *in* Kedo 1963.

4. MP15 30 min. ox. (C) TCD 59515 – **K61-4**
7. MP15 30 min. ox. (C) TCD 59515 – **B51-1**

Figs. 8 - 10 *Cordylosporites marciae* (Winslow) Playford & Satterthwait 1985

8. MP15 15min ox (B) TCD 59515 – **K41-1**
9. MP27 no ox (A) TCD 59527 – **K64-1**
10. MP15 15min ox (B) TCD 59515 – **C37-4**

Figs. 11 & 12 *Dictyotriletes flavus* Keegan 1977

11. MP54 1hr ox (A) TCD 59554 – **K34-2**
12. MP28 no ox (A) TCD 59528 – **P32-3**

Figs. 13 - 16 *Emphanisporites schultzii* McGregor 1973

13. TL1 (2) TCD56753– **G48-1**
14. TL8 (0) TCD59616 – **C62-4**
15. MP10 15min ox (D) TCD 59510 – **P45-2**
16. TL3 (1) TCD56755 –**V72-1**

Figs. 17 - 19 *Emphanisporites annulatus* McGregor 1961

17. MP14 no ox. (A) TCD 59514 – **P52-4**
18. MP10 no ox. (A) TCD 59510 – **Q65-4**
19. MP10 no ox. (A) TCD 59510 – **K59**

Fig. 20 *Emphanisporites hibernicus* Clayton, Higgs & Keegan 1977

20. TL1 (2) TCD56753– **H71-3**

Figs. 21 & 22 *Emphanisporites minutus* Allen 1965

21. TL7 (1) TCD56756 –**V41**
22. TL7 (1) TCD56756 – **F69-2**

Figs. 23 – 24 *Emphanisporites rotatus* (McGregor) McGregor 1973

23. MP10 no ox (A) TCD 59510 – **N67**
24. SUN1 TCD56751 – **F50-4**

Plate 4

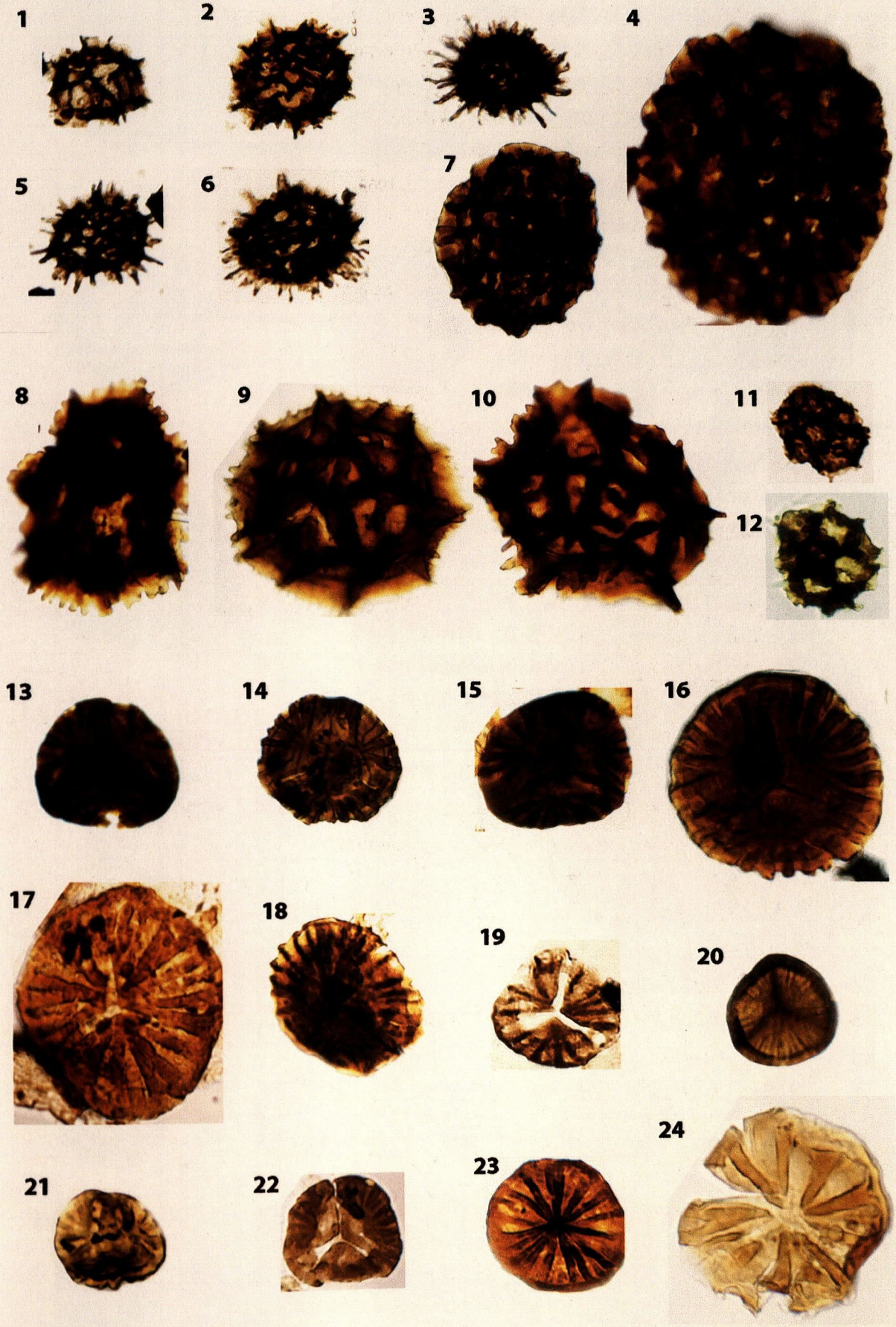


PLATE 5

Figs. 1 & 2 *Knoxisporites literatus* (Waltz) Playford 1963

1. MP46 no ox. (A) TCD 59546– **U58-3**
2. MP34 no ox. (A) TCD 59534 – **S67-2**

Fig. 3 *Knoxisporites triangularis* Higgs, Clayton & Keegan 1988

MP35 no ox. (A) TCD 59535 – **N56-4**

Figs. 4, 5, 7 & 8 *Knoxisporites concentricus* (Byvscheva) Playford & McGregor 1993.

4. MP8 no ox. (B) TCD 59508 – **G69-2**
5. MP12 15 min. ox. (A) TCD 59512 – **W50-4**
7. MP2 no ox. (A) TCD 59502 – **J54-2**
8. MP12 no ox. (A) TCD 59512 – **Q62-2**

Figs. 6 & 9 *Knoxisporites* cf. *triradiatus* Hoffmeister, Staplin & Malloy *sensu* Sullivan 1964a

6. MP14 no ox. (A) TCD 59514 – **Y50**
9. MP28 no ox. (A) TCD 59528 – **F41**

Fig. 10 *Knoxisporites* cf. *concentricus*

MP8 no ox. (B) TCD 59508 – **C54-3**

Figs. 11 – 14 *Tumulispora tuberosus* (Sullivan) Carson 1995

11. MP55 no ox. (X) TCD 59555 – **P62-1**
12. MP55 45 min. ox. (X) TCD 59555 – **C64-4**
13. MP55 no. ox. (Y) TCD 59555 – **V52-3**
14. MP55 45 min. ox. (B) TCD 59555 – **H66-2**

Figs. 15 & 20 *Tumulispora ordinaria* Staplin & Jansonius 1964

15. MP15min ox. (A) TCD 59515 – **C47-3**
20. MP5 no ox. (A) TCD 59505 – **H35-2**

Figs. 16 – 18 *Tumulispora malevkensis* (Kedo) Turnau 1978

16. MP28 no ox. (A) TCD 59528 – **O32-3**
17. MP37 no ox. (A) TCD 59537 – **O48-2**
18. TL3 (1) TCD56755 – **Q53-2**
19. TL8 (0) TCD59616 – **H54**

Plate 5

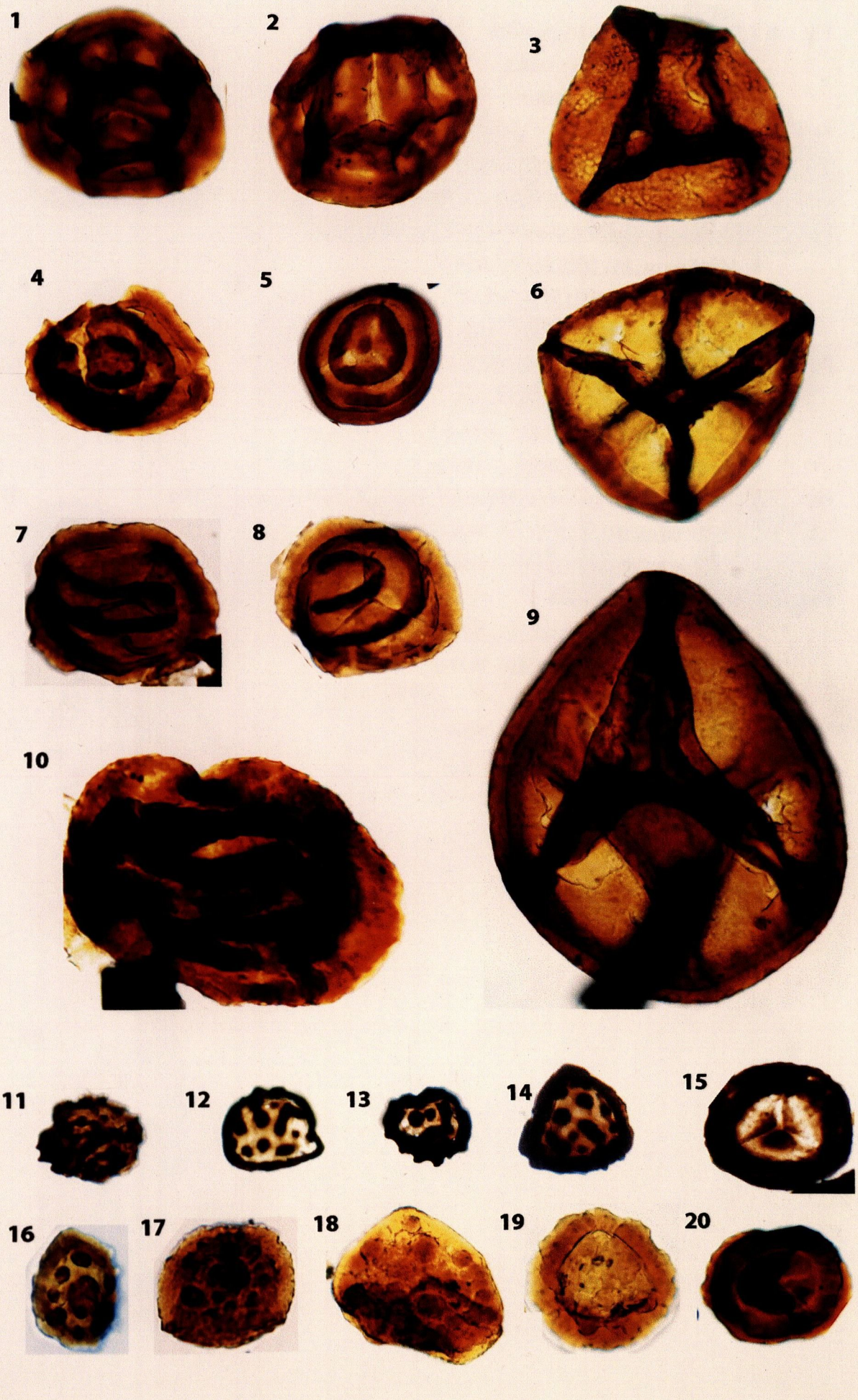


PLATE 6

Fig. 1 & 4 *Murospora dubitata* Higgs 1975a

1. TL8 (0) 2 TCD59616 – **O38-2**
4. TL7 (3) TCD56756 – **U60-3**

Figs. 2 & 3 *Murospora* sp. A

2. MP2 no ox. (A) TCD 59502 – **R52-1**
3. MP12 30 min. ox. (B) TCD 59512 – **F58-4**

Figs. 5 -7 *Cyrtospora cristifera* (Luber) Van der Zwan 1979

5. MP43 no ox. (A) TCD 59543 – **K36-3**
6. MP43 no ox. (A) TCD 59543 – **L61**
7. MP43 no ox. (A) TCD 59543 – **L62**

Figs. 8 – 10 *Auroraspora macra* Sullivan 1968

8. MP2 no ox. (A) TCD 59502 – **C36-4**
9. MP2 no ox. (A) TCD 59502 – **D55-4**
10. MP2 no ox. (A) TCD 59502 – **J46- 2**

Figs. 11 & 12 *Auroraspora solisortus* (Hoffmeister, Staplin & Malloy) Turnau 1978

11. MP10 no ox. (B) TCD 59510 – **W36-2**
12. MP2 no ox. (B) TCD 59502 – **Q50- 4**

Figs. 13 – 16 *Teichertospora torquata*

13. MP10 no ox. (B) TCD 59510 – **X44-1**
14. MP10 no ox. (B) TCD 59510 – **W37-3**
15. TL7 (1) TCD56756 – **O48-2**
16. MP10 no ox. (A) TCD 59510 – **W66-3**

Fig. 17 *Calyptosporites triangulatus* Higgs 1975a

NP28 no ox. (A) TCD 59528 – **U57-3**

Plate 6

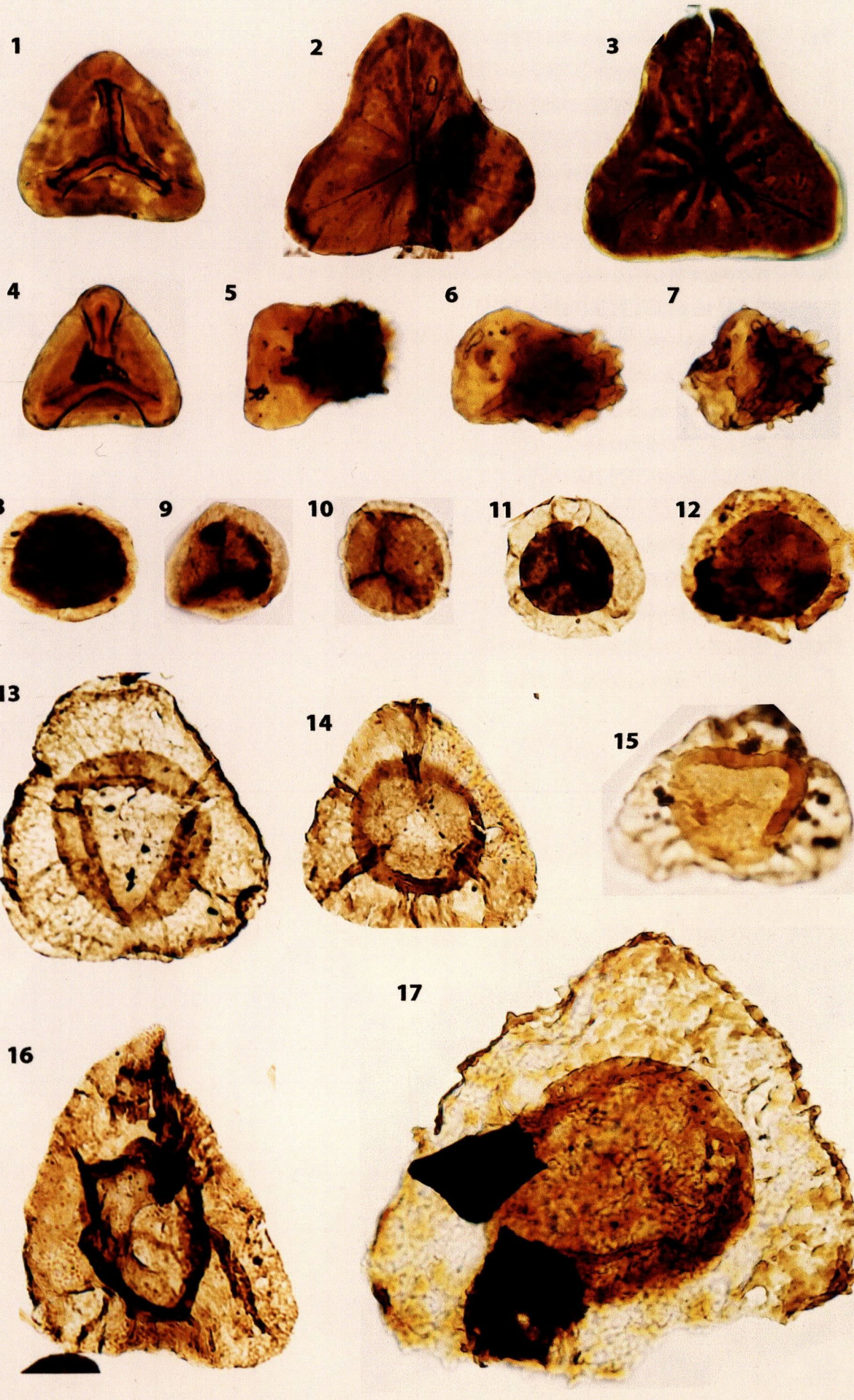


PLATE 7

Figs. 1 – 3 *Spinozonotriletes uncatus* Hacquebard 1957

1. MP34 no ox (A) TCD 59534 – **N51-2**
2. MP2 no ox (C) TCD 59502 –**P35-2**
3. MP34 no ox (A) TCD 59534 – **C38-4**

Figs. 4 – 5 *Spinozonotriletes impensus* Higgs, Clayton & Keegan 1988

4. MP12 30min ox (A) TCD 59512 – **Q55-1**
5. MP10 no ox (B) TCD 59510 – **M63-1**

Fig. 6 *Discernisporites micromanifestus* (Hacquebard) Neves & Owens 1966

WC24 no ox (C) TCD59645 – **F43-3**

Figs. 8 & 9 *Densosporites spitsbergensis* Playford 1962

8. MP12 no ox (A) TCD 59512 – **O43-3**
9. MP10 no ox (A) TCD 59510 – **U63-3**

Figs. 7, 11, 13 & 14 *Indotriradites explanatus* (Luber) Playford 1991

7. TL1 (XI) TCD56753 –**W9-4**
10. TL1 (XI) TCD56753 – **M57-4**
11. MP15 45min ox. (A) – **W58-1**
13. MP15 30 min ox. (B) – **U54-3**
14. MP13 15min ox. (A) – **K41-4**

Fig. 12 *Crassispora maculosa* (Knox) Sullivan 1964a

12. MP10 no ox. (A) TCD 59510 – **F67-2**

Plate 7

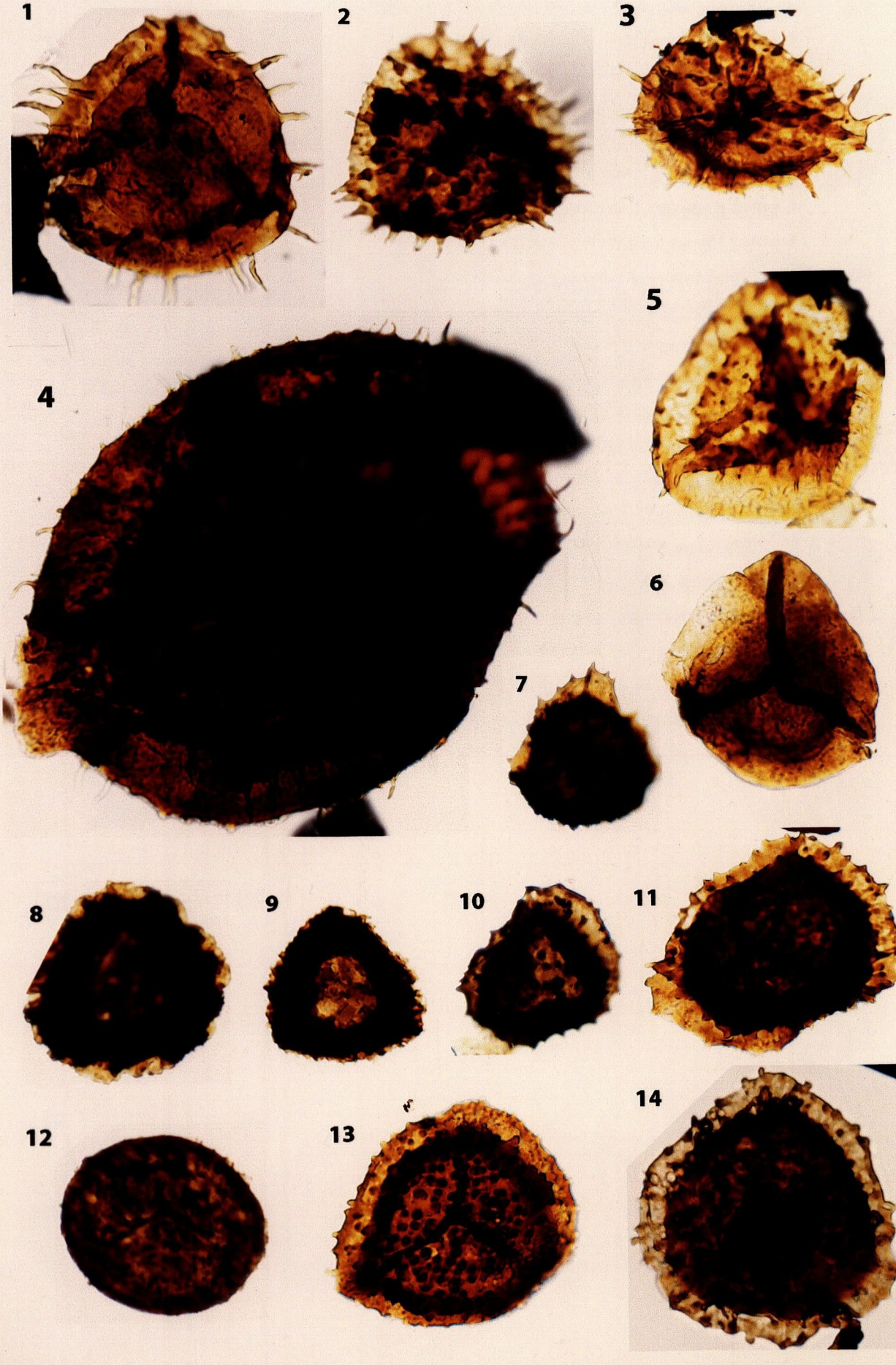


PLATE 8

Figs. 1 & 6 *Retispora macroreticulata* (Kedo) Byvscheva 1985

1. MP10 15 min. ox. (D) TCD 59510 – **C44-4**
6. MP2 no ox. (B) TCD 59502 –**U68-4**

Figs. 2 -5 *Retispora lepidophyta* (Kedo) Playford 1976

2. MP10 no ox. (A) TCD 59510 –**V48-2**
3. MP10 15 min. ox. (D) TCD 59510 – **T44-1**
4. MP10 no ox (B) TCD 59510 – **C59-3**
5. MP10 15 min. ox. (D) TCD 59510 – **F42-2**

Figs. 7 - 10 *Endoculeospora gradzinskii* Turnau 1975

7. MP10 no ox. (B) TCD 59510 – **K30-2**
8. MP10 15 min. ox. (A) TCD 59510 – **C44-2**
9. MP10 no ox. (A) TCD 59510 – **L62-2**
10. MP10 no ox. (A) TCD 59510 – **K60-1**

Figs. 11 - 14 *Grandispora echinata* Hacquebard 1957

11. TL1 (2) TCD56753 – **M47-4**
12. MP11 no ox. (X) TCD 59511 – **F58-2**
13. MP28 no ox. (B) TCD 59528 –**G47-2**
14. MP28 no ox. (C) TCD 59528 – **E48 4**

Figs. 15 - 18 *Grandispora cornuta* Higgs 1975a

15. MP10 no ox. (A) TCD 59510 – **X63-3**
16. MP10 15 min. ox. (D) TCD 59510 – **N41-2**
17. MP12 30 min. ox. (C) TCD 59512 – **R40-1**
18. MP12 15 min. ox. (A) TCD 59512 – **C47-2**

Plate 8

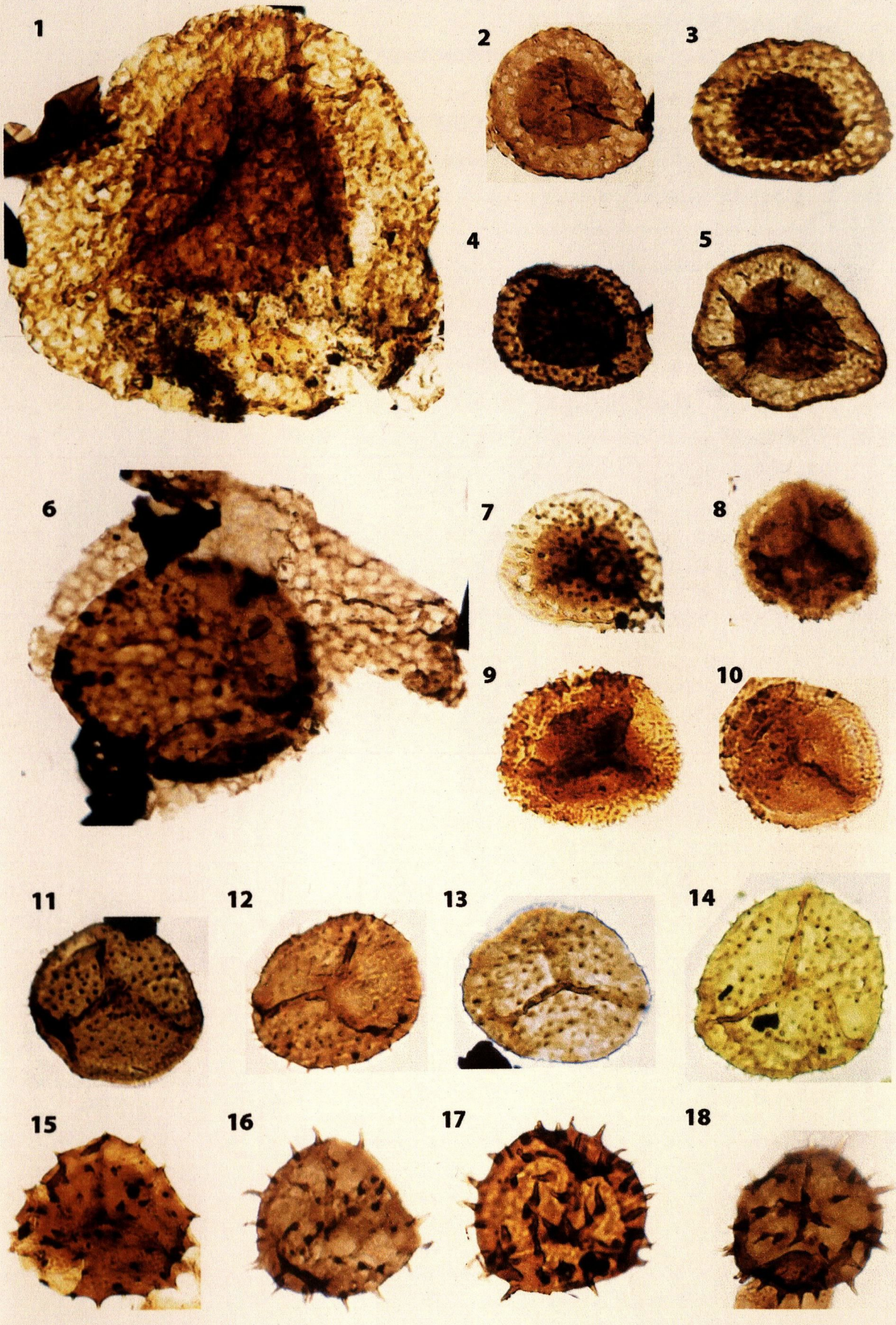


PLATE 9

Fig. 1 *Grandispora douglastownense* McGregor 1973

TL3 (1) TCD56755 – **W57-2**

Figs. 2 & 4 *Grandispora ? macrotuberculata* (Arkhangelskaya) McGregor 1973

2. MP28 no ox. (A) TCD 59528 – **P52-2**
4. MP55 30 min. ox. (A) TCD 59555 – **W51-3**

Fig. 3 *Grandispora megaformis* (Richardson) McGregor 1973

SUN 3 (II) TCD56752 – **N37-1**

Figs. 5 - 7 *Rugospora flexuosa* (Jushko) Streel 1974

5. MP2 no ox. (A) TCD 59502 – **D41-2**
6. MP10 no ox. (A) TCD 59510 – **X58**
7. MP11 no ox. (x) TCD 59511 – **F67**

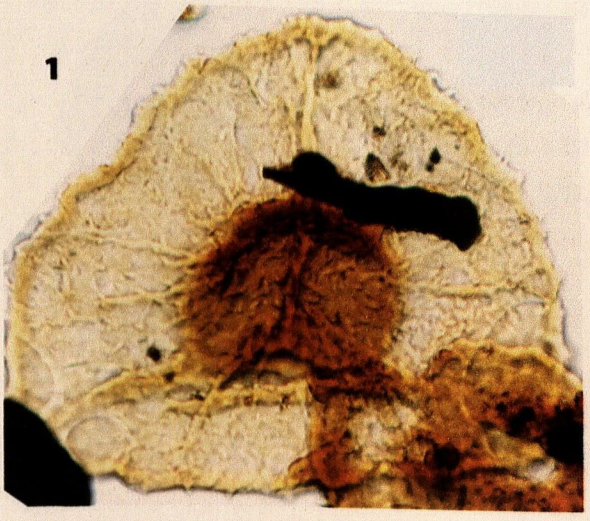
Fig. 8 *Rugospora polptycha* Neves & Ioannides 1974

MP27 no ox. (A) TCD 59527 – **Q53-4**

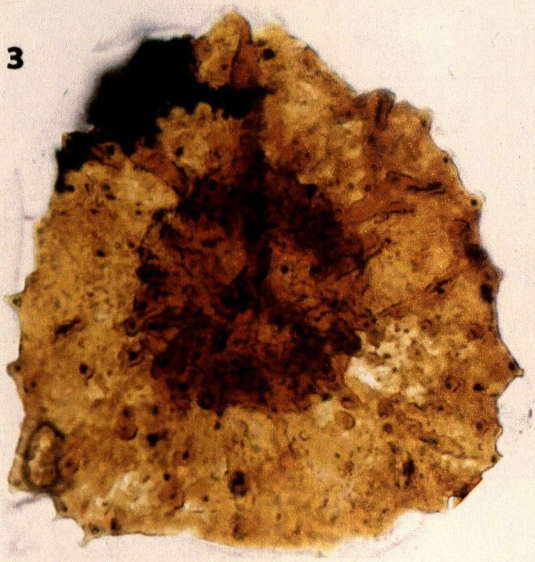
Figs. 9 -12 *Rugospora radiata* (Jushko) Byvscheva

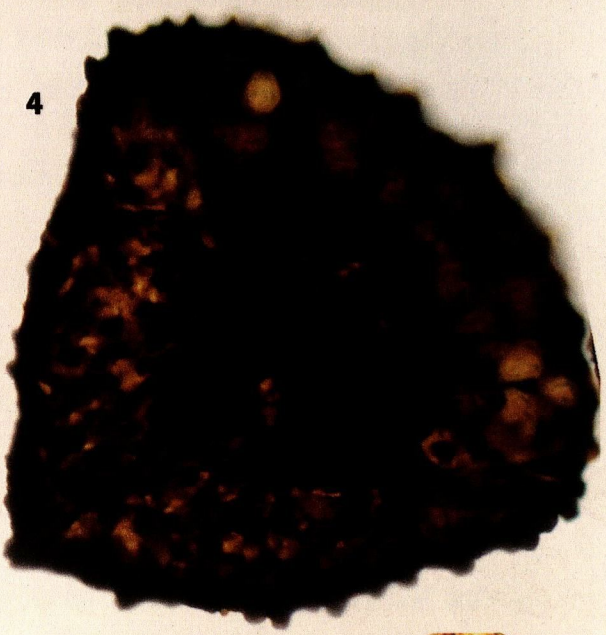
9. MP6 no ox. (A) TCD 59506 –**V53**
10. MP10 no ox. (B) TCD 59510 – **P35**
11. MP10 no ox. (A) TCD 59510 – **X58**
12. MP10 no ox. (B) TCD 59510 – **L68-1**

Plate 9

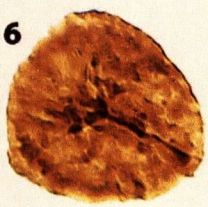




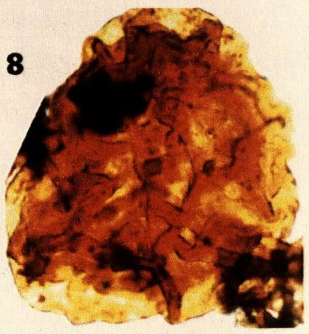


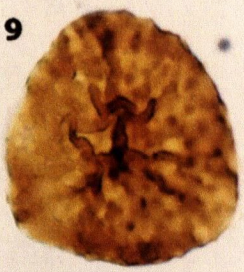














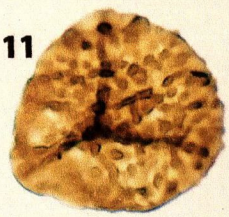




PLATE 10

Figs. 1 - 7 *Spelaeotriletes balteatus* (Playford) Higgs 1975a

1. WC24 no. ox. (B) TCD59645 – **B54-3**
2. CA11 (Coarse) 45 min. ox. TCD 59571 – **K46-1**
3. CA11 (Fine) 30 min. ox. (A) TCD 59571 – **V56-4**
4. CA11 (Fine) 30 min. ox. (A) TCD 59571 –**W39-2**
5. CA11 no. ox. (A) TCD 59571 – **D62-2**
6. CA11 no. ox. (A) TCD 59571 – **J69-2**
7. CA11 no. ox. (A) TCD 59571 – **N60-2**

Fig. 8 *Spelaeotriletes* sp. A

WC24 no. ox. (C) TCD59645 – **F56**

Figs. 9 -12 *Spelaeotriletes cabottii* Utting, Keppie & Giles, 1989

9. CA11 (Fine) 30 min. ox. (A) TCD 59571 – **W31**
10. WC24 no ox. (A) TCD59645 – **E45-3**
11. WC24 no ox. (A) TCD59645 – **E45-3**
12. CA11 no ox. (A) TCD 59571 –**K42-1**

Figs. 13 - 16 *Spelaeotriletes galearis* Brittain & Higgs 2009

13. CA11 (Coarse) TCD 59571 – **J42**
14. CA11 (Coarse) TCD 59571 – **D39-1**
15. MP34 no ox. (A) TCD 59534 – **G50-2**
16. CA11 (Fine) 30 min. ox. (A) TCD 59571 –**P65-3**

Figs. 17 - 24 *Spelaeotriletes pretiosus* (Playford) Neves & Belt 1970

17. WC24 (C) TCD59645 – **E59**
18. WC24 (C) TCD59645 – **M44-2**
19. WC24 no ox. (A) TCD59645 – **R47**
20. WC24 no ox. (A) TCD59645 – **P34-1**
21. WC24 no ox. (A) TCD59645 – **Q58**
22. WC21 no ox. (A) TCD59644 – **W33-3**
23. WC24 (C) TCD59645 –**F43**
24. WC24 (C) TCD59645 – **K40-4**

Plate 10

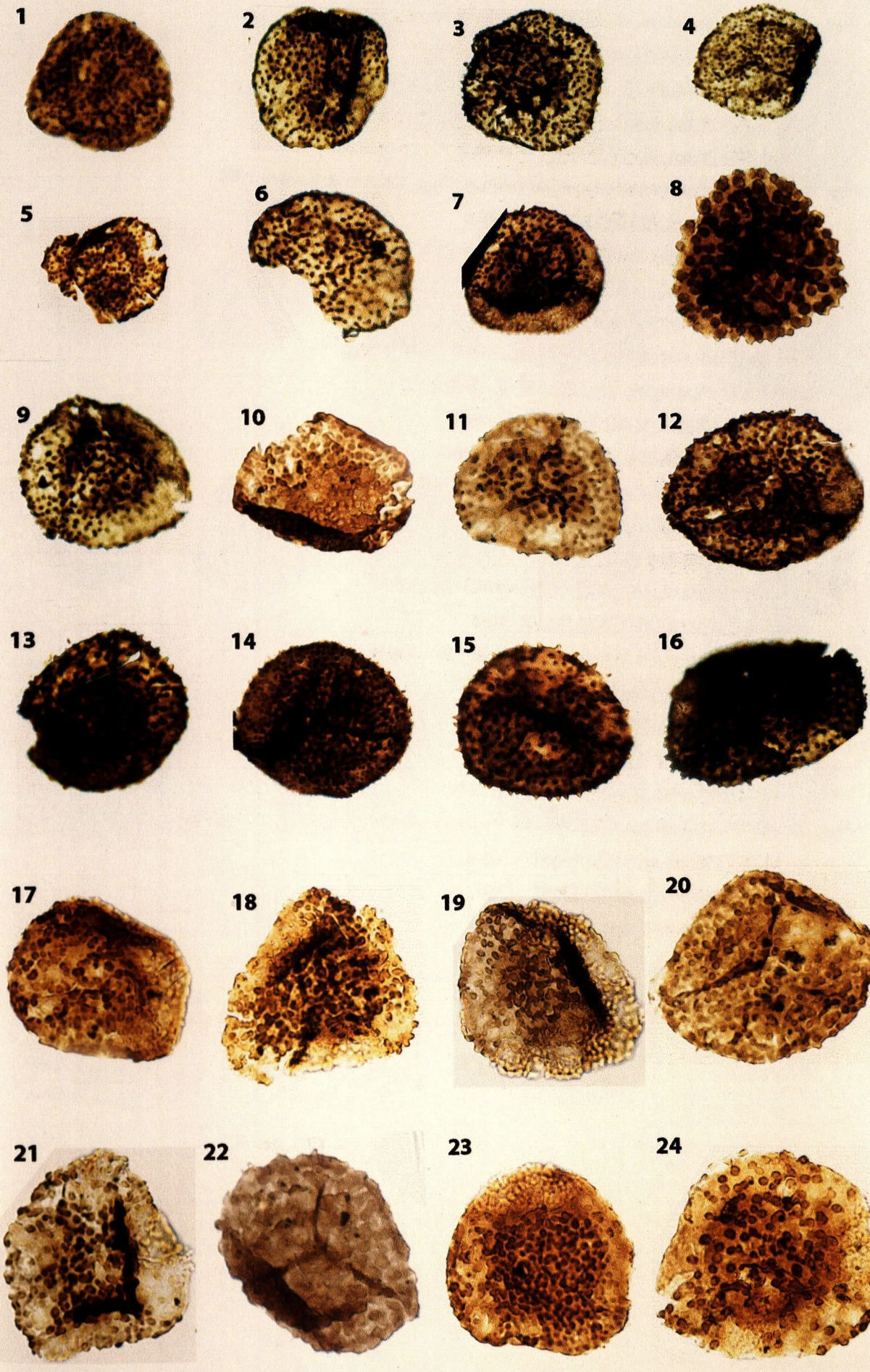


PLATE 11

Figs. 1 - 4 *Vallatisporites pusillites* (Kedo) Dolby & Neves

1. TL3 (1) TCD56755 – **Q66**
2. TL3 (1) TCD56755 – **J37-1**
3. MP10 no ox. (B) TCD 59510 – **K64-4**
4. MP11 no ox. (A) TCD 59511 – **W38-2**

Figs. 5, 10 & 14 *Velamisporites caperatus* (Higgs) Higgs, Clayton & Keegan 1988

5. MP10 no ox. (B) TCD 59510 – **H52-2**
10. MP10 30 min. ox. (C) TCD 59510 – **R59-2**
14. MP10 no ox. (A) TCD 59510 – **B55-3**

Figs. 6 - 9 *Vallatisporites vallatus* Hacquebard 1957

6. MP15 30 min ox (B) TCD 59515 – **U56**
7. MP15 30 min. ox. (B) TCD 59515 – **U56-2**
8. MP15 45min ox (A) TCD 59515 – **N60**
9. MP15 45 min. ox. (A) TCD 59515– **J50-3**

Figs. 10 - 13 *Vallatisporites verrucosus* Hacquebard 1957

10. MP10 no ox. (A) TCD 59510 – **Y56-1**
11. MP10 no ox. (B) TCD 59510 – **C55-2**
12. MP10 no ox. (A) TCD 59510 – **W42-2**
13. MP10 no ox. (B) TCD 59510 – **H64**

Figs. 15 - 18 *Vallatisporites hystricosus* (Winslow) Byvscheva 1985

15. MP10 no ox. (A) TCD 59510 – **J53**
16. MP10 no ox. (B) TCD 59510 – **K64-4**
17. MP10 no ox. (B) TCD 59510 – **W47-1**
18. MP10 no ox. (A) TCD 59510 – **V39-2**

Figs. 19 & 20 *Vallatisporites ciliaris* (Luber) Sullivan 1964b

19. MP2 no ox. (A) TCD 59502 – **P42-4**
20. MP2 no ox. (A) TCD 59502 – **Q50**

Figs. 21 & 22 *Radiizonates mirabilis*

21. MP10 no ox. (B) TCD 59510 – **H52-2**
22. WC24 no ox. (A) TCD59645 – **N49-2**

Plate 11

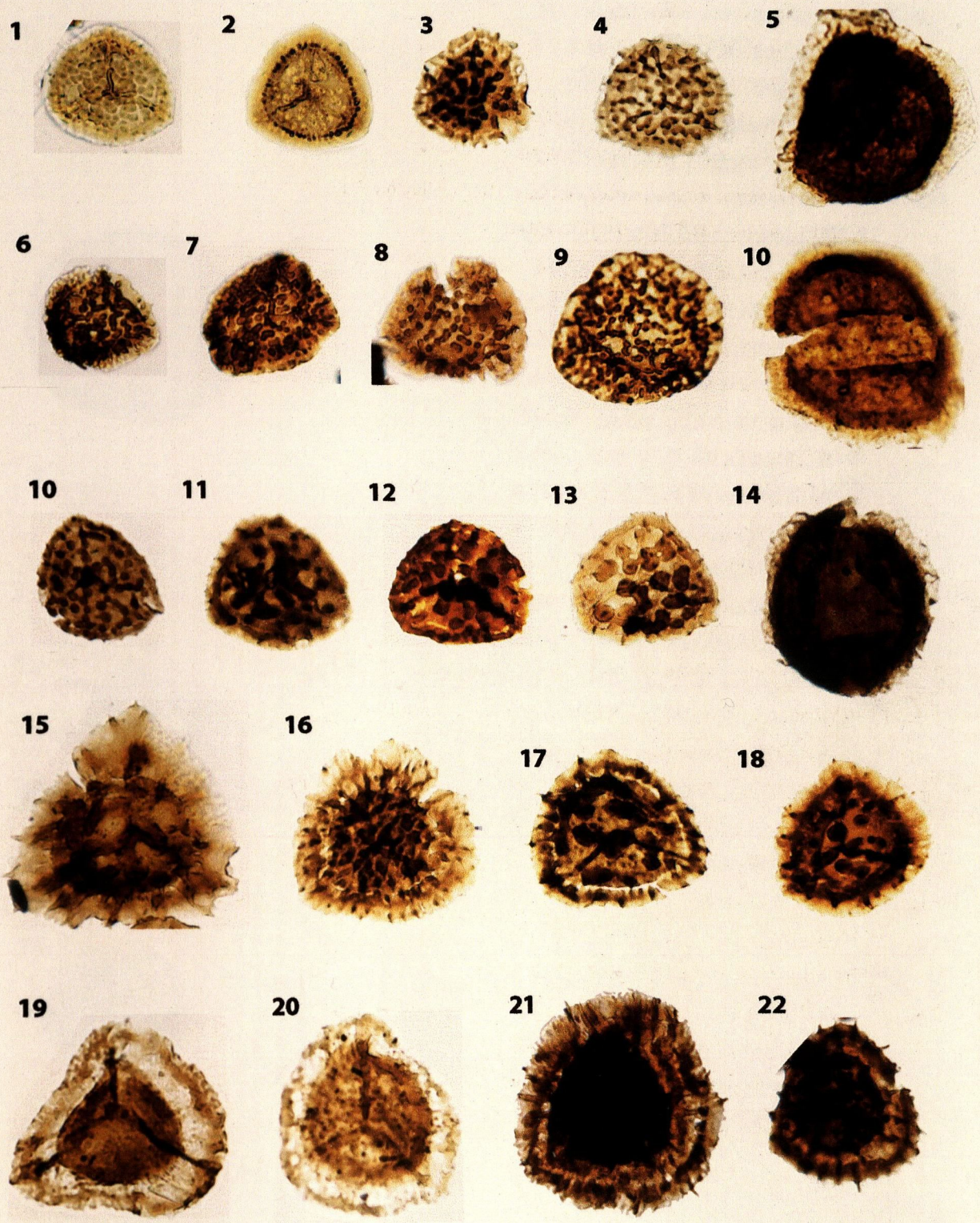


PLATE 12

Figs. 1 - 4 *Laevigatosporites minor* Loose 1934

1. TMW 1 (A) TCD59614 – **P42-1**
2. TMW 1 (B) TCD59614 – **U36-4**
3. SUN 1 (Boiled) TCD56751 – **P47-1**
4. SUN 1 (Boiled) TCD56751 – **L37-2**

Figs. 5 - 8 *Latosporites* sp. A *sensu* Owens 1971

5. NP15 30min ox (B) TCD 59515– **X41-1**
6. MP5 no ox (A) TCD 59505 – **C38-1**
7. MP49 no ox (B) TCD 59549 – **S48-3**
8. MP37 no ox (A) TCD 59537 – **O45-1**

Figs. 9 - 12 *Aratrisporites saharaensis* Loboziak, Clayton & Owens 1986

9. WC24 no ox (A) TCD59645 – **Q45-2**
10. WC24 no ox (B) TCD59645 – **E52-2**
11. WC24 no ox (B) TCD59645 – **Q37-3**
12. WC24 no ox (C) TCD59645 – **G37-1**

Figs. 13, 16, 17 & 19 *Hystricosporites* sp.

13. TL9 TCD59617 – **R73-2** x250 magnification
16. TL8 (0) TCD59616 – **J60-1** x250 magnification
17. SUN2 (A) TCD56752 – **X66** x250 magnification
19. SUN2 (A) TCD56752 – **Y65-4**

Figs. 14, 15 & 18 *Ancyrospora* spp.

14. SUN2 (II) TCD56752 – **X53-2**
15. SUN3 (1) TCD56751A – **L40 (1)** x250 magnification
18. SUN2 (II) TCD56752 – **Y59-3**

Plate 12

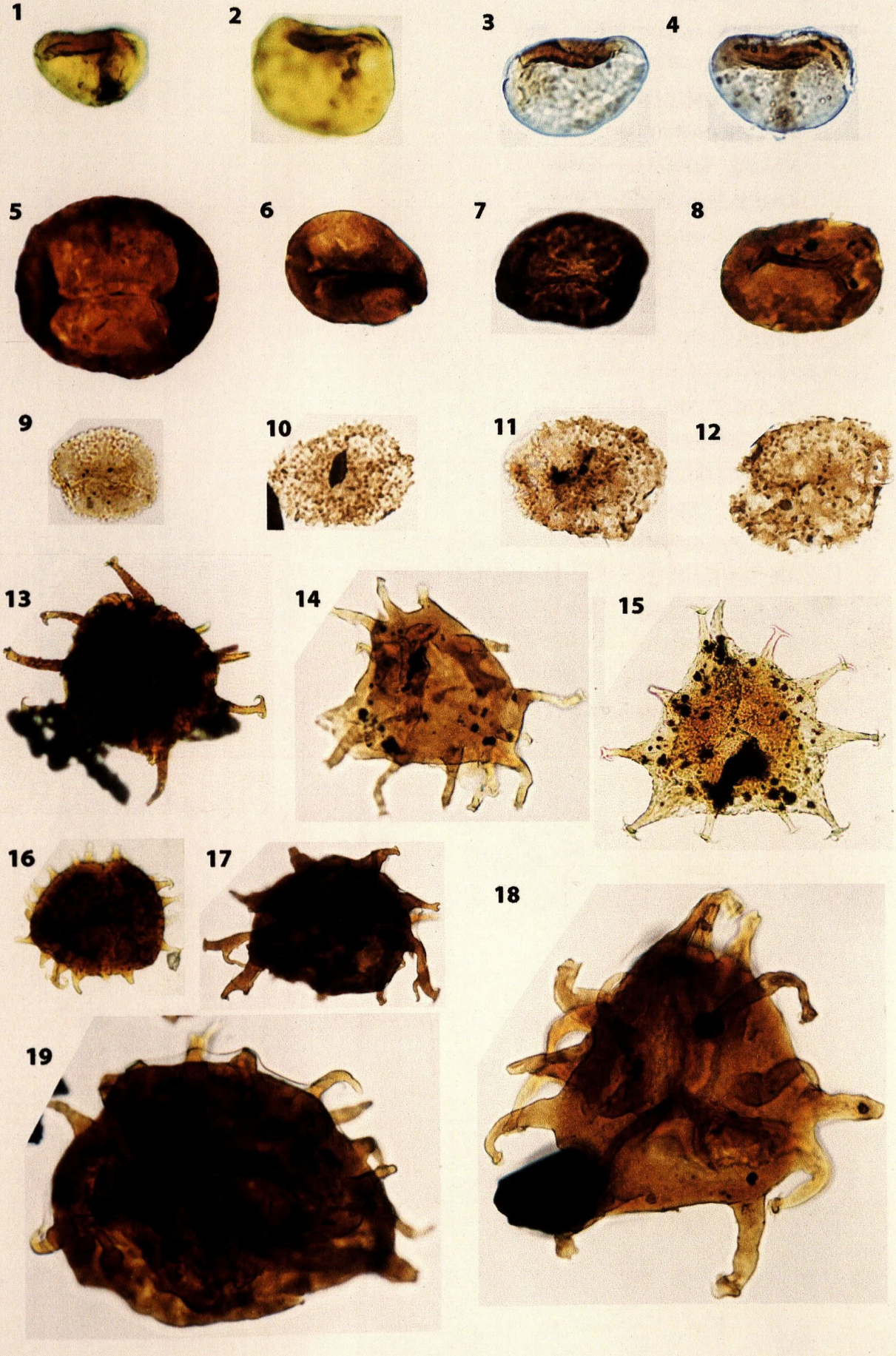


PLATE 13

Figs. 1, 2 & 5 *Veryhachium* sp.

1. MP10 no ox (A) – **W66-3**
2. TL8 (0 2) – **J64**
3. WC9 no ox (A) **K41-2**

Figs. 3, 4, 7 & 8 *Uhellium* ? *elongatum*

3. SUN3 TCD56751A – **E36-2**
4. SUN3 TCD56751A – **F49-4**
7. MP49 15min ox (A) – **J45-1**
8. WC7 (A) TCD59629 (A) – **M50-3**

Fig. 6 *Veryhachium arcarium*

NP6 no ox (A) – **V61-4**

Fig. 9 *Gorgonisphaeridium ohioense*

CC5 TCD59606 – **W60-2**

Figs. 10 & 11 *Umbellasphaeridium saharium*

10. SUN3 TCD56751A – **R71-4**
11. CC1 TCD59609 – **X34-1**

Figs 12 – 14 *Gorgonisphaeridium* sp.

12. CC5 TCD59606 – **P40**
14. CC5 TCD59606 – **X51-3**

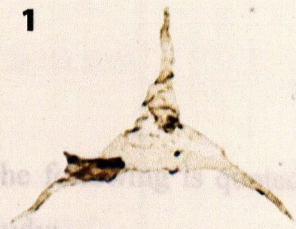
Figs. 15 & 17 *Tasmanites* sp.

15. CC10 TCD59602 – **Y14-2**
17. CC5 TCD59606 – **M64**

Fig. 16 *Maranhites* sp.

- TL7 (1) – **X70-3**

Plate 13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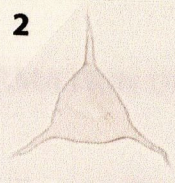
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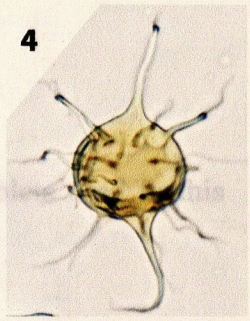
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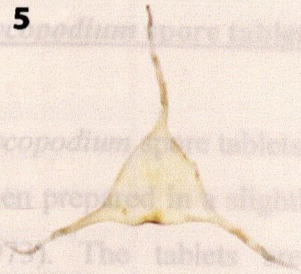
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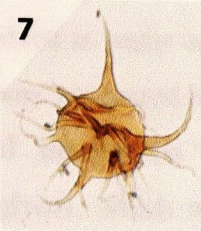
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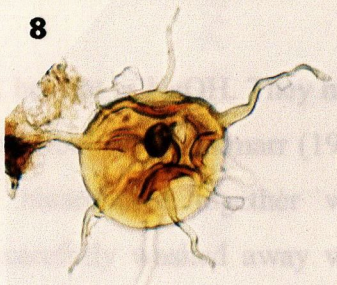
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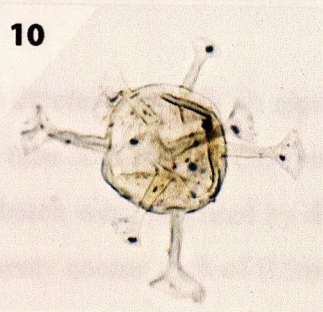
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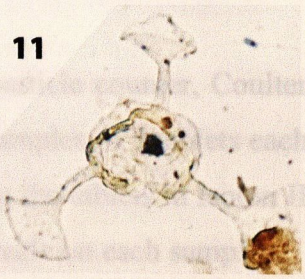
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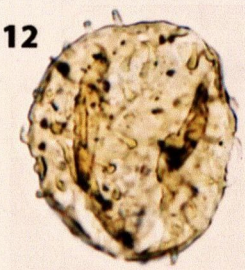
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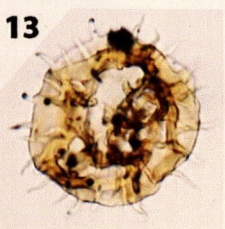
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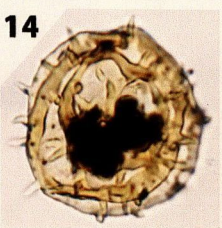
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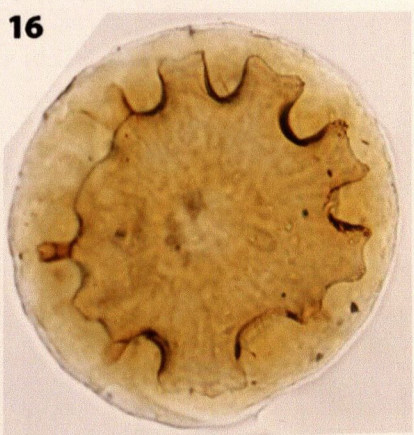
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APPENDIX I

INFORMATION ON SPORE TABLETS

The following is quoted from the manufacturers of the Lycopodium tablets used in this study:

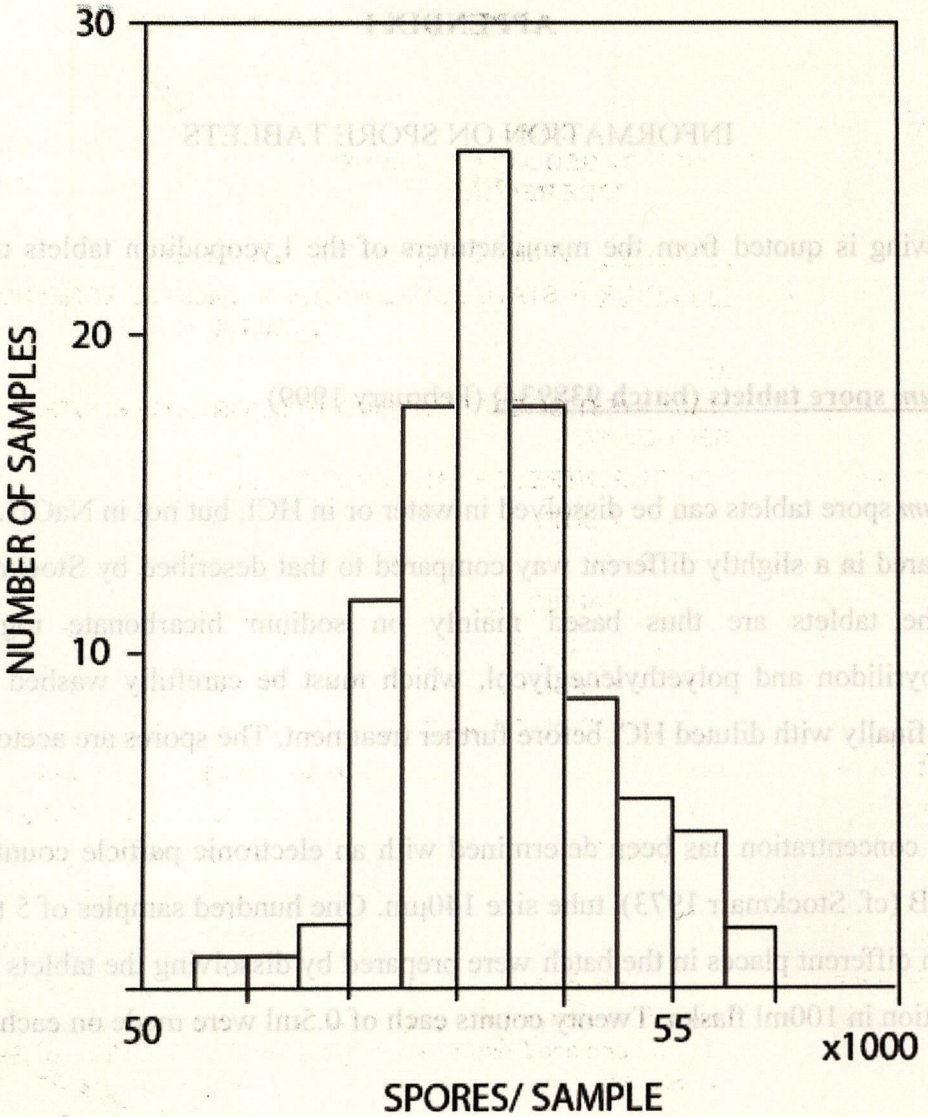
***Lycopodium* spore tablets (batch 938934)** (February 1999)

Lycopodium spore tablets can be dissolved in water or in HCl, but not in NaOH. They have been prepared in a slightly different way compared to that described by Stockmarr (1971, 1973). The tablets are thus based mainly on sodium bicarbonate together with polyvinylpyrilidon and polyethyleneglycol, which must be carefully washed away with water and finally with diluted HCl before further treatment. The spores are acetolysed.

The spore concentration has been determined with an electronic particle counter, Coulter Counter ZB (cf. Stockmarr 1973), tube size 140µm. One hundred samples of 5 tablets each taken from different places in the batch were prepared by dissolving the tablets in Isoton II NaCl solution in 100ml flasks. Twenty counts each of 0.5ml were made on each sample.

Result: X= 53.394 s = +/- 953 V = +/- 1.8%

For one tablet: X = 10,679



Appendix I - Fig. 1. Number of spores per sample. after University of Lund (1999).

APPENDIX II

File No. 3256

ODNR
DIVISION OF GEOLOGICAL SURVEY
CORE RECORD

COUNTY:	WILLIAMS 7.5 Min. QUADRANGLE: BLAKESLEE
TOWNSHIP:	SUPERIOR > STATE COORDINATES X: 1,409,950 ZONE: NORTH Y: 696,700
SECTION:	17
MEASURED:	1300ft. WEST OF EAST LINE AND 150ft.NORTH OF SOUTH LINE OF SECTION 17.
LOCATION REMARK:	SOUTH MONTPELIER SAND AND GRAVEL PIT.
PROPERTY OWNER	STONE COUNTY
CORE DESIGNATION (Project):	COGEOMAP
PURPOSE OF CORE:	STRATIGRAPHIC TEST
DRILLER(S):	MITCHELL & CLARY
DRILLING Co.	ODNR, DIVISION OF GEOLOGICAL SURVEY
DRILLED FOR:	ODNR, DIVISION OF GEOLOGICAL SURVEY
SURFACE ELEVATION:	845ft. **DATUM FOR ELEVATION:** SEA LEVEL
DATE STARTED:	Apr-93 **DATE COMPLETED:** JULY 1992
LOGGED BY:	G.E. LARSEN **DATE LOGGED:** JULY 1992
CORE DIAMETER:	NCQ **No. of CORE BOXES:** 239
TOTAL DEPTH:	2590ft. **DIRECTION OF HOLE:** VERTICAL
DISPOSITION OF CORE	Stored in the core repository of the ODNR, Division of Geological Survey.
REMARKS:	Core hole geophysically logged by BPB Instrument Inc. Caliper, Gamma Ray, Neutron and Density logs on file at the ODNR, Division of Geological Survey.

TOP ft.	BOTTOM ft.	THICKNESS ft.	DESCRIPTION
0.0	191.0	191.0	Rotary to bedrock; sand and gravel. Bedrock surface on the Mississippian Coldwater Shale.
			COLDWATER SHALE FORMATION
191.0	195.0	4.0	Rotary, shale; casing set 4 feet into bedrock.
195.0	332.7	137.0	Shale, greyish green to greenish black to medium grey: clayey, fissile, occasionally pyritic and burrowed, laminated in places, occasionally slickensided, siderite and carbonate nodules common, occasional vertical fractures; carbonate nodules are very abundant in lower 2.7 feet, basal 1.0 feet is a nodular greenish grey argillaceous fine crystalline glauconitic dolostone; sharp irregular lower contact.
			SUNBURY SHALE FORMATION
332.7	343.5	10.8	Shale, brownish black to greyish black; fissile, laminated in places, slightly silty, pyritic in places, top 0.1 feet burrowed, occasional fish scale; gradational lower contact
			BEDFORD SHALE FORMATION
343.5	376.2	32.7	Shale, very light grey to medium gray to grayish olive green; thinly laminated silty and clayey shale, pyritic, burrowed; occasional gypsum lamination or streak, siderite nodules common; sharp irregular pyritic contact.
			ANTRIM SHALE MEMBER (OHIO SHALE Fm)
376.2	577.7	201.5	Shale, brownish black to dark yellowish brown to olive grey; slightly silty fissile, laminated in places, pyritic in places; occasional gypsum streaks and laminations, calcareous & clayey intercalations and thin interbeds common below 470.0 feet, vertical fractures common throughout interval, burrows and fossils common in calcareous intervals, petroliferous odour, driller reported hole made gas around 382 feet.; sharp irregular contact.
			TRAVERSE GROUP **- TENMILE CREEK DOLOMITE EQUIVALENT**
577.7	589.8	12.1	Limestone, brownish grey to pale yellowish brown to pale brown; fine to medium crytalline, argillaceous, dolomitic in places, thin to medium bedded; interval is 2.3 ft. thick, pyrite common throughout interval; fossiliferous; sharp irregular lower contact.
589.8	600.7	10.9	Limestone, yellowish grey to medium grey, has a slight brownish colour; medium crystalline, dolomitic, thin to medium bedded, vuggy in places; dolostone zone in top.

MYLAN PARK CORE DESCRIPTION

Key to abbreviations used:

Lithologies

Lst. - Limestone

Mdst. - Mudstone

Pyr. – Pyrite

Sh. - Shale

Slst. - Siltstone

Sst. - Sandstone

Features

ARG. – Argillaceous

BRW. – Burrows

CALC. – Calcareous

FeSt. INCL. – Ironstone inclusions

FOSS. – Fossiliferous

QTZ. – Quartzose

RED – Red beds.

SDY. – Sandy

Sl. CLS. – Shale clasts

SLTY. – Silty

Sst. STR. – Sandstone streaks

XBD. – Cross-bedding.

TOP FT.	BOTTOM FT.	THICKNESS FT.	DESCRIPTION	LITHOLOGY	
	1688.93	2.72	Red with grey green top to 0.20', slickensides, slightly silty, one calcareous nodule below 1687.75', gradational lower contact on colour.	Mdst.	RED
1688.93	1689.90	0.97	Medium grey green with faint, fine mottles & streaks, gradational lower contact on bedding change.	Mdst.	
1689.90	1692.97	3.07	Medium grey green and banded red, light grey green and medium grey, predominately medium grey in basal 0.12', soft clay zone, very fissile, very fine grained, sharp lower contact.	Sh.	
			TOP OF GREENBRIER LIMESTONE FORMATION		
1692.97	1698.67	5.70	Light grey, fine grained, hard, very fine, crenulated fractures, nodular with medium grey green matrix in basal 1.00' abundant fossils in basal 0.50', sharp lower contact.	Lst.	
1698.67	1698.99	0.32	Medium grey green, non-calcareous, soft zone in middle, sharp lower contact on colour, 1 brachiopod piece.	Sh.	
1698.99	1699.12	0.13	Red, non-calcareous, sharp lower contact on colour.	Sh.	RED
1699.12	1699.31	0.19	Medium grey green, non-calcareous with thin calcite bands, no fossils seen, gradational lower contact on colour.	Sh.	
1699.31	1701.35	2.04	Medium dark grey, mostly non-calcareous with very thin calcite bands, brachiopod and pelecopods, lingula, gastropod, gradational lower contact on increasing calcite cement	Sh.	
1701.35	1703.77	2.42	Medium grey, silty, very fine, light grey, ripple streaks, pelecypod, basal 0.30' finely nodular to brecciated, sharp lower contact.	Lst.	ARG
1703.77	1705.53	1.76	Light grey green, hard, non-calcareous, sparce pyrite, weakly calcareous in basal 0.50', sharp lower contact.	Slst.	
1705.53	1755.30	49.77	Light grey, hard cyclically interbedded, light medium and dark grey beds, some light grey beds are nodular, some vertical fractures, few calcite filled streaks, crynoids gastropods, brachiopods seen at various intervals, coral at 1739.30' more fossiliferous below 1725.00', thinner beds 0.50' & less thick from 1745.00' to base, gradational lower contact at basal light grey bed.	Lst.	
1755.30	1758.90	3.60	Medium gray, hard, abundant gastropods, crinoids, & fossil fragments throughout, sharp lower contact at light grey bed.	Lst.	FOSS.
1758.90	1765.21	6.31	Interbedded light grey, mostly nodular limestone in beds approximately 0.60' down to0.20' with medium grey beds, more argillaceous than above, becoming slightly fissile to 1765.04', less fossiliferous than above, orbiculoid at 1764.30' sharp lower contact at colour and compositon change.	Lst.	FOSS.
1765.21	1772.40	7.19	Predominatley light grey to white, very fine grained, moderately abundant ostracods visible on acid etched surfaces, hard, very thin (<1 mm) crenulated vertical fractures filled with dark material, some sub horizontal fractures filled with white calcite, few medium grey beds with more abundant fossils - crinoids - from 0.05' - 0.20' thick, light grey beds from 0.20' to 1.10' thick, arbitrary sharp lower contact at top of thicker medium grey beds.	Lst.	FOSS.
1772.40	1775.55	3.15	Predomintely medium grey beds from 0.40' to 0.70' thick, abundant crinoids, occasionaly pelecypods, occasional pyrite nodules, interbedded light grey beds from 0.15' - 0.40' thick, arbitrary sharp lower contact at top of thicker light grey limestone bed.	Lst.	FOSS.
1775.55	1776.85	1.30	Light grey, hard, very fine grained, abundant white calcite in sub-horizontal and vertical fractures fills, sharp lower contact at bedding change.	Lst.	FOSS.
1776.85	1778.65	1.80	Medium grey, faintly laminated, somewhat crystalline, abundant fine, rounded grains on etched surface, probably quartz grains, no fossils evident, sharp lower contact on colour and composition change.	Lst.	FOSS.
			BASE OF GREENBRIER LIMESTONE FORMATION		

1778.65	1781.60	2.95	Medium grey green, non-calcareous with abundant light grey to white ripple laminated to ripple cross-laminated fine grained lime sand streaks, few calcareous nodules to base faint, coarse, red mottles and streaks from 1780.80' to base, gradational lower contact with mixing of colour.	Sh.	
1781.60	1786.78	5.18	Red with common, fine to coarse, faint to distinct, light and medium grey green mottles and streaks, few faint, coarse calcareous nodules, one large nodule at 1785.80', abundant slickensides, becoming bedded to base, sharp lower contact on colour.	Clst.	RED
1786.78	1788.84	2.06	Medium grey green, weakly calcareous to calcareous, *Spirorbis* (?), some ostracods visible on acid etched surfaces, pelecypods, sharp lower contact.	Sh.	CALC
1788.84	1789.20	0.36	Light grey, hard, white calcareous streaks in top, ostracods (?), sharp lower contact.	Lst.	
			TOP OF BIG INJUN SANDSTONE MEMBER		
1789.20	1798.44	9.24	Light grey green with light grey streaks, ripple laminations, possibly bioturbated or soft sediment deformation, fine to medium grained strongly calcareous sandy zones are qtz. rich, sharp lower contact.	Sst.	CALC
1798.44	1809.53	11.09	Light grey, zones of planar laminations and planar ripple laminations, calcareous to strongly calcareous, fine to medium grained, breakage in wafers 2cm thick at 1801.00' - 1802.00', with rounded grains, fairly fine grained at base, sharp lower contact on colour.	Sst.	CALC
1809.53	1816.53	7.00	Light grey, fine grained, fairly clean, ripple laminations with abundant light grey green shaley streaks and laminations, finer grained at base, sharp lower contact.	Sst.	CALC.
1816.53	1823.66	7.13	Light grey green, very fine grained, weakly calcareous, bioturbated (?), light grey green disrupted shale laminations sharp lower contact.		
1823.66	1824.46	0.80	Light grey, fine to medium grained, with medium to dark grey mica rich zones especially at the top and at the bottom sharp lower contact	Sst.	CALC.
1824.46	1825.08	0.62	Light grey to white, slightly calcareous, very fine grained, fairly clean, abundant cement, sharp lower contact.	Sst.	
1825.08	1826.56	1.48	Light grey, fairly clean with some mica zones, faint planar laminations and planar cross laminations, sharp lower contact.	Sst.	CALC.
1826.56	1834.96	8.40	Light grey, planar cross laminated, alternating medium grey and light grey to white laminations, white laminations have calcite cement, fine grained, gas show 1827.40' to base, sharp lower contact.	Sst.	XBD.
1834.96	1835.96	1.00	Light grey, fine to medium grained, weakly calcareous, zones of floating course grains in fine to medium grained matrix, sharp lower contact on colour and grainsize.	Sst.	
1835.96	1836.28	0.32	Light grey, very fine grained, massive, silty, slightly calcareous, sharp lower contact	Sst.	
1836.28	1836.41	0.13	Medium grey green, non-calcareous, sharp lower contact.	Slst.	
1836.41	1836.78	0.37	Medium grey green, non-calcareous, few floating coarse grains, sharp lower contact.	Sst.	
1836.78	1838.73	1.95	Light grey, fine to medium grained, scattered coarse grains floating in matirx, few pyrite nodule, sharp lower contact.	Sst.	
1838.73	1839.36	0.63	Light grey with light grey green streaks, fine to medium grained, sharp, irregular lower contact.	Sst.	
1839.36	1840.94	1.58	Light grey, fine grained, quartzose, with dark grey mica laminations especially 1840.30' - base, sharp lower contact.	Sst.	QTZ.
1840.94	1842.87	1.93	Light grey, medium grained, mostly quartz with moderately abundant black pyrite organic grains up to 1mm in diameter odour of oil, sharp lower contact.	Sst.	
1842.87	1843.17	0.30	Light grey, very fine grained, mica, planar cross laminated, sharp lower contact.	Sst.	

1843.17	1845.70	2.53	Light grey, medium grained, mostly quartz, moderately abundant pyritic organic grains up to 1mm, planar cross laminations, show of gas, sharp lower contact.	Sst.	
1845.70	1847.12	1.42	Light grey, fine grained, some mica, massive, light oil smell show of gas, sharp lower contact.	Sst.	
1847.12	1851.31	4.19	Light grey, fine grained, ocassional mica, non-calcareous, planar cross laminated, mica on surfaces, ocassional shale clasts, show of gas, some change in lamination direction, sharp lower contact.	Sst.	XBD.
1851.31	1852.30	0.99	Light grey, fine to medium grained, abundant light to medium grey shale clasts, sharp lower contact.	Sst.	Sh. CLS.
1852.30	1854.25	1.95	Light grey, planar cross laminated similar to unit two above this one, sharp lower contact.	Sst.	
1854.25	1857.15	2.90	Light grey, fine grained, mostly quartz, massive to 1.00', planar ripple laminated from below top 1.00' to base, large medium grey shale clasts at top and at 1855.25', finer shale streaks and clasts 1856.20' - 1856.50', sharp lower contact.	Sst.	
1857.15	1861.50	4.35	Light grey, fine grained, ripple laminated, fine mica, occasional medium grey shale streaks, gradational lower contact with bedding change.	Sst.	
1861.50	1863.29	1.79	Light grey, fine grained, faintly planar cross laminated, mica in top 0.50', massive below, sharp lower contact on gas show	Sst.	QTZ.
1863.29	1864.31	1.02	Fine grained, planar laminated to planar ripple laminated, slightly inclined, abundant mica, oil odour, gas show, sharp lower contact.	Sst.	XBD.
1864.31	1870.65	6.34	Light grey, fine grained, massive, gas show, occasional medium grained grey shale clasts particularly abudant in basal 1.20', sharp lower contact, gas show and oil shows 1867.50' -base, large vertical fractures 1867.00" - 1867.50'	Sst.	QTZ.
1870.65	1871.70	1.05	Medium grey with light grey, very fine sandstone streaks in basal 0.30' irregular sandston masses in top 0.30' (part of - slump), sharp lower contact.	Sh.	Sst. STR.
1871.70	1872.72	1.02	Light grey, fine grained, mostly quartz, moderately abundant medium grey shale clasts 5 mm long, shale streaks in basal 0.10', sharp lower contact.	Sst.	
1872.72	1872.98	0.26	Medium grey, fine mica, pyrite, sharp, angular lower contact.	Sh.	
1872.98	1876.72	3.74	Fine grained, light grey, dark mica streaks, ripple laminated, abundant mica, medium grey shale bands at 1876.70' - base sharp lower contact.	Sst.	
1876.72	1880.56	3.84	Light grey, fine grained, some mica, fairly clean, gas show/ oil odour, medium grey shale layer 1880.08' - 1880.13', sharp lower contact on grain size.	Sst.	
1880.56	1881.60	1.04	Light grey, fine grained, abundant medium grey shale clasts and pebbles, light green, shale streaks, abundant black organic streaks, large medium grey shale clasts 1881.42' - 1881.45', sharp lower contact.	Sst.	Sh. CLS.
1881.60	1883.93	2.33	Medium grey, silty, sharp lower contact on grain size change.	Sh.	
1883.93	1887.38	3.45	Medium grey, slightly silty, few slickensides, light grey and red clasts, shale zone 1884.00' - 1884.20' with gas show, no fossils seen, gradational contact on colour and composition	Sh.	
1887.38	1889.17	1.79	Medium dark grey, fine with fine mica, slickensides, zone of faint, fine to coarse, light and medium grey shale clasts from 1887.60' - 1887.20', lenses of very fine grained sandstone with medium grey brown shale clasts within lower 0.40', no fossils seen, wavy sharp lower contact.	Sh.	
1889.17	1891.54	2.37	Light grey green, fine grained, low angle planar laminations and ripple laminations, abundant dark minerals and ripple laminations, abunadant dark minerals and rock grains, mica, dark mica rich streaks in basal 0.20', sharp lower contact on colour and composition, gas show (73 units).	Sst.	

1891.54	1897.85	6.31	Light grey, medium grained, dark minerals, rock grains, mica mostly multi-directional ripple cross laminations from top to 1895.00' - base, few medium grey shale clasts & occasional streaks across core from top to 1895.30', irregular dark grey shale clasts from 0.03' to 0.30' across at 1895.25', moderately abundant dark grey shale clasts from 3mm to 3cm long from 1895.00' to base, gas show (93 units) high angle sharp lower contact.	Sst.	Sh. CLS.
1897.85	1898.20	0.35	Dark grey, slickensides, few organic rich fragments, may be very large clast at top of lag deposit, sharp lower contact.	Sh.	
1898.20	1900.07	1.87	Light grey, fine grained, very abundant, closely packed medium grey shale clasts 5mm to 2cm thick and extending across core, channel lag deposit, sharp lower contact.	Sst.	Sh. CLS.
1900.07	1905.00	4.93	Medium grey with occasional light to medium grey bands, fine, occasional fine mica, fissile, occasional possible sand filled burrows below 1902.00', light grey, very sandy/ silty bands from 1902.44' - 1902.60' - 1903.69', no fossils seen, arbitrary, gradational lower contact.	Sh.	
1905.00	1952.67	45.67	Shale is a medium grey, fine, fissile beds from 0.05' to approximately 1.00' thick, some light to medium grey silty zones especially at 1909.00', no fossils seen, occasional grey brown sideritic bands up to 0.10' thick throughout, interbedded with light grey, very fine grained silty, sandstone bed and irregulat lenses from 0.03' - 0.90' thick, occasional burrows evident throughout, some pyritized, some soft sediment deformation or general bioturbation in sandstone.	Sh.	Sst. INBD.
1952.67	1964.78	12.11	Sandstone beds are light grey, very fine-grained, very micaceous, silty, predominantly planar with some low angle planar cross laminations and few zones of slight ripple laminations, more discrete beds with much less soft sediment deformations than unit above, beds vary from 0.05' - 1.40' thick occasional horizontal and vertical burrows, especially from 1962.00' to 1963.00', shale beds are medium grey from 0.05' to 0.30' thick, some fine organic fragments, some pyritized, fissile, fine.	Sh.	Sst. INBD.
1964.78	1965.97	1.19	Medium dark grey, slightly silty, fine mica, no fossils seen, sharp lower contact.	Sh.	
			TOP OF SQUAW SANDSTONE MEMBER		
1965.97	1979.00	13.03	Light grey, fine grained, moderately abundant rock grains, mica, zones of rippled mica streaks, zones of ripple cross laminations, flat ripple laminations, massive & planar cross laminations, thin shale laminations at 1973.35', dark grey, fine shale clasts from 1973.95' to 1974.07', large shale clasts at 1975.15, strong gas show throughout, gradational lower contact on composition change.	Sst.	
1979.00	1981.55	2.55	Light grey, fine grained, 'cleaner' but still many dark grains, occasional organic grains, occasional mica, faint planar laminations in top 0.50', massive to base, gas show, sharp lower contact.	Sst.	
1981.55	1981.74	0.19	Abundant rounded and long streaks of pyrite in a matrix of fine sand, mica and abundant coalified organic material, sharp lower contact, gas show.	Pyr.	
1981.74	1985.10	3.36	Light grey, fine grained, 'cleaner' but still dark grains, occasional organic grains, weakly developed stylolites, breaks in poker chips' from 1982.70' to 1983.00', light medium grey shale clasts from 1984.35' to 1984.80', gas show throughout faintly planar cross to ripple laminate, sharp lower contact with shale.	Sst.	
1985.10	1985.15	0.05	Medium grey, thin bed or large clasts, sharp lower contact.	Sh.	
1985.15	1985.37	0.22	Light grey, fine grained, ripple laminated to ripple cross laminated, bright coalified organic material, pyrite nodules, streaks, gas show, gradational lower contact.	Sst.	
1985.37	1986.20	0.83	Medium dark grey, few faint, thin, very fine grained sandstone streaks in transitional zones at top and bottom of unit, carbonaceous or coaly plant fragments, gradational lower contact.	Sh.	

1986.20	1986.67	0.47	Light grey, very fine grained, mica and rock grains, carbonaceous or coaly organic material, ripple laminated to ripple cross laminated, high angle sharp lower contact, gas show.	Sst.	
1986.67	1986.75	0.08	Medium grey with dark grey to black clasts, probably large clasts, high angle sharp lower contact.	Sh.	
1986.75	1989.34	2.59	Light grey, fine grained, dark material and few rock grains, few grains, few coarse organic grains or small clasts, minor mica, massive, sharp lower contact on bedding change.	Sst.	
1989.34	1990.39	1.05	Light grey, very fine grained, mostly flat ripple laminated with some ripple cross laminations to base, abundant mica rich laminations, gas show, angular, sharp lower contact.	Sst.	
1990.39	1992.63	2.24	Light grey, fine grained, minor mica, moderately abundant very fine grained, dark (organic?) grains with few coarse grains, organic grains, planar laminations, few dark grey, thin shale streaks in basal 0.60', gas show sharp lower contact.	Sst.	
1992.63	1992.98	0.35	Light grey, fine grained, one large, irregular, black shale from 1992.68' - 1993.76', other fine to coarse medium grey to dark grey shale clasts, pyrite nodules, sharp lower contact, gas show.	Sst.	Sh. CLS.
1992.98	1998.50	5.52	Light grey, fine to medium grained, quartz with minor dark minerals, mica and organic grains in top 1.00' moderately abundant rock grains, organic grains, mica in rest of unit, massive in top 1.00', rest shows of planar laminations to planar cross laminations with changing directions, some minor planar laminated zones, mica rich zone from 1995.75' to 1996.00', gas show, sharp lower contact.	Sst.	
1998.50	1998.68	0.18	Light grey, fine grained, with light grey brown, rounded and elongated siderite pebbles, gas show, high angle sharp lower contact.	Sst.	FeSt. INCL.
1998.68	1999.33	0.65	Light grey, medium grained, quartz with minor accessory minerals, faint planar cross laminations, 'poker chip' fractures in basal 0.30', sharp lower contact. Gas show.	Sst.	QTZ.
1999.33	1999.64	0.31	Light grey, fine grained matrix with abundant rounded to lenticular siderite pebbles up to 13 mm diameter and 5cm long, few dark shale pebbles, high angle sharp lower contact. Gas show.	Sst.	FeSt. INCL.
1999.64	2001.24	1.60	Light grey, fine grained, moderately abundant mica, dark mineral grains, rock bands, faint flat ripple laminations, gas show, sharp lower contact.	Sst.	
			BASE OF SQUAW SANDSTONE MEMBER		
2001.24	2002.66	1.42	Light grey, very fine grained, mostly ripple laminated in laminations from 0.02' and bes to 0.30' thick with medium grey shale laminations from 0.01' to beds 0.25' thick, gradational lower contact.	Sst.	Sh. INBD.
2002.66	2005.56	2.90	Light to medium grey, silty and sandy, poorly bedded, possible plant or bivalve at 2002.80', vertical fracture from 2003.10' to 2003.50', angular, sharp lower contact.	Sh.	
2005.56	2006.80	1.24	Light to medium grained grey, very fine grained, planar laminated to flat ripple laminated, bioturbated (burrowed?) or soft sediment deformation at 2005.90' and in basal 0.15', few light grey to brown siderite pebbles in top 0.15', dark grey shale break from 2006.16' - 2006.20', sharp lower contact.	Sst.	
2006.80	2007.40	0.60	Medium grey, silty, micaceous, hard, siderite pebbles in base, sharp lower contact.	Sh.	SLTY.
2007.40	2013.58	6.18	Medium to dark grey laminations and thin beds from 1 -2 mm to 2 cm thick, interlaminated/ interbedded with light to medium grey very fine grained to silty ripple laminations & beds, from 1 -2 mm to 2 -3 cm thick, common mostly horizontal sand filled burrows, pelecypods (?) at 2007.50', no others seen, sharp lower contact at increasing sand and gas show.	Sh.	BRW.
2013.58	2015.19	1.61	Light grey, very fine grained, ripple laminated sandstone beds 0.03' to 0.40' thick, gas detected but not visible, sharp lower contact.	Sst.	Sh. INBD.

2015.19	2016.25	1.06	Light grey, very fine grained with moderately abundant light grey and light grey brown mostly elongate, siderite pebbles up to 6cm long and 1.75 cm thick, possbile bivalves in basal 0.07', sharp lower contact.	Sst.	FeSt. INCL.
2016.25	2017.60	1.35	Medium grey, very fine, fissile, featureless but for an occasio-ional fine pyritic nodule, no fossils seen, gradational lower contact at increasing sandstone with depth.	Sh.	
2017.60	2018.90	1.30	Medium grey with a few light to medium grey, very fine grain-ed, faint sandy laminations less than 5 mm thick, no fossils seen, sharp lower contact at colour and texture change.	Sh.	Sst. STR.
2018.90	2019.90	1.00	Light to medium grey, hard, fine mica, sharp lower contact.	Sh.	SLTY.
2019.90	2026.02	6.12	Medium grey, fissile, fine, few light grey, very fine grained, rippled sandstone streaks approximately 5mm to 1cm thick, increasing to basem very nicey preserved orbiculoids showing relief at 2024.68', no other fossils seen, zone of medium gr-ained white sand in shale from 2024.85' - 2024.97', one sand-stone streak with sharp/ angular top & bottom contacts, fine grained, light grey, 0.14' thick at 2025.35', occasional faint silty streaks 2025.23' - base, sharp, angular lower contact.	Sh.	
			TOP OF WEIR SANDSTONE MEMBER		
2026.02	2030.38	4.36	Fine grained, light grey to white, very clean with very faint low angle to flat planar cross laminations, occasional darker silty streaks, dark grey shale streaks 0.02' thick at 2029.70', occ-asional angular shale rip-ups, very fine grained to 0.04' long 2030.18' to base, sharp lower contact on colour and lithology.	Sst.	
2030.38	2033.75	3.37	Light grey, fine to very fine grained, with dark grey shale str-eaks & thin beds to 0.20', faint planar to ripple remnant bed-ding below 2033.00', shale contains some pyritized and coaly plant fragments, gassy smell at 2031.10' - 2031.35', very hard and crystalline sandstone 2032.10' - 2031.38', more grey than other sand with 'poker chip' fractures, very clean quartz arenite (?), sharp lower contact on colour and start of gas show, locally small.	Sst.	Sh. STR.
2033.75	2044.42	10.67	Fine grained, light grey, gas show, flat planar laminations top to 2034.90', non bedded 2034.90' - 2036.25' with 2 low angle planar cross laminations at 2035.33', flat planar cross lamin-ations 2036.25' - 2036.54', low angle, approximately 15 degree planar laminations grading to non bedded at base 2036.54' - 2037.45', slightly silty, light medium grey to grey with flat plan-ar laminations 2037.45' -2038.65', non bedded 2038.65 - 2038.8 thin shaley medium grey streaks with	Sst.	
2044.42	2044.52	0.10	Gas show, light medium grey, flat bedded, hard sharp lower contact on colour and lithology.	Slst.	SDY.
2044.52	2045.00	0.48	Light grey, fine grained, non bedded, very clean possibly qtz. arenite at top, very well cemented, sharp lower contact on lithology, gas show.	Sst.	
2045.00	2047.00	2.90	Light grey, fine grained, lithic arenite, rounded grains, low angle planar laminations and flat planar laminations, locally non bedded, occasional thin mm scale silty / shaley / or mica rich streaks, low angle planar cross beds 2045.00' - 2046.62', flat planar ripple laminations 2046.62' - 2047.89', possible dewat-ering feature at 2046.65', silty streaks 2047.89' - 2047,90', sharp lower contact at base of silty streaks.	Sst.	
2047.00	2050.86	2.96	Fine grained, light grey to white, very hard, well cemented, nearly a quartz arenite, darker mineral streaks 2049.00' - 2050.07', non bedded 2050.07' - 2050.84', sharp lower cont -act on increase of streaks	Sst.	
2050.86	2053.11	2.25	Fine grained, light grey, hard, clean with few scattered dark mineral streaks less than 1 mm, low angle planar cross beds very weakly calcareous below 2049.00', locally mica rich streaks, sharp lower contact on lithology.	Sst.	
2053.11	2053.57	0.46	Medium grey with lighter grey sandy / silty streaks, abundant plant debris, mica, very weakly calcareous in silt-rich zones, pyrite blebs, thin and elongate to 0.07' x 1mm to base, wavy lower contact on lithology.	Sh.	SLTY.

2053.57	2054.25	0.68	Fine grained, light grey, dark thin mineral rich streaks throughout, flat planar laminations on top 0.50', low angle planar lamination to base, base sharp on bedding.	Sst.	
2054.25	2056.44	2.19	Fine grained, non bedded, weakly calcareous to 2056.23', well cemented with few rock fragments, well rounded grains, sharp, angular, lower contact on lithology and colour, pyritized shale fragments at 2056.16'.	Sst.	
2056.44	2056.58	0.14	Medium grey, with light grey sandy streaks, low angle to flat planar bedding, sharp lower contact on lithology.	Slst.	SDY.
2056.58	2057.55	0.97	Very fine grained, locally very weakly calcareous, low angle to flat planar laminations, sharp lower contact on lithology.	Sst.	
2057.55	2059.15	1.60	Light medium grey, very fine grained, locally silty, very weakly calcareous, dirty sand, silty streaks 0.02' thick, medium grey at 2058.16', low angle planar laminations to massive throughout, very faint bedding, occasional coarse sandstone pebbles to base, base sharp on lithology.	Sst.	
2059.15	2059.32	0.17	Medium grey, abundant fossil plant trash, lower 0.07' is channel lag with coarse light grey, sandstone pebbles, medium grey shale pebbles and rock fragments up to 0.04' x 0.10', whole unit may be channel lag, sharp lower contact on lithology.	Sh.	
2059.32	2059.71	0.39	Light grey, very fine grained grades to siltstone, grey at base, low angle planar cross laminations, mica, calcareous zone ends at 2059.55', sharp lower contact on lithology & colour.	Sst.	CALC.
2059.71	2059.92	0.21	Light grey, fine grained, slightly silty, dirty sandstone with medium grey shale streaks to 0.05' thick, sharp lower contact on lithology.	Sst.	Sh. STR.
2059.92	2063.82	3.90	Very fine grained, light grey to grey, very faint low angle planar laminations to non bedded locally weakly calcareous, gas show 2045.00' - 2063.80', very occasional carbonized plant fragments, thin fossil hash approximately 0.01' at 2061.90' with crinoid columnals, brachiopod fragments, some of the crinoid parts appear to be more 5 sided than round, possible pelecypods in lower 0.10' has few very thin shale rip-ups less than 1mm x 5mm, sharp lower contact on lithology.	Sst.	
2063.82	2064.70	0.88	Medium grey with silty streaks, light medium grey to grey, micaceous, occasional scattered plant material, sharp, wavy lower contact on lithology.	Sh.	
2064.70	2067.84	3.14	Medium grey, with dark grey shale with medium dark grey silty streaks, occasional thin very fine grained sandy streaks at top, silty streaks to base, occasional irregular pyritized masses < 0.02' scattered below 2066.50', horizontal burrows 2067.75', very occasional, very small coaly plant trash, sand streaks have ripples, sharp lower contact on colour and lithology.	Sh.	Sst. STR.
2067.84	2069.35	1.51	Grey to light medium grey, flat planar laminations, very fine grained sandy grains scattered throughout, sharp lower contact on colour and lithology.	Slst.	
2069.35	2088.62	19.27	Dark grey, with medium to dark grey siltstone streaks less than or equal to 1mm, flat bedded, horizontal and vertical burrows, occasional very fine grained, light grey sandy streaks possible micro fault at 2073.40', rounded irregular pyrite blebs at 2076.50', locally micaceous, scattered plant trash, few medium to coarse, distinct irregular to rounded, siderite nodules below 2085.00', very fine mica on some bedding planes, burrows diminish.	Sh.	Sst. INBD.
2088.62	2090.23	1.61	Light grey, very hard, weakly to non-calcareous top to 2088.72', moderately to strong 2088.72' - 2089.89', non-calcareous to base, slightly darker grey top and bottom, fairly non-bedded except for one visible flat planar lamination to base, sharp lower contact on colour and lithology.	Slst	CALC.
2090.23	2090.40	0.17	Medium dark grey, very occasional scattered plant debris, sharp lower contact on lithology and colour.	Sh.	
2090.40	2093.68	3.28	Grey with occasional dark grey shale streak in upper 0.20', slightly sandy (very fine grained) to base, flat bedded, occasional mica, very weakly calcareous in zones, either thin dark grey shale wisps or very poorly preserved shells at 2091.81', dense, sharp lower contact.	Slst.	

2093.68	2095.00	1.32	Light grey, slightly darker top to 2094.00' possibly bioturbated, occasional medium grey shaley clasts in upper half, mica sharp lower contact on lithology and colour.	Slst.	
2095.00	2108.01	13.01	Medium dark grey with light grey siltstone streaks up to 0.08', abundant horizontal burrows, occasional vertical burrows, non-bedded siltstone bed 2098.77' - 2099.30', increasingly silty to 2105.00', grades to siltstone with shale streaks at base, bioturbated 2105.00' to base, very occasional poorly preserved plant trash (some pyritized).	Sh.	Slst. INBD.
2108.01	2112.93	4.92	Medium to dark grey with light grey silty streaks, slightly bioturbated with horizontal burrows, otherswise flat bedded, occasional scattered partially pyritized plant debris, one shell fragment, possibly on orbiculoid at 2110.59', increasingly silty to base with scattered mica, sharp lower contact on lithology.	Sh.	Slst. INBD.
2112.93	2125.20	12.27	Light grey with medium grey shale streaks, locally very burrowed, especially to top, mica, one shell fragment at 2114.50' increasingly bioturbated to base, calcareous band at 2112.52' - 2112.54', 2113.04' - 2113.07', very hard 2113.50' to 2125.00' sharp lower contact on colour, large J-shaped burrow approx. 0.15' at base on unit into next unit.	Slst.	
2125.20	2131.63	6.43	Medium grey, nearly a shale, flat bedded with occasional light grey, very, very fine grained sandy or silty streaks, scattered fine mica, truncated ripples or movement created feature that appears similar to a Lepidodendron impression at 2125.82', well bedded, purer silt to base with ripple laminations, sharp lower contact on lithology and colour, very hard basal 0.40'.	Slst.	
2131.63	2135.65	4.02	Dark grey with light grey silty streaks, abundant burrowing, pelecypod at 2133.10', 2133.78', pelecypods & other scattered fragments, very bioturbated 2135.00' to base, sharp lower contact on colour.	Sh.	FOSS.
2135.65	2138.65	3.00	Light grey to grey with medium grey shale streaks, non bedded to 2136.11', bioturbated 2136.11' to base, occasional small shale pebbles 2136.24', mica, sharp lower contact on colour and lithology.	Slst.	Sh. STR.
2138.65	2140.60	1.95	Medium grey, with light grey to grey silty streaks, bioturbated, orbiculoid at 2139.24', sharp lower contact on increasing silt.	Sh.	SLTY
2140.60	2145.15	4.55	Light grey, with dark grey shale streaks below 2141.85', very bioturbated top 2141.00', non bedded with weakly calcareous 2141.00' - 2141.85', sharp lower contact.	Slst.	Sh. STR.
2145.15	2166.68	21.53	Medium grey to dark grey with light grey to grey silty streaks and zones up to 0.40', bioturbated throughout, locally very heavily, especially at 2150.90' - 2151.50', 2154.05' - 2154.50', and 2156.00' - 2157.00', 2165.00' - 2165.00', occasional scattered plant debris, two brachiopods and one pelecypod at 2145.62', small branched crinoid arm at 2146.11', locally micaceous, pelecypod at 2148.90' to 2165.00', increasingly shaley to base, medium grey with	Sh.	FOSS.
2166.68	2167.34	0.66	Light grey to grey, faint very low angle planar beds, sharp lower contact on lithology and colour.	Slst.	
2167.34	2174.03	6.69	Medium grey with light grey to grey siltstone streaks and thin beds, hard, occasional vertical burrows, flat planar to ripple laminations, poorly preserved plant debris, bivalve fragments at 2172.20', pelecypod fragments at 2172.88', sharp lower contact on lithology.	Sh.	Slst. INBD.
2174.03	2194.89	20.86	Grey with dark grey streaks, burrowed, abundant pelecypods, 2176.80' - 2177.10', increasing burrows below 2180.00', pelecypods 2181.83' - 2185.00', coalified and partially pyritized plant stem at 2184.46', scattered pelecypods 2185.00 - 2192.50', very bioturbated 2185.00 to base, increasingly shaley to base, arbitrary lower contact.	Slst.	FOSS.
2194.89	2205.00	10.11	Medium grey, flat bedded, silty streaks throughout, light grey, hard, flat ripple laminations below 2202.30', occasional thin pyritized plant debris below 2204.00', occasional very dark grey thin < 0.01' shale streaks, sharp lower contact on lithology.	Sh.	SLTY.

2205.00	2206.15	1.15	Grey, abundant burrows throughout increasing to base, shaley wisps throughoutm sharp lower contact with thin zone on mixing.	Slst.	BRW.
2206.15	2209.42	3.27	Light grey to grey with dark grey shaley zones, hard, occasional small pelecypods throughout below 2207.60', orbiculoid 2208.05', burrowed to base, arbitrary lower contact on increasing burrows.	Slst.	FOSS.
			TOP OF MURRYSVILLE SANDSTONE MEMBER		
2209.42	2212.33	2.91	Grey to light grey, gas show 2209.63' - 2209.71', faint planar laminations, horizontal and vertical burrows, sharp lower contact on lithology.	Slst.	BRW.
2212.33	2212.78	0.45	Light grey, weakly calcareous, faint planar beds, sharp lower contact on lithology.	Slst.	CALC.
2212.78	2221.50	8.72	Light grey, grey and medium grey mixed, horizontal and vertical burrows, gas show 2213.50' - 2215.20' in quartz pebble conglomerate lag, 2217.17' - 2220.78', occasional very thin dark grey mixed shale streaks, pyritized shale or siderite pebbles at 2216.50', 2217.30', locally micaceous, silty shale streaks, dark grey 2220.77' - 2220.96', sharp lower contact on lithology.	Slst.	BRW.
2221.50	2223.08	1.58	Very fine grained with coarse grained quartz pebble conglomerate at base, grey, medium grey mixed with abundant dark silty matrix, gas show 2222.07' - 2223.08', rounded shale pebbles to 0.06' diameter, silty or shaley streaks throughout, sharp lower contact.	Sst.	
			BASE OF MURRAYSVILLE SANDSTONE MEMBER		
2223.08	2236.26	13.18	Dark grey, occasional very fine mica concentrations, pelecypod fragments at 2228.48', very small carbonaceous and pyritized plant fragments, occasional thin concentrations of fine grained sandstone in wisps, unidentified shell fragment at 2233.98', slightly silty to base, gradational lower contact on increasing silty streaks.	Sh.	
2236.26	2240.91	4.65	Dark grey with light grey to grey silty streaks and zones, increasing to base, bioturbated, two very well preserved pelecypods at 2236.44', increasingly bioturbated to base, micaceous, small plant fragments, very fine grained, light grey sandy wisps, sharp lower contact.	Sh.	FOSS.
2240.91	2242.58	1.67	Light grey to grey, shaley and sandy streaks, fairly flat bedded with rounded sandy slugs, coarse grained sandy streaks, 2241.68' - 2241.81', with some mixing of coarse grains below, possible burrows, pyritized plant fragments, sharp lower contact on burrows below.	Slst.	
2242.58	2246.74	4.16	Light grey to grey with vertical and horizontal burrows, sharp lower contact.	Slst.	BRW.
2246.74	2249.60	2.86	Medium grey to dark grey, occasional pyrite, occasional siderite nodules at 2247.30', brachiopod at 2248.50', sharp lower contact.	Sh.	FOSS.
2249.60	2254.84	5.24	Burrowed, grey with medium to dark grey shale streaks, slightly increasing shale to base, pyrite blebs at 2250.75', mica, pyritized plant fragments, sharp lower contact on lithology.	Slst.	Sh. STR.
2254.84	2255.36	0.52	Grey, burrowed at top 0.10', low angle planar cross laminations, sharp lower contact.	Slst.	
2255.36	2255.64	0.28	Grey, slightly angular sharp lower contact.	Slst.	BRW.
2255.64	2255.74	0.10	Dark grey, sharp lower contact.	Sh.	
2255.74	2260.57	4.83	Grey with medium grey shale streaks, gas show 2256.00' - 2257.00', locally micaceous, pyritized plant fragements, cleaner silt to base, high angle fractures at 2259.40' and 2260.25', sharp lower contact on lithology.	Slst.	Sh. STR.
2260.57	2267.48	6.91	Grey with dark grey to medium grey shale streaks, slightly ripples, occasional burrows, locally small mica, grades to darker grey at base, rare scattered plant debris, some pyritsed.	Slst.	Sh. STR.

2267.48	2268.10	0.62	Sand streaks, dark grey with light grey to grey silty and sandy streaks, possible tooth fragment at 2267.53', slightly burrowed sharp lower contact on lithology.	Sh.	SLTY.
2268.10	2268.22	0.12	Grey with finely disseminated pyrite in fan shape, plant fragments, sharp lower contact on lithology.	Slst.	

APPENDIX III – SAMPLE DESCRIPTIONS

WILLIAMS COUNTY CORE, OH.

Sample No. **Lithostratigraphic Unit** **Sample Depth in ft.**

WC24 TCD59645 Coldwater Shale Formation (198'10" – 192'2")

Sample contains well preserved, assemblages dominated by various species of *Spelaeotriletes* and *Vallatisporites*. Assemblages include *Spelaeotriletes balteatus*, *S. cabottii*, *S. pretiosus*, *S. resolutus*, *Raistrickia clavata* and *Vallatisporites* spp.

WC21 TCD59644 Coldwater Shale Formation (303'7" – 303'11")

Sample contains an unusual acanthomorph acritarch assemblage; *Micrhystridium stellatum* abundant. Small Leiospheres present. Miospores assemblage well preserved but taxonomic diversity low; species include: *Spelaeotriletes balteatus*, *S. pretiosus*, *Umbonatisporites distinctus* and *Vallatisporites ciliaris*. Occasional particles of brown AOM.

WC20 TCD59643 Coldwater Shale Formation (325'8" – 326')

Sample contains degraded phytoclasts and few poorly preserved spores.

WC23 TCD59442 Sunbury Shale Formation (326'7" – 326'11")

Sample contains only small fragments of highly degraded phytoclast. Miospores very rare.

WC3 TCD59441 Sunbury Shale Formation (333'1" – 333'5")

Sample contains large amounts of brown AOM. No spores recorded, rare Leiospheres present.

WC22 TCD59640 Sunbury Shale Formation (336'4" – 336'8")

Sample contains large amounts of AOM. No spores recorded, rare Leiospheres present.

WC4 TCD59639 Sunbury Shale Formation (339'8" – 340')

Sample contains large amounts of brown AOM similar to that recorded in the samples above and below. No spores recorded in this sample. Rare Leiospheres present.

WC19 TCD59638 Sunbury Shale Formation (340'8" – 340'11")

Sample contains large amounts of brown AOM, which occur as large 'clumps' with 'entrained' pyrite crystals. No spores, acritarchs or scolecodonts recorded at this level. Palynofacies of this sample contrasts with samples immediately below signifying a change in depositional environment.

WC18 TCD59637 Bedford Shale Formation (343'8" – 344')

Sample contains a well preserved and diverse miospore assemblage; spores pale translucent to yellow in colour. Species recorded includes *Cordylosporites marciae*, *Knoxisporites* cf. *triradiatus*, *Retispora lepidophyta*, *Retusotriletes incohatus*, *Rugospora radiata*, *Vallatisporites hystricosus* and *V. verrucosus*. Scolecodonts present. The sample contains a relatively diverse acritarch assemblage containing species including *Gorgonisphaeridium ohioense*, *G. winslowiae* and *Puteoscortum polyankistrum*.

WC17 TCD 56767* Bedford Shale Formation (347'5" – 347'9")

Miospore relatively well preserved; spores typically orange in colour. Assemblage includes specimens assignable to *Emphanisporites rotatus*, *Pustulatisporites* spp., *Verrucosisporites nitidus* and *Retispora lepidophyta*. Tasmanites and Leiospheres both abundant. Acritarch assemblages include *Hystricosphaeirdium* spp., *Gorgonisphaeridium* spp., *Micrhystridium* spp. and *Puteoscortum polyankistrum*.

WC16 TCD59636 Bedford Shale Formation (349'9" – 349'7")

- Slide missing

WC15 TCD 56766* Bedford Shale Formation (353'4" – 353'7")

Relatively diverse miospore assemblages, species recorded include *Punctatisporites* spp., *Reticulatisporites* spp., *Vallatisporites hystricosus*, and *V. pusillites*. Acritarchs present; *Gorgonisphaeridium* spp. common. Pyrite crystals abundant. Specimens of *Tasmanites* spp. abundant; commonly pyritised.

WC14 TCD59635 Bedford Shale Formation (353'4" – 353'7")

Miospore assemblages of relatively low diversity species include *Cordylosporites marciae*, *Laevigatosporites* spp. *Retispora lepidophyta*. Spores pyritised. 'Fluffy' AOM abundant, orange/ brown in colour. Tasmanites present.

WC13 TCD59634 Bedford Shale Formation (355'5" – 355'8")

- Slide missing

WC12 TCD59633 Bedford Shale Formation (356'3" – 359'7")

Sample contains large amounts of orange/ brown AOM, Tasmanites and acanthomorph acritarchs. Miospore assemblage consists primarily of simple laevigate spores e.g. *Punctatisporites* spp. and *Retusotriletes* spp. Some rare specimens *Retispora lepidophyta* and *Vallatisporites* spp.

WC11 TCD 56765* Bedford Shale Formation (359'3" – 359'7")

Miospores poorly preserved; assemblage of low diversity; spores typically pale yellow in colour. Small 'clusters' of AOM (~50μm) are present as are fragmented phytoclasts. Tasmanites and acritarchs both present.

WC10 TCD59632 Bedford Shale Formation (360'9" – 361'1")

Phytoclast material consists of a mix of well preserved opaque woody fragments, and highly degraded cuticle. Acritarch assemblage moderately diverse. Tasmanites and acritarchs both well preserved. Miospore assemblage well preserved and highly diverse; spores yellow in colour; *Retispora lepidophyta* common.

WC9 TCD59631 Bedford Shale Formation (362'5" – 362'9")

Sample contains significant quantities of highly degraded and fragmented phytoclast material. Acritarchs present. Miospore diversity moderately high and preservation typically good; spores yellow/orange in colour. *Retispora lepidophyta* common.

WC8 TCD59630 Bedford Shale Formation (366'5" – 355'8")

Assemblage consists primarily of degraded phytoclast matter and miospores. Miospores well preserved and diversity is moderately high. *Retispora lepidophyta* present in

abundance. Acritarchs also present. Miospores in this sample are typically orange/ yellow in colour and contrast with the acritarchs which are essentially transparent.

WC7 TCD59629 Bedford Shale Formation (370'6" – 370'10")

This sample contains predominantly phytoclast material poorly preserved miospores; yellow/ orange in colour. Tasmanites and acritarchs both present in abundance. Miospore assemblages of relatively low diversity; dominated by simple laevigate forms including *Retusotriletes incohatus*. AOM present.

WC6 TCD59628 Bedford Shale Formation (375'4" – 375'8")

Sample contains virtually no AOM when compared with those immediately below. Occasional poorly preserved *Retispora lepidophyta*.

WC5 TCD59627 Uppermost Antrim Shale (376'7" – 377'1")

Large amounts of AOM, orange/ brown in colour, present as small fragments (<60μm) in diameter. Miospore diversity and abundance low, preservation moderately good; spores yellow/orange in colour.

WC1 TCD59626 Upper Antrim Shale (571' – 571'3")

Sample contains large amounts of orange/ brown AOM which contains small pyrite crystals. Miospore preservation very poor, diversity very low. Tasmanites present.

WC2 TCD59625 Upper Antrim Shale (577'3'' – 577'9")

Sample contains large amounts of orange/ brown AOM which contains small pyrite crystals. Miospore preservation very poor, diversity very low. Tasmanites present.

Sample No. **Lithostratigraphic Unit**

SUN4 TCD59625 Berea Sandstone Formation

Miospore assemblage well preserved and diverse. Species recorded include *Archaeozonotriletes* sp., *Murospora dubitata*, *Rugospora radiata*, *Secarisporites* sp. *Teichertospora torquata*, *Vallatisporites hystricosus* and *Verrucosisporites nitidus*. Sample also contains reworked specimens of *Grandispora megaformis*. Low diversity acritarch assemblage comprised primarily of *Gorgonisphaeridium* spp.

SUN3 TCD59623 Bedford Shale Formation

Sample contains a diverse and well preserved miospore assemblage. Species recorded include *Punctatisporites* spp., *Retispora lepidophyta*, *Teichertospora torquata*, *Vallatisporites hystricosus* and *V. pusillites*. *Ancyrospora* and *Hystricosporites* spp. both present. Low diversity acritarch assemblage comprised primarily of *Gorgonisphaeridium* spp.

SUN2 TCD56752* Bedford Shale Formation

Diverse and well preserved miospore assemblage recorded. Miospore assemblage includes *Cordylosporites marciae*, *Gorgonispora crassa*, *Punctatisporites* spp., *Retispora lepidophyta*, *Vallatisporites hystricosus*, *V. pusillites* and *V. verrucosus*. Rare pyritised leiospheres present. Sample devoid of AOM.

SUN1 TCD56751* Bedford Shale Formation

Miospore assemblage well preserved and diverse, species include *Emphanisporites schultzii*, *Gorgonispora crassa*, *Retispora lepidophyta*, *Retusotriletes incohatus*, *Rugospora flexuosa*, *Teichertospora torquata*, *Vallatisporites hystricosus* and *V. pusillites*. *Ancyrospora* and *Hystricosporites* spp. both present. Acritarch assemblage includes *Gorgonisphaeridium* spp. Occasional Tasmanites, Leiospheres and Scolecodonts recorded. Sample devoid of AOM.

Sample No. **Lithostratigraphic Unit**

TL10 TCD59620 Berea Sandstone Formation

Miospore assemblage moderately well preserved; taxonomic diversity relatively low. Species include *Punctatisporites* spp., *Retispora lepidophyta* and *Retusotriletes incohatus*. Some rare *Hystricosporites* spp. recorded. Acritarch assemblage of low diversity, includes rare specimens of *Gorgonisphaeridium* spp. and *Veryhachium* sp.

TL9 TCD59619 Berea Sandstone Formation

Sample contains a moderately well preserved miospore assemblage of low diversity. Species recorded include *Auroraspora macra*, *Calamospora* spp., *Retispora lepidophyta*, *Retusotriletes incohatus*, *Vallatisporites hystricosus* and *V. verrucosus*. Some rare *Hystricosporites* spp. recorded. Spores commonly show pyrite 'scarring'. Leiospheres present but rare.

TL8 TCD59618 Berea Sandstone Formation

Sample contains a moderately preserved low diversity miospore assemblage. Species recorded include *Murospora dubitata*, *Retispora lepidophyta*, *Rugospora radiata*, *Vallatisporites hystricosus* and *V. pusillites*. AOM present.

TL7 TCD59617 Bedford Shale Formation

Sample contains a moderately well preserved and diverse miospore assemblage. Species recorded include *Calamospora* spp., *Cyrtospora cristifera*, *Punctatisporites* spp., *Retispora lepidophyta*, *Vallatisporites hystricosus* and *V. pusillites*. Some rare *Hystricosporites* spp. recorded.

TL6 TCD59616 Bedford Shale Formation

Miospore assemblage well preserved and relatively diverse. *Retispora lepidophyta* abundant. Assemblage includes *Calamospora* spp., *Rugospora radiata*, *Vallatisporites hystricosus* and *V. pusillites*. Occasional *Tasmanites* sp. recorded.

TL5 TCD56756* Bedford Shale Formation

Sample contains a diverse and well preserved miospore assemblage. *Retispora lepidophyta* dominant. Other species recorded include *Retispora lepidophyta*, *Verrucosisporites nitidus*. Some rare *Hystricosporites* spp. recorded. Spores often highly pyritised. AOM absent in the sample. Phytoclast material common. Acritarch assemblage includes *Umbellasphaeridium* sp. *Veryhachium* sp.

TL4 TCD59615 Bedford Shale Formation

Sample almost entirely barren. Very rare *Retispora lepidophyta*, *Vallatisporites hystricosus* and *Tasmanites* sp. recorded.

TL3 TCD56755* Bedford Shale Formation

Miospore assemblages diverse and well preserved. *Retispora lepidophyta* particularly abundant. Other species encountered include *Emphanisporites rotatus*, *Retusotriletes incohatus*, *Vallatisporites hystricosus*, *V. pusillites* and *V. verrucosus*. *Ancyrospora* spp. rare. Sample contains small particles of AOM. Rare reworked specimens of *Grandispora douglastownense*. Acritarch assemblage includes *Gorgonisphaeridium* spp., *Maranhites* sp., *Unellium elongatum*. *Tasmanites* sp. present but rare.

TL2 TCD56754* Bedford Shale Formation

Assemblage dominated by *Retispora lepidophyta*. Miospore assemblage includes *Indotriradites explanatus*, *Retusotriletes incohatus*, *Rugospora radiata*, *Vallatisporites hystricosus*. Sample entirely devoid of AOM. Phytoclast material common; consists of small 'broken' fragments. Acritarch assemblage includes *Gorgonisphaeridium* spp *Tasmanites* present but rare.

TL1 TCD56753* Bedford Shale Formation

Sample contains a highly abundant and well preserved miospore assemblage. Assemblage dominated by *Retispora lepidophyta*. Other miospore species recorded include *Cordylosporites marciae*, *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*, *Rugospora radiata*, *Vallatisporites hystricosus*, *V. pusillites* and *V. verrucosus*. Acritarch assemblage includes *Gorgonisphaeridium* spp and *Unellium elongatum*. Sample entirely devoid of AOM. Phytoclast material common. *Tasmanites* present but rare.

TENER MOUNTAIN WOOD, OH.

Sample No. **Lithostratigraphic Unit**

TMW2 TCD59614 Ohio Shale Formation

Sample contains significant quantities of AOM. Tamanites and acritarchs both relatively common and well preserved. Miospores well preserved but relatively rare. Miospore assemblage dominated by simple, round, laevigate, acamerate species. Phytoclasts rare, typically occurring as small (<100μm) fragments.

TMW1 TCD59613 Ohio Shale Formation

AOM and phytoclasts both present in abundance. Miospores assemblage well preserved, assemblages includes *Knoxisporites triangularis*, *Punctatisporites* spp., *Retusotriletes incohatus*, *Rugospora flexuosa*, *and Vallatisporites hystricosus*. *Ancyrospora* spp. common. Tasmanites and Leiospheres both abundant.

VANCEBURG, KY.

Sample No. **Lithostratigraphic Unit**

VAN2 TCD59612 Ohio Shale Formation (Huron Member)

Amorphous organics dominate sample. Tasmanites very common, acritarchs present but rare. Miospores well preserved assemblage of low diversity, dominated by small, simple, laevigate taxa. Phytoclasts present and well present – relatively rare.

VAN1 TCD59611 Ohio Shale Formation (Huron Member)

Sample dominated by AOM, which occurs as large 'golden-brown' particles. Tasmanites abundant and well preserved. Miospores well preserved but rare. Phytoclast material very rare.

THREE LICK TYPE SECTION - I-64 ROADCUT (MOREHEAD), KY.

Sample No. **Lithostratigraphic Unit**

NL 97 TCD 59652 Three Lick Bed

Amorphous organics common, degraded? – consisting primarily of yellow/ brown particles. Tasmanites abundant and well preserved. Miospore assemblage well preserved, typified by small acamerate forms. Phytoclast material common and well preserved, typically occurring as lath-shaped fragments or long (>100μm) 'ribbon-like' fibres.

NL 96 TCD 59651 Three Lick Bed

Sample contains large quantities of brown AOM, occurring primarily as small (30- 50μ) clumps, larger particles (>100μm) also present but less common. Tasmanites common. Miospores relatively rare but well preserved, assemblage dominated by small, laevigate taxa. Phytoclasts common and well preserved, typically occurring as lath-shaped fragments or long ribbon like fibres.

NL 95 TCD 59650 Three Lick Bed

Sample dominated by yellow/ brown AOM. Tasmanites present and relatively abundant. Miospore assemblage well preserved and of moderately low taxonomic diversity. Phytoclasts relatively common, consisting of opaque lath-shaped fragments and remnant tracheid tissue.

NL 94 TCD 59649 Three Lick Bed

Note: Sample contains large amounts of silicates which have survived acid digestion. Amorphous organics appear to be common. Tasmanites present. Miospores and phytoclasts relatively rare.

NL 93 TCD 59648 Three Lick Bed

Sample missing?

Sample No. **Lithostratigraphic Unit**

CC12 TCD59610 Chattanooga Shale Formation

Sample contains large amounts of AOM, phytoclast material relatively common. Miospores rare. *Tasmanites* sp. and Leiospheres both common.

CC1 TCD59609 Chattanooga Shale Formation – Three Lick Bed (upper lick)

Sample devoid of AOM. Miospore assemblage of restricted taxonomic composition, species include *Auroraspora macra*, *Retusotriletes incohatus*. Acritarch assemblage includes *Gorgonisphaeridium* spp., *Polyedrixium* spp. Tasmanites and Leiospheres common.

CC2 TCD59608 Chattanooga Shale Formation – Three Lick Bed

Sample contains large amounts of AOM, phytoclasts rare. Tasmanites and Leiospheres both abundant. Miospores not recorded at this level.

CC3 TCD 56737* Chattanooga Shale Formation – Three Lick Bed (middle lick)

Sample contains abundant palynomorphs and phytoclasts; both heavily pyritised. AOM also largely pyritised. Miospores recorded include *Murospora dubitata*. Tasmanites and Leiospheres both common. Acritarch assemblage includes *Gorgonisphaeridium* spp. *Polyedrixium* spp., *Unellium elongatum*.

CC4 TCD59607 Chattanooga Shale Formation – Three Lick Bed

Sample contains large amounts of AOM; phytoclasts present as small elongate fragments. Tasmanites and Leiospheres both common. Miospores rare; assemblage composed of simple laevigate taxa, e.g. *Retusotriletes incohatus*.

CC5 TCD59606 Chattanooga Shale Formation– Three Lick Bed (bottom lick)

Palynofacies contrasts with that of samples immediately below; sample contains a relatively large proportion of phytoclasts and palynomorphs; AOM present in small 'clumps'. Acritarch assemblage relatively diverse, including species such as

Cymatiosphaera sp., *Gorgonisphaeridium ohioense*, *G. winslowiae*, *Polyedrixium*. Tasmanites and Leiospheres both common. Miospore assemblage, well preserved but commonly pyritised, species present include *Indotriradites explanatus*, *Laevigatosporites* sp., *Punctatisporites* spp., *Retusotriletes incohatus* and *Vallatisporites hystricosus*.

CC6 TCD59605 Chattanooga Shale Formation

Sample contains abundant AOM and small phytoclast fragments (50-100µm). Miospores rare but well preserved, species recorded include *Emphanisporites rotatus*, *Punctatisporites* spp. and *Retusotriletes incohatus*. Tasmanites and Leiospheres both common.

CC7 TCD59604 Chattanooga Shale Formation

Sample contains abundant AOM and small phytoclast fragments (50-100µm). Very rare *Retusotriletes incohatus* and *Punctatisporites* spp. Tasmanites and Leiospheres both present.

CC11 TCD59603 Chattanooga Shale Formation

Sample contains abundant large particles of AOM (<500µm). Very rare *Retusotriletes incohatus* and *Punctatisporites* spp. Tasmanites and Leiospheres both present.

CC10 TCD59602 Chattanooga Shale Formation

Small 'fragments' of AOM (<100µm) common. Leiospheres abundant. Spore assemblage consists primarily of simple laevigate taxa, e.g. *Retusotriletes incohatus*, but occasional specimens *Vallatisporites hystricosus* recorded.

CC9 TCD59601 Chattanooga Shale Formation

- No slide

CC8 TCD 59602 Chattanooga Shale Formation

Sample contains large amounts of AOM. Miospores rare but well preserved; spore species present consist primarily of simple laevigate taxa, e.g. *Retusotriletes incohatus*. Leiospheres common.

Sample No. **Lithostratigraphic Unit** **Field Unit (after Bjerstedt 1986a)**

CA15 TCD 59575 'Upper' Price Formation Unit 78

Miospores rare in this interval. Phytoclasts abundant but highly degraded, consists primarily of small opaque clasts (<50µm).

CA14 TCD 59574 'Upper' Price Formation Unit 72

- *Sample not processed*

CA13 TCD 59573 'Upper' Price Formation Unit 70

The sample contains a well preserved low diversity assemblage. Miospore assemblage dominated by *Spelaeotriletes balteatus*. *Crassispora* cf. *maculosa*, Punctatisporites *planus*, *Vallatisporites cilliaris*, *V. vallatus* Phytoclasts abundant but highly degraded, consist of a mixture of semi opaque woody particles (~150µm) and clear non woody plant tissue.

CA12 TCD 59572 'Upper' Price Formation Unit 68

Assemblage dominated by *Spelaeotriletes balteatus*. *Crassispora* cf. *maculosa*, *Raistrickia* sp., *Retusotriletes crassus*, *Vallatisporites vallatus* and *Verrucosisporites nitidus*. Very rare specimens of *Retispora lepidophyta* recorded. Phytoclasts abundant but highly degraded, consist of a mixture of semi opaque woody particles (~300µm) and clear non woody plant tissue.

CA11 TCD 59571 'Upper' Price Formation Unit 66

Miospore assemblages well preserved but of low diversity. Assemblage dominated by *Spelaeotriletes balteatus*. Additional species recorded include *Calamospora* spp., *Punctatisporites* spp., *Retusotriletes crassus*, *Vallatisporites vallatus* and *Verrucosisporites nitidus*.

CA10 TCD 59570 'Upper' Price Formation Unit 66

Sample contains large quantities of opaque woody fragments (<300μm). Miospore assemblage of limited taxonomic diversity but well preserved. Species recorded include *Calamospora* spp., *Spelaeotriletes balteatus* and *Vallatisporites cilliaris*.

CA9 TCD 59569 'Upper' Price Formation Unit 63

Sample contains a great abundance of highly fragmented opaque woody tissue. Miospores rare and poorly preserved, often heavily pyritised and unidentifiable.

CA8 TCD 59568 'Upper' Price Formation Unit 62

Miospore assemblage relatively diverse and moderately well preserved. Assemblage includes *Auroraspora* macra, *Grandispora echinata*, *Punctatisporites* spp., *Raistrickia* cf. *clavata*, *Raistrickia* sp., *Retispora macroreticulata*, *Spelaeotriletes* cf. *microspinosus*, *Retusotriletes crassus* and *Verrucosisporites nitidus*. Sample contains large quantities opaque woody tissue.

CA7 TCD 59567 'Upper' Price Formation Unit 59

Miospores abundant but poorly preserved, often opaque and pyritised. Species included *Calamospora* spp., *Grandispora echinata*, *Knoxisporites literatus*, *Punctatisporites* spp., *Retispora lepidophyta*, *Retusotriletes crassus*, *Rugospora radiata*, *Teichertospora torquata*, *Umbonatisporites* sp. and *Vallatisportes vallatus*. Rare acritarchs recorded, including *Veryhachium* spp. Sample contains large quantities opaque woody tissue.

CA6 TCD 59566 'Upper' Price Formation Unit 58

This sample contains a miospore assemblage of low diversity and of poor preservation spores typically 'pitted' with pyrite crystals. Spores often entirely opaque and fragmented; even upon oxidation the vast majority of spores are unidentifiable. Species recorded include *Calamospora* spp., *Crassispora* cf. *maculosa*, *Retusotriletes crassus* and *Spinozonotriletes* sp. Phytoclast material consists of degraded of semi translucent plant fragments and opaque woody tissue.

CA5 TCD 59565 Sunbury Shale Member Unit 56

Miospore assemblage of low diversity and of poor preservation spores typically 'pitted' with pyrite crystals. Some rare specimens of *Crassispora* cf. *maculosa* recorded otherwise spores unidentifiable. Phytoclast material consists almost entirely of small opaque woody fragments.

CA4 TCD 59564 Sunbury Shale Member Unit 51

- Slide missing

CA3 TCD 59563 Sunbury Shale Member Unit 47

Sample contains a poorly preserved miospore assemblage of relatively low diversity. Spores often entirely opaque and 'cracked'. Miospore species recorded include *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*, *Teichertospora torquata*, *Vallatisporites hystricosus* Ancyrospora spp. and *Hystricosporites* spp. relatively common. Acritarch assemblage includes rare specimens of *Veryhachium* spp.

CA2 TCD 59562 Cloyd Conglomerate Member Unit 43

Miospore assemblage of low diversity and of poor preservation spores typically 'pitted' with pyrite crystals and often unidentifiable. Species recorded include rare specimens of *Retusotriletes crassus*, *R. incohatus* and *Vallatisporites hystricosus*. Rare acanthomorph acritarchs recorded. Phytoclast material consists primarily of semi translucent and opaque woody tissue.

CA1 TCD 59561 Cloyd Conglomerate Member Unit 43

Miospore assemblage moderately diverse and poorly preserved; spores commonly pyritised and 'pitted'. Miospore assemblage includes *Auroraspora macra*, *Punctatisporites* spp., *Retusotriletes crassus*, *Spelaeotriletes* sp. *Spinozonotriletes* sp. and *Vallatisporites hystricosus*. Phytoclasts abundant but highly degraded, consist of a mixture of semi opaque woody particles and clear non woody plant tissue. Acritarchs rare, assemblages consists primarily of small acanthomorph forms,

Sample No. **Lithostratigraphic Unit** **Field Unit (after Bjerstedt 1986a)**

ALT4 TCD 59561 Upper Price member Unit 23

Sample dominated by opaque/ semi-opaque phytoclast matter. Miospore assemblages of moderately low diversity, dominated primarily by various species of *Spelaeotriletes*. Miospore preservation moderately good to poor. No marine indicators recorded.

ALT3 TCD 59561 Upper Price member Unit 23

Opaque/ semi-opaque phytoclast matter abundant. Opaque particles typically angular and lath-shaped. Semi-opaque phytoclasts often degraded and fragmentary – other particles well preserved displaying remnant scaliriform pitting typically of tracheid tissues. No cuticle tissue recorded. Miospore assemblages moderately to poorly preserved and of low diversity. Assemblages dominated by various species of *Spelaeotriletes*.

ALT2 TCD 59561 Upper Price member Unit 23

Sample contains significant quantities of black, opaque phytoclast material. Miospores relatively well preserved. However, the miospore assemblage is largely diluted by the sheer abundance of phytoclasts present in the sample. Miospore assemblage of relatively low diversity, dominated by *Spelaeotriletes* sp. No marine indicators recorded.

ALT1 TCD 59561 Upper Price member Unit 23

Sample dominated by degraded semi-opaque phytoclasts. Miospores relatively rare and moderately well preserved. Miospore assemblages dominated by various species of Spelaeotriletes.

Sample No. **Sample Depth in ft.**

MP56 - TCD 59556 (1778.06-1781.60 ft.)

- *Sample not processed.*

MP55 - TCD 59555 (1787.42-1787.50 ft.)

Sample contains a poorly preserved miospore assemblage of relatively low diversity; spores brown/ black in colour. Miospore assemblage includes *Calamospora* spp., *Crassispora* cf. *maculosa*, *Retusotriletes crassus*, *Spelaeotriletes pretiosus* and *Tumulispora tuberosus*. Sample contains relatively rare specimens of *Retispora lepidophyta*. Sample contains large quantities of opaque woody phytoclast material. Rare reworked specimens of *Grandispora macrotuberculata*.

'Big Injun Sandstone'

MP54 - TCD 59554 (1883.34-1883.47 ft.)

Miospore assemblage rather poorly preserved and of relatively low diversity; spores brown/ black in colour. Sample contains species including *Cyrtospora cristifera*, *Dictyotriletes* sp. nov., *Punctatisporites* spp., and *Vallatisporites* sp. Sample contains a mix of opaque woody phytoclasts and translucent non woody material. Occasional particles of grey/ brown AOM.

MP53 - TCD 59553 (1886.65-1886.93 ft.)

The sample contains a moderately preserved miospore assemblage of limited taxonomic diversity. Miospore assemblage contains species including *Cyrtospora cristifera*, *Knoxisporites literatus*, *Knoxisporites* cf. *triradiatus*, *Raistrickia* cf. clavata, *Retusotriletes crassus*, *Spelaeotriletes balteatus*, *S. pretiosus*, *Tumulispora ordinarius* and *Umbonatisporites distinctus*. Sample contains large quantities of opaque woody phytoclast material.

MP52 - TCD 59552 (1898.12-1898.17 ft.)

Miospores rare and poorly preserved; often brown/ black in colour. This sample contains > 96% opaque woody phytoclasts particles (50 - 500μm)

MP51 - TCD 59551 (1903.29-1903.34 ft.)

Sample contains a poorly preserved miospore assemblage of moderate diversity; spores brown/ black in colour. Miospore assemblage includes *Crassispora* cf. *maculosa*, *Laevigatosporites* sp., *Retusotriletes crassus*, *Verrucosisporites nitidus*. Occasional acritarchs encountered. Phytoclasts mainly black opaque woody particles.

MP50 - TCD 59550 (1906.54-1906.63 ft.)

Miospore assemblage moderately well preserved moderately diverse; miospores brown/ black. Species recorded include *Auroraspora macra*, *Calamospora* spp., *Knoxisporites* cf. *triradiatus*, *Laevigatosporites* sp., *Punctatisporites* spp., *Retusotriletes crassus* and *R. incohatus*. Some poorly preserved 'reworked' specimens of *Retispora lepidophyta*, *Rugospora radiata* and *Vallatisporites pusillites*. Sample contains large amounts of opaque phytoclasts and semi-translucent non-woody tissue. Rare particles of AOM present.

MP49 - TCD 59549 (1913.47-1913.53 ft.)

Sample contains a relatively well preserved and diverse miospore assemblage which contrasts with the assemblages recorded in samples immediately below; miospores yellow/orange/ brown in colour; occasionally pyritised. Species recorded include *Auroraspora macra*, *Calamospora major*, *Crassispora* cf. *maculosa*, *Cordylosporites marciae*, *D. trivialis*, *Grandispora echinata*, *Knoxisporites literatus*, *Punctatisporites* spp., *Raistrickia* sp., *Spelaeotriletes pretiosus* and *Verrucosisporites nitidus*. Rare specimens of *Retispora lepidophyta* present. Scolecodonts and acritarchs recorded but both are relatively uncommon.

MP48 - TCD 59548 (1922.08-1922.17 ft.)

Sample contains a rather poorly preserved miospore assemblage of moderately low taxonomic diversity; miospores brown/ black in colour and occasionally pyritised. Miospore assemblage contains species including *Punctatisporites* spp., *Retusotriletes*

crassus, *Spelaeotriletes pretiosus*. Low diversity assemblages. Sample contains relatively rare specimens of *Retispora lepidophyta*. Phytoclast material consists primarily of translucent and semi translucent 'non-woody' tissue.

MP47 - TCD 59547 (1931.42-1931.48 ft.)

- *Sample not processed.*

MP46 - TCD 59546 (1940.42-1940.49 ft.)

Miospore assemblage moderately well preserved and of relatively low taxonomic diversity; spores orange/ brown/ black in colour; palynomorphs commonly corroded and fragmented. Species recorded include *Crassispora maculosa*, *Punctatisporites* spp. and *Vallatisporites* spp. Rare specimens of *Retispora lepidophyta* present. Sample contains elongate phytoclast fragments up to ~800µm long.

MP45 - TCD 59545 (1946.50-1946.56 ft.) 'Squaw Sandstone'

- *Sample not processed.*

MP44 - TCD 59544 (1965.35-1965.43 ft.) 'Squaw Sandstone'

Sample contains a moderately well preserved miospore assemblage of low diversity; miospores orange brown; occasional pyritisation of spores. Miospore assemblage *Auroraspora macra*, *Convolutispora major*, *Crassispora maculosa*, *Cordylosporites marciae*, *Retusotriletes crassus*, *Spelaeotriletes pretiosus* and *Verrucosisporites nitidus*. Sample contains black/ opaque phytoclasts (50-200µm).

MP43 - TCD 59543 (1985.10-1985.15 ft.) 'Squaw Sandstone'

The sample contains a relatively well preserved miospore assemblage; miospores orange/ brown in colour. Miospore assemblage includes *Convolutispora major*, *Retusotriletes crassus*, *Spelaeotriletes pretiosus* and *Verrucosisporites nitidus*. Extremely well preserved specimens of *Cyrtospora cristifera* occur in abundance. Rare specimens of *Retispora lepidophyta*, well preserved, pale/ translucent in colour. Phytoclasts present but less abundant than in samples below 2007.19-2007.28 ft.; consists primarily of opaque fragments (50-250µm).

MP42 - TCD 59542 (1986.11-1986.17 ft.) 'Squaw Sandstone'

- *Sample not processed.*

MP41 - TCD 59541 (1986.66-1986.72 ft.) 'Squaw Sandstone'

Sample contains an unusual miospore assemblage which is well preserved but of low diversity. The miospore assemblage is dominated by a single species, *Cyrtospora cristifera*. The sample contains large quantities of orange/ brown AOM, up to 2000µm but typically 50 - 200µm. Phytoclasts very rare in this sample; consist primarily of small opaque fragments (~50µm).

MP40 - TCD 59540 (2004.55-2004.65 ft.)

The sample contains a poorly preserved miospore assemblage of low diversity; spores orange/brown/ black; palynomorphs commonly pyritised. Miospore assemblage includes species such as *Auroraspora macra*, *Spelaeotriletes pretiosus*, *Punctatisporites* spp. Occasional occurrences of *Ancyrospora* spp. and *Vallatisporites hystricosus*; often poorly preserved and highly degraded. Sample contains significant quantities of opaque (pyritised) phytoclasts.

MP39 - TCD 59539 (2007.19-2007.28 ft.)

Miospore assemblage relatively well preserved and moderately diverse; miospore orange/ brown in colour. Assemblage includes *Calamospora* spp., *Convolutispora major*, *Emphanisporites rotatus*, *Knoxisporites* cf. *triradiatus*, *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*. Rare specimens of *Retispora lepidophyta*; well preserved, pale in colour and essentially translucent. Sample contains brown/ black clasts phytoclast material (50-300µm) and lesser amounts of translucent 'non-woody' sheet-like fragments.

MP38 - TCD 59538 (2011.22-2011.30 ft.)

- *Sample not processed.*

MP37 - TCD 59537 (2016.50-2016.60 ft.)

Sample contains a moderately diverse and well preserved miospore assemblage; spores orange/brown/ black colour, occasionally pyritised. Miospore assemblages includes *Auroraspora macra*, *Calamospora* spp., *Crassispora maculosa*, *Dictyotriletes trivialis*, *Grandispora echinata*, *Knoxisporites literatus*, *Retusotriletes crassus*, *Spelaeotriletes pretiosus*, *Tumulispora triangulatus* and *Verrucosisporites nitidus*. Rare specimens *of Retispora lepidophyta*; pale brown in colour. Occasional particles of grey/ black AOM. Sample contains opaque phytoclasts (50-200µm). Sample contains occasional acritarchs.

MP36 - TCD 59536 (2018.40-2018.48 ft.)

- *Sample not processed.*

MP35 - TCD 59535 (2019.25-2019.30 ft.)

Miospore assemblage moderately well preserved and of low diversity; spores orange/ brown/ black in colour, occasionally pyritised. Species recorded include *Calamospora* spp., *Convolutispora major*, *Cordylosporites marciae*, *Crassispora maculosa*, *Cyrtospora cristifera*, *Dictyotriletes trivialis*, *Punctatisporites* spp., *Retusotriletes crassus*, *Spelaeotriletes pretiosus* and *Verrucosisporites nitidus*. Sample contains brown/ black clasts phytoclast material (50-300µm) and lesser amounts of translucent 'non-woody' sheet-like fragments.

MP34 - TCD 59534 (2021.53-2021.60 ft.)

The sample contains a beautifully preserved and highly diverse miospore assemblage; spores yellow/ orange in colour. Miospore assemblage contains species including *Calamospora* spp., *Cordylosporites marciae*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Grandispora echinata*, *Latosporites* sp., *Punctatisporites* spp., *R. incohatus*, *Retusotriletes crassus*, *Spelaeotriletes balteatus*, *S. pretiosus*, *Vallatisporites hystricosus* and *Verrucosisporites nitidus*. In addition to the taxa listed above the sample also contains some well preserved specimens of *Retispora lepidophyta*. Occasional acritarch and scolecodonts specimens recorded at this interval. Phytoclast material consists of a mixture of brown/ black clasts phytoclast material (50-300µm) and lesser amounts of translucent 'non-woody' sheet-like fragments.

MP33 - TCD 59533 (2024.36-2024.47 ft.)

Sample contains a well preserved miospore assemblages of moderately high taxonomic diversity; spores orange/ brown. Species recorded included *Calamospora* spp., *Convolutispora major*, *Crassispora maculosa*, *Indotriradites explanatus*, *Punctatisporites* spp., *Raistrickia clavata*, *Retusotriletes crassus*, *Spelaeotriletes pretiosus*, *Tumulispora triangulatus* and *Verrucosisporites nitidus*. Rare poorly preserved specimens of *Ancyrospora* spp. Phytoclast material consists primarily of brown/ black clasts (50-150µm) and lesser amounts of translucent 'non-woody' sheet-like fragments.

'Weir Sandstone'

MP32 - TCD 59532 (2053.29-2053.34 ft.)

Miospore assemblage relatively well preserved and of moderately low diversity; spores orange/ brown in colour; occasionally pyritised. Species recorded include *Punctatisporites* spp., *Spelaeotriletes pretiosus* and *Vallatisporites* spp. Occasional specimens of *Retispora lepidophyta*; pale yellow in colour. Sample contains small (50-100µm) particles of grey/black AOM. Rare acritarchs recorded. Phytoclast material consists primarily of brown/ black clasts (50-200µm) and lesser amounts of translucent 'non-woody' fragments. Occasional particles of brown/black AOM present.

MP31 - TCD 59531 (2059.22-2059.28 ft.)

Sample contains a moderately well preserved miospore assemblage of moderately high diversity; spores orange/brown colour. Miospore assemblage includes *Dictyotriletes fimbriatus*, *Latosporites* sp., *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes pretiosus* and *Vallatisporites* spp. Some very poorly preserved specimens of *Emphanisporites rotatus*; grey/ black in colour. Occasional specimens of *Retispora lepidophyta* and *Rugospora radiata* recorded. Sample contains acritarchs but they are relatively uncommon. Phytoclasts consist primarily of opaque woody fragments, up to 1000µm but typically 50 -100µm; some translucent 'non-woody' fragments. Occasional particles of orange/brown AOM.

MP30 - TCD 59530 (2063.90-2063.99 ft.)

This sample contains a nicely preserved and highly diverse miospore assemblage; miospores typically yellow/ orange in colour; occasionally pyritised. Species recorded include *Calamospora* spp., *Cyrtospora cristifera*, *Emphanisporites rotatus*, *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes pretiosus* and *Vallatisporites* spp. Some rare specimens of *Retispora lepidophyta* present; often pale and translucent in colour. The sample contains acritarchs and scolecodonts but both are relatively rare. Occasional particles of brown AOM. Phytoclast material comprised of semi translucent particles and 'sheet-like' material and dark woody clasts.

MP29 - TCD 59529 (2065.43-2065.50 ft.)

Miospore assemblage well preserved and moderately diverse; spores yellow/ orange in colour. *Spelaeotriletes pretiosus* abundant in this sample. Other species recorded include *Cordylosporites marciae*, *Crassispora maculosa*, *Dictyotriletes trivialis*, *D. trivialis*, *Emphanisporites rotatus*, *Punctatisporites* spp., *Raistrickia* sp., *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes cabottii* and *Vallatisporites* spp. Phytoclasts consist primarily of opaque woody fragments (<100µm); some translucent 'non-woody' fragments.

MP28 - TCD 59528 (2070.32-2070.40 ft.)

This sample contains a beautifully preserved and highly diverse miospore assemblage; spores yellow/ orange in colour; spores occasionally pyritised. Miospore assemblages includes *Calamospora* spp., *Convolutispora major*, *Cordylosporites marciae*, *Cyrtospora cristifera*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Latosporites* sp., *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes pretiosus*, *Vallatisporites* spp. and *Verrucosisporites nitidus*. Specimens of *Retispora lepidophyta* also relatively abundant and well preserved; the colour of these specimens is typically pale and contrasts with the orange colour of the other spores in the assemblage. Rare reworked specimens of *Grandispora macrotuberculata* present. Phytoclasts consist primarily of opaque woody fragments (50 - 150µm). Rare scolecodonts and acritarchs recorded.

MP27 - TCD 59527 (2077.42-2077.52 ft.)

Sample contains a relatively well preserved miospore assemblage of moderately high diversity; spores yellow/ orange in colour (some opaque black); occasionally pyritised.

Miospore species recorded include *Auroraspora macra*, *Calamospora* spp., *Convolutispora major*, *Cordylosporites marciae*, *Crassispora* cf. *maculosa*, *Punctatisporites* spp., *Pustulatisporites dolbii*, *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes pretiosus*, *Vallatisporites vallatus* and *Verrucosisporites nitidus*. Rare specimens of *Retispora lepidophyta* recorded; well preserved. Acritarchs present in the assemblage but relatively uncommon. Phytoclasts consist primarily of opaque woody fragments (<250μm); some translucent 'non-woody' fragments.

MP26 - TCD 59526 (2081.24-2081.33 ft.)

Sample contains a well preserved miospore assemblage of high taxonomic diversity. Species recorded include *Calamospora* spp., *Crassispora* cf. *maculosa*, *Cyrtospora cristifera*, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Knoxisporites literatus*, *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus* and *Spelaeotriletes pretiosus*. Rare occurrences of *Retispora lepidophyta*. Phytoclasts consist primarily of opaque woody fragments (50 -100μm).

MP25 - TCD 59525 (2086.54-2086.64 ft.)

Miospore assemblage relatively well preserved and of moderate diversity; spores orange brown in colouration; occasional pyritisation. Species recorded include *Cordylosporites marciae*, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes balteatus*, *S. pretiosus*, *Vallatisporites* spp. and *Verrucosisporites nitidus*. Rare occurrences of *Retispora lepidophyta*. Rare *Leiosphaeridium* sp. recorded. Sample contains primarily of opaque woody fragments (<100μm) with some translucent 'non-woody' clasts; however, the overall character of the palynofacies appears to have changed when compared to that of the underlying samples. The ratio of spores to phytoclasts has increased.

MP24 - TCD 59524 (2096.32-2090.39 ft.)

The preservation of miospore assemblage in this sample is relatively poor. Miospore assemblage includes *Latosporites* sp., *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes pretiosus*, *Vallatisporites* spp. and *Verrucosisporites nitidus*. Occasional specimens of *Retispora lepidophyta* recorded. Phytoclast material abundant; consists primarily of opaque woody fragments (50 -150μm).

MP23 - TCD 59523 (2097.77-2097.83 ft.)

Sample contains a relatively well preserved miospore assemblage of moderate diversity. Species recorded include *Auroraspora macra*, *Crassispora maculosa*, *Grandispora echinata*, *Punctatisporites* spp., *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes pretiosus*, *Vallatisporites* spp., and *Verrucosisporites nitidus*. Rare occurrences of *Retispora lepidophyta*; specimens very well preserved, spores translucent and appear to have a different thermal history to the other components of the assemblage which are typically orange/ brown and colour. Phytoclasts consist primarily of opaque woody fragments (<100µm); some translucent 'non-woody' fragments. Occasional Scolecodonts recorded.

MP22 - TCD 59522 (2107.48-2107.57 ft.)

Miospore assemblage poorly preserved and of relatively low diversity; spores orange/brown to black/opaque in colour. Assemblage contains species including *Cordylosporites marciae*, *Indotriradites explanatus*, *Knoxisporites literatus*, *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes pretiosus* and *Vallatisporites* spp. Rare occurrences of *Retispora lepidophyta*; spores translucent and appear to have a different thermal history to the other components of the assemblage. Phytoclasts consist primarily of opaque large woody fragments (<800µm).

MP21 - TCD 59521 (2111.76-2111.82 ft.)

Sample contains a poorly preserved miospore assemblage of limited diversity; miospores often opaque and pyritised. Species recorded include: *Cordylosporites marciae*, *Crassispora maculosa*, *Indotriradites explanatus*, *Punctatisporites* spp., *Retusotriletes crassus* and *R. incohatus*. *Spelaeotriletes pretiosus* appears for the first time. Rare occurrences of *Retispora lepidophyta* and *Vallatisporites hystricosus* recorded. Phytoclast material consists mainly of opaque woody fragments (50-200µm). Sample contains occasional acritarchs.

MP20 - TCD 59520 (2132.19-2132.27 ft.)

Miospore assemblage moderately well preserved; often pyritised. Assemblages include *Calamospora* spp., *Convolutispora major*, *Cordylosporites marciae*, *Emphanisporites*

rotatus, *Indotriradites explanatus*, *Latosporites* sp., *Punctatisporites* spp., *Pustulatisporites dolbii*, *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes* cf. *pretiosus*. Rare occurrences of *Retispora lepidophyta* and *Vallatisporites hystricosus* also recorded. Phytoclast material consists mainly of opaque woody fragments (50-200µm). Rare acritarchs and scolecodonts present.

MP19 - TCD 59519 (2139.87-2139.96 ft.)

Sample contains a relatively well preserved miospore assemblage; miospores often pyritised and fragmented. Species recorded include *Convolutispora major*, *Cyrtospora cristifera*, *Retusotriletes incohatus*, *R. famenensis*, *Spelaeotriletes balteatus*. Rare specimens of *Retispora lepidophyta* recorded. Phytoclast material consists mainly of opaque woody fragments (50-200µm). Sample contains occasional Scolecodonts.

MP18 - TCD 59518 (2147.63-2147.75 ft.)

Miospore assemblage well preserved and of moderately high diversity. Species documented include *Auroraspora macra*, *Convolutispora* spp., *Cyrtospora cristifera*, *Indotriradites explanatus*, *Punctatisporites* spp., *Pustulatisporites dolbii*, *Raistrickia* sp., *Retusotriletes crassus*, *R. incohatus*, *Spelaeotriletes* cf. *pretiosus*, *Vallatisporites vallatus*. Very rare occurrences of *Retispora lepidophyta*. Rare specimens of *Veryhachium* sp. Phytoclast material consists mainly of opaque woody fragments (50-200µm). Rare Scolecodonts recorded.

MP17 - TCD 59517 (2159.29-2159.37 ft.)

Sample contains a reasonably well preserved miospore assemblage of moderately low diversity; spores commonly pyritised. Species recorded include *Cyrtospora cristifera*, *Indotriradites explanatus*, *Latosporites* sp., *Raistrickia* cf. *clavata*, *Raistrickia* sp., *Retusotriletes incohatus*, *Punctatisporites* spp. and *Verrucosisporites nitidus*. Phytoclast material consists mainly of opaque woody fragments (50-200µm). Sample contains rare acritarchs.

MP16 - TCD 59516 (2163.55-2163.62 ft.)

Miospore assemblage very well preserved and taxonomically diverse; spores occasionally pyritised. Species include: *Cordylosporites marciae*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Gorgonispora crassa*, *Retusotriletes*

crassus, *R. incohatus*, *Punctatisporites* spp. *Pustulatisporites dolbii*, *Vallatisporites vallatus* and *Verrucosisporites nitidus*. Acritarch assemblage includes *Cymatiosphaeridium* sp. Occasional *Leiosphaeridium* sp. recorded. Phytoclast material consists of a mixture of opaque woody fragments (50-300µm) and non woody, semi translucent 'sheet like' tissues.

MP15 - TCD 59515 (2172.60-2172.68 ft.)

Sample contains a diverse, abundant and well preserved miospore assemblage. Species recorded include: *Convolutispora major*, *Cordylosporites marciae*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Pustulatisporites dolbii*, *Retusotriletes incohatus*, *Vallatisporites vallatus* and *Verrucosisporites nitidus*. Rare occurrences of *Retispora lepidophyta*, *Vallatisporites hystricosus* and *H. pusillites*. Phytoclast material consists mainly of opaque woody fragments (50-200µm). Rare occurrences of acritarchs and scolecodonts.

MP14 - TCD 59514 (2195.89-2196.95 ft.)

Miospores abundant, assemblage well preserved and diverse; spores occasionally pyritised. Species recorded include: *Calamospora* spp., *Cordylosporites marciae*, *Crassispora* cf. *maculosa*, *Cyrtospora cristifera*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Latosporites* sp., *Pustulatisporites dolbii*, *Retusotriletes incohatus*, *Vallatisporites hystricosus*, *V. vallatus*. Rare occurrences of *Retispora lepidophyta* of *Vallatisporites pusillites*. Sample contains rare acritarchs and scolecodonts. Phytoclast material consists of a mixture of opaque woody fragments (50-300µm) and non woody, semi translucent 'sheet like' tissues.

MP13 - TCD 59513 (2201.00-2201.08 ft.)

Sample contains a moderately diverse and moderately well preserved miospore assemblage; spores occasionally pyritised. Miospore assemblage includes specimens of *Cordylosporites marciae*,, *Emphanisporites rotatus*, *Indotriradites explanatus*, *Retispora lepidophyta*, *Retusotriletes crassus*, *Vallatisporites vallatus*. *Cyrtospora cristifera* becomes an abundant component of the assemblage for the first time in this sample. Rare acritarchs recorded. Phytoclast material dominated by opaque woody fragments (50-300µm). Sample contains rare scolecodonts.

'Murrysville Sandstone'

MP12 - TCD 59512 (2225.34-2225.40 ft.)

Miospores in this sample are extremely abundant, miospore assemblage well preserved and highly diverse. Species recorded include *Auroraspora macra*, *Calamospora* spp., *Crassispora* cf. *maculosa*, *Emphanisporites rotatus*, *Punctatisporites* spp., *Retispora lepidophyta*, *Retusotriletes crassus*, *Rugospora radiata*, *Tumulispora concentricus*, *Vallatisporites hystricosus*, *V. verrucosus* and *Verrucosisporites nitidus*. Occasional specimens of *Ancyrospora* spp. Acritarchs relatively rare, assemblage includes *Stellinium* spp. and poorly preserved specimens of *Veryhachium* sp. Rare scolecodonts recorded.

MP11 - TCD 59511 (2230.20-2230.28 ft.)

Miospore assemblage well preserved and diverse; spores yellow/orange/ brown in colour; occasionally pyritised. Sample contains species including *Auroraspora macra*, *Emphanisporites rotatus*, *Grandispora cornuta*, *Retispora lepidophyta*, *Retusotriletes crassus*, *R. incohatus*, *Rugospora flexuosa*, *R. radiata*, *Tumulispora concentricus*, *Vallatisporites hystricosus*, *V. pusillites* and *Verrucosisporites nitidus*. *Ancyrospora* spp. and *Hystricosporites* spp. both common and relatively well preserved. Rare acritarchs recorded. . Sample contains opaque, woody phytoclasts (50 -250μm) and smaller fragments (~100μm) non woody tissue. Sample contains rare scolecodonts.

MP10 - TCD 59510 (2232.36-2232.44 ft.)

Sample contains an abundant, well preserved and diverse miospore assemblage. Species recorded include *Gorgonispora crassa*, *Grandispora echinata*, *Punctatisporites* spp., *Retispora lepidophyta*, *R. macroreticulata*, *Rugospora radiata*, *R. flexuosa*, *Tumulispora concentricus*, *Vallatisporites hystricosus*, *V. verrucosus* and *Verrucosisporites nitidus*. Extremely rare *Cyrtospora cristifera* 1st appear. Well preserved *Ancyrospora* spp. and *Hystricosporites* spp. Acritarch assemblage well preserved; includes *Gorgonisphaeridium* spp. Sample contains large (<600μm) opaque woody phytoclasts and smaller (~100μm) non woody tissue. Rare scolecodonts recorded.

MP9 - TCD 59509 (2237.81-2237.88 ft.)

Miospore assemblage relatively well preserved and moderately diverse. Miospore assemblage includes *Auroraspora macra*, *Calamospora* spp., *Retispora lepidophyta*, *Rugospora radiata*, *R. flexuosa*, *Vallatisporites hystricosus*, *V. pusillites*, *V. verrusosus* and *Verrucosisporites nitidus*. Sample contains well preserved *Ancyrospora* spp. Phytoclasts material dominated by small (<100µm) opaque woody clasts and some poorly preserved 'sheet-like', semi translucent tissue.

MP8 - TCD 59508 (2241.37-2241.47 ft.)

Miospore assemblage very well preserved; taxonomic diversity high. Species include *Auroraspora macra*, *Emphanisporites rotatus*, *Retispora lepidophyta*, *Rugospora radiata*, *Vallatisporites hystricosus* and *Verrucosisporites nitidus*. *Ancyrospora* spp. and *Hystricosporites* spp both recorded. Rare acanthomorph acritarchs recorded. Phytoclasts consist of small (<100µm) opaque woody fragments and 'sheet-like' semi translucent plant tissue.

MP7 - TCD 59507 (2243.48-2243.55 ft.)

Sample contains a poorly preserved miospore assemblage; spores orange/brown/ black in colour; spores commonly pyritised and 'corroded'. Miospore assemblage contains species including Auroraspora macra, *Punctatisporites* spp., *Retispora lepidophyta*, *Vallatisporites hystricosus* and *V. pusillites*. *Ancyrospora* spp. and *Hystricosporites* both present. Sample contains phytoclasts which are typically black, opaque and pyritised. Not a particularly interesting sample.

MP6 - TCD 59506 (2249.00-2449.08 ft.)

Miospore preservation moderate to poor; miospores brown/ black in colour; spores typically pyritised and fragmented. The sample contains a miospore assemblage which includes *Auroraspora macra*, *Retispora lepidophyta*, *Rugospora flexuosa*, *R. radiata*, *Tumulispora concentricus* and *Vallatisporites hystricosus* and *V. pusillites*. *Ancyrospora* spp. and *Hystricosporites* both present. Sample contains large amount of black 'woody' phytoclasts which are typically 50-300µm but up to 500µm.

MP5 – TCD 59505 (2250.50-2250.56 ft.)

The sample contains a well preserved and diverse miospore assemblage. Miospore assemblage contains species including *Auroraspora macra*, *Punctatisporites* spp., *Retispora lepidophyta*, *Retusotriletes crassus*, *R. incohatus*, *Teichertospora torquata*, *Vallatisporites hystricosus*. *Ancyrospora* spp. and *Hystricosporites* spp both common and well preserved. Rare acanthomorph acritarchs recorded. Phytoclast material consists primarily of large opaque woody material (up to 900µm) and smaller fragments of translucent plant tissue. Rare Scolecodonts recorded.

MP4 – TCD 59504 (2255.06-2255.23 ft.)

- *Sample not processed?*

MP3 – TCD 59503 (2255.50-2255.54 ft.)

Miospore assemblage well preserved (although miospores occasionally pyritised) and moderately diverse. Species recorded include *Auroraspora macra*, *Retispora lepidophyta*, *Punctatisporites* spp. *Vallatisporites hystricosus* and *Verrucosisporites nitidus*. Rare *Ancyrospora* spp. and *Hystricosporites* spp. Sample contains small fragments (~50µm) of opaque woody fragments and semi translucent plant tissue. Rare Scolecodonts recorded.

MP2 – TCD 59502 (2255.67-2255.73 ft.)

- *Sample not processed.*

MP1 – TCD 59501 (2258.82-2258.94 ft.)

Sample contains abundant phytoclast material consisting of opaque fragments. Miospore assemblage very poorly preserved, miospores pyritised and unidentifiable. Very rare recognisable specimens of *Retispora lepidophyta*. Occasional acanthomorph acritarchs recorded.

Sample No. **Lithostratigraphic Unit**

CR1 TCD 59598 Burgoon Sandstone Formation

Miospore assemblage poorly preserved and of low diversity; spores brown/ black; miospores unidentifiable. Phytoclast material consists primarily of opaque woody clasts typically 50 - 100µm. Sample contains small quantities of brown AOM.

CR2 TCD 59597 Burgoon Sandstone Formation

Sample contains a miospore assemblage which is poorly preserved and of low diversity; spores brown/ black which are unidentifiable. Phytoclast material consists primarily of opaque woody clasts typically 50 - 100µm. Sample contains small quantities of orange/ brown AOM.

CR3 TCD 59596 Burgoon Sandstone Formation

Miospore assemblage poorly preserved and of low diversity and abundance; spores brown/ black; miospores unidentifiable. Phytoclast material consists primarily of opaque woody clasts typically 50 - 100µm. Sample contains small quantities of brown AOM. Sample essentially barren.

CR4 TCD 59595 Burgoon Sandstone Formation

Sample contains a poorly preserved miospore assemblage of low diversity; spores brown/ black and unidentifiable. Phytoclast material consists primarily of opaque woody clasts typically 50 - 100µm. Sample contains small quantities of orange/ brown AOM.

CR5 TCD 59594 Burgoon Sandstone Formation

- Sample missing.

CR6 TCD 59593 Rockwell Formation?

Sample contains a moderately well preserved assemblage of relatively high diversity; miospores brown/ black in colour. Species recorded in this sample include *Aratrisporites saharaensis*, *Crassispora* cf. *maculosa*, *Cyrtospora cristifera*, *Neoraistrickia loganensis*,

Spelaeotriletes balteatus, *S. pretiosus* and *Vallatisporites* spp. This sample contains significant quantities of opaque woody phytoclasts and highly degraded semi translucent non-woody fragments.

ALTOONA, PA.

Sample No. **Lithostratigraphic Unit**

AL1 TCD 59592 Burgoon Sandstone Formation

Sample contains a poorly preserved miospore assemblage of low diversity; spores rare and often unidentifiable. Phytoclast material consists primarily of opaque woody clasts typically 50 - 100µm. Large quantities of orange/ brown AOM present. Barren sample.

AL2 TCD 59591 Burgoon Sandstone Formation

Sample entirely devoid of miospores. Phytoclast material consists primarily of opaque woody clasts typically 50 - 100µm. Sample contains small quantities of orange/ brown AOM. Barren sample.

AL3 TCD 59590 Rockwell Formation

Sample contains a poorly preserved miospore assemblage of low diversity; spores brown/ black, badly preserved and essentially unidentifiable. Phytoclast material consists primarily of opaque woody clasts typically 50 - 100µm. Sample contains small quantities of brown/ black AOM. Barren sample.

WARRIOR'S PATH, PA.

Sample No. **Lithostratigraphic Unit**

WP1 TCD 59589 Burgoon Sandstone Formation

Sample contains a poorly preserved miospore assemblage of low diversity; spores rare, black in colour and largely unidentifiable. Miospore species recorded include some rare specimens assignable to *Calamospora* spp., *Neoraistrickia loganensis*, *Punctatisporites* spp. and *Spelaeotriletes balteatus*. Phytoclast material consists primarily of highly fragmented opaque woody clasts typically 50 - 100µm. Moderate amounts of orange/ brown AOM present.

WP2 TCD 59588 Burgoon Sandstone Formation

Sample contains a rather poorly preserved miospore assemblage of low diversity; spores brown/ black and pyritised. Species recorded include *Calamospora* spp., *Spelaeotriletes balteatus* and *S. pretiosus*. Phytoclast material consists of large amounts of black woody clasts and brown semi translucent woody fragments.

WP3 TCD 59587 Burgoon Sandstone Formation

Miospore assemblage poorly preserved and of relatively low diversity; spores brown/ black and pyritised. Species recorded include *Calamospora* spp., *Punctatisporites* spp., *Spelaeotriletes balteatus* and *S. pretiosus*. Phytoclast material consists primarily of large amounts of black woody clasts and brown semi translucent woody fragments

WP4 TCD 59586 Burgoon Sandstone Formation

Sample contains a rather poorly preserved miospore assemblage of low diversity; spores brown/ black and pyritised. Species recorded include *Calamospora* spp., *Punctatisporites* spp., *Spelaeotriletes balteatus* and *S. pretiosus*. Phytoclast material consists primarily of large amounts of black woody clasts and brown semi translucent woody fragments.

WP5 TCD 59585 Burgoon Sandstone Formation

Sample contains a poorly preserved miospore assemblage of low diversity; spores rare, black in colour and largely unidentifiable. Miospore species recorded include some rare

specimens assignable to *Calamospora* spp., *Crassispora* cf. *maculosa*, *Neoraistrickia loganensis*, *Punctatisporites* spp., *Spelaeotriletes balteatus* and *S. pretiosus*. Phytoclast material consists primarily of fragmented opaque woody clasts typically 50 - 100µm and brown semi-translucent clasts.

WP6 TCD 59584 Burgoon Sandstone Formation

Miospore assemblage rather poorly preserved and of moderate diversity; spores brown/ black. Species recorded include *Calamospora* spp., *Crassispora* cf. *maculosa*, *Tumulispora ordinarius* and *Vallatisporites* spp. Phytoclast material consists primarily of large amounts of black woody clasts and brown semi translucent woody fragments.

WP7 TCD 59583 Burgoon Sandstone Formation

Sample contains a miospore assemblage of moderate preservation and restricted taxonomic diversity; miospores typically brown/ black in colour. Species recorded include *Calamospora* spp., *Cyrtospora cristifera*, *Punctatisporites* spp and *Spelaeotriletes pretiosus*. Phytoclast material consists of abundant particles of black woody tissue (50-400µm) and brown semi translucent woody fragments.

WP8 TCD 59582 Burgoon Sandstone Formation

Miospore assemblage poorly preserved and of restricted taxonomic diversity; miospores typically black in colour (occasionally brown) and commonly pyritised. Species recorded include *Calamospora* spp., *Crassispora* cf. *maculosa* and *Punctatisporites* spp. Sample contains moderate amounts of orange and brown AOM. Phytoclast material consists primarily of fragmented opaque woody clasts typically 50 - 100µm and brown semi-translucent clasts.

WP9 TCD 59581 Rockwell Formation

Sample contains a poorly preserved miospore assemblage of moderately low diversity; spores brown/ black in colour. Taxa recorded include *Calamospora* spp., *Punctatisporites* spp. and *Spelaeotriletes pretiosus*. AOM, orange brown in colour and moderately abundant. Phytoclast material dominated by semi translucent brown fragements; lesser amounts of opaque phytoclasts present in the sam

APPENDIX IV – CURATION OF SAMPLES

WILLIAMS COUNTY CORE

Sample No.	TCD No.	Lithostratigraphic Unit
WC 24	**TCD59645**	COLDWATER SHALE FORMATION
WC 21	**TCD59644**	"
WC 20	**TCD59643**	"
WC 23	**TCD59442**	"
WC 3	**TCD59441**	SUNBURY SHALE FORMATION
WC 2	**TCD59640**	"
WC 4	**TCD59639**	"
WC 19	**TCD59638**	"
WC 18	**TCD59637**	BEDFORD SHALE FORMATION
WC 17	**TCD 56767* (A, B)**	"
WC 16	**TCD59636**	"
WC 15	**TCD56766* (A – E)**	"
WC 14	**TCD59635**	"
WC 13	**TCD59634**	"
WC 12	**TCD59633**	"
WC 11	**TCD 56765* (A – B)**	"
WC 10	**TCD59632**	"
WC 9	**TCD59631**	"
WC 8	**TCD59630**	"
WC 7	**TCD59629**	"
WC 6	**TCD59628**	"

WC 5	**TCD59627**		ANTRIM SHALE (OHIO SHALE Fm.)
WC 1	**TCD59626**		"
WC 2	**TCD59625**		"

SUNBURY (BIG WALNUT CREEK)

Sample No.	TCD No.		Lithostratigraphic Unit
SUN 4	**TCD59624**		BEREA SANDSTONE FORMATION
SUN 3	**TCD59623**		BEDFORD SHALE FORMATION
SUN 2	**TCD56752***	**A - D**	"
SUN 1	**TCD56751***	**A - F**	"

THREE LOCKS QUARRY

Sample No.	TCD No.		Lithostratigraphic Unit
TL 10	**TCD59620**		BEREA SANSTONE FORMATION
TL 9	**TCD59619**		"
TL 8	**TCD59618**		"
TL 7	**TCD59617**		BEDFORD SHALE FORMATION
TL 6	**TCD59616**		"
TL 5	**TCD56756***	**A-C**	"
TL 4	**TCD59615**		"
TL 3	**TCD56755***	**A -B**	"
TL 2	**TCD56754***	**A -E**	"
TL 1	**TCD56753***	**A -C**	"

TENOR MOUNTAIN WOOD

Sample No.	TCD No.	Lithostratigraphic Unit

TMW 1	**TCD59614**	HURON/ CLEVELAND MEMBER
TMW 2	**TCD59613**	"

VANCEBURG

Sample No.	TCD No.	Lithostratigraphic Unit
VAN 1	**TCD59612**	HURON MEMBER (OHIO SHALE)
VAN 2	**TCD59611**	"

THREE LICK TYPE SECTION (I-64)

Sample No.	TCD No.	Lithostratigraphic Unit
NL 97	**TCD 59652**	THREE LICK MEMBER
NL 96	**TCD 59651**	"
NL 95	**TCD 59650**	"
NL 94	**TCD 59649**	"
NL 93	**TCD 59648**	"

CLAY CITY QUARRY

Sample No.	TCD No.	Lithostratigraphic Unit
CC 12	**TCD59610**	CHATTANOOGA SHALE
CC 1	**TCD59609**	TOP LICK (THREE LICK MEMBER)
CC 2	**TCD59608**	CHATTANOOGA SHALE
CC 3	**TCD56737*** (A – D)	MID LICK (THREE LICK MEMBER)
CC 4	**TCD59607**	CHATTANOOGA SHALE
CC 5	**TCD59606**	BASE LICK (THREE LICK MEMBER)
CC 6	**TCD59605**	CHATTANOOGA SHALE
CC 7	**TCD59604**	"
CC 11	**TCD59603**	"

CC 10	**TCD59602**	"
CC 9	**TCD59601**	"
CC 8	**TCD 59600**	"

CALWELL ROADCUT

Sample No.	TCD No.	Lithostratigraphic Unit
CA 15	**TCD59575**	UPPER PRICE FORMATION
CA14	**TCD59574**	"
CA 13	**TCD59573**	"
CA 12	**TCD59572**	"
CA 11	**TCD59571**	"
CA 10	**TCD 59570**	"
CA 9	**TCD 59569**	"
CA 8	**TCD 59568**	"
CA 7	**TCD 59567**	"
CA 6	**TCD 59566**	"
CA 5	**TCD 59565**	SUNBURY SHALE MEMBER
CA 4	**TCD 59564**	"
CA 3	**TCD 59563**	"
CA 2	**TCD 59562**	CLOYD CONGLOMERATE MEMBER
CA 1	**TCD 59561**	"

ALTA ROADCUT

Sample No.	TCD No.	Lithostratigraphic Unit
ALT 4	**TCD 59656**	UPPER PRICE FORMATION

MP 13	**TCD 59513**	"	
MP 12	**TCD 59512**	SUB-MURRYSVILLE SANDSTONE	
MP11	**TCD 59511**	"	
MP 10	**TCD 59510**	"	

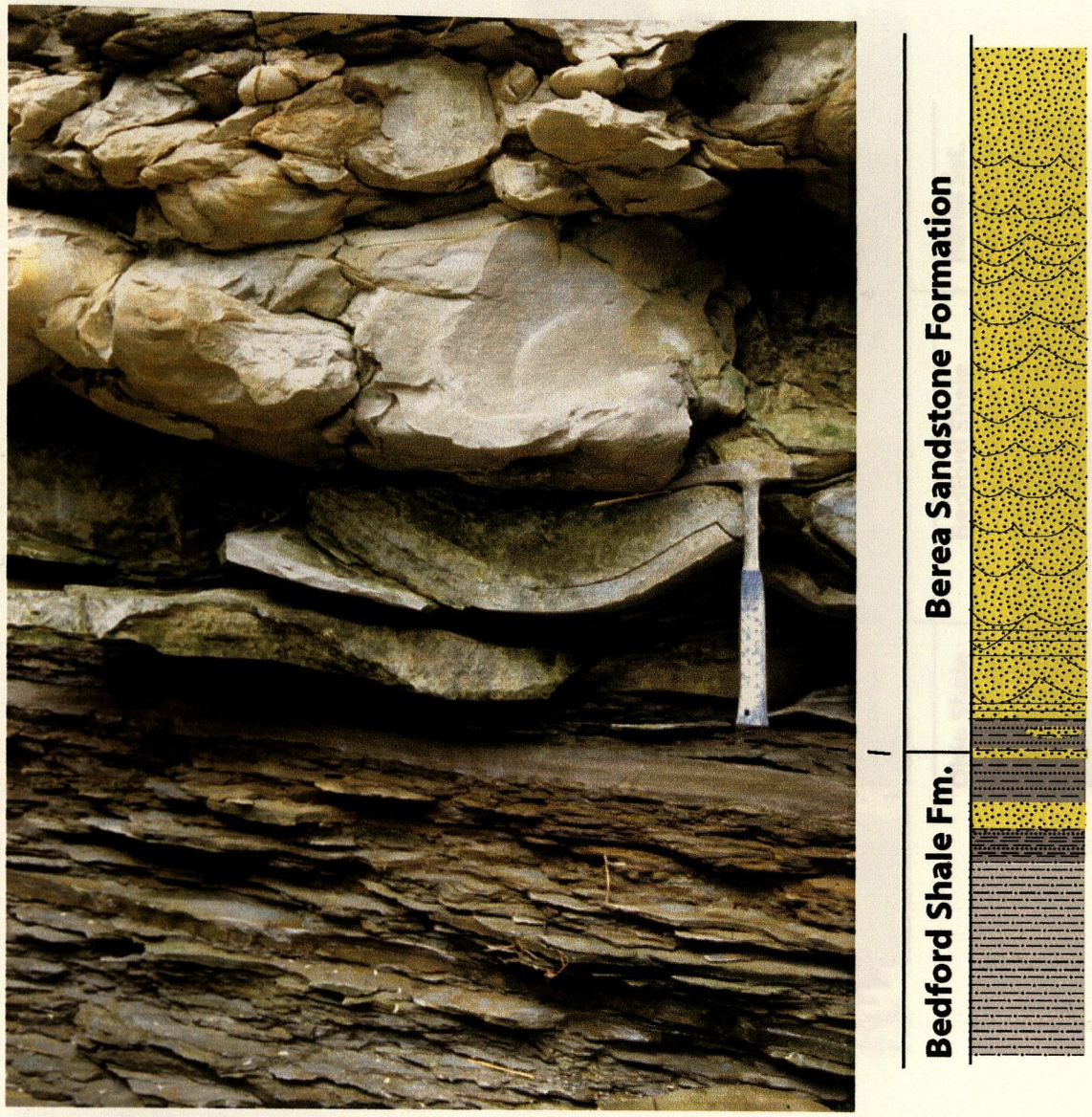
AL 1	**TCD 59592**	BURGOON SANDSTONE FORMATION
AL 2	**TCD 59591**	"
AL 3	**TCD 59590**	ROCKWELL FORMATION

WARRIOR'S PATH

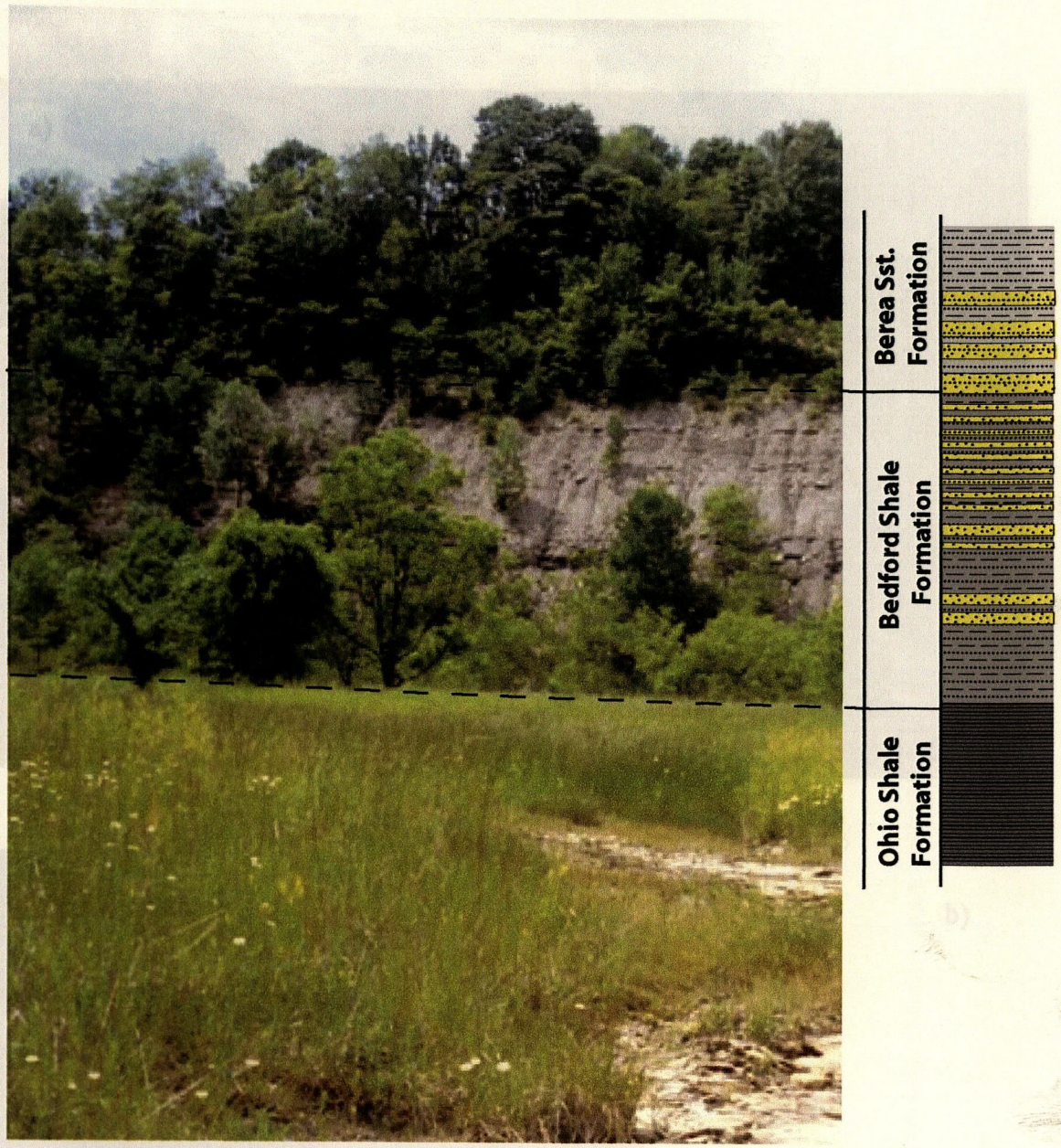
Sample No.	TCD No.	Lithostratigraphic Unit
WP 1	**TCD 59589**	BURGOON SANDSTONE FORMATION
WP 2	**TCD 59588**	"
WP 3	**TCD 59587**	"
WP 4	**TCD 59586**	"
WP 5	**TCD 59585**	"
WP 6	**TCD 59584**	"
WP 7	**TCD 59583**	"
WP 8	**TCD 59582**	"
WP 9	**TCD 59581**	ROCKWELL FORMATION

MP 37	**TCD 59537**	"
MP 36	**TCD 59536**	"
MP 35	**TCD 59535**	"
MP 34	**TCD 59534**	"
MP 33	**TCD 59533**	"
MP 32	**TCD 59532**	SUB-WEIR SANDSTONE
MP 31	**TCD 59531**	"
MP 30	**TCD 59530**	"
MP 29	**TCD 59529**	"
MP 28	**TCD 59528**	"
MP 27	**TCD 59527**	"
MP 26	**TCD 59526**	"
MP 25	**TCD 59525**	"
MP 24	**TCD 59524**	"
MP 23	**TCD 59523**	"
MP 22	**TCD 59522**	"
MP 21	**TCD 59521**	"
MP 20	**TCD 59520**	"
MP19	**TCD 59519**	"
MP 18	**TCD 59518**	"
MP 17	**TCD 59517**	"
MP 16	**TCD 59516**	"
MP 15	**TCD 59515**	"
MP 14	**TCD 59514**	"

APPENDIX V – FIELD PHOTOS



Appendix V - Fig. 1. Field Photograph of the Big Walnut Creek section, Sunbury, Delaware County, Ohio. The boundary between the Bedford Shale and the overlying Berea Sandstone is indicated by the dashed line. Note the flow rolls in the lower Berea Sandstone.



Appendix V - Fig. 2. Photograph of the Three Locks Quarry. The floor of the quarry is approximately coincident with the boundary between the Bedford Shale and the underlying Ohio Shale (foreground). The Bedford Shale/ Berea Sandstone boundary approximates the upper tree line.



Appendix V - Fig. 3. a) Tener Mountain Wood sample locatlity in Adams County, Ohio.
b) Vanceburg locality, Lewis County, Kentucky.



Appendix V - Fig. 4. Clay City Quarry, Powell County, Kentucky. Approximate position of the Three Licks Bed indicated by the dashed lines.



Appendix V – Fig. 5. Photograph of the base of the Caldwell section. The boundary between the Cloyd Conglomerate Member and the overlying Sunbury Shale Member is place to the right of the drainage pipe at the base of the pale grey lithology.



Appendix V – Fig. 6. Cramer locality, Pennsylvania. Top of the Burgoon Sandstone overlain by approximately 2 metres of red and green mudstone. This is overlain by approximately 6 metres of cross- bedded calcareous sandstone of the Loyalhanna Formation.



Appendix V – Fig. 7. Herringbone x-stratification in the Loyalhanna Formation. Cramer, Pennsylvania.



Appendix V – Fig. 8. X-beds in the Burgoon Sandstone Formation overlain by Loyalhanna Formation. Cramer locality, Pennsylvania.



Appendix V – Fig. 9. Beth standing at the CR1 sample locality. (Photo 3378)



Appendix V – Fig. 10. CR2 sample locality – greenish, silty shale, a bed a few inches thick.



Appendix V – Fig. 11. CR4 sample locality – greenish silty shale Interbedded in sandstone. (Photo 3380).



Appendix V – Fig. 12. Trough cross-bedding in the Burgoon Sandstone Formation. Cramer locality, Pennsylvania.



Appendix V – Fig. 13. Interbedded thin sandstones and shales – CR 6 sample locality. Presumably Rockwell Formation.



Appendix V – Fig. 14. Rockwell Formation, top dirty sandstone and shales. Cramer locality, Pennsylvania.





Appendix V – Fig. 15 a & b Cross bedding in the Loyalhanna Formation – West end of the reservoir. Altoona, Pennsylvania.





Appendix V – Fig. 16) a Burgoon Sandstone Formation – b Green shale within the Burgoon Sandstone – samples site for AL1 – Altoona locality, Pennsylvania.





Appendix V – Fig. 17) a & b Sample locality for sample AL2. This sample is positioned slightly higher than AL1 and closer to the top of the Burgoon Sandstone. Altoona, Pennsylvania.





Appendix V – Fig. 18 a & b – Uppermost Rockwell Formation – sample locality for AL3.



Appendix V – Fig. 19 a & b – Burgoon Sandstone Formation – sample site for WP3. Warrior's Path State Park, Pennsylvania.



Appendix V – Fig. 20 Shale zone within thick sandstone of the Burgoon – sample site for WP4.



Appendix V – Fig. 21 Cross-bedding within the Burgoon Sandstone – several metres below WP5 and above sample WP6.

Enclosure I. Range chart for the Mylan Park core displaying occurence data for selected miospore and megaspore taxa. Strat. column based on West Virginia Geological & Economic Survey (WVGES) core description (see Appendix III). * *denotes partial or incomplete.*

Depth (ft.)

Chronostratigraphy: Devonian* | Lower Carboniferous (Mississippian)*

System: Famennian | Kinderhookian | Osagean | Mera-mecian*

Stage: Famennian | Kinderhookian | Osagean | Mera-mecian*

Lithostratigraphy: Price Formation | Greenbrier Limestone

Formation: Price Formation | Greenbrier Limestone

Member: Murrys-ville | 'Weir' sandstone | 'Squaw' sandstone | 'Big Injun' sandstone

Lithology

Interval not sampled

Sample Numbers

Sample Depth

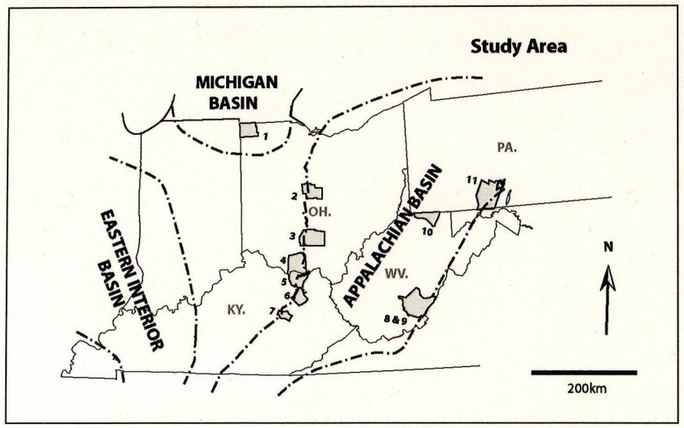
Megaspores

1 *Hystricosporites* spp.
2 *Ancyrospora* spp.
3 *Rugospora flexuosa*
4 *Retispora cassicula*
5 *Vallatisporites cilliaris*
6 *Rugospora radiata*
7 *Raistrickia minor*
8 *Spinozonotriletes uncatus*
9 *Retusotriletes phillipsii*
10 *Calamospora pallida*
11 *Calamospora nigrata*
12 *Calamospora perrugosa*
13 *Auroraspora macra*
14 *Calamospora liquida*
15 *Vallatisporites hystricosus*
16 *Knoxisporites* cf. *triradiatus*
17 *Punctatisporites planus*
18 *Retispora lepidophyta*
19 *Vallatisporites pusillites*
20 *Emphanisporites rotatus*
21 *Retusotriletes incohatus*
22 *Retusotriletes triangulatus*
23 *Vallatisporites verrucosus*
24 *Velamisporites caperatus*
25 *Verrucosisporites nitidus*
26 *Grandispora cornuta*
27 *Teichertospora torquata*
28 *Punctatisporites irrasus*
29 *Knoxisporites concentricus*
30 *Endoculeospora gradzinskii*
31 *Murospora dubitata*
32 *Emphanisporites hibernicus*
33 *Tumulispora ordinarius*
34 *Convolutipora vermiformis*
35 *Latosporites* sp. A
36 *Knoxisporites literatus*
37 *Retusotriletes crassus*
38 *Knoxisporites* cf. *concentricus*
39 *Dicytotriletes flavus*
40 *Cordylosporites marciae*
41 *Densosporites spitsbergensis*
42 *Emphanisporites annulatus*
43 *Bascaudispora submarginatus*
44 *Retusotriletes fammenensis*
45 *Tumulispora malevkensis*
46 *Indotriradites explanatus*
47 *Murospora* sp. A
48 *Grandispora echinata*
49 *Spinozonotriletes impensus*
50 *Gorgonispora crassa*
51 *Verrucosisporites oppresus*
51 *Convolutispora major*
53 *Cyrtospora cristifera*
54 *Crassispora cf. maculosa*
55 *Vallatisporites vallatus*
56 *Calamospora microrugosa*
57 *Calamospora parva*
58 *Spelaeotriletes balteatus*
59 *Spelaeotriletes pretiosus*
60 *Grandispora ? douglastownense*
61 *Raistrickia macrura*
62 *Calyptosporites triangulatus*
63 *Umbonatisporites abstrusus*
64 *Raistrickia clavata*
65 *Knoxisporites triangularis*
66 *Anapiculatisporites fundiensis*
67 *Spelaeotriletes cabotii*
68 *Cordylosporites shawneensis*
69 *Aratrisporites saharaensis*
70 *Neoraistrickia logani*

Miospores

Miospore Zones: LN | VI | PC

Enclosure II. Correlation chart for sections investigated in the current study.



SYSTEM | N. AMERICAN STAGE | EUROPEAN STAGE | MIOSPORE ZONE

CARBONIFEROUS * (MISSISSIPPIAN *) — MERAMECIAN ? — VISEAN — ?

OSAGEAN — KINDERHOOKIAN ? — TOURNAISIAN — Tn1 — ?

DEVONIAN * — BRADFORDIAN — FAMENNIAN — Fa2d — Tn2 - Tn3

PC

VI

LN

LL / LE?

1) WILLIAMS COUNTY CORE

Coldwater Shale Formation

Antrim Shale

Bedford Shale

Sunbury

PC

VI?

LN

LL / LE?

2) BIG WALNUT CREEK

Sunbury

Berea

Bedford

LN

3) THREE LOCKS

Sunbury

Berea

Bedford Shale Formation

Ohio Shale

LN

4) TENER MOUNTAIN WOOD

Bedford Shale Fm. *

Ohio Shale Formation *

Three Lick

Huron Member *

Cleveland Member

LL / LE?

5) VANCEBURG

Bedford Shale Fm. *

Ohio Shale Formation *

Three Lick

Huron Member *

Cleveland Member

LL / LE?

6) THREE LICK TYPE/ MOREHEAD

?

PC

VI

LN

Bed ford

Ohio Shale Formation *

Huron Member *

Three Lick

Cleveland Member

* data from Coleman & Clayton (1987)

7) CLAY CITY

Sunbury equivalent

Chattanooga Shale

Three Lick

LN

8) CALDWELL

?

Price Formation

'Upper un-named' member

Sunbury Shale Member

Cloyd Conglomerate Member

PC

VI

LN

9) ALTA

Price Formation

'Upper un-named' member

PC

10) MYLAN PARK

?

Price Formation

Big Injun' sandstone

Squaw'

'Weir'

Coffee Shale Mbr.

Berea Sandstone

3

LN

4

VI

LN

11) WARRIOR'S PATH

?

Loyal-hanna

Burgoon Sandstone Formation

Rockwell Fm.

PC

?

Thickness

ft. m.

100 30

250 90 80 70 60 50 40 30 20 10 0

200 150 100 50

OHIO — KENTUCKY — WEST VIRGINIA — PENNSYLVANIA

Independent biostratigraphic data

1 ☆ *Spathognathodus antepositicornis* (Hass, 1947; de Witt 1970)

2 ☆ *Siphonodella* spp. (Hass, 1947; de Witt 1970)

3 ☆ *Cyrtospirifer* spp. (Carter & Kammer, 1990)

4 ☆ *Schuchertella macensis* & *Verkhotomia nascens* (Carter & Kammer, 1990)