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PALYNOLOGICAL CORRELATION OF MISSISSIPPIAN (CARBONIFEROUS) STAGES IN WESTERN EUROPE AND THE USA

by

SARAH E. HEAL

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

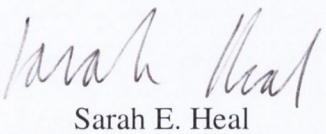
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Sarah E. Heal

SUMMARY

Palynological assemblages from the Late Devonian – Mississippian of Kentucky and the Mississippi Valley have been studied. Productive samples have been obtained from two outcrops situated in northeast Kentucky and eight outcrops and 21 cores from Illinois, Missouri and Iowa in the Mississippi Valley. Spores, acritarchs, prasinophytes and scolecodonts have been recovered. The miospores, acritarchs and prasinophytes have been systematically described and illustrated. In total, 124 miospore taxa have been recognised. Eight species and a single spore type have been described in open nomenclature. Twenty-seven acritarch taxa have been recognised.

Miospore assemblages from northeast Kentucky correlate well with those from Western Europe and are assigned to the Western European Miospore Biozonation. Five biozones have been recognised. Assemblages from the Cleveland Member of the Ohio Shale and the Bedford Shale are assigned to the Late Devonian LN Biozone. Assemblages from the Sunbury Shale, Jacobs Chapel and Rockford Limestone are assigned to the oldest Mississippian VI Biozone. Assemblages from the Henley Member of the Borden Formation and the Henley and Portsmouth members of the Cuyahoga Formation are assigned to the mid-late Tournaisian BP and PC biozones. Assemblages from the Farmers Member and Nancy Member of the Borden Formation and the upper part of the Portsmouth Member of the Cuyahoga Formation are assigned to the late Tournaisian CM Biozone. The interpretation of a Late Devonian – Early Mississippian age is in agreement with previous palynological studies undertaken in northeast Kentucky and Ohio and supports previous independent conodont and ammonoid studies.

Miospore assemblages from the Mississippian of the Mississippi Valley are very different to those recorded from Kentucky and Western Europe, with many key European zonal taxa having very different ranges in the Mississippi Valley. A separate miospore biozonation is proposed for the Mississippian of the Mississippi Valley. Seven miospore biozones are proposed. In ascending order, these are the *Cyclogranisporites commodus* Biozone, the *Spelaeotriletes obtusus* Biozone, the *Prolycospora rugulosa* Biozone, the *Crassispora aculeata* Biozone, the *Cingulizonates bialatus* Biozone, the *Crassispora maculosa* Biozone and the *Cirratriradites annuliformis* Biozone.

The earliest Mississippian (Kinderhookian) strata yielded an impoverished miospore assemblage, dominated by survivor taxa from the latest Devonian mass extinction. These assemblages are assigned to the *Cyclogranisporites commodus* Biozone. At the Osagean-Meramecian boundary, the Burlington, Keokuk, Lower Warsaw and Upper Warsaw yielded assemblages assigned to the *Spelaeotriletes obtusus* Biozone. Five biozones are recognised from the Chesterian. Cypress Formation assemblages are assigned to the *Prolycospora rugulosa* Biozone, Fraileys Shale assemblages are assigned to the *Crassispora aculeata* Biozone and Hardinsburg Sandstone assemblages are assigned to the *Cingulizonates bialatus* Biozone. Assemblages from the Tar Springs Sandstone, Waltersburg Formation, Menard Limestone and Palestine Sandstone are assigned to the *Crassispora maculosa* Biozone. The youngest Mississippian assemblages are recorded from the upper Chesterian Kinkaid Limestone and are assigned to the *Cirratriradites annuliformis* Biozone.

Reworked early to late Devonian acritarchs have been identified from the Kinderhookian and Osagean of Kentucky and the Mississippi Valley. Palynomorph assemblages from the Hannibal Shale and equivalent units in the Mississippi Valley are dominated by acanthomorph acritarchs.

Palynofacies analysis of the Kentucky samples indicates a distal suboxic-anoxic basin environment in the latest Devonian and a highly proximal environment in the Early Mississippian. This is consistent with the interpretation of a prodelta environment in the Late Devonian, and the southwest progression of the Borden Delta in the Early Mississippian.

Palynofacies analysis of Kinderhookian strata in the Mississippi Valley indicates a shelf to basin environment consistent with the palaeogeographical position of the Mississippi Valley in the early Carboniferous. The depositional environment of the Lower Warsaw is a highly proximal shelf environment which reflects the regressive phase of the Osagean sedimentary cycle. Palynofacies analyses of the Chesterian strata of the Mississippi Valley indicate a high terrestrial input and show fluctuations between proximal basin and shelf environments. This reflects shifts in the position of the palaeo-shoreline at the mouth of the Michigan River, northeast of the Mississippi Valley.

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CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

A decision by the IUGS Subcommission on Carboniferous Stratigraphy to globally recognise the Mississippian and Pennsylvanian as subsystems of the Carboniferous (Heckel & Clayton 2006), has highlighted difficulties in correlating stages on a global scale. A great deal of biostratigraphic work has been undertaken in Western Europe and North America, and zonal schemes using various fossil groups have been published for both areas (e.g. Collinson *et al.* 1962; Sandberg *et al.* 1972; Brenckle *et al.* 1974; Sando 1990; Poty *et al.* 2006). A comprehensive miospore biozonation has been published for Western Europe (Clayton *et al.* 1977; Higgs *et al.* 1988; Owens *et al.* 2004). European affinities have been suggested for some of the miospore assemblages within the USA and tentative palynological correlations with Europe have been published, but no biozonation has been proposed for the Mississippian within its type area. This is mainly due to the dominance of carbonate rich strata prevalent in the Mississippi Valley; however, clastic units from the area have yielded palynological assemblages and these units are the focus of this study.

1.2 OBJECTIVES

The main objective of the study was to analyse palynological assemblages from the Mississippian strata of the Mississippi Valley and to correlate them with the existing miospore biozones established in Western Europe. Previous studies of the lower Mississippian in Kentucky have recognised assemblages which closely resemble those of a similar age in Western Europe. Further samples were collected from this area and the assemblages were re-examined.

During the course of the project it has become apparent that miospore assemblages from the Mississippi Valley are quite different to those from Western Europe, with many key zonal taxa exhibiting very different ranges. Therefore, an additional objective has been to erect a separate miospore biozonation for the Mississippian of the Mississippi Valley.

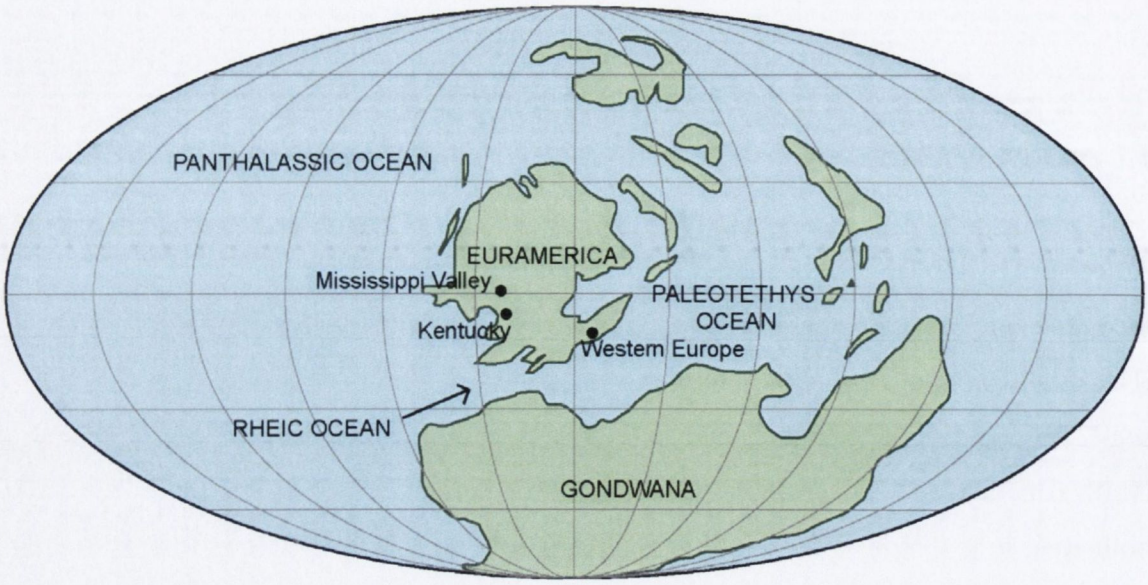


Figure 1.1 Palaeogeographic reconstruction of the Early Carboniferous (365 Ma) showing the locations of Western Europe, the Mississippi Valley, and Kentucky (base map after Scotese 2006)

A third objective is to carry out palynofacies analysis to determine palaeoenvironments, and to analyse how this may have affected the distribution of assemblages.

1.3 GLOBAL PALAEOGEOGRAPHY

In Mississippian time, two major landmasses dominated the globe – Gondwana in the southern hemisphere and Euramerica in the mid-latitude and to the north (Figure 1.1). Euramerica comprised present day Europe and North America and these two areas were aligned along a similar palaeolatitude. Similar floral and microfloral assemblages are recognised in Mississippian sediments from both Europe and North America, and a close resemblance to these assemblages was anticipated in the Mississippi Valley region.

1.4 OVERVIEW OF GEOLOGICAL SETTING IN THE MIDWEST USA

The Mississippian strata of the Midwest USA were deposited during a period of relatively high sea levels. The area was composed of a series of basins and arches which can be recognised by shallow marine deposits i.e. shelf, platform and shallow basin (Figure 1.2). Two of these basins are studied herein - the Appalachian Basin and Eastern Interior Basin (or Illinois Basin). Major landmasses were situated to the North, North East and South.

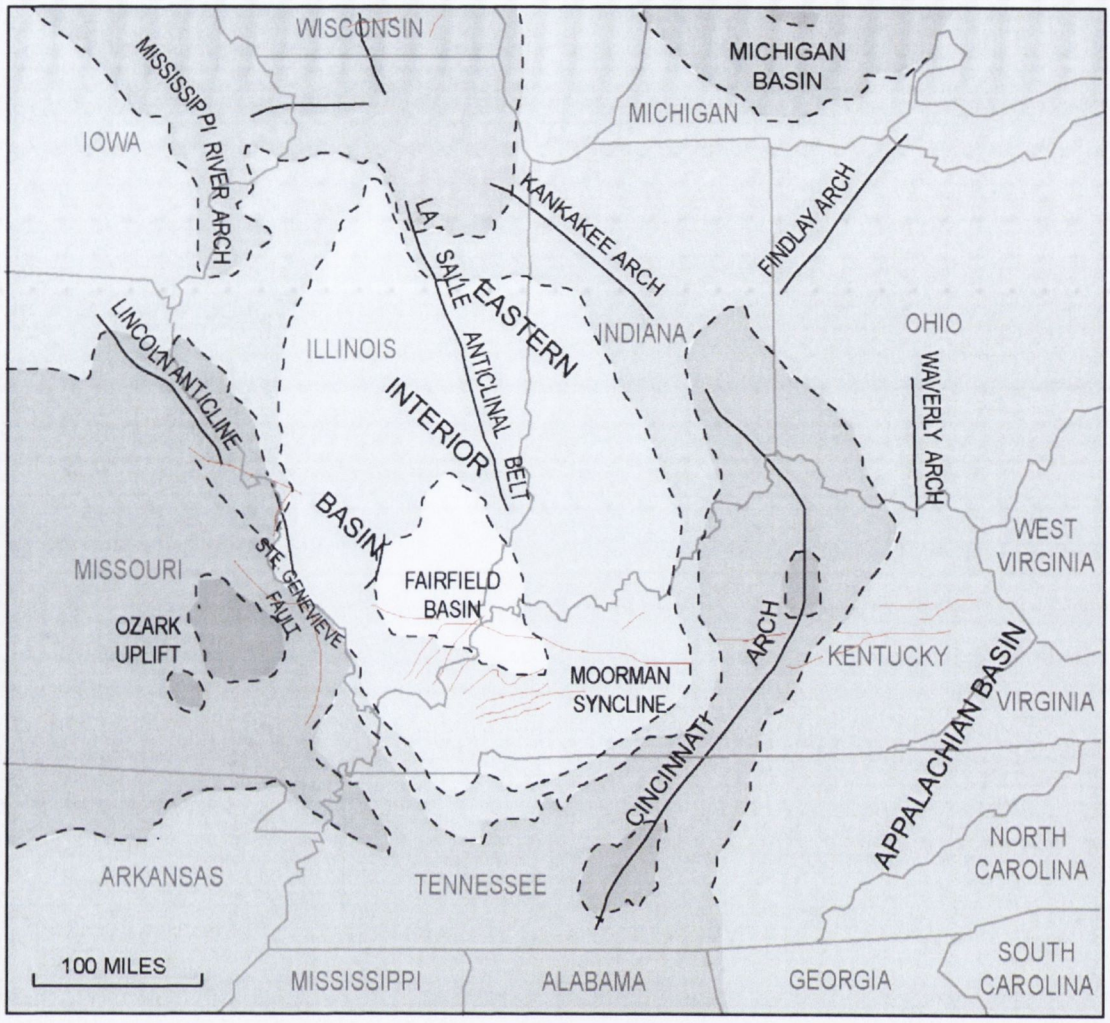


Figure 1.2 Generalized structural elements of Kentucky and the Mississippi Valley (after Sable and Dever 1990). Dashed lines show palaeodepths, darker shading indicates a higher elevation. Red Lines are major faults and fault zones. Solid black lines indicate positive features.

The palaeoclimate of Euramerica was generally warm and arid and remained relatively stable throughout the Mississippian. Environmental fluctuations as a result of sea level transgressions and regressions are easily recognised as a result of the shallow palaeoenvironments and proximity to land (for example, the cycle of clastic and limestone deposition throughout the Chesterian). Disconformities and hiatuses can be recognised between some units. In general these are due to small scale localised tectonic movements, deposition on uneven topographic relief and subaerial and submarine deposition, rather than widespread tectonic activity or eustatic sea level change (Sable & Dever 1990).

The geological setting and lithology of each area and specific rock units sampled will be discussed in detail below. The stratigraphic relationship of units is shown in Figure 1.3. In section 1. 4. 2 units from the upper Devonian to lower Osagean are described; units above

this level are not included in this study, and have not been described. Relevant units from northern Kentucky are also included. In section 1. 4. 4 units from the Mississippi Valley are described; only units relevant to the present study are included.

1. 4. 1 GEOLOGICAL SETTING - KENTUCKY

In the Mississippian, Kentucky straddled parts of both the Eastern Interior and the Appalachian Basin. These were separated by a structure known as the Cincinnati Arch. The Eastern Interior Basin sediments comprise around 2800 ft (950 m) of Mississippian age strata in eastern Kentucky, and in the Appalachian Basin, Mississippian sediments comprise around 2000 ft (650 m) (Sable & Dever 1990). In this report only sediments from the Appalachian Basin were studied from Kentucky and this area is described below; the Eastern Interior Basin is studied from the Mississippi Valley type area (Illinois, Missouri and Iowa) and this is referred to in section 1.4.3.

Mississippian rocks in Kentucky are dominated by limestone and dolomite; these two lithologies comprising about two thirds of the strata. Carbonate deposition dominated the Kinderhookian and continued throughout the rest of the Mississippian. The Kinderhookian is characterised by fine-grained carbonates, indicating low-energy environments. The Osagean and early Meramecian are characterised by deltaic sediments prograding in a westerly direction and carbonate deposition which was spreading from the west. These sediments are generally coarser and well-sorted, indicative of shallower higher energy environments. The Meramecian is dominated by carbonate units, again these are low-energy deposits. The Chesterian is characterised by alternating periods of carbonate and clastic deposition, indicating fluctuations between low and high-energy depositional environments (Sable & Dever 1990).

During the Mississippian the major source of terrestrially derived sediments in western Kentucky were the highland areas to the northeast and east (present day Appalachians and Canadian Shield). Sediments were transported from these areas and deposited in a deltaic environment - in the Kinderhookian these were deposited by the Borden Delta (making up the strata of the Borden Formation) and in the Chesterian they formed other less extensive delta complexes. Highlands to the south of Kentucky may have also provided a minor source of terrestrial material. Most marine sediments were deposited in widespread shallow and very shallow platform and shelf environments. Slightly deeper perideltaic

Subsystem	Global Stages	North American Stages	NE Kentucky (Vanceburg) (Sandberg *et al.* 2002)	NE Kentucky (Morehead) (Sable & Dever 1990)	Mississippi Valley: W Illinois (Atherton *et al.* 1975)	NE Missouri & N Illinois (Thompson 1986)	SE Missouri (Thompson 1986)	Central & SW Missouri (Thompson 1986)	SE Iowa (Witzke & Bunker 2005)
MISSISSIPPIAN	SERPUKHOVIAN	CHESTERIAN	PENNSYLVANIAN	Pennington Formation	Grove Church Sh	PENNSYLVANIAN	PENNSYLVANIAN	PENNSYLVANIAN	PENNSYLVANIAN
					Kinkaid Ls				
					Degonia Ss				
					Clore				
					Palestine Ss				
					Menard Ls				
					Waltersburg				
					Vienna Ls		Vienna Ls		
					Tar Springs Ss		Tar Springs Ss		
					Glen Dean Ls		Glen Dean Ls		
					Hardinsburg Ss		Hardinsburg Ss		
					Okaw Gr: Haney Ls		Okaw Fm: Haney Ls Mb		
					Okaw Gr: Fraileys Sh		Okaw Fm: Fraileys Sh Mb		
					Okaw Gr: Beech Creek		Okaw Fm: Beech Creek Ls Mb		
					Cypress Ss		Cypress Ss		
					Paint Creek Gr: Ridenhower		Paint Creek Fm: Ridenhower Mb		
					Paint Creek Gr: Bethel Ss		Paint Creek Fm: Bethel Ss Mb		
					Paint Creek Gr: Downeys Bluff Ls		Paint Creek Fm: Downeys Bluff Ls Mb		
					Yankeetown Ss		Yankeetown Ss		
				Newman Lst: Upper Member	Renault Ls		Renault Fm		
					Aux Vases Ss		Aux Vases Ss		
					Ste Genevieve	Ste Genevieve	Ste Genevieve		Pella
	VISEAN	MERAMECIAN		Newman Lst: Ste Genevieve Limestone Member	St Louis Ls	St Louis Ls	St Louis Ls		St Louis
					Salem Ls	Salem Ls	Salem Ls	Salem Ls	
				Newman Lst: St Louis Ls Member	Ullin Ls				Sonora
					Sonora				
				Borden Formation: Renfro Mb	Warsaw Sh	Warsaw Sh	Warsaw Sh	Warsaw Sh	Warsaw Shale: Upper
									Warsaw Shale: Lower
				Borden Formation: Nada Member	Keokuk Ls	Keokuk Ls	Keokuk Ls	Keokuk Ls	Keokuk Formation: Upper
				Borden Formation: Cowbell Mb					Keokuk Formation: Lower
			Logan Fn						
		OSAGEAN	Cuyahoga Fm: Vanceburg Mb	Borden Formation: Nancy Mb	Burlington	Burlington Limestone	Burlington Limestone	Burlington Limestone	Burlington Formation: Cedar Fork Mb
			Cuyahoga Fm: L. Portsmouth Mb						Burlington Formation: Haight Cr Mb
			Cuyahoga Fm: Buena Vista Member	Borden Formation: Farmers Member					
			Cuyahoga Fm: Henley Bed RL JC	Borden Formation: Henley Bd	Fern Glen		Fern Glen		Burlington Formation: Dolbee Cr Mb
					Meppen Ls	Pierson Ls	Meppen Ls	Pierson Ls	
	TOURNAISIAN	KINDER-HOOKIAN	Sunbury Shale	New Albany Shale: Sunbury Shale	North Hill Gr: Starrs Cave Ls	Chouteau Limestone	Bachelor Fm	Chouteau Group: Northview Formation	Wassonville
					North Hill Gr: Prospect Hill Sts				SC Mb
					North Hill Gr: Mc Craney Ls			Sedalia Formation	Prospect Hill Sts
								Compton Ls	
					Hannibal Shale	Hannibal Shale			
					Horton Creek	Horton Creek	Bushberg Ss	Bachelor Fm	McCraney Ls
Devonian	Famennian		Berea Ss	Berea Ss	Louisiana Limestone	Louisiana Limestone	Glen Park Limestone	Chattanooga Shale	Louisiana Limestone
			Bedford Sh	Bedford Sh					
			Ohio Sh	Ohio Sh					

Figure 1.3 Stratigraphic nomenclature of the Mississippian Subsystem in Kentucky and the Mississippi Valley. Abbreviations are as follows: Ls - limestone, Sh - shale, Ss - sandstone, Sts - siltstone, Gr - group, Fm - formation, Mb - member, RL - Rockford Limestone, JC - Jacobs Chaple, SC - Starrs Cave, Cr - Creek.

environments are recognised from the Kinderhookian, Osagean and early Meramecian, during a period of seaway opening and deepening. During the Chesterian the Appalachian Basin became more restricted and shallower deltaic sediments are again recognised (Sable & Dever 1990).

Structural features such as the Cincinnati Arch and the adjoining Waverly Arch played a major role in influencing deposition and restricting water flow in and out of the Appalachian Basin. These features were formed during the Late Devonian. Tectonic activity during the Mississippian itself included the relative uplift of the transcontinental arch west of Kentucky and the relative subsidence of the Eastern Interior Basin and other areas. This caused the restriction of seaways to and from the Appalachian Basin during the Meramecian and Chesterian. A regional southwest and west tilting of sediments occurred during the Osagean, Meramecian and Chesterian.

1. 4. 2 KENTUCKY STRATIGRAPHY

Late Devonian Series

Cleveland Member of the Ohio Shale

The Ohio Shale, named from exposures in Ohio, consists mainly of organic rich, fissile shale and thinly interbedded siltstone. It is recognised as a black shale unit throughout northeast and east central Kentucky. The Ohio Shale grades laterally into the Chattanooga Shale in the south and southeast, and the New Albany Shale to the north and west. The thickness of the unit ranges from around 35m to 140m (100ft to 400ft) (Sable & Dever 1990, p. 31, fig.12).

Bedford Shale and Berea Sandstone

The Bedford Shale and Berea Sandstone conformably overlie the Ohio Shale in eastern Kentucky. Throughout most of Kentucky the two are discreet units but in some areas they interfinger. The Bedford Shale is made up of grey to greenish grey claystone with pyritic nodules and thin siltstones (Sable & Dever 1990). The Berea Sandstone overlies the Bedford Shale and is generally a fine-grained, light-grey subgreywacke sandstone, and commonly shows structures such as cross bedding and ripple marks (Sable & Dever 1990).

The two units thin to the southwest, where the Bedford Shale has a wider lateral range than the Berea Sandstone. The Bedford and Berea exhibit a maximum thickness of 70m (200ft) in eastern and southeastern Kentucky. The main sediment source of the Bedford and Berea was the area to the east and northeast of the present Appalachian Mountains (Pepper *et al.* 1954). In the study area the Bedford is a grey silty mudstone, and is about 7m (20ft) thick, the Berea Sandstone is not present.

Kinderhookian Stage

Sunbury Shale

The Sunbury Shale conformably overlies the Bedford and Berea, and marks the base of the Mississippian Subsystem in northeast Kentucky. The boundary was previously placed within the Bedford-Berea complex on conodont and plant fossil evidence (De Witt 1970), but has more recently been placed at the base of the Sunbury Shale using conodonts and miospores (Eames 1978; Coleman & Clayton 1987).

The unit consists of fissile, organic-rich claystone and siltstone – generally termed a 'black shale' deposit, similar to that of the Late Devonian Ohio Shale. It is a distinctive, wide-ranging and, therefore, a stratigraphically useful horizon, and is recognised as the basal unit of the Mississippian Subsystem in eastern and northeastern Kentucky (Sable & Dever 1990; Coleman 1991). It ranges from 2-8m (10-25ft) thick in northeastern Kentucky and becomes thicker towards the southeast to reach a maximum thickness of 19m (55ft) (Sable & Dever 1990). Conodonts have been recognised from the Sunbury Shale at various localities (Cooper 1931; Sandberg *et al.* 2002). The Sunbury Shale is interpreted as the result of deposition during a marine transgression, in an anaerobic, deep-water environment (Sable & Dever 1990). In the study area the Sunbury Shale is described as "a black, bituminous, pyritic shale" (Coleman & Clayton 1987, p. 75).

Osagean Stage

Borden Formation

The Borden Formation of eastern Kentucky is comprised of "terrigenous detrital clastics...deposited as prograding deltaic wedges" (Sable & Dever 1990, p. 36). The unit is

thickest in eastern and central areas and thins towards the south and west. In the study area the Borden Formation is made up of the Farmers Member, Nancy Member, Cowbell Member, Nada Member and Renfro Member. The Borden typically comprises grey and green mudstone and siltstone with interbedded sandstone layers in the lower part and the upper part is dominated by limestone and dolomite.

Farmers Member

The Farmers Member is the basal unit of the Borden Formation and conformably overlies the Sunbury Shale. In its type area in northeastern Kentucky, the Farmers Member consists of planar bedded sandstones and shales and ranges up to 65m (200ft) thick (Sable & Dever 1990). In the study area the Farmers is 11m (33ft) thick and comprises tabular bedded sandstone and siltstone, with interbedded shales. The base of the unit contains a 1.8m (5ft) thick greenish-grey sandy mudstone, known as the Henley Bed. The Farmers Member is interpreted as a turbidite sequence, and the Henley Bed represents a period of extremely slow sedimentation in the deepest part of the basin (Chaplin 1982; Coleman & Clayton 1987).

Nancy Member

The Nancy Member overlies the Farmers Member. The Nancy comprises green-grey silty shales and siltstones, which are easily weathered between the harder under and overlying members. Fossils, including crinoids and conodonts are common (Work & Mason 2005). The unit rages from around 50 to 100m (150 to 300ft) thick and is interpreted as a prodelta deposit (Sable & Dever 1990). In the study area, the Farmers Member grades upwards into the Nancy Member and the latter is a 20m (60ft) thick green-grey, silty, highly bioturbated shale. The Nancy is the youngest unit of the Borden Formation studied herein.

Cuyahoga Formation

The Cuyahoga Formation is the lateral equivalent of the Borden Formation in northeastern Kentucky and extends throughout southern and eastern Ohio. The Cuyahoga Formation overlies the Sunbury Shale and is made up of silty shales and interbedded sandstone layers. These are interpreted as fluvial, deltaic and marginal marine clastics, deposited in basinal

and shelf environments. The unit is up to 208m (625ft) thick (Collins 1979). Brachiopods, molluscs and crinoids have all been recorded from the unit (Coogan 1996).

The Cuyahoga is comprised of numerous members (Coogan 1996). Those studied in the present report are the Henley Member (or Henley Bed), Buena Vista Member, Portsmouth Member and Vanceburg Member.

In northernmost Kentucky the base of the Henley Bed is marked by the Jacobs Chapel equivalent – a 10cm thick bed of greenish grey phosphatic claystone, containing upper Kinderhookian conodonts, and the Rockford Limestone equivalent – a 30cm thick bed of argillaceous dolomicrite containing upper Kinderhookian/lower Osagean conodonts. The remaining 4.5m (13ft) of the Henley Bed comprises greyish green and red mudstones. The Buena Vista Member is a 2m (6ft) thick yellow-grey mudstone interbedded with green-grey shale. The Portsmouth Member is a 12m (35ft) thick predominantly green-grey mudstone with harder silty layers and is interpreted as the equivalent of the Nancy Member of the Borden Formation. The Vanceburg Member is a yellow-grey siltstone (Sandberg *et al.* 2002).

1. 4. 3 GEOLOGICAL SETTING - MISSISSIPPI VALLEY

The Mississippian Subsystem was named from exposures along the Mississippi River Valley in Iowa, Illinois and Missouri. During the Mississippian this region was part of the Eastern Interior Basin. The Mississippian is over 1065m (3200ft) thick in Southern Illinois, and thins in the northern part of the basin (Atherton *et al.* 1975).

Mississippian deposits in the Mississippi Valley are dominated by limestone, with subordinate siltstone, shale and sandstone appearing throughout. In the lowest part of the subsystem, the lower Kinderhookian is dominated by shale and siltstone. The middle part of the section, the upper Kinderhookian and Valmeyeran (Osagean and Meramecian combined stage), comprises mainly limestone, indicating a relatively deep marine, low energy palaeoenvironment. Palaeosols and sabkha deposits occur around the Osagean - Meramecian boundary, and are attributed to a marine regression around this time (Lane and Brenkle 2005). In the upper part of the Mississippian the Chesterian comprises alternating shaley limestone and shaley sandstone units. As previously noted in section 1.

4. 1, these are recognised as alternating periods of low and high-energy depositional environments, possibly deposited in a deltaic environment (Atherton *et al.* 1975).

In general, three types of limestone are recognised in the Mississippi Valley – very fine grained, cherty limestone, medium-coarse grained, crinoidal or bryozoan limestone, and medium to coarse grained, oolitic limestone. Shales are generally dark greenish grey, with some red and green beds. Sandstones are fine grained and light green-grey, and siltstones are generally light green-grey (Atherton *et al.* 1975). Fossils are commonly found throughout the shale and limestone beds.

The source of most of the clastic sediment in the Mississippi Valley was to the northeast of Illinois. Minor sources were from the northwest in the Iowa region and from the Ozark region to the west in southern Missouri (Figure 1.2). The southeasternmost edge of the Borden Delta reached the Mississippi Valley in the Valmeyeran, providing an additional minor source of siltstones. In the Chesterian most of the coarser grained sandstones were transported from the northeast by the Michigan River (Figure 1.4). Many of the formations in the Chesterian show obvious channel features with massive sandstone lenses pinching in and out within formations, and erosional bases (Atherton *et al.* 1975).

Late Devonian sediments in the western part of the basin (western Illinois) were slightly eroded due to minor uplift at the edge of the Ozarks. This has caused local unconformities at the Devonian/Carboniferous boundary (Atherton *et al.* 1975).

1. 4. 4 MISSISSIPPI VALLEY STRATIGRAPHY

Kinderhookian Stage

Horton Creek Formation

The Horton Creek Formation (also known as the Glen Park Formation) is known from exposures in northeastern Missouri and western Illinois. Where present, it is the basal unit of the Carboniferous and comprises of a basal, thin sandy siltstone, overlain by silty shale, dolomitic limestone and limestone (Atherton *et al.* 1975; Thompson 1986). In its type locality the Horton Creek is around 5.5m (16ft) thick, but varies from several feet to a few inches thick. In the present study the Horton Creek is (0.8m) 2.5ft thick.

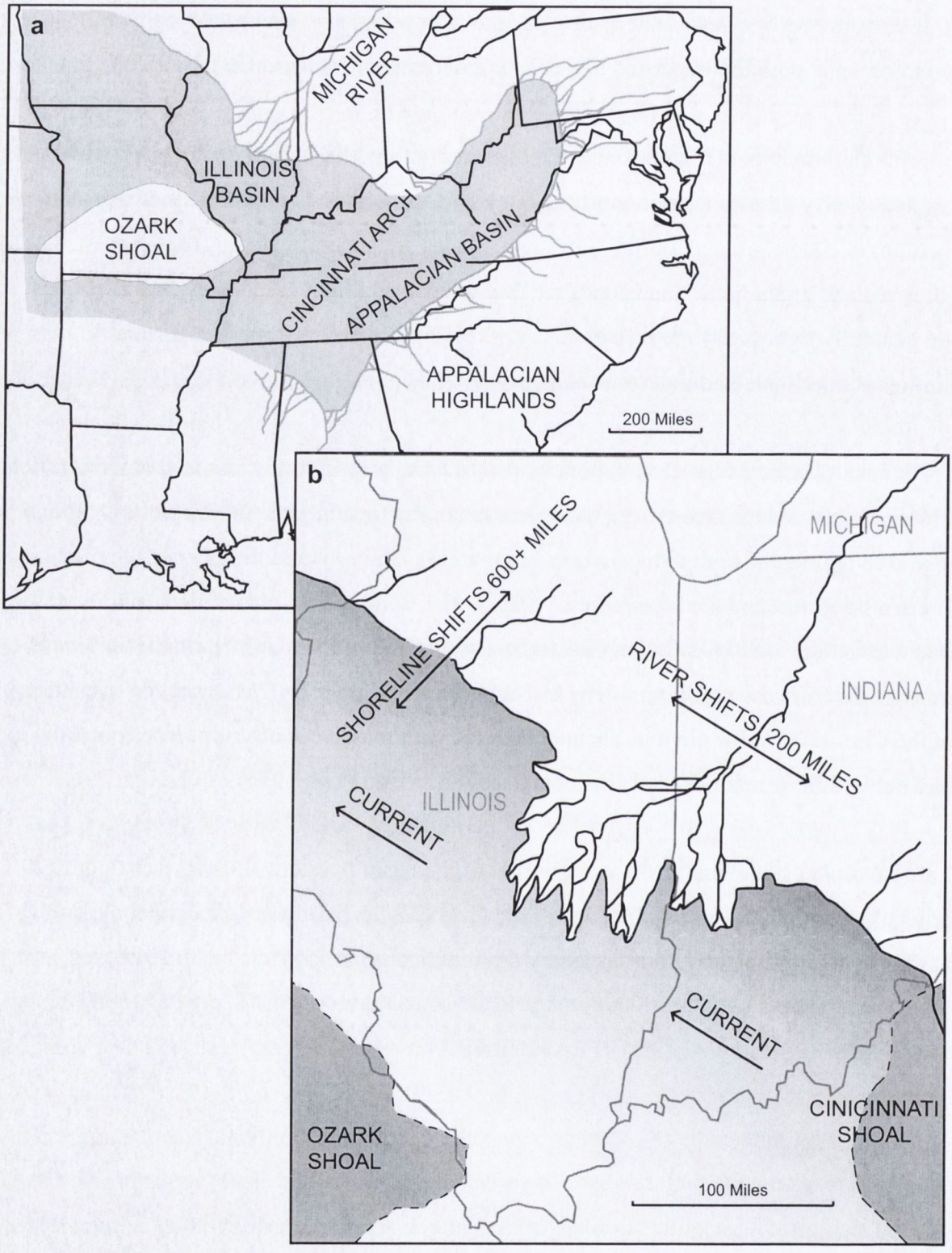


Figure 1.4 Palaeogeography during the middle Chesterian a - Palaeogeography of eastern USA (after McKinney 2002) b - Palaeogeography of the Mississippi Valley (after Atherton *et al.* 1975)

Hannibal Shale Formation

The Hannibal Shale is named from Hannibal, Missouri and consists of green grey siltstone, silty shale and sandy shale. In some areas of northern Missouri a dark grey shaley member, known as the Cuivre Member, can be identified at the base of the Hannibal. At its type

locality the Hannibal conformably rests on Late Devonian sediments but it is unconformably overlain by the Osagean Burlington Limestone (Thompson 1986). The Hannibal has a maximum thickness of 33m (100ft) in parts of western Illinois and is around 25m (75ft) thick in its type region (northwest Missouri). The Hannibal contains abundant conodonts and scarce mega fossils (Atherton *et al.* 1975).

Bachelor Formation

The Bachelor Formation is the equivalent to the base of the Hannibal Shale throughout western and southern Missouri, outside of the Mississippi Valley type region. The formation is composed of a basal (3 inches to 1 ft thick) light green to tan, medium to coarse grained sandstone, overlain by a thin (1-3 inches) grey-green calcareous shale.

Chouteau Limestone

The Chouteau Limestone was named from outcrops in Missouri. In Indiana the same unit is known as the Rockford Limestone. The Chouteau sits conformably atop the Hannibal Shale throughout most of the Mississippi Valley, and ranges from around 6.5m (20ft) to a maximum of around 26.5m (80ft) in western Illinois and more than 35m (100ft) in Missouri. The unit comprises light brown and green-grey lithographic limestone, with wavy bedding planes varying from a few inches to 1 foot thick. Dolomite, chert and geodes occur locally throughout the Chouteau, and fossils are common (Atherton *et al.* 1975). In Missouri the Chouteau is termed the Chouteau Group, and comprises the Compton, Sedalia and Northview formations (Thompson 1986). In this study only the Compton and Northview are sampled.

Compton Limestone

The Compton Limestone is a light blue-grey, fine grained, slightly crinoidal limestone, consisting of beds 6 inches to 2 feet thick. The Compton is around 5m (15ft) thick and its top is gradational with the overlying beds.

Northview Formation

The Northview Formation ranges from a blue brown siltstone in its type area in southwestern Missouri to a blueish dolomitic siltstone to the north. The unit has a

maximum thickness of 30m (90ft) in the type region, but thins and pinches out towards the Mississippi Valley (Thompson 1986).

McCraney Limestone

The McCraney Limestone, named from western Illinois, is the equivalent of the lower part of the Chouteau Limestone in Iowa and western Illinois. In Iowa the McCraney Limestone rests directly on the uppermost Devonian (Witzke & Bunker 2005). The unit has a maximum thickness of 19m (58ft) in western Illinois and thins to the east, and sits conformably on the Hannibal Shale. It comprises alternating brown and grey limestone and dolomite layers, yields conodonts, and represents a local carbonate-producing but fossil-poor environment (Brenckle *et al.* 2005).

Prospect Hill Siltstone

The Prospect Hill Siltstone was named from exposures in southern Iowa, and overlies the McCraney Limestone. In more northern parts of Iowa it lies directly atop the Devonian strata. It is comprised mainly of siltstone, variably light grey to buff, calcareous, pyritic and massively bedded. It has a maximum thickness of 10m (29ft) in western Illinois but thins towards the south, southwest and east. Macrofossils and conodonts have been recovered from the unit (Atherton *et al.* 1975) and it is interpreted as having been deposited in a dysoxic marine environment (Brenckle *et al.* 2005).

Wassonville Formation

The Wassonville Formation is named from southeast Iowa and has a maximum thickness of 47m (140ft) in its northernmost region. It thins to the south, southwest and east and is around 6m (18ft) in the studied section. The Wassonville is a cherty limestone or dolomite probably deposited in an oxygenated open marine environment (Brenckle *et al.* 2005; Witzke & Bunker 2005).

Starrs Cave Limestone

The Starrs Cave is given the rank of formation in western Illinois but is a member of the Wassonville Limestone in Iowa. In its type area in southern Iowa it consists of around 1m

(3ft) of oolitic, fossiliferous, light grey limestone. In Illinois it varies from 70cm-4m (2-12ft) thick and consists of brownish grey, oolitic and locally dolomitic limestone (Atherton *et al.* 1975). In Iowa this is overlain by the Osagean Burlington Limestone. The contact between the two units is sharp and unconformable (Witzke & Bunker 2005).

Osagean/Valmeyeran Stage (Illinois only)

Fern Glen Formation

The Fern Glen Formation is the oldest Osagean unit in eastern Missouri. It generally consists of three layers; a basal, red-brown, geodiferous, crinoidal limestone; a middle red-green, fossiliferous, calcareous shale; and an upper fine-grained limestone with interbedded chert. Brenckle *et al.* (2005, p. 14) state, "the Fern Glen grades upwards and northwards into the Burlington Limestone and is considered to be a basin marginal facies of the Burlington". The unit ranges from 6.5 to 15m (20 to 45ft) thick (Thompson 1986). The Meppen Limestone is recognised as the basal member of the Fern Glen Formation in Missouri. In Illinois the Meppen is given the rank of formation, and is recognised as a 6.5m (20ft) thick dolomitic limestone (Atherton & Palmer 1979).

Pierson Formation

The Pierson Formation is a greenish-grey, fine to coarsely crystalline, relatively chert-free limestone. It overlies the Northview Formation in west central and southern Missouri, where it is the basal unit of the Osagean. It is typically 10-17m (30-50ft) thick, reaching a maximum of 25m (75ft) in southern Missouri (Thompson 1986).

Burlington Limestone

The Burlington Limestone, named from southern Iowa, crops out extensively throughout southern Iowa, Illinois and Missouri. The Burlington typically ranges from 35-50m (100-150ft) thick, with a maximum thickness of 66m (200ft) in Illinois. It is typically a white-grey, coarsely crystalline, crinoidal, medium to thick-bedded limestone. Chert is sparse to common, and concentrated in the middle and upper part of the formation (Atherton & Palmer 1979; Thompson 1986).

In Iowa the Burlington comprises three members. The lowest, the Dolbee Creek Member comprises skeletal packstones and grainstones. The middle Haight Creek Member is made up of cherty dolomites and is enriched in glauconite, providing a recognisable and useful marker for this level throughout Iowa. The upper Cedar Fork Member is a cherty crinoidal limestone and dolomite, a similar lithology to the Keokuk Limestone, and has yielded biostratigraphically useful conodont and foraminiferal faunas (Witzke & Bunker 2005).

The Burlington is interpreted as representing "an extensive region of very uniform, shallow, prograding carbonate shelf deposition" (Thompson 1986, p. 91). The contact with the overlying Keokuk is transitional and difficult to identify (Atherton & Palmer 1979; Thompson 1986).

Keokuk Limestone

The Keokuk Limestone has a similar distribution and lithology to the underlying Burlington, and crops out throughout much of Illinois, Missouri and Iowa. It is a fossiliferous cherty limestone, interbedded with fine-grained limestone, dolomite, and grey calcareous shale. It is generally darker grey and more thinly bedded than the Burlington, with an increased proportion of shale (Atherton & Palmer 1979).

In its type area in southeasternmost Iowa, the base of the Keokuk Limestone is commonly termed the Montrose Chert Member and is rich in chert nodules and bedded cherts (Van Tuyl 1925; Keyes 1985). This member is locally present but is not in evidence in most Keokuk sections (Witzke & Bunker 2005). The Keokuk ranges from 17-33m (50-100ft) thick, typically 20-23m (60-70ft) (Thompson 1986).

Both the Burlington and Keokuk formations are recognised as middle shelf deposits dominated by subtidal open-marine facies with a general absence of mud and shale deposition (Witzke *et al.* 1990; Witzke & Bunker 2005). Hence, they are generally barren in terms of palynological material (see Chapter 4). A modern analogue for this paleoenvironment is suggested on the modern shelf of southern Australia (James *et al.* 2001).

Warsaw Formation

The Warsaw Formation, named from western Illinois, is present throughout the Mississippi Valley. It ranges from 35m to 100m (100ft to 300ft) of siltstone and grey shale and thins to the northwest (Atherton *et al.* 1975). The Warsaw is divided into two members - the Lower and Upper Warsaw and is the type section for the base of the Meramecian. The Osagean/Meramecian Boundary coincides with the boundary between the two members (Kammer *et al.* 1990).

The Lower Warsaw is a light to dark grey silty shale, commonly interbedded with layers of dolomite and limestone. Quartz and calcite geodes are common and locally abundant. The Lower Warsaw is interpreted as a sequence of palaeosols and very marginal marine deposits (sabkha deposits), deposited in an arid climate during a marine regressive phase. The Upper Warsaw comprises blue-grey, thinly bedded shales and fossiliferous limestone, and represents the transgressive phase of the early Meramecian (Brenckle *et al.* 2005). In southern Iowa the Upper Warsaw carbonates (as recognised from the type area) are not present and cannot be used to recognise the Osagean-Meramecian boundary in this area (Witzke & Bunker 2005).

Meramecian Stage

Salem Limestone

The Salem Limestone overlies the Warsaw in western Illinois and eastern Missouri. It is composed of crossbedded fossiliferous limestone, with thin layers of dolomite, chert, sandstone, anhydrite and gypsum (Atherton & Palmer 1979). The Salem is around 35-53m (100-160ft) thick in the southern Mississippi Valley (east central and southeast Missouri), and thins in the north to around 6.5-13m (20-40ft) thick (Thompson 1986). In the northern part of the Mississippi Valley the open-marine Salem grades laterally into the shallower facies of the Sonora Formation.

Sonora Formation

The Sonora Formation is a predominantly sandy unit which overlies the Warsaw, and is the equivalent of the Salem Limestone in northern Illinois. It comprises light grey-brown, fine-

grained sandstones, grey sandy shales and sandy dolomite (Atherton & Palmer 1979). In the Mississippi Valley the Sonora ranges from 65cm to 6m (2ft-18ft) thick.

St Louis Limestone

The St Louis Limestone is described from eastern Missouri. The formation is a fine to lithographic, cherty limestone, ranging from light to dark grey and brown in colour, and containing layers of dolomite and evaporite, blue grey shale and breccias (Atherton & Palmer 1979). Corals are commonly found throughout the unit. The St Louis is laterally extensive throughout the Mississippi Valley and is generally more than 35m (100ft) thick, although it ranges up to 150m (450ft) in Illinois. At its base the St Louis represents restricted peritidal and arid lagoonal environments, becoming slightly less restricted above this. The top of the St Louis is gradational and interbedded with the strata from the overlying Ste Genevieve Limestone (Atherton & Palmer 1979).

Chesterian Stage

Ste Genevieve Limestone

The Ste Genevieve Limestone, at the base of the Chesterian Stage, overlies the St Louis Limestone throughout the Mississippi Valley, Illinois and parts of eastern Kentucky. The Ste Genevieve is a white, massively bedded, sandy, clastic limestone. Thin sandy beds are generally concentrated in the lower part of the unit (Atherton & Palmer 1979; Thompson 1986). In the Mississippi Valley region the formation is usually less than 25m (75ft) thick (Thompson 1986). In Illinois the Ste Genevieve comprises four members and ranges from around 30m (90ft) in western Illinois to a maximum thickness of around 80m (250ft) in southern Illinois (Atherton & Palmer 1979).

Aux Vases Sandstone

The Aux Vases Sandstone marks the beginning of the series of alternating clastic and limestone beds seen throughout Kentucky and the Mississippi Valley, representative of marine fluctuations. Most of these units are traceable laterally, but some are regarded differentially as members or formations between different states.

The Aux Vases Sandstone conformably overlies the Ste Genevieve Limestone. The Aux Vases is predominantly a light grey to green grey, calcareous sandstone to coarse siltstone. Shale is common throughout the unit along with minor dolomite and limestone. In the southern part of the Mississippi Valley the Aux Vases is typically around 6.5-10m (20-30ft) thick in Illinois and 13-20m (40-60ft) in Missouri. It increases in thickness in the northern part of the Mississippi Valley to reach around 18m-23m (55-70ft) in Illinois and more than 35m (100ft) in Missouri (Atherton & Palmer 1979; Thompson 1986).

Renault Limestone

The Renault Limestone is laterally extensive throughout the Mississippi Valley. The lower part of the unit is conglomeratic (limestone, chert and sandstone) at its base and comprises shale and sandy limestone. The upper part comprises grey-blue grey limestone interbedded with red and green shale (Thompson 1986). In Missouri, the formation is typically 15-30m (45-90ft) thick. In southeastern Illinois, the Renault is split into two members the Levias and Shelterville members, and is extremely variable in thickness, ranging from 0-26m (0-80ft), although it is typically around 5m (15ft) thick (Atherton & Palmer 1979; Thompson 1986).

Yankeetown Sandstone

The Yankeetown Sandstone Formation is conformable and gradational with the underlying Renault Limestone. It is named from southwestern Illinois. In this region the Yankeetown is a cherty sandstone, but elsewhere in the Mississippi Valley it is typically sandy and shaley. The sandstone is irregularly bedded and crossbedded, and shales are grey or red in colour. In Illinois the Yankeetown is around 6m (18ft) in outcrop and thickens to around 20-30m (60–90ft) in the subsurface of western Illinois and eastern Missouri (Atherton *et al.* 1975; Atherton & Palmer 1979; Thompson 1986).

Downeys Bluff Limestone

The Downeys Bluff Limestone is known as a formation of the Paint Creek Group in Illinois and as a member of the Paint Creek Formation in Missouri. It is a pink, light brown or white chert, containing crioidal debris. These fossils are often preserved as pink chert in the Mississippi Valley region and are distinctive throughout the unit. In southern Illinois

the Downeys Bluff comprises two layers – a slightly silty or fine sandy lower layer and an upper cherty layer, separated by a thin shale. The Downeys Bluff ranges from 2-6m (6-18ft) thick with a maximum thickness of 9m (28 ft) in southern Illinois (Atherton & Palmer 1979).

Bethel Sandstone

The Bethel Sandstone is named from exposures in Kentucky, again in Illinois it is recognised as a formation and in Missouri it is a member of the Paint Creek Formation. A predominantly sandy unit, the Bethel grades to shale in western Illinois. Sandstones from the Bethel are very coarse and light grey to light greenish grey in colour. The unit contains frequent dark green to grey shaley partings; to the west these become more frequent and red-green in colour, and locally contains small pebbles and a conglomeratic, pebbly base (Atherton *et al.* 1975). The Bethel is around 6.5-13m (20-40ft) thick in the Mississippi Valley.

Ridenhower Formation

The Ridenhower is also given formation status in Illinois and member status in Missouri. It is named from exposures in southwestern Illinois where the formation is around 20m (60ft) thick. Elsewhere in the Mississippi Valley it ranges from 13-23m (40-70ft) thick. The formation is variable throughout its extent, and ranges from dark grey-green shale with fossiliferous limestone beds in its type area to red, green or brown shales with interbedded sandy, oolitic, crinoidal limestone, light to dark grey or brown in colour (Atherton *et al.* 1975). The Ridenhower thickens towards the east and is divided into members (see Chapter 2.3.4 for details). To the west, in the Mississippi Valley, limestone beds become more frequent, and the Ridenhower Member of Missouri is recognised as oolitic, crinoidal, cross-bedded limestone (Thompson 1986).

Cypress Formation

The Cypress Formation, again named from Illinois, is a predominantly sandy unit. In the Mississippi Valley of western Illinois it comprise two recognisable units; the lower part comprises one or two massive sandstone beds, the thinner upper part is typically a sandy and silty shale (Atherton *et al.* 1975). The Cypress thins to the west. In westernmost

Illinois (20-25m / 60-75ft thick) and eastern Missouri (less than 10m / 30ft thick) it comprises grey shale and mudstone, with thin red shales and limestones (Thompson 1986).

Beech Creek Limestone

The Beech Creek Limestone is a relatively thin but persistent unit, recognised as a formation in Illinois and a member of the Golconda Formation in Missouri. It contains argillaceous, dark brown-grey, dense limestone in its lower beds and light brown-grey, fossiliferous limestone in the upper layers. The unit thins from around 12m (35ft) thick in northern Illinois to thin or locally absent shaley beds in southern Illinois (Atherton & Palmer 1979; Thompson 1986). In Missouri it is recognised as a 1.5-6.5m (5-20ft) thick, dark grey to brown fossiliferous limestone (Thompson 1986).

Fraileys Shale

The Fraileys Shale is given the rank of formation in Illinois and recognised as a member in Missouri. In Missouri, the Fraileys is a thin, predominantly shaley member with beds of dark, crinoidal limestone (Thompson 1986). The unit thickens to the east and in Illinois is around 23-30m (70-90ft) thick. In the eastern part of the Mississippi Valley the Big Clifty Sandstone Member occurs in the middle of the Fraileys Shale (Atherton & Palmer 1979).

Haney Limestone

The Haney Limestone comprises coarse grained, fossiliferous limestone and interbedded shale. It is given the rank of formation in Illinois and is the upper member of the Golconda Formation in Missouri (Thompson 1986). It is thickest in the southern part of the Mississippi Valley where it reaches a maximum thickness of 30m (90ft), and thins to the north to less than 5m (15ft). In this area the Haney grades to a shale and is almost indistinguishable from the underlying Fraileys and overlying Hardinsburg (Atherton & Palmer 1979).

Hardinsburg Sandstone

The Hardinsburg Sandstone is typically a light grey and fine-grained sandstone. In Illinois two types of sandstone can be recognised – a thick-bedded, white, fine-grained sandstone,

and a thin-bedded, green-grey, fine grained shaley sandstone or silt. The base of the unit is typically comprised of 10m (30ft) of red, green and dark grey shales with thin beds of limestone and dolomite. The Hardinsburg is conformable with the underlying Haney throughout most of its area, but the base is erosional in some areas. The Hardinsburg ranges from 6.5-12m (20–35ft) thick in the northern part of the Mississippi Valley to 18-25m (55-75ft) thick in the south (Atherton & Palmer 1979).

Glen Dean Limestone

The Glen Dean Limestone, named from exposures in Kentucky, conformably overlies the Hardinsburg Sandstone and comprises buff and grey limestone and interbedded shale and chert. The limestone is coarse-grained, commonly cross-bedded and rich in macrofossils. The unit thins from the south to the north within the Mississippi Valley, and typically ranges 22-27m (65-80ft) thick (Atherton & Palmer 1979; Thompson 1986).

Tar Springs Sandstone

The Tar Springs Sandstone Formation is predominantly a very fine-grained sandstone, white or light grey in colour with minor beds of dark grey, carbonaceous shale, dark green grey siltstone and light to dark green-grey shaley sandstone. Towards the western edge of the Mississippi Valley, in Missouri, the formation is typically buff to rust-brown in colour. The Tar Springs ranges from 15m (45ft) to a maximum of more than 45m (130ft), but is generally around 23 to 40m (68 to 120ft) throughout much of the Mississippi Valley (Atherton & Palmer 1979). The contact with the underlying Glen Dean is variably conformable (gradational in some areas) to unconformable (Thompson 1986).

Vienna Limestone

The Vienna Limestone is the youngest formation of the Chesterian clastic-limestone sequence seen in the western part of the Mississippi Valley (eastern Missouri). In this area the Vienna is seen in very few outcrops, compared with extensive outcropping in southwestern Illinois (Thompson 1986). The Vienna is a thin, brown-grey, fossiliferous, cherty limestone. The Vienna is typically around 1m (3ft) thick throughout most of the Mississippi Valley, but reaches up to 6m (18ft) thick in the southernmost part (Atherton & Palmer 1979). The overlying formations are generally restricted to and named from

southern Illinois, and can be traced into parts of Indiana and Kentucky (Atherton *et al.* 1975, figs. M-45 to M-50).

Waltersburg Formation

The Waltersburg Formation comprises dark grey, carbonaceous shales, variably sandy or silty, and jointed sandstones. In the south of the Mississippi Valley, a thin coal seam is seen in the upper part of the Waltersburg. The unit is thickest in its western extreme (over 35m / 100ft) but is typically 15-23m (45-69ft) thick (Atherton & Palmer 1979).

Menard Limestone

The Menard Limestone comprises argillaceous, dark brown-grey or buff, fine-grained limestone, variably cherty or oolitic, and dark grey, calcareous shale. The unit can be divided into three members, divided by thin shales. It thins from a maximum thickness of 45m (135ft) in the south to around 33-18m (40-55ft) in the north (Atherton & Palmer 1979).

Palestine Sandstone

The Palestine Sandstone comprises sandstone, shale and siltstone. The sandstone is generally grey, fine-grained and shaley; thicker sandstone units tend to be lighter grey to white and coarse to medium-grained. Shales and siltstones are sandy and dark grey. The formation has a number of channel features including massive sandstone lenses, channels cutting into the underlying Menard Limestone and fossilised tree trunks. It is interpreted as a deltaic distributary system. The Palestine thickens to the south and ranges from 8m (25ft) to over 35m (100ft) but is more commonly around 17-20m (50-60ft) (Atherton *et al.* 1975).

Clore Formation

The Clore Formation is comprised mainly of shales with interbedded limestones, the latter increasing in frequency to the south. The Clore is split into three members; the lowest consists of interbedded limestone and shale, the middle is predominantly sandstone with minor shale, and the upper is a limestone with interbedded shale and minor sandstone. Sub-Degonia channels, and some sub-Pennsylvanian channels, cut into the top of the unit,

significantly reduce the thickness. The Clore is around 13-20m (40-60ft) thick in the north, and thickens to a maximum of more than 40m (120ft) in the south (Atherton *et al.* 1975; Atherton & Palmer 1979).

Degonia Sandstone

The Degonia Sandstone is predominantly sandstone, with massive sandstones in its southern extent ranging to thin, grey to dark grey shales in the north. Two major sandstone lenses can be recognised throughout most of the Degonia, although one or both may be absent, and a red shale bed is recognised from the top of the unit. In southwestern Illinois, thin coal seams occur in the mid to upper parts of the unit. The formation is thickest in the Mississippi Valley of western Illinois (43m / 130ft) and thins to around 6m (18ft) in the southeast. In some areas the top of the Degonia is incised by sub-Pennsylvanian channels (Atherton *et al.* 1975; Atherton & Palmer 1979).

Kinkaid Limestone

The Kinkaid Limestone is heavily eroded by pre-Pennsylvanian activity and has a patchy lateral distribution. The Kinkaid is divided into three members, the highest and lowest (Goreville and Negli Creek) are massive cherty limestones which were highly resistant to this erosion. The middle Cave Hill Shale Member consists of calcareous and silty shales and is heavily eroded. The Kinkaid is relatively thick, usually around 40-55m (120-160ft), and ranges from 35m (100ft) in the north to over 55m (170ft) in the south (Atherton *et al.* 1975).

Grove Church Shale

Like the underlying Kinkaid Limestone, the Grove Church Shale has been extensively eroded and occurs only in patches in southern Illinois. The Grove Church is generally a grey fossiliferous shale with interbedded limestone. It has a maximum thickness of 22m (67ft) (Atherton *et al.* 1975).

CHAPTER 2
BIOSTRATIGRAPHY OF THE MISSISSIPPI VALLEY

2. 1 INTRODUCTION

The Mississippian Subsystem was historically defined from the succession of strata exposed in the Mississippi River Valley between Burlington, Iowa and St Louis, Missouri (Witzke & Bunker 2005). During the Late Devonian and Mississippian the North American mid continent was partially covered by shallow seas and deeper basins (Atherton and Palmer 1979; Gray 1979; Gordon 1986) and the area was influenced by frequent transgressions and regressions (Brenckle *et al.* 2005; Witzke & Bunker 2005). As a result, lateral facies change can be observed at a local scale and many units are not continuous across large areas. Further correlation problems occur within sedimentary units which are laterally continuous throughout the Mississippi Valley region, but where subdivisions and names have been independently defined in individual states.

The marine nature of the sediments means that the Mississippian deposits of the Mississippi Valley are rich in marine fossils including conodonts, foraminifera, ammonoids, brachiopods and echinoderms as well as corals, scolecodonts, sponge spicules, fish bones, teeth and scales, gastropods, holothurian sclerites, various shell fragments and trilobites (Canis 1968; Brezinski 1986). Previous biostratigraphic studies of these fossil groups have correlated strata at local, interstate and global levels e.g. Ramsbottom and Saunders (1985), Gordon (1986), Kammer *et al.* (1990) and Becker (1993). Conodonts and ammonoids in particular have been studied extensively throughout the Mississippi Valley. However, palynological studies have been somewhat limited in scope (e.g. Sandberg *et al.* 1972; Eames 1974) and no comprehensive miospore zonation has previously been proposed for the Mississippian within its type area. Some degree of provincialism can be seen in certain fossil groups especially those heavily dependant on palaeoenvironment e.g. trilobites (Brezinski 1986), corals (Sando 1977) and, to a certain extent, ammonoids (Gordon 1986).

2. 2 FOSSIL GROUPS USED FOR BIOSTRATIGRAPHY IN THE MISSISSIPPI VALLEY

2. 2. 1 CONODONTS

A variety of factors such as a pelagic mode of life, abundance within marine sediments and widespread distribution make conodonts excellent zonal fossils for global biostratigraphy, and the group has been studied extensively. Early works include those by Branson (1934), Branson and Mehl (1933; 1934; 1938; 1940; 1941), Youngquist (1947),Youngquist *et al.* (1950) and Youngquist and Downs (1951). Many noteworthy stratigraphic studies of Paleozoic conodont faunas were undertaken in Europe in the 1950s and 1960s by workers such as Ziegler (1959; 1960) and Voges (1960).

Conodonts are abundant within the thick, prevalent limestone units of the Mississippi Valley and have been studied extensively therein. Faunas from the Mississippian of the Mississippi Valley have been the subject of many studies both taxonomic and biostratigraphical (Rexroad 1958; Collinson *et al.* 1959; Scott & Collinson 1961; Collinson *et al.* 1962; Thompson 1967; Thompson & Fellows 1970; Collinson *et al.* 1971; Sandberg *et al.* 1972; Lane 1974; Sandberg *et al.* 1978; Lane & Ormiston 1982; Lane & Brenckle 2005). A conodont zonation for the Mississippian has been developed since the 1960s; significant contributions include those by Collinson *et al.* (1962), Thompson and Fellows (1970), Collinson *et al.* (1971), Sandberg *et al.* (1978), Lane (1974), Lane and Ormiston (1982) and Lane and Brenckle (2005) (Figure 2.1).

2. 2. 2 AMMONOIDS

Although less abundant and more sporadic in their distribution than conodonts, ammonoids have also been widely used in Mississippian biostratigraphy. The suborders Goniatitina and Prolecanitina dominated the Carboniferous (Miller & Furnish 1954); the major emphasis in ammonoid zonation being on the former (Ramsbottom & Saunders 1985). A Late Devonian/early Carboniferous ammonoid zonation was first developed in the early 1900s using the German 'Stufen' terminology, where genera instead of species were used to define time intervals or genozones (Becker 1993). Miller and Collinson (1951) studied Mississippian assemblages from Missouri and demonstrated the use of ammonoids in intercontinental correlation. However, Gordon (1986) showed that the ranges of some common taxa from the Midcontinent of the USA differ in comparison to their European equivalents. Provincialism becomes apparent within the late Viséan and early Namurian although some global transgressive events caused brief periods of global distribution in some taxa (Korn 1997).

STRATIGRAPHY		CONODONT ZONATION									
STAGE	FORMATION (Lane & Brenckle 2005)	MISSISSIPPI VALLEY Collinson *et al.* 1962; 1971	SW MISSOURI Thompson 1967; Thompson & Fellows 1970	MISSISSIPPI VALLEY Lane 1974; Lane & Ormiston 1982	FAUNAL UNITS Lane 1974	MISSISSIPPI VALLEY Lane & Brenckle 2005	GREAT BRITAIN & IRELAND Varker & Sevastopulo 1985				
CHESTERIAN	Grove Church	*Streptognathus unicornis*		*muricatus* U	14	Upper *muricatus*					
				muricatus L	13	Lower *muricatus*					
				unicornis	12	*unicornis*					
	Kinkaid	*Kladognathus-Cavusgnathus naviculus*		*naviculus*	11	*naviculus*					
	Degonia - Menard										
	Waltersburg - Beech Creek	*Kladognathus primus*		*G. bilineatus-C. altus*	10	*bilineatus* U					
		Gnathodus bilineatus-Kladognathus mehli									
	Cypress - Aux Vases	*Gnathodus bilineatus-Cavusgnathus charactus*		*G. bilineatus-C. charactus*	9	*bilineatus* L	*G. bilineatus*		*G. girtyi collinsoni*	BRIGANTIAN	
									L. mononodosa		
	Ste Genevieve								*G. bilineatus*	ASBIAN	
MERAMECIAN	St Louis Ls	*Apatognathus scalenus-Cavusgnathus*		*A. scalenus-Cavusgnathus*	8	*scitulus-scalenus*				HOLKERIAN	
	Salem Ls	*Taphrognathus varians-Apatognathus*		*texanus*	7	*texanus*	*M. beckmanni*	Informal unit with taphronathids	*L. commutata*	ARUNDIAN	
	Upper Warsaw							*L. commutata*			
	Lower Warsaw		*Gnathodus texanus-Taphrognathus*					*G. homopunctatus*	*G. homopunctatus*		
OSAGEAN	Keokuk Ls	*Gnathodus texanus-Taphrognathus*	*Gnathodus bulbosus*							CHADIAN	
			B. distortus-Gnathodus cuneifomis / *G. cuneifomis* / *B. distortus*								
			Bactrognathus-Pseudopolygnathus multistriatus / *Doliognathus latus* / *P. multistriatus*		6	*bulbosus*					
	Burlington	*Bactrognathus-Taphrognathus*		*anchoralis-latus*	5	*anchoralis - latus* *burlingtonensis* / *lanei*	S. anchoralis	*anchoralis-bischoffi*		COURCEYAN	
		Bactrognathus-Polygnathus communis	*G. semiglaber-Polygnathus communis carinus*		4U			*E. burlingtonensis*			
				Upper typicus	4L			*D. latus*			
	Fern Glen-Meppen Ls	*Gnathodus semiglaber-Pseudopolygnathus multistriatus*	*S. cooperi hassi-Gnathodus punctatus* / *G. punctatus* / *S. cooperi hassi*	Lower *typicus*	3B	*multistriatus*	P. c. carina	*D. bouckaerti*	*P. mehli*		
					3A	*communis carinus*		*E. bultyncki*			
				isosticha - Upper crenulata	2	*punctatus*		*E. cf. bultyncki*	*Ps. multistriatus*		
KINDERHOOKIAN	Chouteau	*Siphonodella isosticha-S. cooperi*	*Gnathodus delicatus-S. cooperi cooperi* / *S. cooperi cooperi*		1G	*isosticha - Upper crenulata* U		*D. hassi*			
					1F	L			*P. inornatus-siphonodella*		
		Siphonodella quadruplicata-S. crenulata	*S. quadruplicata*	*Lower crenulata*	1E	*Lower crenulata*	*Siphonodella*				
	Hannibal Shale	*Siphonodella duplicata*	*Siphonodella lobata-S.crenulata*	*sandbergi*	1D	*sandbergi*					
		Siphonodella sulcata	*Siphonodella sandbergi-S.duplicata*	Upper *duplicata*	1C	Upper *duplicata*			*P. spicatus*		
				Lower *duplicata*	1B	Lower *duplicata*					
	Horton Creek	*Protognathodus kuehni-P. kockeli*		*sulcata*	1A	*sulcata*					

Figure 2.1 Mississippian conodont zonations and faunal units proposed for the Mississippi Valley and adjacent areas, Great Britain and Ireland. Stratigraphic units are not to scale.

Regional zonations have recently been refined in both Europe and North America following the genozone concept. These zonations use distinct morphological characteristics within new taxa lineages to determine biostratigraphic subdivisions (Ramsbottom & Saunders 1985; Riley 1990; Kullmann *et al.* 1991; Becker 1993; Becker 1993b) (Figure 2.2). This allows global correlation between the more specific regional zonations. Recent contributions of note include those by Becker and Aboussalam (2005) and Becker (2007). Work by Korn *et al.* (2007) and Becker *et al.* (2006) in North Africa is currently refining the lower Mississippian zonation from this area, and is highly applicable to the North American ammonoid succession.

2. 2. 3 FORAMINIFERA

Foraminifera, like conodonts, are widely used in biostratigraphic correlation. Abundance and preservation potential is high within marine sediments. Benthic forms are more environmentally sensitive and facies dependant than their more recently evolved planktonic relatives, but are still useful for Carboniferous biostratigraphy. Assemblages have been studied extensively throughout western Europe, the Donets Basin and Northeast Russia, Australia and North America, and biozonations have been developed for most of these areas (for examples see Conkin & Conkin 1964; Bogush & Yuferev 1990; Brenckle 1990; Conil *et al.* 1990; Poletaev *et al.* 1990; Lane & Brenckle 2005; Poty *et al.* 2006).

Mississippian foraminiferal assemblages within North America are less diverse than equivalent age assemblages in Europe, Russia and Australia (Brenckle 1990; Lane & Brenckle 2005), and no formal calcareous foraminiferal zonation has been defined for the Mississippian of North America (Menning *et al.* 2006). Conkin & Conkin (1964) and other authors (Conkin *et al.* 1965; Conkin *et al.* 1968) recognised a Kinderhookian arenaceous foraminiferal assemblage from the Mississippi Valley. Brenckle (1990) recognised seven possible global correlation horizons and related them to the Mississippian type area (Figure 2.3). However, the lower three are recognised only in the western part of the USA and northwest Iowa and do not appear in the Mississippi Valley. Indeed, in the Mississippi Valley restricted and/or deep water environments were probably unable to support abundant populations of benthic foraminifera throughout long intervals within the Mississippian (Brenckle *et al.* 2005). Diversity increases are seen in the upper Osagean, the Meramecian and the upper Chesterian, and these are potentially very useful for worldwide correlation (Lane & Brenckle 2005).

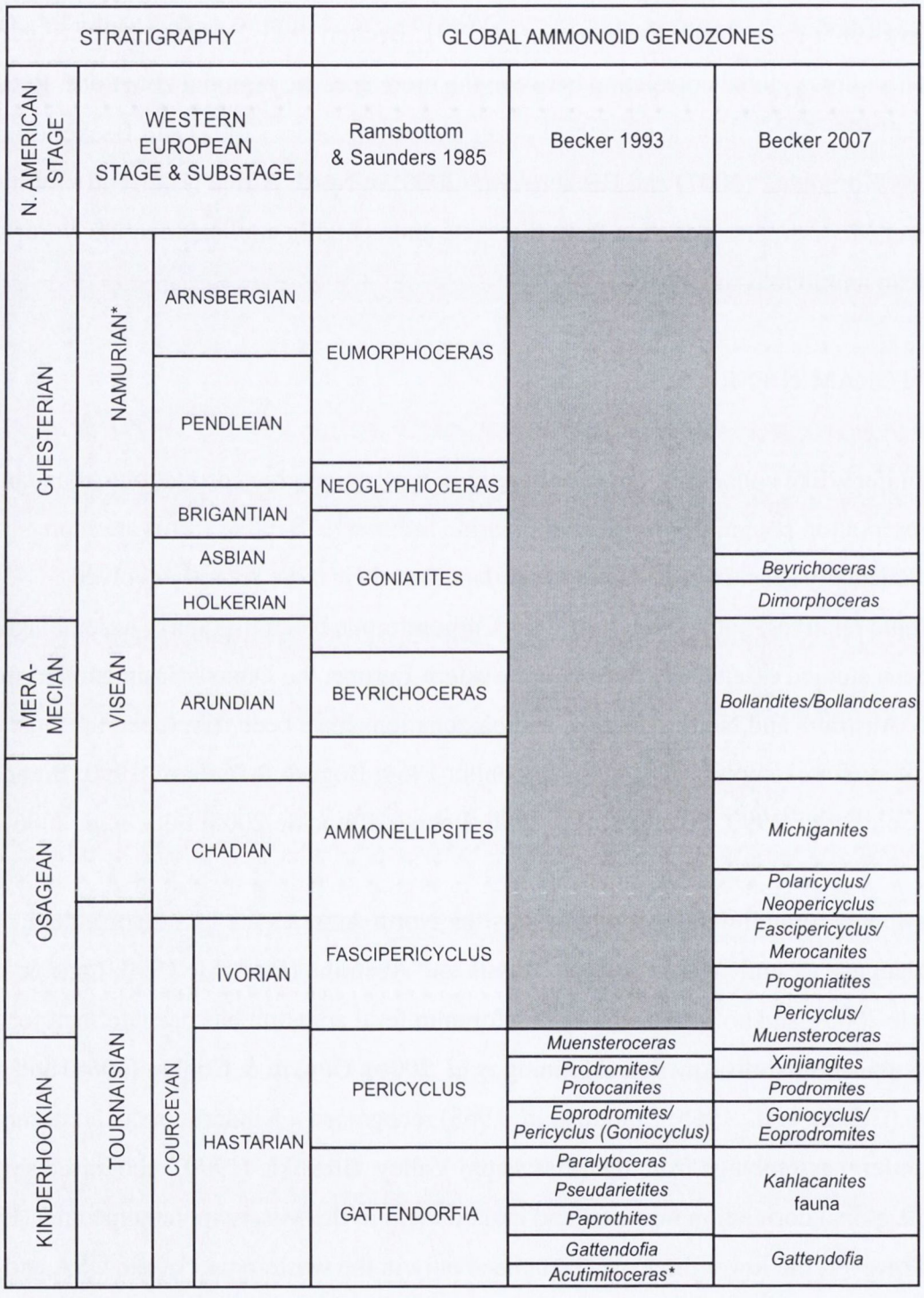


Figure 2.2 Mississippian global ammonoid genozones (*in part). Stratigraphic units are not to scale.

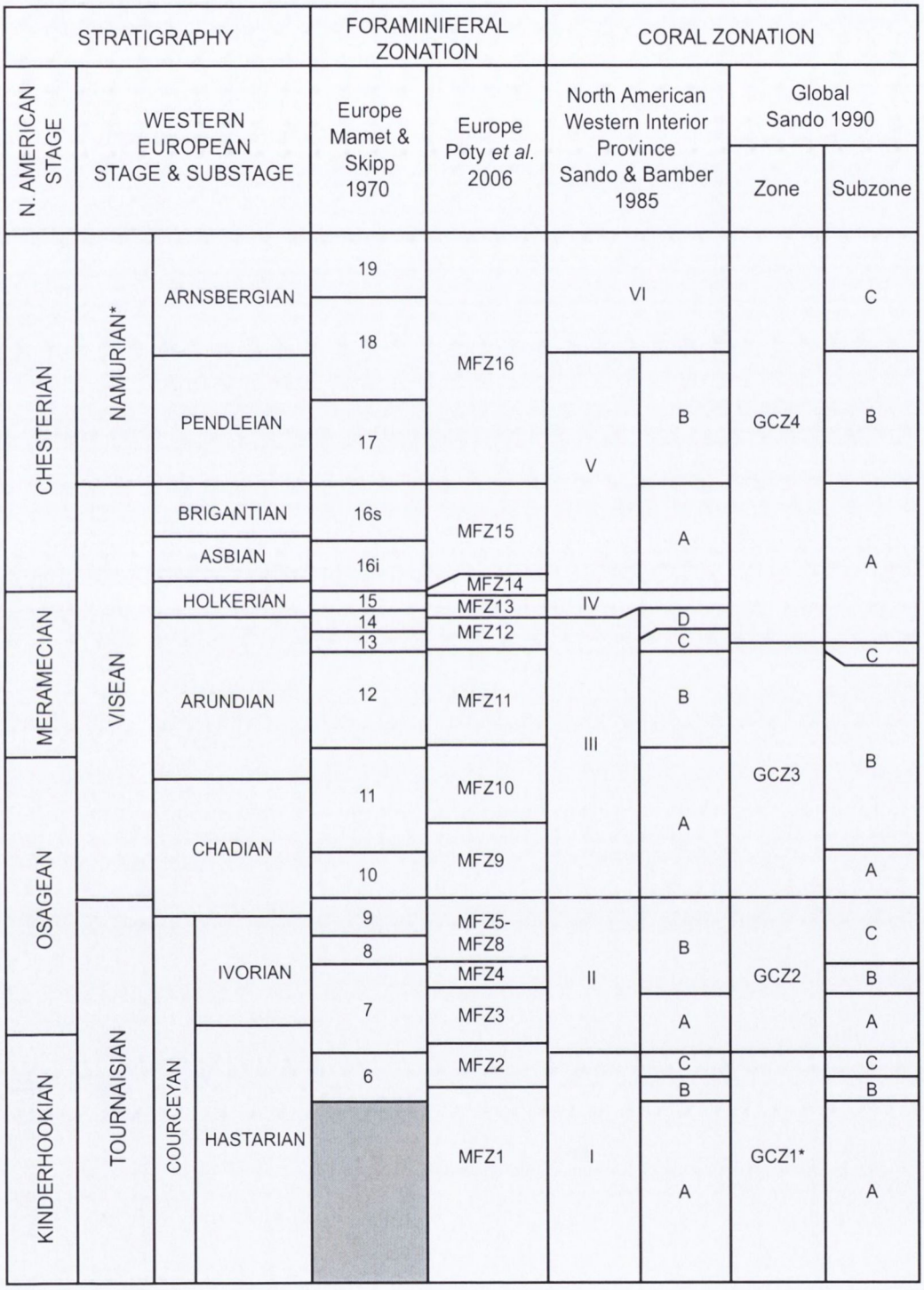


Figure 2.3 Mississippian foraminiferal and coral zonations (*in part). Stratigraphic units are not to scale.

2. 2. 4 CRINOIDS AND BLASTOIDS

Zonal schemes are less well established for these groups than others due to several factors. In general, crinoids and blastoids are less widespread and found in a smaller range of environments than conodonts or ammonoids. Crinoid faunas are mainly known from North America and Europe where similar generic age ranges are recognised. However, ranges seem to differ between these faunas and those recovered from North Africa, suggesting a geographical bias of data. Apparent diversity fluctuations could also possibly be due to incomplete records and variations in taxonomic practices (Sevastopulo *et al.* 1990).

Fragments of several different types of echinoderms are present throughout the Mississippian of the Mississippi Valley. Crinoids and blastoids are the only groups which provide sufficient identifiable specimens for use in biostratigraphy (Sevastopulo *et al.* 1990) and local biozonations have been recognised for these groups (Gahn 2002). Genera have been generally used for correlation as most species have a limited geographical range; however certain species have been used to define boundaries e.g. the first occurrence of the blastoid *Pentremites conoideus* at the base of the Upper Warsaw (Kammer *et al.* 1990).

2. 2. 5 CORALS

Coral assemblages have been described globally from Mississippian sediments. Zonal schemes have been determined for the type area of the Tournaisian and Viséan stages in Western Europe (Conil *et al.* 1990; Poty *et al.* 2006), as well as North America, Western Canada and Alaska (Bowsher 1961; Sando 1977; Sando & Bamber 1985). A large number of coral taxa have been described from the Mississippian of North America. In the Mississippi Valley described faunas are restricted to the late Kinderhookian-early Osagean Chouteau and Burlington limestones and the Meramecian St Louis Limestone (Sando 1977). Chesterian corals have proved useful for local correlation of beds in Kentucky (McFarlan *et al.* 1955).

Coral assemblages are of little use for global correlation due to provincial assemblages dominated by endemic species, long stratigraphic ranges of genera and uncertain taxonomy and distribution of lineages (Sando 1977; Sando 1990). Conil *et al.* (1990) noted the similarity of certain species ranges in Europe and North Africa, but again pointed out that very few taxa are useful for correlation between Europe and North America. However,

changes within certain groups of rugose corals appear to track global events. Four zones and eleven subzones can be defined within the Mississippian based on origin, dispersal and extinction patterns (Figure 2.3) These zones may be a useful tool when used in conjunction with more rigorously tested fossil zonations (Sando 1990).

2. 2. 6 BRACHIOPODS

Brachiopods have also been used extensively for correlation within both Europe and North America (Carter 1990; Legrand-Blain 1990). Assemblages have in the past been useful at a local scale (e.g. brachiopod correlations in Iowa; Fenton 1918; Fenton & Fenton 1935; Anderson 1969; Kammer *et al.* 1990). As with corals, brachiopods are more useful at a regional scale than a global scale, however some similarities between European and American faunas have been noted (e.g. Peigi 1978). Productid and spiriferid taxa have been used for local correlation within western Europe, however a formal brachiopod zonation has yet to be published (Legrand-Blain 1990).

The occurrence of specific taxa within the Mississippian of the Mississippi Valley has been used as a means of local correlation at formation and regional stage level (Kammer *et al.* 1990; Hirt 1991). A synthesis of previous brachiopod studies and fossil material collected from the Mississippi Valley suggests the subdivision of units on the basis of articulate brachiopod genera (Carter 1990). However, many taxa appear to be without close relatives and much work is yet to be carried out in terms of describing and studying individual taxa as well as lineages.

2. 3 BIOSTRATIGRAPHY OF THE SUBDIVISIONS OF THE MISSISSIPPIAN IN THE MISSISSIPPI VALLEY

The main lithological units of the Mississippi Valley as named from western Illinois, eastern Missouri and southern Iowa are described below. Other stratigraphically significant units are also included where additional material has been collected e.g. parts of southern Indiana, west central Missouri and southeast Illinois

Although many of the various lithostratigraphic units discussed have typically been referred to in the literature informally, as for example, 'the Hannibal Shale' or, 'the Louisiana Limestone', their implicit rank is that of formation (see for example, Willman *et*

al. 1975; Thompson 1986). Where this is the case, the traditional American informal use of name is followed.

2. 3. 1 KINDERHOOKIAN

The North American Kinderhookian Stage is equivalent to the lower part of the Western European Tournaisian Stage and the Hastarian Substage (Menning *et al.* 2006), and includes beds between the Late Devonian Louisiana Limestone and the early Osagean Burlington Limestone. The base of the Carboniferous is placed at the base of the Horton Creek Formation (previously known as the 'Glen Park Member' of the Hannibal Shale) (Thompson 1986), and is marked here by the first appearance of the conodonts *Siphonodella sulcata* and *Protognathus kuehni* (Collinson 1961; Sandberg *et al.* 1972). The first occurrence of *Siphonodella sulcata* identifies the base of the Carboniferous as defined by the IUGS (Menning *et al.* 2006). The Kinderhookian substage spans seven siphonodellid conodont zones: *sulcata*, Lower *duplicata*, Upper *duplicata*, *sandbergi*, Lower *crenulata*, Upper *crenulata* and *isosticha* (Lane & Brenckle 2005) (Figure 2.1).

Miller & Collinson (1951) recognised a [Lower] Carboniferous ammonoid fauna from Missouri comprising genera such as *Protocanites*, *Imitoceras* and *Munsteroceras*. Gordon (1986) detailed faunas from the late Kinderhookian and early Osagean of North America and noted the predominant ammonoid genus from the American Midcontinent is *Imitoceras* – especially abundant in the Chouteau Limestone.

In terms of global correlation, the *Gattendorfia*-stufe (Cu I) and *Pericyclus*-stufe (Cu II) of Schindewolf (1927) and Schmidt (1925) encompass the Kinderhookian level in the USA. These zones were later redefined as the *Gattendorfia* and *Pericyclus* zones by Ramsbottom & Saunders (1985). Further refinement of the zonation was proposed by Kullman *et al.* (1991) which places the lower part of the Kinderhookian in the *Gattendorfia-Eocanites* Genozone, and the upper part in the *Goniocyclus-Protocanites* Genozone (Menning *et al.* 2006). Becker (1993) split the *Gattendorfia* zone into four genozones and the *Pericyclus* into a further three, the Kinderhookian ranging almost the entire first 5 genozones (Scott & Collinson 1961). Ramsbottom & Saunders (1985) stated the rare/absent nature of the *Gattendorfia* zone faunas (early – middle Tournaisian) in North America, with the oldest faunas recognised from the late Kinderhookian (late middle Tournaisian) (Gordon 1986). More recently the range of ammonoids in North America has been extended back to the

middle Kinderhookian (early middle Tournaisian) (Work 2002). There has been no section recognised with a continuous goniatite record across the lower - middle Tournaisian from anywhere in the world (Becker 1993b). The *Pericyclus* Zone comprises the upper part of the Kinderhookian and part of the Osagean and ranges slightly higher than the range of the siphonodellid conodonts (Ramsbottom & Saunders 1985).

Horton Creek Formation

The Horton Creek Formation, also known as the Horton Creek Limestone or the Glen Park Limestone, conformably overlies the Late Devonian Louisiana Limestone throughout parts of Missouri and Illinois. Conodont assemblages obtained from the Horton Creek place it within the basal Mississippian *sulcata* Zone (Collinson 1961; Sandberg *et al.* 1972; Lane & Brenckle 2005) and suggest correlation with the European ammonoid lower *Gattendorfia* Stufe (cuI).

Hannibal Shale

The Hannibal Shale is generally recognised as the oldest Kinderhookian formation throughout northeastern Missouri and western Illinois. As such it is the basal formation of the Mississippian Subsystem throughout much of its type area, the Mississippi Valley (Collinson 1961).

A sparse conodont fauna has been recovered from the type section at Hannibal, in northeast Missouri where the Hannibal Shale rests conformably on the Devonian Louisiana Limestone (Branson 1934). However, abundant conodonts have been recovered from the Hannibal Shale at other localities throughout the Mississippi Valley (Collinson 1961; Sandberg *et al.* 1972). Important faunal components include *Spathognathodus aculeatus, Pseudopolygnathus dentilineatus, Protognathodus kuehni, Protognathodus kockeli, Polygnathus communis communis* and scarce *Siphonodella sulcata.*

Early ammonoid studies on the lower Mississippian recognised similar assemblages within the Louisiana Limestone and the Hannibal Shale (Miller & Collinson 1951). Consequently, the Louisiana Limestone of Missouri and Illinois was placed within the Mississippian. However, the Louisiana is now recognised as upper Devonian (Lane & Brenckle 2005). Ammonoid assemblages from the Hannibal Shale have been correlated using conodont

faunas to the European ammonoid *Gattendorfia* Stufe (CuI) and perhaps the lowermost part of the *Pericyclus* Stufe (CuIIα) (Collinson 1961; Canis 1968).

Foraminifera have also been recorded from the Hannibal Shale (Conkin *et al.* 1965). The authors recognised a Kinderhookian age fauna which they noted was more closely related to the overlying Chouteau Formation than the underlying Devonian Louisiana Limestone. However, foraminiferal diversity is low within these sediments and the group is of limited biostratigraphic significance here (Lane & Brenckle 2005).

More recently, conodonts were recovered from a core taken during construction of Clarence Cannon Dam, 50 km to the south west of the Hannibal type section (Work *et al.* 1988). At this locality a complete section of the Hannibal Shale overlies the Horton Creek Limestone and is conformably overlain by the Chouteau Limestone. *Siphonodella sulcata* occurs here within the Cuivre Member – a sandy shale unit which occurs locally at the base of the Hannibal Shale, but is notably absent from the remainder of the Hannibal Shale. Conodont assemblages from the Hannibal Shale at Clarence Cannon Dam include *Siphonodella duplicata, Pseudopolygnathus primus, Siphonodella sandbergi, Siphonodella cooperi* and *Pseudopolygnathus marginatus* and show the Hannibal Shale encompasses the Lower *duplicata* through Lower *crenulata* zones of Sandberg *et al.* (1978) (Work *et al.* 1988; Work 2002; Lane & Brenckle 2005). This suggests the Hannibal Shale correlates with the Hastarian Substage of Europe.

Ammonoids from the Clarence Cannon Dam locality were recovered during construction of the dam, when excavations temporarily exposed the upper and middle portion of the Hannibal Shale (Work 2002). Two new species - *Goniocyclus hannibalensis* Work 2002 and *Eoprodromites kinderhooki* Work, Mapes and Thompson 1988 have been named from this section, alongside *Stockumites*? sp. The authors were unable to record the exact stratigraphic positions of taxa, but were able to restrict them to a relatively short interval. The ammonoid assemblage occurs alongside conodonts identified from the Lower *crenulata* Zone, suggesting a middle Kinderhookian (early-middle Tournaisian, middle Hastarian) age.

New Albany Shale

The New Albany Shale is recognised from southern Indiana and Kentucky as a thick shaley unit straddling the Devonian - Mississippian boundary. Much of the formation lies in the Devonian but conodonts from the uppermost part of the New Albany are indicative of the *sulcata* Zone, and provide correlation with the lower part of the Hannibal Shale (Shaver *et al.* 1986).

Bachelor Formation

The Bachelor Formation is equivalent to the Hannibal Shale in east central, southeastern, southwestern, west central and central Missouri. In the central and western parts it is the basal formation of the Kinderhookian and is overlain by the Compton Limestone. Towards the southeast it overlies the Bushberg Sandstone. Conodonts recovered from sandstones within the Bachelor date it slightly older than middle Kinderhookian. The *Siphonodella sandbergi-S. duplicata* Zone (Sandberg & Klapper 1967) is recognised from the lower part of the Bachelor. In central and southwestern Missouri a shaley member in the upper part of the Bachelor yields a further distinct conodont fauna (*Siphonodella lobata-S. crenulata* Zone of Thompson and Fellows (1970). The Bachelor can be correlated to a thin sandstone bed within the Hannibal Shale by comparison of these conodont faunas (Thompson 1986).

Chouteau Limestone

Canis (1968) identified two conodont assemblage zones within the Chouteau in Missouri – the *Siphonodella quaduplicata-S. crenulata* and the *Siphonodella isosticha-S. cooperi* Zone of Collinson *et al.* (1962). With reference to the more recent zonation by Sandberg *et al.* (1978) (updated by Lane & Brenckle in 2005) most, if not all, of the Chouteau as studied by Canis (1968) belongs to the lower part of the *S. isosticha*-Upper *crenulata* Zone (Gordon 1986). A similar assemblage is recovered from the Chouteau in western Illinois (Brenckle *et al.* 2005). Within the Mississippi Valley the Chouteau is overlain uncomformably by either the Osagean Meppen or Burlington formations, and the upper part of the *S. isosticha*-Upper *crenulata* Zone and the *Gnathodus punctatus* Zone are absent (Brenckle *et al.* 2005). A slightly older faunal assemblage is recognised in northeastern Missouri from the top of the Chouteau Limestone in the McCraney-Chouteau transition beds (Chauffe & Guzman 1997). This suggests placement of the Chouteau

Limestone in the Lower *crenulata* Zone, and indicates a latest Kinderhookian age for the Chouteau in this area, which may be laterally variable elsewhere.

Ammonoid assemblages from the Chouteau appear to be part of a near-worldwide Mississippian assemblage, containing taxa such as *Protocanites lyoni*, *Pericyclus*, *Gattendorfia* and *Imitoceras*. Very similar assemblages are described from the Kinderhookian of the western United States and the Tournaisian of Belgium (Miller & Collinson 1951; Gordon 1986).

The Chouteau contains a sparse calcareous foraminiferal fauna comprising mainly *Earlandia* spp. (Brenckle *et al.* 2005), and a low diversity arenaceous foraminifera fauna (Conkin *et al.* 1968). Early studies of corals from Missouri and Illinois also suggest a Kinderhookian age for the Chouteau Formation (Bowsher 1961; Carlson 1964). However, due to their restricted nature faunal assemblages are sporadic and of limited use for long-range correlation, and are only suitable for local and regional zonations (Sando 1977). Brezinski (1986) identified three trilobite associations, alongside bryozoans, crinoids, brachiopods and corals from the Chouteau Formation. These associations are heavily dependant on lithology and palaeoenvironment and are more indicative of shifts in the local environment than a widespread evolutionary change. Abundant holothurian sclerites have been collected from the lower part of the Chouteau in Missouri (Gutschick *et al.* 1967), but again these microfossils have limited use for correlation.

McCraney Limestone

The McCraney Limestone and the overlying Prospect Hill Siltstone, Starrs Cave Limestone and Wassonville Limestone crop out extensively in Iowa, western Illinois and northeastern Missouri, and have been correlated with the uppermost Hannibal Shale and Chouteau Limestone (Collinson 1961; Brenckle *et al.* 2005). The McCraney Limestone, Prospect Hill Siltstone and Starrs Cave Limestone formed part of the North Hill Group in Iowa and Illinois (Atherton *et al.* 1975), however this grouping has recently been dropped (Witzke *et al.* 1990), and the Starrs Cave Limestone is now considered the basal member of the Wassonville Limestone (Witzke & Bunker 2005).

The McCraney Limestone crops out in a belt from west central Illinois, through northeastern Missouri and into southeastern Iowa. In Illinois the McCraney Limestone

conformably overlies the Hannibal Formation. In Missouri the McCraney conformably overlies the Chouteau Limestone, and together these two units make up the Chouteau Group (Thompson 1986). In Iowa it unconformably overlies the Devonian English River Siltstone. The McCraney contains a diverse fauna of brachiopods (chonetids, rhynchonellids and spiriferids), bivalves, gastropods, ostracodes, corals, echinoderm fragments and arenaceous foraminifera (Witzke *et al.* 1990). Conodont faunas have been recovered from the McCraney Limestone by Scott and Collinson (1961) and more recently by Chauffe and Guzman (1997). Scott and Collinson (1961) correlated the McCraney Limestone of Illinois and Iowa to the upper *Gattendorfia* (CuI) and lowermost *Pericyclus* Stufe (CuII) of the Tournaisian of Europe and to the *sandbergi* Zone of Sandberg *et al.* (1978) and Lane and Brenckle (2005). This correlates the McCraney to the upper part of the Hannibal and the lower part of the Chouteau. Eastwards, in Missouri, faunal assemblages place the McCraney Limestone within the upper part of the Lower *crenulata* Zone, stratigraphically higher than the McCraney of Illinois (Chauffe & Guzman 1997).

Prospect Hill Siltstone

The Prospect Hill Siltstone contains a relatively diverse fauna of bivalves, gastropods and brachiopods, fragments of bryozoans and crinoids, and rare scaphopods and cephalopods (Witzke *et al.* 1990). Conodont assemblages closely resemble those from the McCraney Limestone and correlate the Prospect Hill Siltstone to the Chouteau Limestone of Missouri (Collinson 1961).

Wassonville Limestone

The Starrs Cave Limestone Member is recognised as the basal member of the Wassonville Limestone. It conformably overlies the Prospect Hill Siltstone in parts of southeastern Iowa and western Illinois, but disappears further west in Iowa and to the east in Illinois. Although no conodonts have been collected from the Starrs Cave Limestone, an abundant brachiopod macrofauna suggests correlation with the Chouteau Limestone (Collinson 1961). Several other fossil groups are also recognised including bivalves, gastropods, crinoid debris, corals and trilobites (Witzke *et al.* 1990). The Starrs Cave Limestone is conformable and gradational with the overlying Wassonville Limestone. Where the Wassonville is absent it is unconformably overlain by the Burlington Limestone (Collinson 1961).

In northeastern Missouri and much of Iowa the Prospect Hill Siltstone is overlain conformably by the Wassonville Limestone. Diverse macro and microfaunas are present and include brachiopods, crinoids, corals, sponge spicules, fish bones/teeth and trilobites (see Witzke *et al.* (1990) for a comprehensive list of taxa). Conodont assemblages from the Wassonville Limestone are similar to those from the McCraney Limestone and the Prospect Hill Siltstone, and are dominated by younger *Siphonodella* species (Collinson 1961). The unit is correlated with the Chouteau Limestone of central Missouri (Collinson 1961; Atherton *et al.* 1975).

Compton Limestone

The Compton Limestone overlies the Bachelor Formation in southwestern and central Missouri. In this area it is the basal member of the Chouteau Group along with the overlying Sedalia Limestone and Northview Formation (Thompson 1986). The Compton yields brachiopods including *Schumardella missouriensis*, *Schumardella obsolens*, *Pustula concentrica*, *Chonetes logani* and *Leptaena analoga*, and echinoderms such as the blastoids *Schizoblastus roemeri* and *Schizoblastus sampsoni* and the crinoid *Platycrinites* (Thompson 1986). Conodonts are representative of the *Gnathodus delicatus-Siphonodella cooperi cooperi* Zone (Thompson & Fellows 1970). Arenaceous foraminifera are abundant throughout the Compton Limestone (Conkin *et al.* 1968).

Northview Formation

The Northview Formation along with the underlying Sedalia Formation comprises the upper part of the Chouteau Group in southwestern and central Missouri. Brachiopods, solitary corals and trace fossils are all recorded from the Northview (Thompson 1986). A sparse conodont assemblage indicates a typical Chouteau-type fauna (Canis 1968).

2. 3 .2 OSAGEAN

The North American Osagean regional stage, named from the Osage River in southwest Missouri, encompasses the Meppen Limestone, Fern Glen Formation, Burlington Limestone, Keokuk Limestone and the Lower Warsaw Formation (Kammer *et al.* 1990). It is equivalent to the upper part of the Tournaisian and lower part of the Viséan stages and

the Ivorian, Chadian and Arundian substages of western Europe (Menning *et al.* 2006). Many conodont workers consider the last occurrence of *Siphonodella* as a marker for the upper boundary of the Kinderhookian and lower boundary of the Osagean, although the appearance of *Polygnathus communis carinus* (Thompson 1967; Thompson & Fellows 1970) and the base of the *Gnathodus punctatus* zone (Lane 1974; Lane & Brenckle 2005) have also been proposed as markers for the Kinderhookian - Osagean boundary. The latter definition is preferred herein. Conodont faunas recovered across the boundary in south western Missouri, northeastern Oklahoma and northern Arkansas suggest the boundary is marked by the appearance of *Gnathodus punctatus* and therefore the base of the *punctatus* Zone (Lane & Brenckle 2005). However, in the Mississippi Valley itself the Kinderhookian - Osagean boundary is not present due to an unconformity which removes the upper part of the late Kinderhookian *isosticha*-Upper *crenulata* Zone and the Osagean *punctatus* Zone (Brenckle *et al.* 2005). The Osagean stage comprises eight conodont zones and subzones; *punctatus*, *communis carinus*, *multistriatus*, *latus*, *lanei*, *burlingtonensis*, *bulbosus* and *texanus* (in part) (Lane & Brenckle 2005).

Foraminiferal assemblages become more abundant and diverse within the upper Osagean, and begin to play a significant role in biostratigraphy, especially with the positioning of the Tournaisian – Viséan boundary. The placement of this level in the Mississippi Valley has been the focus of many biostratigraphic studies. The boundary is defined in Europe by the first occurrence of *Eoparastafella simplex* (Devuyst *et al.* 2003), however this taxon does has not been recorded in the Mississippi Valley. The boundary has been variously placed at the Kinderhookian - Osagean boundary (Collinson *et al.* 1971), at the Keokuk - Warsaw contact (Mamet & Skipp 1970), in the upper Burlington (Witzke *et al.* 1990) and at the Burlington - Keokuk contact (Brenckle *et al.* 1974; Brenckle *et al.* 2005). Conodonts from the Burlington Limestone and foraminiferal assemblages in the Keokuk Limestone of Illinois suggest the Tournaisian – Viséan boundary falls within the upper part of the Osagean, around the Burlington – Keokuk boundary (Brenckle *et al.* 1974). Similar changes in conodont faunas are recorded from both Europe and the Mississippi Valley at this level, and the upper part of the Burlington contains the *Bactrognathus-Taphrognathus* Assemblage Zone of Collinson *et al.* (1971) (Brenckle *et al.* 1974). This places it at the top of the Tournaisian Stage, equivalent to the Belgian Ivorian Substage (Menning *et al.* 2006). In the upper middle Keokuk a diverse foraminiferal fauna can be correlated to the British Arundian and Belgian mid-Moliniacian substages of the early Viséan (Brenckle *et al.* 1982).

Only a few occurrences of ammonoids are recorded from the Osagean of the Mississippi Valley. Miller and Furnish (1958) recorded a sparse *Muensteroceras* ammonoid fauna from the Burlington Limestone of Missouri and correlated it to the *Pericyclus* Zone. More abundant faunas and detailed studies come from north eastern and north central Kentucky. Ammonoids have been obtained from the Nancy, Nada and New Providence Shale members of the Borden Formation in north central Kentucky and indicate correlation with the *Pericyclus*, *Fasciprericyclus-Ammonellipsites* and *Bollandites-Bollandoceras* ammonoid genozones (Work & Mason 2003; 2004; 2005; Menning *et al.* 2006). These genozones have been respectively correlated to the Burlington, the Burlington-Keokuk boundary, and the Peerless Park Member and overlying stage (Menning *et al.* 2006).

Fern Glen Formation / Meppen Limestone

The Fern Glen Formation and Meppen Limestone appear in west central and southern Illinois, and east central and south eastern Missouri and are equivalent to the lower part of the Burlington Limestone (Thompson 1986; Brenckle *et al.* 2005). In Illinois the Meppen is given the rank of formation and in Missouri it is recognised as a member of the Fern Glen Formation. The Meppen Limestone contains an Osagean conodont fauna which places it in the *communis carinus* Zone (Lane & Brenckle 2005); younger zones are absent due to an unconformity between the late Kinderhookian and the early Osagean.

The calcareous shales and crinoidal limestones of the Fern Glen Formation become more prevalent in the south where they replace the Meppen Limestone and much of the Burlington Limestone. The formation represents a marginal basin facies around the lower part of the Burlington Shelf and a calcareous microfossil assemblage, with similar taxa to those found in the Burlington Limestone, recorded. Taxa present include *Earlandia* spp., *Mametella chautauquae*, Salebridae, *Stacheia* sp. and *Sphaerinvia piai*. Conodonts from the Fern Glen have proved useful in regional correlations (Thompson 1975); the lower part of the Fern Glen belongs to the *communis carinus* Zone and the upper part ranges the *multistriatus* Zone and *latus* and *lanei* subzones of the *anchoralis-latus* Zone (Brenckle *et al.* 2005). Abundant brachiopods, bryozoans, corals and crinoids are also found throughout the formation (Thompson 1986). Common taxa include the brachiopods *Spirifera vernonensis* and *Spirifera rowleyi*, the bryozoan *Evactinopora sexradiata* and the coral *Cyathaxonia arcuatas* (Atherton *et al.* 1975).

Pierson Formation

The Pierson Formation is the oldest Osagean unit in south western and west central Missouri, where it conformably overlies the Northview Shale. Conodonts recovered from the Pierson include *Polygnathus communis carinus* and place it within the *Gnathodus semiglaber-Polygnathus communis carinus* Zone (Thompson & Fellows 1970) and more recently, the *communis carinus* Zone of Lane & Brenckle (2005). As seen in the type Mississippi Valley the oldest Osagean conodont zone is absent in this part of Missouri.

Burlington Limestone

The Burlington Limestone is widespread throughout much of the American Midcontinent region. In the Mississippi Valley it unconformably overlies the Hannibal Shale and Wassonville Limestone in northeastern Missouri, west central Illinois and southeastern Iowa. It rests conformably on the Osagean Fern Glen Formation further to the south in east central Missouri and southern Illinois. In this area the Fern Glen and underlying Meppen Limestone are lateral equivalents to the lower part of the Burlington (Thompson 1986; Brenckle *et al.* 2005). The Burlington Limestone is thickest in its type area in northern Missouri and southern Iowa, where it can be divided into three members; the lowest Dolbee Creek Member, middle Haight Creek Member and the upper Cedar Fork Member.

The Burlington Limestone is spanned by five conodont zones and subzones. The base of the Burlington (Dolbee Creek Member) is marked by the *multistriatus* Zone in the northern part of the Mississippi Valley. Overlying this, the *latus* and *lanei* subzones are recorded from the middle Burlington (Haight Creek Member), and the *burlingtonensis* Subzone is found in the Cedar Fork Member. Assemblages assigned to the Burlington - Keokuk *bulbosus* Zone are not commonly recorded from the Mississippi Valley; a result of the Osagean low stand at this time (Lane & Brenckle 2005). A crinoid and blastoid biozonation for the Burlington is outlined by Gahn (2002). It comprises three associations (I, II and III) which correspond roughly to the three members. Association I contains the *Dorycrinus unicornis* and *Cryptoblastus melo* biozones, Association II contains the *Uperocrinus pyriformis* and *Globoblastus norwoodi* biozones, and Association III comprises the *Macrocrinus verneuilianus* and *Pentremites elongatus* biozones.

Ammonoids collected by Work and Mason (2003; 2004; 2005) from the Nancy, Nada and New Providence Shale members of the Borden Formation, Kentucky are correlated to the *Pericyclus* and *Fascipericyclus-Ammonellipsites* zones. Associated conodonts correlate these faunas with the lower Burlington (Dolbee Creek Member) and the top of the Burlington/lower Keokuk respectively. This correlates the Dolbee Creek Member to the lower Ivorian Substage of the Belgian upper Tournaisian (Work & Mason 2005), and the top of the Burlington to the latest Tournaisian or earliest Viséan (Work & Mason 2003).

The position of the Tournaisian - Viséan boundary falls within the upper part of the Osagean, around the Burlington – Keokuk boundary (Brenckle *et al.* 1974; Brenckle *et al.* 2005). Foraminifera described from the Cedar Fork Member include *Earlandia* spp., *'Priscella prisca'*, and *Endothyra* spp (Witzke *et al.* 1990; Brenckle *et al.* 2005). On this basis, Witzke *et al.* (1990) suggested that the Tournaisian - Viséan boundary occurs near the base of the Cedar Fork Member within the top of the Burlington. However, Brenckle *et al.* (2005) placed the boundary at the Burlington - Keokuk contact, at a period of similar turnover in European and Mississippi Valley conodont faunas. The *Bactrognathus-Taphrognathus* Assemblage Zone of Collinson *et al.* (1971) is recorded form the upper part of the Burlington (Brenckle *et al.* 1974). This suggests placement at the top of the Tournaisian Stage (Menning *et al.* 2006).

Keokuk Limestone

The Keokuk Limestone conformably overlies the Burlington Limestone throughout the Mississippi Valley. In its type area in southern Iowa, northeastern Missouri, and west central Illinois the lowermost part is dominated by nodules and beds of chert and is known as the Montrose Member (Brenckle *et al.* 2005). In the St Louis area, further to the south, the mid Keokuk Peerless Park Member yields a diverse calcareous foraminiferal assemblage (Brenckle *et al.* 2005). Conodont and foraminiferal assemblages from the Keokuk and Warsaw formations were recorded by Brenckle *et al.* (1974) in their study correlating Mississippi Valley strata to the Tournaisian - Viséan boundary in Europe.

Foraminifera are the most abundant microfossil group in the Keokuk and the most useful for global correlation. Foraminifera are recorded throughout the Keokuk, but are especially abundant and diverse within the Peerless Park Member (Brenckle *et al.* 2005). Here, a late Osagean shallowing event allowed the diversification of shallow water calcareous

foraminifera between the deeper water deposition facies as seen in the rest of the Keokuk (Brenckle *et al.* 2005). Brenckle *et al.* (1974) correlated an assemblage from the Keokuk with the lower Viséan including taxa such as *Earlandia* spp., *Endothyra obseleta* group, *Endothyranella* sp., *Globoendothyra piasae* and *Tetrataxis* spp. A similar diverse early Viséan fauna from the Peerless Park Member supports this placement (Brenckle *et al.* 1982), and furthermore, supports correlation of the underlying Burlington Limestone with the Belgian Ivorian Substage at the top of the Tournaisian (Menning *et al.* 2006).

Brachiopods and conodonts recorded throughout the Keokuk do not show any rapid faunal turnover, suggesting that the changes seen in foraminiferal assemblages in the Peerless Park Member are facies-related (Kammer *et al.* 1990). Conodonts recorded from the Keokuk include *Gnathodus texanus*, *Taphrognathus varians* and *Hindeodella* sp. (Rexroad & Collinson 1965). This places the Keokuk in the *texanus* Zone which ranges from the basal Keokuk though the Osagean - Meramecian boundary into the lower St Louis Limestone (Lane & Brenckle 2005). These faunas are quite different from those at the same level in Europe, but correlations with the *anchoralis-bilineatus* Interregnum of Voges (1960), and the earliest Viséan of the Dinant Basin, Belgium, are suggested (Groessens 1974; Brenckle *et al.* 2005).

Warsaw Formation (Lower Warsaw Member)

The Warsaw Formation of the Mississippi Valley comprises shaley dolomites and limestones, with the lower part rich in geodes (Brenckle *et al.* 2005). The unit is divided into two members, the Upper and Lower Warsaw, originally on a lithostratigraphic basis, but more recently at a position of major faunal change within the Warsaw (Kammer *et al.* 1990).

The Lower Warsaw is less fossiliferous than its upper counterpart. Brachiopods, calcareous foraminifera and echinoderms form the basis for the Lower - Upper Warsaw subdivision, with numerous first occurrences of taxa at the base of the Upper Warsaw. Brachiopod faunas, closely resembling those from the underlying Keokuk, contain a diverse assemblage which includes species such as *Brachythyris suborbicularis*, *Echinoconchus alternatus*, *Prospira bifurcata* and *Torynifer pseudolineatus* (Kammer *et al.* 1990). Calcareous microfossils are sparse in most parts of the Lower Warsaw and disappear as clastic-dolomite deposition becomes prevalent, reflecting terrestrial deposition facies

(Kammer *et al.* 1990; Brenckle *et al.* 2005). A very reduced assemblage with taxa similar to those found in the Keokuk Limestone is recognised and comprises *Tetrataxis* spp., *Globoendothyra piasae* and *Paraarchaediscus* spp. Echinoderm faunas from the Lower Warsaw consist mainly of abundant disarticulated crinoid calyces. Although the overall fauna is diverse, entire calyces are rare and most species are represented by a single specimen (Kammer *et al.* 1990).

Conodont assemblages from the Lower Warsaw are similar to ones from the underlying Keokuk (Rexroad & Collinson 1965), and place the Lower Warsaw in the *texanus* Zone. Palynomorphs have been recovered from outcrops at Geode Glen in the Lower Warsaw type area by Leonard Eames (Eames pers. comm. 2005; Lane & Brenckle 2005). Genera such as *Auroraspora*, *Calamospora*, *Crassispora*, *Densosporites*, *Discernisporites*, *Grandispora*, *Spelaeotriletes* and *Tasmanites* were recorded.

2. 3. 3 MERAMECIAN

The Osagean - Meramecian boundary in the Mississippi Valley has been variously placed at the base of the Warsaw Formation of Illinois, top of the Warsaw of Iowa and the Lower - Upper Warsaw Boundary (Avcin & Koch 1979; Kammer *et al.* 1990). The problem was offset in Illinois and Indiana by the adoption of the term Valmeyeran for the combined Osagean and Meramecian (Atherton *et al.* 1975). Earlier studies focused on lithostratigraphic rather than biostratigraphic changes to define the boundary. However, the highest faunal turnover occurs at the Lower - Upper Warsaw boundary (Kammer *et al.* 1990) and this level is generally accepted as the position of the Osagean - Meramecian boundary.

Within its type area along the Mississippi River in Iowa, Illinois and Missouri the base of the Meramecian is marked by the first occurrences of the brachiopods *Warsawia lateralis*, *Planalvus densa*, *Crossacanthia perlamellosa*, *Setigerites altonensis* and *Tetracamera subcuneata* (Kammer *et al.* 1990). Crinoids and blastoids underwent a major change in evolutionary lineages, with camerate-dominated faunas becoming replaced by cladid-dominated faunas (Kammer *et al.* 1990; Kammer & Ausich 1993; Kammer & Ausich 2006). A single blastoid species, *Pentremites conoideus*, is recognised as a useful marker taxa for the Osagean - Meramecian boundary (Kammer *et al.* 1990). This species occurs throughout the Upper Warsaw and Salem within the Mississippian type region. These

brachiopod and echinoderm assemblages allow correlation beyond the Mississippi Valley. For example the placement of the Osagean - Meramecian boundary within the Ramp Creek Formation of south-central Indiana (Hirt 1991), is based on the first occurrence of *Warsawia lateralis*.

Calcareous microfossils are absent within the Lower Warsaw, but appear within the Upper Warsaw during a trangressional event and associated limestone deposition. The calcareous foraminifera *Globoendothyra baileyi* appears at the Osagean - Meramecian boundary, suggesting a correlation with the middle Viséan of Europe (Kammer *et al.* 1990). The carbonate depositional environments of the Salem and St Louis provide abundant foraminiferal faunas throughout the middle and upper parts of the Meramecian, the most common being species of *Eoendothyranopsis*, *Globoendothyra* and *Paraarchaediscus* (Lane & Brenckle 2005).

Conodont faunas are less diverse and show less faunal turnover in the Meramecian than the underlying Kinderhookian and Osagean. Sparse populations from the Warsaw place the lower and middle parts of the Meramecian in the *texanus* Zone which ranges from the base of the Osagean Keokuk Limestone (Brenckle *et al.* 2005). The appearance of the conodont *Hindeodus penescitulus* within the Upper Warsaw may be useful for recognising the Osagean-Meramecian boundary. The *scitulus-scalenus* Zone is recognised in the upper part of the Meramecian and ranges into the base of the overlying Chesterian (Lane & Brenckle 2005). The lower part of the *Beyrichoceras* ammonoid Genozone encompasses the upper Meramecian and the basal Chesterian Ste Genevieve Limestone (Menning *et al.* 2006). The Meramecian is correlated to the British Holkerian and early Asbian substages and Belgian Livian and early Warnantian substages of mid Viséan age in Europe (Menning *et al.* 2006).

Warsaw (Upper Warsaw Member)

As previously mentioned, fossil assemblages from the Upper Warsaw are noticeably different from those in the underlying Lower Warsaw, and the boundary between the two marks the Osagean - Meramecian stage boundary in the Mississippian type area. Major faunal changes are seen within lineages of echinoderms, brachiopods and calcareous foraminifera, representing the initial Meramecian transgression (Brenckle *et al.* 2005). Crinoid faunas are almost completely different from those of the underlying strata; however the only echinoderm present in most sections and in sufficient numbers is the

blastoid *Pentremites conoideus*. It appears alongside a diverse brachiopod assemblage including the aforementioned Meramecian marker taxa *Warsawia lateralis* and *Tetracamera subcuneata*. Calcareous microfossils in the Upper Warsaw include *Asphaltinoides macadami*, Aoujgaliaceae, endothyrids, *Paraarchaediscus* sp., Planoarchaediscinae, Salebridae and *Tetrataxis/Endotaxis* sp. Kammer *et al.* (1990) suggest the occurrence of *Globoendothyra baileyi* at the base of the Upper Warsaw in parts of the Mississippi Valley may be a useful marker for the Osagean - Meramecian boundary, although they note that the appearance of calcareous microfossils at the boundary is largely facies controlled.

Conodont faunas are similar to those found in the underlying Keokuk and Lower Warsaw, and place the Upper Warsaw in the *texanus* Zone (Rexroad & Collinson 1965). Brenckle *et al.* (2005) suggest the appearance of *Hindeodus penescitulus* (as seen in the type area at Geode Glen, Illinois) may be a useful marker for recognising the base of the Meramecian.

Salem Limestone

The Salem Limestone conformably overlies the Warsaw Formation throughout most of the Mississippi Valley and Indiana. It becomes thicker and more prevalent in the southern part of the Mississippi Valley in southern Illinois and Missouri where it approximates the St Louis Limestone, and is absent in the northern-most parts of the Mississippi Valley, where it is seemingly represented by the Sonora Formation (Brenckle *et al.* 2005).

Calcareous microfossil assemblages from the Salem are sparse and include taxa such as *Asphaltinoides macadami*, *Earlandia* spp., endothyrids, *Paraarchaediscus* sp., *Pseudoammodiscus priscus* and Salebridae (Brenckle *et al.* 2005). Conodont assemblages mirror those found in the underlying Warsaw Formation and include the species *Taphronathus varians*, *Gnathodus texanus* and *Hindeodus penescitulus*, indicating its placement in the *texanus* Zone (Rexroad & Collinson 1965).

Sonora Formation

The Sonora Formation is a thin, sandy limestone unit which overlies the Warsaw Formation in the northern part of the Mississippi Valley, in southern Iowa, northeastern Missouri and west central Illinois. It is equivalent to the Salem Limestone further to the

south. A very sparse foraminiferal assemblage is recorded from the Sonora including *Eoendothyranopsis scitula* and *Globoendothyra baileyi* (Brenckle *et al.* 2005). Other fossil groups recorded from the Sonora include bryozoans, crinoids, blastoids, brachiopods, gastropods, corals and trilobites (Witzke & Bunker 2002).

St Louis Limestone

The St Louis Limestone is a thick limestone unit, widespread throughout the Mississippi Valley and Midwest USA. In northern Missouri and southern Iowa it rests conformably on the Sonora Formation. In the St Louis type area it overlies the Salem Limestone, and thins towards its southern margins where it grades into the Salem, and can be informally spilt into an upper and lower member (Brenckle *et al.* 2005).

In the St Louis type area the lower part of the St Louis Limestone contains a very diverse and abundant calcareous microfossil assemblage including the long-ranging *Endothyra* spp., *Endothyra obsoleta* group, *Globoendothyra piasae* and *G. baileyi*, alongside the first appearances of *Paraarchaediscus convexus* and *Endothyranopsis* sp. These faunas persist into the upper St Louis where a few new species appear - the *Endothyra bowmani* group, *Endostaffella discoidea* and *Endothyra phrissa* (Lane & Brenckle 2005).

Corals have also been useful for correlating the lower part of the unit. *Acrocyanthus* (‘*Lithostrotionella*’) has been recorded in a bed from the lower St Louis in its type area and can be traced into the Salem Limestone further south. This illustrates a gradation from near-shore palynofacies of the St Louis into more the more open marine Salem (Brenckle *et al.* 2005). *Lithostrotion* is also recorded from the St Louis of the Mississippi Valley (Sando 1977) and this suggests correlation with the Belgian Livian Substage, mid Viséan (Poty *et al.* 2006).

Conodont faunas from the basal part of the unit are similar to those found in the Keokuk, Warsaw and Salem, and again belong to the *texanus* Zone. A faunal change is detected in the mid to upper St Louis where a diverse assemblage comprises species such as *Cavusgnathus unicornis*, *Taphrognathus varians*, *Hindeodus penescitulus* and *Hindeodus scitulus* (Rexroad & Collinson 1963). This places the mid-upper St Louis in the *scitulus-scalenus* Zone. The short-ranging *Taphrognathus-Cavusgnathus* transitional form is also found; this species generally occurs in the basal part of the *scitulus-scalenus* Zone only.

Taxa associated with the overlying Lower *bilineatus* Zone - *Lochriea commutata* and *Paragnathodus homopunctatus*, appear in the uppermost St Louis in its type area, however index taxa for this zone do not appear until the base of the Ste Genevieve Limestone (Brenckle *et al.* 2005).

2. 3. 4 CHESTERIAN

The Chesterian of the Mississippi Valley is a sequence of alternating limestones, shales and sandstones, and includes units ranging from the Ste Genevieve Limestone to the Grove Church Shale. Much of the previous biostratigraphic work focused on the calcareous units (McFarlan *et al.* 1955; Rexroad & Collinson 1961). The base of the Chesterian is recognised by significant changes in conodonts, foraminifera, brachiopods and corals at the St Louis - Ste Genevieve boundary (Mapes & Waters 1987). Of these, conodonts and calcareous microfossils are the most abundant fossil groups within the Chesterian, and the most useful for global correlation. The base of the Chesterian is marked by the first appearance of the asteroarchaediscin foraminifera *Asteroarchaediscus* and *Neoarchaediscus* which occur at the base of the Ste Genevieve Limestone (Lane & Brenckle 2005). This coincides with the base of the Lower *bilineatus* Conodont Zone (Lane & Brenckle 2005). The Chesterian spans six conodont zones in total; the Lower *bilineatus*, Upper *bilineatus*, *naviculus*, *unicornis*, Lower *muricatus* and Upper *muricatus*.

Foraminiferal diversity declines in the Mississippi Valley in the earliest part of the Chesterian. This level approximates the upper Viséan in Europe, however none of the larger foraminifera commonly found at this level in Europe are present in the Mississippi Valley (Lane & Brenckle 2005). Recent advances have been made towards defining the position of the Viséan - Serpukhovian boundary within the mid-Chesterian of the USA. In Europe and across the Moscow Basin and the Urals, this level is defined by the first appearance of the conodont *Lochriea ziegleri*, a lineage that has not been identified in North America. However, foraminiferal assemblages from Europe, Russia and North America show some similarities between continents. Assemblages from the Chesterian type sections of the Mississippi Valley have been studied in detail and the base of the Serpukhovian is now correlated to the base of the Beech Creek Formation (Kulagina *et al.* 2008). Above this level, assemblages show very little faunal turnover until the upper Chesterian Menard Limestone, where the appearance of *Eosigmoilina* and *Brenckleina*

coincide with the base of the *naviculus* Zone, providing correlation with the Serpukhovian Stage (Lane & Brenckle 2005; Menning *et al.* 2006).

Ammonoids are not commonly found in the Chesterian of the Mississippi Valley, and are better known from the Appalachian Basin further to the east. The *Lusitanoceras-Lyrogoniatites* Genozone is recognised in the Beech Creek Limestone (Furnish & Saunders 1971) and suggests correlation of the mid-Chesterian with the British Brigantian Substage of latest Viséan age. However, this correlation is disputed by more recent foraminifera evidence (Kulagina *et al.* 2008).

The Grove Church Shale is the youngest formation included in the Chesterian (known as the Grove Church Shale Member of the Kinkaid Formation in Illinois). The Grove Church Shale contains the youngest conodonts seen in the Mississippian of the Mississippi Valley, placing it in the *unicornis* Zone. The top part of the *unicornis* Zone and the overlying Lower and Upper *muricatus* zones are present in parts of the American Midcontinent, but are absent in the Mississippi Valley due to a regional unconformity at the Mississippian - Pennsylvanian boundary (Lane & Brenckle 2005).

Ste Genevieve Limestone

The Ste Genevieve Limestone is the oldest Chesterian formation. Abundant larger fossils are found within the Ste Genevieve, mainly crinoid fragments of the taxa *Platycrinites ('Platycrinus') penicillus* and *Pugnoides ottumwa* (Atherton *et al.* 1975). The formation contains a sparse foraminiferal assemblage including *Asteroarchaediscus* cf. *A. parvus, Endostafella discoidea, Endothyra bowmani* group, *Neoarchaediscus* sp., and *Paraarchaediscus koktjubensis*; all long-ranging upper Viséan - Serpukhovian taxa (Lane & Brenckle 2005; Kulagina *et al.* 2008). Conodont faunas are also generally sparse, and in many outcrops are poorly preserved or absent. *Cavusgnathus unicornis*, *Cavusgnathus regularis, Cavusgnathus altus*, *Hindeodus cristulus*, *Magnilaterella robusta* and *Gnathodus bilineatus* are all found within the Ste Genevieve and indicate placement within the Chesterian in the Lower *bilineatus* Zone (Lane & Brenckle 2005).

Pella Formation

The Pella Formation of southeast Iowa has been correlated with both the St Louis Limestone and Ste Genevieve Limestone of the type Mississippian. It is now recognised as equivalent to the latter (Groves & Beason 2006). Conodont assemblages recovered from the Pella resemble those of the Ste Genevieve and include *Gnathodus bilineatus*, *Hindeodus cristulus* and *Cavusgnathus unicornis* and similar placement within the Lower *bilineatus* Zone (Witzke & Bunker 2005). Calcareous microfossil assemblages from the Pella are dominated by long-ranging taxa such as *Earlandia* spp., *Asphaltinella* sp. and salebrids. However, the presence of *Asteroarchaediscus rugosus* and other Asteroarchaediscinae place the Pella within the upper part of the Ste Genevieve (Groves & Beason 2006).

Aux Vases Sandstone

The Aux Vases Sandstone is present throughout much of western Illinois and southeastern Missouri as a very sandy limestone. It is the first major sandstone of the Chesterian succession of alternating clastic and limestone formations, found in outcrop throughout much of the Mississippi Valley (Brenckle *et al.* 2005). No fossils have been recovered from the Aux Vases.

Renault Formation

The Renault Formation overlies the Aux Vases Sandstone throughout Missouri, Illinois, Indiana and Kentucky. Plant fragments of *Lepidodendron* are present in the sandy beds and crinoids (e.g. *Talarocrinus*) and bryozoans (e.g. *Lyropora*) are present in the limestones (Thompson 1986). In Illinois the Renault is split into two members - the Levias Limestone Member and Shelterville Limestone Member (Atherton *et al.* 1975). The Levias Member contains the crinoid *Platycrinites penicillus* and the Shelterville contains *Talarocrinus*. On this basis the Meramecian - Chesterian boundary was previously defined at the contact between the two members (Atherton *et al.* 1975).

Conodonts recovered from the Renault include *Gnathodus bilineatus* and *Cavusgnathus charactus* and show it ranges from the upper part of the Lower *bilineatus* Zone to the base of the Upper *bilineatus* Zone (Collinson *et al.* 1971).

Yankeetown Formation

The Yankeetown Formation overlies the Renault Formation throughout Missouri, Illinois, and Indiana. In the latter it is regarded as a member of the Paoli Formation. It comprises calcareous sandstones and shales with crinoids present in some layers (Atherton *et al.* 1975). The Yankeetown is unfossiliferous.

Downeys Bluff Limestone

The Downeys Bluff Limestone Formation (or member as it is regarded in Indiana) overlies the Yankeetown Formation. Crinoids are present throughout; many are replaced by pink chert making them useful markers for the unit (Atherton *et al.* 1975). Collinson *et al.* (1971) reported conodonts belonging to the *Gnathodus bilineatus-Cavusgnathus charactus* Zone (Upper *bilineatus* Zone of Lane and Brenckle 2005).

Paoli Formation

In Kentucky and Indiana the Shelterville Member of the Renault Limestone, Yankeetown Sandstone and Downeys Bluff Limestone are referred to as members of the Paoli Formation. This unit overlies the Levias Limestone or the Aux Vases Sandstone where the former is absent. Conodonts are generally sparse throughout the Paoli Formation but are diagnostic of the Upper *bilineatus* Zone (Rexroad & Liebe 1962).

Bethel Sandstone

The Bethel Sandstone overlies the Downeys Bluff Limestone in Illinois and Missouri and the Paoli Formation in Indiana and Kentucky. It is a predominantly sandstone unit with shaley partings. Plant fossils, including *Lepidodendron*, are found throughout (Atherton *et al.* 1975).

Ridenhower Formation

The Ridenhower Formation is a limestone unit named from southern Illinois. In Illinois the formation comprises three members – the Beaver Bend Limestone, Sample Sandstone and Reelsville Limestone. In Indiana, these members are classified as formations. The blastoid

Pentremites and the bryozoans *Cystodictya* and *Archimedes* are fairly common throughout (Atherton *et al.* 1975). Conodonts and calcareous microfossils are also recorded from the formation (Brenckle *et al.* 2005). Conodonts belong to the Upper *bilineatus* Zone and include *Cavusgnathus unicornis*, *Vogelgnathus campbelli*, *Hindeodus cristulus* and *Gnathodus modocensis* (Rexroad & Horowitz 1990; Brenckle *et al.* 2005). Calcareous microfossils include *Asteroarchaediscus* sp., *A. rugosus* group, *Earlandia* spp., *Endostafella* sp., *Neoarchaediscus* sp., *Paraarchaediscus* sp. and *Pseudoglomospira* sp.

Cypress Sandstone

The Cypress Sandstone, along with the Tar Springs Sandstone, is the thickest and most widespread sandstone unit of the Chesterian, reaching up to 200 feet thick in southern Illinois. In Indiana it is referred to as the Elwren Formation in outcrop and the Cypress Formation in the subsurface. As with many of the other clastic units of the Chesterian, plant fossils are common and include *Lepidodendron* trunks (Atherton *et al.* 1975). Collinson *et al.* (1971) reported conodonts from the Cypress which placed it in their uppermost *Gnathodus bilineatus-Cavusgnathus charactus* Zone. Lane and Brenckle (2005) placed it in the upper *bilineatus* Zone.

Beech Creek Limestone

The Beech Creek Limestone is a fossiliferous limestone which yields dominant crinoids together with ammonoids, conodonts, foraminifera and brachiopods. In Illinois and Indiana the Beech Creek is recognised as a formation, and in Missouri it is classified as a member of the Golconda Formation along with the overlying Fraileys Shale and Haney Limestone (Atherton *et al.* 1975; Thompson 1986). The late Viséan ammonoid *Lyrogoniatites* (now *Neoglyphioceras*, according to D.M. Work (Brenckle *et al.* 2005)) was recorded by Furnish and Saunders (1971). On this evidence the Viséan – Namurian/Serpukhovian boundary was placed at the Beech Creek - Fraileys Shale contact (Menning *et al.* 2006).

A diverse foraminiferal assemblage has recently been recorded from the Beech Creek Limestone, and this has redefined the Viséan – Namurian/Serpukhovian boundary. The assemblage includes abundant *Zellerinella discoidea*, "*Millerella*" *totula* and *Neoarchaediscus postrugosus* (Kulagina *et al.* 2008), the latter two of which appear near the level of *Lochriea ziegleri* in Russia. This correlates the Beech Creek to the basal

Serpukhovian, and places the Viséan – Serpukhovian boundary at the Cypress - Beech Creek contact. Impoverished assemblages from the overlying Haney and Glen Dean Limestones are also correlated to the lower Serpukhovian on the presence of *Neoarchaediscus* cf. *N. probatus* and *Neoarchaediscus* cf. *N. postrugosus* (Kulagina *et al.* 2008).

Fraileys Shale

The Fraileys Shale is regarded as a formation in Illinois and as a member in Missouri. The unit yields abundant bryozoans, with the genus *Archimedes* reaching a peak in species and abundance within the Fraileys and overlying Haney. Brachiopods are also common; the *Pterotocrinus capitalis* Range Zone spans the lower part of the Fraileys Shale and the *'Camarophoria'-Stenoscisma explanata* Range Zone extends from the Fraileys to the top of the Chesterian (Atherton *et al.* 1975). Previously placed at the base of the Serpukhovian (Furnish & Saunders 1971), the Fraileys Shale is now regarded as early Namurian/Serpukhovian on the basis of foraminifera from the underlying Beech Creek (Kulagina *et al.* 2008).

In Illinois the Big Clifty Sandstone Member is recognised at the base of the Fraileys Shale, however this unit is not recognised in Missouri (Thompson 1986). In Indiana the Big Clifty is given formation status and is equivalent to much of the Fraileys Shale interval (Atherton *et al.* 1975).

Haney Limestone

The Haney Limestone overlies the Fraileys Shale and is recognised from exposures throughout much of southern Illinois. In Indiana, it is classified as the Haney Limestone Member of the Golconda Formation (Thompson 1986). An impoverished conodont fauna is observed, with long-ranging taxa such as the dominant *Cavusgnathus unicornis*, as well as *Gnathodus bilineatus*, *Gnathodus girtyi* and *Lochriea commutata* placing the Fraileys within the Upper *bilineatus* Zone (Brenckle *et al.* 2005). Calcareous microfossils include *Neoarchaediscus* cf. *N. probatus* and *Neoarchaediscus* cf. *N. postrugosus* and place the Haney in the early Serpukhovian (Kulagina *et al.* 2008).

Hardinsburg Sandstone

The Hardinsburg Sandstone is a sandy/shaley unit which was named from Kentucky about 200 miles to the east of the Mississippi Valley. It is widespread throughout Indiana, Illinois and Missouri. The Hardinsburg falls within the upper part of the *Gnathodus bilineatus-Cavusgnathus altus* Zone of Collinson *et al.* (1971), and the Upper *bilineatus* Zone (Lane & Brenckle 2005). Calcareous microfossils have been recorded from shaley limestone beds within the Hardinsburg in the Mississippi Valley, southern Illinois. These include *Asphaltinoides macadami*, *Earlandia* spp. and *Endothyra* sp. (Brenckle *et al.* 2005).

Glen Dean Limestone

The Glen Dean Limestone (and the overlying Tar Springs Formation) was also named from Kentucky. Bryozoans, blastoids and conodonts are common, and brachiopods, corals and crinoids also occur (Thompson 1986). The bryozoan *Prismopora serrulata* and the blastoid *Pentremites spicatus* are characteristic and the unit is equivalent to the *Pterotocrinus acutus-Pterotocrinus bifurcates* Assemblage Zone (Atherton *et al.* 1975). Conodonts recovered from the Glen Dean are again mostly long-ranging taxa assigning the unit to the Upper *bilineatus* Zone, e.g. *Cavusgnathus* spp., *Kladognathus* spp. and *Hindeodus* spp. (Rexroad 1958; Brenckle *et al.* 2005). The Viséan – Namurian/Serpukhovian boundary has been variously placed just below or within the Glen Dean on the basis of crinoid faunas from Indiana and Kentucky (Horowitz & Perry 1961), at the base of the Glen Dean based on foraminifera (Mamet & Skipp 1970), and the base of the overlying Tar Springs based on archaediscid foraminifera (Owens *et al.* 1977). Most recently, the Glen Dean has been identified as early Serpukhovian based on comparison of foraminiferal assemblages from the Mississippi Valley and Russia (Kulagina *et al.* 2008).

Tar Springs Sandstone

The Tar Springs Sandstone is named from Kentucky and overlies the Glen Dean Limestone throughout Illinois, Missouri, Indiana and Kentucky. It is interpreted as a deltaic unit and variably consists of sandstones and shales with some carbonate-rich layers and thin coal beds near the top of the formation (Atherton *et al.* 1975; Thompson 1986). Fossils are scarce and mostly consist of terrigenous plant material (Thompson 1986).

Vienna Limestone

The Vienna Limestone, named from southern Illinois, contains conodonts, foraminifera, bryozoans and crinoids. In Illinois the unit is referred to as a formation, but in Indiana the Vienna is regarded as a member of the Branchville Formation along with the overlying Waltersburg Sandstone and the lower part of the Menard Limestone. Larger fossils from the Vienna include the bryozoan *Prismopora serrulata* and the bivalve *Sulcatopinna missouriensis* (Atherton *et al.* 1975). Conodonts were described by Rexroad (Lane & Brenckle 2005) from exposures of the Vienna Formation near its type area in Chester, Illinois and from the Vienna Member in southern Indiana and Illinois. These include *Cavusgnathus altus*, *Cavusgnathus unicornis*, *Hindeodus cristulus*, *Kladognathus mehli* and *Lamdagnathus fragilidens*, and place the Vienna within the *Kladognathus primus* Zone of Collinson *et al.* (1971) or, more recently, the Upper *bilineatus* Zone (Lane & Brenckle 2005). Foraminifera have been recorded from the Branchville Formation of Indiana and previously placed in North American Foraminiferal Zone 17 (Mamet & Skipp 1970) providing correlation with the Namurian. Recent detailed studies of the Mississippian type region (Kulagina *et al.* 2008) described a foraminiferal assemblage containing endothyrids, namely *Semiendothyra* sp., as well as *Eostaffella* ex gr. *cooperi*, *Eostaffellina* aff. *decurta* and *Eostaffellina* ex gr. *paraprotvae*. On this basis, the authors correlate the Vienna to the middle part of the Serpukhovian.

Waltersburg Formation

The Waltersburg Formation overlies the Vienna Limestone in Illinois. It is absent in Missouri where the Vienna is the youngest recognised Mississippian unit (Thompson 1986), and is present in parts of Indiana as the Waltersburg Member of the Branchville Formation. No fossils have been recorded from the Waltersburg.

Menard Limestone

The Menard Limestone contains abundant and diverse conodonts and foraminifera. The brachiopods *Spirifer increbescens* and *Composita subquadrata*, and the bivalve *Sulcatopinna missouriensis* are recorded, and the lower part of the Menard contains the *Pentremites fohsi* Range Zone (Atherton *et al.* 1975). Stratigraphically important foraminifera have previously correlated the Menard with the base of the Serpukhovian

(Brenckle *et al.* 2005). Eosigmoilinid foraminifera appear with the first occurrence of *Eosigmoilina robertsoni* and *Brenckleina rugosa*. *Brenckleina rugosa* appears just below the ammonoid *Eumorphoceras* (early Serpukhovian) in Arkansas and also suggests correlation of the Menard with the base of the Serpukhovian (Baxter & Brenckle 1982). More recently, foraminiferal assemblages from the Menard have been correlated with the upper Serpukhovian of the Donets Basin (Kulagina *et al.* 2008). The conodont fauna is diverse and contains the species *Cavusgnathus naviculus* marking the base of the *naviculus* Zone (Lane & Brenckle 2005), previously the *Kladognathus-Cavusgnathus naviculus* Zone of Collinson *et al.* (1971).

Palestine Sandstone

The Palestine Sandstone overlies the Menard and is recognised as a terrestrial unit. Fossilised tree trunks of *Lepidodendron* have been found throughout the Palestine Sandstone (Atherton *et al.* 1975).

Clore Formation

The Clore Formation is a calcareous shale unit recognised from Illinois. A bryozoan and brachiopod fauna is recorded. Bryozoan genera include *Archimedes*, *Batostomella* (along with the index fossil *Batostomella nitidula*) and *Rhombopora*. *Spirifer increbescens* and *Composita subquadrata* are common among the brachiopods (Atherton *et al.* 1975).

Degonia Sandstone

The Degonia Sandstone overlies the Clore throughout Illinois. As with the underlying sandstone layers, the Degonia contains plant fossils, most commonly *Lepidodendron* (Atherton *et al.* 1975).

Kinkaid Limestone

The Kinkaid Limestone is the uppermost limestone unit of the Mississippian in the Mississippi type region and consists of three members; the Negli Creek Limestone, the Cave Hill Shale and the Goreville Limestone. Brachiopods, bryozoans, blastoids, conodonts and foraminifera are all commonly found throughout the Kinkaid (Atherton *et*

al. 1975). Conodonts from the Kinkaid are assigned to the *naviculus* Zone. Foraminifera are correlated to the late Serpukhovian (Brenckle *et al.* 2005). Of the three members the Goreville Limestone yields the most abundant calcareous microfossils, overlying the sparse Negli Creek and terrestrial Cave Hill Shale. Kulagina *et al.* (2008) sampled shaley partings from the Goreville and recognised a foraminiferal assemblage comprised of abundant and diverse eostaffelids and eosigmoilinids. On this basis they correlate the Kinkaid Limestone with the uppermost Serpukhovian of the Donets Basin.

Grove Church Shale

The Grove Church Shale is the youngest Mississippian formation in the Mississippi Valley, occurring in Illinois and southwest Indiana. In parts of Illinois it is regarded as the uppermost member of the Kinkaid. In its type area in southern Illinois it contains a diverse conodont assemblage including *Adetognathus unicornis* and *Hindeodus minutus* which, amongst others, are indicative of the *unicornis* Zone. This is the highest conodont fauna in the type Mississippian and notably different from the underlying Kinkaid fauna (Rexroad & Burton 1961). Two additional Mississippian conodont zones, the Lower and Upper *muricatus* zones are absent in the Mississippi Valley, but are found further to the west in southern Nevada (Brenckle *et al.* 2005). Early foraminiferal works recorded late Serpukhovian taxa such as *Consobrinella aspera*, *Endothyra acuta*, *Endothyra excentralis*, *Trepeilopsis mississippiana* and *Millerella* sp. from the shale beds (Cooper 1947), and affinities to Pennsylvanian assemblages have been noted (Atherton *et al.* 1975). More recently, additional taxa have been recorded from the limestones (Brenckle *et al.* 2005).

CHAPTER 3
MISSISSIPPIAN MIOSPORES

3. 1 INTRODUCTION

Three types of spores and pollen are present in Mississippian microfloral assemblages; trilete and monolete miospores and saccate pollen. Trilete miospores are by far the most common, with monolete miospores making up a minor component or completely absent from many assemblages. Saccate pollen do not appear until the upper part of the Mississippian (lower Namurian of Europe/upper Chesterian of North America). Alete miospores (e.g. *Schopfites claviger*) are also occasionally present (Clayton 1996).

3. 2 FLORAL PROVINCES

Present day floral provinces are restricted by continental margins and most are defined by specific climatic regions. Similarly, several different floral assemblages and their associated microfloral assemblages are evident throughout the Mississippian. Sullivan (1965; 1967) recognised five of these assemblages or 'suites' in the Mississippian. In the lower Mississippian he recognised the '*Vallatisporites* Suite', ranging across parts of North America, Western Europe, North Africa and Australia, and the '*Lophozonotriletes* Suite', represented by large cingulate taxa such as *Tumulispora rarituberculata*, restricted to present day high latitudes in the Northern Hemisphere. These are replaced in the upper Mississippian by the '*Grandispora* Suite' and the '*Monilospora* Suite' respectively. A further upper Mississippian low diversity assemblage, the 'Kazakhstan Suite', was described from Kazakhstan.

These suites were renamed by Clayton (1985) who used the term 'microfloras'. Further to the existing assemblages outlined by Sullivan (1965; 1967), two additional microfloras were identified (Figure 3.1). The '*Spelaeotriletes balteatus* Microflora' (later named the '*Aratrisporites saharaensis* Microflora' Clayton *et al.* (1990) was named from North Africa and the Middle East. This microflora contains many taxa apparently restricted to this region such as *Aratrisporites saharaensis*, *Spelaeotriletes owensii* and *Vallatisporites agadesi*. The second microflora, the '*Granulatisporites frustulentus* Microflora' is recognised from Australia (Kemp *et al.* 1977; Clayton 1985). A transitional assemblage

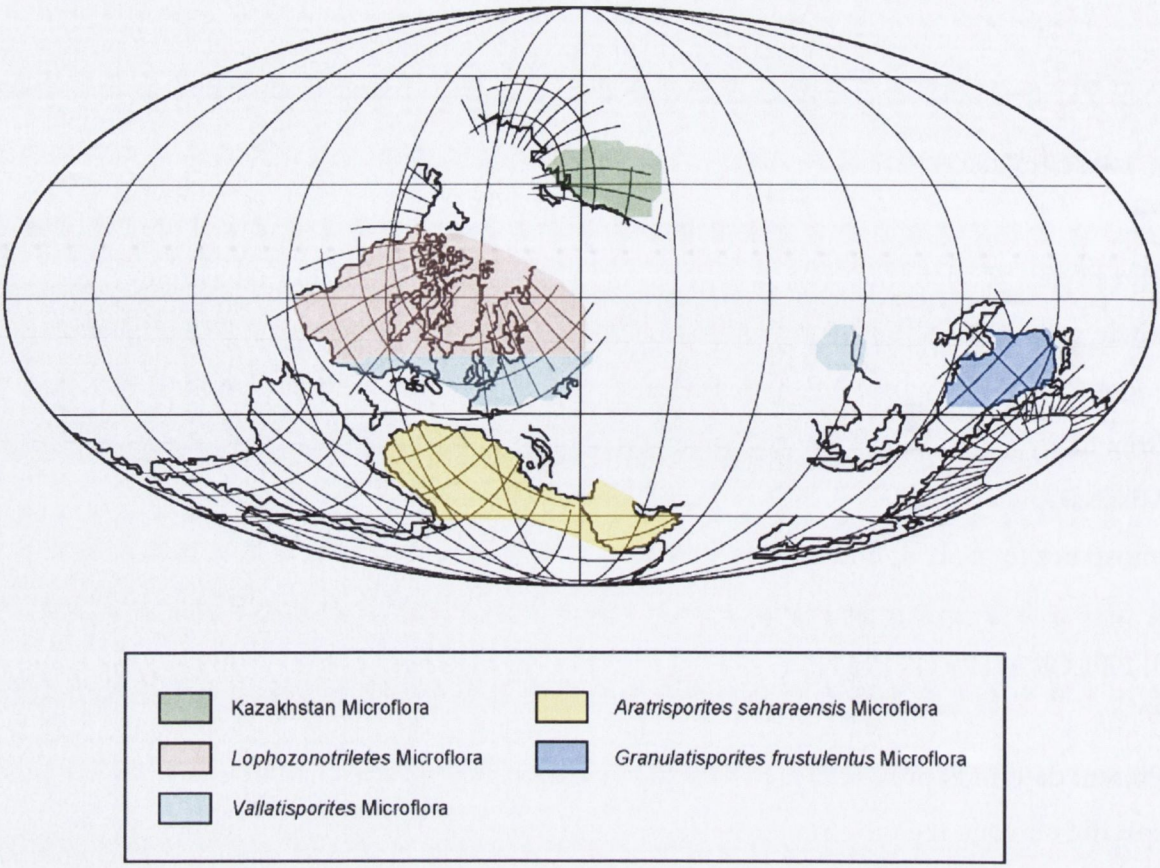


Figure 3.1 Early Mississippian (mid-Tournaisian - early Viséan) distribution of microfloras (after Clayton 1985; Clayton *et al.* 1990)

containing elements of both the Australian and African microfloras has also been identified from Brazil (Loboziak *et al.* 1991).

3. 3 PALYNOFLORAS OF NORTH AMERICA AND WESTERN EUROPE

During the early part of the Carboniferous, North America, Europe and parts of Northern Africa formed the palaeocontinent of Euramerica. As stated above, this results in similar microfloral assemblages being recorded from Mississippian sediments in these areas despite their present day geographical remoteness from each other, e.g. the *Vallatisporites* and *Grandispora* microfloras are recognised from both North America and Europe (Clayton 1996). A great deal of work has been carried out on Mississippian age European miospore assemblages and a detailed miospore biozonation scheme has been erected for the entire Carboniferous. This scheme is detailed in the following section. Much less work has been carried out on the Mississippian palynology of North America, and very little within the Mississippi Valley itself. No miospore biozonation has been suggested for this

area, although attempts have been made to correlate the North American material with the existing European Miospore Biozonation. Correlation with the European Miospore Biozonation is the main focus of the present study.

Clayton *et al.* (1990) outlined six major events in the Mississippian of Europe, North Africa and North America which may be used as global biostratigraphic markers. These are listed below in ascending stratigraphic order.

1. Extinction of *Retispora lepidophyta* at the Devonian - Carboniferous boundary.
Part of a larger group of taxa which all disappear at the system boundary, this species was extremely common in the Late Devonian and as such its absence from lower Carboniferous sediments is notable in most sections spanning the Devonian – Carboniferous boundary. Because of its abundance within latest Devonian strata this species occasionally appears as a reworked component in early Carboniferous assemblages (Playford & McGregor 1993; Clayton *et al.* 1998).

2. First appearance of *Spelaeotriletes pretiosus* in the mid Tournaisian.
The first appearance of *Spelaeotriletes pretiosus* has been noted at a similar level in Western Europe (Clayton *et al.* 1978), Atlantic Canada (Utting 1987; Utting *et al.* 1989), North America (Coleman & Clayton 1987), Poland (Turnau 1975; Turnau 1978) and North Africa (Loboziak & Clayton 1988)

3. First appearance of *Lycospora pusilla* around the Tournaisian - Viséan boundary.
This species appears in small numbers in the latest Tournaisian (Neves *et al.* 1972), and increases in numbers to dominate Viséan assemblages within Europe (Higgs *et al.* 1988b). The *Lycospora pusilla* (Pu) Biozonal boundary has variously been placed at the first appearance of *Lycospora pusilla* and at the first abundant occurrence of *Lycospora pusilla* (Clayton *et al.* 1977; Owens *et al.* 1977b; Higgs *et al.* 1988; Stephenson *et al.* 2004). The first appearance of *Lycospora pusilla* is now accepted as defining the base of the Pu (Higgs *et al.* 1988b).

The exact chronostratigraphic position of the base of the Pu Biozone is uncertain, mainly due to uncertainty surrounding the placement of the Tournaisian – Viséan boundary. The Tournaisian – Viséan boundary was first formally defined in the Dinant Basin (Conil *et al.* 1969). Since then, significant facies control of the index taxon in the stratoype section has

been recognised and the global stratotype section and point (GSSP) for the base of the Viséan has been redefined from southern China (Devuyst *et al.* 2003; Work 2008). The base of the Pu zone was previously correlated with the base of the Chadian Regional Substage, just below the base of the Viséan Stage (Higgs *et al.* 1988b). However, the Chadian has been redefined on foraminiferal evidence to coincide with the base of the Viséan (Devuyst *et al.* 2003). The base of the Pu Biozone is therefore, presently uncertain.

4. First appearance of *Tripartites vetustus* at the base of the late Viséan.
The appearance of *Tripartites vetustus* and associated taxa have been noted at this level from assemblages in the Midcontinent of the USA, Western Europe, the Donets Basin, Russia and Gansu, China (Clayton *et al.* 1990). The associated taxon *Grandispora spinosa* appears in the late Viséan of Atlantic Canada (Utting 1987), and *Rotaspora fracta* appears at a similar level in Western Canada (Utting *et al.* 1989). This group of taxa appears to be mainly restricted to the '*Grandispora* Microflora' (Clayton *et al.* 1990).

5. First appearance of monosaccate pollen in the early Namurian.
Monosaccate pollen such as *Florinites* spp. and *Potonieisporites elegans* (Wilson & Coe) Wilson & Venkatachala first appear in the late Mississippian in the *Grandispora*, *Monilospora* and *Aratrisporites saharaensis* microfloras (Felix & Burbridge 1967; Neves & Belt 1970; Owens *et al.* 1978; Utting 1987; Coquel *et al.* 1988; Utting & Giles 2008)

6. Extinction of *Tripartites vetustus* and *Rotaspora* spp. in the latest Mississippian.
Clayton *et al.* (1990) note that these two taxa both disappear abruptly in the Arnsbergian Regional Substage in Western Europe. A similar disappearance is noted from the late Chesterian of North America (Hoffmeister *et al.* 1955; Felix & Burbridge 1967)

3. 4 WESTERN EUROPEAN MIOSPORE ZONATION

The present Western European miospore zonation is based on miospore assemblages from the Dinantian of the British Isles as described by Neves et al (1972). This interval spans the latest Famennian and the earliest Namurian, and the authors recognised eight concurrent range zones – the *Vallatisporites pusillites – Retispora lepidophyta* (PL) Zone, the *Verrucosisporites nitidus – Vallatisporites vallatus* (NV) Zone, the *Schopfites claviger – Auroraspora macra* (CM) Zone, the *Lycospora pusilla* (Pu) Zone, the *Velamisporites tessellatus – Schulzospora campyloptera* (TC) Zone, the *Raistrickia nigra – Triquitrites*

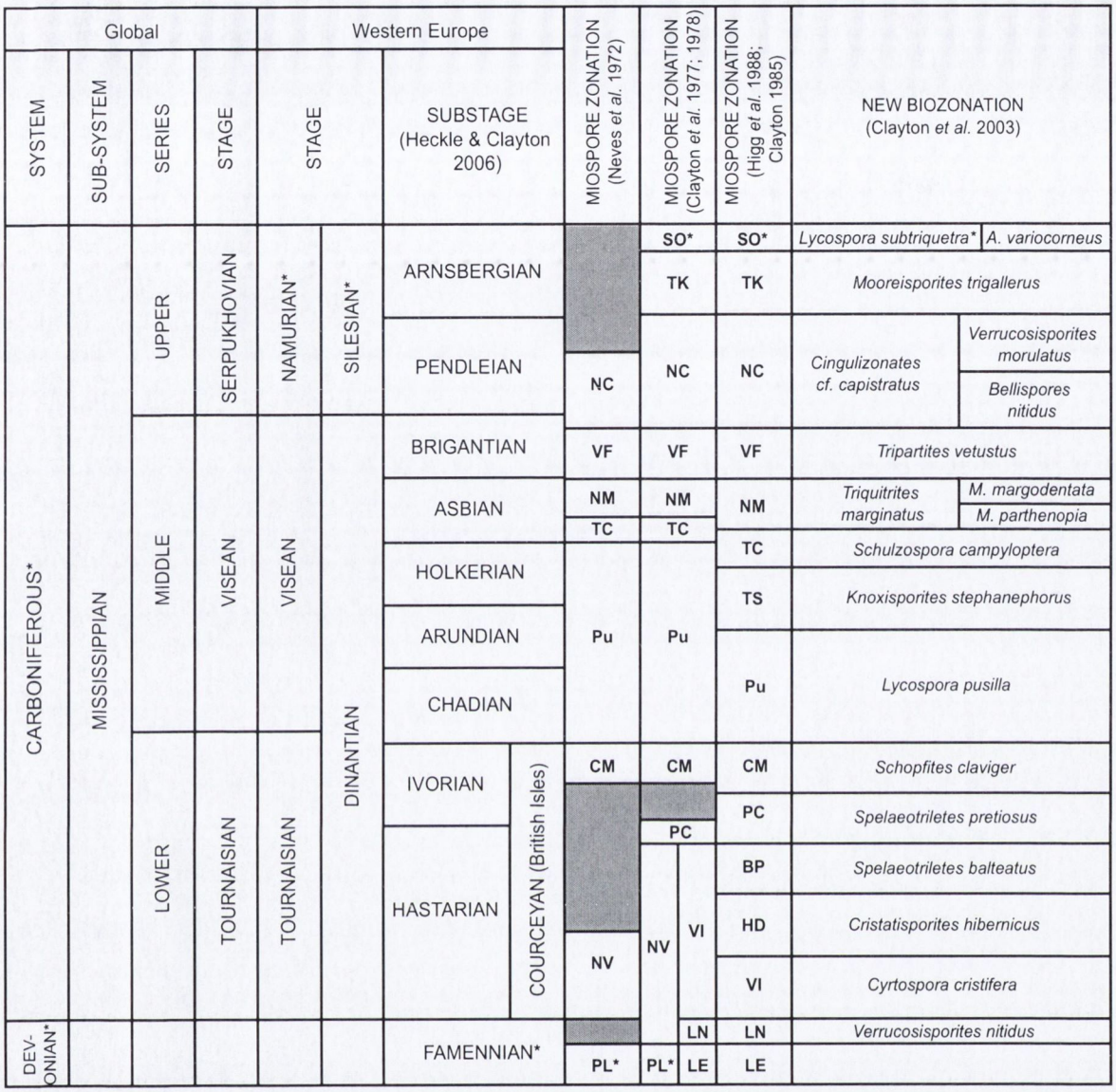


Figure 3.2 Miospore biozonations of Western Europe (*in part)

marginatus (NM) Zone, the *Tripartites vetustus – Rotaspora fracta* (VF) Zone and the *Bellispores nitidus – Reticulatisporites carnosus* (NC) Zone (Figure 3.2). Two key taxa were normally selected as index species. These biozones have since been redefined following the repositioning of the base of the Tournaisian, and the zonation has been refined and extended to encompass the entire Mississippian (e.g. Clayton *et al.* 1977; Owens *et al.* 1977; Clayton *et al.* 1978; Clayton 1985; Higgs *et al.* 1988). Further work on the European miospore zonation is currently underway to incorporate new data on the ranges of certain taxa and assemblages. Notable changes include the erection of sub-biozones and the renaming of assemblage zones after a single index species (Clayton *et al.* 2003).

Where referred to in the present study, the miospore zonation used is that of Clayton *et al.* (1977), and where applicable, the updated zonations of Clayton (1985) and Higgs *et al.* (1988; 1988b). The updated biozonation of Clayton *et al.* (2003) has not yet been published in full and is not widely used. Therefore, the original biozone names are used throughout this work. This scheme is still in common usage and widely referred to in palynological studies of the Mississippian. The definitions and key components of these schemes are outlined below, as well as the pending single-taxon biozone names (Clayton *et al.* 2003).

3. 4. 1 *Retispora lepidophyta – Verrucosisporites nitidus* (LN) Biozone

The base of the LN Biozone is defined by the first appearance of *Verrucosisporites nitidus* (Naumova) Playford. Also appearing at or near this level are *Tumulispora malevkensis* Naumova in litt. Kedo, *Vallatisporites verrucosus* Hacquebard and *Densosporites spitsbergensis* Playford.

Common components of the assemblage include *Retispora lepidophyta* (Kedo) Playford, *Vallatisporites pusillites* (Kedo) Dolby & Neves, *Rugospora flexuosa* (Jushko) Streel, *Indotriradites explanatus* (Luber) Playford and many taxa from the preceding biozones. *Verrucosisporites nitidus* is sparse at the base of the LN biozone but becomes more common in the higher assemblages. In the upper part of the biozone *Umbonatisporites abstrusus* (Playford) Clayton and *Retusotriletes crassus* Clayton occur. LN assemblages are typically diverse, containing many taxa from the preceding biozones as well as a group of taxa which later become common elements of the succeeding Carboniferous biozones.

The LN Biozone has been renamed the *Verrucosisporites nitidus* Biozone in the revised biozonation of Clayton *et al.* (2003).

Age of the LN Biozone

Higgs *et al.* (1988) described the LN Biozone as being "exclusively Lower Tournaisian (Lower Tn1b) in age. The upper limit of the biozone equates closely with the top of the Devonian system." The latter part of this definition is still true; however the International Union of Geological Sciences (IUGS) has more recently divided the Upper Devonian Series into two stages - the Frasnian and Famennian, and places the base of the Tournaisian

Stage at the base of the Mississippian Series (Gradstein *et al.* 2004; Heckel & Clayton 2005). This places the LN Biozone within the uppermost part of the Famennian Stage. Higgs and Streel (1984) showed that LN assemblages occur below conodont faunas of the upper *Siphonodella sulcata* (with *Protognathus kockeli*) Zone in Germany (Figure 2.1) and correlations have been drawn with Russia (Avchimovitch *et al.* 1988). Assemblages indicative of the LN Biozone have not been recorded from Belgium, but correlation with the basal 'Strunian' beds of the Calcaire de Hastière has been suggested (Higgs *et al.* 1992).

3. 4. 2 *Vallatisporites verrucosus – Retusotriletes incohatus* (VI) Biozone

The base of the VI Biozone is marked by the disappearance of a distinctive group of taxa including *Retispora lepidophyta*, *Vallatisporites pusillites*, *Rugospora flexuosa*, *Diducites versabilis* (Kedo) emend Van Veen, *Diducites plicabilis* Van Veen, *Crassispora catenata* Higgs and *Velamisporites caperatus* Higgs.

The extinction of the above species marks a very significant change in the microfloral succession. Basal VI Biozonal assemblages are very restricted in composition compared to assemblages from the preceding LN Biozone and are usually dominated by simple laevigate forms such as *Retusotriletes incohatus* Naumova emend Streel and *Punctatisporites irrasus* Hacquebard. Many species from the underlying biozone are also characteristic of the basal VI, for example, *Vallatisporites verrucosus*, *Verrucosisporites nitidus*, *Verrucosisporites scurrus* (Naumova) McGregor & Camfield, *Indotriradites explanatus*, *Spelaeotriletes crustatus* Higgs, *Tumulispora malevkensis*, *Raistrickia variabilis* Dolby & Neves and *Latosporites* sp.

Just above the base of the VI Biozone a number of species appear for the first time. These include *Cyrtospora cristifera* (Luber) Van der Zwan, *Tumulispora triangularis* Hughes and Playford, *Spelaeotriletes obtusus* Higgs, *Corystisporites costatus* Higgs *et al.*, *Spelaeotriletes resolutus* Higgs and *Auroraspora corporiga* Higgs *et al.* At a slightly higher level the species *Raistrickia corynoges* Sullivan, *Crassispora maculosa* (Knox) Sullivan, *Geminospora spongiata* Higgs *et al.* and *Knoxisporites triangularis* Higgs *et al.* appear.

In the new updated miospore biozonation Clayton *et al.* (2003) renamed the VI Biozone the *Cyrtospora cristifera* Biozone.

Age of the VI Biozone

The base of the VI Biozone approximates to the base of the Carboniferous System (Clayton et al 1974), and the bases of the Courceyan (George *et al.* 1976) and Hastarian Regional Substages in the British Isles and Belgium respectively. Miospore assemblages from Germany show that the VI Biozone is associated with the *Siphonodella sulcata* Conodont Zone and the *Acutimitoceras prorsum* goniatite fauna (Higgs & Streel 1984). VI Biozone assemblages have been recorded from the basal part of the Hastière Formation in the Namur Synclinorium of Belgium (Higgs *et al.* 1992). Diagnostic conodonts are absent from these beds, but the base of the overlying HD is certainly no younger than the *Siphonodella sandbergi* Conodont Zone (of Sandberg *et al.* 1978) and probably lies within this zone or the underlying *Siphonodella duplicata* Zone.

3. 4. 3 *Cristatisporites hibernicus – Umbonatisporites distinctus* (HD) Biozone

Higgs *et al.* (1988) defined the base of the HD Biozone on the first appearances of the species *Cristatisporites hibernicus* (Higgs) Higgs and *Umbonatisporites distinctus* (Clayton). However, in the Namur Synclinorium of Belgium, *Umbonatisporites distinctus* is absent from the HD assemblages in the basal part of the Hastière Formation and appears later than *Cristatisporites hibernicus* (Higgs *et al.* 1992). The authors suggest that the base of the HD Biozone be defined on the first appearance of *Cristatisporites hibernicus* and that *Umbonatisporites distinctus* is a useful marker for the middle part of the biozone. Other stratigraphically useful taxa appearing at the base of the HD Biozone include *Schopfites delicatus* Higgs, *Baculatisporites fusticulus* Sullivan and *Neoraistrickia cymosa* Higgs.

Most of the species present in the VI Biozone persist into the HD Biozone, most commonly *Verrucosisporites nitidus*, *Auroraspora corporiga*, *Raistrickia corynoges*, *Retusotriletes incohatus*, *Crassispora maculosa*, *Corbulispora cancellata* (Waltz) Bharadwaj & Verkatachala, *Convolutispora caliginosa* Higgs *et al.*, *Convolutispora major* (Kedo) Turnau, *Dictyotriletes trivialis* Naumova in litt. Kedo, *Knoxisporites literatus*

(Waltz) Playford and *Knoxisporites triangularis*. Less commonly occurring taxa include *Cyrtospora cristifera*, *Neoraistrickia cymosa* Higgs *et al.* and *Tumulispora* spp.

The HD Biozone has been renamed the *Cristatisporites hibernicus* Biozone in the revised scheme of Clayton *et al.* (2003).

Age of the HD Biozone

HD biozonal assemblages have been recorded from the lower part of the *Siphonodella crenulata* Conodont Zone in Germany (Higgs & Streel 1984) and the *Siphonodella sandbergi* and lower part of the *Siphonodella crenulata* Zone in the Namur Synclinorium of Belgium (Higgs *et al.* 1992). This places the assemblage within the lower and middle parts of the Hastarian Stage.

3. 4. 4 *Spelaeotriletes balteatus – Rugospora polyptycha* (BP) Biozone

The base of the BP Biozone is defined by the first appearance of *Spelaeotriletes balteatus* (Playford) Higgs. Other diagnostic species appearing at or close to the base of the biozone are *Tumulispora tuberosus* Sullivan and *Vallatisporites vallatus* Hacquebard. *Vallatisporites verrucosus* reappears in the base of this biozone after an absence in the underlying HD Biozone. *Spelaeotriletes cabotii* Utting has its first appearance in the upper part of the BP Biozone (Brittain & Higgs 2007). Brittain & Higgs (2007) suggest that, with further study, this species could form the basis of a new subzone.

The majority of the species present in the HD Biozone persist into the BP Biozone. *Rugospora polyptycha* Neves & Ioannides first appears infrequently in the HD Biozone. However, it is a characteristic element of the BP Biozone. *Spelaeotriletes obtusus* and *Spelaeotriletes resolutus* disappear near the base of the overlying PC Biozone.

The BP Biozone has been renamed the *Spelaeotriletes balteatus* Biozone in the revised miospore biozonation of Clayton *et al.* (2003)

Age of the BP Biozone

The BP Biozone is considered to be mid Tournaisian in age. In Belgium it is associated with the higher part of the lower *Siphonodella crenulata* Zone and lower part of the upper *Siphonodella crenulata* Zone (Higgs *et al.* 1992). In Ireland the BP Biozone has been correlated with the *Polygnathus spicatus* Biozone (Higgs *et al.* 1988; Brittain & Higgs 2007) (Figure 2.1).

3. 4. 5 *Spelaeotriletes pretiosus – Raistrickia clavata* (PC)

The base of the PC Biozone is defined by the first appearance of *Spelaeotriletes pretiosus* (Playford) Neves & Belt. Other diagnostic species appearing at or close to the base of the biozone include *Raistrickia clavata* Hacquebard emend Playford, *Raistrickia condylosa* Higgs, *Kraeuselisporites mitratus* Higgs, *Granulatisporites microgranifer* Ibrahim and *Vallatisporites microspinosus* Higgs *et al.*

Spelaeotriletes pretiosus is relatively uncommon in the lower part of its range and becomes more common higher in the biozone. Many typical BP taxa are carried over from the preceding zone, most commonly *Spelaeotriletes balteatus*, *Vallatisporites vallatus*, *Vallatisporites verrucosus*, *Rugospora polyptycha*, *Spinozonotriletes uncatus* Hacquebard, *Auroraspora macra* Sullivan, *Densosporites spitsbergensis* Playford, *Retusotriletes crassus*, *Retusotriletes incohatus*, *Plicatispora scolecophora* (Neves & Ioannides) Higgs *et al.* and *Discernisporites sullivani* Higgs & Clayton.

A few species appear just above the base of the PC Biozone. These include *Colatisporites decorus* (Bharadwaj & Venkatchala) Williams, *Apiculatisporites heteroconus* Clayton and *Spelaeotriletes galearis* Brittain & Higgs.

The uppermost part of the PC Biozone is distinguished by the first appearance of a group of sparse and infrequently occurring species including *Prolycospora rugulosa*, (Butterworth & Spinner) Turnau, *Anaplanisporites baccatus* (Hoffmeister *et al.*) Smith & Butterworth, *Anaplanisporites centrosus* Higgs *et al.*, *Crassispora trychera* Neves & Ioannides and *Colatisporites denticulatus* Neville. At, or close to the base of the overlying CM Biozone, several distinctive taxa disappear including *Indotriradites explanatus*, *Cyrtospora cristifera*, *Tumulispora malevkensis* and *Spinozonotriletes impensus* Higgs.

Clayton *et al.* (2003) renamed the PC Biozone the *Spelaeotriletes pretiosus* Biozone in their revised miospore biozonation.

Age of the PC Biozone

Conodont assemblages from Ireland suggest that the base of the PC Biozone lies within the local *Polygnathus spicatus* Biozone below the disappearance of the evolved siphonodellids (Clayton *et al.* 1978). In the lower part of the PC Biozone, the appearance of *Spelaeotriletes galearis* correlates closely with the *Polygnathus spicatus -Polygnathus inornatus* Zonal boundary (Brittain & Higgs 2007). This places the base of the biozone within the late Middle Tournaisian. The base of the overlying CM Biozone is suggested to occur within the Upper Tournaisian (Clayton *et al.* 1978; Higgs *et al.* 1988b) in the *Pseudopolygnathus multistriatus* Zone (Higgs *et al.* 1988). In Belgium the base of the PC Biozone occurs within the upper *Siphonodella crenulata* Zone (Higgs *et al.* 1992).

3. 4. 6 *Schopfites claviger – Auroraspora macra* (CM) Biozone

The base of the CM Biozone is marked by the first appearance of *Schopfites claviger* Sullivan emend Higgs *et al.*

The following association characterises the CM Biozone; *Anaplanisporites baccatus*, *Auroraspora macra*, *Colatisporites decorus*, *Colatisporites denticulatus*, *Crassispora trychera*, *Baculatisporites fusticulus*, *Schopfites claviger*, *Tumulispora triangularis*, *Plicatispora scolecophora*, *Raistrickia corynoges* and *Retusotriletes incohatus*. The upper part of the biozone is characterised by the appearance of large coarsely ornamented forms of *Convolutispora* such as *Convolutispora circumvallata* Clayton, common *Acanthotriletes* cf. *A. macrogaleatus* Phillips and Clayton and rare occurrences of *Radiizonates mirabilis* Clayton, *Anapiculatisporites hystricosus* Playford and *Acanthotriletes hacquebardi* Playford (Higgs *et al.* 1988; Stephenson *et al.* 2004). Stephenson *et al.* (2004) noted this appearance of *Acanthotriletes* cf. *A. macrogaleatus* in the upper part of the CM Biozone and proposed the miospore/ostracod *Acanthotriletes* cf. *A. macrogaleatus-sulcella affiliata* Assemblage for the upper CM to the base of the Pu.

The CM Biozone is distinguished from the overlying Pu Biozone by the absence of *Lycospora pusilla* (Ibrahim) Somers.

The CM Biozone has been renamed the *Schopfites claviger* Biozone by Clayton *et al.* (2003).

Age of the CM Biozone

The CM Biozone is late Tournaisian in age (Higgs *et al.* 1988). Throughout Ireland the base of the biozone is associated with the *Polygnathus mehli* Conodont Zone. The base of the overlying Pu biozone is less well constrained, but has been suggested just below the base of the Viséan, very close to the Tournaisian – Viséan boundary (Phillips and Clayton 1980).

3. 4. 7 *Lycospora pusilla* (Pu) Biozone

The base of the Pu Biozone is marked by the first occurrence of the genus *Lycospora*, namely the species *Lycospora pusilla* (Ibrahim).

Lycospora pusilla first appears in small numbers just below the base of the Pu Biozone. In the past, the base of the biozone has been defined by both the first appearance of *Lycospora pusilla* (Clayton *et al.* 1978; Higgs *et al.* 1988b; Stephenson *et al.* 2004) and at the level where *Lycospora pusilla* becomes abundant or dominant within assemblages (e.g. Owens *et al.* 1977b). The first appearance of *Lycospora pusilla* is now accepted as definiting the base of the Pu, however the sudden occurrence of large numbers of *Lycospora* within the Pu Biozone may be a useful correlation horizon (Higgs *et al.* 1988b). Pu Biozonal assemblages are characterised by species first appearing in the underlying CM Biozone.

Age of the Pu Biozone

The base of the Pu Biozone has previously been correlated with the base of the Chadian Regional Substage, just below the Tournaisian - Viséan boundary (Higgs *et al.* 1988b). However, the redefinition of the base of the Viséan has been the focus of much recent discussion by the Subcommission on Carboniferous Stratigraphy (SCCS) (Devuyst *et al.*

2003; Sevastopulo *et al.* 2007; Work 2008). The base of the Chadian Substage of the Viséan has been redefined to coincide with the base of the Viséan Stage, and the base of the Viséan is now defined at the entry of the foraminifer *Eoparastaffella simplex simplex* in the lineage *E. simplex ovalis – E. simplex simplex* (Devuyst *et al.* 2003). The base of the Pu Miopore Biozone is, therefore, correlated with the upper part of the Courceyan Substage, in the uppermost Tournasian (Clayton *et al.* 2003).

In Ireland, foraminiferal and conodont studies indicate at least a late Tournaisian age for the underlying CM Biozone. The earliest recorded Pu Biozonal assemblages are of early Viséan age (Higgs *et al.* 1988).

3. 4. 8 *Knoxisporites triradiatus – Knoxisporites stephanephorus* (TS) Biozone

The base of the TS Biozone is marked by the appearance of *Knoxisporites triradiatus* Hoffmeister *et al.* and *Knoxisporites stephanephorus* Love.

The TS Biozone was introduced by Clayton (1985), and corresponds with the entrance of an assemblage comprising the two index species and *Tholisporites biannulatus* Neves, in what was previously regarded as the upper part of the Pu Biozone (Higgs *et al.* 1988b). Other taxa appearing at this level include *Tricidarisporites* spp. and *Rotaspora* spp.

TS biozonal assemblages are transitional in composition between older Pu assemblages dominated by Tournaisian taxa and younger TC assemblages dominated by new Viséan taxa (Higgs *et al.* 1988b). Densospores such as *Densosporites intermedius* Butterworth & Williams and *Densosporites pseudoannulatus* Butterworth & Williams appear in the upper part of the TS Biozone. A number of taxa ranging from the Pu Biozone disappear at the base of the overlying TC Biozone; these include *Schopfites claviger*, *Raistrickia clavata*, *Raistrickia corynoges*, *Rugospora polyptycha* and *Convolutispora circumvallata* (McLean *et al.* 2005).

The TS Biozone has been renamed the *Knoxisporites stephanephorus* Biozone by Clayton *et al.* (2003)

Age of the TS Biozone

The TS Biozone has been recognised in Northern England (Clayton *et al.* 1977) and Ireland (Higgs *et al.* 1988b). In the East of Ireland in Armagh the base of the biozone is associated with a late Arundian – early Holkerian microfauna (Higgs *et al.* 1988b; McPhilemy 1989), but is in general recognised as mid - late Arundian. The base of the overlying TC Biozone falls within the mid Holkerian Substage (Higgs *et al.* 1988b). The TS Biozone has recently been spilt into 2 biozones in the North Sea at the first appearance of *Densosporites* spp. at the Arundian – Holkerian boundary (McLean *et al.* 2005).

3. 4. 9 *Velamisporites tessellatus – Schulzospora campyloptera* (TC) Biozone

The base of the TC Biozone is marked by the appearance of the genus *Schulzospora*, commonly *Schulzospora campyloptera* (Waltz) Hoffmeister *et al.*

Other distinctive species occurring in the lower part of the biozone include *Waltzispora planiangulata* Sullivan, *Verrucosisporites baccatus* Staplin, *Crassispora aculeata* Neville, and *Velamisporites tessellatus* (Staplin) Coleman. Species of the genus *Densosporites* become notably more abundant within assemblages. An association of relatively short ranging species occurs in the upper part of the TC Biozone; these include *Tripartites distinctus* Williams, *Triquitrites marginatus* Hoffmeister *et al.*, *Cribrosporites cribellatus* Sullivan and *Potonieisporites delicatus* Playford.

The TC Biozone has been renamed the *Schulzospora campyloptera* Biozone (Clayton *et al.* 2003).

Age of the TC Biozone

The base of the TC Biozone falls within the mid Holkerian and ranges into the lower Asbian (Clayton *et al.* 1977; Higgs *et al.* 1988b; McLean *et al.* 2005)

3. 4. 10 *Raistrickia nigra – Triquitrites marginatus* (NM) Biozone

The base of the NM Biozone is marked by the first occurrence of the species *Raistrickia nigra* Love.

Several other species occur at the base of the NM including *Densosporites* cf. *D. velatus* Felix & Burbridge, *Murospora parthenopia* Neves & Ioannides, *Monilospora mutabilis* (Staplin) Clayton, *Spelaeotriletes arenaceus* Neves & Owens and *Kraeuselisporites echinatus* Owens *et al.* A group of species including *Tripartites distinctus* Williams in Neves *et al.* and *Ahrensisporites duplicatus* Neville that appeared within the upper part of the TC Biozone disappear within the lower part of the NM Biozone, as do the species *Densosporites* cf. *D. velatus* and *Monilospora mutabilis*. This level has more recently been used to divide the NM Biozone into two subzones (McLean *et al.* 2005). The uppermost part of the *Murospora parthenopia* Subzone is recognised by the disappearance of *Murospora parthenopia* and the overlying *Murospora margodentata* Subzone is marked by the first appearance of the species *Murospora margodentata* Beju.

The NM Biozone has been renamed the *Triquitrites marginatus* Biozone by Clayton *et al.* (2003).

Age of the NM Biozone

The NM Biozone corresponds to the upper part of the Asbian, with the base of the overlying VF Biozone corresponding to the Asbian – Brigantian boundary (Clayton *et al.* 1977).

3. 4. 11 *Tripartites vetustus – Rotaspora fracta* (VF) Biozone

The base of the VF Biozone is marked by the first appearance of the species *Tripartites vetustus* Schemel.

A large group of species first appear at the base of the biozone. These include *Tripartites nonguerickei* (Horst) Butterworth and Williams, *Triquitrites trivalvis* (Waltz) Potonié & Kremp, *Rotaspora fracta* (Schemel) Smith & Butterworth, *Rotaspora knoxi* Butterworth & Williams, *Savitrisporites nux* (Butterworth & Williams) Smith & Butterworth, *Crassispora maculosa* (Knox) Sullivan, *Spencerisporites radiatus* (Ibrahim) Felix & Parks and *Grandispora spinosa* Hoffmeister *et al.* These are all fairly long-ranging species which extend into the succeeding biozone. Species disappearing in the VF

Biozone include *Murospora margodentata* and *Verrucosisporites baccatus*. *Cribrosporites cribellatus* disappears at the base of the overlying NC Biozone.

The VF Biozone has been renamed the *Tripartites vetustus* Biozone by Clayton *et al.* (2003).

Age of the VF Biozone

The base of the VF Biozone corresponds to the base of the Brigantian Regional Substage (George *et al.* 1976) and the biozone encompasses most of this stage.

3. 4. 12 *Bellispores nitidus – Reticulatisporites carnosus* (NC) Biozone

The base of the NC Biozone is marked by the first appearance of the species *Cingulizonates* cf. *C. capistratus* (Hoffmeister *et al.*) Staplin & Jansonius *sensu* Smith & Butterworth. In the new revised zonation of Clayton *et al.* (2003) the biozone has been renamed the *Cingulizonates* cf. *C. capistratus* Biozone.

The NC Biozone is characterised by many species common to the underlying VF Biozone including *Raistrickia nigra*, *Tripartites vetustus*, *Tripartites trilinguis* (Horst) Potonié & Kremp, *Crassispora maculosa*, *Grandispora spinosa*, *Spelaeotriletes arenaceus* and *Kraeuselisporites echinatus*. The species *Bellispores nitidus* (Horst) Sullivan emend Smith & Butterworth also appears at the base of the NC Biozone

Owens *et al.* (2004) split the NC Biozone into two sub-biozones. The *Bellisporites nitidus* Sub-Biozone ranges into the lower part of the NC Biozone. The overlying *Verrucosisporites morulatus* Sub-Biozone is defined by the appearance of *Verrucosisporites morulatus* (Knox) Smith & Butterworth, *Ahrensisporites guerickei* Neves, *Potonieisporites elegans* (Wilson & Kosanke) Wilson & Venkatachala and rare *Crassispora kosankei* (Potonié & Kremp) Bharadwaj. The base of the overlying TK Biozone coincides with the range tops of *Reticulatisporites carnosus* (Knox) Neves, *Rotaspora fracta* and *Raistrickia nigra*.

Age of the NC Biozone

Using associated goniatite data, Clayton *et al.* (1977) placed the base of the NC Biozone within the late Brigantian and the base of the overlying TK biozone close to the Pendleian – Arnsbergian boundary. The base of the NC Biozone and *Bellisporites nitidus* Sub-Biozone has been redefined by Owens *et al.* (2004) on the basis of evidence from Northern England (e.g. Marshall & Williams 1971) and is located in the uppermost Brigantian at the base of the P2c Ammonoid Subzone. The base of the *Verrucosisporites morulatus* Sub-Biozone is placed at the Viséan – Namurian boundary (at the P2 – E1 ammonoid Sub-Zone boundary). The base of the overlying TK Biozone is placed at the E1 - E2 ammonoid Sub-Zone boundary and has been correlated with the Pendleian – Arnsbergian boundary (Owens *et al.* 1977; Owens *et al.* 2004) (Figure 2.2).

3. 4. 13 *Stenozonotriletes triangulus – Rotaspora knoxi* (TK) Biozone

The base of the TK Biozone was originally defined by the first appearances of *Punctatisporites giganteus* Neves, *Punctatisporites pseudopunctatus* Neves and *Stenozonotriletes triangulus* Neves. Since then, studies have shown many of these first appearances are localised events and of little stratigraphic value for long-distance correlation (e.g. Owens *et al.* 2002). The base of the biozone has therefore been redefined at the first appearance of *Mooreisporites trigallerus* Neves as well as *Stenozonotriletes triangulus*.

The TK Biozone and part of the overlying SO Biozone encompass the Arnsbergian Stage in the lower part of the Namurian, and as such represent an interval of major turnover within early Namurian miospore assemblages (Owens *et al.* 2004). New species appearing within the TK Biozone include *Mooreisporites fustis* Neves and *Reinschospora speciosa* (Loose) Schopf *et al.*, and the disappearance of *Tripartites trilinguis* and *Rotaspora ergonuli* (Agrali) Sullivan & Marshall is noted. The base of the overlying SO Biozone is marked by the further disappearance of many typical Viséan taxa including *Rotaspora knoxi*, *Triquitrites marginatus*, *Triquitrites trivalvis* and *Tripartites vetustus*.

The TK Biozone has been renamed the *Mooreisporites trigallerus* Biozone in the updated miospore zonal scheme of Clayton *et al.* (2003).

Age of the TK Biozone

The base of the TK Biozone is within the lower Namurian at the base of the Arnsbergian Regional Substage. The base of the biozone can be correlated to the E1 - E2 goniatite zonal boundary (Clayton *et al.* 1977; Owens *et al.* 2004) and the upper part has been correlated with the mid E2b zone (Owens & Burgess 1965).

3. 4. 14 *Lycospora subtriquetra – Kraeuselisporites ornatus* (SO) Biozone

The base of the SO Biozone is marked by the first appearance of the following species; *Lycospora subtriquetra* (Luber) Potonié & Kremp, *Kraeuselisporites ornatus* *Apiculatisporis variocorneus* Sullivan and *Camptotriletes superbus* Neves.

In the revised miospore biozonal scheme of Clayton *et al.* (2003) the SO Biozone has been renamed the *Lycospora subtriquetra* Biozone. The biozone spans the mid Carboniferous boundary and has been split into two sub-biozones around this point – the *Apiculatisporis variocorneus* Sub-Biozone and the *Cirratriradites rarus* Sub-Biozone (Owens *et al.* 2004). The boundary between the two is based on the frequent occurrence of *Cirratriradites rarus* (Ibrahim) Schopf *et al.*, and the range tops of *Schulzospora campyloptera*, *Crassispora maculosa*, *Microreticulatisporites concavus* Butterworth & Williams and *Bellispores nitidus*.

Age of the SO Biozone

The SO Biozone ranges from the middle part of the Arnsbergian Regional Substage to the upper part of the Alportian Regional Substage (mid E2b to base of R1 goniatite zones) as determined by Clayton *et al.* (1977), and spans the Mississippian – Pennsylvanian boundary. The appearance of the conodont *Declinognathodus noduliferus* is used to define the Mississippian - Pennsylvanian boundary (Lane *et al.* 1999), but no definitive change within palynofloral assemblages is observed at this level. However, the boundary between the *Apiculatisporis variocorneus* and *Cirratriradites rarus* sub-biozones correlates with the Arnsbergian – Chokierian boundary, which occurs just below the Mississippian – Pennsylvanian boundary. This may prove a useful level for recognising the mid Carboniferous boundary in non-marine sections.

3. 5 PREVIOUS PALYNOLOGICAL STUDIES OF THE MISSISSIPPIAN OF THE USA

Previous palynological studies have been somewhat limited in scope and are mostly centred on areas outside of the Mississippi Valley, where oil and gas have generated commercial interest, and where palaeoenvironments were better suited to preserving organic material. Very few studies have been published on the Mississippian type area, and no comprehensive miospore zonation has been proposed for the Mississippian of the Midwest USA. However, European affinities have been suggested for some of the miospore assemblages outside of the Mississippi Valley and tentative palynological correlations with Europe have been published. The ranges of previous palynological studies on the Mississippian of the USA are shown in Figure 3.3.

Hoffmeister *et al.* (1955) described miospores from the Chesterian (Upper Mississippian) Hardinsburg Formation of Illinois and Kentucky, and compared these assemblages with those described from Tournaisian - Viséan coals of the former Soviet Union. They identified diverse miospore assemblages dominated by *Lycospora*, together with abundant *Punctatisporites*, *Densosporites*, *Granulatisporites* and *Schulzospora*.

Winslow (1962) investigated miospore assemblages from the Upper Devonian and Lower Mississippian of Ohio. Formations sampled include the Olentangy Shale, Ohio Shale, Chagrin Shale, Bedford Shale, Berea Sandstone, Sunbury Shale, Cuyahoga Formation, Black Hand Formation and Logan Formation. Late Devonian assemblages are characterised by common *Retispora lepidophyta* and are typically of European LN Biozonal assemblages. This taxa is absent in earliest Mississippian assemblages, which closely resemble VI to PC biozonal assemblages (Winslow 1962).

Felix and Burbridge (1967) described and named miospores from the Springer Formation of Southern Oklahoma. Commonly recorded taxa include *Granulatisporites*, *Ibrahimispores*, *Leiotriletes*, *Punctatisporites*, *Mooreisporites*, *Spinozonotriletes* and *Waltzispora*. Assemblages were dated as latest Mississippian - early Pennsylvanian.

Sandberg *et al.* (1972) compared conodonts and spore assemblages across the Devonian – Carboniferous boundary in both central USA and Europe. In the Mississippi Valley samples were taken from the Saverton Shale, Louisiana Limestone, Glen Park Formation

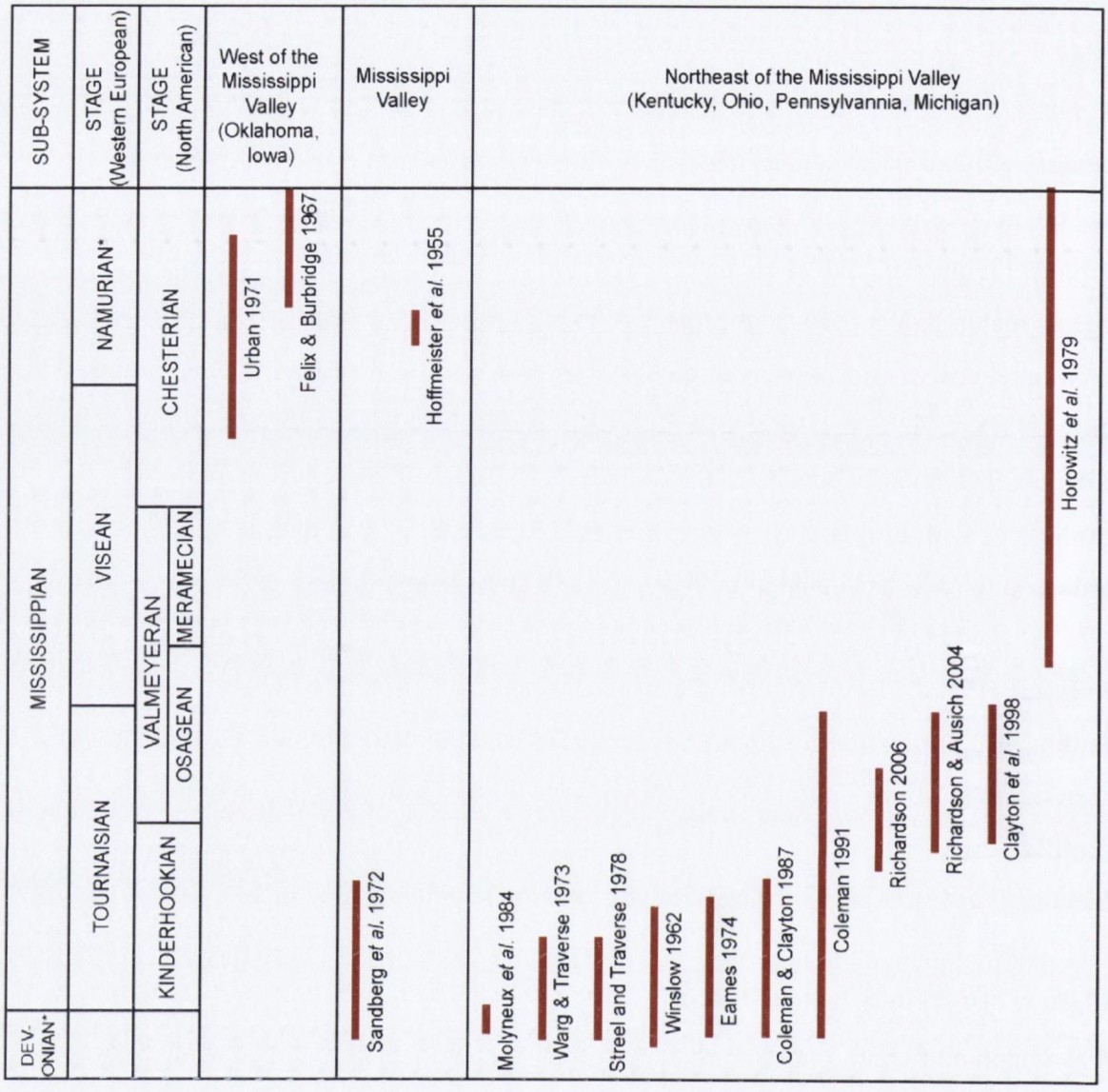


Figure 3.3 Stratigraphic ranges of previous palynological studies of the Mississippian of the USA

and the Hannibal Shale. Conodonts were more prevalent than miospores due to the predominantly limestone facies in this area, however, late Devonian miospore assemblages dominated by *Retispora lepidophyta* were recognised from the Saverton Shale.

Warg and Traverse (1973) studied Devonian – Carboniferous miospores from the Catskill and Pocono formations of Central Pennsylvania. *Retispora lepidophyta* was commonly recorded at the base of the succession and decreased in abundance throughout. The succession is therefore interpreted as a transitional Devonian-Carboniferous boundary section.

Eames (1974) reported miospores from the Bedford Shale, Berea Sandstone and Cuyahoga Group of northeastern Ohio. Assemblages from the Bedford and Berea comprise similar taxa to those recorded from the Bedford Shale of Ohio by Winslow (1962) including *Retispora lepidophyta*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus*. *Retispora lepidophyta* was notably absent from the overlying Cuyahoga Group.

Streel and Traverse (1978) identified two miospore assemblages from the Devonian – Mississippian boundary near Horseshoe Curve, Pennsylvania. The lower of the two is dominated by *Retispora lepidophyta* and is typical of European Late Devonian assemblages. The upper is dominated by *Indotriradites explanatus* and is typical of European earliest Mississippian assemblages.

Horowitz *et al.* (1979) provided an in-depth biostratigraphical study of the upper Osagean to the base of the Pennsylvanian of Tennessee, and an intercontinental correlation. The palynology was studied by Neves who recognised the Viséan (TC Biozone), Namurian A (NC Biozone) and Namurian B.

Molyneux *et al.* (1984) assigned miospore assemblages from the Bedford Shale and the overlying Berea Sandstone at Sunbury, Ohio, to the western European LN Biozone of Higgs *et al.* (1988). On this basis, the authors suggested that both the Bedford Shale and Berea Sandstone are of Late Devonian age.

Coleman and Clayton (1987) studied miospore assemblages from Morehead, Kentucky and assigned these to the western European LN, VI, and PC biozones (Higgs *et al.* 1988). The HP and BP Biozones were not recognised from Kentucky. In her thesis, Coleman (1991) examined Upper Devonian – Lower Mississippian miospore assemblages from Kentucky and Indiana. Assemblages from Kentucky were again assigned to the LN, VI and PC Biozones. Assemblages from Indiana were unlike any previously published earliest Mississippian assemblages and Coleman (1991) noted that correlation with Western Europe was not possible.

Clayton *et al.* (1998) described miospores from the Cuyahoga and Logan formations of northeastern Ohio. Both formations yield assemblages which can be assigned to the western European PC Biozone. The Cuyahoga is placed in the latest Kinderhookian and the Logan Formation is earliest Osagean.

Richardson and Ausich (2004) reported miospores from the Borden Delta (Osagean) from Kentucky and Indiana and correlated them with the PC and CM biozones. *Lycospora pusilla* was also recognised from south central Indiana; however, the authors regard this occurrence an effect of floral provincialism in North America during the Early Mississippian. More recently, Richardson (2006) described an assemblage from the Coldwater Shale in Michigan which he assigned to the European BP Biozone (Higgs *et al.* 1988), a palynostratigraphic unit previously unrecognized in the USA. Richardson (2006) also reported PC Zonal assemblages from the overlying Marshall Sandstone.

CHAPTER 4

SAMPLES AND PREPARATION METHODS

4. 1 SAMPLES

Samples were collected from outcrops and cores during fieldwork undertaken in October 2005, July 2006 and October 2006. Core material was also collected and shipped by the Missouri Department of Natural Resources, Division of Geology and Land Survey. The location of the sampled outcrops and cores is shown in Figure 4.1.

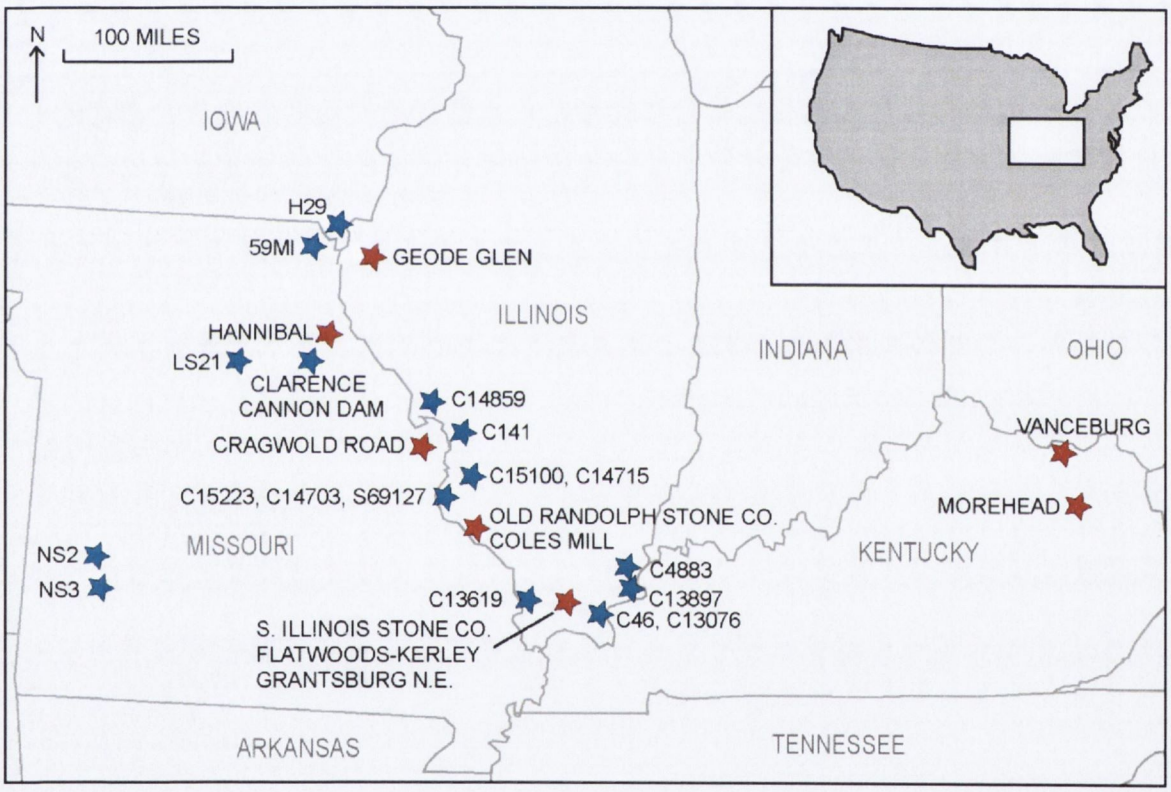


Figure 4.1 Sample localities. Red stars indicate outcrops, blue stars indicate cores

A total of 212 samples were collected, 115 of these came from outcrops and 97 from cores. Twenty-nine of these samples were found to have a very high proportion of carbonate and therefore unsuitable for palynology, and are not included in this report. The remaining 183 samples were suitable for palynological analysis (Figures 4.2 and 4.3). The size of the samples was approximately 50g but in the case of some cores as little as 5g was taken. Samples were processed and analysed for palynology in the Department of Geology, Trinity College Dublin. One hundred and twenty-four samples were palynologically productive and 67 were barren in terms of palynomorphs. Of the barren samples, 12 were used for palynofacies analysis. The remaining samples comprise inorganic minerals and crystals that were not removed during processing. Palynologically productive samples are

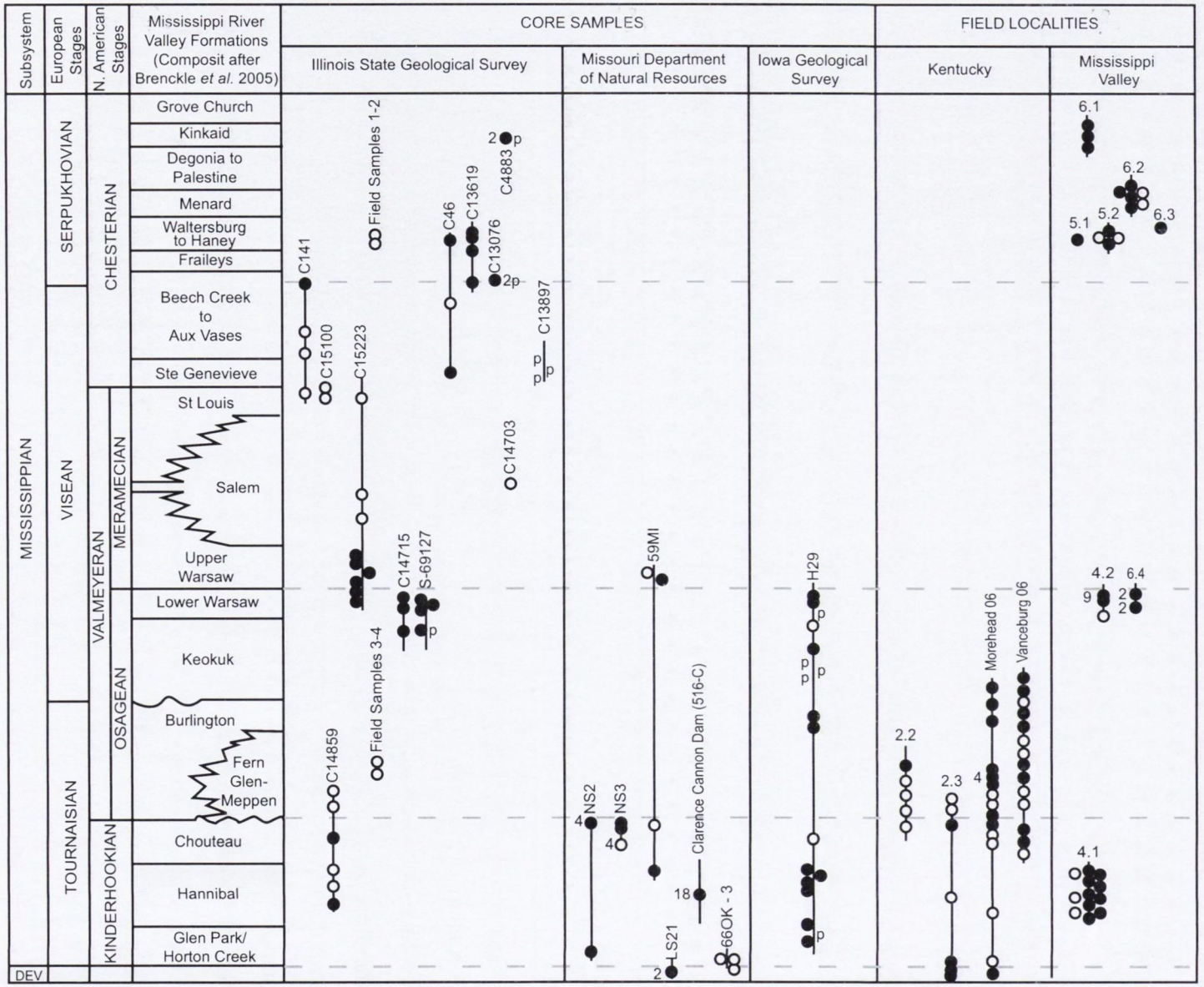


Figure 4.2 Samples collected from Kentucky and the Mississippi Valley. The following numbers refer to field localities:
Kentucky
2.2 - Milepost 135, I64; 2.3 - Exit 133, I64;
Missouri
4.1 - Highway 79, Hannibal; 6.4 - Cragwold Road, St Louis Co.;
Illinois
4.2 - Geode Glen, Warsaw, Hancock Co.; 5.1 - Old Randolph Stone Co., Randolph Co.; 5.2 - Coles Mill, Chester, Randolph Co.; 6.1 - Southern Illinois Stone Co., Johnson Co.; 6.2 - Flatwoods-Kerley Railroad, Johnson Co.; 6.3 - Grantsburg NE Railroad, Johnson Co.

KEY
- ● Productive
- O Barren
- p Palynofacies

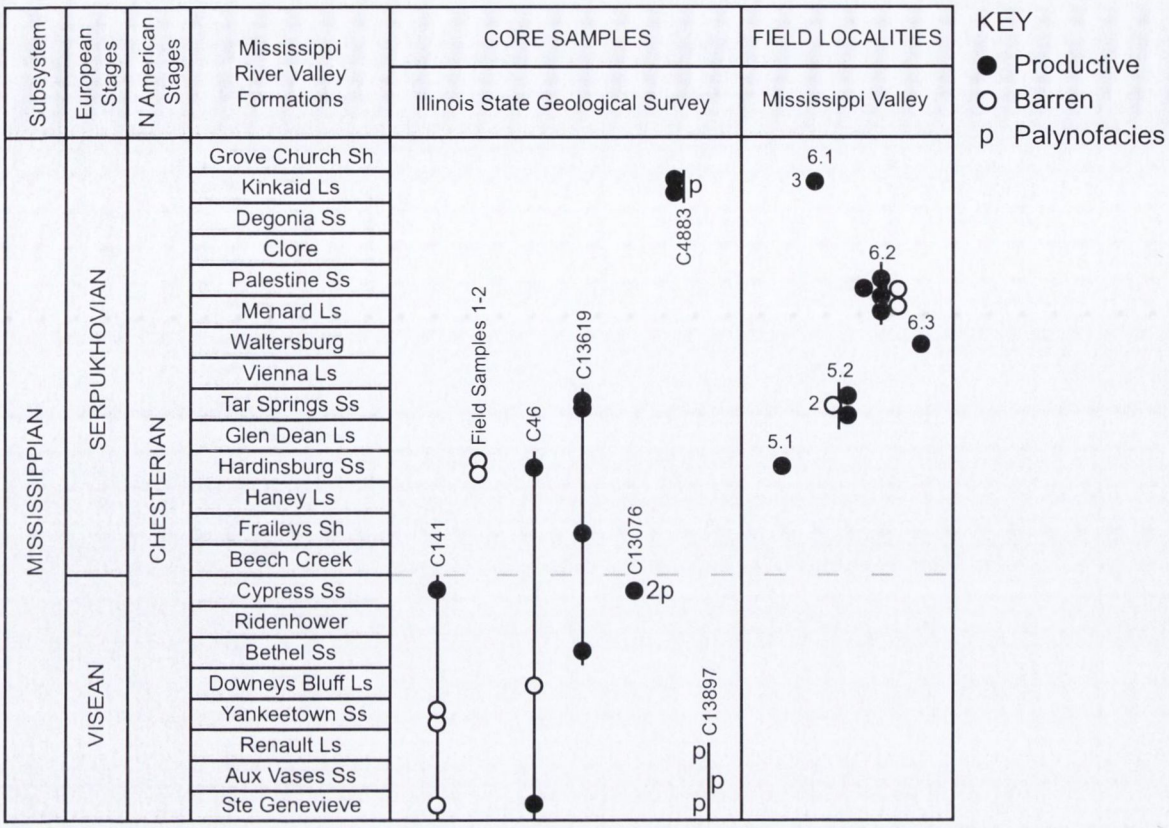


Figure 4.3 Samples collected from Chesterian sections in Kentucky and the Mississippi Valley. The following numbers refer to outcrop localities: 5.1 - Old Randolph Stone Co., Randolph Co.; 5.2 - Coles Mill, Chester, Randolph Co.; 6.1 - Southern Illinois Stone Co., Johnson Co.; 6.2 - Flatwoods-Kerley Railroad, Johnson Co.; 6.3 - Grantsburg NE Railroad, Johnson Co.

described below. Stratigraphic logs are shown in figures 4.4 – 4.28, and further sampling data are given in Appendix I.

4. 1. 1 KENTUCKY OUTCROP SAMPLES

Seven outcrops were sampled from central, east central and northeast Kentucky. The two most eastward localities are richer in grey and black shales than those from the rest of Kentucky – these are the AA highway near Vanceburg, Lewis County and Interstate 64 near Morehead, Rowan County. At Vanceburg, shales and muds are interbedded with thinner, harder more silty layers – fifteen samples were taken; of these nine were productive (Figure 4.4). At Morehead three productive samples were obtained from the upper Devonian black and grey shales of the Ohio Shale and Bedford Shale formations. Twenty seven samples were taken from the overlying Sunbury Shale and Farmers Member of the Borden Formation, eleven of these were productive. Three productive samples were taken from the Nancy Member (Figure 4.5). The five localities further to the west are rich in carbonates and were deemed unsuitable for palynological processing.

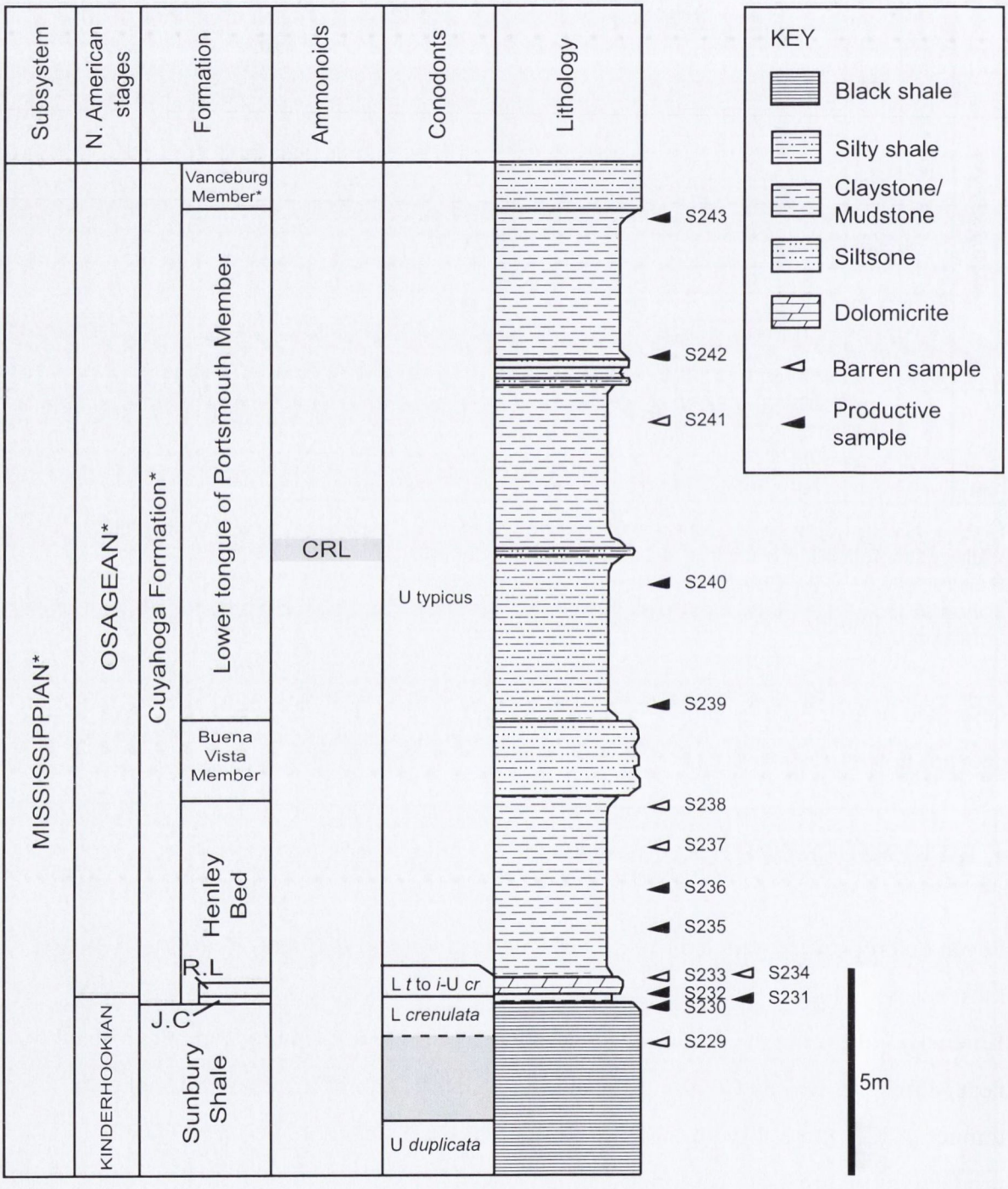


Figure 4.4 Stratigraphic log of the AA Highway Section at Brightman Cemetery, Vanceburg, Kentucky (* in part). Abbreviations are as follows: CRL - Cave Run Lake fauna, R.L - Rockford Limestone, J.C - Jacobs Chapel.

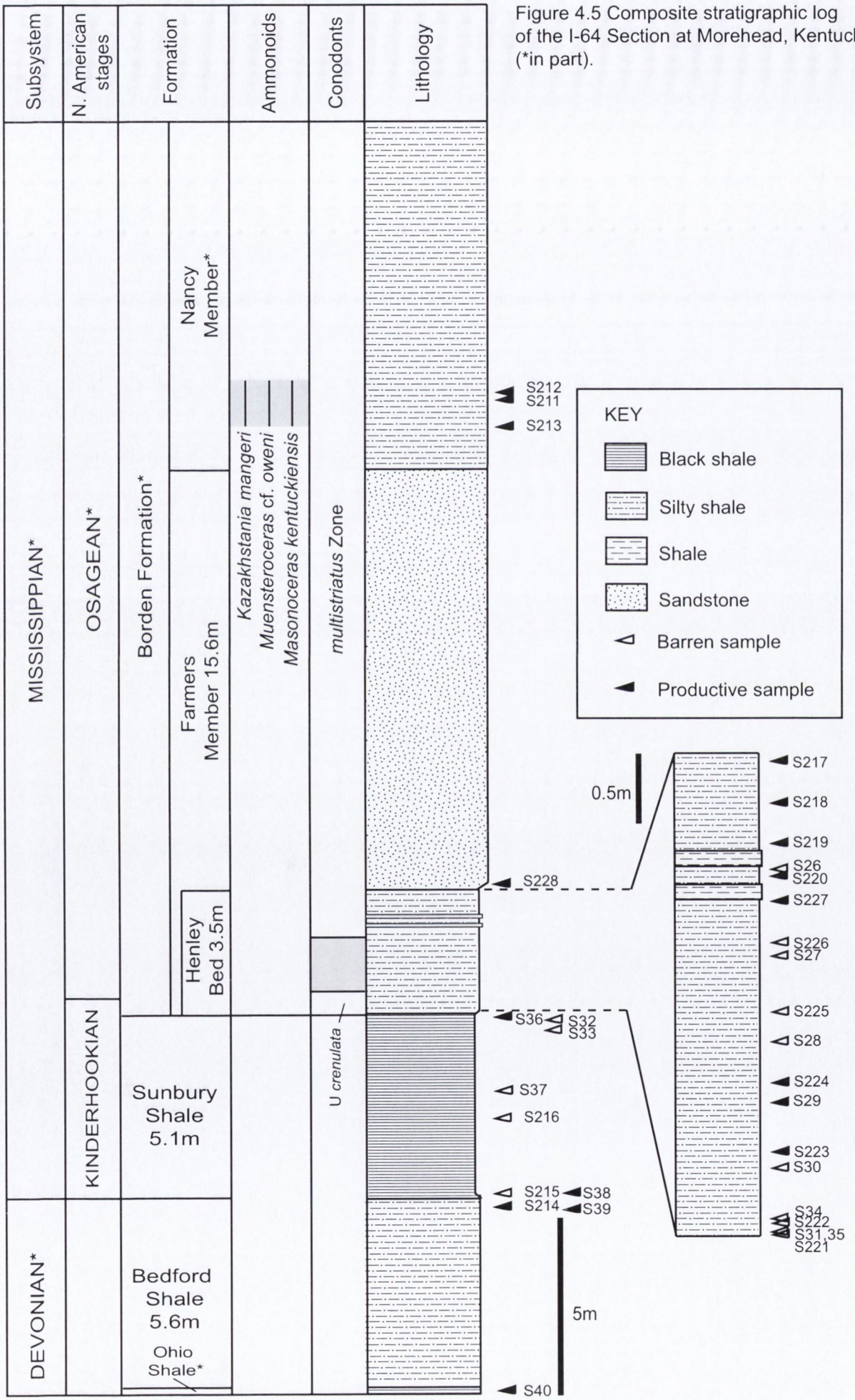


Figure 4.5 Composite stratigraphic log of the I-64 Section at Morehead, Kentucky (*in part).

4. 1. 2 MISSISSIPPI VALLEY OUTCROP SAMPLES

Eight outcrops were sampled from eastern Missouri and western Illinois in the Mississippi River Valley. Outcrops of Kinderhookian, Osagean and Meramecian age consist mainly of thick limestones or dolomitic units interbedded within thinner shaley beds. This means that sampling in the lower part of the Mississippian of the Mississippi Valley is quite patchy and sporadic. In the Kinderhookian section, thirteen samples were taken from the Hannibal Shale, at its type locality near Hannibal, Missouri (Figure 4.6). Nine of these proved productive. At the Osagean - Meramecian boundary ten samples were taken from the interbedded shales and dolomites of the Lower Warsaw at Geode Glen, Illinois (Figure 4.7). Nine of these were productive. A further four productive samples were obtained from a more seaward facies of the Lower and Upper Warsaw formations further to the south at Cragwold Road, Missouri (Figure 4.8). Shales become more widespread in the Chesterian, so a more continuous succession of samples was recovered from this interval. One sample was recovered from the Hardinsburg Sandstone at the Old Randolph Stone Company, Illinois (Figure 4.9). Four samples (two productive) were taken from the Tar Springs Sandstone at Coles Mill, Illinois (Figure 4.10). One sample was taken from the shales of the Waltersburg Formation at Grantsburg Northeast railroad cutting, Illinois (Figure 4.11) and six samples (three productive) were taken from shaley intervals within the nearby Menard and Palestine Limestones at the Flatwoods-Kerley railroad cutting (Figure 4.12). Three productive samples were taken from the Kinkaid Formation and Caseyville Formation, the youngest Mississippian rocks sampled, from the Southern Illinois Stone Company Quarry (Figure 4.13).

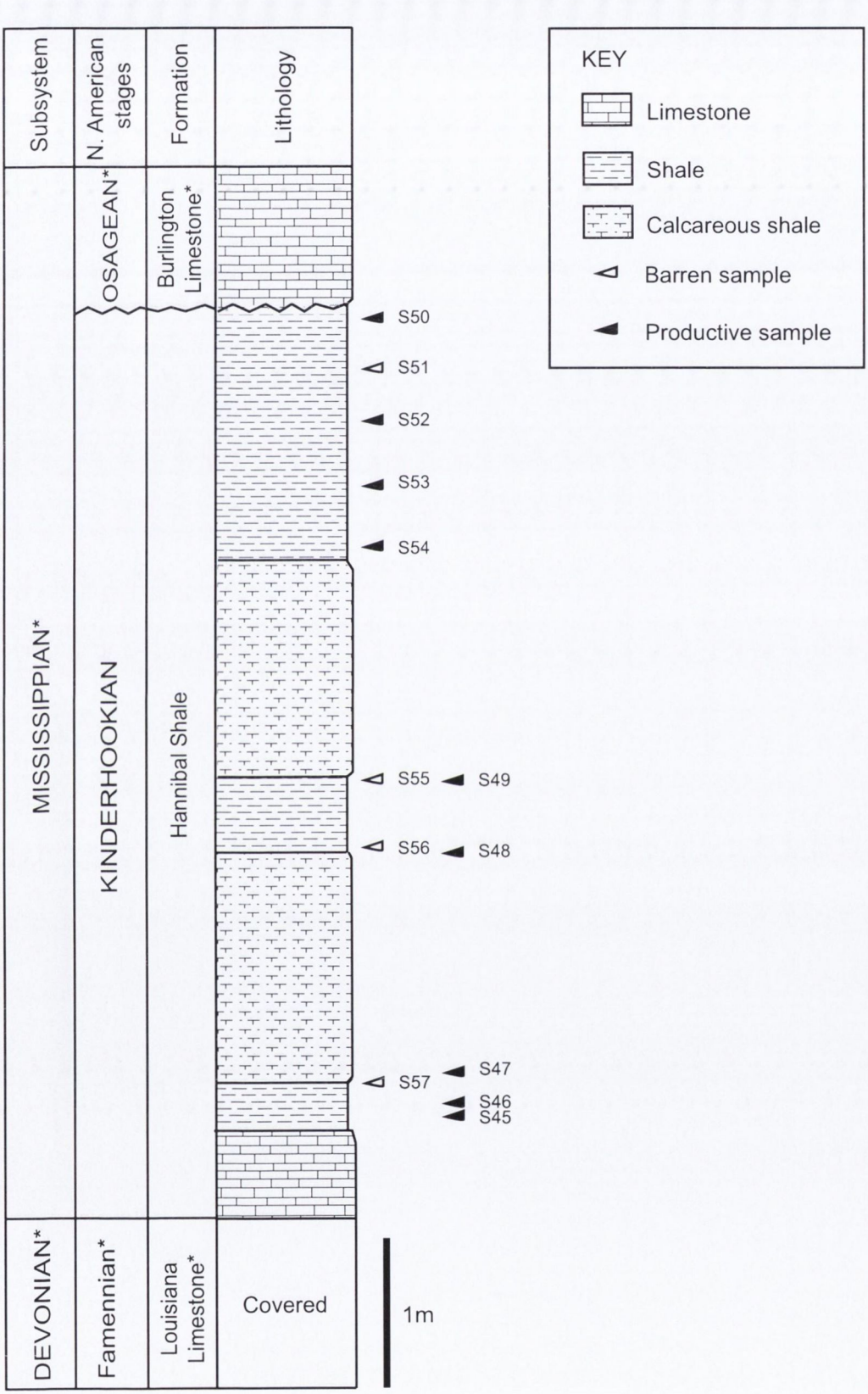


Figure 4.6 Stratigraphic log of the Hannibal section, Highway 79, Missouri (* in part).

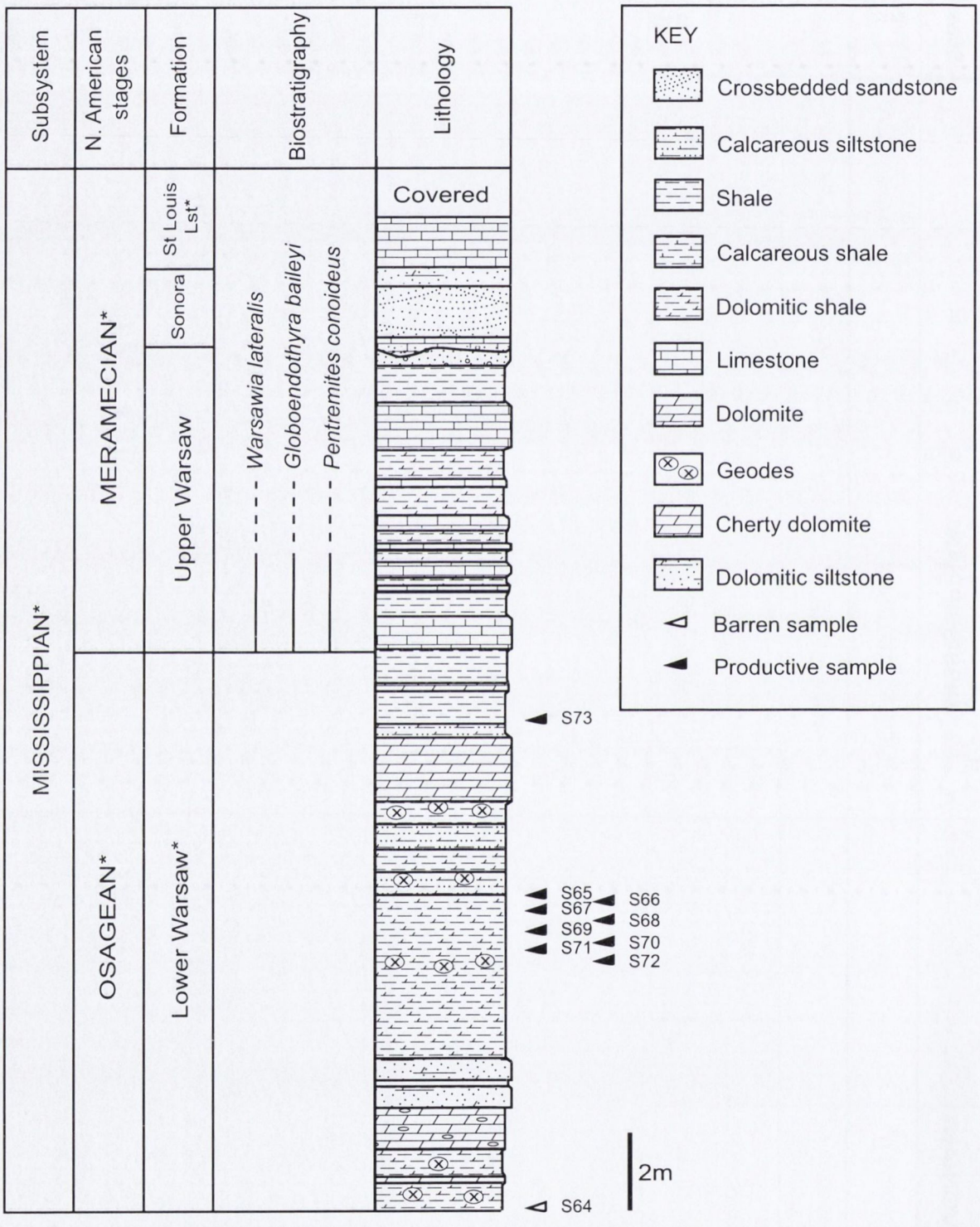


Figure 4.7 Stratigraphic log of the Geode Glen section, Illinois (* in part).

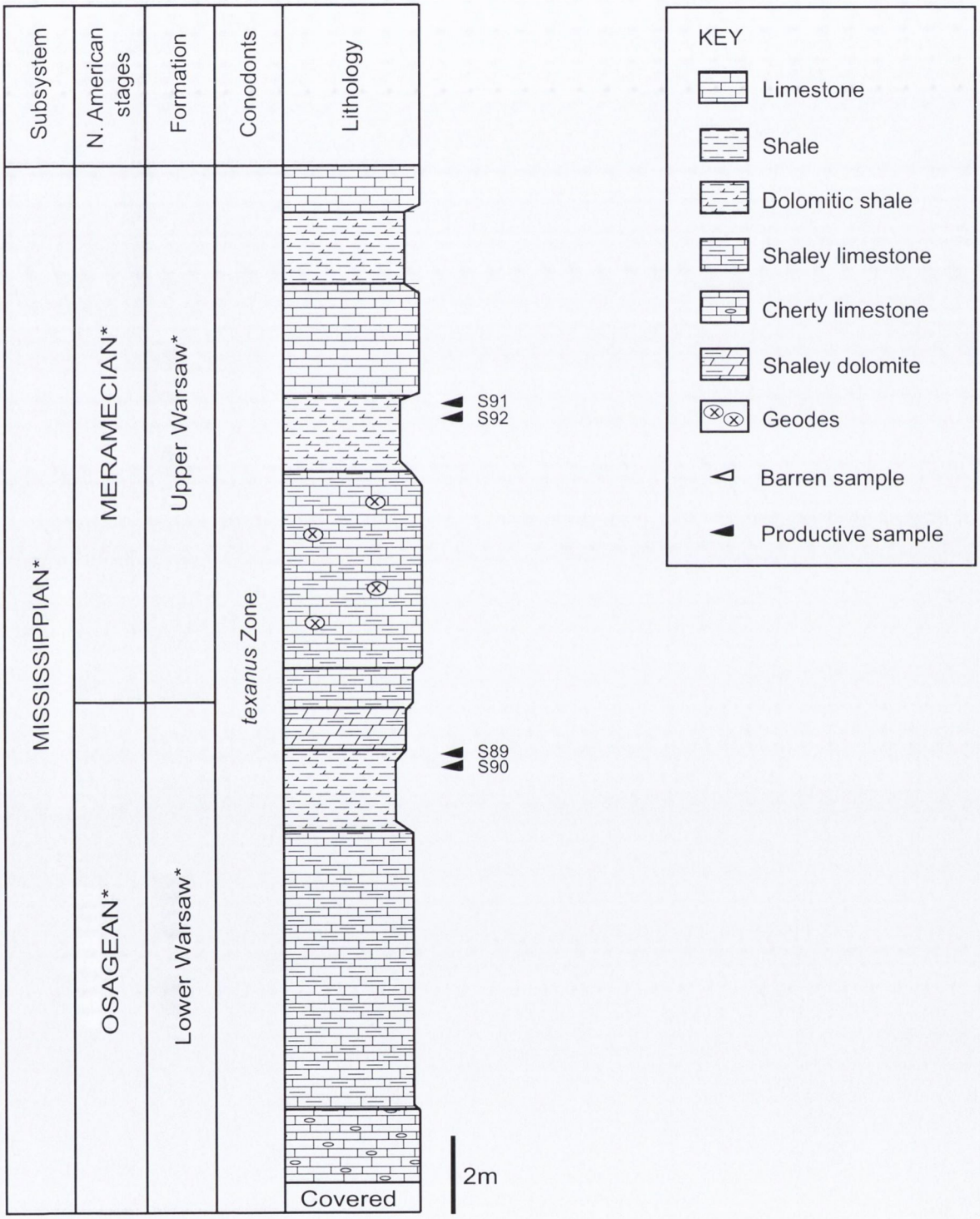


Figure 4.8 Stratigraphic log of the Cragwold Road section, Illinois (* in part).

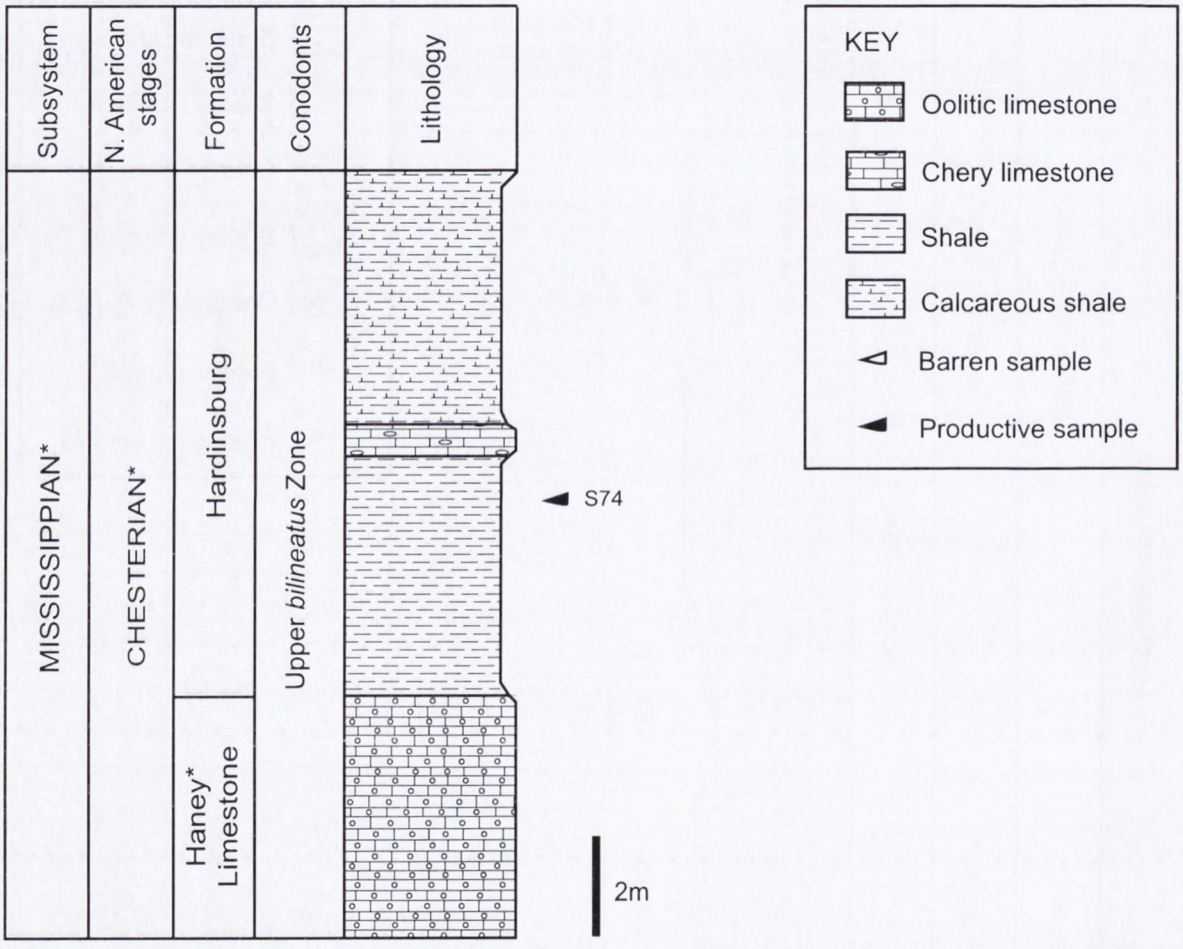


Figure 4.9 Stratigraphic log of the Old Randolph Stone Company Quarry section, Johnson County, Illinois (* in part).

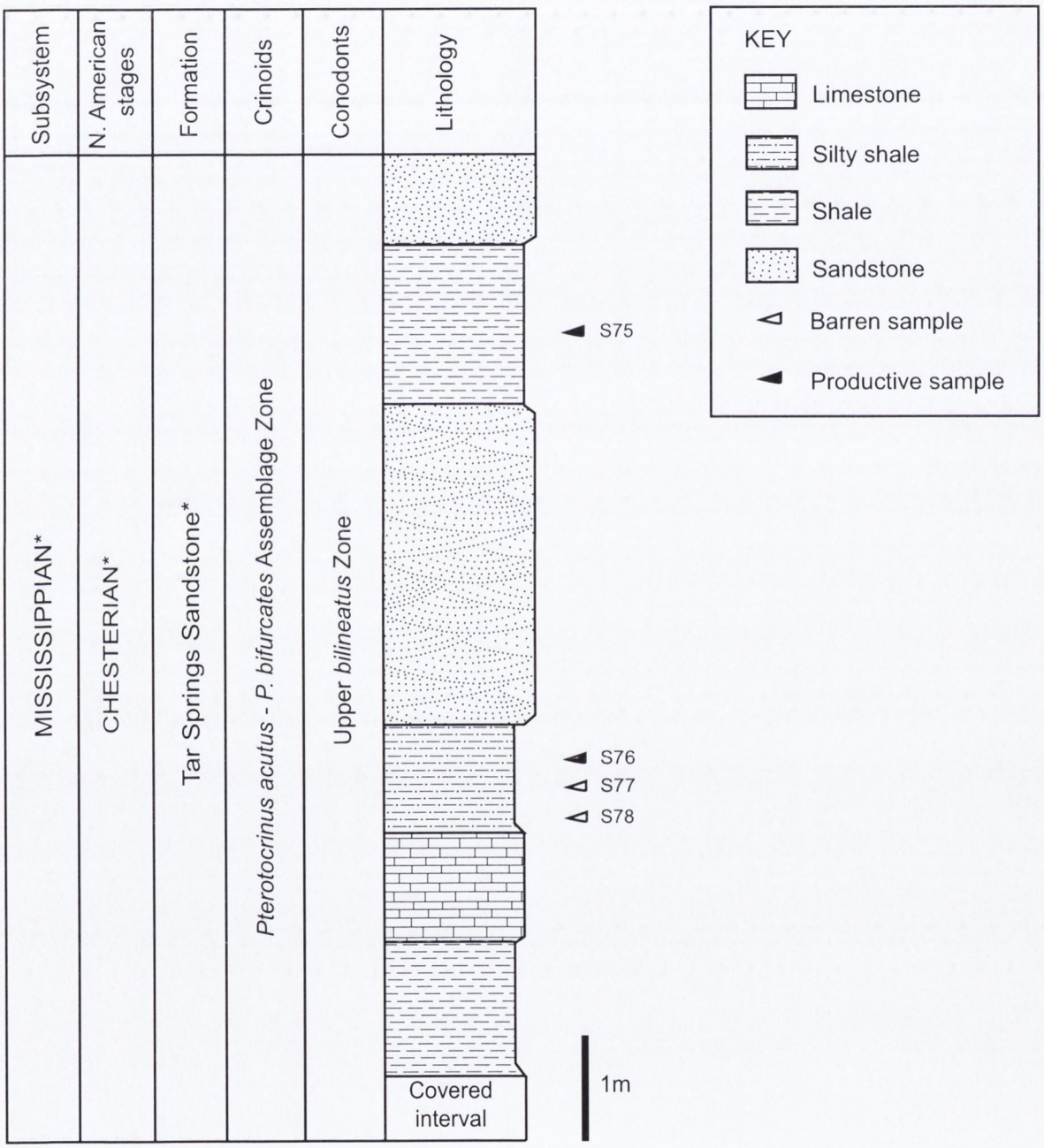


Figure 4.10 Stratigraphic log of the Coles Mill section, Chester, Randolph County, Illinois (* in part).

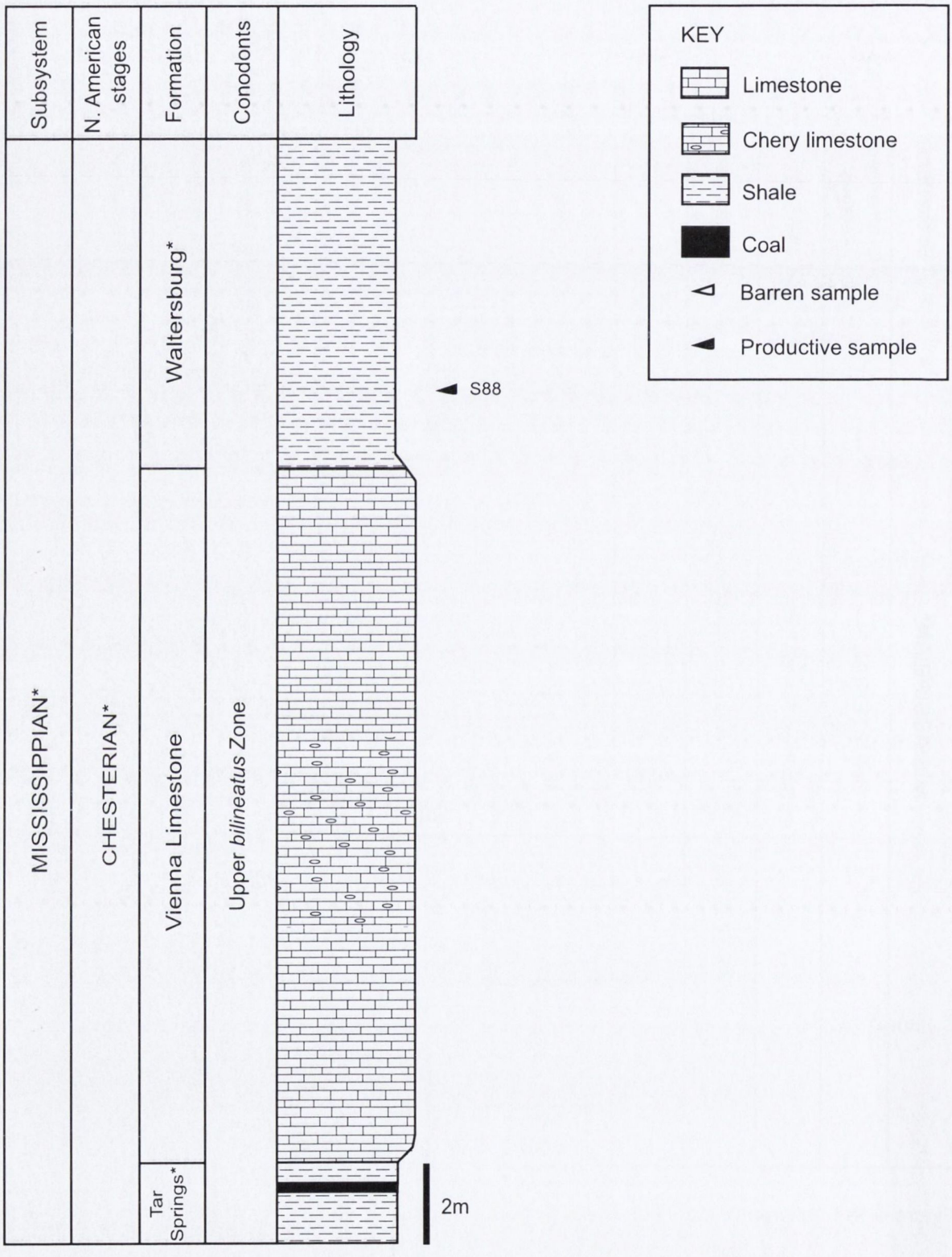


Figure 4.11 Stratigraphic log of the Grantsburg NE Railroad section, Johnson County, Illinois (* in part).

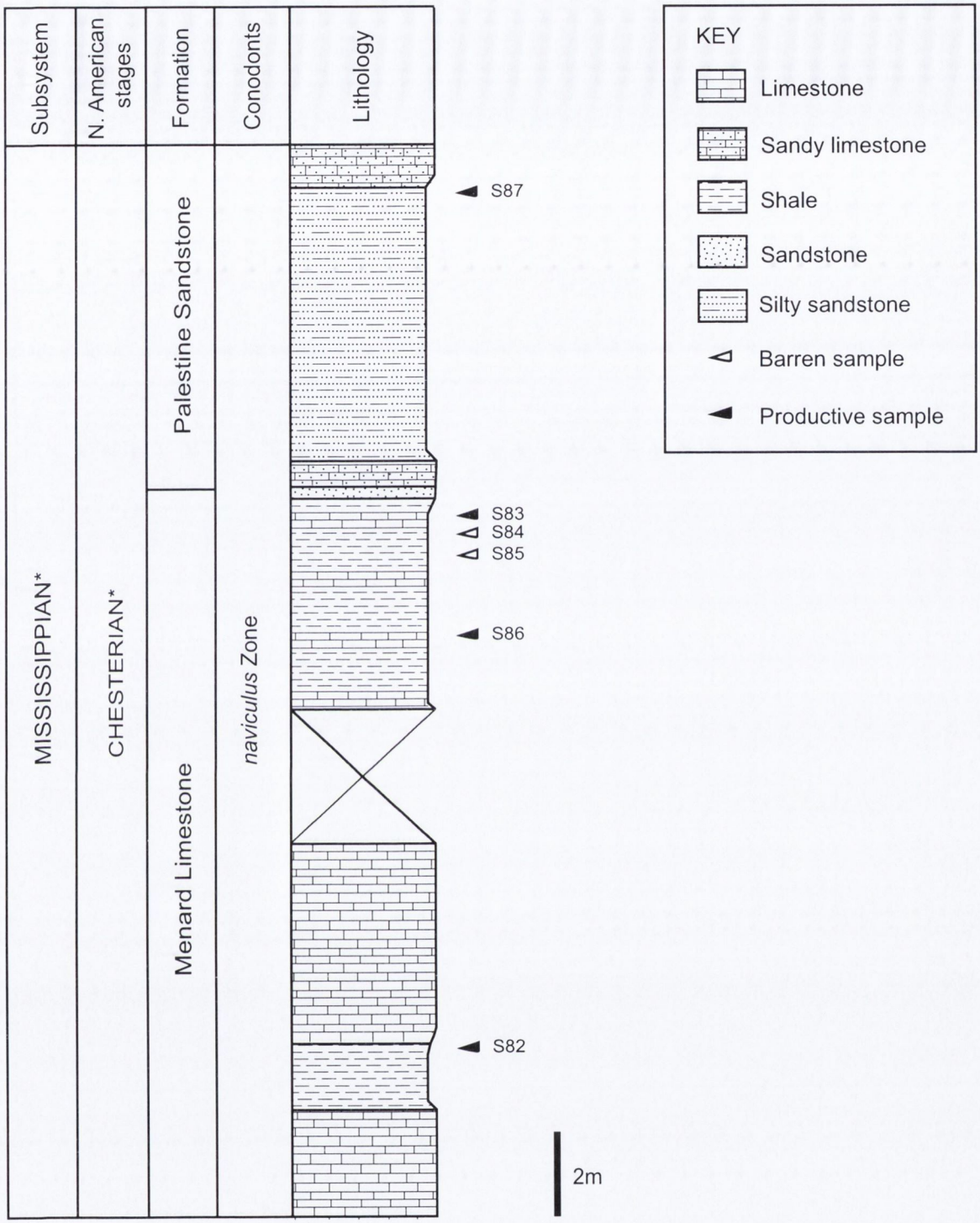


Figure 4.12 Stratigraphic log of the Flatwoods-Kerley Cemetery Railroad section, Johnson County, Illinois (* in part).

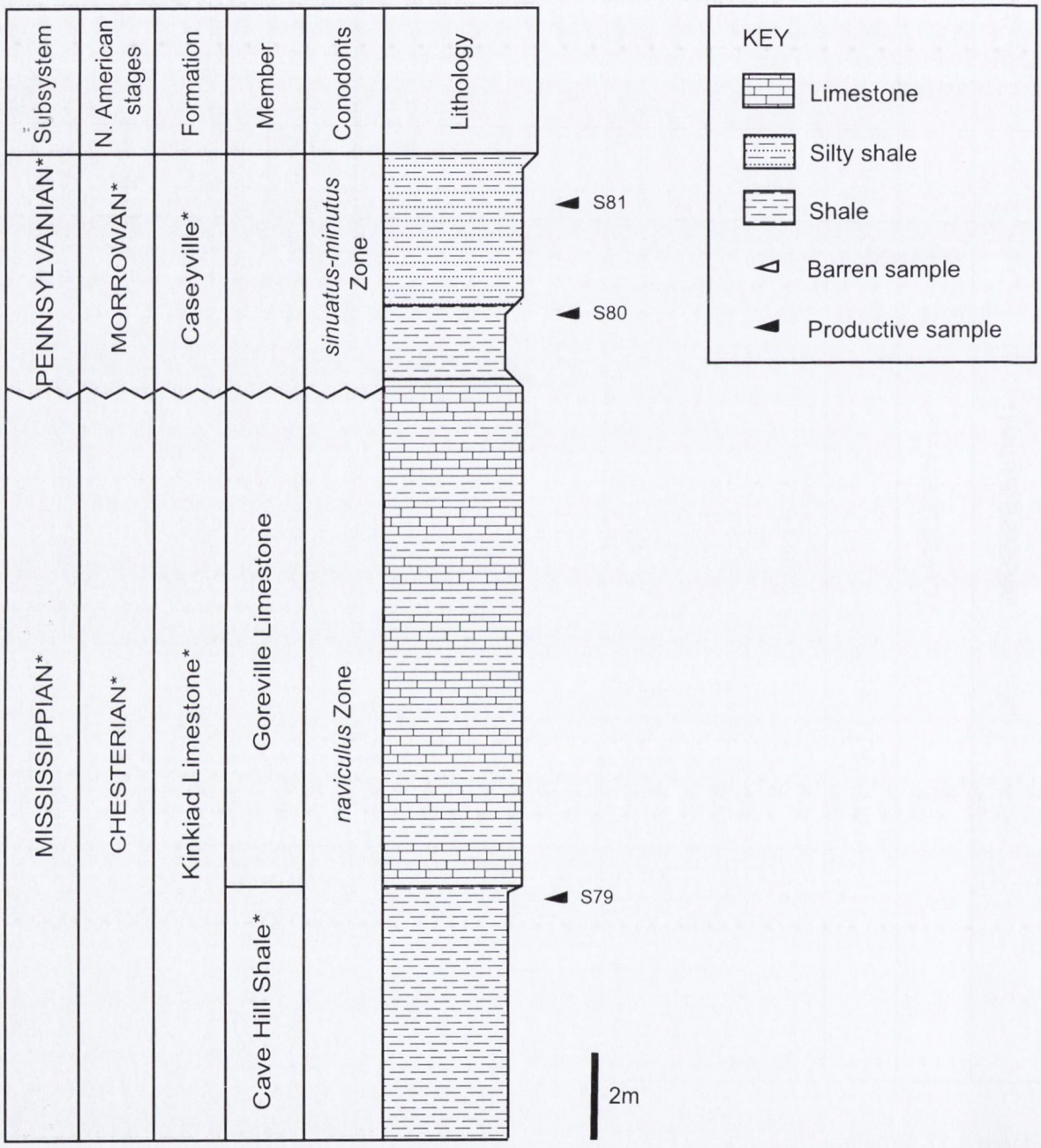


Figure 4.13 Stratigraphic log of the Southern Illinois Stone Company Quarry, Johnson County, Illinois (* in part).

4. 1. 3 CORE SAMPLES

Cores samples were observed and sampled at four state geological surveys – Illinois State Geological Survey, Indiana Geological Survey, Missouri Department of Natural Resources, and Iowa Geological Survey. Cores from Illinois, Missouri and Iowa were sampled. The sample size was dependent on the width of core and varied between surveys and types of core. In general, half the core diameter was available for sampling, and in most cases this provided sufficient-sized samples (around 20g).

Illinois

A total of fourteen cores were sampled from the Illinois survey, ranging through the entire Mississippian. The nine productive cores are described below.

C14859 was drilled in Jersey County, western Illinois and ranges from the latest Devonian to the Osagean Fern Glen Limestone (Figure 4.14). It consists of 33m (110ft) of limestones with a few shale-rich intervals. Shaley beds were sampled throughout, but the only productive samples were obtained from the 11m (37ft) of Hannibal Shale. Six samples were taken and two were productive.

C141 was drilled in Madison County, western Illinois and consists of 213.5m (712ft) of limestone, silty sandstone and mudstone ranging from the St Louis Limestone into the Pennsylvanian (Figure 4.15). Four samples were taken from the St Louis Limestone, Yankeetown Sandstone and Cypress Sandstone, only one (from the Cypress Sandstone) was productive.

C14715 was drilled at a quarry in St Clair County, western Illinois (Figure 4.16). Totalling 72m (240ft), it ranges across the Osagean - Meramecian boundary from the Keokuk Limestone to the Salem Limestone. Three samples (all productive) were taken from the Lower Warsaw which consists of interbedded shales, dolomites and limestones.

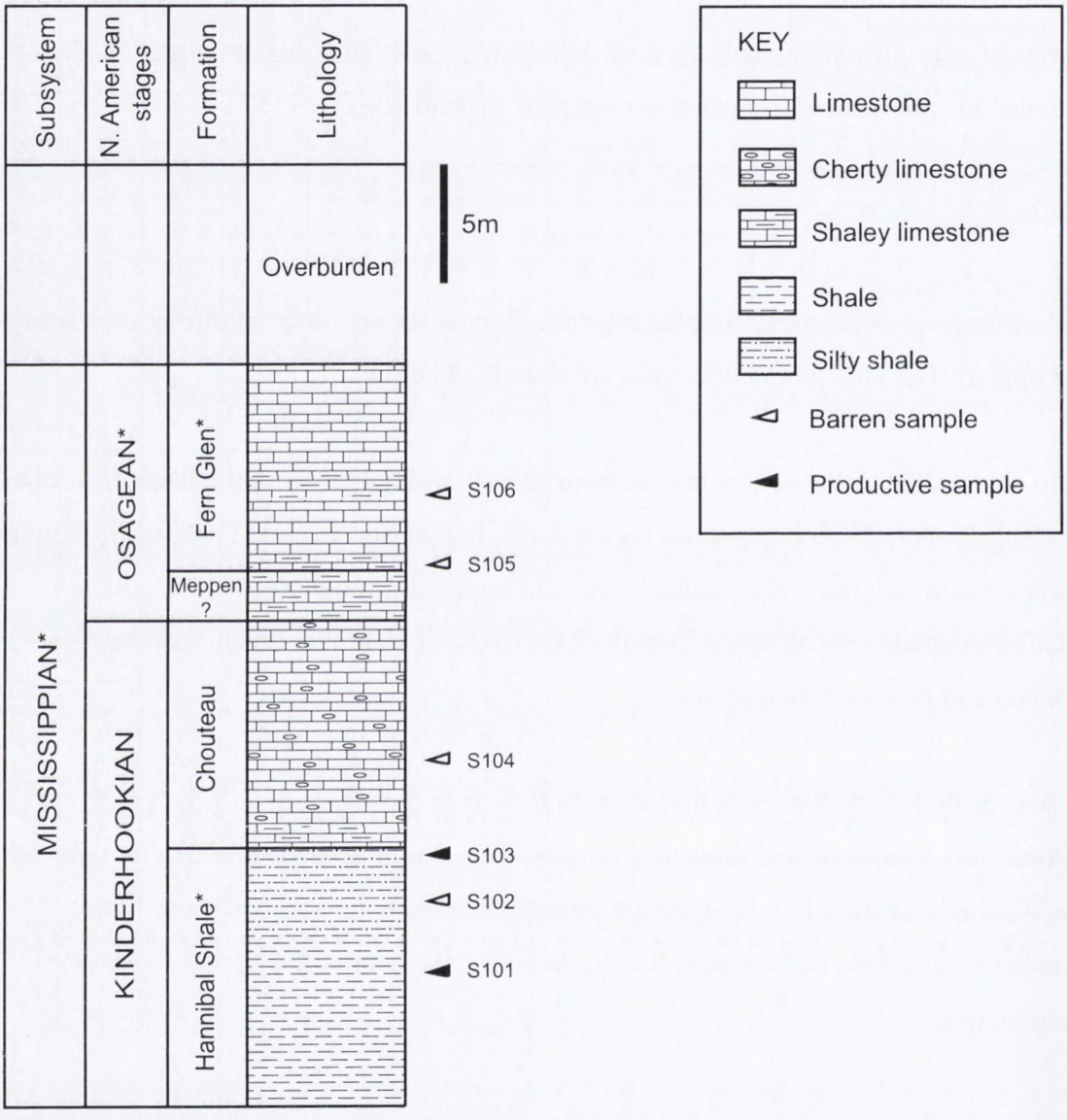


Figure 4.14 Stratigraphic log of core C14859, Jersey County, Illinois (* in part).

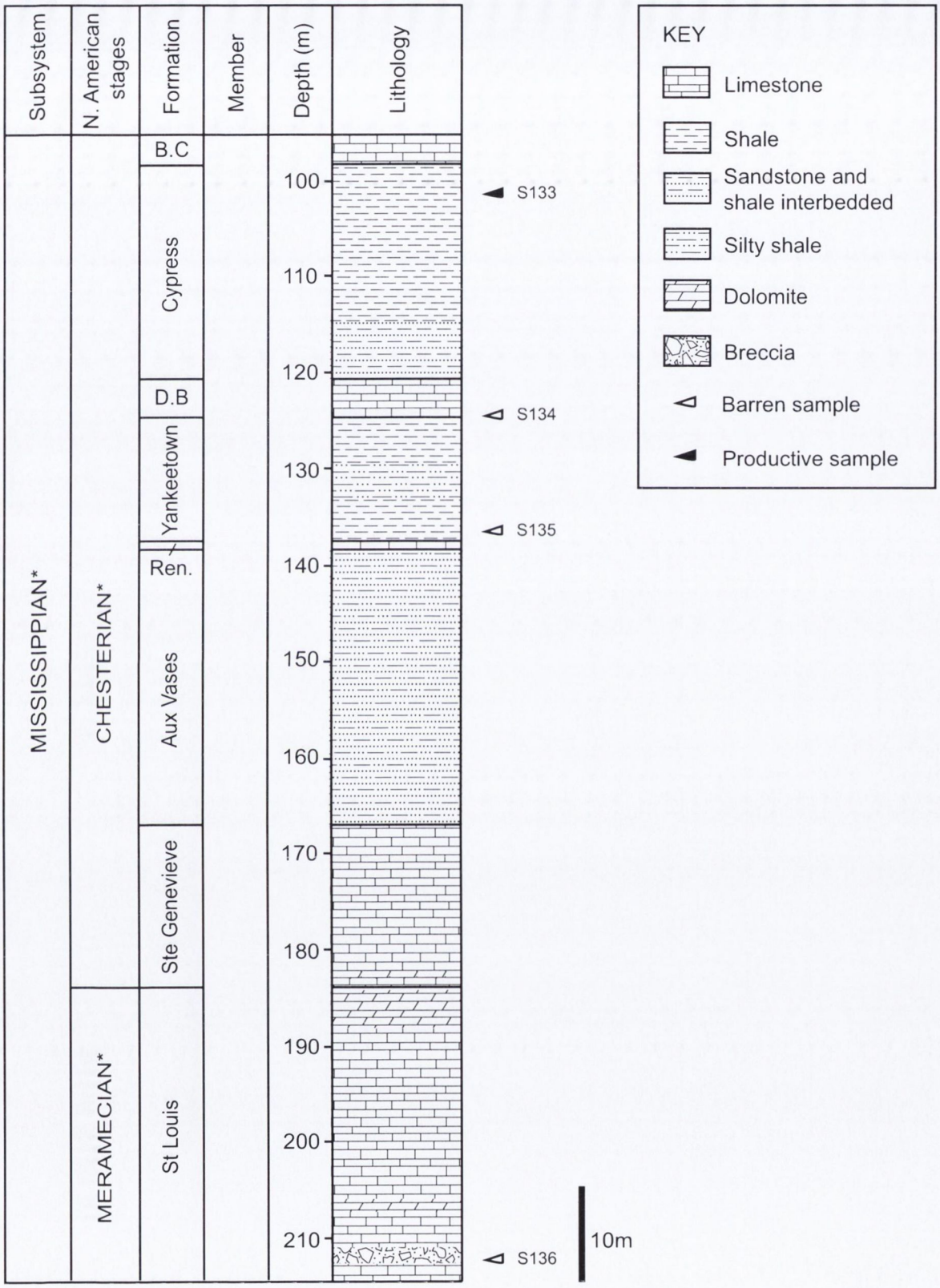


Figure 4.15 Stratigraphic log of core C141, Madison County, Illinois (* in part). Abbreviations are as follows: B.C - Beech Creek, D.B - Downies Bluff, Ren. - Renault.

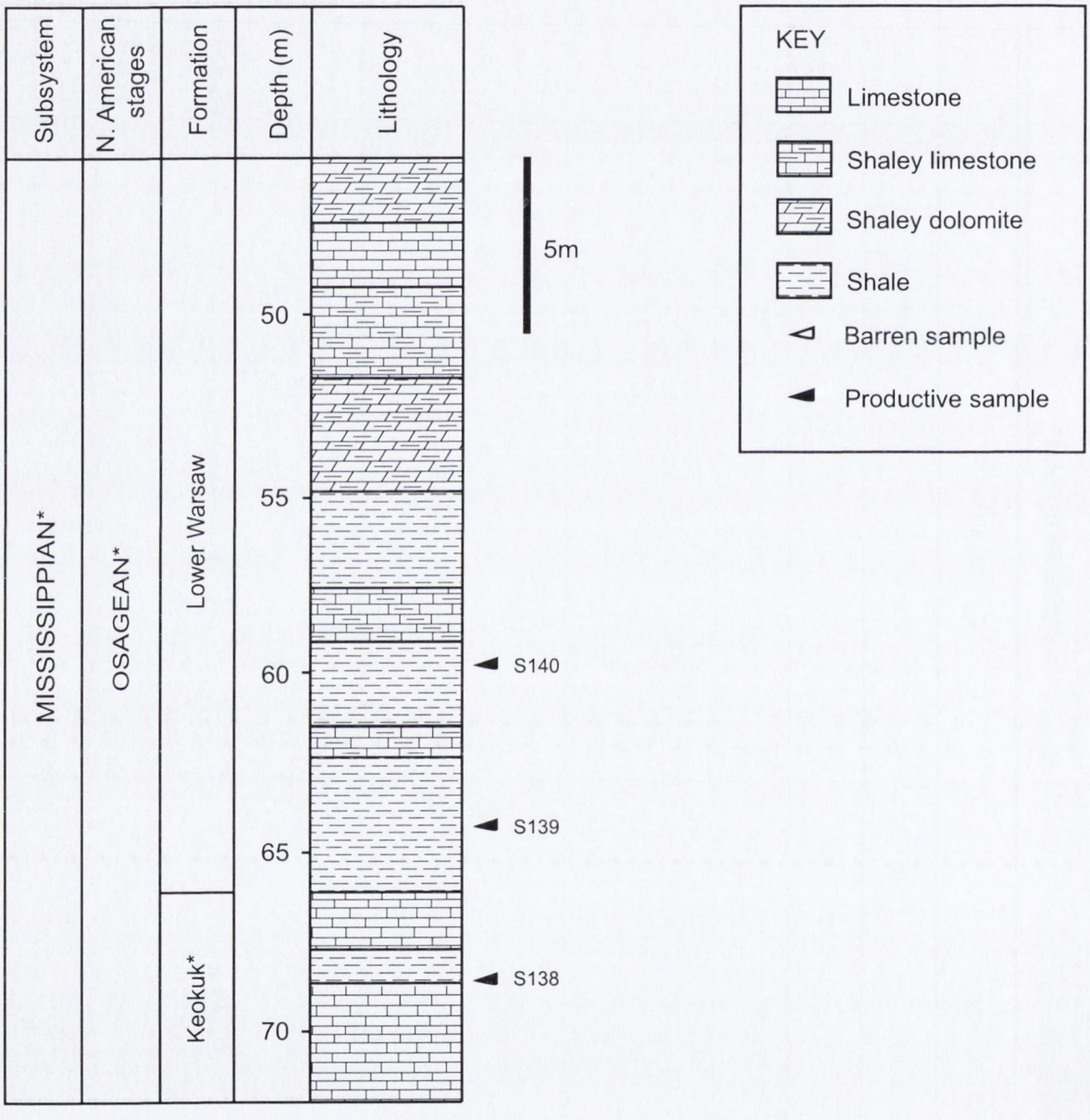


Figure 4.16 Stratigraphic log of core C14715, St Clair County, Illinois (* in part).

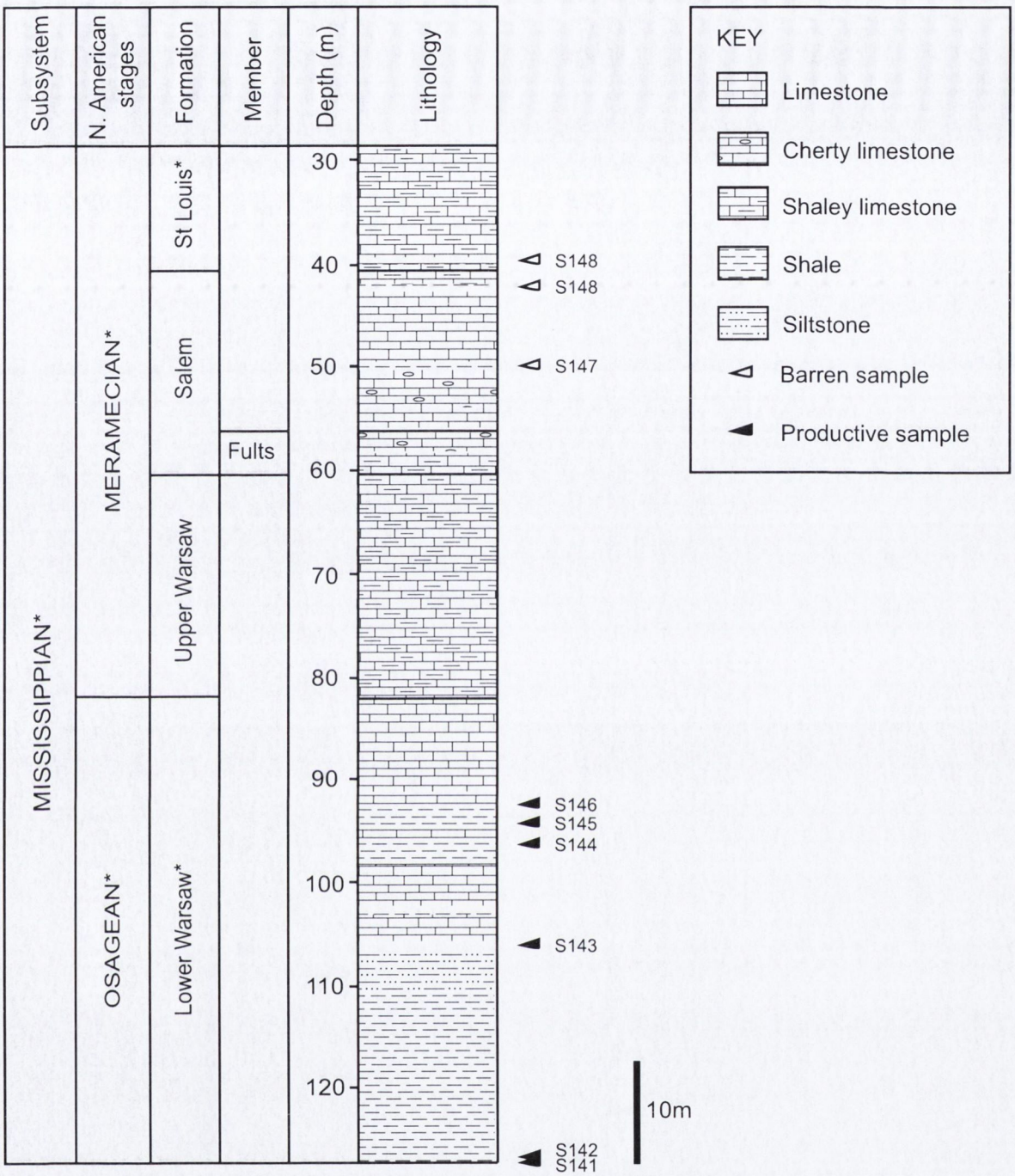


Figure 4.17 Stratigraphic log of core C15223, Monroe County, Illinois (* in part).

C15223 comes from Monroe County, western Illinois and comprises 168.5m (562ft) of limestone, dolomites, shales and siltstones (Figure 4.17). It ranges from the Fern Glen Formation to the St Louis Formation. Six productive samples were taken from the shale-rich Lower Warsaw. Three samples taken from shaley partings in the Salem and St Louis Limestones were barren.

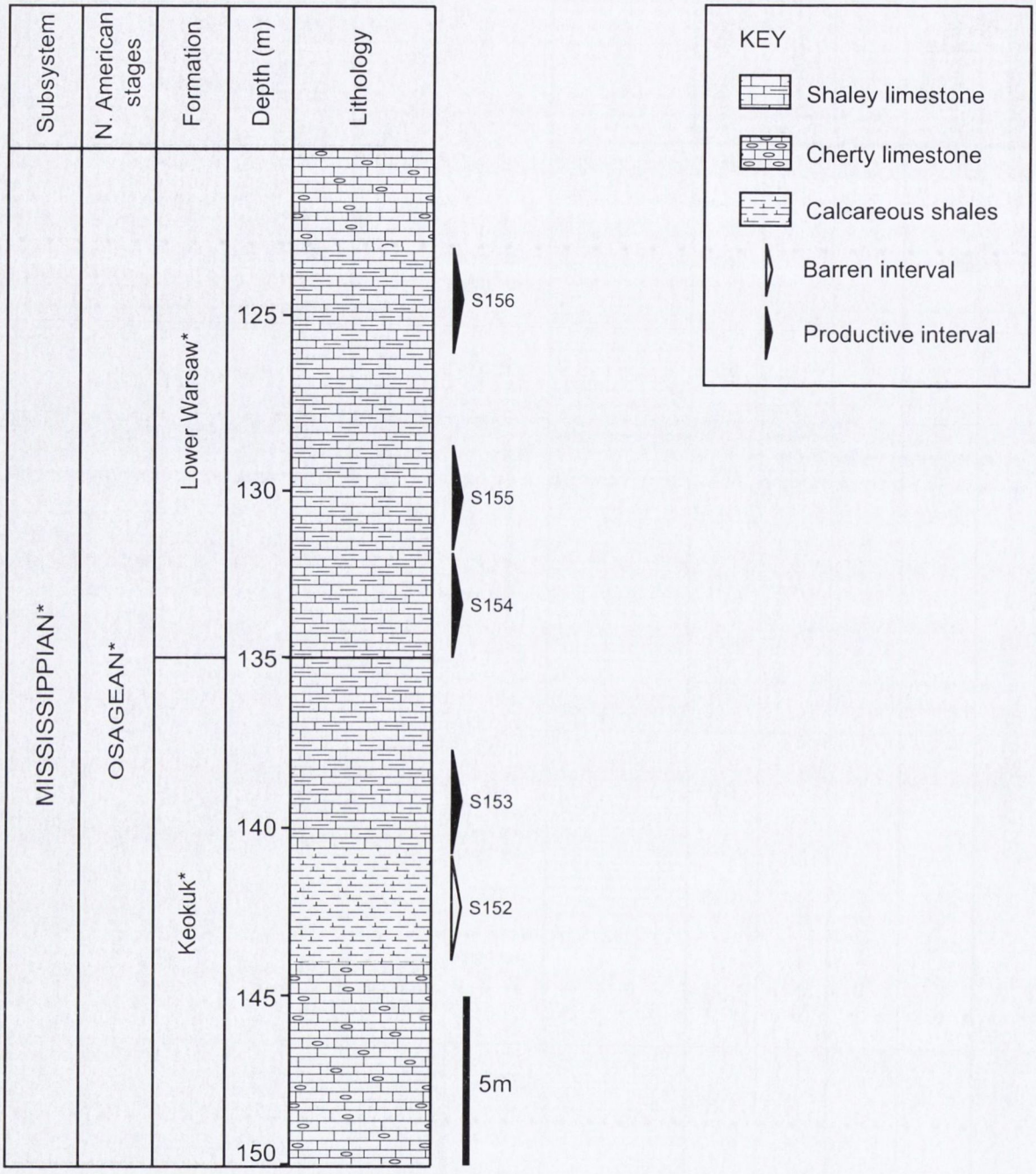


Figure 4.18 Stratigraphic log of core S69127, Monroe County, Illinois (* in part). Samples are cuttings collected every 10 ft.

S69127 is a sample set of cuttings taken from a well drilled in Monroe County (Figure 4.18). Chips were collected at 3m (10 ft) intervals throughout the 126m (420ft) core. Most of the sample set comprises limestones and siltstones ranging from the Burlington Limestone to the St Louis Limestone, shales become dominant in the top of the Keokuk and lowermost Warsaw. Five samples were collected from this interval, four of which proved productive.

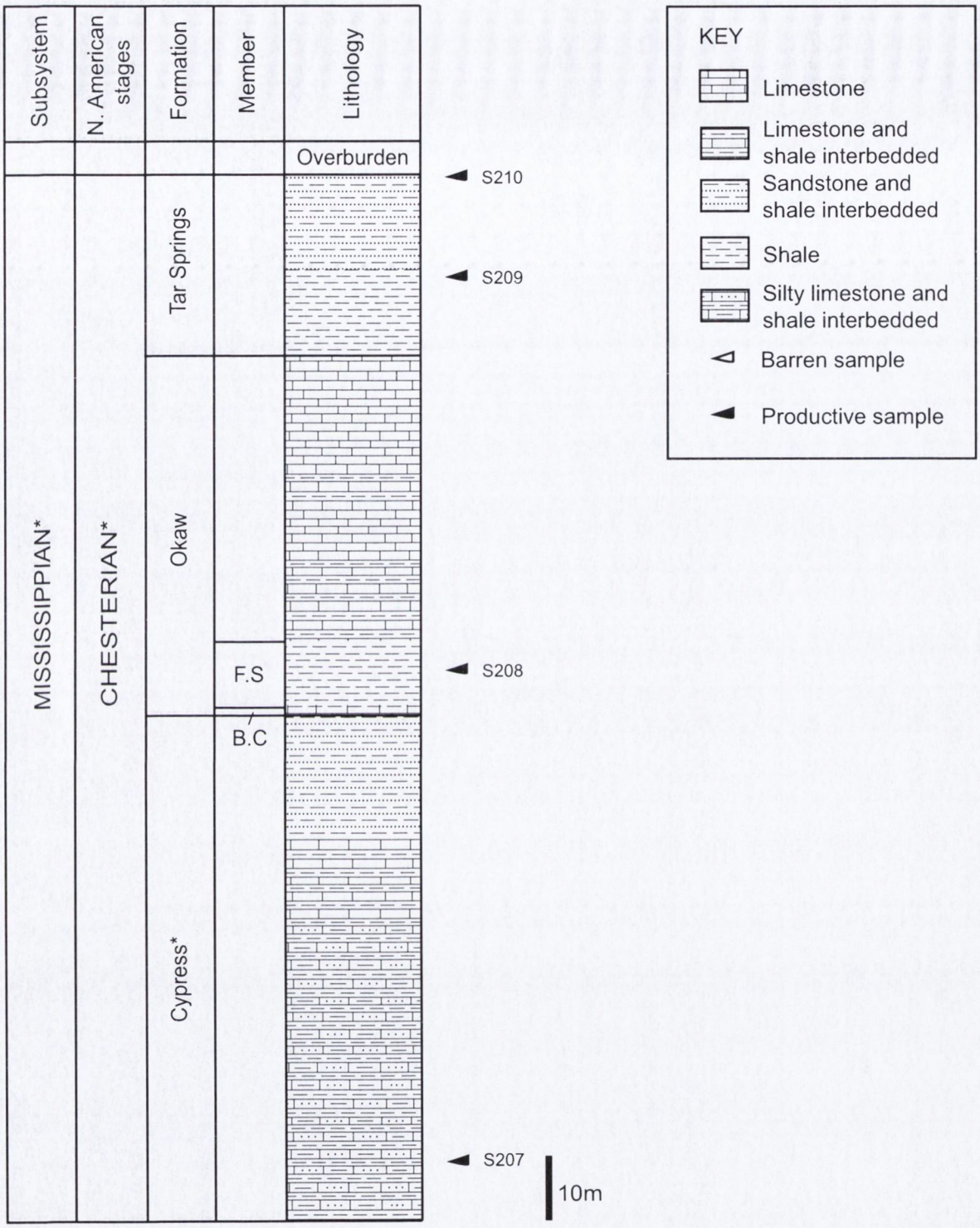


Figure 4.19 Stratigraphic log of core C13619, Union County, Illinois (* in part). Abbreviations are as follows: F.S - Fraileys Shale, B.C - Beech Creek.

C13619 was drilled in Union County, southwest Illinois (Figure 4.19). It comprises 216m (720ft) of limestones, sandstones and shales ranging from the basal Chesterian Ste Genevieve Limestone into the mid Chesterian Tar Springs Sandstone. The upper 90m (300ft) of the core was sampled. One sample was taken from the Fraileys Shale and two were taken from the Tar Springs Sandstone, all three were productive. A fourth sample was

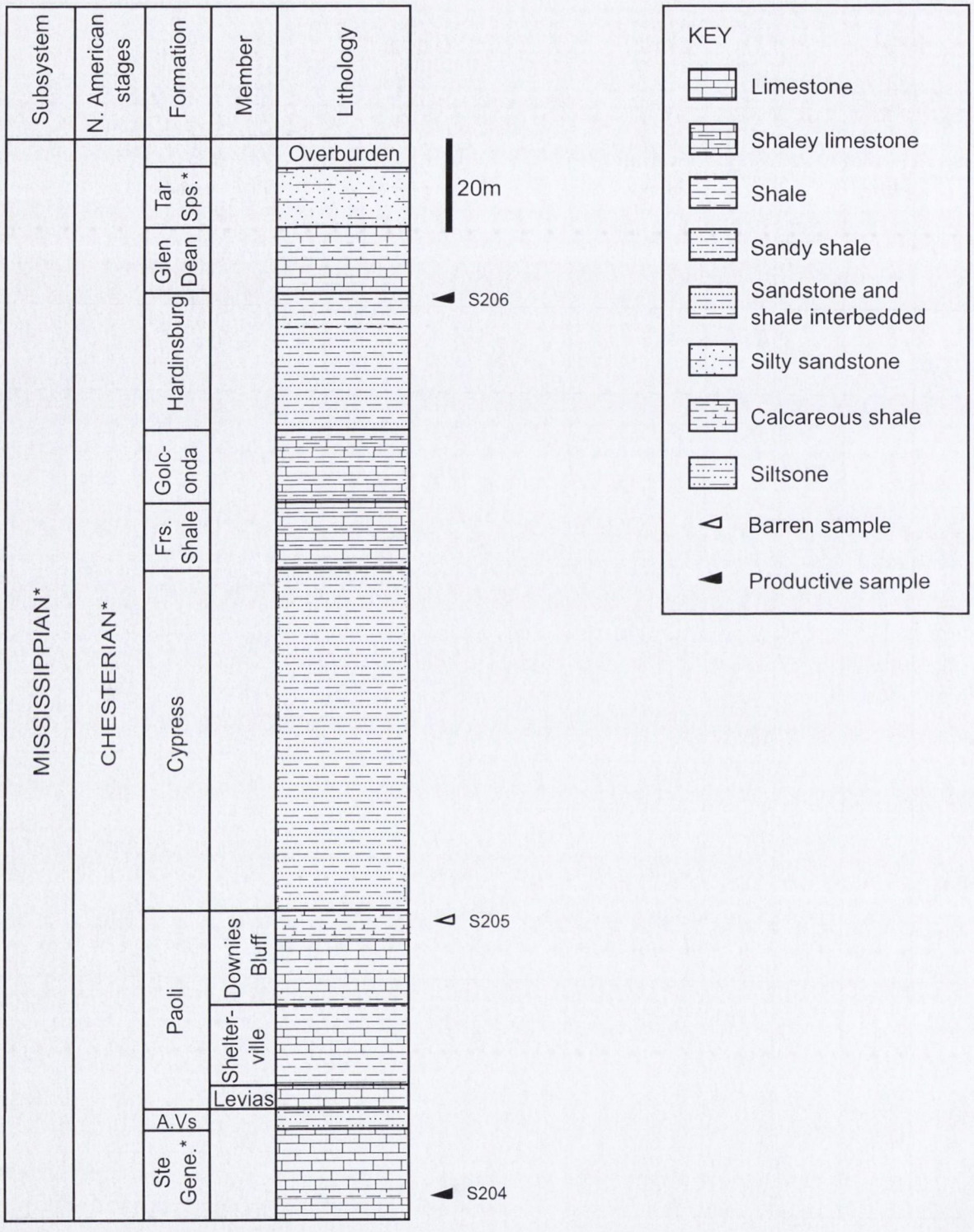


Figure 4.20 Stratigraphic log of core C46, Pope County, Illinois (* in part). Abbreviations are as follows: Tar Sps. - Tar Springs, Frs. Shale - Fraileys Shale, A.Vs - Aux Vases, Ste Gene. - Ste Genevieve.

taken from beds identified as the Cypress Formation, however, the exact stratigraphic position is unknown and it is not included in this study.

C46 comes from Pope County, southern Illinois (Figure 4.20). The core is 223m (743ft) thick and ranges from the Ste Genevieve to the Tar Springs. As in the previously

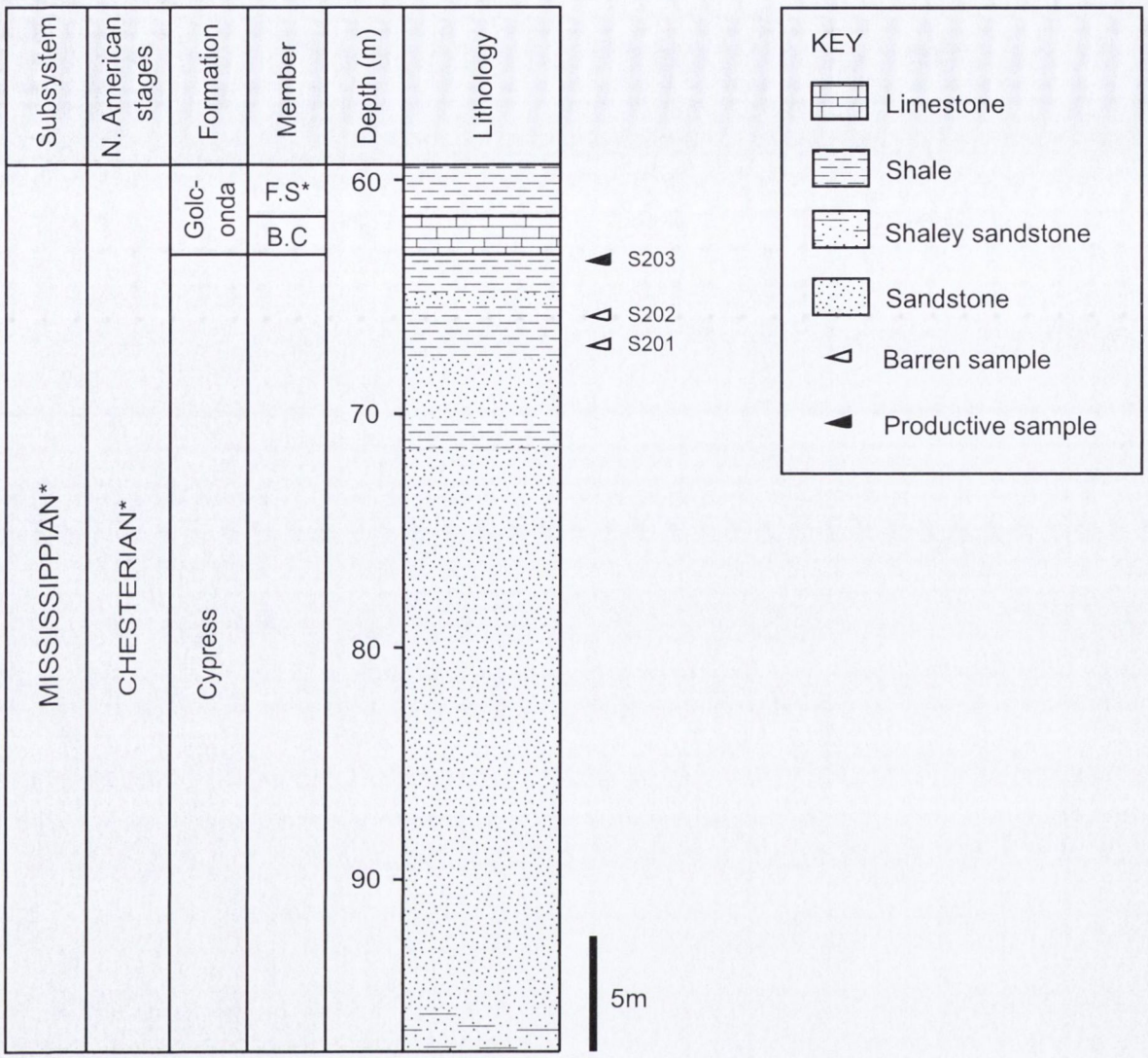


Figure 4.21 Stratigraphic log of core C13076, Pope County, Illinois (* in part). Abbreviations are as follows: F.S - Fraileys Shale, B.C - Beech Creek.

mentioned core it comprises limestones, sandstones and shales. Three samples were taken, the first from a shaley parting within the Ste Genevieve Limestone, the second from the Paoli Formation (Downies Bluff Member) and the third from the interbedded shales and sandstones of the Hardinsburg Sandstone. Samples from the Ste Genevieve and the Hardinsburg were productive.

C13076 was also drilled in Pope County (Figure 4.21). It comprises 141m (470ft) of interbedded Chesterian limestones, sandstones, shales and mudstones ranging from the Bethel Sandstone to the Hardinsburg Formation. Three samples were taken from the Cypress Formation one of which was productive.

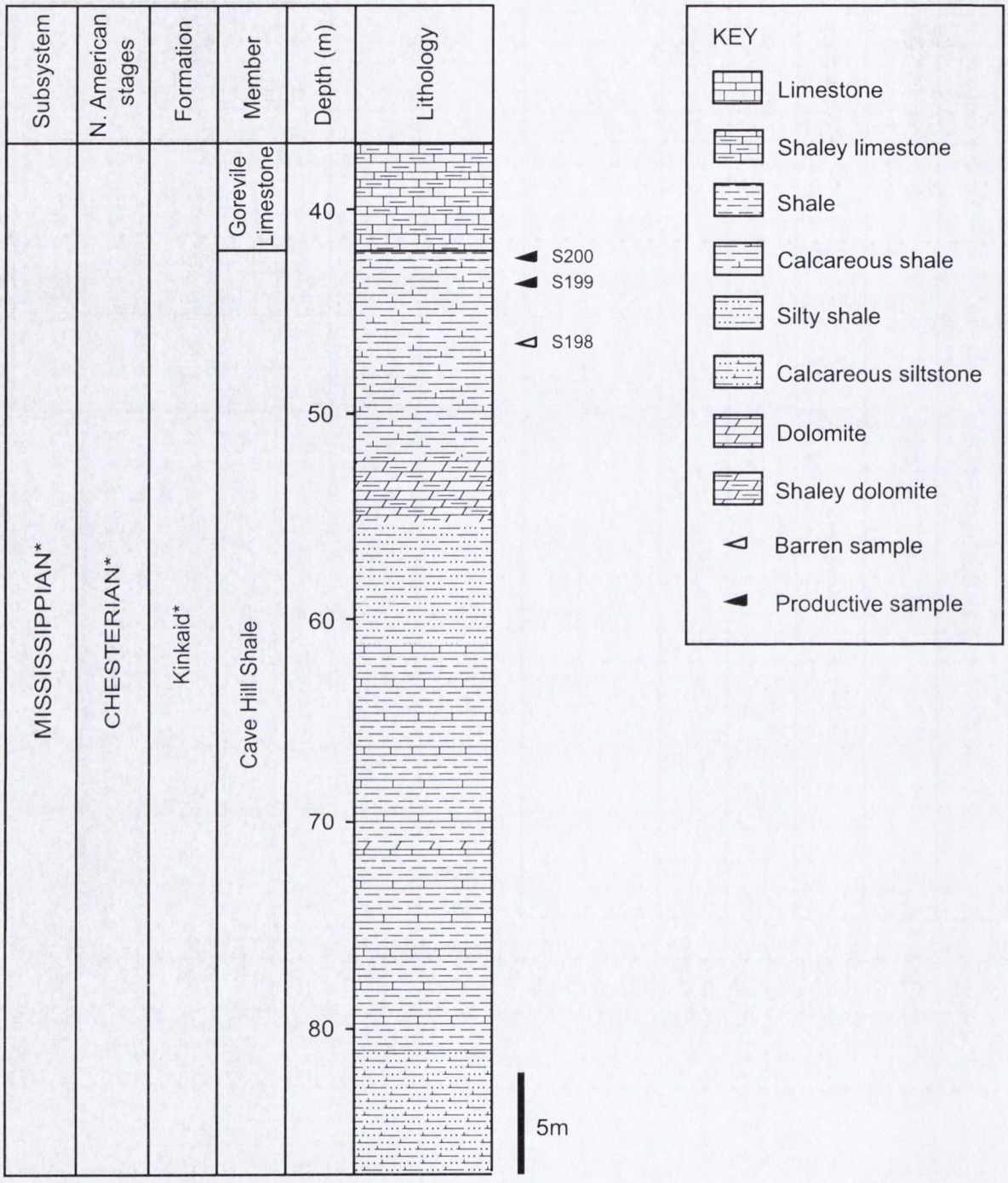


Figure 4.22 Stratigraphic log of core C4883, Gallatin County, Illinois (* in part).

C4883 is the most eastward lying of the Illinois cores, and comes from Gallatin County, southern Illinois (Figure 4.22). It comprises 75m (250ft) of limestones, shales and siltstones ranging from the Kinkaid Limestone in the upper Chesterian to the lowest Pennsylvanian. Three samples were taken from the shale-rich Cave Hill Member of the Kinkaid, two of which are productive.

Missouri

Material collected from the Missouri Department of Natural Resources was among the oldest material sampled. Six cores ranging from the Kinderhookian to Meramecian were sampled from the Missouri Department of Natural Resources, five of which proved productive.

The NS-2 and NS-3 cores were drilled in southwest Missouri, from Cedar County and Dade County respectively (Figures 4.23 and 4.24). As such they are positioned some way from the Mississippi Valley, and the stratigraphy differs slightly (Thompson 1986). However, correlation with the Mississippi Valley units is well established and they are included in this study. NS-2 is 491m (1637ft) deep, and ranges as far down as Precambrian basement schists and quartzites. Overlying this is 450m (1500ft) of Devonian dolomitic mudstones and sandstones, and around 30m (100ft) of Mississippian siltstones, shales and limestones ranging as high as the earliest Osagean Pierson Formation. A single productive sample was obtained from the green-grey shales of the Bachelor Formation (oldest Mississippian, Hannibal/Horton Creek equivalent) and four productive samples were obtained from the shales and siltstones of the Northview Formation (youngest Kinderhookian, Chouteau equivalent). NS-3 has a similar range and similar lithologies as NS-2; 470m (1565ft) of core ranging from the Precambrian to the Mississippian Pierson Formation. Two samples were taken from shale-rich horizons within the Compton Limestone Formation - both proved barren. Four samples were taken from the Northview Shale, two of which were productive (Figure 4.24).

LS21 was drilled in Randolph County, northeast Missouri (Figure 4.25). It comprises 144m (480ft) of limestones, shales and dolomites ranging from the Devonian Cedar Valley Limestone to the Osagean Warsaw Formation, and is uncomformably overlain by 12m (40ft) of undifferentiated Pennsylvanian shales, mudstones and coal. Two productive samples were obtained from the Latest Devonian, dark grey Chattanooga Shale. These are the oldest samples from the Mississippi Valley included in this study.

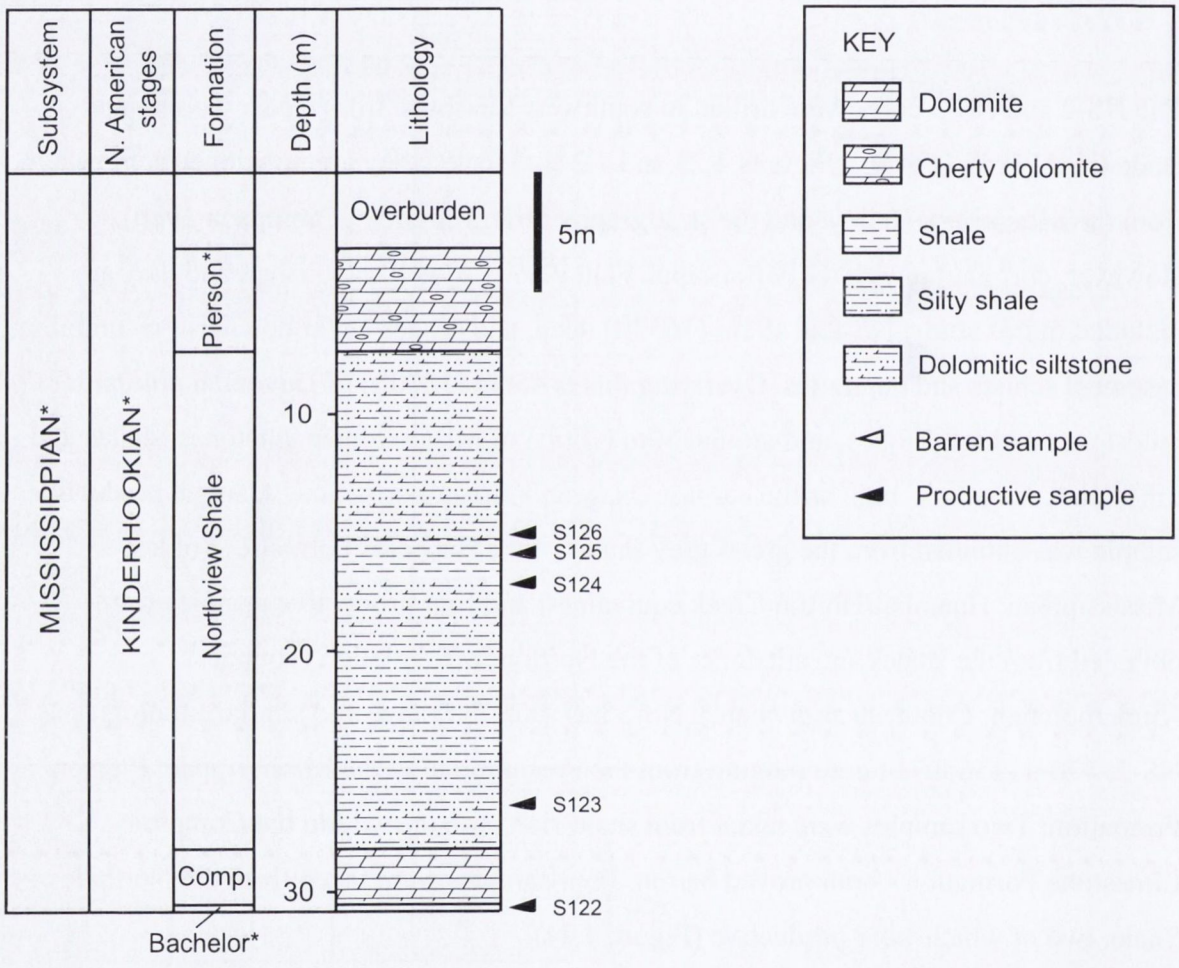


Figure 4.23 Stratigraphic log of core NS2, Cedar County, Missouri (* in part). Abbreviations are as follows: Comp. - Compton Limestone.

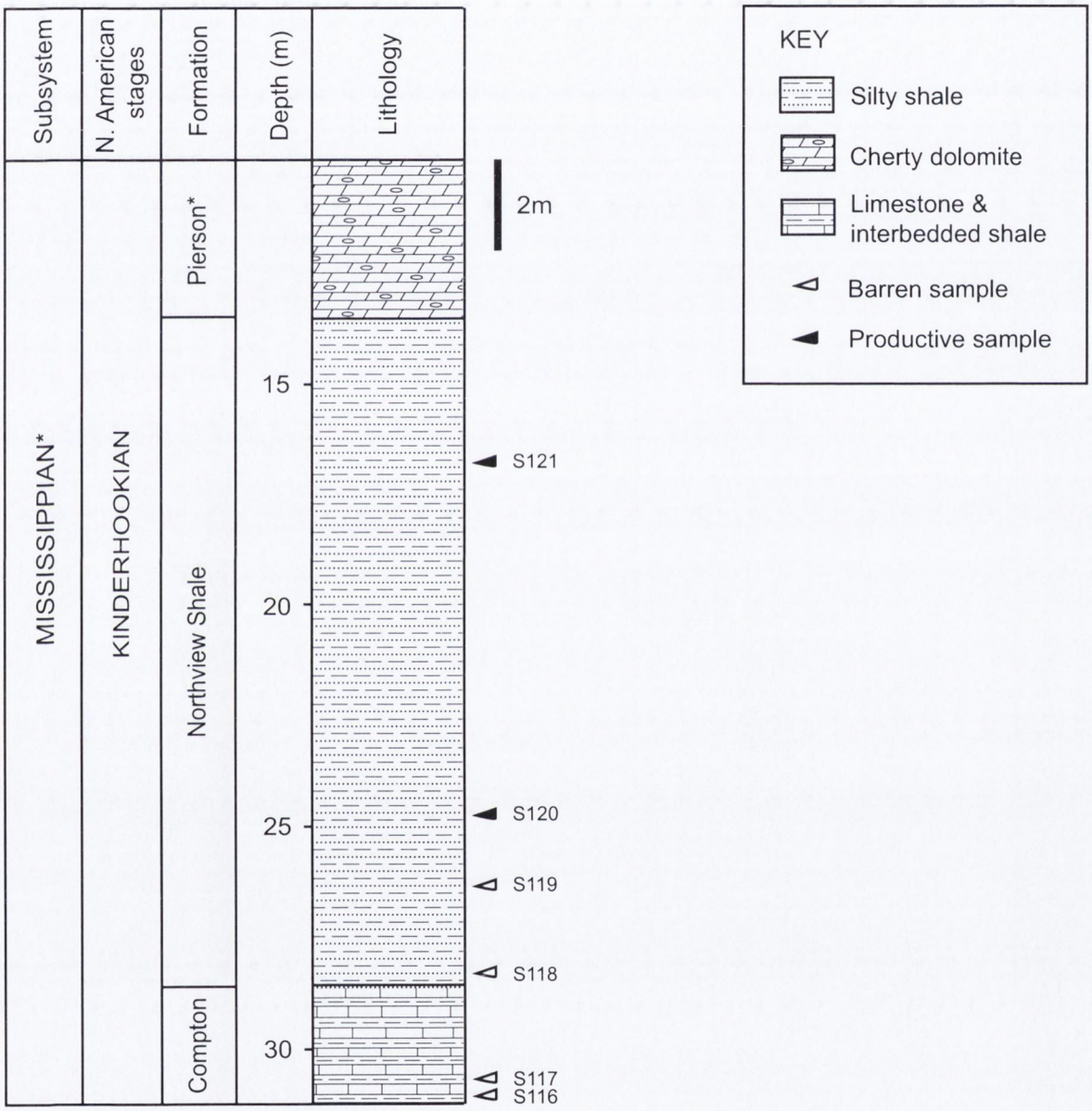


Figure 4.24 Stratigraphic log of core NS3, Dade County, Missouri (* in part).

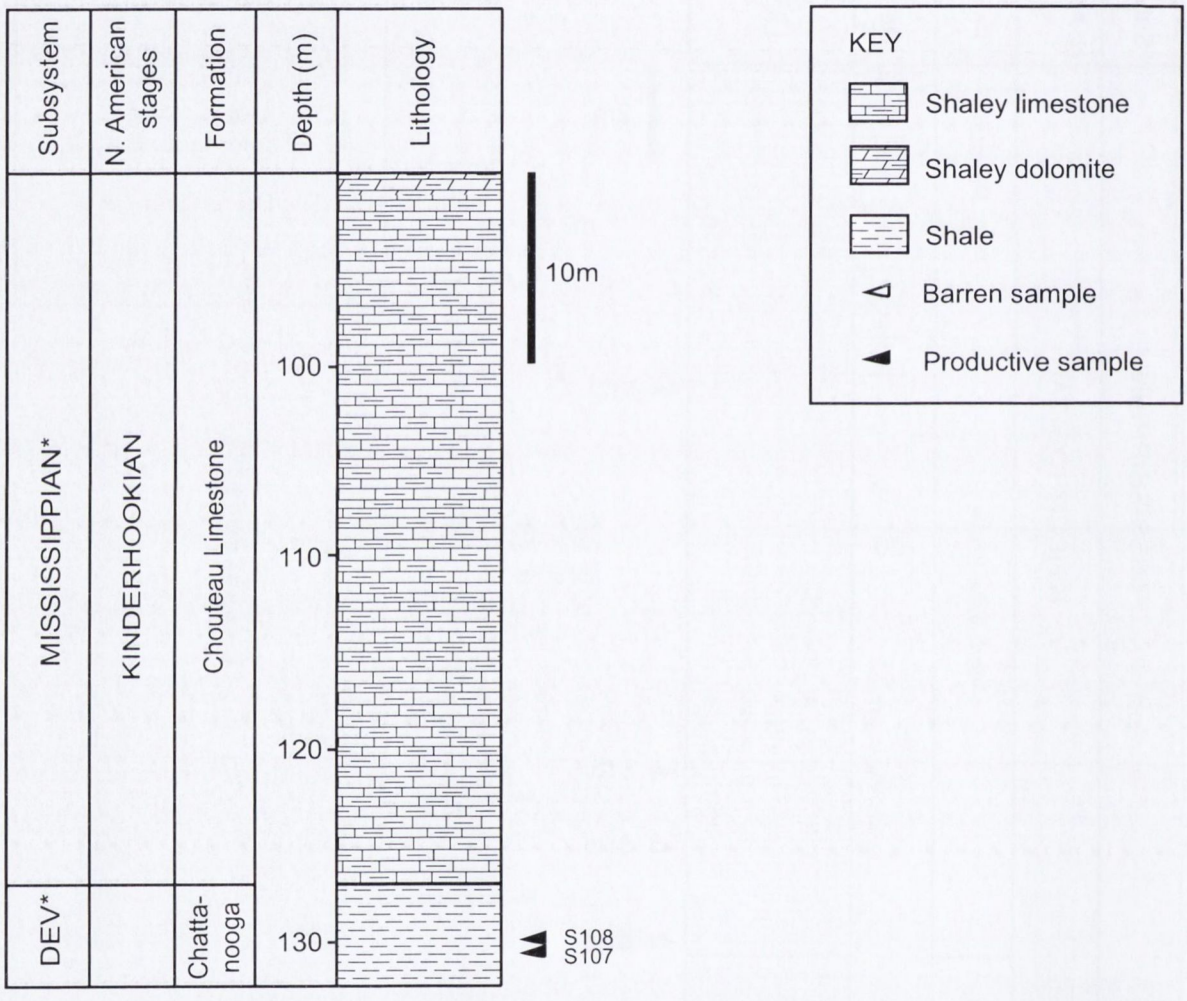


Figure 4.25 Stratigraphic log of core LS-21, Randolph County, Missouri (* in part).

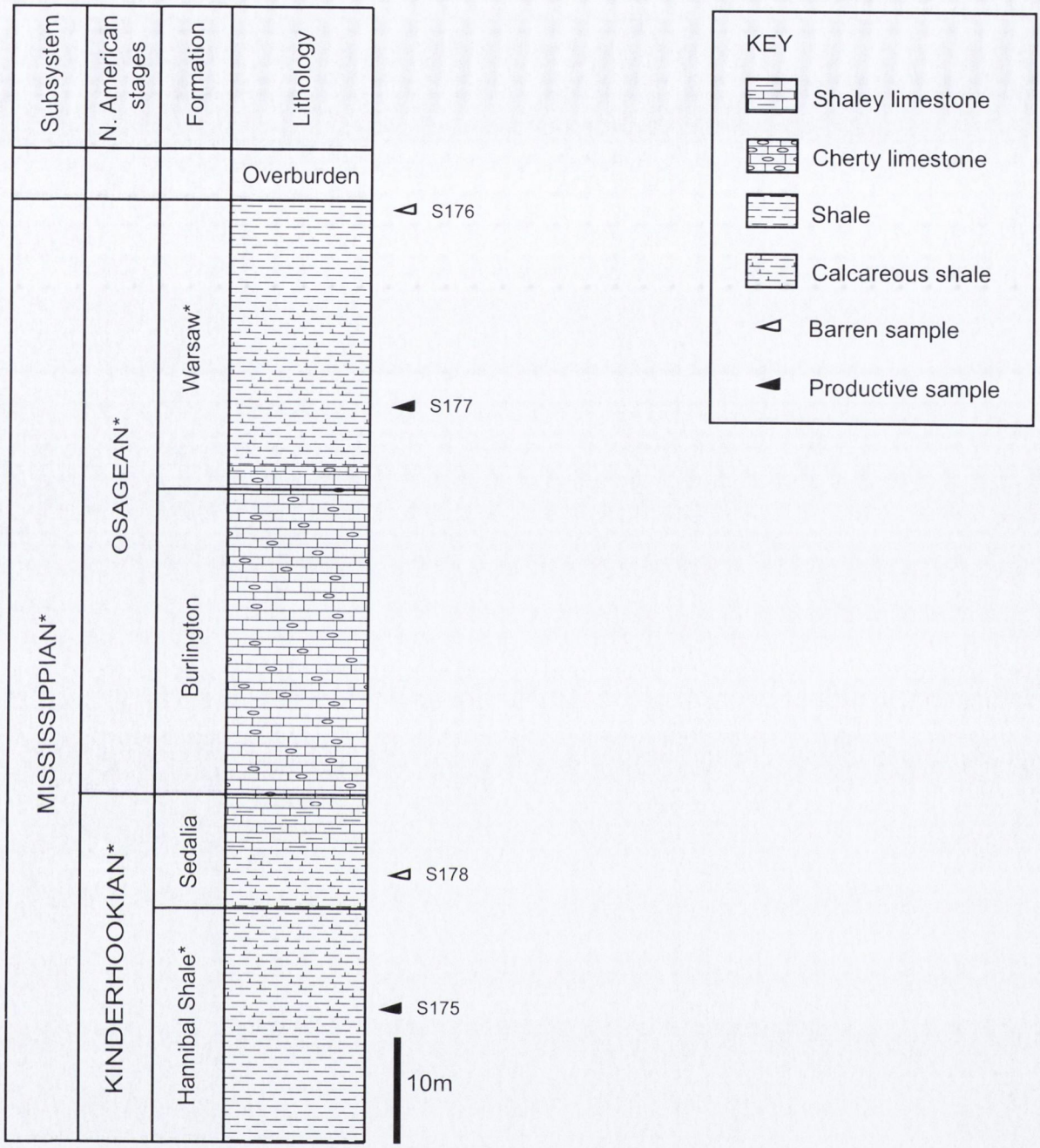


Figure 4.26 Stratigraphic log of core 59-Mi, Clark County, Missouri (* in part).

Core 59MI comes from Clark County in north easternmost Missouri (Figure 4.26). The location of the core is very close to the type area for the Keokuk Formation and is around 37 km north of the Hannibal Shale type area. The material available for sampling consists of well cuttings, meaning sample sizes were very small (5g). Again the Precambrian is reached, with most of the 995m (3315ft) core comprising Devonian sediments. One sample was taken from the Hannibal Shale, one sample was taken from the grey shales within the predominantly limestone Sedalia Formation (Chouteau equivalent), and two samples were

taken from the limey shales of the Warsaw Formation. A single sample from the Warsaw proved productive.

Core 516-C comes from a borehole drilled by the U.S. Army Corps of Engineers during the construction of Clarence Cannon Dam on Salt River, approximately 50 km to the southwest of Hannibal and 11 km north of the town of Perry, in Ralls County, northeast Missouri (Figure 4.27). The core was kindly sampled and shipped by the Missouri Department of Natural Resources, Division of Geology and Land Survey. At this site the Louisiana Limestone is overlain by the Horton Creek Limestone, a 0.8m (2.5ft) thick micritic carbonate unit, which, where present, is regarded as the base of the Mississippian (Thompson, 1986). This unit is overlain by the Cuivre Member of the Hannibal Shale; 2.1m (7ft) of dark gray shale with sandstone lenses. Above the Cuivre Member, the remainder of the Hannibal Shale comprises 22.9m (75ft) of gray to grayish-green bioturbated shales and siltstones conformably overlain by the Chouteau Limestone. The Hannibal Shale was sampled in detail from this core at 2cm (0.8 inch) intervals. Eighteen samples were taken, two from the Horton Creek Limestone, two from the Cuivre Member and fourteen from the Hannibal Shale. All proved productive.

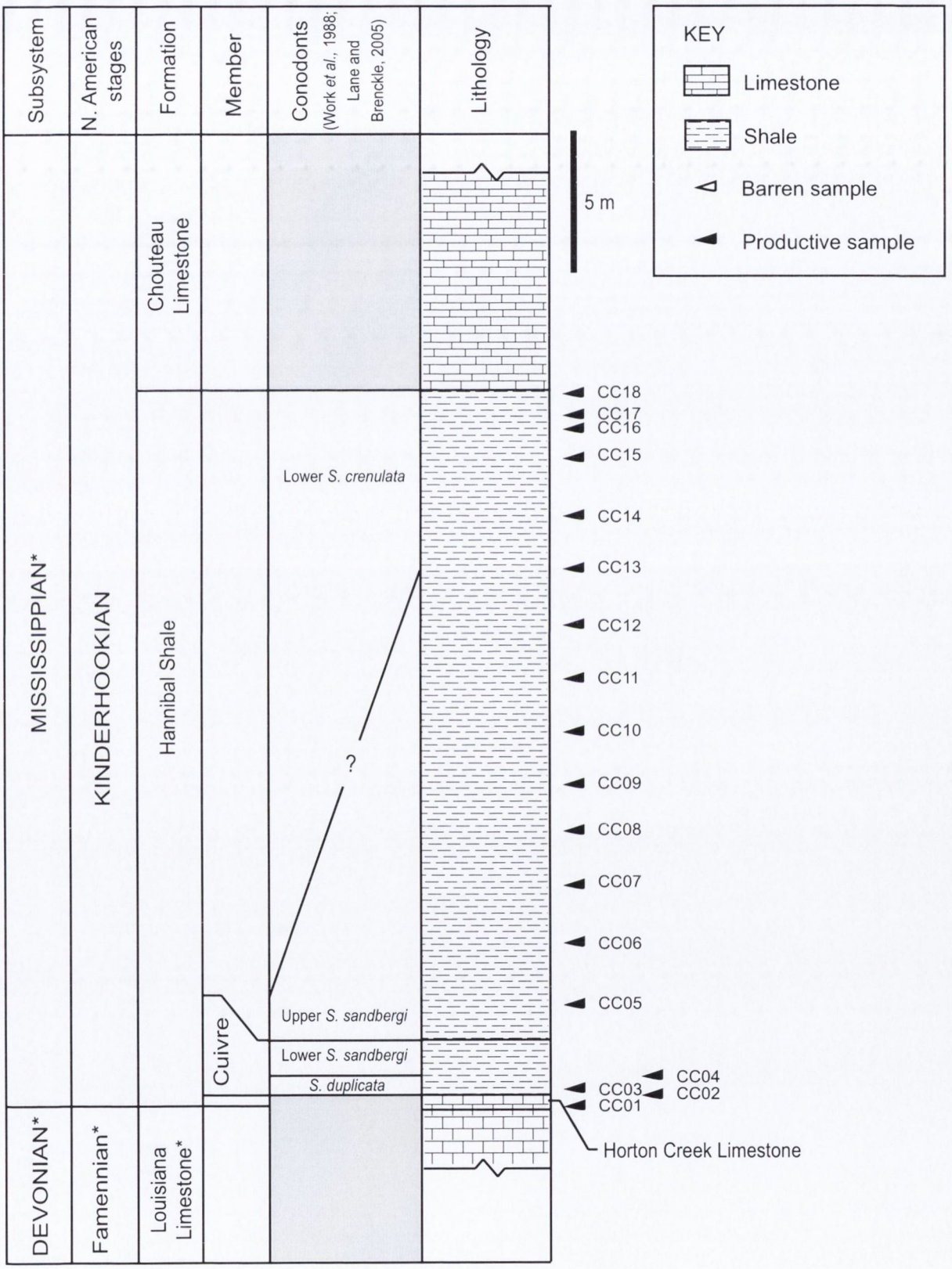


Figure 4.27 Stratigraphic log of the Clarence Cannon Dam section, Missouri (* in part).

Iowa

A single core, H-29, was sampled from the Iowa Survey (Figure 4.28). The core comes from Lee County in south easternmost Iowa in the Keokuk type area, and ranges from the Late Devonian Saverton Shale to the Osagean Lower Warsaw. It comprises 224m (748ft) of mainly shales and siltstones, with a few carbonate-rich layers. Eighteen samples were taken, eleven of which were productive. In the Kinderhookian, three samples were taken from the McCraney Formation (Lower Hannibal equivalent), two of which were productive, four samples were taken from the Prospect Hill Formation (Upper Hannibal equivalent), three of which were productive and one barren sample was taken from the Wassonville Formation (Chouteau equivalent). In the Osagean, two productive samples were taken from shaley lenses with the Burlington Limestone, five samples (one productive) were taken from shales within the Keokuk Limestone and three samples (two productive) were taken from the calcareous shales of the Lower Warsaw.

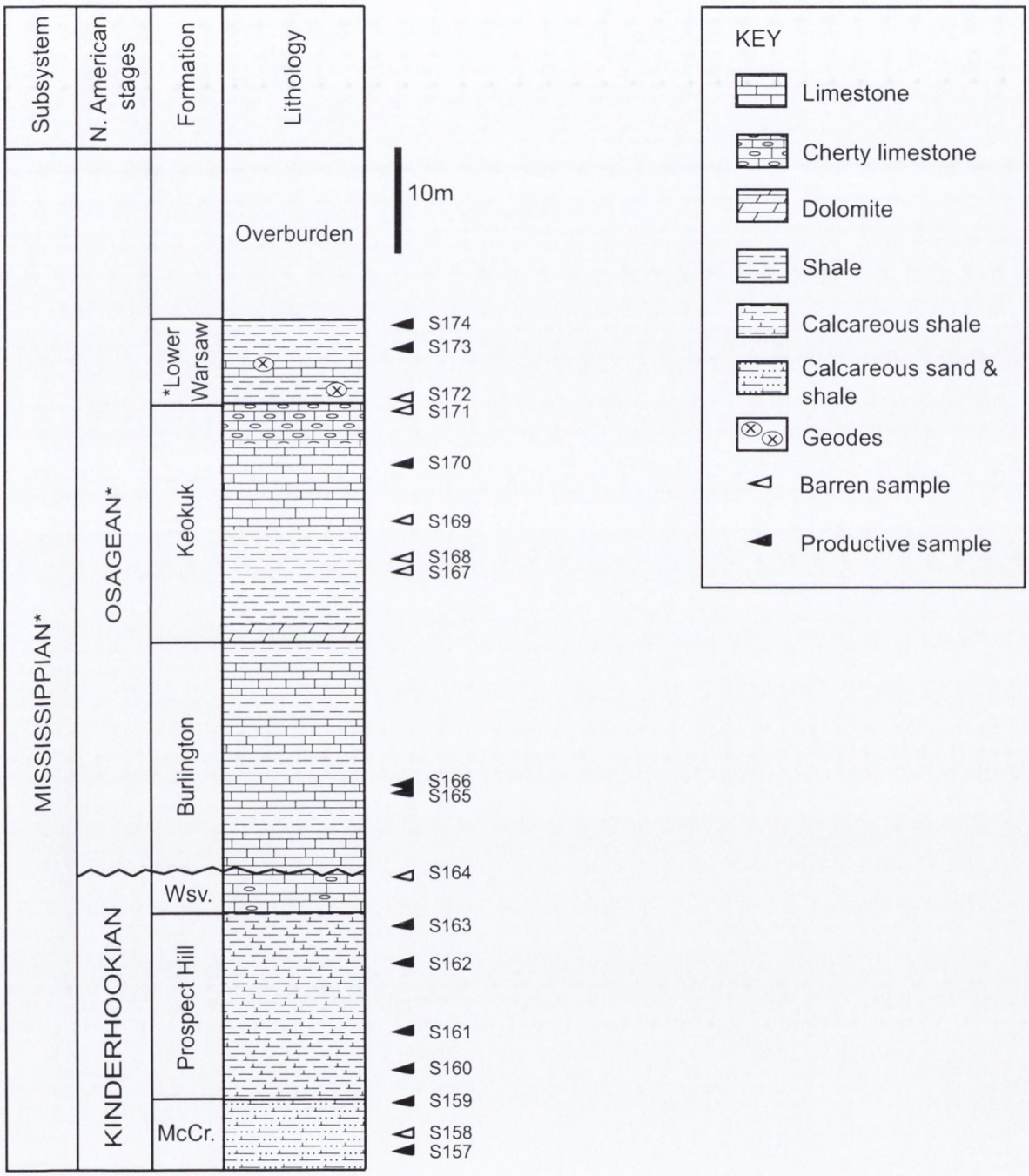


Figure 4.28 Stratigraphic log of core H29, Lee County, Iowa (* in part). Abbreviations are as follows: McCr. - McCraney, Wsv. - Wassonville.

4. 2 PREPARATION OF SAMPLES FOR PALYNOLOGICAL ANALYSIS

Approximately 50g of rock was taken from each sample and crushed into fragments of 1cm or smaller. Samples were washed in tap water to remove surface mud and dust, and tested for carbonate by adding approximately 50ml cold 32% hydrochloric acid (HCl). The samples were left for at least 12 hours to ensure the reaction was completed and then decanted with tap water until neutral. Palynomorphs were tested for by using hydrofluoric acid (HF) digestion in a Prolab Maxidigest 3.6 microwave unit; 50ml of 60% HF was added to 5g of sample and heated at 50% power for 30 minutes. Samples were allowed to cool, neutralised by decanting in tap water and checked for palynomorphs. Productive samples were then processed using standard palynological techniques. 50ml of HF was added to 20g of sample in a polythene beaker which was then placed in a water bath set to 30°C. This was to remove silicates. In the case of a vigorous reaction the beaker was topped up with tap water to slow the reaction. After 24 hours a further 100ml of HF was added to the sample. Samples were stirred twice a day until broken down and no longer 'gritty', then decanted and topped up with tap water six times until neutral. Ten milliliters of the unsieved neutralised residue was saved as stock. Residues were sieved through a 20μm mesh sieve. Microscope slides were prepared using the sieved residues. All slides were prepared as strew mounts using Cellosize dispersal agent and Elvacite cold-setting resin. The remaining residue was placed in a glass beaker with 50ml of HCl and brought to the boil (to remove fluorite crystals that may have formed during processing); the residue was decanted with tap water and mounted. Samples were then examined to determine if oxidation was required. Sixty-one samples required oxidation in 65% nitric acid (HNO_3). Oxidation times varied but averaged 20 - 40 minutes. A few samples required further oxidation using fuming nitric acid. The oxidised residues were decanted with tap water until neutral and mounted. In some cases samples were placed in an ultrasonic bath for 15 seconds – 1 minute to break down large clumps of AOM which obscured spore identification.

Palynological slides were examined using a Nikon palynological microscope. Photographs were taken for reference using a Nikon Coolpix digital camera attached to the microscope. Plate quality photographs were taken using a Nikon DXM1200 digital camera attached to a Nikon Eclipse E600 microscope and Nikon Act-1 software. Plates were constructed in Adobe Illustrator 10. England Finder co-ordinates are given for all specimens figured; slides were all viewed with the label to the left. Slides are housed in the Geological Museum of Trinity College Dublin, Dublin, Ireland.

CHAPTER 5
TERMINOLOGY

5. 1 BASIC MORPHOGRAPHIC TERMINOLOGY OF MIOSPORES

Miospores are described in terms of their size, shape, trilete mark, structure and ornamentation. In this study, the miospore terminology of Smith & Butterworth (1967) and Playford and Dettman (1996) is followed.

1. Size – Miospores range in size from 10-200μm. In the present study most miospores are less than 100μm; a single megaspore (<200μm) is recorded.

2. Shape – Refers to the equatorial outline of the spore, otherwise known as the 'amb' (Figure 5.1).

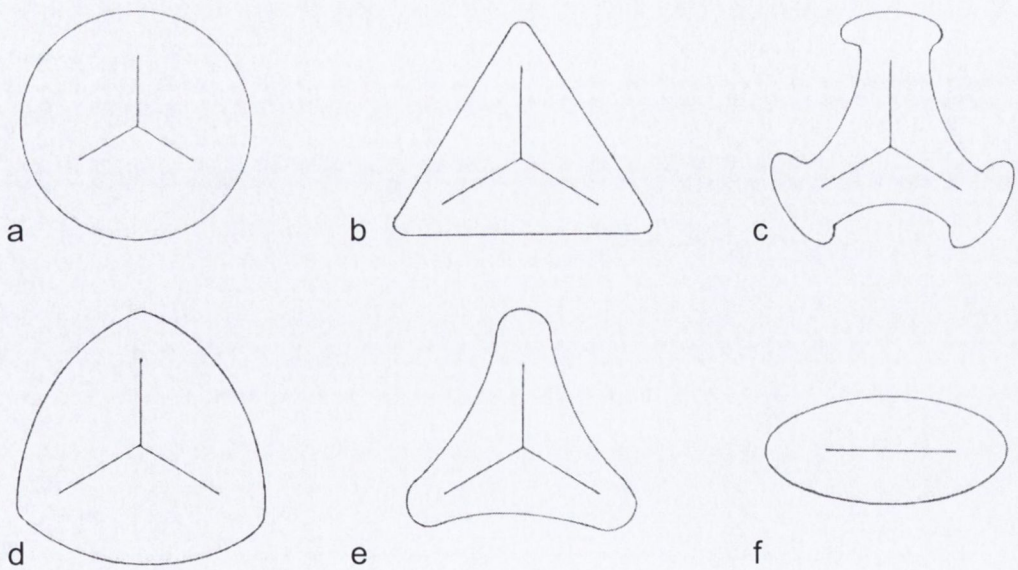


Figure 5.1 Characteristic amb shapes, a-e tetrahedral trilete spores; f - tetragonal monolete spore - a) Circular; b) triangular; c) subtriangular with concave sides and laterally expanded apices; d) convexly subtriangular; e) concavely subtriangular; f) elliptical (after Playford & Dettman 1996).

3. Trilete mark – The aperture, or suturae, of a spore is situated on the proximal surface and may be monolete or trilete, depending on the structure of the tetrad (Figure 5.2). Important features of the trilete mark include the length of the suturae and associated curvaturae and labrae.

4. Structure – The most significant structural feature of miospores is their camerate/acamerate nature. Acamerate spores show no internal separation of the exine layers. Camerate spores show separation of the intexine and exoexine and possess a distinctive inner body. Equatorial extensions and thickenings of the exoexine are also important for generic classification (Figure 5.3).

5. Ornamentation – The ornamentation (sculpture) of the outer layer of the exine is often a useful characteristic for determination of genera and species. Ornamentation may be in the form of positive projections (e.g. spinae, verrucae) and ridges (e.g. rugulae, muri) or negative ornamentation (e.g. fovoelae, vermiculi) (Figure 5.4).

5. 2 BASIC MORPHOGRAPHIC TERMINOLOGY OF ACRITARCHS

Six major features of acritarch morphology are generally recognised as important criteria for defining genera. These are - vesicle shape and symmetry; shape and distribution of processes; solidity or otherwise of processes; whether hollow processes are open or closed from the vesicle cavity; eilyma (wall) structure/sculpture; and excystment opening (Playford 2003). These features and the related terminology are illustrated in figures 5.5-5.7.

1. Vesicle shape and symmetry – Most fossil acritarchs are persevered as flattened specimens, therefore vesicle shape is usually expressed in two-dimensional terms (see Figure 5.5 for examples). Most taxa recorded in the present study are spherical acanthomorph/stellate forms.

2. Shape and distribution of processes – Processes are normally prominent and elongated elements which protrude from the spore body. The number, length and shape of processes is usually consistent at species level, but a great deal of variation exists within the acritarchs as a whole (Figure 5.6 a-o).

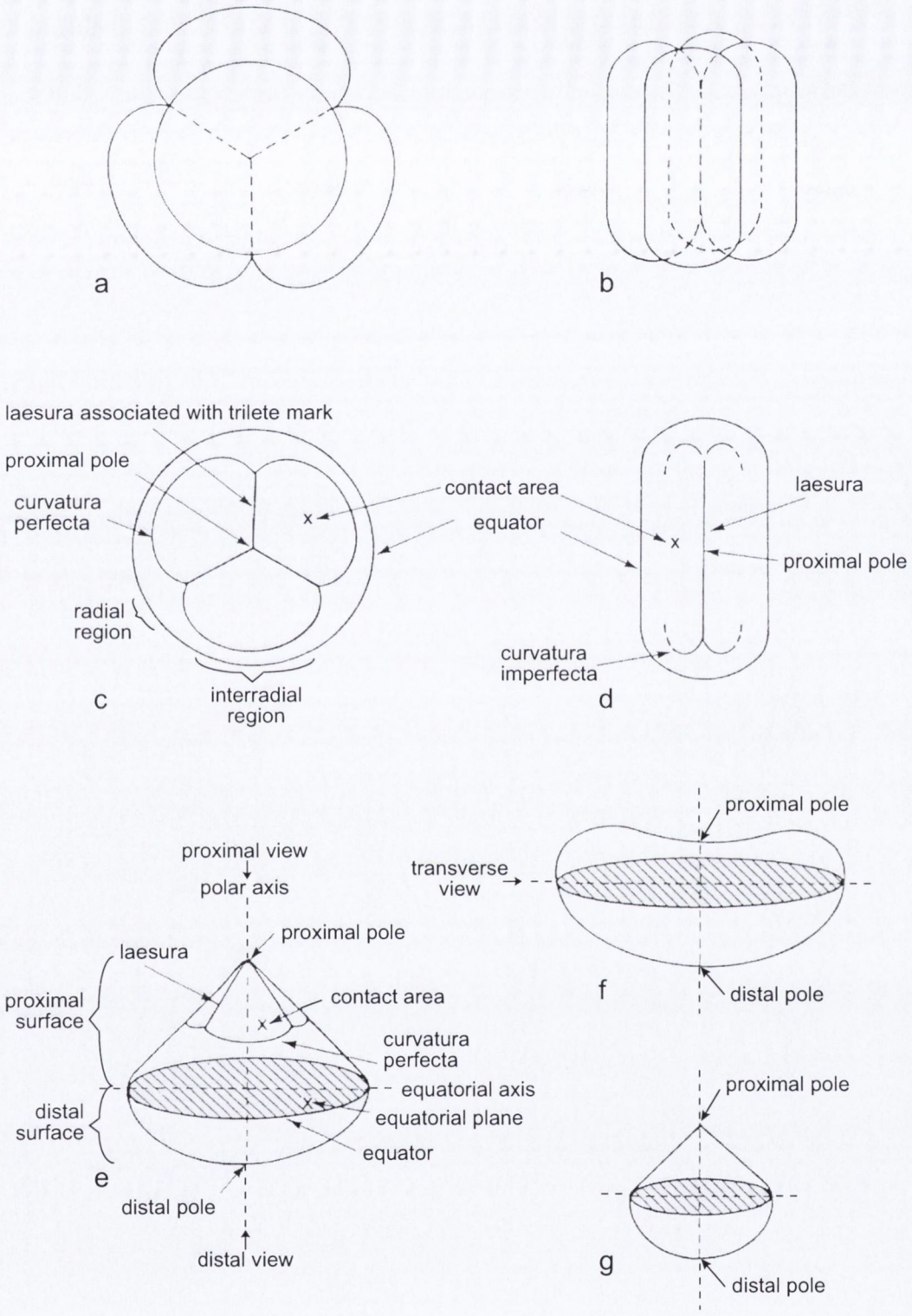


Figure 5.2 Tetrad associations, symmetry, orientation and trilete mark characteristics - a) Tetrahedral tetrad of radiosymmetric spores; b) tetragonal tetrad of bilaterally symmetrical spores; c) Proximal view of trilete spore from tetrahedral tetrad; d) proximal view of monolete spore from tetragonal tetrad; e) equatorial view of trilete spore; f) equatorial longitudinal view of monolete spore; g) equatorial transverse view of monolete spore (after Smith & Butterworth 1967; Playford & Dettman 1996).

3. Solidity or otherwise of processes – Processes may be hollow or solid.

4. Closed/open processes – Processes either open into, and freely communicate with the vesicle cavity or are plugged at the base (Figure 5.6 p-t).

5. Eilyma (wall) structure/sculpture – The vesicle wall may be single- or double-layered and may be covered in relatively fine negative or positive ornamentation.

6. Excystment opening – Different types of excystment structures are illustrated in Figure 5.7. Most of the taxa recorded from Kentucky and the Mississippi Valley possess a simple median split (e.g. Plate 18, Figure 13).

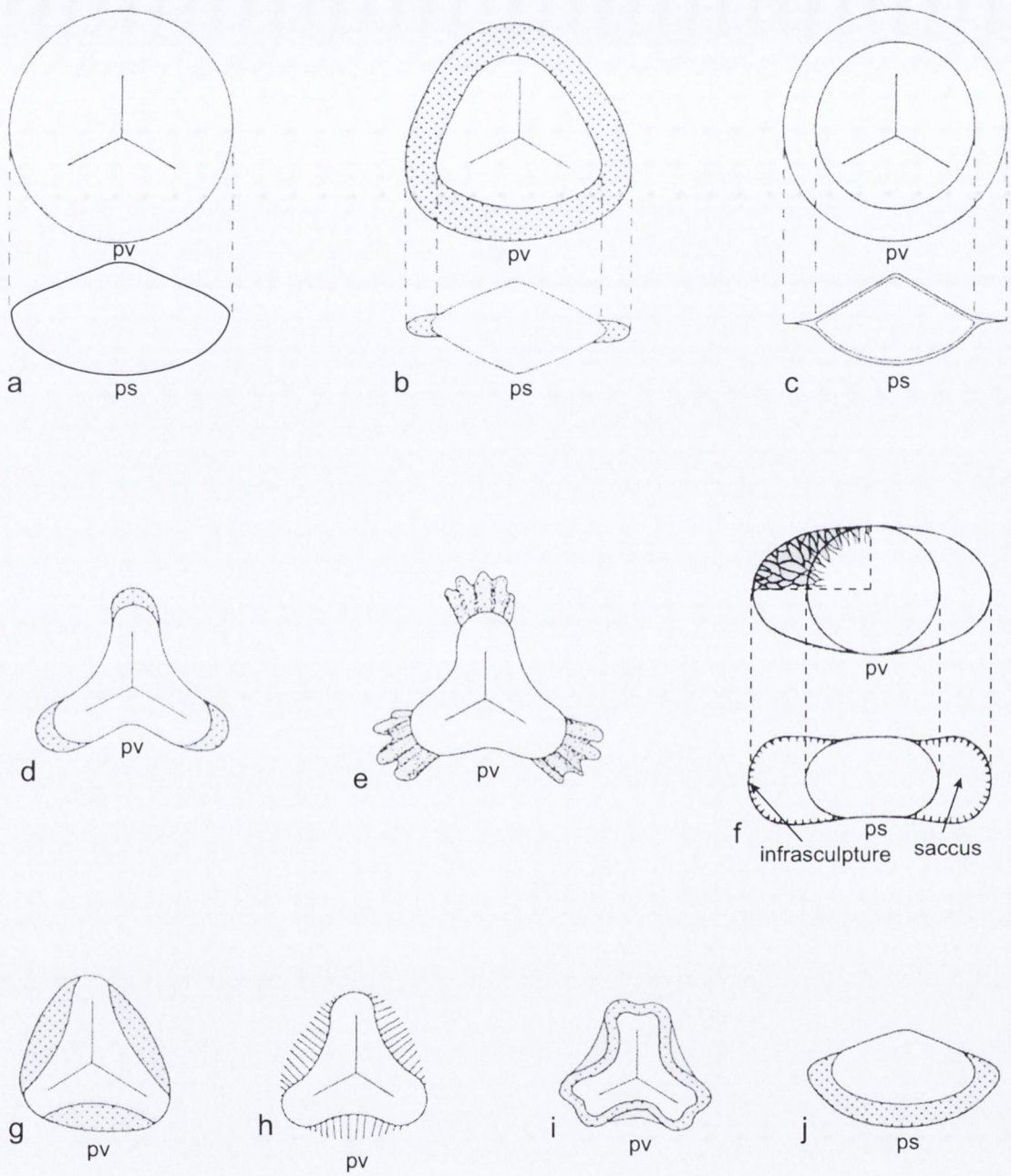


Figure 5.3 Structural characteristics of spore exines and modifications of spore walls, a - acamerate trilete spore; b-e, g-j - camerate trilete spores; f - saccate trilete spore - a) single layered exine; b) cingulum; c) zona; d) valvae; e) auriculae; f) saccus; g) interradial crassitude; h) corona; i) kyrtome; j) patina (equatorial/distal). Abbreviations are as follows: pv - polar view, ps - polar section. (after Smith & Butterworth 1967; Playford & Dettman 1996).

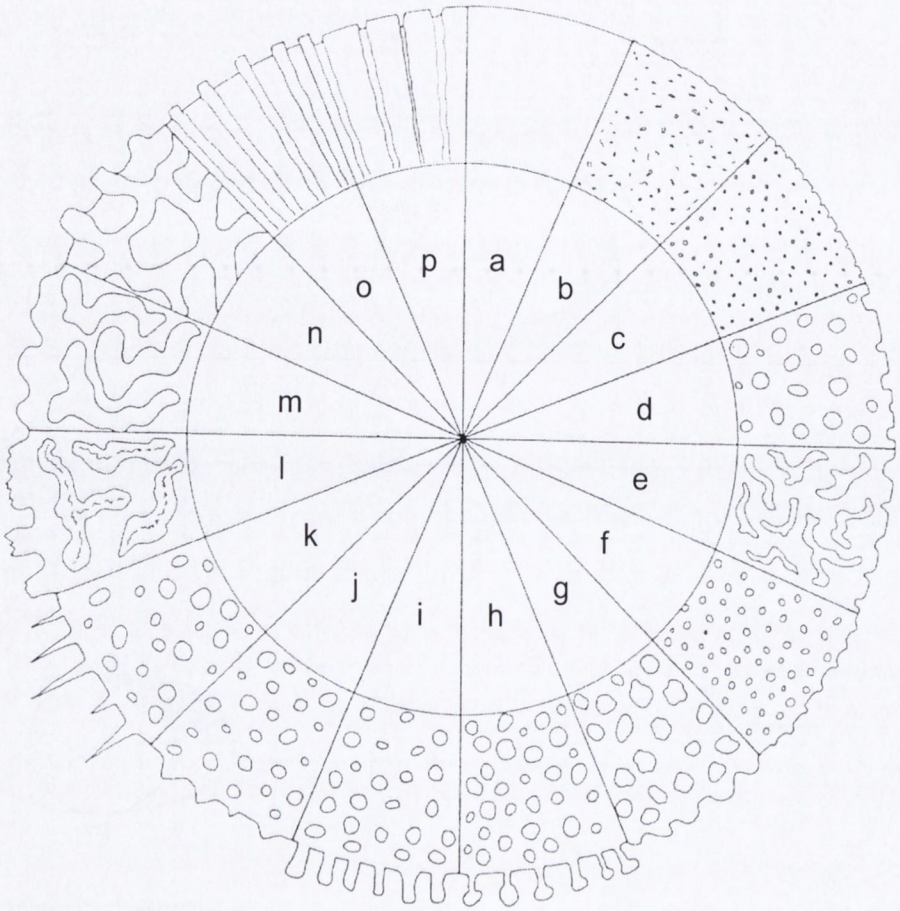


Figure 5.4 Composite schematic diagram of characteristic surface features of spore walls, a - unsculptured; b-p - various sculpturing modes. Each sector shows the sculpturing pattern in profile (optical section, as at equator) around the periphery and in plan view elsewhere - a) laevigate; b) scabrate; c) punctate; d) foveolate; e) vermiculate; f) granulate; g) verrucate; h) pilate; i) baculate; j) conate; k) spinose; l) cristate; m) rugulate; n) reticulate; o) cicatricose; p) canaliculate. (after Playford & Dettman 1996).

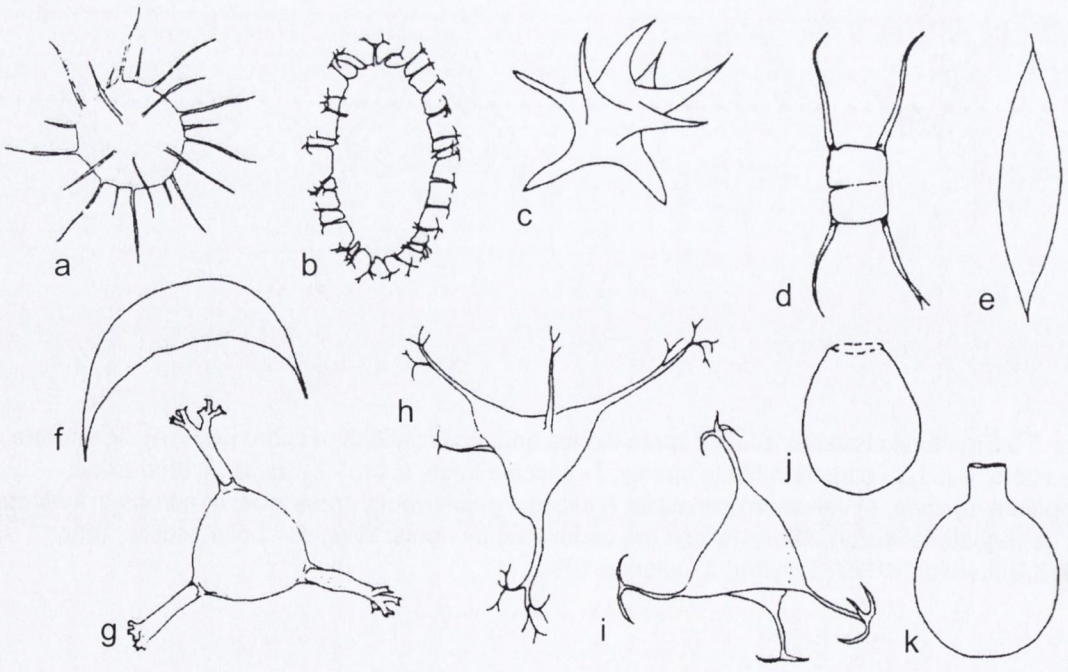


Figure 5.5 Basic acritarch shapes - a) spheroidal; b) ellipsoidal; c) stellate; d) rectangular; e) fusiform; f) crescentic; g) triapsidate; h) triquitrate; i) tetrahedral; j) ovoid; k) flask-shaped (after Playford 2003).

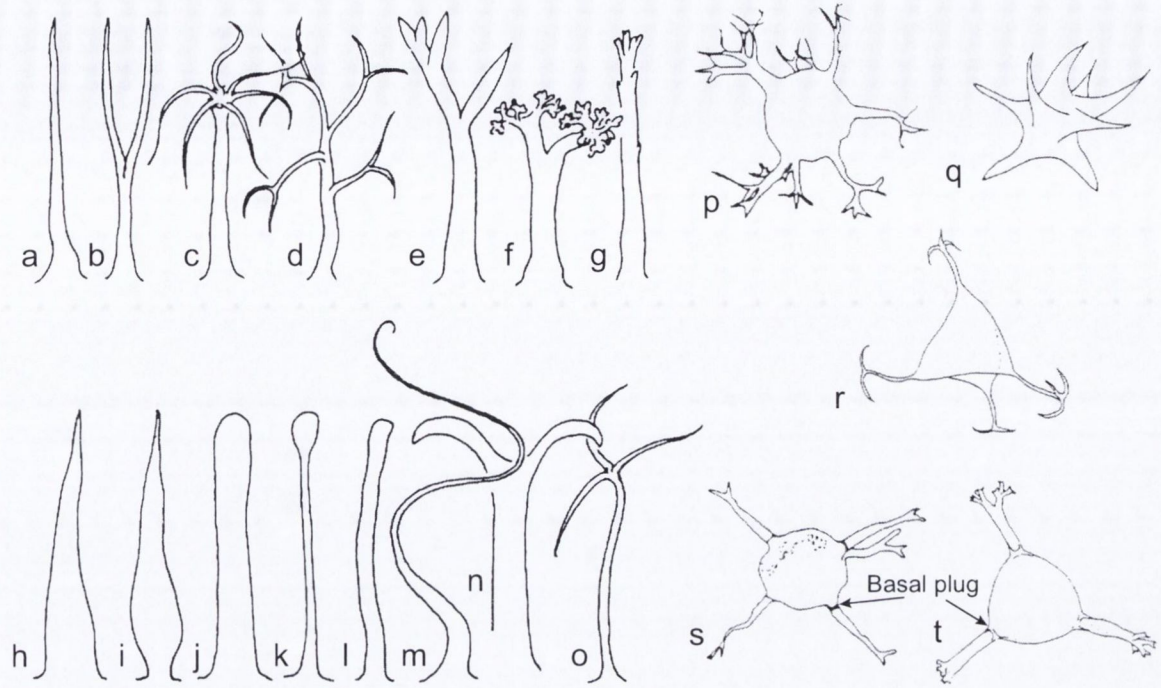


Figure 5.6 Acritarch processes - a), h) simple, spine-like (acuminate); b) bifurcate; c), o) palmate; d)-g), n) branching (various modes); i) with basal constriction; j) cylindical; k) capitate (with bulbous or clavate termination; l) flagelliform (whip-like); p)-r) processes open into and freely communicating with vesicle cavity; s), t) processes plugged (after Playford 2003).

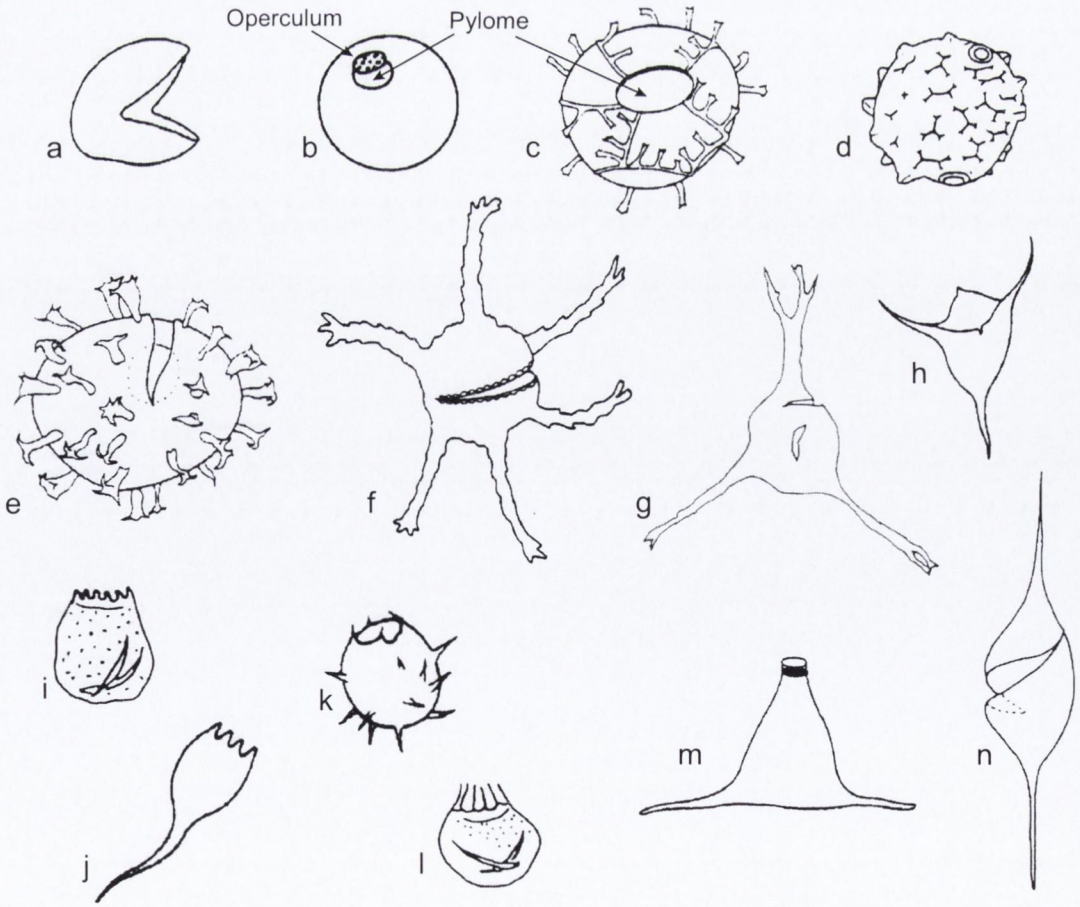


Figure 5.7 Types of excystment openings - a) median split; b), c) pylome and operculum; d) with two pylomes; e), g) simple lateral rupture; f) lateral rupture and ornamented borders; h) epityche; i), j) minium; k), l) minitium; m) epibystra; n) trochospiral suture (after Playford 2003).

CHAPTER 6
SYSTEMATIC PALYNOLOGY

6. 1 NOMENCLATURE AND CLASSIFICATION OF MIOSPORES

The botanical affinities of most Palaeozoic miospores are unknown and this has resulted in classification schemes based on morphology (Potonié & Kremp 1955; Neves & Owens 1966; Smith & Butterworth 1967; Playford & Dettmann 1996). Spores are named in accordance with the International Code of Botanical Nomenclature (McNeill *et al.* 2007), which recognises the use of form-genera to describe the dissociated parts of fossil plants (i.e. leaves, roots, pollen, fruiting bodies etc.) (Playford & Dettmann 1996). Most pre-Quaternary plant fossils are preserved in this manner and fossil associations of parent plants and spores are rare (e.g. Bek & Opluštil 2004).

Classification of spores at the suprageneric level has been discussed and various schemes proposed. An early scheme was proposed by Potonié and Kremp in 1955. Modifications to the scheme of Potonié & Kremp (1955) were suggested by Dettmann (1963), Neves & Owens (1966) and Smith & Butterworth (1967).

The scheme of Neves & Owens is followed herein and is shown in Figure 6.1. This scheme is similar to that of Dettmann (1963). Slight modifications are made; Neves & Owens (1966) used the term 'camerate' instead of 'cavate', as the original definition of cavate applies to pollen grains where the intexine and exoexine have separated, and the exoexine is reticulate (Smith & Butterworth 1967; Faegri & Iversen 1989). Dettmann's use of 'Perino-' to describe cavate (camerate) monolete and trilete spores is rejected and 'Perinotriletes' is retained for spores possessing a perispore, and the term 'Cameratriletes' is proposed for trilete miospores which do not posses a true perine (Neves & Owens 1966).

6. 2 SYSTEMATIC PALYNOLOGY

NOTES ON SYSTEMATIC DESCRIPTIONS

The original diagnosis or description of species is given where possible. Where the original diagnosis is not given or requires translation (e.g. Naumova 1953; Potonié & Kremp 1955; Menéndez & Azcuy 1972), translations and descriptions are taken from Smith &

Dianostic feature	Category																Rank
	SPORITES																Anteturma
Aperture	TRILETES													MONO-LETES	HILATES		Turma
Stratification	ACAMERATITRILETES							CAMERATITRILETES						PERINO-TRILETES			Suprasubturma
Equatorial features / Membrane attachment	AZONOTRILETES			ZONOTRILETES				SOLUTITRILETES		MEMBRANATITRILETES							Subturma
Sculpture / Equatorial thicknening /extension	LAEVIGATI	APICULATI	MURONATI	AURICULATI	TRICASSITI	PSEUDOCINGULATI	CINGULATI	PLANATI	DECORATI	CONTINUATI	MEMBRANATI	PATINATI	CINGULICAMERATI	POLYCAMERATI	VARIOCAMERATI		Infraturma

Figure 6.1 Suprageneric classification scheme proposed by Neves & Owens 1966.

Butterworth (1967) and Higgs *et al.* (1988). Where spore taxa have been emended, the original and/or emended diagnosis or description is given as appropriate. Occurrence data refer to occurrences within the Mississippi Valley and Kentucky as recorded in this study. Eight new spore taxa are described. These have been left in open nomenclature pending publication - *Leiotriletes* sp. A, *Acanthotriletes* sp. A, *Apiculatisporites* sp. A, *Converrucosisporites* sp. A, *Rugospora* sp. A , *Vallatisporites* sp. A, *Vallatisporites* sp. B and *Vallatisporites* sp. C.

Plates are located in Appendix II

Antetuma: SPORITES H. Potonié 1893
Turma: TRILETES (Reinsch) Dettman 1963
Suprasubturma: ACAMERATITRILETES Neves & Owens 1966
Subturma: AZONOTRILETES (Luber) Dettman 1963
Infraturma: LAEVIGATI (Bennie & Kidston) R. Potonié 1956

Genus CALAMOSPORA Schopf in Schopf, Wilson & Bentall 1944

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

Remarks: A number of species of *Calamospora* possess few defining characteristics and thin, structureless, unornamented exines. They are defined by their size.

Calamospora liquida Kosanke 1950

Plate 1, figure 2.

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

Holotype: Kosanke 1950, pl. 9, fig. 1.

Type Locality: Shoal Creek Coal, Bond Co., Illinois, USA; Pennsylvanian.

Size: 56-106μm (39 specimens) (Higgs *et al.* 1988). 70-90μm (2 specimens, present study).

Original Description: (Kosanke 1950, p. 41-42) Spores are radial trilete, spherical, or have numerous plications of the spore coat. The holotype measures 81.6 x 84μm and the known size range is from 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 commissure is usually thin but distinct. The area contagionis is not present. The spore coat is laevigate and translucent. It is less than 2μm in thickness, which probably accounts for the numerous plications.

Remarks: This species is defined by its relatively long trilete rays.

Occurrence: Hannibal Shale; Lower Warsaw; Waltersburg, Mississippi Valley.

Calamospora microrugosa (Ibrahim) Schopf, Wilson & Bentall 1944

Plate 1, figure 4.

1932 *Sporonites microrugosus* Ibrahim in Potonié, Ibrahim & Loose, p. 447, pl. 14, fig. 9.
1944 *Calamospora microrugosus* (Ibrahim) Schopf, Wilson & Bentall 1944, p. 52.

Holotype: Ibrahim 1932, pl. 14, fig. 9.

Type Locality: Ägir Seam, Ruhr Coalfield, Germany; top of Westphalian B.

Size: 70-100μm (Potonié & Kremp 1955). 72-100μm (4 specimens, present study).

Diagnosis: (Smith & Butterworth 1967, p. 133, translated from description and diagnosis in Potonié & Kremp 1955, p.49) Amb more or less circular, often very irregular due to compression folding. Laesurae weakly ridged, straight or flexuose, one-third of radius. Exine structureless, about 2/3μm in thickness. Secondary compression folds numerous.

Remarks: This species is defined by its size range of 70-100μm.

Occurrence: Chattanooga Shale; Bachelor Formation; Northview Shale; Hannibal Shale; McCraney; Prospect Hill; Keokuk; Lower Warsaw; Tar Springs Sandstone; Hardinsburg

Sandstone; Menard Limestone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Sunbury Shale; Henley Bed, Borden Formation; Jacobs Chapel; Rockford Limestone; Portsmouth Member, Cuyahoga Formation, Kentucky.

Calamospora nigrata (Naumova) Allen 1965

Plate 1, figure 5.

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.

Size: 90-100μm (Naumova 1953). 60-80μm (26 specimens, Allen 1965). 60μm (single specimen, present study).

Original Diagnosis: (Naumova 1953, p. 23, in Russian).

Remarks: This species is defined by its dark contact areas.

Occurrence: Hannibal Shale; Northview Shale; Burlington; Lower Warsaw; Cypress Sandstone; Fraileys Shale; Tar Springs Sandstone; Menard Limestone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Henley Bed; Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Calamospora pallida (Loose 1932) Schopf, Wilson & Bentall 1944

Plate 1, figure 3.

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.

Holotype: Loose 1932, pl. 18, fig. 31.

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

Size: 55-70μm (Potonié & Kremp 1955). 55-70μm (2 specimens, present study).

Diagnosis: (Smith & Butterworth 1967, p. 135, translated from description and diagnosis in Potonié & Kremp 1955, p. 50) Amb circular to oval. Laesurae weakly ridged, straight, up to one-third of radius. Exine about 1μm thick.

Remarks: This species is defined by its size range of 55-70μm. Of all the *Calamospora* species in the USA samples, *Calamospora pallida* is the most common.

Occurrence: Chattanooga Shale; Bachelor Formation; Northview Shale; Hannibal Shale; McCraney; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Upper Warsaw; Ste Genevieve; Hardinsburg Sandstone; Tar Springs Sandstone; Menard Limestone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Sunbury Shale; Bedford Shale; Henley Bed; Nancy Member, Borden Formation; Jacobs Chapel; Portsmouth Member; Rockford Limestone, Cuyahoga Formation, Kentucky.

Calamospora parva Guennel 1958

Plate 1, figure 6.

Holotype: Guennel 1958, p. 71, fig. 16.

Type Locality: Outcrop coal, Upper Block *b* zone, Daviess County, Indiana, USA; Pottsville Series.

Size: 32-45μm (Guennel 1958). 38-55μm (5 specimens, present study).

Original Description: (Guennel 1958, p. 70) Spores are trilete and radially symmetrical, originally spherical in shape, and round to elliptical in compressed state. Folding due to the membranous nature of the spore coat, which is laevigate to infragranulose, is common. The

exine may be thicker and darker in the contact areas. The trilete rays are short and measure from 5 to 7μm. The longest diametric measurement ranges from 32 to 45μm and averages 37μm. The holotype is 38μm at the longest diameter.

Remarks: This species is defined by its size of 30-55μm.

Occurrence: Chattanooga Shale; Bachelor Formation; Northview Shale; Hannibal Shale; McCraney; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Upper Warsaw; Ste Genevieve; Bethel Sandstone, Cypress Sandstone; Fraileys Shale; Hardinsburg Sandstone; Tar Springs Sandstone; Waltersburg; Menard Limestone; Kinkaid Limestone, Mississippi Valley. Bedford Shale; Henley Bed, Borden Formation; Jacobs Chapel; Rockford Limestone; Farmers Member; Nancy Member, Kentucky.

Calamospora perrugosa (Loose 1934) Schopf, Wilson & Bentall 1944
Plate 1, figure 1.

1934 *Laevigati-sporites perrugosus* Loose p. 145, pl. 7, fig. 13.
1944 *Calamospora perrugosa* (Loose) Schopf, Wilson & Bentall, p. 52.

Holotype: Loose 1934, pl. 7, fig. 13.

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

Size: >100μm (Potonié & Kremp 1955) 150-152μm (2 specimens, present study).

Original Description: (Smith & Butterworth 1967, p. 137, translated from diagnosis in Potonié & Kremp 1955, p. 51) Amb oval to round. Laesurae simple, straight, one-third of radius or more. Exine relatively thin, markedly folded.

Remarks: This is the largest of the species of *Calamospora*, and is defined by its size range of >100μm.

Occurrence: Hannibal Shale; Burlington; Lower Warsaw; Cypress Sandstone; Tar Springs Sandstone, Mississippi Valley. Henley Bed, Farmers Member, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus LEIOTRILETES (Naumova) Potonié & Kremp 1954

Type species: *Leiotriletes sphaerotriangulus* (Loose) Potonié & Kremp 1954

Leiotriletes trivialis Naumova 1953

Plate 1, figure 7.

Holotype: Naumova 1953, p. 164, pl. 5, fig. 14. No 3450/3788.

Type Locality: Russian Platform, Russia; Upper Devonian.

Size: 25-35μm (Naumova, 1953). 40-46μm (5 specimens, present study).

Original Diagnosis: Naumova, 1953, p. 45, in Russian.

Diagnosis: (Higgs *et al.* 1988, p. 51) Trilete acamerate miospores. Amb triangular with convex sides and rounded to pointed apices. Suturae distinct, straight and accompanied by distinct narrow labra, 1-2.5μm in overall width, which extend to the equatorial margin. Exine thin or finely infragranulate.

Occurrence: Chattanooga Shale; Hannibal Shale; Northview Shale; Prospect Hill; Burlington; Lower Warsaw; Kinkaid Limestone, Mississippi Valley. Henley Bed, Borden Formation; Jacobs Chapel; Portsmouth Member, Cuyahoga Formation, Kentucky.

Leiotriletes tumidus Butterworth & Williams 1958

Plate 1, figure 8.

Holotype: Butterworth & Williams 1958, pl. 1, fig. 11.

Type Locality: Kilsyth Coking Seam, Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian.

Size: 34-52μm (23 specimens, Butterworth & Williams 1958). 49μm (single specimen, present study).

Original Diagnosis: (Smith & Butterworth 1967, p.124, from Butterworth & Williams 1958, p. 359) Elongated triangular in outline; spore coat smooth. Proximal hemisphere tumid, typically with ray folds.

Description: (Smith & Butterworth 1967, p. 124) Amb subtriangular, sides straight or convex, angles rounded. Laesurae simple, straight, two-thirds of radius or greater, frequently reaching almost to equator. Prominent folds, often of unequal length, frequently accompany the laesurae. Exine less than 2μm in thickness.

Occurrence: Caseyville Formation, Mississippi Valley.

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

Plate 1, figure 9.

1988 *Leiotriletes* sp. Higgs, Clayton & Keegan, p. 51, pl. 1, fig. 6.

Size: 40-50μm (8 specimens, Higgs *et al.* 1988). 44-55μm (2 specimens, present study).

Description: Trilete acamerate miospores. Amb triangular with convex sides and pointed apices. Suturae distinct, simple, small, around 1/3 of the spore radius. Exine around 1.5μm in thickness, laevigate, with darkened presumably thickened zone developed adjacent to the suturae.

Remarks: This species is very similar to *Leiotriletes* sp. of Higgs *et al.* 1988.

Occurrence: McCraney; Keokuk, Mississippi Valley.

Genus PUNCTATISPORITES Ibrahim emend. Potonié & Kremp 1954

Type species: *Punctatisporites punctatus* (Ibrahim) Ibrahim 1933

Punctatisporites irrasus Hacquebard 1957

Plate 1, figure 10.

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

Holotype: Hacquebard 1957, pl. 1, fig. 7.

Type Locality: West Gore and Blue Beach Samples, Horton Group, Nova Scotia, Canada; Mississippian.

Size: 67-83μm (20 specimens, Hacquebard 1957), 50-108μm (3 specimens, present study).

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 often present and of major proportions; diameter 67-83 microns (on twenty specimens).

Occurrence: Northview Shale; McCraney; Lower Warsaw; Kinkaid Formation, Mississippi Valley. Henley Bed, Borden Formation, Kentucky.

Punctatisporites minutus (Kosanke 1950) Peppers 1964

Plate 1, figure 12.

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

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

Size: Holotype 29μm (Kosanke 1950). 22-42μm (18 specimens, Smith & Butterworth 1967). 29-42μm (9 specimens, present study).

Original Diagnosis: (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 punctate.

Description: (Smith & Butterworth 1967) Laesurae usually straight (6-11μm), unless spore is compressed obliquely; contact areas sometimes slightly darkened. No detectable sculpture at spore margin; very finely granulate or punctuate. Appearance of exine may be due to infrasculpture. Folding slight or absent.

Remarks: This species is distinguished from other species of *Punctatisporites* by its smaller size.

Occurrence: Hannibal Shale; Northview Shale; McCraney; Lower Warsaw; Cypress Sandstone, Mississippi Valley. Henley Bed, Nancy Member, Borden Formation, Kentucky.

Punctatisporites planus Hacquebard 1957

Plate 1, figure 11.

Holotype: Hacquebard 1957, p. 308, pl. 1, fig. 12.

Type Locality: West Gore and Blue Beach Samples, Horton Group, Nova Scotia, Canada; Mississippian.

Size: 50-64μm (12 specimens, Hacquebard 1957). 45-60μm (17 specimens, present study).

Original 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 2 microns thick; occasionally one major compression fold; diameter 50-64 microns (on twelve specimens).

Occurrence: Chattanooga Shale; Bachelor Formation; Northview Shale; Hannibal Shale, McCraney; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Upper Warsaw; Cypress Sandstone; Hardinsburg Sandstone; Tar Springs Sandstone; Menard Limestone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Sunbury Shale; Bedford Shale;

Henley Bed; Farmers Member, Nancy Member, Borden Formation; Jacobs Chapel; Rockford Limestone; Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus RETUSOTRILETES Naumova emend. Streel 1964

Type species: *Retusotriletes simplex* Naumova 1953

Retusotriletes communis Naumova 1953

Plate 2, figure 2.

Holotype: Naumova 1953, pl. 15.

Type Locality: Zadonsk Beds, Russkiy Brod, Orel Province, USSR; Devonian.

Size: 45-57μm (25 specimens, Higgs *et al.* 1988). 47-52μm (3 specimens, present study).

Original Diagnosis: (Naumova 1953, in Russian).

Description: (Higgs *et al.* 1988, p. 52) Trilete acamerate miospores, amb rounded. Suturae distinct, straight to slightly sinuous, or with narrow labra 1.5-2.5μm overall width; suturae extending 1/2-3/4 of the spore radius, and terminating in curvaturae perfectae. Contact areas smooth, well defined, often with a slightly darkened outer margin. Exine 1.5-3μm in thickness laevigate to scabrate.

Occurrence: Hannibal Shale; Lower Warsaw; Waltersburg; Menard Limestone, Mississippi Valley. Henley Bed, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Retusotriletes crassus Clayton, Johnston, Sevastopulo & Smith 1980

Plate 2, figure 3.

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.* 1980, p. 90, fig. 3 D, G & H.

Type Locality: Channel sample depth 200-205 ft, Ballyvergin borehole, County Clare, Ireland.

Size: 43-73μm (Clayton *et al.* 1980). 48μm (1 specimen, present study).

Original Diagnosis: (Clayton *et al.* 1980, p.97) Spores radial, trilete, acamerate. Amb circular to oval, or rarely rounded 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 exoexine is relatively thick and more or less laevigate.

Occurrence: Hannibal Shale; Northview Shale; Keokuk; Lower Warsaw, Mississippi Valley. Henley Bed, Farmers Member, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Retusotriletes famenensis Naumova 1953

Plate 2, figures 7 & 8.

1953 *Retusotriletes famenensis* Naumova, pl. 15, fig. 18 *non* p. 110, pl. 1b, fig. 44.

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

Type Locality: Russian Platform, Upper Devonian.

Original Diagnosis: (Naumova 1953, in Russian).

Size: 42-57μm (22 specimens, Higgs *et al.* 1988). 51-60μm (2 specimens, present study).

Description: (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 3/4 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.

Occurrence: Hannibal Shale; McCraney; Lower Warsaw; Menard Limestone, Mississippi Valley.

Retusotriletes incohatus Sullivan 1964b

Plate 2, figure 4.

1964b *Retusotriletes incohatus* Sullivan, p. 1251-1252, pl. 1, figs. 5-7.
1974 *Aneurospora incohata* (Sullivan) Streel in Becker *et al.*, p. 24.

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

Type Locality: Lower Limestone Shales of Puddlebrook, Forest of Dean, Gloucestershire, South West England; Mississippian.

Size: 35-70μm (100 specimens, Sullivan 1964b). 32-66μm (52 specimens, present study).

Original Description: (Sullivan 1964b, p. 1251) 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 of the radius of spore. Tecta straight or sinuous, may be bounded by narrow lips with frilled margins, or they may be surmounted by 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 discernable in the contact areas. The exine outside of the contact areas is darker in colour and is characteristically laevigate. Secondary folds are rare; sometimes parallel sided folds surround part of the equator.

Remarks: The species is abundant throughout the Mississippian of Kentucky and the Mississippi Valley.

Occurrence: Chattanooga Shale; Bachelor Formation; Northview Shale; Hannibal Shale; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Upper Warsaw; Hardinsburg Sandstone; Waltersburg; Menard Limestone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Sunbury Shale; Bedford Shale; Henley Bed, Nancy Member, Borden Formation; Jacobs Chapel; Rockford Limestone; Portsmouth Member, Cuyahoga Formation, Kentucky.

Retusotriletes triangulatus (Streel) Streel 1967

Plate 2, figure 5.

1964 *Phyllothecotriletes triangulatus* Streel, p. 237, pl. 1, figs. 3-5.
1967 *Retusotriletes triangulatus* Streel (Streel), p. 24-25.
1976 *Retusotriletes piperatus* Playford, p 10-11, pl. 1, figs. 14-17.

Holotype: Streel 1964, p. 237, pl. 1, fig. 4.

Type Locality: Vesdre Syncline, Goé, East Belgium; Middle Devonian (Lower Givetian).

Size: 36-74μm (40 specimens, Higgs *et al.* 1988). 67μm (Single specimen, present study).

Original Diagnosis: (Streel 1964, in French).

Description: (Higgs *et al.* 1988, p. 52-53) 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 presumably thickened apical zone developed at the proximal pole. Outline of darkened zone conformable with amb, with apices coincident with suturae and extending up to 1/2 the spore radius. Darkened zone uniform or slightly thinner towards the pole. Large compression folds common.

Occurrence: Prospect Hill; Lower Warsaw; Menard Limestone; Kinkaid Limestone, Mississippi Valley. Henley Bed, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus WALTZISPORA Staplin 1960

Type species: *Waltzispora lobophora* (Waltz) Staplin 1960

Waltzispora polita (Hoffmeister, Staplin & Malloy) Smith & Butterworth 1967

Plate 2, figure 1.

1955 *Granulati-sporites politus* Hoffmeister, Staplin & Malloy, p. 389, pl. 36, fig. 13.
1967 *Waltzispora polita* (Hoffmeister, Staplin & Malloy) Smith & Butterworth, p. 159-160, pl. 6, fig. 4.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 389, pl. 36, fig. 13.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 26-38µm (Hoffmeister *et al.* 1955). 33-35µm (2 specimens, present study).

Original Description: (Hoffmeister *et al.* 1955, p. 389) Spores radial, trilete; proximal outline subtriangular, interradial margins concave or slightly convex, radial margins rounded; original lenticular shape in dictated by preferred proximal-distal orientation; surface smooth to infra-punctate; trilete suture broad, two-thirds to three-fourths spore radius; spore coat moderately thin, transparent to translucent.

Occurrence: Palestine Sandstone, Mississippi Valley.

Infraturma: APICULATI (Bennie & Kidston) R. Potonié 1954

Genus ACANTHOTRILETES Naumova emend. Potonié & Kremp 1954

Type species: *Acanthotriletes cilicatus* (Knox) Potonié & Kremp 1954

Acanthotriletes falcatus (Knox) Potonié & Kremp 1955

Plate 2, figure 9.

1948 18K, Knox, p. 157, fig. 15.

1950 *Spinoso-sporites falcatus* Knox, p. 131, pl. 17, fig. 205.

1955 *Acanthotriletes falcatus* (Knox) Potonié & Kremp, p. 84.

1967 *Acanthotriletes falcatus* (Knox) Potonié & Kremp; Smith & Butterworth, p. 178-179, pl. 8, figs. 11-12.

Neotype: No holotype was cited by Knox (1950). Smith & Butterworth 1967, p. 178-179, pl. 8, fig. 11.

Type Locality: Possil Main Seam, Cawder Cuilt borehole, Central Coalfield, Scotland; Namurian.

Size: Neotype 42μm, 29-47μm (Smith & Butterworth 1967). 47-49μm (2 specimens, present study).

Diagnosis: (Smith & Butterworth 1967, p. 178, from diagnosis in Knox 1950, p. 313) Triangular miospores, triradiate mark extending to the margin. Surface with spinose processes, 5-7μm long, straight or curved and spaced 3-5μm apart.

Occurrence: Burlington; Keokuk; Lower Warsaw; Upper Warsaw, Mississippi Valley.

Acanthotriletes persibus Higgs 1975

Plate 2, figures 10 & 11.

Holotype: Higgs 1975, p.395, pl. 1, fig. 14.

Type Locality: Lyraun Cove Shale Member (check), Porters Gate Formation, Hook Head, County Wexford, Ireland; Mississippian.

Size: 33-51μm (30 specimens, Higgs 1975). 43μm (1 specimen, present study).

Original Diagnosis: (Higgs 1975, p. 395) Trilete acamerate miospores; amb rounded to oval. Suturae usually indistinct, length three-fourths or more of spore radius, in some cases bordered by thin labra 1-2μm in over-all width. Ornament of broad-based spinae 2-6μm in length, present on both surfaces. Spinae with discrete bases, subcircular in outline, convex-sided, 1-2μm in width, tapering abruptly to less than 1μm in diameter from about one-third of their length. Distance between spinae 2-3μm, approximately 30-40 projecting from equatorial margin. Exine thin, infrapunctate, and consistently showing concentric compression folds.

Occurrence: Chattanooga Shale; Hannibal Shale; Prospect Hill, Mississippi Valley.

***Acanthotriletes* sp. A**

Plate 2, figure 12.

Size: 48μm (single specimen).

Description: Trilete acamerate miospore. Amb subtriangular. Trilete mark obscured. Ornament of spinae and coni on the proximal and distal surfaces. Spinae and coni 2-3μm high, bases of spinae 1-2μm wide, bases of coni 2-6μm wide. Ornament discreet and evenly spaced. Around 26 spines occur on the spore margin.

Occurrence: Jacobs Chapel, Cuyahoga Formation, Kentucky.

Genus ANAPLANISPORITES Jansonius 1962

Type species: *Anaplanisporites telephorus* (Klaus) Jansonius 1962

Anaplanisporites centrosus Higgs, Clayton & Keegan 1988

Plate 3, figure 1.

Holotype: Higgs, Clayton & Keegan 1988, pl. 3, fig. 3.

Type Locality: Sample P45, depth 715' 4", borehole DM 64, Killarecastle, 6.5km northeast of Moate, County Westmeath, Ireland; Mississippian.

Size: 36-46μm (20 specimens, Higgs *et al.* 1988). 30-38μm (2 specimens, present study).

Original Diagnosis: (Higgs *et al.* 1988, p. 54) Miospores trilete, acamerate. Amb subcircular to circular, suturae indistinct to distinct, straight, extending to equator of the miospore. Exine thin, 0.5-1μm. Distal surface and equator bear a dense ornament of coni, regularly disposed, which taper to narrow pointed apices, occasionally curved, 1-3μm in height and 0.5-2μm in width. Grana infrequently occur between the coni. Between 1 and 3 compression folds normally are present.

Occurrence: Lower Warsaw, Mississippi Valley.

Genus ANAPICULATISPORITES

Type Species: *Anapiculatisporites isselburgensis* Potonié & Kremp 1954

Anapiculatisporites hystricosus Playford 1964

Plate 3, figure 2.

Holotype: Playford 1964, p. 16-17, pl. 3, fig. 15. GSC No. 13096.

Type Locality: GSC loc. 6408, Cheverie Formation, Horton Group, Nova Scotia, Canada; Mississippian.

Size: 38-58μm (25 specimens, Playford 1964). 46μm (1 specimen, present study).

Original Diagnosis: (Playford 1964, p. 16) Spores radial, trilete; amb convexly subtriangular. Laesurae more or less straight, distinct to perceptible, extending to equatorial margin or almost so; accompanied by relatively dark, slightly elevated lips that are 3-4μm in overall width. Proximal surface laevigate. Whole of distal surface prominently sculptured with broadly based spinae and coni; sculpturing elements mainly discrete but sometimes fused in groups of up to three individuals. Bases of spinae-coni subcircular in surface view, 1-4μm (average 2.5μm) in diameter, up to 7μm apart. Spinae

taper abruptly from their broad, conical, somewhat bulbous bases, thus possessing sharp, slender, apical portions; overall length of spinae 3-6μm. Coni are identical to basal parts of spinae; in lateral view, coni are rounded to slightly pointed, 1-2.5μm (average 1.5μm) in height. Approximately 15-28 coni and spinae project from equatorial margin. Exine 1.5-2.5μm thick, excluding sculpture.

Occurrence: Chattanooga Shale; Keokuk; Lower Warsaw, Mississippi Valley.

Genus APICULATISPORITES

Apiculatisporites sp. A

Plate 3, figure 3.

Size: 44-53μm (3 specimens).

Description: Acamerate trilete miospores, amb subcircular. Trilete mark distinct, simple, straight, extending 3/4 of spore radius. Distal surface covered in coni; discreet, 3-4μm in height, bases 4-6μm in width. Exine around 3μm thick. 23-25 elements projecting at equator.

Occurrence: Prospect Hill Siltstone, Mississippi Valley.

Genus APICULIRETUSISPORA Streel emend. Streel 1967

Type species *Apiculiretusispora brandtii* Streel 1964

Apiculiretusispora fructicosa Higgs 1975

Plate 3, figure 4.

1962 *Retusotriletes verrucosus* Caro-Moniez, pl. 1, figs. 1-2, *non R. verrucosus* (Naumova in litt.) Kedo 1955.

1974 *Apiculiretusispora verrucosa* (Caro-Moniez) Streel *in* Becker *et al.*, p. 24.

1975 *Apiculiretusispora fructicosa* Higgs, p. 395, pl. 1, figs. 23-25.

Holotype: Higgs 1975, p. 395, pl. 1, fig. 25.

Type Locality: Old Red Sandstone, West Hook Head, County Wexford, Ireland.

Size: 55-90μm (34 specimens, Higgs 1975). 49-62μm (3 specimens, present study).

Original Diagnosis: (Higgs 1975, p. 395) Trilete acamerate miospores; amb subcircular. Suturae distinct, simple or with narrow labra, straight, length ⅔-¾ of the spore radius, terminating in curvature perfectae. Contact areas distinct, laevigate and slightly depressed. Remainder of exine bearing dense to sparsely distributed ornament of coni, pila and short bacula. Elements discreet, with rounded or flattened tops, 1.5-4μm in width and 0.5-2μm in width. Exine approximately 2μm in thickness, in many cases with dark, presumably thickened areas adjacent to suturae.

Occurrence: Chattanooga Shale; Hannibal Shale; Northview Shale; McCraney; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Upper Warsaw, Mississippi Valley. Bedford Shale; Sunbury Shale; Henley Bed, Farmers Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Apiculiretusispora occulta Turnau (Coleman 1991)

Plate 3, figures 5 & 6.

1978 *Apiculiretusispora occultus* Turnau, p. 5, pl. 1, fig. 8.
1991 *Apiculiretusispora occulta* Coleman, p. 58, pl. 2, figs. 2-3.

Holotype: Turnau 1978, pl. 1, fig. 8, slide VII/74.

Type Locality: Wierzchovo 9 borehole, 3424.0m, North West Poland; Mississippian.

Size: 38-54μm (21 specimens, Turnau 1978). 50-61μm (3 specimens, present study).

Original Diagnosis: (Turnau 1988, p. 5-6) Spores trilete, amb subcircular. Laesurae straight, extending ½ radius of spores, simple or accompanied by narrow lips. Exine covered all over by irregularly distributed grana of different size; these are always less than

1μm in diameter, most often 1-2μm apart, apparently loosely connected with the exine. Arcuate ridges reduced, indistinct. Contact faces considerably to only slightly thinner than the remaining spore surface. The ornament partly or completely missing.

Remarks: This species is placed in the genus *Apiculiretusispora* because of its granulate ornament.

Occurrence: Prospect Hill; Burlington; Keokuk, Mississippi Valley. Henley Bed, Farmers Member, Borden Formation, Kentucky.

Genus CONVERRUCOSISPORITES Potonié & Kremp 1954

Type species: *Converrucosisporites triquetrus* (Ibrahim) Potonié & Kremp 1954

Converrucosisporites* cf. *C. sulcatus (Wilson & Kosanke) Potonié & Kremp

Plate 3, figure 10.

Size: 56-84μm (4 specimens, present study).

Description: Trilete acamerate miospores, amb subtriangular. Suturae simple, straight, extending 1/2 to 2/3 of the spore diameter. Both surfaces covered in dense verrucae, discrete, few fused. Verrucae typically uniform on a single specimen, 4-8μm basal width, 2-5μm in height. Exine thick, usually 3-4μm in thickness.

Remarks: The ornament of this species closely resembles that of *Verrucosisporites nitidus*, but spores are subtriangular in outline. Specimens are similar to *Converrucosisporites sulcatus* (Wilson & Kosanke) Potonié & Kremp 1955, but are slightly larger than those described by Wilson & Kosanke (1944); no measurement of the verrucae are given in the original description.

Occurrence: Chattanooga Shale; Hannibal Shale; Prospect Hill; Lower Warsaw; Tar Springs Sandstone, Mississippi Valley. Jacobs Chapel; Rockford Limestone, Cuyahoga Formation, Kentucky.

***Converrucosisporites* sp. A**

Plate 3, figure 9.

Size: 40μm (single specimen).

Description: Trilete acamerate miospores; amb triangular, sides concave, angles broadly rounded. Outline of spore irregular. Laesurae straight, simple extending 3/4 to 4/5 of the spore radius. Distal and proximal exine covered by verrucae with rounded apices, 1-2μm in height, and 2-6μm in width. Ornamentation slightly modifies the margin. Thick exine, 3-4μm.

Remarks: *Converrucosisporites* sp. A is similar to *Converrucosisporites armatus* Dybová & Jachowicz but has a more rounded and lower ornament.

Occurrence: Bedford Shale, Kentucky.

Genus CRASSISPORA (Bharadwaj) emend. Sullivan 1964

Type species: *Crassispora kosankei* (Potonié & Kremp) Bharadwaj emend. Smith & Butterworth 1967

Crassispora aculeata Neville 1968

Plate 3, figure 7.

Holotype: Neville 1968, p. 443-446, pl. 2, fig.5.

Type Locality: Lower Ardross Limestone, East Fife Coast section between St Monace and Pittenweem, Scotland; Viséan.

Size: 56-96μm (25 specimens, Neville1968). 92-102μm (2 specimens, present study).

Original Diagnosis: (Neville 1968, p. 443-444) Spores subcircular. Trilete mark prominent; the rays extend to, or nearly to, the spore margin and are accompanied by high ray folds. Apical papillae are usually visible in intertectal areas and strongly developed curvaturae are often seen. The crassitude is poorly developed and usually appears as only a

slight darkening. The exine is about 1.5-2μm thick but usually there is at least one fold present. The exine is infrapunctate and bears spines on the distal surface which are present at the margin and overlap onto the proximal surface at the extremities of the rays. These spines rarely approach cones and range in length from about 1.5-14μm and in basal width from about 1-5.5μm. Between 10 and 30 spines occur at the equator but most frequently about 20 are present. On individual specimens they are fairly constant in size. The spines either taper gradually or have slightly bulbous bases and are often bent over near the tips. A mixture of these two types of spine can occur on individual specimens.

Range: Upper Viséan (Neville 1968).

Remarks: Because of their dark colour and thick walls, specimens of *Crassispora aculeata* in the present study closely resemble *Spinozonotriletes uncatus*. The two species are defined by the occurrence of a radial crassitude (darker, thickened radial band) in the former.

Occurrence: Fraileys Shale; Waltersburg; Menard Limestone, Mississippi Valley.

Crassispora kosankei (Potonié & Kremp) Bharadwaj 1957

Plate 3, figure 8.

1955 *Planisporites kosankei* Potonié & Kremp, p. 71, pl. 13, figs. 208-213.
1957 *Planisporites ovalis* Bharadwaj, p. 86, pl. 23, figs. 9-10.
1957b *Crassispora ovalis* Bharadwaj, p. 126, pl. 25, figs. 73-76.
1957b *Crassispora kosankei* (Potonié & Kremp) Bharadwaj, p. 127.
1957 *Apiculatisporites apiculatus* (Ibrahim) Dybová & Jachowicz (*non sensu* Ibrahim), p. 87, pl. 15, figs. 1-4.

Holotype: Potonié & Kremp 1955, pl. 13, fig. 208.

Type Locality: Seam R_1, Friedrich Thyssen 2/5 (Wehofen) Colliery, Ruhr Coalfield, Germany; Westphalian.

Size: 68-85μm (Potonié & Kremp 1955). 67-74μm (2 specimens, present study).

Diagnosis: (Smith & Butterworth 1967, p. 234 emended from Potonié & Kremp 1955, p. 71) Amb circular to subcircular or oval; in equatorial view shape more or less lenticular, somewhat distorted by crassitudinous thickening at the equator. Laesurae simple, extending nearly to amb; not usually apparent, or split wide open to give a triangular-shaped tear in polar region. Exine with finely granulate or punctate infrasculpture. Distal surface covered by small coni rarely exceeding 2μm in height or breadth, irregularly distributed, bases not touching; up to 5μm between coni which project at margin. Proximally, ornament is lacking or greatly reduced. Exine in region of crassitudinous thickening darker in colour than in polar region.

Occurrence: Caseyville Formation, Mississippi Valley.

Crassispora maculosa (Knox) Sullivan 1964

Plate 3, figures 11 & 12.

1948 23K Knox, p. 158, fig. 26.

1950 *Verrucoso-sporites maculosus* Knox, p. 318.

1955 *Apiculatisporis maculosus* (Knox) Potonié & Kremp, p. 78.

1964 *Crassispora maculosa* (Knox) Sullivan, p. 376.

Holotype: None designated by Knox (1950). Lectotype: Smith & Butterworth 1967, pl. 18, fig 8.

Type Locality: Dunfermline Splint Seam, Lumphinnans No. 1 Colliery, West Fife Coalfield, Scotland; Namurian.

Size: 100-120μm (Knox 1950). 84-108μm (5 specimens, present study).

Diagnosis: None given in Sullivan 1964 (Smith & Butterworth 1967, p. 235) Amb circular. Laesurae ridged; ridges narrow and flexuose, one-half to three-quarters of spore radius. Equatorial craasitude 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.

Remarks: *Crassispora maculosa* becomes very common in the Chesterian of the Mississippi Valley.

Occurrence: Keokuk; Tar Springs Sandstone; Waltersburg; Menard Limestone; Kinkaid Limestone, Mississippi Valley.

Genus CYCLOGRANISPORITES Potonié & Kremp 1954

Type species: *Cyclogranisporites leopodi* (Kremp) Potonié & Kremp 1954

Cyclogranisporites commodus Playford 1964

Plate 3, figure 13.

Holotype: Playford 1964, p. 12-13, pl. 2, fig. 3-5. GSC No. 13069.

Type Locality: GSC loc. 6400, Horton Group, Nova Scotia, Canada; Mississippian.

Size: 32-52μm (20 specimens, Playford 1964). 36-46μm (10 specimens, present study).

Original Diagnosis: (Playford 1964, p. 12) Spores radial, trilete, originally spherical; amb subcircular to oval. Laesurae distinct, simple, straight; length about two thirds of amb radius. Exine about 1μm thick. Proximal and distal hemispheres sculptured with closely spaced (0.5-1μm apart), minute grana having circular to polygonal bases up to 1.5μm (usually 0.5-1μm) in greatest diameter; height of grana averages 0.5μm. Proximal polar sculpture often relatively finer than that of distal surface. Peripheral, arcuate folding common. Equatorial margin finely notched.

Occurrence: Bachelor Formation; Hannibal Shale; Northview Shale; McCraney; Burlington; Keokuk; Lower Warsaw; Cypress Sandstone; Hardinsburg Sandstone, Mississippi Valley. Jacobs Chapel of Henley Member, Cuyahoga Formation, Kentucky.

Genus GRANULATISPORITES (Ibrahim) Potonié & Kremp 1954

Type species: *Granulatisporites granulatus* Ibrahim 1933

Granulatisporites granulatus Ibrahim 1933

Plate 4, figure 1.

1933 *Granulati-sporites granulatus* Ibrahim, p. 22, pl. 6, fig. 51.

1955 *Granulatisporties granulatus* Ibrahim; Potonié & Kremp, p. 58, pl. 12, figs. 157-160.

Holotype: Ibrahim 1933, pl. 6, fig. 51.

Size: 25-35μm (Potonié & Kremp 1955). 30-41μm (2 specimens, present study).

Type Locality: Bismarck Seam, Ruhr Coalfield, Germany; Westphalian.

Original Diagnosis: (Smith and Butterworth 1967, p. 140, translated from Potonié & Kremp 1955, p. 58) Amb triangular; sides generally slightly convex, rarely concave. About 55 grana on the margin; grana rather more than 1μm in diameter.

Occurrence: Cypress Sandstone; Menard Limestone, Mississippi Valley.

Granulatisporites microgranifer Ibrahim 1933

Plate 4, figure 2.

1933 *Ganulati-sporites microgranifer* Ibrahim, p. 22, pl. 5, fig. 32.

1938 *Azonotriletes microgranifer* (Ibrahim) Luber in Luber & Waltz, pl. 7, fig. 92.

1955 *Granulatisporites microgranifer* Ibrahim; Potonié & Kremp, p. 58, pl. 2, figs. 149-151.

Holotype: Ibrahim 1933, pl. 5, fig. 32.

Type Locality: Ägir Seam, Ruhr Coalfield, Germany; Westphalian B.

Size: Holotype 32.5μm (Ibrahim 1933). 25-40μm (Potonié & Kremp 1955). 30-42μm (3 specimens, present study).

Original Diagnosis: (Smith and Butterworth 1967, p. 140, translated from Potonié & Kremp 1955, p. 58) Amb triangular with more or les concave sides. Approximately 100 grana on the margin.

Description: (Smith and Butterworth 1967, p. 140) Amb triangular, angles narrowly rounded, sides concave. Laesurae simple, straight, one-half to two-thirds of spore radius. Ornament of minute grana, bases touching; barely discernable at the equator; fairly even in distribution. Exine very thin, folding frequent.

Remarks: This species is rare in samples from Kentucky.

Occurrence: Henley Bed, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky. Kinkaid Limestone; Mississippi Valley.

Genus NEORAISTRICKIA Potonié 1956

Type species: *Neoraistrickia truncatus* (Cookson) Potonié 1956

Neoraistickia loganensis (Winslow) Coleman & Clayton 1987

Plate 4, figures 3 & 4.

1962 *Granulatisporites logani* Winslow, p. 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 logani* (Winslow) Coleman & Clayton, pl. 1, figs. 5-9, text-fig. 5.

1997 *Umbonatisporites baculatus* Coquel & Moreau-Benoit; Abdesselan-Rouighi & Coquel, pl. II, fig. 9.

2003 *Mooreisporites* sp. of Atta-Peters & Anan-Yorke, p. 17, text-fig. 2, 7.

2003 *Mooreisporites* sp. of Melo & Loboziak, pl. V, fig. 9.

2009 *Neoraistrickia loganesis* (Winslow) Coleman & Clayton; Playford & Melo, p. 5-7, pl. 1, figs. 1-12; pl. 2, figs. 1-10; text-fig. 3.

Holotype: Winslow 1962, pl. 22, fig. 11.

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

Size: 50-95μm (20 specimens, Coleman & Clayton 1987), 39-103μm (100 specimens, Playford & Melo 2009). 46μm (2 specimens, present study).

Emended Diagnosis: (Coleman & Clayton 1987, p. 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.

Remarks: The range of *Neoraistrickia loganensis* recorded in the present study is similar to the range given by Coleman and Clayton (1987).

Occurrence: Burlington; Keokuk, Mississippi Valley. Henley Bed, Nancy Member, Borden Formation, Kentucky.

Genus PILOSISPORITES Delcourt & Sprumont 1955

Type species: *Pilosisporites trichopapillosus* (Thiergart 1933) Delcourt & Sprumont 1955

Pilosisporites verutus Sullivan & Marshall 1966

Plate 4, figure 5.

1966 *Pilosisporites verutus* Sullivan & Marshall, p. 267-268, pl. 1, fig. 10.

Holotype: Sullivan & Marshall 1966, pl. 1, fig. 10.

Type Locality: Shales below Blackbyre Limestone, Locality 3, sample no. 66, Midland Valley, Scotland; Lower Carboniferous.

Size: 40-50μm (9 specimens, Sullivan & Marshall 1966), 36μm (single specimen, present study).

Original Diagnosis: (Sullivan & Marshall 1966, p. 267-268) Amb triangular with straight or slightly concave sides; exine ornamented with prominent spines 3-8μm high and up to 3.5μm wise in basal diameter; spines larger and more densely set at the apices.

Original Description: (Sullivan & Marshall, p. 268) Amb triangular with straight or slightly concave sides and rounded apices. Exine 1.5μm thick, laevigate, but may be pitted due to corrosion. Trilete mark well defined, rays two-thirds of the radius of the spore. Distal and equatorial portions of the exine ornamented with spines 3-8μm in length and 1.5-3.5μm wide at the base. Spines are usually evenly tapered, but in some examples (pl. 1, fig. 11) there may be a slight constriction near the top, and the crests are then more rounded. The spinose ornamentation is typically coarser and denser at the apices. Spines are set about 1μm apart at the equator and 3-7μm apart on the distal surface.

Occurrence: Tar Springs Sandstone, Mississippi Valley.

Genus PUSTULATISPORITES Potonié & Kremp 1954

Type species: *Pustulatisporites pustulatus* Potonié & Kremp 1954

Pustulatisporites dolbii Higgs, Clayton & Keegan 1988

Plate 4, figure 6.

1970 *Pustulatisporites* cf. *P. gibberosus* (Hacquebard) Playford; Combaz & Streel, p. 230, pl. 3, fig. 2.

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

Holotype: Higgs, Clayton & Keegan 1988, p. 56, pl. 4, fig. 9.

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

Size: 45-65μm (53 specimens, Higgs *et al.* 1988), 44-47μm (2 specimens, present study).

Original Diagnosis: (Higgs *et al.* 1988, p. 56) Trilete acamerate miospores. Amb subcircular to 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 discreet or rarely coalescent, evenly distributed but never crowded and reduced or absent on the proximal surface.

Occurrence: Chattanooga Shale; Hannibal Shale; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Upper Warsaw, Mississippi Valley. Bedford Shale, Kentucky.

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

Type species: *Raistrickia grovensis* Schopf in Schopf, Wilson and Bentall 1944

Raistrickia aculeata Kosanke 1950

Plate 5, figure 1.

Holotype: Kosanke 1950, pl. 10, fig. 9.

Type Locality: McCleary's Bluff Coal, Illinois, USA; McLeansboro Group.

Size: 62-74μm (Kosanke 1950), 82μm (single specimen, present study).

Diagnosis: (Smith and Butterworth 1967, p. 180, from description in Kosanke 1950, p. 46). Laesurae simple, about two-thirds radius, inconspicuous. Ornament of numerous, long, slightly tapering, blunt spines, 7-10μm in length and 2-2.5μm in breadth.

Occurrence: Keokuk, Mississippi Valley.

Raistrickia clavata Hacquebard emend. Playford 1964

Plate 4, figures 7 & 8.

1957 *Raistrickia clavata* Hacquebard, p. 310, pl. 1, fig. 25.

1957 *Raistrickia pistillata* Hacquebard, p. 310-311, pl. 2, fig. 2.

1964 *Raistrickia clavata* (Hacquebard) Playford, p. 24-25, pl. VI, figs. 5-10.

Holotype: Hacquebard 1957, pl. 1, fig. 25.

Type Locality: West Gore, Horton Group, Nova Scotia; Mississippian.

Size: 48-85μm (140 specimens, Playford 1964). 64-69μm (2 specimens, present study).

Original Description: (Hacquebard 1957, p. 310) Spore radial, trilete; subtriangular with convex sides and rounded corners in proximal view; trilete distinct, two-thirds spore radius; ornamentation large club-shaped projections, relatively closely set; projections 7-8.5 microns long, 3-4 microns wide at base, 6-7 microns wide at top, where they are thickened; nine projections occur at equator; spore coat 2 microns thick.

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 some specimens, ranges from half to nine-tenths of spore radius. Prominent, comprehensive, pilate sculpture consisting of crowded to loosely distributed, smooth, discreet, club- or mushroom-shaped processes; small, pointed to rounded coni and some verrucae often additional 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 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.

Occurrence: Lower Warsaw; Menard Limestone; Palestine Sandstone, Mississippi Valley. Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Raistrickia condylosa Higgs 1975

Plate 4, figure 11.

Holotype: Higgs 1975, p. 396, pl. 2, fig.16.

Type Locality: Porters Gate Formation, Hook Head, County Wexford, Ireland; Mississippian.

Size: 66-120μm (26 specimens, Higgs 1975). 52μm (single specimen, present study).

Original Diagnosis: Trilete acamerate miospores; amb subcircular to rounded-triangular. Suturae distinct or obscured by ornament, simple, straight, length one-half to two-thirds of spore radius. Exine 1-3μm in thickness, bearing prominent baculate sculpture, which is densely to sparsely distributed and slightly reduced on proximal surface, 5-30μm in length, 1-4μm in width, parallel-sided to slightly curved, with rounded or more commonly, bulbous terminations, 2-6μm in width; pointed elements rare. Processes broad-based, 3-7μm in diameter, discrete, but may fuse to form low ridges, 1-3μm in height. Arcuate compression folds common.

Occurrence: Menard Limestone, Mississippi Valley.

Raistrickia fulva Artüz 1957

Plate 4, figures 14 & 15.

Holotype: Artüz 1957, pl. 3, fig. 19.

Type Locality: Sülü Seam, Zonguldak Coalfield, Turkey; Westphalian.

Size: 40-55 μm (Artüz 1957). 41-53μm (2 specimens, present study).

Original Diagnosis: (Smith & Butterworth 1967, p.180, from description in Artüz 1957, p. 246) Rounded-triangular. Laesurae reach to margin. Exine covered by 4-5μm, finger-shaped warts which are distinctly recognisable at the amb.

Occurrence: Hardinsburg Sandstone; Waltersburg Sandstone, Mississippi Valley.

Raistrickia macrura (Luber) Dolby and Neves 1970

Plate 4, figures 10 & 13.

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, p. 637, pl. 1, fig 7.

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

Type Locality: Portishead Beds, Burrington Combe, Mendips; England; Early Carboniferous.

Size: 51-63μm (8 specimens, Dolby & Neves 1970). 33-38μm (2 specimens, present study).

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 1/2 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.

Occurrence: Prospect Hill; Keokuk, Mississippi Valley. Bedford Shale, Henley Bed, Farmers Member, Borden Formation, Kentucky.

Raistrickia saetosa (Loose) Schopf, Wilson & Bentall 1944
Plate 4, figure 12.

1932 *Sporonites saetosus* Loose in Potonié, Ibrahim & Loose, p. 452, pl. 19, fig. 56.
1933 *Setosi-sporites saetosus* (Loose) Ibrahim, p. 26.
1944 *Raistrickia saetosa* (Loose) Schopf, Wilson & Bentall, p. 56.

Holotype: Potonié & Kremp 1955, pl. 15, fig. 264, after Loose 1932.

Type Locality: Bismarck Seam, Ruhr Coalfield, Germany; Westphalian.

Size: 60-90μm (Potonié & Kremp 1955). 66μm (1 specimen, present study).

Diagnosis: (Smith & Butterworth 1967, p. 181, translated from Potonié & Kremp 1955, p. 87) Laesurae two-thirds radius; bacula up to 14μm in length, varying in size, ends partly cleaved.

Occurrence: Hardinsburg Sandstone, Mississippi Valley. Henley Bed, Farmers Member, Borden Formation, Kentucky.

Raistrickia variabilis Dolby & Neves 1970

Plate 4, figure 16.

1960 *Hystrichospaeridium trifurcatum* Eisenack; Caro Moniez, pl. 17, figs, 10-11.
1967 *Raistrickia* sp. Nevels & Dolby, pl. 1, fig. 4.
1970 *Raistrickia variabilis* Dolby & Neves, p. 636, p.1, fig. 6.

Holotype: Dolby & Neves 1970, p. 636-637, pl. 1, fig. 6. (53μm).

Type Locality: Portishead Beds, Upper Old Red Sandstone, Burrington Combe, Mendip Hills, England; Late Devonian.

Size: 37-78μm (Dolby & Neves 1970). 41μm (single specimen, present study).

Original Description: (Dolby & Neves 1970, p. 636) Spores radial, trilete and acamerate. Amb circular to oval. Exine granular to finely wrinkled. Thickness difficult to determine but greater than 2μm. Trilete rays half to three-quarters the spore radius in length and usually obscured by the ornament. Tecta straight to sinuous and where well developed they are sometimes surrounded by a narrow area of thinner exine up to 3μm wide. The ornament is moderately densely distributed and consists of baculae 6-16μm high with bases 3.5-7μm in diameter. The longer ones tend to be parallel sided or only slightly tapering but the shorter ones taper markedly. The processes, often broken, broaden slightly near their tops which are either blunt or slightly multifurcate. 20-40 processes project from the equator.

Occurrence: Lower Warsaw, Mississippi Valley. Nancy Member, Borden Formation; Henley Member, Jacobs Chapel, Cuyahoga Formation, Kentucky.

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

Plate 4, figure 9.

1988 *Raistrickia* sp. A Higgs, Clayton & Keegan 1988, p. 59, pl. 5, fig. 4.

Size: 38-50μm (6 specimens, Higgs *et al.* 1988). 33-48μm (5 specimens, present study).

Description: Trilete acamerate miospores. Amb subcircular. Suturae obscured by ornament. Exine ornamented with bacula 3-6μm high, 1.1-3μm in diameter. Sides of elements parallel or upwardly convergent, tops rounded, fattened or expanded. Elements mostly discrete, some fused at the base to form areas of reticulation.

Remarks: Specimens closely resemble those described by Higgs *et al.* 1988. The ornament is similar to that of *Raistrickia spathula* but specimens are smaller.

Occurrence: Caseyville Formation, Mississippi Valley. Sunbury Shale; Jacobs Chapel; Rockford Limestone; Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus SCHOPFITES Kosanke 1950

Type species: *Schopfites dimorphus* Kosanke 1950

Schopfites claviger Sullivan emend. Higgs, Clayton & Keegan 1988

Plate 5, figures 2 & 3.

1968 *Schopfites claviger* Sullivan, p. 121, pl. 25, figs. 1-10.

1986 *Raistrickia claviger* (Sullivan) Playford & Satterthwait, p. 16, pl. 6, figs. 1-4, text-fig. 3.

1988 *Schopfites claviger* (Sullivan) Higgs, Clayton & Keegan, p. 59-60, pl. 5, figs. 6-8, 13.

1990 *Raistrickia clavigera* (Sullivan) Playford & Satterthwait; Playford, p. 85-125, pl. 2, figs. 7, 8.

Holotype: Sullivan 1968, p. 121, pl. 25, fig. 9.

Type Locality: Cementstone Group, Ayrshire, Scotland; Mississippian.

Size: 40-52μm (28 specimens, Sullivan 1968). 47-49μm (4 specimens, present study).

Emended Diagnosis: (Higgs *et al.* 1988, p. 59-60) Miospores trilete, acamerate or camerate. Amb subcircular to circular. Suturae indistinct to distinct, extend almost to equator of miospore. Intexine, 1-1.5μm in thickness, indistinct to distinct, approximately conformable with the amb, 3/4 to 5/6 of the miospore diameter. Distal surface and equator ornamented with pila, rounded bacula and rare coni and verrucae. The size of the elements range from 1-5μm in height and 0.5-3μm in width, the mean height and width is 3.1μm and 1.75μm respectively. The minimum mean height and width on any specimen are 3μm and 1μm. Sculptural elements are normally discreet though the density and distribution of the elements may be variable on any specimen giving a patchy appearance. Exoexine, 1-2μm in thickness, occasionally folded. Proximal surface and intexine laevigate.

Remarks: This species is common throughout the Osagean, Meramecian and Chesterian of the Mississippi Valley.

Occurrence: Cypress Sandstone; Fraileys Shale; Hardinsburg Sandstone; Tar Springs Sandstone; Waltersburg; Menard Limestone; Kinkaid Limestone, Mississippi Valley. Farmers Member, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus TRICIDARISPORITES Sullivan & Marshall 1966

Type species: *Tricidarisporites balteolus* Sullivan & Marshall, 1966

Tricidarisporites* cf. *T. arcuatus Neville in Neves *et al.* 1973

Plate 5, figure 4.

Size: 46μm (single specimen, present study).

Description: Trilete acamerate miospore. Amb subtriangular, sides straight, apical angles rounded. Folding of exine common at radial apices. Suturae indistinct, simple, gaping, extending 4/5 of spore radius, and distinguished by a lighter (thinner?) trilete zone. Ornamentation consists of grana and pila. Ornament concentrated on distal surface and in interradial areas, becoming smaller and sparser towards apices and on proximal surface. Pila approximately 1μm high in interradial areas to <1μm at apices.

Remarks: A single, rather poorly preserved specimen was found in the Mississippi Valley samples which is similar to *Tricidarisporites arcuatus* although labra are not observed. *Tricidarisporites fasciculatus* (Love) Gueinn *et al.* in Neves *et al.* 1973 has more pronounced labra and is ornamented on the distal surface as well as the interradial margins.

Occurrence: Tar Springs Sandstone, Mississippi Valley.

Genus UMBONATISPORITES Hibbert & Lacey 1969

Type species: *Umbonatisporites variabilis* Hibbert & Lacey 1969

Umbonatisporites distinctus Clayton 1971

Plate 5, figures 5 & 6.

1960 *Apiculatisporites* sp. Balme, p. 28, pl. 4, figs. 10-11.

1971 *Umbonatisporites distinctus* Clayton, p. 591, pl. 4, figs. 4-6.

1971 *Acanthotriletes turriculaeformis* Kemp & Playford *in* Playford, p. 20, pl. 6, figs. 7-15.

1976 *Dibolisporites distinctus* (Clayton) Playford, p. 16, pl. 2, figs. 9-12.

Holotype: Clayton 1971, pl. 4, fig. 4.

Type Locality: Sample 5, Birnieknowes bore at 1259ft. 3ins., 1.5 miles NW of Cockburnspath, East Scotland.

Size: 43-126μm (53 specimens, Clayton 1971). 64-90μm (2 specimens, present study).

Original Diagnosis: (Clayton 1971, p. 592) Amb circular to oval. Trilete mark rarely seen. Suturae straight, simple, length 1/3 to 1/2 of spore radius. Ornament evenly distributed over spore surface except contact areas, which have extremely reduced ornament or are devoid of all ornament. Ornament consists mainly of cylindrical elements with either one or two constrictions, and flat or slightly concave tops, surmounted by a single spina or conus.

Occurrence: Henley Bed, Borden Formation, Kentucky.

Genus VERRUCOSISPORITES Ibrahim emend. Smith 1971

Type Species: *Verrucosisporites verrucosus* (Ibrahim) Ibrahim 1933

Verrucosisporites nitidus (Naumova 1953) Playford 1964

Plate 5, figure 7.

1953 *Lophotriletes grumosus*, Naumova p. 57, pl. 7, figs. 14, 15.
1956 *Lophotriletes* aff. *grumosus*, (Naumova) Ishchnko, p. 40, pl.7, fig. 74.
1963 *Verrucosisporites nitidus*, (Naumova) Playford, p.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 p. 1252-3, pl. 1, figs. 9-15.

Holotype: Naumova 1953, p. 576, pl. 7, fig. 14 or 15; holotype not indicated by Naumova, according to Playford (1964). Holotype designated by Playford 1964, p.14, pl. III, figs. 3-6.

Type Locality: (Naumova 1953) Petino Beds (Upper Frasnian); Petino, Voronezh region, U.S.S.R; Devonian.

Size: 40-64μm (Naumova 1953). 30-64μm (Ischenko 1956). 33-58μm (9 specimens, present study).

Amplification of Diagnosis: (Playford 1964, p. 14) Spores radial, trilete; amb circular, subcircular, or roundly subtriangular. Laesurae simple, straight to sinuous, perceptible to

obscure (often semi-hidden by sculpture); length one half to four fifths of amb radius. Comprehensive, relatively coarse sculpture consisting of numerous, smooth, discreet, 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 5µm). 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.

Remarks: Specimens of *Verrucosisporites nitidus* from the Mississippi Valley material appear to be at the lower end of the size range given for this species.

Occurrence: Chattanooga Shale; Northview Shale; Hannibal Shale; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Cypress Sandstone; Waltersburg; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Sunbury Shale; Bedford Shale; Henley Bed; Farmers Member, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation; Kentucky.

Infraturma: MORORNATI Potonié & Kremp 1954

Genus CONVOLUTISPORA Hoffmeister, Staplin & Malloy 1955

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

Convolutispora caliginosa Clayton & Keegan *in* Clayton, Keegan & Sevastopulo 1982

Plate 5, figure 8.

1967 *Convolutispora* sp. Neves & Dolby, pl. 2, fig. 7.

1977 *Convolutispora* sp. Clayton *et al.* pl. 5, figs. 17-18.

1977 *Convolutispora* sp. A. Keegan, p. 548, pl. 2, figs. 6-9.

1982 *Convolutispora caliginosa* Clayton & Keegan in Clayton, Keegan & Sevastopulo, p. 522, pl. 1, figs. 5, 6, 8, 9.

Holotype: Clayton, Keegan & Sevastopulo 1982, p. 522, pl. 1, fig. 6.

Type Locality: Sample 9, Ardmore, County Waterford, Ireland; Carboniferous.

Size: 49-76μm (25 specimens, Clayton *et al.* 1982). 59μm (1 specimen, present study).

Original Diagnosis: (Clayton *et al.* 1982, p. 522) Amb circular to subcircular. Trilete mark indistinct; typically obscured by ornament. Suturae straight, simple; length 2/3 – 3/4 spore radius. Exine 1.5-3μm thick, rarely folded. Ornament on both distal and proximal surfaces consists of flat-topped to rounded, anastomising ridges 3-6μm high, but reduced in the contact areas. The 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 a similar order to their width. Non-polar compressions are common.

Occurrence: Portsmouth Member, Cuyahoga Formation, Kentucky.

Convolutispora florida Hoffmeister, Staplin & Malloy 1955

Plate 5, figures 9 & 10.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 384, pl. 38, fig. 6.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 39-50μm (Hoffmeister *et al.* 1955). 45-60μm (14 specimens, present study).

Original Description: (Hoffmeister *et al.* 1955, p. 384) Spores radial, trilete; proximal outline circular to subcircular; ornamentation closely packed coarse obervermiculate convoluted ridges, often flattened by compression; trilete rays slightly exceed one-half spore radius, usually obscured, lips raised; spore coat relatively thick, translucent; diameter 39-50 microns, ridges 2.8-6.3 microns wide.

Occurrence: Hannibal Shale; Northview Shale; Keokuk; Lower Warsaw, Cypress Sandstone; Hardinsburg Sandstone; Tar Springs Sandstone; Menard Limestone; Caseyville Formation, Mississippi Valley. Sunbury Shale; Henley Bed, Borden Formation, Kentucky.

Convolutispora mellita Hoffmeister, Staplin & Malloy 1955

Plate 5, figure 11.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 384-385, pl. 38, fig. 10.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 60-85μm (Hoffmeister *et al.* 1955). 56μm (single specimen, present study).

Original Description: (Hoffmeister *et al.* 1955, p. 384-385) Spores radial, trilete; outline circular, folding generally absent; surface strongly convolute with broad anastomising ridges, producing a roughly reticulate appearance; trilete rays obscure, but may be detected as faint lines by varying plane of focus; length slightly over one-half spore radius; spore coat relatively thick, translucent; diameter 60-85 microns, width of ridges 2.8-5.6 microns.

Occurrence: Jacobs Chapel Bed of Henley Member, Cuyahoga Formation, Kentucky.

Convolutispora permixta Higgs, Clayton & Keegan 1988

Plate 5, figure 12.

Holotype: Higgs, Clayton & Keegan 1988, p. 63-64, pl. 6, figs. 14-17.

Type Locality: Sample P78, 1375' 4" Borehole DM 64, Killarecastle, Moate, County Westmeath, Ireland; Lower Mississippian.

Size: 50-105μm (20 specimens, Higgs *et al.* 1988). 60μm (1 specimen, present study).

Original Diagnosis: (Higgs *et al.* 1988, p. 63-64) Miospores trilete, acamerate. Amb rounded triangular to subcircular. Suturae indistinct, obscured by ornament. Exine 1-3μm in thickness, ornamented with smooth often anastomising ridges with interspersed verrucae. The ridges, which are rounded or flat topped, 1-3μm high and 1-6μm wide, often branch irregularly, up to 40μm in length. The channels and occasional lumina between the ridges are variable in width but are normally wider than the width of the ridges. The

interspersed verrucae have a circular to subcircular outline, usually discrete, 1-3μm high and 1-4μm in width.

Occurrence: Farmers Member, Borden Formation, Kentucky.

Convolutispora tessellata Hoffmeister, Staplin & Malloy 1955

Plate 5, figures 13 & 14.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 385, pl. 38, fig. 9.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 45-86μm (Hoffmeister *et al.* 1955). 61-73μm (4 specimens, present study).

Original Description: (Hoffmeister *et al.* 1955, p. 385) Spores radial, trilete; originally spherical; outline circular to subcircular, conspicuous folding lacking; ornamentation thick, irregular, partly anastomising, broad ridges of variable width and height, narrow to rounded in profile; trilete suture present but obscured by ornamentation; spore coat relatively thick, translucent; diameter 45-86 microns, ridges 2.8-6.5 microns wide, 2-5.6 microns high.

Occurrence: Cypress Sandstone; Menard Limestone; Caseyville Formation, Mississippi Valley.

Convolutispora* cf. *C. usitata *sensu* Smith & Butterworth 1967

Plate 5, figure 15.

1967 *Convolutispora* cf. *C. usitata* Playford; Smith & Butterworth, p. 188, pl. 9, figs. 7, 8.

Size: 40-61μm (3 specimens, present study).

Description: Trilete acamerate miospores. Amb subcircular. Laesurae simple, straight or curved, around 2/3 of spore radius, generally obscured by ornament. Ornament of closely-spaced muri, with low and well rounded tops. Muri are separated by narrow vermiculi or enclose small, irregularly-shaped lumina. Width of muri 2-8μm, height 1-2μm, width of vermiculi and lumina narrower or the same width as muri. Exine including ornament 3-5μm thick.

Remarks: Specimens are similar to those described by Smith & Butterworth (1967) from Carboniferous coal seams in Great Britain. Spores assigned to *Convolutispora* cf. *C. usitata* differ from the type in having a smaller size and thinner exine.

Occurrence: Ste Genevieve; Cypress Sandstone; Fraileys Shale, Mississippi Valley. Farmers Member, Borden Formation, Kentucky.

Genus CORDYLOSPORITES Playford & Satterthwait 1985

Type species: *Cordylosporites sepositus* Playford & Satterthwait 1985

Remarks: This genus is characterised by possessing muri with modified crests, normally in the form of rounded or blunt projections, e. g. bacula, pila or verrucae (Playford & Satterthwait 1985). Playford & Satterthwait (1985) reassigned a number of species from the genera *Dictyotriletes*, *Raistrickia* and *Reticulatisporites* to the genus *Cordylosporites*.

Cordylosporites marciae (Winslow) Playford & Satterthwait 1985

Plate 6, figure 2.

1962 *Reticulatisporites? fimbriatus* Winslow, p. 58-59, pl. 14, figs. 1-3; pl. 22, fig. 21.
1970 *Dictyotriletes fimbriatus* (Winslow) Kaiser, p. 95, pl. 19, figs. 4-6.
1985 *Cordylosporites marciae* (Winslow) Playford & Satterthwait, p. 144.

Holotype: Winslow 1962, pl. 14, figs. 1, 1a, 1b; pl. 22, fig. 21.

Type Locality: Locality 1, Bedford Shale, Chippewa Creek section, Brecksville, Cuyahoga County, Ohio; USA.

Size: 69-115μm (including reticulation), 52-80μm (excluding reticulation) (Winslow 1962). 52-74μm (excluding reticulation) (2 specimens, present study).

Original Diagnosis: (Winslow 1962, p. 58-59) Spores trilete, prominently reticulate, muri papillate...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 distal 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 8μm-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 2.1 to 3.1μm to much thicker along muri. Surface smooth; coat yellow to orange and dark brown by transmitted light.

Occurrence: Bedford Shale, Morehead, Kentucky.

Genus DICTYOTRILETES Naumova *ex* Ischenko emend. Smith & Butterworth 1967

Type species: *Dictyotriletes bireticulatus* (Ibrahim) Potonié & Kremp, 1955

Dictyotriletes cheveriensis (Playford) Bertlesen 1972

Plate 6, figure 1.

1964 *Reticulatisporites cheveriensis* Playford, p. 30-31, pl. 9, figs. 1-3.

1972 *Dictyotriletes cheveriensis* (Playford) Bertlesen, p. 46-47, pl. XIV, figs. 1-3.

Holotype: Playford 1964, pl. 9, fig. 1.

Type Locality: Cheverie Formation, Horton Group, Nova Scotia, Canada; Mississippian.

Size: 69-130μm (15 specimens, Playford 1964), 88μm (1 specimen, present study).

Original Diagnosis: (Playford 1964, p. 30-31) Spores radial, trilete; amb circular, subcircular or roundly subtriangular. Laesurae obscure to perceptible, simple, straight; length approximately 1/2 to 3/4 of spore radius. Proximal and distal surfaces have prominent, irregular, reticulate sculpture with high, narrow, membranous muri enclosing large polygonal lumina. Muri 6-16μm high, producing conspicuous 'pseudoflange' at margin. Muri usually highly contorted due to compression, frequently partly lost in preservation and/or preparation. Sides of muri tapering, tops more or less sharply pointed; mural junctions thickened. Lumina irregular in shape and size, ranging from 6-30μm in greatest diameter. Exine 2.5-5μm thick, excluding muri.

Occurrence: Lower Warsaw, Mississippi Valley.

Dictyotriletes trivialis Naumova in litt. Kedo 1963

Plate 6, figure 5.

1970 *Dictyotriletes rudis* Staplin; Dolby M.S. p. 78, pl. 4 figs. 7-8.

Holotype: None designated.

Type Locality: Hole 75, middle phytostratigraphic zone of the Cherepet Horizon (ch_2), Zhitkovichi district, Gommel province; Byelorussia.

Size: 55-90μm (45 specimens, Higgs *et al.* 1988). 40-64μm (4 specimens, present study).

Original Diagnosis: (Kedo 1963, p. 52, in Russian).

Description: (Higgs *et al.* 1988, p. 64) Trilete acamerate miospores; amb subcircular. Suturae usually indistinct, simple, straight 1/2 to 3/4 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.

Occurrence: Hannibal Shale; Lower Warsaw; Cypress Sandstone; Fraileys Shale; Menard Limestone, Mississippi Valley. Nancy Member, Borden Formation; Henley Member, Cuyahoga Formation, Kentucky.

Genus MICRORETICULATISPORITES (Knox) Potonié & Kremp 1954

Type species: *Microreticulatisporites lacunosus* (Knox) Potonié & Kremp 1954

Microreticulatisporites araneum Higgs, Clayton & Keegan, 1988

Plate 6, figure 3.

1977 *Dictyotriletes* sp. Keegan, p. 552, pl. 2, figs. 13-14.

1978 *Dictyotriletes* sp. B, Playford, p. 128, pl. 8, figs. 8-10.

1988 *Microreticulatisporites araneum* Higgs, Clayton & Keegan, p. 65, pl. 7, figs. 6, 9-10.

Holotype: Higgs, Clayton & Keegan 1988, p. 65, pl.7, fig. 9.

Type Locality: Harrylock Formation, Hook Head, County Wexford, Ireland; Mississippian.

Size: 30-52μm (14 specimens, Higgs *et al.* 1988). 66μm (single specimen, present study).

Original Diagnosis: (Higgs *et al.* 1988, p. 65) Trilete acamerate miospores; amb subcircular to convexly triangular. Suturae distinct, simple or with narrow labra, often gaping, straight to slightly sinuous and extending to the spore margin. Exine 1.5-2.4μm in thickness, ornamented with close reticulation of fine muri. Muri 0.5-1.5μm in thickness, enclosing lumina 2-6μm in width. Lumina polygonal to subcircular in shape. Reticulation normally comprehensive but occasionally less evident near equator and on the proximal surface.

Occurrence: Bachelor Formation, NS2, Mississippi Valley.

Microreticulatisporites hortonensis Playford 1964

Plate 6, figures 4, 7 & 8.

1957 *Microreticulatisporites* sp. A of Hacquebard, p. 311, pl. 2, fig.6.

Holotype: Playford 1964, p. 28, pl. 8, fig. 3. GSC No. 13147.

Type Locality: GSC loc. 6400, Horton Group, Nova Scotia, Canada; Mississippian.

Size: 41-58μm (25 specimens, Playford 1964), 40-66μm (3 specimens, present study).

Original Diagnosis: (Playford 1964, p. 28) Spores radial, trilete; amb circular, subcircular, or broadly roundly subtriangular. Laesurae distinct to perceptible, simple, straight, often unequal; length one half to four fifths amb radius. Microreticulate sculpture developed on both proximal and distal surfaces. Lumina 1-5μm apart, sharply defined in low focus; shape irregular on same specimen, ranging from circular (diameter 0.5-2μm) to narrowly, sinuously, sometimes dichotomously, elongate (up to 6μm long). Muri smooth, relatively broad; average height 1μm. Exine 1.5-2.5μm thick (including muri).

Occurrence: Cypress Sandstone, Mississippi Valley. Farmers Member, Borden Formation, Kentucky.

Genus EMPHANISPORITES McGregor 1960

Type species: *Emphanisporites rotatus* (McGregor) McGregor 1973

Emphanisporites rotatus (McGregor) McGregor 1973

Plate 6, figures 6 & 9.

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

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

1961 *Emphanisporites rotatus* McGregor, p. 3, pl. 1, figs. 1, 2, 3, 4.

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

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

Note: A full list of synonyms and possible synonyms is recorded in McGregor (1973).

Holotype: The holotype (McGregor 1961, p. 3) has been lost. A lectotype is designated from the original material (McGregor 1973, p. 47, pl. 6, figs. 9, 10). Hypotypes are given (McGregor, pl. 6, figs. 11, 12, 13).

Type Locality: Battery Creek Formation, near Douglastown, Gaspé Bay.

Size: 32-84μm (160 specimens, McGregor 1973). 38-62 (4 specimens, present study).

Emended Diagnosis: (McGregor 1973, p. 47) Trilete miospores, amb broadly subtriangular to circular. Sutures simple or with low, narrow labra, extend to or nearly to the equator. Distal hemisphere unsculptured; proximal face with 4 to 10 radial, spoke-like ridges in each interradial sector. Ridges widest towards the equator, narrowing proximally and commonly fused to form a thick, slightly darker zone around the proximal pole. On some specimens there may be little or no merging of the ridges at the pole, and on some the ribs may extend only part way towards the pole, the apex of the spore being devoid of ridges or other sculpture. Ridges may bifurcate or trifurcate towards the equator. Laesurae commonly flanked by ridges. Wall about 1.5-3μm thick distally, and on some specimens 1-2μm thicker (cingulate) in a narrow zone at the equatorial region of the distal hemisphere. Curvaturae have been detected on some specimens, but they are usually not evident because the rays are long, and the spore rarely is compressed laterally.

Remarks: This species of *Emphanisporites* is easily recognised by its ornamentation of radiating proximal ribs.

Occurrence: Bedford Shale; Henley Bed, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Subturma: ZONOTRILETES Waltz 1935
Infraturma: AURICULATI (Schopf 1938) Dettmann 1963

Genus TRIPARTITES (Schemel) Potonié & Kremp 1954

Type species: *Tripartites vetustus* Schemel 1950

Tripartites vetustus Schemel 1950

Plate 6, figures 10-14.

1943 *Triletes* (*Zonales*) *trilinguis* Horst (thesis), pl. 7, figs. 55-56.

1950 *Tripartitites vetustus* Schemel, pl. 40, fig. 11.

1955 *Tripartites trilinguis* (Horst) Potonié & Kremp; Horst, p. 176, pl. 23, fig. 55, 56.

1956 *Tripartites trilinguis* (Horst) Potonié & Kremp, p. 92.

1967 *Tripartites trilinguis* (Horst) Smith & Butterworth, p. 208, pl. 13, figs. 6-9.

Holotype: Schemel 1950, pl. 40, fig. 11.

Type Locality: Coal about 550' above top of Madison Formation, Daggett County, Utah, USA; Mississippian.

Size: 30-40μm, body 19-25μm, flange 10-15μm (Schemel 1950). 30-50μm (Smith & Butterworth 1967). 33-37μm (7 specimens, present study).

Original Diagnosis: (Smith & Butterworth 1967, p. 209, from description in Schemel 1950, p. 242) Amb subtriangular, angles broadly rounded or blunt, interradial margins moderately to strongly concave. Laesurae 1-2μm shorter than radius in length. Equatorial flange widest at corners and very narrow, or absent, in the interradial regions; plicated in the widest portions. Flange laevigate; remainder of exine laevigate to minutely punctuate.

Description: Spores radial trilete, angles broadly rounded, interradial angles strongly concave. Laesurae simple, straight, extend to 4/5 of the spore radius. Equatorial flange widest at corners where it is between 8-10μm wide and absent or very thin in the interradial region (1-3μm wide). Flange plicated at radial apices, darker than central spore body and gradually thinning towards equator. One 'flange' is commonly enlarged. Spore body laevigate to finely punctate.

Remarks: The first occurrence of *Tripartites vetustus* marks the base of the VF Miospore Biozone of Western Europe. *Tripartites vetustus* and *Tripartites trilinguis* (Horst) Smith & Butterworth are regarded as synonyms. In the Mississippi Valley specimens one 'flange' is typically slightly enlarged.

Occurrence: Burlington Limestone; Fraileys Shale; Hardinsburg Sandstone; Tar Springs Sandstone; Waltersburg; Palestine Sandstone; Kinkaid Limestone, Mississippi Valley.

Genus TRIQUITRITES Wilson & Coe 1940

Type species: *Triquitrites arculatus* Wilson & Coe 1940

Triquitrites marginatus Hoffmeister, Staplin & Malloy

Plate 6, figures 15 & 16.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 397, pl. 39, fig. 12.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 42-61μm (Hoffmeister *et al.* 1955), 38-45μm (3 specimens, present study).

Original Description: (Hoffmeister *et al.* 1955, p. 397) Spores radial, trilete; axial view sublenticular; proximal view subtriangular, radial margins convex, interradial margins concave; equatorial flange distinct, widest at radial margins, narrow or absent at the interradial margins; central body laevigate, flange faintly fluted, thicker than central body; trilete rays distinct, simple, almost equal to central body radius; spore coat relatively thick, lacking conspicuous folding, translucent; size range 42-61 microns, flange at radial positions 5.6-11 microns.

Occurrence: Fraileys Shale; Tar Springs Sandstone; Waltersburg, Mississippi Valley.

Infraturma: CINGULATI (Potonié & Klaus) Dettman 1963

Genus KNOXISPORITES Potonié & Kremp 1954 emend. Neves 1961

Type species: *Knoxisporites hageni* Potonié & Kremp 1954

Knoxisporites concentricus (Byvscheva) Playford & McGregor 1993

Plate 7, figures 7 & 8.

1976 *Converrucosisporites concentricus* Byvscheva, p. 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* Higgs, Clayton & Keegan, p. 67, pl. 8, figs. 7-10.

1991 *Tumulispora concentrica* Coleman, p. 79-80, pl. 16, fig. 1.

1993 *Knoxisporites concentricus* (Byvscheva) Playford & McGregor, p. 28, pl. 13, figures 1-8.

Holotype: Byvscheva 1976, pl. 17, fig.1.

Type Locality: Malevskova Horizon, Borehole 277; USSR.

Size: 45-75μm (Higgs *et al.* 1988), 45-50 (4 specimens, present study).

Original Diagnosis: Byvscheva 1976, p. 83-84 (In Russian).

Description: (Higgs *et al.* 1988, p. 67) Trilete acamerate cingulated 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.

Occurrence: Fraileys Shale; Menard Limestone, Mississippi Valley.

Knoxisporites literatus (Waltz) Playford 1963

Plate 7, figures 1 & 3.

1938 *Zonotriletes literatus* Waltz *in* Luber & Waltz, p. 18, pl. A, fig. 11.

1956 *Euryzonotriletes literatus* (Waltz) Ishchenko, p. 52-53, pl. 9, fig. 108.

1956 *Anulatisporites literatus* (Waltz) Potonié & Kremp, p. 111.

1957 *Cincturasporites literatus* (Waltz) Hacquebard & Barrs, p. 22-24, 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: None designated.

Size: 56-102μm (75 specimens, Playford 1963). 52-93μm (3 specimens, present study).

Original Diagnosis: Luber & Waltz 1938, p. 18.

Description: (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 than the equatorial outline of the spore body. Distal surface 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.

Occurrence: Prospect Hill; Burlington; Cypress Sandstone; Tar Springs Sandstone; Caseyville Formation, Mississippi Valley. Bedford Shale, Kentucky.

Knoxisporites stephanephorus Love 1960

Plate 7, figure 2.

Holotype: Love 1960, pl. II, fig. 1.

Type Locality: Pumpherston Shell Bed, South Queensferry, Midland Valley of Scotland; Viséan.

Size: 40-90μm (61 specimens, Love 1960). 72μm (single specimen, present study).

Original Diagnosis: (Love 1960, p. 118) Circular in equatorial outline, globose; trilete rays long, with thickened or folded lip structures; exine laevigate, but bearing two thickened rings equatorially, with interradial connections, and a thickened region on distal pole; folds sometimes accompany the thickening.

Occurrence: Caseyville Formation, Mississippi Valley.

Knoxisporites triradiatus Hoffmeister, Staplin & Malloy 1955

Plate 7, figures 4 & 5.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 391, pl. 37, fig. 12.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 50-88µm (Hoffmeister *et al.* 1955). 57-65µm (2 specimens, present study).

Original Description: (Hoffmeister *et al.* 1955, p. 391) Spores radial, trilete; outline circular, sometimes folded into a roughly rectangular shape; arcuate compression folds indicate a probable subspherical form; orientation usually proximal-distal; proximal surface smooth; equatorial thickening or girdle broad, with three acute inward projections at the radial positions which extend to or slightly beyond the ends of the trilete rays; distal surface smooth, three bands of thickening radiate from the pole to join the equatorial girdle and are rotated 60 degrees from the trilete mark of the proximal surface; trilete rays distinct, lips moderate, length two–thirds spore radius; spore coat sub-transparent, colour amber brown; diameter 55-88 microns.

Occurrence: Tar Springs Sandstone, Mississippi Valley. Henley Member, Cuyahoga Formation, Kentucky.

Genus MUROSPORA Somers 1952

Type species: *Murospora kosankei* Somers 1952

Murospora dubitata Higgs 1975

Plate 7, figure 6.

1964 *Leiotriletes ornatus* Ishchenko; Sullivan p. 1251, pl. 1, fig. 1.

1975 *Murospora dubidata* Higgs p. 397-398, pl. 3, figs. 18, 19.

Holotype: Higgs 1975, p. 398, pl. 3, fig. 18.

Type Locality: Houseland Sandstone Member, Porters Gate Formation, Hook Head, County Wexford, Ireland; Mississippian.

Size: 43-68μm (24 specimens, Higgs 1975). 55μm (Single specimen, present study).

Original Diagnosis: (Higgs 1975, p. 398) Trilete acamerate, cingulate miospores; amb subtriangular, with rounded apices and concave to slightly convex sides. Trilete mark straight, accompanied by conspicuous labra which extend to spore margin. Labra thickened, in many cases partly or totally obscuring suturae, 5-10μm wide for approximately three fourths of spore radius, and widening at radial extremities up to 25μm. Equatorial cingulum distinct to obscure, uniform, smooth sided, 5-13μm in thickness. Exine and cingulum laevigate.

Occurrence: Lower Warsaw, Mississippi Valley.

Genus STENOZONOTRILETES (Naumova) Potonié 1958

Type species: *Stenozonotriletes conformis* Naumova 1953

Stenozonotriletes triangularis Neves 1961

Plate 7, figure 9.

Holotype: Neves 1961, p. 268, pl. 33, fig. 7.

Type Locality: Hipper Sick, Derbyshire (Loc. 12), England; Carboniferous.

Size: 60-80μm (25 specimens, Neves 1961), 53μm (single specimen, present study).

Original Diagnosis: (Neves 1961, p. 268) Equatorial outline triangular, sides straight to slightly convex, apices rounded; equatorial girdle narrow, 4-8μm wide, and smooth.

Description: Trilete, acamerate miospore; amb circular. Trilete mark straight, accompanied by thick, dark, conspicuous labra extending to spore margin. Labra gaping and folded, around 4-6μm wide, thinning slightly at equatorial margin. Cingulum distinct and uniform, conformable with spore body, outline smooth, around 6μm in diameter. Exine and cingulum laevigate.

Occurrence: Caseyville Formation, Mississippi Valley.

Genus TUMULISPORA Staplin & Jansonius 1964

Type species: *Tumulispora variverrucata* (Playford) Staplin & Jansonius 1964

Remarks: This genus includes cingulate/verrucate taxa. The genus includes several species originally assigned to the non-cingulate genus, *Lophozonotriletes* (Avchimovitch *et al.* 1988).

Tumulispora malevkensis (Kedo) Turnau 1978

Plate 7, figures 10-12.

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.

1988 *Lophozonotriletes malevkensis* Naumova in litt. Kedo; Higgs, Clayton & Keegan, p. 67, pl. 8, figs, 11-13.

1988 *Tumulispora malevkensis* (Kedo) Turnau ; Avchimovitch, Byvscheva, Higgs, Streel & Umnova, p. 173-174, pl. 3, figs. 8-9.

Holotype: Naumova in litt. Kedo, p. 87, pl. 10, figs. 240, 241.

Type Locality: Hole 23, middle phytostratigraphic zone of the Malevkia horizon (ml_2), Yelsk district, Gomel province, Byelorussia.

Size: 32.5-52μm (20 specimens, Turnau 1978). 35-55μm (5 specimens, present study).

Original Diagnosis: (Kedo 1963, p. 87) Spore round, less frequently rounded triangular, perispore dense, covered with sparse, quite large tubercles 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 3/4 of the spore radius. Distal surface ornamented with rounded to 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.

Remarks: Playford and McGregor (1993) suggest *Tumulispora malevkensis* is synonymous with *Tumulispora rarituberculata* (Luber) Playford (1991), however this concept is not followed herein.

Occurrence: Lower Warsaw, Mississippi Valley. Henley Bed, Borden Formation; Jacobs Chapel; Portsmouth Member, Cuyahoga Formation, Kentucky.

Infraturma: MEMBRANATI Neves 1961

Genus PROPRISPORITES Neves 1958

Type species: *Proprisporites rugosus* (Neves 1958)

Proprisporites laevigatus Neves 1961

Plate 7, figure 13.

Holotype: Neves 1961, p. 33, fig. 9.

Type Locality: Marine shales with *Hudsonoceras proteum*, Congleton Edge ganister quarry, Staffordshire; Sabdenian Stage.

Size: 70-115μm (15 specimens, Neves 1961). 73μm (single specimen, present study).

Original Diagnosis: (Neves 1961, p. 269) Size range 70-115μm, holotype 77μm; equatorial outline of the spore body rounded triangular; trilete rays three-quarters radius of the spore body; exo-exine translucent, laevigate and strongly folded over the laevigate spore body.

Original Description: (Neves 1961, p. 269-270) Colour light brown; exine laevigate. Spore body compact, outline smooth and regular. The outer spore membrane is plicated into a series of sinuous folds which run over the surface of the spore body. The folds in places lie parallel to the compressed spore margin, where they appear as membranous projections; they may also appear as subconical projections at the spore outline when the fold axis lies at an angle to the outline.

Remarks: This species is normally restricted to the Namurian in Western Europe but has been recorded from older rocks in Portugal (Pereira 1999).

Occurrence: Cypress Sandstone, Mississippi Valley.

Infraturma: PATINATI Butterworth & Williams 1958

Genus CYRTOSPORA Winslow 1962

Type species: *Cyrtospora cristifera* (Luber) emend. Van der Zwan 1979 (original type species of *C. clavigera* Winslow 1962 is regarded as a junior synonym of *C. cristifera*)

Cyrtospora cristifera (Luber) emend. Van der Zwan 1979

Plate 8, figures 1 & 2.

1941 *Azonotriletes cristifera* Luber *in* Luber &Waltz, pl. 1, fig. 10.

1957 *Lophozonotriletes cristifera* (Luber) Kedo, pl. 1, fig. 10.

1962 *Cyrtospora clavigera* Winslow, pl. 22, figs. 18-20.

1966 *Tholisporites cristifera* (Luber) Luber.

1976 *Anisozonotriletes cristifera* (Luber) Byvscheva, pl. 13, figs. 3-6, pl. 15, fig. 3.

1979 *Cyrtospora cristifera* (Luber) emend. Van der Zwan.

Holotype: Luber & Waltz 1941, pl. 1, fig. 10.

Type Locality: Palaeozoic USSR.

Size: 45-71μm (56 specimens, Higgs *et al.* 1988). 46-50μm (2 specimens, present study).

Original Diagnosis: Luber & Waltz 1941, p. 12.

Description: (Higgs *et al.* 1988, p. 68) Trilete acamerate miospores. Amb subcircular to convexly triangular. Suturae distinct, simple, straight, length 3/4 or more of the spore radius. Exine 1-2.5μm in thickness. Proximal surface laevigate. Distal surface bears an elongated thickening, mainly concentrated at 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 or fused, with convex, concave or parallel sides and rounded or flattened tops. Specimens are commonly preserved in oblique lateral compression.

Remarks: Van der Zwan (1979) and Van der Zwan & Walton (1981) established three variants of *Cyrtospora cristifera*. In the present study specimens are rare and poorly preserved so a broad species concept is adhered to (after Higgs *et al.* 1988). This species is notably absent within the Hannibal Shale and generally rare in the rest of the Mississippi Valley samples.

Occurrence: Lower Warsaw, Mississippi Valley. Jacobs Chapel and Rockford Limestone of the Henley Member, Cuyahoga Formation, Kentucky.

Suprasubturma: CAMERATITRILETES Neves & Owens 1966

Subturma: SOLUTITRILETES Neves & Owens 1966

Infraturma: PLANATI Neves & Owens 1966

Genus AURORASPORA Hoffmeister, Staplin & Malloy emend. Richardson 1960

Type species: *Auroraspora solisorta* Hoffmeister, Staplin & Malloy 1955

Remarks: Richardson (1960) emended the generic description to exclude forms with a limbus. "Radial, trilete, monosaccate spores, central body margin distinct; completely enclosed by a bladder which has no limbus and is unornamented" (Richardson 1960, p. 49).

Auroraspora balteola Sullivan 1964

Plate 8, figure 3.

Holotype: Sullivan 1964, p. 377, pl. 61, fig. 1.

Type Locality: Edgehills coal, Drybrook Sandstone, Forest of Dean Basin, Gloucestershire, England; Carboniferous.

Size: 85-125μm (51 specimens, Sullivan 1964). 65-75μm (3 specimens, present study).

Original Diagnosis: (Sullivan 1964, p. 377) Size (51 specimens) 85-125μm, mean 110μm; amb circular, subtriangular or oval; spore body three-quarters total radius of the spore; exine of spore body and saccus minutely infrapunctate; trilete rays half to three-quarters radius of the spore; saccus 1.5-2μm thick.

Remarks: This species is distinguished from *Auroraspora solisorta* by its slightly larger intexine which comprises a larger proportion of the total spore diameter.

Occurrence: Cypress Sandstone; Tar Springs Sandstone; Menard Limestone, Mississippi Valley.

Auroraspora macra Sullivan 1968

Plate 8, figures 4 & 5.

Holotype: Sullivan 1968, pl. 27, fig. 7.

Type Locality: Cementstone Group, Ayrshire, Scotland; Mississippian.

Size: 48-68μm (65 specimens, Sullivan 1968). 42-53μm (7 specimens, present study).

Original Diagnosis: (Sullivan 1968, p. 124) Amb subcircular to irregular; exoexine laevigate, intexine laevigate to scabrate; trilete mark exceeds two-thirds radius of spore body.

Description: Trilete, camerate miospores; amb subcircular. Suturae straight, simple, extending to 2/3 to 3/4 of the spore body. Intexine distinct, outline conformable with amb, laevigate and approximately 2/3 to 3/4 of the spore body. Exoexine thin, laevigate, often irregularly folded; equatorially darkened band sometimes present.

Remarks: *Auroraspora macra* is the most common of the species of *Auroraspora* and is common to abundant in assemblages of Osagean age and younger.

Occurrence: Chattanooga Shale; Hannibal Shale; Northview Shale; Prospect Hill Siltstone; Burlington Limestone; Keokuk; Lower Warsaw; Cypress Sandstone; Fraileys Shale; Hardinsburg Sandstone; Tar Springs Sandstone; Menard Limestone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Bedford Shale; Henley Bed, Nancy Member, Borden Formation; Jacobs Chapel; Rockford Limestone; Portsmouth Member, Cuyahoga Formation, Kentucky.

Auroraspora solisorta Hoffmeister, Staplin & Malloy 1955

Plate 8, figures 6-8.

1955 *Auroraspora solisortus* Hoffmeister, Staplin & Malloy, pl. 37, fig. 3.

1972 *Auroraspora* cf. *A. solisortus* Hoffmeister, Staplin & Malloy; Bertelsen, p. 57, pl. 23, figs. 7-8.

1978 *Auroraspora* cf. *A. solisortus* Hoffmeister, Staplin & Malloy; Turnau, p. 10-11, pl. 4, figs. 17-18.

Holotype: Hoffmeister, Staplin & Malloy 1955, pl. 37, fig. 3.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 61-78μm (Hoffmeister *et al.* 1955); 50-60 μm (10 specimens, Higgs *et al.* 1988); 74-86μm (10 specimens, present study).

Original Description: (Hoffmeister *et al.* 1955, p.381) 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 commissure, 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.

Remarks: This species is common throughout the Osagean, Meramecian and Chesterian.

Occurrence: Northview Shale; Lower Warsaw; Cypress Sandstone; Fraileys Shale; Tar Springs Sandstone; Menard Limestone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Bedford Shale; Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Auroraspora* cf. *A. solisorta Hoffmeister, Staplin & Malloy 1955

Plate 8, figure 9.

Size: 170μm (single specimen).

Description: Camerate trilete miospores; amb subtriangular. Exoexine thin, laevigate. Suturae extend to spore margin, bordered by thick labra (8-12μm wide) and folded over due to compression. Intexine laevigate comprises 1/3 of total spore diameter, 40μm wide and subtriangular. Outline of intexine conformable to the amb.

Remarks: This species resembles *Auroraspora solisorta* in possessing an inner body surrounded by a thin exoexine, but *Auroraspora solisorta* is smaller in size.

Occurrence: Farmers Member, Borden Formation, Kentucky.

Genus COLATISPORITES Williams *in* Neves *et al.* 1973

Type species: *Colatisporites decorus* (Bharadwaj & Venkatachala) Williams *in* Neves *et al.* 1973

Colatisporites decorus (Bharadwaj & Venkatachala) Williams *in* Neves *et al.* 1973

Plate 8, figure 10.

1961 *Tholisporites decorus* Bharadwaj & Venkatachala, p. 39, pl. 10, figs. 142-146.

1973 *Colatisporites decorus* (Bharadwaj & Venkatachala) Williams *in* Neves *et al.*, p. 41, pl. 2, figs. 11-13.

1974 *Colatisporites decorus* (Bharadwaj & Venkatachala) *in* Neves & Ioannides, pl. 7, figs. 10-11.

1980 *Colatisporites decorus* (Bharadwaj & Venkatachala) Williams 1973, Van der Zwan, p. 141-143, pls. III & IV.

Holotype: Bharadwaj & Venkatachala 1961, p. 39, pl. 10, fig. 142.

Type Locality: Pyramidenberg, Spitsbergen; Lower Carboniferous.

Size: 45-75μm (64 specimens, Williams *in* Neves *et al.* 1973). 53-60μm (2 specimens, present study).

Original Diagnosis: (Bharadwaj & Venkatachala 1961, p. 39).

Emended Diagnosis: (Williams *in* Neves *et al.* 1973, p. 41) Radial, trilete, camerate miospores. Amb circular, subcircular or oval. Suturae simple or with thin, low labra, straight or wavy, length greater than half radius of intexine, may extend to intexine margin. Intexine thin, laevigate; intexine margin distinct, more or less conformably with equatorial

outline. Degree of cameration variable, exoexine probably attached to intexine on both proximal and distal surfaces. Exoexine strongly infrapunctate. Folding very infrequent.

Remarks: James (2003) placed this genus in the suprasubturma Cameratitriletes, subturma Solutitriletes, and infraturma Planati.

Occurrence: Tar Springs Sandstone, Mississippi Valley.

Infraturma: DECORATI Neves & Owens 1966

Genus GRANDISPORA Hoffmeister, Staplin and Malloy emend. Neves & Owens 1966

Type species: *Grandispora spinosa* Hoffmeister, Staplin & Malloy 1955

Grandispora acuta (Kedo) Byvscheva 1980

Plate 9, figures 5 & 8.

1963 *Archaeozonotriletes acutus* Kedo, p. 71, pl. 7, fig. 167.

1980 *Grandispora acuta* (Kedo) Byvscheva, p. 55.

1980 *Asperispora acutus* (Kedo) Van der Zwan, p. 226, pl. 13, figs. 1-5.

1985 *Cymbosporites acutus* (Kedo) Byvscheva, p. 127, pl. 24, fig. 13.

1988 *Spinozonotriletes saurotus* Higgs, Clayton & Keegan, p. 77, text-fig. 28c; pl. 15, figs. 1-3, 7.

1993 *Grandispora saurota* (Higgs, Clayton & Keegan) Playford & McGregor, p. 38-39, pl. 17, figs. 1-11.

2000 *Grandispora acuta* (Kedo) Byvscheva; Higgs, Avchimovitch, Loboziak, Maziane-Serraj, Stempien-Salek & Streel, p.213, pl. 1, figs. 1-6.

Holotype: Kedo 1963, p. 71, pl. 7, fig. 167.

Type Locality: Pripyat Depression, Russia.

Size: 30-70μm (Higgs *et al.* 2000). 44-60μm (3 specimens, present study).

Emended Description: (Higgs *et al.* 2000, p. 213; CIMP working group of the *Grandispora* complex) Trilete camerate miospores. Amb convexly triangular. Suturae distinct and accompanied by flexuous labra, 2-4.5μm in height, and extending 3/4 or more of the spore radius. Exoexine infragranulate, 1.5-3μm thick, ornamented equatorially and distally with galeae and insubordinate wide based spines and cones. Elements typically subcircular in basal outline, 1.5-8μm in basal diameter, normally 3-10μm in height, rarely up to 14μm. Spacing of sculptural elements variable, from densely to widely spaced; discrete to basally coalescent. Intexine laevigate, thin (less than 1μm), distinct to barely perceptible, conformable with amb and comprising 3/4 to 4/5 of the total spore radius.

Remarks: This species is characterised by a thin exoexine and prominent bulbous spines.

Occurrence: Prospect Hill; Keokuk; Lower Warsaw; Hardinsburg Sandstone, Mississippi Valley.

Grandispora cornuta Higgs 1975

Plate 9, figures 1 & 2.

Holotype: Higgs 1975, p. 398-399, pl. 4, fig. 4.

Type Locality: Old Red Sandstone, Hook Head, County Wexford, Ireland.

Size: Exoexine 45-84μm, intexine 39-69μm (33 specimens, Higgs 1975). 46-85μm (6 specimens, present study).

Original Diagnosis: (Higgs 1975, p. 398-399) 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 ¾ 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 and 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.

Occurrence: Lower Warsaw; Menard Limestone, Mississippi Valley. Henley Bed, Farmers Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Grandispora echinata Hacquebard 1957

Plate 9, figures 6 &7.

Holotype: Hacquebard 1957, p. 317, pl. 3, fig.17.

Type Locality: Horton Group, Coal from West Gore, 20 miles north-east of Windsor; Nova Scotia, Canada; Mississippian.

Size: Exoexine 62-93μm, intexine 47-70μm (12 specimens, Hacquebard 1957). 68-72μm (5 specimens, present study).

Original Description: (Hacquebard 1957, p.317) Spores radial, trilete; central body enclosed by bladder, both subcircular to broadly rounded triangular in proximal view; trilete generally not distinct, rays simple, extending to the 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 spinae 1.5-2 (4) μm long and 2-6μm apart.

Occurrence: Hannibal Shale; Northview Shale; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Fraileys Shale; Tar Springs Sandstone; Kinkaid Limestone, Mississippi Valley. Henley Bed, Farmers Member, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Grandispora spinosa Hoffmeister, Staplin & Malloy 1955

Plate 9, figures 3 & 4.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 388-389, pl. 39, fig. 10.

Type Locality: Hardinsburg Formation, Webster County, Kentucky; Chesterian.

Size: Exoexine 100-143μm, intexine 84-100μm (Hoffmeister *et al.* 1955). Exoexine 80-132μm, intexine 72-94μm (5 specimens, present study).

Original Description: (Hoffmeister *et al.* 1955, p. 388) Spores radial, trilete; proximal view of central body and bladder circular to subcircular; both bladder and central body punctuate to slightly granulose; bladder of equal width around the central body, spinose, processes 2-8μm long and 8-25μm apart; trilete indistinct, simple, perhaps extends to edge of central body.

Remarks: Specimens of *Grandispora spinosa* are generally rare in the present study area, and conform closely to the original description of *Grandispora spinosa* from the Hardinsburg Formation.

Occurrence: Prospect Hill; Lower Warsaw; Fraileys Shale; Tar Springs Sandstone; Waltersburg, Mississippi Valley. Henley Bed, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus RETISPORA Staplin 1960

Type species: *Retispora florida* Staplin 1960

Retispora lepidophyta (Kedo) Playford 1976

Plate 9, figures 9 & 10.

1957 *Hymenozonotriletes lepidophytus* Kedo, p. 24, pl. 2, figs. 19-21.

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 *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.

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: Byelorussia, USSR; Upper Armenian/Lower Mississippian.

Size: 27-122μm (90 specimens, Playford 1976). 62-68μm (20 specimens, present study).

Original Diagnosis: Kedo 1957.

Description: (Playford 1976, p. 45) Spores radial, trilete; amb convexly subtriangular, occasionally subcircular, periphery smooth to slightly undulant. Laesurae with conspicuous lip development, 1-5μm in overall width, straight to slightly sinuous, extending to or almost to equator where very weak curvature are occasionally perceptible. Commissures often obscured by lips; where visible, extend about ⅔ to ¾ of distance to intexine's equatorial margin. Exoexine 1.5-2.5μm thick, sometimes slightly thicker at equatorial margin; finely structured (infragranulate) overall (scabrate-finely punctuate in corroded examples). Distal surface of exoexine reticulate to foveolate/vermiculate; lumina circular, subcircular, or rounded-elongate, maximum dimension 0.7-6μm; muri 0.5-7μm wide, flat-topped (smooth or with minute scattered conate or granulate projections). Sculptural pattern fairly regular or irregular; distal exoexine sometimes develops highly imperfect reticulum due to narrow, discontinuous muri. Intexine ca. 1-2μm thick, virtually smooth, outline ± conformable with exoexine; three interradial papillae (each ca. 5μm in maximum dimension) observed in some specimens, especially corroded ones. Several examples possess double-layered intexinal body in which a very thin inner layer is contracted 1-4μm from outer intexine.

Remarks: *Retispora lepidophyta* is a very common component in Late Devonian assemblages from western Europe and North America. In the European miospore zonation (Clayton *et al.* 1977) the Devonian/Carboniferous boundary is defined by the disappearance of *Retispora lepidophyta* (Chapter 3). In the present study, rare specimens of *Retispora lepidophyta* are recorded from early Carboniferous rocks. These are interpreted

as reworked. *Retispora lepidophyta* recorded from the present study is towards the smaller end of the size range given by Playford (1976), and specimens are of a fairly uniform size.

Occurrence: Hannibal Shale; Northview Shale; Lower Warsaw, Mississippi Valley (rare). Bedford Shale (abundant); Henley Bed; Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation (rare), Kentucky.

Genus RUGOSPORA Neves & Owens 1966

Type species: *Rugospora corporata* Neves & Owens 1966

Rugospora flexuosa (Jushko) Streel 1974

Plate 10, figure 1.

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, table 1, fig. 4.

Type Locality: Podmoskov Basin, USSR; Upper Mississippian.

Size: 40-80μm (64 specimens, Higgs *et al.* 1988). 60-62μm (2 specimens, present study).

Original Diagnosis: Jushko 1960.

Description: (Description not given by Streel *in* Becker *et al.* (1974), therefore description by Higgs, Clayton & Keegan (1988, p.72) is followed). Trilete camerate miospores; amb convexly triangular. Suturae distinct, straight to slightly sinuous, bordered by labra and extending almost to spore margin. Exine two layered, although separation of exinal layers is often barely discernable. 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.

Occurrence: Bedford Shale, Kentucky.

Rugospora lactuosa Higgs, Clayton & Keegan 1988

Plate 10, figure 5.

1984 *Convolutispora* sp. Higgs & Streel, pl. 2, fig. 9.

1988 *Rugospora lactuosa* Higgs, Clayton & Keegan, p. 72-73, pl. 12, figs. 10, 13-14.

Holotype: Higgs, Clayton & Keegan 1988, pl. 12, fig. 13.

Type Locality: Oldtown Bay Formation, Hook Head, County Wexford; Ireland.

Size: 96-160μm (14 specimens, Higgs *et al.* 1988). 102μm (single specimen, present study).

Original Diagnosis: (Higgs *et al.* 1988, p. 72) Trilete camerate miospores. Amb subcircular but often irregular. Suturae usually obscure, simple straight, length 3/4 of the spore radius. Exine densely ornamented with high flexuous muroid folds on both surfaces. Folds 6-18μm in height, 1.5-3μm, and 10-45μm in length; characteristically sinuous and flexuous, often folded back on themselves, and in some cases becoming appressed. Folds branch and overlap but do not form a reticulum. Occasionally small (3-4μm) subcircular swellings developed on the edge of the folds. Folds on proximal surface less dense. Intexine thin, weakly defined to barely perceptible, size approximately 4/5 of the total spore radius.

Occurrence: Burlington Limestone, Mississippi Valley.

Rugospora minuta Neves & Ioannides 1974

Plate 10, figure 2.

Holotype: Neves & Ioannides 1974, p. 79, pl. 8, fig. 7.

Type Locality: At 2563 ft (781.2 m) in the Spilmersford Borehole, East Lothian; Scotland. Lower Carboniferous.

Size: 37-60μm (30 specimens, Neves & Ioannides 1974). 35 μm (single specimen, present study).

Original Diagnosis: (Neves & Ioannides 1974, p. 79) Spores radial, trilete, camerate; amb circular, oval to rounded triangular; intexine laevigate, spore body 28 to 54μm in diameter, degree of cameration variable. Trilete mark barely perceptible, suturae straight to slightly sinuous, reaching spore body margin. Exoexine laevigate to infrapunctate; crumpled into complex series of tight muroid folds mainly on distal surface; no apparent pattern other than in equatorial region where they appear somewhat radially disposed and encroach slightly on to proximal surface. Folds simple or bifurcating, 3 to 4.5μm high, 0.5 to 3μm wide.

Occurrence: Kinkaid, Mississippi Valley.

Rugospora polyptycha Neves & Ioannides 1974

Plate 10, figures 3, 4 & 7.

Holotype: Neves & Ioannides 1974, p. 80, pl. 8, fig. 2.

Type Locality: At 2563 ft (781.2 m) in the Spilmersford Borehole, East Lothian; Scotland. Lower Carboniferous.

Size: 48-110μm (20 specimens, Neves & Ioannides 1974). 60-130 μm (3 specimens, present study).

Original Diagnosis: (Neves & Ioannides 1974, p. 80) Spores radial, trilete, camerate; amb subcircular to triangular, suturae usually obscured, 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 groves; folds reduced in equatorial overlap region but cause wavy detail to spore outline. Folds up to 6.5μm wide meandering and ramifying.

Occurrence: Burlington; Keokuk; Lower Warsaw; Menard Limestone, Mississippi Valley.

Rugospora* cf. *R. polyptycha

Plate 10, figure 10.

Size: 50μm (single specimen, present study).

Description: Trilete camerate miospore. Amb subtriangular, angles rounded, sides convex. Suturae slightly sinuous, accompanied by thick labra extending to spore margin. Labra 2-4μm thick and thickening slightly towards equator. Exoexine laevigate, bears ornament of indistinct muri, most prominent near the labra, and becoming less prominent towards equator. Equatorial outline slightly irregular. Intexine indistinct.

Remarks: This specimen bears similar ornament to *Rugospora polyptycha* but the ornament on *Rugospora* cf. *R. polyptycha* is less pronounced.

Occurrence: Henley Bed, Borden Formation, Kentucky.

***Rugospora* sp. A**

Plate 10, figure 6.

Size: 40-46μm (4 specimens, present study).

Description: Trilete camerate (?) miospores; amb subcircular to rounded triangular. Suturae indistinct, slightly flexuous, extending to the edge of the central darkened area. Intexine barely perceptible. Exoexine ornamented with low verrucae and muri, around 1μm in height. Verrucae are mostly discrete, with a basal diameter of around 4-5μm, some fused to form irregular and convoluted muri. A lighter coloured band is observed around the central body, surrounded by a darker equatorial band 10-14μm wide, approximately 1/3 of

spore radius. This outer band is covered in dense flexuous, radially arranged muri, giving a fluted appearance.

Remarks: This species closely resembles *Rugospora minuta* but the equatorial radial arrangement of muri is more pronounced than in the specimens of Neves and Ioannides (1974).

Occurrence: Tar Springs Sandstone; Waltersburg; Menard Limestone, Mississippi Valley.

Genus SPELAEOTRILETES Neves & Owens 1966

Type species: *Spelaeotriletes triangularis* Neves & Owens 1966

Spelaeotriletes balteatus (Playford) Higgs 1975

Plate 10, figures 9 & 12.

1963 *Spinozonotriletes balteatus* Playford p. 657, pl. 94, figs. 4-6.
1964 *Crassispora balteata* (Playford) Sullivan p. 376.
1971 *Grandispora balteata* (Playford) Playford p. 46.
1975 *Spelaeotriletes balteatus* (Playford) Higgs p. 400, pl. 6, fig 10.

Holotype: Playford 1963, p. 657-658, pl. 95, fig. 4.

Type Locality: Triugen, Spitsbergen; Lower Carboniferous.

Size: Exoexine 51-102μm, intexine 30-59μm (40 specimens, Playford 1963). 52-100μm (2 specimens, present study).

Original Diagnosis: (Playford 1963, p. 657) 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 limbate equatorial margin. Intexine indistinct to perceptible, roundly subtriangular. Distal surface of exoexine densely and uniformly sculptured with small, simple spinae which sometimes coalesce to form a regulate 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.

Remarks: This species was transferred from the genus *Spinozonotriletes* to *Spelaeotriletes* by Higgs (1975). In the European miospore zonation (Clayton *et al.* 1977) the first appearance of *Spelaeotriletes balteatus* marks the base of the BP Biozone.

Occurrence: Top Hannibal Shale; Burlington; Keokuk; Lower Warsaw; Upper Warsaw; Cypress Sandstone; Tar Springs Sandstone; Menard Limestone, Mississippi Valley. Henley Bed, Farmers Member, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Spelaeotriletes cabotii Utting, Keppie & Giles 1989

Plate 10, figures 8 & 11.

1989 *Spelaeotriletes cabotii* Utting, Keppie & Giles, p. 133, pl. 5.3, figs. 8-13, 15.

Holotype: Utting, Keppie & Giles 1989, p. 133, pl. 5.3, fig. 8. GSC. No. 89954.

Type Locality: GSC Loc. C-146224. Antigosh Basin, Lakeville Cliff Section, unnamed Formation below Wilkie Brook Formation, Horton Group, Nova Scotia; Mississippian.

Size: 49-93μm (35 specimens, Utting *et al.* 1989). 40-95μm (64 specimens, Brittain & Higgs 2008). 60-73μm (3 specimens, present study).

Original 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 percent of overall diameter. Trilete rays virtually straight, extending almost to margin of intexine; associated folds of 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 to 1μm. Toward to the pole, verrucae coalesce to form a rugulate pattern in some specimens. Coni, spinae and rare bacula more abundant at equatorial margin than in centre.

Remarks: This species is also recognised from early Carboniferous sections in southern Ireland (Brittain & Higgs 2008). *Spelaeotriletes cabotii* is distinguished from *Spelaeotriletes balteatus* by possessing a mammilate/verrucate ornament rather than a spinose/cristate ornament. *Spelaeotriletes cabotii* is distinguished from *Spelaeotriletes pretiosus* by a smaller exoexinal diameter (40-95μm compared to 98-195μm), and smaller ornament (<=5μm in width compared to <=8μm).

Occurrence: Lower Warsaw, Mississippi Valley. Portsmouth Member, Cuyahoga Formation, Kentucky.

Spelaeotriletes crustatus Higgs 1975

Plate 11, figure 1.

1975 *Spelaeotriletes crustatus* Higgs, pl. 6, figs. 7-9; *non* pl. 6, figs. 4-6.
1977 *Spelaeotriletes exiguus* Keegan, p. 556, pl. 4, figs, 7-10.
1978 *Spelaeotriletes resolutus* Higgs *in* Van der Zwan & Van Veen, pl. 2, fig. 1.
1980 *Spelaeotriletes resolutus* Higgs *in* Van der Zwan, pl. 18, fig. 5.

Holotype: Higgs 1975, pl. 6, fig. 7.

Type Locality: Old Red Sandstone, Hook Head, County Wexford, Ireland; Late Devonian.

Size: Exoexine 55-110μm, intexine 45-82μm (66 specimens, Higgs *et al.* 1988). Exoexine 80μm, intexine 66μm (single specimen, present study).

Original Diagnosis: (Higgs 1975, p. 399) Trilete camerate miospores; amb convexly triangular, with rounded apices. Suturae distinct, straight to slightly sinuous, bordered by narrow labra and ray folds up to 7μm in height. Length of suturae exceeding three-fourths of spore radius and terminating in curvaturae perfectae. Exoexine 2-3μm in thickness;

distal surface and equator densely ornamented, with fine to coarse grana, and, less commonly, coni and small spinae. Sculptural elements subcircular to polygonal in basal outline, 0.5-2μm in width, and up to 2μm in height; discrete but in many cases fused to give short, irregularly shaped rugulae. Intexine distinct to obscure, thin, laevigate; outline almost conformable with amb, comprising three-fourths or more of total spore diameter and attached to exoexine on proximal surface only. Large concentric folds present in many cases along outer margin of intexine, and up to six variably defined, apical papillae developed in some cases.

Occurrence: Keokuk, Mississippi Valley.

Spelaeotriletes galearis Brittain & Higgs 2008

Plate 11, figures 3-5.

Holotype: Brittain & Higgs 2008, p.114, pl. 2, figs. I, K.

Type Locality: Lumsdins Bay South, Hook Head, County Wexford; Ireland. 1m below the top of the Houseland Sandstone Member, Porter's Gate Formation; Mississippian.

Size: Exoexine 60-104μm, intexine 40-72μm (17 specimens, Brittain & Higgs 2008).

Original Diagnosis: (Brittain & Higgs 2008, p. 114) 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, 2-3μm thick at the equator. Distal surface of exoexine and equatorial margin densely ornamented with regularly to irregularly distributed galeae; subordinate spinae and coni may also occur. Elements normally discrete and well spaced, but bases may be fused. Ornament basal diameter 1-10μm; height 0.5-5μm, holotype height 1-5μm; basal diameter 1.5-4μm. Intexine thin, laevigate, forming 50-75% of total spore diameter, but often poorly discernible due to density of ornament.

Remarks: This species has not been recognised in the Mississippi Valley.

Occurrence: Portsmouth Member, Cuyahoga Formation, Kentucky.

Spelaeotriletes obtusus Higgs 1975

Plate 11, figure 2.

Holotype: Higgs 1975, p. 400, pl. 6, fig. 2.

Type Locality: Old Red Sandstone, east Hook Head, County Wexford, Ireland.

Size: Exoexine 54-94μm, intexine 33-64μm (81 specimens, Higgs 1975). 54-94μm (92 specimens, Higgs *et al.* 1988). 71μm (1 specimen, present study).

Original Diagnosis: (Higgs 1975, p. 400) Trilete camerate miospores; amb circular to convexly triangular. Suturae distinct, straight or slightly sinuous, extending almost to equator and terminating in curvature imperfectae. Suturae accompanied by ray folds, 2-6μm in height. Distal and equatorial surfaces of exoexine densely ornamented with discrete, low, round or flat-topped bacula, coni, and pila. Elements subcircular in basal outline, 2-4μm in height and 1-3μm in width. Ornament on proximal surface restricted to radial extremities. Intexine distinct to barely perceptible, thin, laevigate, outline conformable to amb and size approximately ½ to ¾ of overall diameter. Attachment to exoexine on proximal surface only. Exine infragranulate, compression folds common.

Remarks: This species has not been recorded from the lowest Carboniferous (VI equivalent) in the study area.

Occurrence: Burlington; Lower Warsaw; Hardinsburg Sandstone; Kinkaid Limestone, Mississippi Valley. Henley Bed, Farmers Member, Nancy Member, Borden Formation, Kentucky.

Spelaeotriletes pretiosus (Playford) Neves & Belt 1970

Plate 11, figures 6-9.

1964 *Pustulatisporites pretiosus* Playford p. 19, pl. 4, figs. 9-7; pl. 5, fig. 1; text fig. 1a.

1969 *Pustulatisporites* cf. *P. pretiosus* Playford *in* Lanzoni & Magloire, p. 454, pl. 1, figs. 17-19.

1970 *Spelaeotriletes pretiosus* (Playford) in Neves & Belt, p. 1241.

1987 *Spelaeotriletes pretiosus* var. *pretiosus* (Playford) Neves & Belt emend. Utting p. 33-35, pl. 4, figs. 1-8.

Holotype: Playford 1964, pl. IV, fig. 6 GSC. No. 13109.

Type Locality: GSC. loc. 6407, West Shore of Avon River (325ft South of Blue Beach Fault), Cheverie Formation, Horton Group, Nova Scotia; Mississippian.

Size: 98-195μm (115 specimens, Playford 1964). Exoexine 68-110μm, intexine 35-70μm (27 specimens, Higgs *et al.* 1988). Exoexine 60-100μm, intexine 49-70μm (8 specimens, present study).

Original Diagnosis: (Playford 1964, p. 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 many verrucae, accompanied be 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 3/4 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 to12μm high reach equator, sinuous in outline. Curvaturae imperfectae generally visible. Exoexine infragranlulate, 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 at equatorial margin. Verrucae relatively low, broadly rounded, sometimes bearing 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 4μm. Irregular secondary folding common.

Remarks: The first appearance of *Spelaeotriletes pretiosus* marks the base of the PC Miospore Biozone of western Europe (Clayton *et al.* 1977).

Occurrence: Keokuk; Lower Warsaw; Upper Warsaw; Waltersburg; Kinkaid Limestone, Mississippi Valley. Henley Bed, Farmers Member, Nancy Member, Borden Formation; Henley Member; Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus VELAMISPORITES Bharadwaj & Venkatachala 1962

Type species: *Velamisporites rugosus* Bharadwaj & Venkatachala 1962

Remarks: Spores that are wholly enveloped by a thin outer layer should not be assigned to *Perotrilites* (Erdtman) Couper 1953, as the type species of this genus is zonate, and should be transferred to *Velamisporites* (Playford 1971).

Velamisporites magnus (Hughes & Playford 1961) Playford 1971

Plate 12, figure 1.

1961 *Perotrilites magnus* Hughes & Playford, p. 33, pl. 2, figs. 5-6.

1971 *Velamisporites magnus* (Hughes & Playford) Playford, p. 52.

Holotype: Hughes and Playford 1961, p. 33, pl. 2, fig. 5.

Type Locality: Sample B685, Lower Carboniferous, Spitsbergen.

Size: 98-156μm (16 specimens, Hughes & Playford 1961). 80-85μm (3 specimens, present study).

Original Diagnosis: (Hughes & Playford 1961, p. 33) Spores radial, trilete; amb rounded triangular to subcircular. Perine very thin, hyaline, laevigate to infragranulate, relatively close-fitting (usually about 6μm beyond spore body equator), weakly folded. Laesurae straight, simple, extending for approximately 1/2 to 2/3 of the radius of the spore body. Exine thin (1.5-2.5μm), laevigate, frequently broadly folded owing to compression.

Original Description: (Hughes & Playford 1961, p. 33) Holotype 155μm in diameter; amb subcircular, closely enveloped by infragranulate perine; laesurae distinct, length approximately 2/3 spore body radius; exine 2μm thick, with several large folds.

Remarks: This species was transferred from *Perotrilites* to the genus *Velamisporites* by Playford (1971) due to its camerate rather than zonate nature.

Occurrence: Hannibal Shale; Tar Springs Sandstone; Menard Limestone, Mississippi Valley. Nancy Member, Borden Formation, Kentucky.

Velamisporites perinatus (Hughes & Playford) Playford 1971
Plate 12, figures 3 & 4.

1961 *Perotrilites perinatus* Hughes & Playford, p. 33, pl. 2, figs. 7-10.
1971 *Velamisporites perinatus* (Hughes & Playford) Playford, p. 52.

Holotype: Hughes & Playford, p. 33, pl. 2, fig. 7.

Type Locality: Sample B685, Spitsbergen; Lower Carboniferous.

Size: 44-90μm (16 specimens, Hughes & Playford 1961). 45-48μm (2 specimens, present study).

Original Diagnosis: (Hughes & Playford 1961, p. 33) Spores radial, trilete; amb circular to triangular, usually convexly subtriangular. Perine very thin, hyaline, laevigate to finely granulate, loose-fitting, usually wrinkled and folded, standing out 4-10μm beyond equatorial margin of spore body. Laesurae 2/3 to 5/6 radius of spore body, straight and sometimes with weak, narrow labiae. Exine laevigate, thickness 2.5-4μm.

Description: (Hughes & Playford 1961, p. 33) Holotype diameter 62μm (excluding perine); amb subtriangular with rounded apices and slightly convex sides; perine standing out 4μm from spore body equator; laesurae distinct, length 5/7 spore body radius; exine 3μm thick.

Remarks: This species was transferred from *Perotrilites* to the genus *Velamisporites* by Playford (1971) due to its camerate rather than zonate nature.

Occurrence: Portsmouth Member, Cuyahoga Formation, Kentucky.

Velamisporites tessellatus (Staplin 1960) Coleman 1991

Plate 12, figure 2.

1960 *Alatisporites tessellatus* Staplin, p. 31, pl. 7, fig. 10.
1973 *Perotrilites tessellatus* (Staplin) Neville in Neves *et al.* p. 39-40, figs. 9-10, 11.
1991 *Velamisporites tessellatus* (Staplin) Coleman, p. 91, pl. 8, fig 12.

Holotype: Staplin 1960, pl. 7, fig. 10.

Type locality: Golata Formation, Alberta, Canada; Upper Mississippian.

Size: 85μm (Coleman1991). 94μm, including perine, 84μm excluding perine (1 specimen, present study).

Original Diagnosis: (Staplin 1960, p. 31).

Description: Trilete camerate miospores, amb rounded subcircular. Laesurae simple, indistinct and obscured by folding. Perine very thin, hyaline, laevigate, fairly close to spore body; borders spore body by around 5μm. Strongly folded giving the spore an uneven outline. Exine fairly thick (around 4-5μm), laevigate, covered by reticulate ornament. Muri around 3μm high and 1μm wide.

Remarks: This species was transferred from the genus *Perotrilites* to the genus *Velamisporites* by Coleman (1991) because it is camerate but not zonate.

Occurrence: Cypress Sandstone; Hardinsburg Sandstone; Menard Limestone; Mississippi Valley.

Subturma: MEMBRANATITRILETES Neves & Owens 1966

Infraturma: CONTINUATI Neves & Owens 1966

Genus DISCERNISPORITES (Neves 1958) Neves & Owens 1966

Type species: *Discernisporites irregularis* Neves & Owens 1966

Discernisporites micromanifestus (Hacquebard 1957) Sabry & Neves 1971

Plate 12, figures 5-7.

1957 *Endosporites micromanifestus* Hacquebard, p. 317, pl. 3, figs. 16.

1958 *Discernisporites concentricus* Neves, p. 5, pl. 3, fig, 7.

1960 *Auroraspora micromanifestus* (Hacquebard) Richardson, p. 51.

1971 *Discernisporites micromanifestus* (Hacquebard) Sabry & Neves, pl. 3, fig.11.

Holotype: Hacquebard 1957, p. 317, pl. 3, fig. 16.

Type Locality: Horton Group, West Gore, Nova Scotia; Mississippian.

Size: Diameter 58-100μm, spore body 37-67μm (14 specimens, Hacquebard 1957). 40-58μm (20 specimens, present study).

Original description: (Hacquebard 1957, p. 317) Identical with *Endosporites macromanifestus* [(Hacquebard 1957, p. 317) Spores radial, trilete; convexly subtriangular in proximal view; trilete distinct, rays with flanges (bladder folds) to equator or nearly so; central body thin, margin distinct, conformable to equatorial outline; bladder thin strongly folded, particularly over body, extending 20-39 microns beyond body margin; body exine probably laevigate, bladder very finely infragranulose to almost smooth, without inner reticulation; limbus not present] but smaller, and bladder generally more distinctly

infragranulose; width of bladder beyond central body 10-18(24) microns; diameter 58-100 microns, body 37-67 microns (on fourteen specimens).

Remarks: Sabry & Neves assigned this species to the genus *Discernisporites*. Apical papillae are noted on some specimens within the present study, this feature is also seen in Irish specimens of *Discernisporites micromanifestus* (Higgs, Clayton & Keegan 1988).

Occurrence: Chattanooga Shale; Northview Shale; Hannibal Shale; McCraney; Lower Warsaw; Ste Genevieve; Cypress Sandstone; Fraileys Shale; Hardinsburg Sandstone; Tar Springs Sandstone; Waltersburg; Menard Limestone; Palestine Sandstone; Caseyville Formation, Mississippi Valley. Henley Bed, Farmers Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Discernisporites* cf. *D. Micromanifestus (Hacquebard 1957) Sabry & Neves

Plate 12, figure 8.

Size: 70μm (single specimen, present study).

Description: Trilete camerate miospore; amb convexly triangular. Suturae distinct, straight to slightly sinuous, gaping, slightly thickened with low labra. Trilete mark extends almost to spore equator. Intexine laevigate conformable with amb; concentric folds on the intexine conformable with amb suggest partial proximal attachment of the intexine to the exoexine. Exoexine thin and laevigate.

Remarks: *Discernisporites micromanifestus* has similar proportions and features but does not show concentric folding of the intexine.

Occurrence: Tar Springs Sandstone, Mississippi Valley.

Discernisporites sullivani Higgs & Clayton 1984

Plate 12, figure 9.

Holotype: Higgs & Clayton 1984, p. 18-19, pl. 2, fig. 14.

Type Locality: Sample Ma6, Lower Limestone Shale, Maesbury, eastern Mendips, England; Mississippian.

Size: 60-105μm (18 specimens, Higgs & Clayton 1984). 41-45μm (2 specimens, present study).

Original Diagnosis: (Higgs & Clayton 1984, p. 18-19) Trilete camerate miospores. Amb convexly triangular. Suturae accompanied by sinuous and flexuous ray folds, 3-7μm in height, which extend to the spore margin. Intexine distinct to barely perceptible, with outline conformable with amb. Intexine laevigate, diameter 1/2 to 4/5 of the total diameter. Exoexine ornamented distally with grana and coni. Elements 0.5-2.5μm in height, 1-1.5μm in diameter, discrete or fused to form short rugulae up to 5μm in length. Ornament is densely to evenly distributed over the distal surface or occasionally concentrated at the distal pole. Exine often bears large taper point compression folds and three variably defined apical papillae.

Occurrence: Prospect Hill; Menard Limestone, Mississippi Valley.

Genus GEMINOSPORA Balme 1962

Type species: *Geminospora lemurata* Balme emend. Playford 1983

Geminospora spongiata Higgs, Clayton & Keegan 1988

Plate 12, figures 11 &12.

1975 *Geminospora* cf. *G. lemurata* Higgs, p. 400, pl. 6, fig.17.

Holotype: Higgs, Clayton & Keegan 1988, p. 77, pl. 14, fig. 12.

Type Locality: Sample 8, Houseland Sandstone Member, Hook Head, County Wexford, Ireland; Mississippian.

Size: 30-53μm (48 specimens, Higgs *et al.* 1988). 45-70μm (10 specimens, present study).

Original Diagnosis: (Higgs *et al.* 1988. p. 77) Trilete camerate miospores, amb subcircular but more commonly convexly triangular. Suturae distinct, sometimes gaping, straight to slightly sinuous and bordered by labra 2-3μm in overall width. Suturae extend ¾ or more of the spore radius and terminate in curvaturae. Exoexine thickened equatorially with a gradual crassitude 4-6μm in thickness, the inner margin of which is often ill defined and spongeous in appearance. Exoexine ornamented distally with grana and occasional small coni; elements discrete and/or fused 0.5-1.5μm in size. Intexine thin, distinct to indistinct but usually perceptible, with outline normally conformable with exoexine and occupying ½ to 4/5 (normally 3/4) of spore diameter. Intexine regularly or eccentrically separated from exoexine, laevigate and sometimes bearing concentric compression folds along the outer edge.

Occurrence: Northview Shale; Burlington; Keokuk; Lower Warsaw, Mississippi Valley. Farmers Member, Borden Formation; Rockford Limestone, Cuyahoga Formation, Kentucky.

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

Plate 12, figures 10 & 13.

Size: 50-75μm (32 specimens, Higgs *et al.* 1988). 38-58μm (17 specimens, present study).

Description: Trilete camerate miospores, amb circular to subcircular. Suturae distinct, simple, occasionally with low labra, straight and extending ½-¾ of the spore radius. Suturae commonly terminating in curvaturae. Exine thick, 3-5μm, usually laevigate although sometimes infragranulate. Exoexine consists of two layers, closely appressed or variably separated. Central body distinct. Intexine conformable with amb, thin and laevigate.

Remarks: This species of *Geminospora* conforms closely to the description of *Geminospora* sp. A by Higgs *et al.* (1988, p. 77, pl. 14, fig. 8), and to *Stenozonotriletes extensus* var. *major* Naumova 1953 as described by Hacquebard (1957, p. 314, pl. 2, figs, 19-20).

Occurrence: Chattanooga Shale; Hannibal Shale; McCraney; Prospect Hill; Burlington; Keokuk; Lower Warsaw; Hardinsburg Sandstone; Tar Springs Sandstone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley. Bedford Shale; Sunbury Shale; Henley Bed, Farmers Member, Nancy Member, Borden Formation; Jacobs Chapel; Rockford Limestone; Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus SPINOZONOTRILETES Hacquebard emend. Neves and Owens 1966

Type species: *Spinozonotriletes uncatus* Hacquebard 1957

Spinozonotriletes uncatus Hacquebard 1957

Plate13, figures 1 & 2.

Holotype: Hacquebard 1957, pl. 3, fig. 8.

Type Locality: Horton Group, Nova Scotia, West Gore and Blue Beach samples; Mississippian.

Size: 82-148µm (9 specimens, Hacquebard 1957). 70-105µm (20 specimens, Higgs *et al.* 1988). 73-83µm (2 specimens, present study).

Original Description: (Hacquebard 1957, p. 316) Spores radial, trilete; convexly subtriangular in proximal view; trilete distinct, rays flange-like, extending to equator; central body margin not distinct, fairly dense; perispore thick, forming a dense flange 12-25 microns wide; perispore surface smooth but carrying stout spines that radiate from body margin and from equator but also occur more randomly and less frequently in center on both proximal and distal sides; spines 4-15 (20) microns long, 3-6 microns wide at base, sharply pointed, tips often bent over; about twenty-one spines occur at equator; diameter 82-148 microns (exclusive of spines), body 62-103 microns (on nine specimens).

Remarks: The specimens recorded from Kentucky and the Mississippi Valley are generally smaller in size than those recorded by Hacquebard (1957), and are of a similar size range to those recorded from Ireland by Higgs *et al.* (1988). Complete specimens are rare and only two specimens are suitable for size comparison in the present study.

Occurrence: Fraileys Shale; Tar Springs Sandstone; Menard Limestone; Palestine Sandstone, Mississippi Valley. Henley Bed, Nancy Member, Borden Formation, Kentucky.

Infraturma: CINGULICAMERATI Neves & Owens 1966

Genus CINGULIZONATES (Dybová and Jachowicz) emend. Butterworth, Jansonius, Smith & Staplin 1964

Type species: *Cingulizonates bialatus* (Waltz) Smith & Butterworth 1967

Remarks: This genus encompasses species bearing a cuestra on the cingulum.

Cingulizonates bialatus (Waltz) Smith & Butterworth 1967

Plate 13, figures 3 & 4.

1938 *Zonotriletes bialatus* Waltz *in* Luber & Waltz, p. 22, pl. 4, fig. 51.

1941 *Zonotriletes bialatus* var. *undulatus* Waltz *in* Luber & Waltz, p. 28, pl. 5, figs. 71*a*, b.

1941 *Zonotriletes bialatus* var. *costatus* Waltz *in* Luber & Waltz, p. 29, pl. 5, fig. 72.

1956 *Densosporites bialatus* (Waltz) Potonié & Kremp, p. 114.

1956 *Hymenozonotriletes bialatus* var. *undulatus* (Waltz) Ishchenko, p. 63-64, pl. 12, figs. 135-137.

1957 *Cingulizonates tuberosus* Dybová and Jachowicz, p. 171, pl. 53, figs. 1-4.

1958 *Densosporites striatus (*Knox) Butterworth & Williams, p. 380, pl. 3, fig. 36.

1967 *Cingulizonates bialatus* (Waltz) Smith & Butterworth, p. 260-261, pl. 21, figs. 3-4.

Holotype: Not designated.

Type locality: Bed 6, Verkhni-Goubakhin Colliery, Kalinin Shaft, Kiezel region: U.S.S.R.. Lower Carboniferous.

Size: 25-60μm (Luber & Waltz 1941), 36-48μm, thickened part of cingulum 2-9μm, thin part 2-8μm (Smith & Butterworth 1967). 37-44μm (10 specimens, present study).

Original Diagnosis: (Smith & Butterworth 1967, p. 260, translated from Luber & Waltz 1941) Body rounded-triangular or ovate. Rays seldom seen but somewhat shorter than

radius of spore body. Flange thin, broad, with undulating surface and irregular margin; inner edge thickened, smooth or striated, sometimes with large tubercles projecting into the thinner outer flange.

Remarks: Smith & Butterworth (1967) transferred this species to the genus *Cingulizonates* due to the presence of a cuesta on the inner margin of the cingulum.

Occurrence: Hardinsburg Sandstone; Kinkaid Limestone, Mississippi Valley.

Cingulizonates capistratus (Hoffmeister, Staplin & Malloy) Staplin & Jansonius 1964
Plate 13, figures 5, 6, 9 & 10.

1955 *Densosporites capistratus* Hoffmeister, Staplin & Malloy, p. 386, pl. 36, figs.14, 15.
1964 *Cingulizonates capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jansonius, p. 105.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 386, pl. 36, fig. 15.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 41-61μm (Hoffmeister *et al.* 1955). 42-58μm (6 specimens, present study).

Original Description: (Hoffmeister *et al.* 1955, p. 386) Spores radial, trilete; outline convexly subtriangular; thickened equatorial region divided into three zones, inner zone thick, middle zone variable in thickness, composed of radiating crowded variable rods or cylindrical processes, outer zone thin and translucent, tapering to an even outer margin; central body granulose; widely scattered minute conical spines sometimes present on outer zone; trilete rays, when preserved, appear as narrow ridges extending to the inner edge of equatorial region; size range 41-61 microns.

Occurrence: Hardinsburg Sandstone; Tar Springs Sandstone; Waltersburg; Kinkaid Limestone; Caseyville Formation, Mississippi Valley.

Cingulizonates* cf. *C. capistratus (Hoffmeister, Staplin & Malloy) Staplin & Jansonius 1964 *sensu* Smith & Butterworth 1967

Plate 13, figures 7 & 8.

1958 *Densosporites capistratus* Hoffmeister, Staplin & Malloy; Butterworth & Williams, pl. 3, figs. 44, 45.
1958 *Densosporites variabilis* (Waltz) Potonié & Kremp; Butterworth & Williams, pl. 3, figs. 32-34.
1967 *Cingulizonates* cf. *C. capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jasonius; Smith & Butterworth, p. 261-262, pl. 21, figs. 5, 6.

Size: Spore diameter 41-60μm, cingulum width 8-20μm (Smith & Butterworth 1967). 40-56μm (12 specimens, present study).

Description: (Smith & Butterworth 1967, p. 261-262) In these specimens the central area is foveolate compared with the granulate ornament of *C. capistratus senso stricto*. The cingulum is somewhat greater than 50% of total diameter. The spores described and figured by Butterworth & Williams (1958) as *Densosporites variabilis* (Waltz) Potonié & Kremp and *Densosporites capistratus* differed only in the extent of the radiating processes of the cingulum; in specimens assigned to the former these processes exceptionally extended almost to the equator of the spore to form arches enclosing irregularly shaped alveolae, whereas in those assigned to the latter these were confined to the middle zone.

Occurrence: Fraileys Shale; Tar Springs Sandstone; Palestine Sandstone, Mississippi Valley.

Genus CIRRATRIRADITES Wilson & Coe 1940

Type species: *Cirratriradites saturni* (Ibrahim) Schopf, Wilson & Bentall 1944

Cirratriradites annuliformis Kosanke & Brokaw (*in* Kosanke 1950)

Plate 13, figures 11 & 12.

Holotype: Kosanke 1950, pl. 7, fig. 4.

Type Locality: No. 6 Coal, Fulton County, Illinois, USA. Mississippian (Carbondale Group).

Size: 68-104μm, spore body 56-84μm, zona 5-12μm (Smith & Butterworth 1967). 80-100μm (4 specimens, present study).

Diagnosis: (Smith & Butterworth 1967, p. 256 from description in Kosanke 1950, p. 35) Amb rounded-triangular; laesurae distinct, extending to the margin of zona. Exine of body sharply punctuate with four or more foveae on the distal surface; zona minutely radially striate. Body exine over 2μm thick. Folding rare.

Occurrence: Waltersburg; Kinkaid Limestone; Caseyville Formation, Mississippi Valley.

Genus CRISTATISPORITES Potonié & Kremp emend. Butterworth, Jansonius, Smith & Staplin 1964

Type species: *Cristatisporites indignabundus* (Loose) Potonié & Kremp 1954

Cristatisporites menendezii (Menéndez & Azcuy) Playford 1978

Plate 14, figures 1-3.

1972 *Ancistrospora verrucosa* Menéndez & Azcuy, p. 162-163, pl. 1, figs. 1-6; pl. 3, figs. 3-5; text-fig. 1, 2a.

1978 *Cristatisporites menendezii* (Menéndez & Azcuy) Playford, p. 137-138, pl. 10, figs. 3-6.

Holotype: Menéndez & Azcuy 1972, p. 162-163, pl. 1, figs. 1, 2; text-fig. 1.

Type Locality: Lagares Formation, Paganzo Basin, La Rioja Province, Argentina; Carboniferous.

Size: 57-87μm (100 specimens, Menéndez & Azcuy 1972). 46-81μm (30 specimens, Playford 1978). 45-58 (4 specimens, present study).

Original Diagnosis: Menéndez & Azcuy 1972, p. 162. In Spanish.

Description: (Playford 1978, p. 137-138) Spores radial, trilete; amb convexly subtriangular. Laesurae straight or slightly sinuous; simple or accompanied by narrow elevated lips that are up to 2μm wide overall; laesurae extend to inner margin of cingulum or almost so. Prominent biform sculpture developed over whole of distal surface, including (and especially upon) cingulum, and often encroaching marginally on cingulate proximal face. Sculpture consists of coarse mammoid verrucae with subcircular bases (diameter 3.5-10μm, occasionally up to 17μm; and height of ca. 2-7μm). Verrucae discrete, also fused to form coarse sinuous ridge-like structures up to ca. 25 μm long (usually much less). Sculptural elements normally equipped with slender, spinose accessory projections, 0.5-1.5 μm broad basally, 1-6.5 μm high. Exine otherwise scabrate or finely irregularly pitted (presumed corrosion effect). Intexinal body often evident, but only vaguely; usually in close proximity to outer layer.

Occurrence: Keokuk; Lower Warsaw, Mississippi Valley.

Genus DENSOSPORITES Berry emend. Butterworth, Jansonius, Smith & Staplin 1964

Type species: *Densosporites convensis* Berry (1937)

Densosporites anulatus (Loose) Potonié & Kremp 1956

Plate 14, figures 4-6.

1932 *Sporonites anulatus* Loose *in* Potonié, Ibrahim & Loose, p. 451, pl. 18, fig. 44.
1934 *Zonales-sporites* (*Anulati-sporites*) *anulatus* Loose, p. 151.
1944 *Densosporites anulatus* (Loose) Schopf, Wilson and Bentall, p. 40.
1956 *Anulatisporites anulatus* (Loose) Potonié & Kremp, p. 112, pl. 17, figs. 365-72.
1950 *Denso-sporites reynoldsburgensis* Kosanke, p. 33, pl. 6, figs. 9-11.

Holotype: Potonié & Kremp 1956, pl. 17, fig. 365 after Loose.

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

Size: 35-60μm (Potonié & Kremp 1956). 38-41μm (6 specimens, present study).

Original Diagnosis: (Smith & Butterworth 1967, p. 239, translated from Potonié & Kremp 1956, p. 112) Cingulum relatively uniform and smooth, having scaly structure. Amb smooth. Central area relatively much lighter than cingulum. Infragranulation obscure. Tetrad mark scarcely discernable.

Occurrence: Lower Warsaw; Hardinsburg Sandstone; Tar Springs Sandstone; Palestine Sandstone, Mississippi Valley. Portsmouth Member, Cuyahoga Formation, Kentucky.

Densosporites* cf. *D. crassigranifer Artüz

Plate 14, figure 7.

Size: 56μm (total spore diameter) 32μm (inner body) (single specimen, present study).

Description: Trilete cinguli-camerate miospores; amb convexly triangular with rounded apices. Suturae distinct, straight, simple, gaping and extending to the cingulum. Exoexine extended equatorially to form a dark cingulum, up to 10μm in width. Exoexine laevigate. Zona bears equatorial ornament of wide pillae, tops rounded, 3-4μm in height, and 2-8μm in width (most between 2-4μm wide), pillae occasionally fused to form large equatorial extensions up to 28μm in width.

Remarks: The ornament of *Densosporites* cf. *D. crassigranifer* closely resembles that of *Densosporites crassigranifer*. However, the extent of fusion between pila is more extreme in the former.

Occurrence: Tar Springs Sandstone, Mississippi Valley.

Densosporites gracilis Smith & Butterworth 1967

Plate 14, figure 8.

Holotype: Smith & Butterworth 1967, p. 240, pl. 19, fig. 7.

Type Locality: Dicky Gobbler Seam, Caldwell Ashley House borehole, South Derbyshire Coalfield, England; Westphalian.

Size: Spore diameter 27-42μm, cingulum 4-10μm (Smith & Butterworth 1967). Spore diameter 39μm, cingulum 8-10μm (single specimen, present study).

Original Diagnosis: (Smith & Butterworth 1967, p. 240) Amb round to subtriangular or oval. Laesurae flexuose, extending almost to equator of spore. Cingulum (about 37% of total spore diameter) laevigate, granulate, vermiculate, or having small spinae; also often lobate and sometimes with dissections. Outline irregular. Central area granulate with dissections, or vermiculate.

Occurrence: Lower Warsaw, Mississippi Valley.

Densosporites intermedius Butterworth & Williams 1958

Plate 14, figures 9-11.

1955 *Densosporites tenuis* Hoffmeister, Staplin & Malloy, p. 387, pl. 36, figs. 18, 19, 23.
1958 *Densosporites intermedius* Butterworth & Williams, p. 379, pl. 3, figs. 38, 39.
1967 *Densosporites intermedius* Smith & Butterworth, p. 240-241, pl. 19, figs. 9, 10.

Holotype: Smith & Butterworth 1967, pl. 19, fig. 10.

Type Locality: Seam at 2082' 2", Righead borehole, West Fife Coalfield, Scotland; Namurian.

Size: 37-51μm, cingulum width 8-15μm (Smith & Butterworth 1967). 42-56μm (8 specimens, present study).

Original Diagnosis: (Smith & Butterworth 1967, p. 240, from diagnosis in Butterworth & Williams 1958, p. 379) Outline round to rounded-triangular. Central area thin, unornamented, or slightly granular. Tetrad mark not always seen; rays narrow, extending to the edge of the central area. Cingulum broad, roughly one-half spore radius;

differentiated into a darker, thicker, inner zone and a lighter equatorial zone. Margin smooth or slightly notched.

Remarks: *Densosporites tenuis* Hoffmeister, Staplin & Malloy is conspecific with *Densosporites intermedius*. However, the former name is invalid due to the existence of *Densosporites tenuis* (Loose) Potonié & Kremp.

Occurrence: Burlington; Fraileys Shale; Hardinsburg Sandstone; Tar Springs Sandstone; Waltersburg; Palestine Sandstone; Kinkaid Limestone, Mississippi Valley.

Densosporites psuedoannulatus Butterworth & Williams 1958

Plate 14, figures 12 & 13.

Holotype: Smith & Butterworth 1967, p. 241, pl. 19, fig. 11.

Type Locality: Seam at 2982' 2", Righead borehole, West Fife Coalfield, Scotland; Namurian.

Size: 35-51μm (Butterworth & Williams 1958). 49-57μm (3 specimens, present study).

Diagnosis: (Smith & Butterworth, p. 241, from diagnosis in Butterworth & Williams 1958, p. 379) Amb round to subtriangular. Laesurae not always seen; rays simple, extending to edge of central area. Margin smooth or finely serrated. Central area thin, finely granulate, frequently showing arcuate folding at the margin. Cingulum massive, breadth roughly equal to radius of central area; uniform in thickness; smooth to slightly spinose and often with characteristic radial fractures on the interradial margin.

Occurrence: Fraileys Shale; Hardinsburg Sandstone, Mississippi Valley.

Densosporites spinifer Hoffmeister, Staplin & Malloy 1955

Plate 14, figures 14 & 15.

Holotype: Hoffmeister, Staplin & Malloy 1955, p. 386, pl. 36, fig. 17.

Type Locality: Hardinsburg Formation, Carter No. 3 Borehole (TCO-82), Webster County, Kentucky, USA; Chesterian.

Size: 32-48μm (Hoffmeister *et al.* 1955). 35-36μm (2 specimens, present study)

Original Description: (Hoffmeister *et al.* 1955, p. 386) Spores radial, trilete; outline convexly subtriangular; equatorial region of nearly equal thickness throughout its width, only slightly thinner at outer margin, almost opaque; ornamentation, central body granulose, spines of equatorial region scattered to crowded, 2-6μm long, sometimes divided, extremely variable in shape and disposition; outer margin spinose; trilete sutures, when preserved, extend slightly into the thickened equatorial region; diameter 32-48μm.

Occurrence: Tar Springs Sandstone; Palestine Sandstone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley.

Genus INDOTRIRADITES (Tiwari) emend. Foster 1979

Type species: *Indotriradites korbaensis* Tiwari 1964

Indotriradites explanatus (Luber) Playford 1991

Plate 14, figures 16 & 17.

1941 *Zonotriletes explanatus* Luber *in* Luber & Waltz, p. 10, pl. 1, fig. 4.

1963 *Hymenozonotriletes explanatus* (Luber) Kedo, p. 67, pl. 6, figs. 144-147.

1973 *Samarisporites* sp. cf. *Hymenozonotriletes explanatus* (Luber) Kedo; Streel, p. 404, p. 2, fig. 1.

1974 *Hymenozonotriletes tenuicostatus* Kedo, p. 45-46. pl. 11, figs. 8-10.

Holotype: Luber *in* Luber & Waltz 1941, pl. 1, fig. 4.

Type Locality: Palaeozoic USSR.

Size: 60-90μm (Kedo 1963). 63-80μm (9 specimens, present study).

Original Diagnosis: Luber *in* Luber & Waltz 1941.

Description: Amb is convexly subtriangular, occasionally subcircular. Outline of spore irregular due to ornamentation. Laesurae straight to slightly sinuous, extend to inner margin of zona, with narrow labra. Exine is bilayered, with exoexine extended equatorially to form a zona (10-20μm) with a relatively thick inner border. Intexine distinct to obscure. Ornament is variable; dominantly conate, with some spinae, bacula and verrucae; elements discrete with circular bases, 1-5μm wide and 1-6μm high. Height tends to be uniform on a single specimen.

Remarks: Playford (1976) discussed the generic placement of this species and noted that placement within *Hymenozonotriletes* was tentative. The species was later transferred to the genus *Indotriradites* (Playford 1990). The specimens in the present study are relatively small compared to those described previously.

Occurrence: Keokuk; Lower Warsaw, Mississippi Valley. Henley Bed, Borden Formation, Kentucky.

Genus KRAEUSELISPORITES (Leschik) Jansonius 1962

Type species: *Kraeuselisporites dentatus* Leschik 1956

Kraeuselisporites mitratus Higgs 1975

Plate 15, figures 1 & 2.

Holotype: Higgs 1975, p. 401, pl. 6, fig. 18.

Type Locality: Lyraun Cove Shale Member, Porters Gate Formation, East Hook Head, County Wexford, Ireland; Mississippian.

Size: Exoexine 53-76μm, intexine 34-58μm (26 specimens, Higgs 1975). 67-75μm (2 specimens, present study).

Diagnosis: (Higgs 1975, p. 401) Trilete cinguli-camerate miospores; amb rounded to convexly triangular. Suturae distinct, straight to sinuous, extending to spore margin and

accompanied by ray folds up to 3μm in height. Exoexine slightly thickened over distal surface and extended equatorially to form a thin, slightly fibrous flange, 6-12μm in width. Distal surface and flange ornamented with closely spaced galeae and spinae, which are broad or bulbous-based, 2-5μm in diameter, tapering either uniformly or sharply to pointed apices, over-all height 4-10μm. Elements normally discrete, but in some cases fused at bases, usually in pairs. Intexine distinct to obscure, laevigate, outline conformable with amb, centrally positioned, and forming two-thirds to three-fourths of total spore diameter. Exine infragranulate, with some body folds.

Occurrence: Lower Warsaw, Mississippi Valley. Henley Bed, Borden Formation, Kentucky.

Genus LYCOSPORA Schopf, Wilson & Bentall emend. Somers 1972

Type species: *Lycospora pusilla* (Ibrahim) Somers 1972

Remarks: Somers (1972) considered the original type species – *Lycospora micropapillata* (Wilson & Coe) Schopf, Wilson & Bentall 1944, to be a junior synonym of *Lycospora pusilla*.

Lycospora pusilla (Ibrahim) emend. Somers 1972

Plate 15, figures 5-8.

1932 *Sporonites pusillus* Ibrahim *in* Potonié, Ibrahim & Loose, p. 448, pl. 15, fig. 19.

1933 *Zonales-sporites pusillus* Ibrahim, p. 32, pl. 2, fig. 20.

1938 *Zonotriletes pusillus* (Ibrahim) Waltz *in* Luber & Waltz, pl. 3, fig. 33; pl. 8, fig. 105.

1944 *Lycospora pusillus* (Ibrahim) Schopf, Wilson & Bentall, p. 54.

1955 *Cirratriradites uber* Hoffmeister, Staplin & Malloy, p. 383, pl. 36, fig. 24.

1955 *Cirratriradites pseudoannulatus* Hoffmeister, Staplin & Malloy, p. 383, pl. 36, fig. 25.

1967 *Lycospora pusilla* (Ibrahim) Schopf, Wilson & Bentall; Smith & Butterworth, p. 251-252, pl. 20, figs. 10-12.

1972 *Lycospora pusilla* (Ibrahim); Somers, p. 66, pl. I, fig.11.

Holotype: Potonié & Kremp 1956, pl. 17, fig. 351 after Ibrahim.

Type Locality: Ägir Seam, Ruhr Coalfield, Germany; Westphalian.

Size: 30-40μm (Potonié & Kremp 1956). 22-35μm (Smith & Butterworth 1967). 34-42μm (20 specimens, present study).

Diagnosis: (Smith & Butterworth 1967, p. 251, translated from Potonié & Kremp 1956, p. 103) Tecta straight, fine, ornamented with small grana. Cingulum about one-ninth of radius. Amb slightly and fairly regularly indented ('korrodiert'). Exine finely granulate.

Description: Trilete cinguli-camerate miospores, amb rounded to convexly triangular. Laesurae straight, simple, sometimes gaping, extending to margin of inner body. Accompanied by slightly raised distinct labra around 2-3μm wide. Darkened (thickened) ridge around margin of spore body, around 2μm wide. Cingulum thin, variable in width, (6-12μm) width generally consistent on a single specimen. Spore body and cingulum laevigate or more often finely granulate. Margin smooth or crenulate, although this may be an effect of preservation or processing in some specimens.

Remarks: The holotype of *Lycospora pusilla* is poorly preserved and the nature of the cingulum is uncertain. This has caused problems with identification, and the species has previously been described as both a cingulate species (Ibrahim in Potonié, Ibrahim & Loose 1932) and a cingulizonate species (Somers 1972). Recent studies by Bek and Opluštil (2006) have redefined *Lycospora pusilla* as a cingulate species i.e. *Lycospora pusilla sensu* Ibrahim *non* Somers.

Two species of *Cirratriradites* identified by Hoffmeister *et al.* (1955), closely resemble *Lycospora pusilla* in their size, finely granulate to granulate ornament and apparent possession of a cingulum ('equatorial flange' of Hoffmeister *et al.* 1955), and have been included as synonyms above.

Occurrence: Cypress Sandstone; Hardinsburg Sandstone; Tar Springs Sandstone; Waltersburg; Menard Limestone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley.

Genus PROLYCOSPORA Turnau 1978

Type species: *Prolycospora claytonia* Turnau 1978

Prolycospora rugulosa (Butterworth & Spinner) Turnau 1978

Plate 15, figures 3 & 4.

1967 *Lycospora rugulosa* Butterworth & Spinner, p. 10, pl. 2, figs. 1, 2.

1978 *Prolycospora rugulosa* (Butterworth & Spinner) Turnau, p. 10.

Holotype: Butterworth & Spinner 1967, p. 10, pl. 2, fig. 1.

Type Locality: Half-inch coal, Lewis Burn Group, Lewis Burn, Northumberland, England; Lower Carboniferous.

Size: 20-38μm (60 specimens, Butterworth & Spinner 1967). 43-52μm (20 specimens, present study).

Original Diagnosis: (Butterworth & Spinner 1967, p. 10) Amb circular to rounded triangular, margin minutely crenulate. Laesurae distinct, simple, extending almost to the equator; apical papillae prominent. Proximal surface minutely granulose or punctate, distal surface rugulose. Cingulum tapering, plicated, 2-3μm wide, barely discernible. Exine thin but rarely folded.

Remarks: This species was reassigned to the genus *Prolycospora* because of its very narrow and uniformly thick cingulum (Turnau 1978). It has a first occurrence preceding *Lycospora* in western Europe.

Occurrence: Cypress Sandstone; Fraileys Shale; Menard Limestone; Kinkaid Limestone, Mississippi Valley.

Genus RADIIZONATES Staplin & Jansonius 1964

Type species: *Radiizonates aligerens* (Knox) Staplin & Jansonius 1964

Radiizonates mirabilis Phillips & Clayton 1980

Plate 15, figures 9-11.

Holotype: Philips & Clayton 1980, p. 128, fig. 9 M.

Type Locality: Sample C, Leckascannalmore Member, Capnagower Formation, Clare Island, County Mayo; Mississippian.

Size: 48-97μm (17 specimens, Phillips & Clayton 1980). 48-63μm (3 specimens, present study).

Original Diagnosis: (Phillips & Clayton 1980, p. 128) Trilete, camerate, cingulizonate miospores. Trilete mark distinct to indistinct. Suturae straight, extend to the outer margin of the spore body, accompanied by low, sinuous ray-folds, which extend beyond the terminations of the suture, almost to the equator. Amb subcircular to rounded convexly triangular. Spore body 0.5-0.7 overall diameter, conformable with the amb. The zona has a prominently thickened inner margin which, in most specimens is linked by radiating thickened ribs to an outer thickened zone at, or just in from the equator. The distal surface of the spore body is sparsely ornamented by small coni or grana, which are also occasionally present on the distal surface of the zona and at the equator. Intexine membranous, rarely seen.

Occurrence: Keokuk; Lower Warsaw; Fraileys Shale; Kinkaid Limestone, Mississippi Valley.

Genus VALLATISPORITES Hacquebard 1957 emend. Sullivan 1964b

Type species: *Vallatisporites vallatus* Hacquebard 1957

Remarks: This genus encompasses trilete camerate miospores with an internally vacuolate equatorial border (Sullivan 1964b). In his original generic description Hacquebard (1957) uses the term perispore to refer to the exoexine. The emended description of Sullivan (1964b) recognises an exoexine.

Vallatisporites ciliaris (Luber) Sullivan 1964

Plate 16, figures 1 & 2.

1938 *Zonotriletes ciliaris* Luber *in* Luber & Waltz, pl. 6, fig. 82.

1964b *Vallatisporites ciliaris* (Luber) Sullivan, p. 370-371, pl. 59, figs. 14-15, text-fig. 3.

Holotype: Luber *in* Luber& Waltz 1938, pl. 6, fig. 82.

Type Locality: Lower Carboniferous coals of the Karaganda Basin, USSR.

Original Diagnosis: Luber *in* Luber & Waltz 1938.

Size: 50-70μm (60 specimens, Sullivan 1964). 53-65μm (5 specimens, present study).

Description: (Sullivan 1964, p. 370-371) 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 5μm 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 3μm high and 3.5μm wide at 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 the spiked helmet of 'Pickelhaube' 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 mammilate elements by the length of the spine. In certain specimens of this species galeae form the dominant ornamentation. The equatorial border maintains a constant proportion 2/5 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 residual strands 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.

Occurrence: Burlington; Keokuk; Lower Warsaw; Upper Warsaw; Fraileys Shale, Mississippi Valley. Farmers Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Vallatisporites hystricosus (Winslow) Byvscheva 1985

Plate 16, figure 3.

1962 *Cirratriradites hystricosus* Winslow p. 40, 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: Winslow 1962, pl. 18, fig. 5.

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

Size: 46-84μm (Stephenson & Owens 2006). 56-70μm (3 specimens, present study).

Description: (Stephenson & Owens 2006, p. 72) Radial, trilete, cinguli-camerate miospores. Amb rounded triangular to subcircular. Outline of inner body may be conformable with equatorial margin of spore or more circular resulting in the equatorial cinguli-zonate structure being wider in the radial positions. Trilete mark distinct, sutures straight, extending to margin of inner body, accompanied by elevated, flexuous folds of the exoexine, up to 4μm in the polar region but decreasing in height and extending to the equatorial margin. Intexine thin, laevigate or finely infrapunctate, forming inner body. Exoexine closely adpressed to intexine except in the equatorial plane where a well developed cuniculus indicates limited separation. Exoexine extended in the equatorial plane to form bizonate cingulum consisting of a thinner, inner, extensively vacuolated zone with closely spaced radially orientated vacuoles separated by narrow walls, and a thicker outer zone. Distal surface of exoexine bears galeate ornament of variable density; elements

are largest and most densely distributed in the distal polar region and finer and less densely distributed towards the equatorial margin. Small sharply pointed coni may be located in the spaces between the galeate elements. Individual galeae up to 10μm high and 7μm in basal diameter, consisting of a rounded basal boss, surmounted by a sharply pointed, slender spinae. Fusion of bases between adjacent elements forms irregular vermicular elements with common spinose crests, particularly in the polar region. Numerous elements project at the equatorial margin.

Remarks: *Vallatisporites hystricosus* is similar to *Vallatisporites pusillites* but possesses coarser ornament including galeate elements, 3-16μm in height (Avchimovitch *et al.* 1988). Stephenson and Owens (2006) note the possible gradation between the two species. In the present material, *Vallatisporites hystricosus* is noted from a single sample from the Bedford Shale, Kentucky.

Occurrence: Bedford Shale, Kentucky.

Vallatisporites pusillites (Kedo) Dolby & Neves emend. Byvscheva 1985

Plate 16, figures 4 & 5.

1957b *Hymenozonotriletes pusillites* Kedo, p. 22, pl. 1, fig. 1.

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, figs. 3-4, *non* fig. 1-2.

1985 *Vallatisporites pusillites* (Kedo) Dolby & Neves emend. Byvscheva, p. 135-136, pl. 27, fig. 1-3.

Holotype: Kedo 1957b, pl. 1, fig. 1.

Type Locality: Palaeozoic USSR.

Size: 42-73μm (30 specimens, Dolby & Neves 1970). 53-56 (3 specimens, present study).

Original Diagnosis: Kedo 1957b, p. 22. In Russian.

Description: (Dolby & Neves 1970, p. 639) Spores radial, trilete and camerate. Amb rounded triangular. Exine two layered and finely granular. Intexine forms a central body which makes up 60(72)82% of the total spore diameter and is attached over the distal and proximal surfaces. Trilete mark generally distinct. Tecta straight to slightly sinuous, about 3µm high and wide, and equal in length to spore radius. Ornament consists of galeate spines with a spacing 1-5µm. They vary from 10µm in length with a 3.5µm basal diameter and only slightly swollen, to typical galeae with 5µm diameter bases surmounted by 5µm spines. The bases commonly coalesce into a series of irregular ridges carrying 2-5 spines. Smaller and more delicate processes are found on the equatorial margin. All spines bend over radially towards the circumference.

Separation of the exoexine and intexine forming a cuniculus along the equator of the inner body is a common feature, intermittently developed or continuous in a zone up to 2µm wide. This zone is commonly surrounded by a slightly thicker band of exine. The exoexine from here to the spore equator forms a cingulum which may contain circular to elliptical vacuoles up to 8.5µm long in the radial direction. These may form an irregular zone about two-thirds the width of the cingulum.

Remarks: *Vallatisporites pusillites* is very similar to *Vallatisporites hystricosus* but possesses relatively finer ornamentation in which non-galeate elements are more common. Complete morphological gradation may exist between the two species (Stephenson & Owens 2006). Avchimovitch *et al.* (1988, p. 175) define *Vallatisporites pusillites* as possessing "a dense ornament of coni and subordinate grana and spinae up to 2µm in height".

Occurrence: Burlington Limestone, Mississippi Valley. Sunbury Shale, Kentucky.

Vallatisporites vallatus Hacquebard 1957

Plate 16, figures 6, 8 & 9.

1957 *Vallatisporites* sp. A Hacquebard, p. 313, pl. 2, fig. 13.

1957 *Vallatisporites vallatus* Hacquebard, pl. 2, fig. 12.

Holotype: Hacquebard 1957, pl. 2, fig. 12.

Type Locality: West Gore and Blue Beach, Horton Group, Nova Scotia, Canada; Mississippian.

Size: Overall diameter 60-70μm, body 35-41μm (5 specimens, Hacquebard 1957). 45-56μm (10 specimens, present study).

Original Description: (Hacquebard 1957, p. 312) Spores radial, trilete; convexly subtriangular in proximal view; trilete usually distinct, lips slightly raised, extending to equator or nearly so; central body thin, margin well defined, often folded; in central area, perispore has minute grana and small cones, 1-2 microns in diameter, 2-3 microns apart; perisporal extension with rampart-like inner part, up to 8 microns wide, and flange-like outer part, 6-10 microns 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.

Description: Trilete cinguli-camerate miospores; amb convexly triangular. Suturae straight or slightly sinuous, extending to the spore margin, often obscured by ornament. Exoexine infrapunctate, extended equatorially to form a cingulum, cingulum usually around 1/3 of the total spore diameter. Cingulum comprises an inner light zone and outer darker zone and is internally vacuolated. Vacuoles between 2-4μm in radial width and often fused. Exoexine bears distal ornament of coni, grana and small spinae, around 0.5-4μm in height and 1-2μm in basal diameter. Ornament discrete or fused, less prominent on the cingulum. Intexine distinct, laevigate, outline conformable with amb.

Occurrence: Hannibal Shale; Burlington; Keokuk; Lower Warsaw; Tar Springs Sandstone; Palestine Sandstone, Mississippi Valley. Henley Bed, Farmers Member, Nancy Member, Borden Formation; Rockford Limestone; Portsmouth Member, Cuyahoga Formation, Kentucky.

Vallatisporites verrucosus Hacquebard 1957

Plate 16, figure 7.

Holotype: Hacquebard 1957, p. 313, pl. 2, fig. 13.

Type Locality: West Gore and Blue Beach, Horton Group, Nova Scotia, Canada; Mississippian.

Size: Overall diameter 55-64μm, body 41-47μm (5 specimens, Hacquebard 1957). 43-50μm (11 specimens, present study).

Original Description: (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) microns in diameter; perisporal extension with narrow, groove-like inner part, only 1 micron wide, and flange-like outer part 6-10 microns 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.

Remarks: In his original generic description Hacquebard (1957) uses the term perispore to refer to the exoexine. The emended description of Sullivan (1964b) recognises an exoexine.

Occurrence: Hannibal Shale; Burlington; Keokuk; Lower Warsaw, Mississippi Valley. Henley Bed, Farmers Member, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation, Kentucky.

Vallatisporites sp. A

Plate 16, figures 10, 11, 13 & 14.

Size: 32-42μm (5 specimens, present study).

Description: Trilete cinguli-camerate miospores, amb usually convexly triangular. Suturae distinct to obscure. Intexine laevigate, outline conformable with the amb and extending approximately 2/3 of total spore diameter. Exoexine extended equatorially to form a thin cingulum. The cingulum comprises 1/3 of the total spore diameter. The border appears bizonate: there is an inner light zone (6-10μm in width) and an outer dark one (around 2μm

in width). 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. Some strands separate the vacuoles and give a radially patterned appearance. Ornament of low coni and spinae on distal exoexine and equatorial margin; ornament up to 1μm in height.

Remarks: *Vallatisporites* sp. A is typically much smaller in size than other species of *Vallatisporites* commonly found in the Mississippi Valley. This species is very common in the Lower Warsaw.

Occurrence: Hannibal Shale; Keokuk; Lower Warsaw, Mississippi Valley. Henley Bed, Farmers Member, Borden Formation, Kentucky.

***Vallatisporites* sp. B**

Plate 16, figure 12.

Size: 45-62μm (3 specimens, present study).

Description: Trilete cinguli-camerate miospores, amb subtriangular. Suturae obscure. Intexine distinct, laevigate, outline conformable with the amb and extending approximately 1/2 of total spore diameter. Miospores laevigate or granulate. Exoexine extended equatorially to form a cingulum. The cingulum comprises 1/2 of the total spore diameter. Three bands can be identified on the cingulum, an inner vacuolate band around 4-8μm wide, a thicker middle band around 2-6μm wide and an outer zona; variably 4-10μm wide. The cingulum is generally laevigate or may have some small (1-2μm high) spines on the darker band.

Remarks: *Vallatisporites* sp. B is common in Osagean age strata of the Mississippi Valley.

Occurrence: Hannibal Shale; Keokuk; Lower Warsaw; Upper Warsaw; Tar Springs Sandstone, Mississippi Valley. Henley Bed, Farmers Member, Borden Formation, Kentucky.

***Vallatisporites* sp. C**

Plate 16, figures 15 & 16.

Size: 46-58μm (3 specimens, present study).

Description: Trilete cinguli-camerate miospores, amb subtriangular. Suturae obscure. Intexine distinct, laevigate. Outline conformably with the amb and extending approximately 1/2 of total spore diameter. Exoexine laevigate or granulate; exoexine extended equatorially to form a cingulum. The cingulum comprises 1/3 of the total spore diameter. Cingulum is vacuolated – vacuoles generally fused to form a light band up to 10μm thick. The cingulum is laevigate or may have some small (1-2μm high) spines on the darker band.

Remarks: This species is very similar to *Vallatisporites* sp. B but lacks the outer zona on the cingulum.

Occurrence: Keokuk; Lower Warsaw, Mississippi Valley.

Suprasubturma: PERINOTRILETES Erdtman 1947

Genus SCHULZOSPORA Kosanke 1950

Type species: *Schulzospora rara* Kosanke 1950

Schulzospora campyloptera (Waltz) Hoffmeister, Staplin & Malloy.

Plate 17, figures 1 & 2.

1884 No. 619, Reinsch, p. 60, pl. 22, fig. 231 D.

1938 *Zonotriletes campylopterus* Waltz *in* Luber and Waltz, p. 16, pl. 3, fig. 39; pl. A, fig. 15.

1955 *Schulzospora campyloptera* (Waltz) Hoffmeister, Staplin & Malloy, p. 396.

1958 *Dilobozonotriletes campylopterus* (Waltz) Ischenko, p. 94, pl. 12, figs. 160, 161.

Holotype: Not Known.

Type Locality: Seam 46, Skakulin Colliery, Selizharovo, Moscow Basin.

Size: 90-114μm x 65-75μm, body 60-70μm (Luber & Waltz 1938). 73-78μm x 35-42μm, body 37-41μm (12 specimens, present study).

Original Diagnosis: (Smith & Butterworth 1967, p. 274, translated from diagnosis in Luber & Waltz 1938) Outline approximately oval; pseudosaccus thin, of variable width, three or four times wider at equator than poles, giving the spore an oval rather than a round shape; pseudosaccus margin crenulate. Laesurae indistinct, rays one-third to two-thirds spore radius, not all of equal length. Exine microreticulate, more distinct on the pseudosaccus than on the body.

Remarks: Specimens of *Schulzospora campyloptera* from the Mississippi Valley are smaller in size range compared to those of Luber & Waltz (1938).

Occurrence: Cypress Sandstone; Fraileys Shale; Hardinsburg Sandstone; Tar Springs Sandstone; Waltersburg; Menard Limestone; Palestine Sandstone; Kinkaid Limestone; Caseyville Formation, Mississippi Valley.

Schulzospora rara Kosanke 1950

Plate 17, figures 3, 5 & 7.

1950 *Schulzospora rara* Kosanke, p. 53-54, pl. 13, figs. 5-8.

Holotype: Kosanke 1950, pl. 13, fig. 8.

Type Locality: Battery Rock Coal, Hardin County, Illinois; USA. Caseyville Group.

Size: 70-105μm x 50-75μm, body 48-75μm (Balme 1952). 68-97μm x 52-66μm, body 52-62μm (10 specimens, present study).

Original Diagnosis: (Smith & Butterworth 1967, p. 277 taken from description in Kosanke 1950, p. 53) Outline elliptical, body spherical. Trilete rays at least 20μm in

length, distinct, lips poorly developed. Pseudosaccus and body finely punctate. Exine thin, not exceeding 2μm.

Occurrence: Cypress Sandstone; Tar Springs Sandstone; Waltersburg; Menard Limestone; Palestine Sandstone, Mississippi Valley.

Genus SPENCERISPORITES Chaloner 1951

Type species: *Spencerisporites radiatus* (Ibrahim) Felix & Parks 1959

Spencerisporites radiatus (Ibrahim) Felix & Parks 1959

Plate 17, figure 6.

1932 *Sporonites radiatus* Ibrahim *in* Potonié, Ibrahim & Loose, p. 449, pl. 16, fig. 25.

1933 *Zonales-sporites radiatus* Ibrahim, p. 28, pl. 3, fig. 25.

1934 *Triletes karczewskii* Zerndt, p. 27, pl. 31, fig. 3.

1944 *Triletes radiatus* (Ibrahim) Schopf, Wilson & Bentall, p. 24.

1946 *Microsporites karczewskii* (Zerndt) Dijkstra & Van Vierssen Trip, p. 64, pl. 4, fig. 40.

1951 *Spencerisporites karczewskii* (Zerndt) Chaloner, p. 862, text-figs. 1-2, 6-7.

1959 *Spencerisporites radiatus* (Ibrahim) Felix & Parks, p. 362, pl. 1, figs. 1-4 and pl. 2, figs. 1-4.

Holotype: Potonié & Kremp 1955, pl. 20, fig. 400, after Ibrahim 1932.

Type Locality: Ägir Seam, Ruhr Coalfield, Germany; top of Westphalian B.

Size: 270-440μm (Potonié & Kremp 1956). 220 x 276μm (single specimen, present study).

Diagnosis: (Smith & Butterworth 1967, p. 269, abbreviated from Chaloner 1951 for *Spencerisporites karczewskii*) Spore body circular in equatorial plane. Triradiate ridges prominent, normally folded sideways by compression. Proximal body wall ornamented by fine broken lines which radiate from three points placed symmetrically, one on each of the three contact faces. Distal surface probably smooth. The wing as a whole is subtriangular

in equatorial plane. Cuticle of wing thinner than that of the body and both surfaces show a pattern of rather indefinite intersecting lines. Marginal rim of uniform width.

Description: Spore pseudosaccate, trilete, amb subtriangular. Laesurae indistinct, obscured by accompanying labra which are about 4μm in width, extend around 2/3 of diameter of inner body, each of the three contact faces ornamented by fine broken lines radiating from a central point. Inner body laevigate, margin conformable with amb, radius just smaller than half total spore radius. Pseudosaccus thin, laevigate to finely granulate, heavily folded. Limbus around 10μm in width, regular, outline smooth.

Remarks: Specimens of this species are rare and are heavily folded. No specimens are preserved in polar view making determination of characteristics very difficult.

Occurrence: Kinkaid Limestone, Mississippi Valley.

Anteturma: POLLENITES Potonié 1931
Turma: SACCITES Erdtman 1947
Subturma: MONOSACCITES (Chitaley) Potonié & Kremp 1954
Infraturma: ARADIATES Bharadwaj 1957

Genus FLORINITES Schopf, Wilson & Bentall 1944

Type species: *Florinities pellucidus* (Wilson & Coe 1940) Wilson 1958

Florinites* cf. *F. visendus (Ibrahim) Schopf, Wilson & Bentall

Plate 17, figure 4.

Size: 115 x 170μm (single specimen, present study).

Description: Spores pseudosaccate, trilete (?), amb oval, possibly originally circular. Laesurae indistinct, do not appear to extend past the outline of the spore body. Pseudosaccus thin, reticulate, and commonly folded. Limbus 4-6μm in width. Body apparently laevigate, darker (and therefore possibly thicker) than psuedossacus, distinct; diameter 1/3 of total spore diameter.

Remarks: This specimen is heavily folded. No specimens are preserved in polar compression making determination of characteristics very difficult.

Occurrence: Palestine Sandstone, Mississippi Valley.

INCERTAE SEDIS

Genus HYSTRICOSPORITES

Hystricosporites* cf. *H. porcatus (Winslow) Allen 1965

Plate 17, figure 8.

Size: 76μm (single specimen, present study).

Description: Trilete miospore, acamerate. Suturae obscure. Amb subcircular. Exine bears an ornament of long, grapnel-like processes. Processes up to 45μm in length, typically 36-40μm, 4μm wide at the base, tapering slightly and terminating in bifurcate tips. Ornament unevenly distributed, present at poles, absent from remainder of spore body.

Remarks: This spore resembles *Hystricosporites porcatus* but differs in its smaller size and in the concentration of ornament around the mid section of the spore.

Occurrence: Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus UNCERTAIN

Spore Type A

Plate 17, figure 9.

Size: 94μm (single specimen, present study).

Description: Trilete, acamerate miospores. Amb subcircular. Suturae indistinct, partly obscured by ornament, simple, straight extending at least 1/3 of total spore radius.

Darkened area indicating possible thickening at proximal apical pole. Dense ornament of discreet, elongated spinae, 12-25μm in length, bases 4-8μm wide. Ornament apparently covers both surfaces.

Remarks: A single specimen of this species is recorded. The specimen broadly resembles *Ibrahimispores brevispinosus* Neves, but preservation is poor and the trilete mark is obscured.

Occurrence: Hardinsburg Sandstone, Mississippi Valley.

6. 3 NOMENCLATURE AND CLASSIFICATION OF ACRITACHS AND PRASINOPHYTE PHYCOMATA

Acritarchs are defined as organisms 'of uncertain origin', and as such, the biological affinities of most acritarchs are unknown (Downie *et al.* 1963; Evitt 1963). Acritarch classification, like that of pollen and spores, is based on purely morphological characteristics (Strother 1996; Playford 2003). Acritarchs and prasinophyte phycomata are named in accordance with the International Code of Botanical Nomenclature, where they are recognised as form-genera and form-species.

There has been, and still is, controversy over how morphology should be used to define acritarch taxa at a suprageneric level. Morphological characteristics used to define genera have also been the focus of much discussion (e.g. Sarjeant & Stancliffe 1994; Stancliffe & Sarjeant 1994; Stancliffe & Sarjeant 1996). Certain fossil cysts originally assigned to the Group Acritarcha have since been recognised as fossil phycomata belonging to the chlorophyte algal family Prasinophyceae (Wall 1962; Tappan 1980), and four groups are generally recognised as belonging to the prasinophytes (Strother 1996). These are - *Tasmanites* and related genera, characterised by thick walls and radial pores; *Cymatiosphaera* and other reticulate-murinate genera; *Pterospermella*, with a spherical central body and large equatorial flange; and *Leiosphaeridia*, which are simple, smooth walled spheres.

Downie *et al.* (1963) proposed a suprageneric classification for the group, comprising 13 subgroups, based on external morphology and method of excystment. This was later modified by a number of authors including Downie (1973), Tappan (1980) and Strother (1996). Strother (1996) condensed the acritarchs (excluding the prasinophyte phycomata) into eight groups – the *Baltisphaeridium* group, *Navifusa* group, sphaeromorph acritarchs, *Micrhystridium-Veryhachium* group, *Leiofusa* group, *Acanthodiacrodium* group, *Visbysphaera* group and 'other acritarchs.' Because of heterogeneity and wide variation in some categories these classifications are not widely accepted, and most authors list acritarch taxa alphabetically (Playford 2003). This approach is followed herein.

6. 4 SYSTEMATIC PALYNOLOGY

Notes on systematic descriptions

Synonymies given include the original designation, emended designations and important transferred taxa. The original diagnosis or description of species is given where possible. Where the original diagnosis is not given or requires translation, descriptions are taken from Playford (1977), Wicander & Playford (1985) or Playford & McGregor (1993). Where spore taxa have been emended the original and/or emended diagnosis or description is given as appropriate.

Division: CHLOROPHYTA Pascher 1914
Class: PRASINOPHYCEAE Christensen 1962
Family: CYMATIOSPHAERACEAE Mädler 1963

Genus CYMATIOSPHAERA O. Wetzel emend Deflandre & Cookson 1955
Type species: *Cymatiosphaera radiata* O. Wetzel 1933

Cymatiosphaera ambotrocha Wicander & Loeblich 1977
Plate 18, figure 1.

1977 *Cymatiosphaera ambotrocha* Wicander & Loeblich, p. 135-136, pl. 1, figs. 3-6.

Holotype: Wicander & Loeblich 1977, p. 135-136, pl. 1, figs. 4, 5.

Type Locality: American Smelting and Refining Company core, I-4 well, Antrim Shale, Porter County, Indiana; U.S.A. Upper Devonian.

Size: 46-54μm (Wicander & Loeblich 1977). 45-49μm (2 specimens, present study).

Original Description: (Wicander & Loeblich 1977, p. 135-136) Vesicle circular in outline, 46-54μm in diameter, wall granulate, grana 0.6-1μm in diameter with rounded tips, evenly distributed over vesicle wall surface; each hemisphere with 5 fields surrounding a central circular field, fields bordered by laevigate ridges, about 5μm high, which radiate from the central field to the vesicle periphery, thus dividing each hemisphere into 5

polygonal fields surrounding the central field; the hemispheres on opposite sides are offset a half-field from each other, with light microscopy 10 fields appear to surround a central 5-sided field; the distance from the central ridge to the vesicle periphery, or the radiating sides of the 5 fields surrounding the central one, is 16-18μm long; a laevigate, diaphanous, equatorial flange 2-3μm wide surrounds the vesicle; no method of excystment observed.

Remarks: This species is typically recorded from the Late Devonian. Wicander & Loeblich (1977) recorded it from the Famennian-Frasnian of Indiana.

Occurrence: Hannibal Shale, Mississippi Valley; Bedford Shale, Kentucky.

Cymatiosphaera chelina Wicander & Loeblich 1977

Plate 18, figures 2, 3.

1977 *Cymatiosphaera chelina* Wicander & Loeblich, p. 137, pl. 2, figs. 5-6.

Holotype: Wicander & Loeblich 1977, p. 137, pl. 2, fig. 6.

Type Locality: American Smelting and Refining Company core, I-4 well, Antrim Shale, Porter County, Indiana; U.S.A. Upper Devonian.

Size: 25-37μm (Wicander & Loeblich 1977). 38-49μm (8 specimens, Wicander & Playford 1985). 44-50μm (3 specimens, present study).

Original Description: (Wicander & Loeblich 1977, p. 137) Vesicle circular-subcircular in outline, 25-37μm in diameter, vesicle divided into about 20 5 or 6-sided polygonal fields per hemisphere, each field 6-7μm in diameter; fields separated by low, narrow, laevigate, diaphanous ridges, 1μm high; ridges fairly stiff, although some may be flexible, presenting the fields with a wavy appearance; vesicle surface within fields is reticulo-cristate, very low, thin, interconnecting laevigate ridges forming a network of 4 to 6-sided polygonal sub fields, 1-2μm in diameter; excystment by simple splitting of vesicle wall.

Remarks: This species is typically recorded from the Late Devonian, for example, the Frasnian–lower Famennian of the Antrim Shale of Indiana (Wicander & Loeblich 1977;

Wicander 1983) and the upper Frasnian Lime Creek Formation of Ohio (Wicander & Playford 1985). The size range of specimens in the present study is closer to the size range given by Wicander & Playford (1985) than to that given by Wicander & Loeblich (1977).

Occurrence: Chattanooga Shale, Hannibal Shale, Bachelor Formation, McCraney Limestone, Prospect Hill Siltstone, Mississippi Valley; Rockford Limestone, Cuyahoga Formation, Kentucky.

Cymatiosphaera* cf. *C. parvicarina *sensu* Wicander & Playford 1985

Plate 18, figure 4.

1985 *Cymatiosphaera* cf. *Cymatiosphaera parvicarina* Wicander 1974; Wicander & Playford, p. 104, p. 12, figs. 1A-B.

Size: 59-68μm (3 specimens, Wicander & Playford 1985). 62-70μm (2 specimens, present study).

Description: (Wicander & Playford 1985, p. 104) Vesicle circular in outline, wall 1.8-2.1μm thick; surface divided into 12-18 nearly equidimensional, pentagonal to hexagonal lacunae, 10-20.6μm in maximum width and delimited by low, laevigate, diaphanous muri, 2.1-3μm high and 1.8-2μm wide; lacunae floors scabrate; no excystment structure observed.

Occurrence: Chattanooga Shale, Hannibal Shale, Mississippi Valley; Henley Bed, Borden Formation, Kentucky.

Cymatiosphaera perimembrana Staplin 1961

Plate 18, figures 5, 6.

1961 *Cymatiosphaera perimembrana* Staplin, p. 417, pl. 49, figs. 16, 17.
1977 *Cymatiosphaera platoloma* Wicander & Loeblich, p. 140, pl. 3, figs, 3,4.

Holotype: Staplin 1961, p. 417, pl. 49, fig, 16.

Type Locality: Duvernay Member, Woodbend Formation, Alberta; Canada. Upper Devonian.

Size: 22-36μm (Staplin 1961). Overall diameter 25-32μm; diameter of vesicle 18-22μm (20 specimens, Wicander & Playford 1985). 46-49μm (3 specimens, present study).

Original Diagnosis: (Staplin 1961, p. 417) Vesicle spherical to ellipsoidal; laevigate; surrounded by a tightly fitting diaphanous membrane that is gathered into a fine reticulum; lacunae polygonal, 4-8 microns across, muri very fine; membrane stiffened by fine rods that arise from the muri, 3-5 microns long; membrane extends 2.5-5 microns beyond vesicle margin.

Remarks: This species is typically recorded from the Late Devonian e.g. the Frasnian-Famennian of the Antrim Shale of Indiana (Staplin 1961; Wicander & Loeblich 1977) and the Frasnian of the Lime Creek Formation of Ohio (Wicander & Playford 1985). The specimens recorded in the present study are notably larger than those recorded by Staplin (1961) and Wicander & Playford) (1985).

Occurrence: Keokuk Limestone, Mississippi Valley; Henley Bed, Borden Formation, Portsmouth Member, Cuyahoga Formation, Kentucky.

Cymatiosphaera cf. *C. perimembrana*

Plate 18, figure 7.

Size: 34μm (single specimen, present study).

Description: Vesicle circular in outline, eilyma thin; laevigate; surface divided into 8 nearly equidimensional, pentagonal to hexagonal lacunae, 14μm in maximum width and delimited by laevigate diaphanous muri, 4-μm high. Excystment is by simple splitting of vesicle wall.

Remarks: This species is similar to *Cymatiosphaera perimembrana* Staplin 1961 but has fewer lacunae.

Occurrence: Burlington Limestone, Mississippi Valley.

Genus DICTYOTIDIUM Eisenack emend. Staplin 1961

Type species: *Dictyotidium dictyotum* (Eisenack) Eisenack 1955

Dictyotidium craticulum (Wicander & Loeblich) Wicander & Playford 1985

Plate 18, figure 8.

1977 *Cymatiosphaera craticula* Wicander & Loeblich, p. 138, pl. 3, figs. 13,14.
1985 *Dictyotidium craticulum* (Wicander & Loeblich) Wicander & Playford, p. 105, pl. 2, figs. 10, 11A-B.

Holotype: Wicander & Loeblich 1977, p. 138, pl. 3, fig. 13.

Type Locality: American Smelting and Refining Company core, I-4 well, Antrim Shale, Porter County, Indiana; U.S.A. Upper Devonian.

Size: 28-32μm (Wicander & Loeblich 1977). 24-29μm (9 specimens, Wicander & Playford 1985). 30μm (single specimen, present study).

Original Description: (Wicander & Loeblich 1977, p. 138) Vesicle circular in outline, 28-32μm in diameter, surface divided into 65-75 five-sided polygonal fields per hemisphere, 3-4μm in diameter; fields formed by low solid, laevigate and generally straight ridges 0.5μm high; some ridges can be flexible; vesicle surface within fields laevigate; excystment is by simple splitting of vesicle wall.

Description: (Wicander & Playford 1985, p. 105) Vesicle circular to subcircular in outline, wall 0.8-1.1μm thick; surface divided into fairly uniform, polygonal (4- to 6-sided) lacunae, 2.2-3.1μm in diameter, by low, laevigate, solid, generally straight, round-topped muri, 0.8-1.1μm high, and 0.8-1μm wide at base; lacunae have laevigate floors; excystment by simple splitting of vesicle wall.

Remarks: This species is typically recorded from the Late Devonian e.g. the upper Frasnian-lower Famennian Antrim Shale of Indiana (Wicander & Loeblich 1977) and the Frasnian Lime Creek Formation of Ohio (Wicander & Playford 1985).

Occurrence: Prospect Hill Siltstone, Mississippi Valley.

Genus POLYEDRYXIUM Deunff ex Deunff 1961

Type species: *Polyedryxium deflandrei* Deunff 1961

Polyedryxium decorum Deunff 1955

Plate 19, figure 4.

1955 *Polyedryxium decorum* Deunff, p. 146-147, pl. 2, fig. 1.

1977 *Polyedryxium decorum* Deunff; Playford, p. 33-34, pl. 15, figs. 4-6; pl. 16, figs. 5-7.

Holotype: Deunff 1955, pl. 2, fig. 1.

Type Locality: Ontario, Canada. Uncertainly dated sample, Middle or possibly Early Devonian in age (Playford 1977).

Size: Vesicle diameter 46-85μm (33 specimens, Playford 1977). Vesicle diameter 40-65μm (22 specimens, Wicander & Playford 1985). Vesicle diameter 42μm (single specimen, present study).

Diagnosis: (Amplification in Playford 1977, p. 33) Vesicle polyhedral, consisting of 6-9 concave faces, each 25-45μm in maximum width, with polygonal (commonly pentagonal or hexagonal) boundaries. Boundaries marked by membranous, crenulated ridges, 4-10μm high, that include thicker strutlike structures that are subcylindrical, essentially hollow and 1-4μm broad. These structures, modifying the otherwise thin, transparent ridges, are normally confined to the latter but may project distally beyond (by up to 16μm) as discreet tubular or chimneylike elements (usually at ridge junctions). In plan view, openings of structures are triangular or elliptical; the former especially at ridge junctions, the latter within a ridge. Vesicle wall single-layered; between ridges 1.5-2.5μm thick, scabrate or

almost psilate under light microscope, microreticulate to microrugulate under scanning electron microscope. Excystment structure not discerned.

Remarks: This species has been recorded from the Lower to Upper Devonian (upper Emsian – upper Frasnian) (e.g. Playford 1977; Wicander & Playford 1985).

Occurrence: Portsmouth Member, Cuyahoga Formation, Kentucky.

Family: LEIOSPHAERIDIACEAE Timofeev 1956 nom. corr. Mädler 1963

Genus LEIOSPHAERIDIA Eisenack 1958

Type species: *Leiosphaeridia baltica* Eisenack 1958

***Leiosphaeridia* spp.**

Plate 18, figure 14.

Size: Vesicle diameter 54-70μm. (5 specimens, Wicander & Playford 2007). 40-73μm (4 specimens, present study).

Discussion: Specimens that are simple, laevigate, with a thin eilyma and spherical are assigned to the genus *Leiosphaeridia*.

Remarks: *Leiosphaeridia* is a cosmopolitan and stratigraphically long-ranging genus (Proterozoic-Recent) (Wicander & Playford 1985; Wicander & Playford 2008).

Occurrence: Hannibal Shale, Mississippi Valley.

Family: PTEROSPERMELLACEAE Eisenack 1972

Genus *Pterospermella* Eisenack 1972

Type species: *Pterospermella aureolata* (Cookson & Eisenack) Eisenack 1972

Pterospermella cerebella Loeblich and Wicander 1976

Plate 19, figures 5, 8.

1976 *Pterospermella cerebella* Loeblich & Wicander, p. 29-30, pl. 10, figs. 5-8.

Holotype: Loeblich & Wicander 1976, p. 29-30, pl. 10, figs. 5-8.

Type Locality: Haragan Formation, Oklahoma; USA. Lower Devonian.

Size: Central vesicle size 33-40μm; Overall size 66-76μm (2 specimens, present study).

Description: Vesicle subcircular in outline; vesicle finely granulate or reticulate centrally becoming laevigate and slightly thickened towards periphery. A thickened band is observed at the vesicle periphery. Equatorial flangelike membrane of fairly uniform width, often heavily folded; width of flange 1/2 to 2/3 diameter of vesicle; thin and transparent; flange possesses radially arranged rodlike thickenings, most extending to outer margin. No excystment structure observed.

Remarks: This species has been previously recorded from the Early Devonian (Upper Gedinnian/Lochkovian) (e.g. Wicander 1986; Wicander pers. comm. 2009). The occurrence of isolated specimens in the Bedford Shale and Henley Bed of the Borden Formation are most likely a result of reworking.

Occurrence: Bedford Shale, Henley Bed, Borden Formation, Kentucky.

Family: TASMANITACEAE Sommer 1956

Genus TASMANITES Newton 1875

Type species: *Tasmanites punctatus* Newton 1875

The genus *Tasmanites* was originally described by Newton (1875). Eisenack (1958), however, was the first to publish a diagnosis.

Generic Diagnosis: (Eisenack 1958, p. 231) Hollow spherical, generally comparatively thick-walled and of a very resistant, yellowish to dark red-brown hyaline organic substance consisting of organic remains which often are preserved in a disc-shaped compressed state or also irregularly folded. Wall with more or less numerous pores which rarely penetrate the entire wall, but often either end blindly in the thick wall from the outside or from the inside. Pylome present, however usually uncommon. The wall pores are not always visible in each specimen of a species. Young examples are indeed always thin-walled and then lack the pylome. They are then not distinct from *Leiosphaeridia*.

***Tasmanites* spp.**

Plate 19, figure 14.

Size: 44-145μm (3 specimens, Wicander & Playford 2008). 38-52μm (4 specimens, present study).

Discussion: Specimens that are simple, psilate, thick-walled and spherical are assigned to the genus *Tasmanites*. A list of valid species is given in Fensome *et al.* (1990).

Remarks: *Tasmanites* is a cosmopolitan and stratigraphically long-ranging genus (Proterozoic-Recent) (Wicander & Playford 2008). *Tasmanites* spp. are recorded throughout the Mississippi Valley and Kentucky as simple, spherical, thick-walled, punctate forms.

Occurrence: Chattanooga Shale, Hannibal Shale, Northview Shale, Bachelor Formation, McCraney Limestone, Prospect Hill Siltstone, Mississippi Valley; Henley Bed, Farmers Member, Borden Formation, Portsmouth Member, Cuyahoga Formation, Kentucky.

Group: ACRITARCHA Evitt 1963

Genus GORGONISPHAERIDIUM Staplin, Jansonius & Pocock 1965

Type species: *Gorgonisphaeridium spicatum* (Staplin) Staplin, Jansonius & Pocock 1965

Gorgonisphaeridium furcillatum Wicander & Playford 1985

Plate 18, figure 9.

1985 *Gorgonisphaeridium furcillatum* Wicander & Playford, p. 106, pl. 3, figs. 1-3.

Holotype: Wicander & Playford 1985, pl. 3, fig. 1.

Type Locality: Lime Creek Formation, Floyd County; USA. Upper Devonian (upper Frasnian).

Size: Vesicle diameter 38-57μm (25 specimens, Wicander & Playford 1985). Vesicle diameter 30-36μm (5 specimens, present study).

Original Diagnosis: (Wicander & Playford 1985, p. 106) Vesicle circular to subcircular in outline; originally spherical; vesicle wall 2.2-2.3μm thick, surface laevigate; processes numerous (±50), solid, laevigate, slightly flexible, distinct from and evenly distributed over vesicle surface, 5-8μm apart; processes subcylindrical to gently tapering to point of furcation at distal extremity (80-90% of distance from proximal base), where majority bifurcate or trifurcate, occasionally bifurcating to second order where they terminate in a sharp point; a few processes remain simply acuminate; proximal process contacts angular to slightly curved; processes of ± constant length on same specimen, 7.3-13.2μm long, and 1.8-3.3μm in basal diameter; excystment by simple splitting of vesicle wall, usually in a nearly equatorial position.

Remarks: This species has been recorded from the Late Devonian (Frasnian) Lime Creek Formation of Ohio (Wicander & Playford 1986).

Occurrence: Hannibal Shale, Mississippi Valley; Sunbury Shale, Portsmouth Member, Cuyahoga Formation, Kentucky.

Gorgonisphaeridium ohioense (Winslow) Wicander 1974

Plate 18, figure 11.

1962 *Hystricosphaeridium ohioensis* Winslow, p. 77, pl. 19, fig. 1.

1974 *Gorgonisphaeridium ohioense* (Winslow) Wicander, p. 26, pl. 12, figs. 7-9.

Holotype: Winslow 1962, p. 77, pl. 19, fig. 1.

Type Locality: Chagrin Shale, Ohio; USA. Upper Devonian.

Size: Vesicle diameter 43-73μm (Wicander 1974). Vesicle diameter 52-80μm (3 specimens, present study).

Description: (Wicander 1974, p. 26) Vesicle spherical, 43-73μm (54μm average) in diameter, wall 2.2μm thick, scabrate; processes numerous, 40-68 (55 average), evenly distributed, solid, laevigate, simple, tapering to a sharp point, 10-19μm (16μm average) long, 2.2μm wide at base, generally stiff, but may be flexible from midpoint to tip; excystment by splitting of vesicle wall.

Remarks: This species has been recorded from the Upper Devonian Chagrin Shale and Cleveland Shale and the Lower Mississippian Bedford Shale of Ohio (Winslow 1962; Wicander 1974; Molyneux *et al.* 1984).

Occurrence: Hannibal Shale, Bachelor Formation, McCraney Limestone, Prospect Hill Siltstone, Mississippi Valley; Bedford Shale, Henley Bed, Farmers Member, Borden Formation, Kentucky.

Gorgonisphaeridium telum Wicander & Playford 1985
Plate 18, figures 12, 13.

1985 *Gorgonisphaeridium telum* Wicander & Playford, p. 106-107, pl. 3, figs. 1-3.

Holotype: Wicander & Playford 1985, p. 106, pl. 3, fig. 1.

Type Locality: Lime Creek Formation, Floyd County; USA. Upper Devonian (upper Frasnian).

Size: Vesicle diameter 14-24μm (25 specimens, Wicander & Playford 1985). Vesicle diameter 30-37μm (3 specimens, present study).

Original Diagnosis: (Wicander & Playford 1985, p. 106) Vesicle circular to subtriangular in outline, originally inflated; vesicle wall 0.8-1μm thick, surface laevigate; processes laevigate, solid, numerous (60-70), straight to slightly curved homomorphic, spinelike and tapering to a simple acuminate distal tip; proximal contacts angular to slightly curved; processes distinct from and evenly distributed over vesicle surface, 1.1-2μm apart, 2-3.5μm long, 0.5-1μm wide at circular base; excystment structure (rarely seen) consisting of simple spilt of vesicle wall, usually in a nearly equatorial position.

Remarks: This species is typically recorded from the Late Devonian (Wicander & Playford 1985).

Occurrence: Prospect Hill Siltstone, Mississippi Valley.

Gorgonisphaeridium winslowiae Staplin, Jansonius & Pocock 1965

Plate 18, figure 10.

1965 *Gorgonisphaeridium winslowii* Staplin, Jansonius & Pocock, p. 193, pl. 19, figs. 11, 18–20, text-fig. 4.

1993 *Gorgonisphaeridium winslowiae* Staplin, Jansonius & Pocock; Playford and McGregor, p. 15, pl. 5, figs. 8-11; pl. 6, figs. 11-12; text-fig. 5.

Holotype: Staplin, Jansonius & Pocock. 1965, p. 193, pl. 19, fig. 11.

Type Locality: Banff Formation, Imperial Grassy Lake No. 3 borehole, Alberta; Canada. Carboniferous (Lower Mississippian).

Size: Vesicle diameter 42-80μm (50 specimens, Playford & McGregor 1993).Vesicle diameter 35-48μm (4 specimens, present study).

Amplification of Diagnosis: (Playford & McGregor 1993, p. 15) Vesicle originally spherical or nearly so; outline circular to subcircular, clearly distinct from processes.

Vesicle wall about 1-2μm thick, laevigate to finely scabrate; often displaying coarse arcuate compression folds. Numerous, solid, elongate, laevigate processes emanating from vesicle wall with angular to slightly curved proximal contacts. Processes straight to curved, tapering regularly (albeit not markedly) from circular to subcircular bases 1.5-3.5μm in diameter to heteromorphic distal termini, which are variably furcate (predominantly, on a given specimen) or simple (i. e., unbranched, acutely pointed to rounded). Furcate distal termini mostly display irregular branching: bifurcate to multifurcate, with first- or second- (occasionally third-) order branching; ultimate branches of variable length (0.7-5μm, usually 1.5-3μm) and configuration. Processes about 10-29μm in overall length, but tending to be fairly uniform on a given specimen; basal separation, variable within and among specimens, ranging from about 2 to 16μm. Excystment structure, rarely evident, consisting of a simple linear split in vesicle wall.

Description: Vesicle circular to subcircular in outline, originally inflated; eilyma 1μm thick, surface laevigate; processes laevigate, solid, numerous, straight to slightly curved, homomorphic, with bifurcate and trifurcate tips; proximal contacts angular to slightly curved; processes 1-2μm apart, 1-2μm long, 0.5-1μm wide at circular base. No excystment structure observed

Remarks: This species has been recorded from the uppermost Devonian and lowermost Carboniferous of Western Canada (Staplin *et al.* 1965; Playford & McGregor 1993) and Ohio (Molyneux *et al.* 1984).

Occurrence: Chattanooga Shale, Hannibal Shale, Prospect Hill Siltstone, Mississippi Valley; Bedford Shale, Borden Formation, Henley Member, Sunbury Shale, Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus LOPHOSPHAERIDIUM Timofeev ex Downie, 1963

Type species: *Lophosphaeridium rarum* Timofeev 1959; by subsequent designation of Downie (1963, p. 630)

Lophosphaeridium segregum Playford 1981

Plate 18, figure 15.

1981 *Lophosphaeridium segregum* Playford *in* Playford & Dring 1981, p. 44-45, pl. 11, figs. 17-19; pl. 12, fig. 17, text-fig. 8.

Holotype: Playford & Dring 1981, pl. 11, fig. 17.

Type Locality: Carnarvon Basin; Western Australia. Late Devonian.

Size: 24-34μm (Playford *in* Playford & Dring 1981). 30-46μm (30 specimens, Wicander & Playford 1985). 39-46μm (3 specimens, present study).

Description: (Wicander & Playford 1985, p. 108) Vesicle circular to subcircular in outline, originally spherical; vesicle wall 1-1.2μm thick, surface laevigate; numerous (>150) solid, laevigate, subcylindrical, homomorphic processes, fairly evenly distributed over vesicle surface, 0.5-2.2μm apart; processes tapering gently toward distal tip, which generally is bluntly truncated, and occasionally incipiently bifurcate to well-defined bifurcate, the point of bifurcation up to 50%, but usually 10% or less from distal tip; processes 1.1-2.2μm long, bases circular, 0.8-1.1μm in diameter; excystment by simple splitting of vesicle wall, generally near the equator.

Remarks: This species has been recorded from the lower Frasnian of Western Australia (Playford & Dring 1981) and the upper Frasnian Lime Creek Formation of Ohio (Wicander & Playford 1985).

The size range of specimens in the present study is closer to that of Wicander & Playford (1985) than that of Playford and Dring (1981).

Occurrence: Hannibal Shale, McCraney Limestone, Keokuk Limestone, Mississippi Valley; Henley Bed, Borden Formation, Portsmouth Member, Kentucky.

Genus MICRHYSTRIDIUM Deflandre 1937 emend. Sarjeant 1967

Type species: *Micrhystridium inconspicuum* Deflandre 1937

Micrhystridium ampliatum Wicander & Playford 1985

Plate 18, figure 17.

1985 *Micrhystridium ampliatum* Wicander & Playford, p. 112, pl. 4, figs. 1-3, 6.

Holotype: Wicander & Playford 1985, pl. 4, fig. 1.

Type Locality: Lime Creek Formation, Floyd County; USA. Upper Devonian (upper Frasnian).

Size: Vesicle diameter 24-35μm (25 specimens, Wicander & Playford 1985). Vesicle diameter 23-29μm (20 specimens, present study).

Original Diagnosis: (Wicander & Playford 1985, p. 112) Vesicle circular to subcircular in outline, originally spherical; vesicle wall 1.1-1.3μm thick, surface laevigate; 11-18 hollow, laevigate, homomorphic, slightly flexible, spinelike processes drawn out from, and freely communicating with, vesicle interior; processes 13.5-21.6μm long, tapering from a subcircular base, 2-5.4μm in diameter, to a simple acuminate tip; proximal contacts curved; excystment by simple splitting of vesicle wall.

Remarks: *Micrhystridium ampliatum* is similar to *Micrhystridium stellatum* but has a larger vesicle and slightly fewer processes. *Micrhystridium ampliatum* is common to abundant in samples throughout the Mississippi Valley and Kentucky.

Occurrence: Chattanooga Shale, Hannibal Shale, Bachelor Formation, Compton Limestone, Northview Shale, Prospect Hill Siltsone, Burlington Limestone, Mississippi Valley; Sunbury Shale, Farmers Member, Nancy Member, Borden Formation, Henley Member, Portsmouth Member, Cuyahoga Formation, Kentucky.

Micrhystridium stellatum Deflandre 1945

Plate 18, figure 16.

1945 *Micrhystridium stellatum* Deflandre, p. 65, pl. 3, figs. 16-19.

Holotype: Deflandre 1945, pl. 3, fig. 16.

Type Locality: Montagne Noire, France. Silurian.

Size: Vesicle diameter 12-18μm (25 specimens, Wicander & Playford 1985). Vesicle diameter 18-24μm (10 specimens, present study).

Description: Vesicle circular to subcircular in outline, originally inflated; eilyma thin, 0.5μm in thickness, laevigate; 14-21 hollow, homomorphic, spinelike, laevigate processes, with sharply acute tips. Processes open into, and freely communicating with vesicle interior; processes 5-10μm long, 2-3μm wide at bases; bases circular, proximal contacts curved. Excystment by splitting of vesicle wall.

Remarks: This species has been recorded from the Silurian to Early Mesozoic (Playford 1977). *Micrhystridium stellatum* is common to abundant in samples throughout the Mississippi Valley and Kentucky.

Occurrence: Chattanooga Shale, Hannibal Shale, Compton Limestone, Northview Shale, McCraney Limestone, Prospect Hill Siltstone, Lower Warsaw, Mississippi Valley; Rockford Limestone, Henley Bed, Borden Formation, Portsmouth Member, Cuyahoga Formation, Kentucky.

Genus MULTIPLICISPHAERIDIUM Staplin 1961, restricted by Staplin, Jansonius & Pocock 1965, emend. Eisenack 1969

Type species: *Multiplicisphaeridium ramisinosum* Staplin 1961

Multiplicisphaeridium ramusculosum (Deflandre 1945) Lister 1970

Plate 19, figure 1.

1942 *Hystrichosphaeridium ramusculosum* Deflandre, p.476; Figs. 2-6 (*nom. nud.*).
1945 *Hystrichosphaeridium ramusculosum* Deflandre, p. 63; pl. 1, figs. 8-16; Figs. 38, 39.
1959 *Baltisphaeridium ramusculosum* (Deflandre) Downie, p. 59; Pl. 11, fig. 38.

1970 *Multiplicisphaeridium ramusculosum* (Deflandre) Lister, p. 92-93; Pl. 11, figs. 8, 11-14; Fig. 25a.

Holotype: Figured by Deflandre 1945, p. 63, pl. 1, figs. 8-10; DC, Slide AY19; First figured by Deflandre 1942, p. 476, text-fig. 2, 3.

Type Locality: Calcareous Silurian of Roquemaillère, Montagne Noire, France.

Size: Vesicle diameter 14-28μm (Lister 1970). 24-26μm (2 specimens, present study).

Original Disgnosis: (Translation taken from Lister 1970, p. 93) Globular vesicle in some cases ellispsoial or subspherical, ornamented with processes which are usually greater in length than half the shell diameter, and perhaps equal to this diameter. The processes are of two types. Some are simple and pointed. The others, very characteristic, are ramified in an irregular manner and in addition often carry spines on the main trunk of the process.

Remarks: *Multiplicisphaeridium ramusculosum* is a cosmopolitan, and typically long-ranging species (Late Ordovician to Late Devonian) (Playford 1977; Wicander & Playford 1985).

Occurrence: Hannibal Shale, Bachelor Formation, Mississippi Valley; Rockford Limestone, Cuyahoga Formation, Nancy Member, Borden Formation, Kentucky.

Genus OPPILATALA Loeblich & Wicander 1976

Type species: *Oppilatala vulgaris* Loeblich & Wicander 1976

***Oppilatala* sp.** *sensu* Wicander & Playford 1985

Plate 19, figure 2.

1985 *Oppilatala* sp. Wicander & Playford, p. 114, pl. 4, figs. 4, 5.

Size: Vesicle diameter 28-31μm (3 specimens, Wicander & Playford 1985). Vesicle diameter 30μm (single specimen, present study).

Description: (Wicander & Playford 1985, p. 114) Vesicle circular in outline, wall surface laevigate; numerous (>15) thin-walled, somewhat flexible, distinct, laevigate, cylindrical processes, 14.1-16.6μm long, 1.6-2.5μm wide at circular base; processes hollow, but basally plugged, preventing communication with vesicle interior; proximal contacts angular, process sides remaining straight to point of furcation where they initially bifurcate, then branch again, ultimately to second, third, or occasionally, fourth order; distal tips sharply pointed; no excystment structure observed.

Remarks: A single specimen of *Oppilatala* sp. is recorded from the Henley Bed of the Borden Formation. This specimen resembles those from the upper Frasnian Lime Creek Formation of Ohio assigned to *Oppilatala* sp. by Wicander & Playford (1985).

Occurrence: Henley Bed, Borden Formation, Kentucky.

Genus OZOTOBRACHION Loeblich & Drugg 1968

Type species: *Ozotobrachion palidodigitatus* (Cramer) Playford 1977, originally designated as *Ozotobrachion dactylos* Loeblich & Drugg 1968.

Ozotobrachion furcillatus (Deunff) Playford 1977

Plate 19, figure 3.

1955 *Veryhachium furcillatum* Deunff, p. 146, fig 18.

1966 *Veryhachium vipereum* Deunff, p. 80-81; (1966b), pl. 6, figs. 1-7; pl. X fig. 78.

1968 *Ozotobrachion dicros* Loeblich & Drugg, p. 132, p. 2, figs. 1-7.

1973 *Multiplicisphaeridium dicros* (Loeblich & Drugg) Eisenack & Cramer, p. 605-606.

1973 *Multiplicisphaeridium furcillatum* (Deunff) Eisenack & Cramer, p. 649.

1977 *Ozotobrachion furcillatus* (Deunff) Playford, p. 31, pl. 13, figs. 1-9; pl. 14, figs. 13-16.

Holotype: Deunff 1955, p. 146, fig. 18.

Type Locality: (Deunff 1955) Ontario, Canada. Devonian.

Size: Vesicle diameter 10-33μm (74 specimens, Playford 1977). Vesicle diameter 26μm (Single specimen, present study).

Amplification of diagnosis: (Playford 1977, p. 31) Vesicle usually triangular in outline, less commonly ovate, rectangular or polygonal; wall 0.5-1.2μm thick; psilate to minutely granulate or echinate under the light microscope; scabrate, micrograniulate, microreticulate or rarely, completely psilate under the scanning electron microscope. Processes ± homomorphic, typically three in number, less commonly two, four, five or six; one process normally arising from each vesicle corner. Processes hollow, thin-walled (0.3μm or less), transparent, psilate or sparsely microechinate or micrograniulate; gradually tapering from base; normally bifurcately branched up to third order, the branching usually ± terminal but may begin as little as one third of distance from base to distal extremity. Process interiors closed off from vesicle cavity by distinct basal plug, about 0.7-1.5μm thick. Dimensions of processes: length 18-48μm (usually 35-40μm), basal diameter 2-5μm. Excystment mechanism (rarely seen): a simple, ± linear split in vesicle wall, almost connecting base of one process with an adjacent one.

Remarks: This species is typically recorded from the Early to Middle Devonian (Lochokvian-Givetian) (Playford 1977; Wicander pers. comm. 2009). The occurrence of a single specimen in the Henley Bed of the Borden Formation is most likely a result of reworking.

Occurrence: Henley Bed, Borden Formation, Kentucky.

Genus STELLINIUM Jardiné, Combaz, Magloire, Peniguel & Vachey 1972

Type species: *Stellinium micropolygonale* (Stockmans & Willière) Playford 1977; originally designated as *Stellinium octoaster* (Staplin) Jardiné, Combaz, Magloire, Peniguel & Vachey 1972.

Stellinium comptum Wicander & Loeblich 1977

Plate 19, figure 6.

1977 *Stellinium comptum* Wicander & Loeblich, p. 151-152, pl. 9, figs. 1-6.

Holotype: Wicander & Loeblich 1977, p. 151-152, pl. 9, figs. 1-4.

Type Locality: American Smelting and Refining Company, I-4 well, Antrim Shale, Porter County, Indiana; U.S.A. Upper Devonian.

Size: Overall size 60-71μm (Wicander & Loeblich 1977, p. 151). Length along one side 22-28μm (10 specimens, Wicander & Playford 1985). 65-70μm (2 specimens, present study).

Description: (Wicander & Loeblich 1977, p. 151-152). Vesicle quadrate in outline, sides 25-31μm in length, straight to slightly concave, wall finely costate and granulate; 5 or 6 (generally 6) hollow, distinct, generally stiff processes, 12-17μm long, 4-5μm wide at base, drawn out from the vesicle and tapering to a sharp, solid (2μm long) tip, 4 of these processes lie in the same plane and rise from the corners of the vesicle, the other two processes arise on opposite ends from the vesicle center, perpendicular to the plane of the vesicle, all 6 processes opening into and communicating freely with the vesicle interior, process wall surface is granulate with a low central ridge extending from the distal tip down the processes and onto the vesicle surface to merge at the center of the vesicle; overall size of the species is 60-71μm; no method of excystment observed.

Remarks: Commonly recorded from the Late Devonian e.g. the upper Frasnian-lower Famennian of Indiana (Wicander & Loeblich 1977). Also recorded from the middle Devonian (Givetian) of Ohio (Wicander & Wood 1981).

Occurrence: Chattanooga Shale, Hannibal Shale, Prospect Hill Siltstone, Burlington Limestone, Mississippi Valley.

Genus UMBELLASPHAERIDIUM Jardiné, Combaz, Magloire, Peniguel & Vachey 1972

Type species: *Umbellasphaeridium saharicum* Jardiné, Combaz, Magloire, Peniguel & Vachey 1972

Umbellasphaeridium saharicum Jardiné, Combaz, Magloire, Peniguel & Vachey 1972

Plate 19, figure 7.

1964 *Hystrichosphaeridium* sp. *in* Regali, p. 176, fig. 8.

1964 Hystrichosphere *in* Wray pl. 1, fig. 3.

1965b *Hystrichosphaeridium* sp. *in* Brito, p. 2, pl. 1, figs. 5-8.

1972 *Umbellasphaeridium saharicum* Jardiné, Combaz, Magloire, Peniguel & Vachey, p. 303, pl. 2, fig. 11-12; pl. 3, fig. 1.

Holotype: Jardiné, Combaz, Magloire, Peniguel & Vachey 1972, p. 303, pl. 2, fig. 12.

Type Locality: Basin d'Illizi, TESSELIT survey no. 101, core 40, 2060m.

Size: Vesicle size 30-50µm, appendages 20-50µm (Jardiné *et al.* 1974). Vesicle size 35µm, appendages 20-26µm (single specimen, present study).

Description: (Jardiné *et al.* 1972, p. 303, translated from French) Spherical body with a relatively thick wall; 4-10 thick cylindrical appendages, long, terminating in a broad, transparent, membranous, hollow funnel.

Remarks: Wood (1984) recorded this species from the Cleveland Shale and Bedford Shale of Ohio and Ontario and stated this species differs from *Umbellasphaeridium deflandrea* by having fewer (4-10) and longer (20-50µm) processes. Molyneux *et al.* (1984) also recorded this species from the Bedford Shale. This is a cosmopolitan species recorded from the Frasnian-Famennian-?Early Carboniferous (Le Hérisse *et al.* 2000; Wicander pers. comm. 2009).

Occurrence: Henley Bed, Borden Formation, Kentucky.

Genus UNELLIUM Rauscher 1969

Type species: *Unellium piriforme* Rauscher 1969

Unellium piriforme Rauscher 1969

Plate 19, figure 9.

1969 *Unellium piriforme* Rauscher, p. 35-56, figs. 1-6.

1974 *Micrhystrdium piriforme* (Rauscher) Stockmans & Willière, p. 29.
1985 *Unellium piriforme* Rauscher; Wicander & Playford, p. 118, pl. 6, figs. 10, 11.

Holotype: Rauscher 1969, p. 35-56, figs. 1-6.

Type Locality: Normandy; France. Devonian.

Size: Vesicle diameter 12-19μm (20 specimens, Wicander & Playford 1985). Vesicle diameter 15-24μm (2 specimens, present study).

Description: (Original description in French, therefore description taken from Wicander & Playford 1985, p. 118) Vesicle pyriform in outline; vesicle wall 0.6-0.8μm thick, surface laevigate; processes hollow, fairly stiff, opening into vesicle interior; processes distinct from vesicle, and spinelike in shape, tapering gently from circular bases to simple acuminate tips; one process larger than others and situated at polar position; major process 7.6-8.9μm long, 3.5-5μm in basal diameter with curved proximal contacts; numerous minor processes (15-22), evenly distributed over vesicle, 5-7.7μm long, 1-1.8μm basal diameter, proximal contacts angular to slightly curved; excystment by splitting of vesicle wall at base of major process.

Remarks: This species has been reported from the Middle-Upper Devonian e.g. from the lower Frasnian of Australia (Playford 1981) and the upper Frasnian of Ohio (Wicander & Playford 1985).

Occurrence: Hannibal Shale, Northview Shale, Mississippi Valley; Henley Bed, Borden Formation, Kentucky.

Unellium winslowiae Rauscher 1969

Plate 19, figure 12.

1969 *Unellium winslowiae* Rauscher, p. 36, figs. 7-13.
1985 *Unellium winslowiae* Rauscher; Wicander & Playford, p. 118-119, pl. 7, figs. 1-2.

Holotype: Rauscher 1969, p. 36, figs. 7-13.

Type Locality: Normandy; France. Devonian.

Size: Vesicle diameter 16-20μm (20 specimens, Wicander & Playford 1985). Vesicle diameter 28μm (single specimen, present study).

Description: (Original description in French, therefore description taken from Wicander & Playford 1985, p. 118-119) Vesicle subcircular to semicircular in outline; vesicle wall 0.4-0.6μm thick, surface laevigate; processes distinct, somewhat stiff, hollow, opening into vesicle interior; processes laevigate, spinelike, tapering from irregular bases to simple acuminate distal tips; two major processes at opposite poles with straight to slightly convex side free of minor processes between them; major processes 7.7-11μm long, 2.5-4μm in basal diameter; 17-23 regularly distributed, minor processes 4.4-6.6μm long, 0.9-1.3μm wide at base; proximal process contacts generally angular; no excystment sructure observed.

Remarks: This species has been reported from the Middle-Upper Devonian e.g. from the lower Frasnian of Australia (Playford 1981) and the upper Frasnian of Ohio (Wicander & Playford 1985).

Occurrence: Prospect Hill Siltstone, Mississippi Valley.

Genus VERYHACHIUM Deunff 1954 emend. Sarjeant and Stancliffe 1994
Type species: *Veryhachium trisulcum* (Deunff) Deunff, 1959

Veryhachium arcarium Wicander & Loeblich 1977
Plate 19, figure 10.

1977 *Veryhachium arcarium* Wicander & Loeblich, p. 154, pl. 10, figs. 1-2.

Holotype: Wicander & Loeblich 1977, p. 154, pl. 10, figs. 1-2.

Type Locality: American Smelting and Refining Company core, I-4 well, Antrim Shale, Porter County, Indiana; U.S.A. Upper Devonian.

Size: Vesicle diameter 13-20μm (Wicander & Loeblich 1977). Vesicle diameter 13-16μm (11 specimens, Wicander & Playford 1985). Vesicle diameter 20-32μm (2 specimens, present study).

Original Description: (Wicander & Loeblich 1977, p. 71-72) Vesicle quadrate in outline, 13-20μm in length, sides of vesicle slightly concave or straight, rarely slightly convex; wall 0.5μm thick, surface texture laevigate under light microscopy; 4 hollow processes, with one drawn out from each corner of vesicle in the same plane, processes slightly flexible or remain straight, tapering gently distally to a sharp point, proximally open into and freely communicate with vesicle interior, remaining hollow to near distal tip; 1-3 hollow, slightly flexible processes arise perpendicular to the plane of vesicle and open and freely communicate with vesicle interior, generally one process arises from the centre of each side, to gently taper to a sharp, distal point; processes 14-18μm in length and 2-3μm wide at their base; surface sculpture of processes laevigate; excystment by formation of an epityche, with splitting of vesicle wall between 2 processes in the same plane of the vesicle.

Remarks: This species is typically recorded from the Late Devonian. In the USA, it has been reported from the upper Frasnian-lower Famennian Antrim Shale of Indiana (Wicander & Loeblich 1977; Wicander 1983) and the upper Frasnian Lime Creek Formation of Iowa (Wicander & Playford 1985).

Occurrence: Hannibal Shale, Mississippi Valley; Henley Member, Cuyahoga Formation, Kentucky.

Veryhachium polyaster Staplin 1961

Plate 19, figure 11.

1961 *Veryhachium polyaster* Staplin, p. 413, pl. 49, fig. 20.

Holotype: Staplin 1961, pl. 49, fig. 20.

Type Locality: Beaverhill Lake? Formation, Alberta; Canada. Upper Devonian.

Size: Overall size 60-70μm (Staplin 1961). Vesicle diameter 14-16μm (specimens, Wicander and Playford 1985). Vesicle diameter 16μm (2 specimens, present study).

Diagnosis: (Staplin 1961, p. 413) Vesicle polyhedral, composed of central area and five long tapering appendages; appendages an integral part of the whole, broad-based, not arising in the same plane; laevigate; overall size 60-70 microns.

Remarks: This species has been recorded from the Middle to Upper Devonian of Canada (Staplin 1961; Playford 1977), the Upper Devonian (Givetian-Frasnian) of Ohio (Wicander & Wood 1981; Wicander & Playford 1985) and the Upper Devonian (Famennian) of Australia (Playford 1981).

Occurrence: Northview Shale, Hannibal Shale, Mississippi Valley.

Veryhachium trispinosum (Eisenack) Deunff 1954

Plate 19, figure 13.

1938 *Hystrichosphaeridium trispinosum* Eisenack, p. 14, 16, text-figs. 2, 3.
1954 *Veryhachium trispinosum* (Eisenack) Deunff, p. 306.
1981 *Veryhachium trispinosum* (Eisenack) Deunff 'complex' Wicander and Wood, p. 67–71.

Holotype: Eisenack 1938.

Size: Vesicle diameter 18-23μm (20 specimens, Wicander & Playford 1985). Vesicle diameter 18-21μm (3 specimens, present study).

Description: (This species has been emended several times. The description given herein is that of Wicander & Playford 1985, p. 121) Vesicle triangular in outline, with slightly convex, ± equal sides; vesicle wall surface laevigate; a process extending from each apex of triangular vesicle; processes simple, hollow, tapering to a distal acuminate tip; processes laevigate, 10.8-16.2μm long, 2.2-2.7μm wide at base, opening into vesicle interior; excystment by development of epityche (rarely seen).

Remarks: *Veryhachium trispinosum* has a cosmopolitan distribution and has been recorded throughout the Ordovician to Permian (Wicander & Playford 1985). The *Veryhachium trispinosum* 'complex' is discussed in detail and a complete synonymy is given in Wicander and Wood (1981).

Occurrence: Hannibal Shale, Mississippi Valley; Henley Bed, Borden Formation, Portsmouth Member, Cuyahoga Formation, Kentucky.

CHAPTER 7
STRATIGRAPHIC PALYNOLOGY

7. 1 INTRODUCTION

The composition and age of the miospore assemblages from each area are described below. Stratigraphic ranges are shown in tables 7.1-7.25. Miospore assemblages from Kentucky have previously been assigned to the European Miospore Biozonation (Clayton *et al.* 1977; Higgs *et al.* 1988) by Coleman & Clayton (1987) and Coleman (1991); this concept is followed below. It was originally hoped that miospore assemblages in the Mississippi Valley could also be assigned to the European Miospore Biozonation. However, it has since become apparent that miospore assemblages from the Mississippi Valley are quite different to those previously described from other parts of the USA and Europe and cannot be assigned to the existing biozonation. A different miospore zonation is therefore proposed for this part of the Illinois Basin.

7. 2 KENTUCKY

Assemblages from Morehead and Vanceburg, Kentucky are generally diverse and well-preserved. Assemblages are tentatively assigned to the LN, VI, BP, PC and CM Miospore Biozones. Prasinophytes and miospores were the only types of palynomorphs recorded. The qualitative compositions of the assemblages from both sections are summarised in tables 7.1 and 7.2. Results are also compared with previous studies from the same area. Ranges of stratigraphically important taxa from Europe and Kentucky are shown in figures 7.1 and 7.2.

Both sections studied are in northwestern Kentucky; however the stratigraphy is different in each section. The latest Devonian black shales and earliest Mississippian Sunbury Shale are recognised from both sections. At Morehead, the remainder of the Kinderhookian and Osagean comprises the Borden Formation. At Vanceburg, the stratigraphy is similar to that of southern Ohio and the Cuyahoga Formation is recognised. Assemblages from both units will be discussed separately.

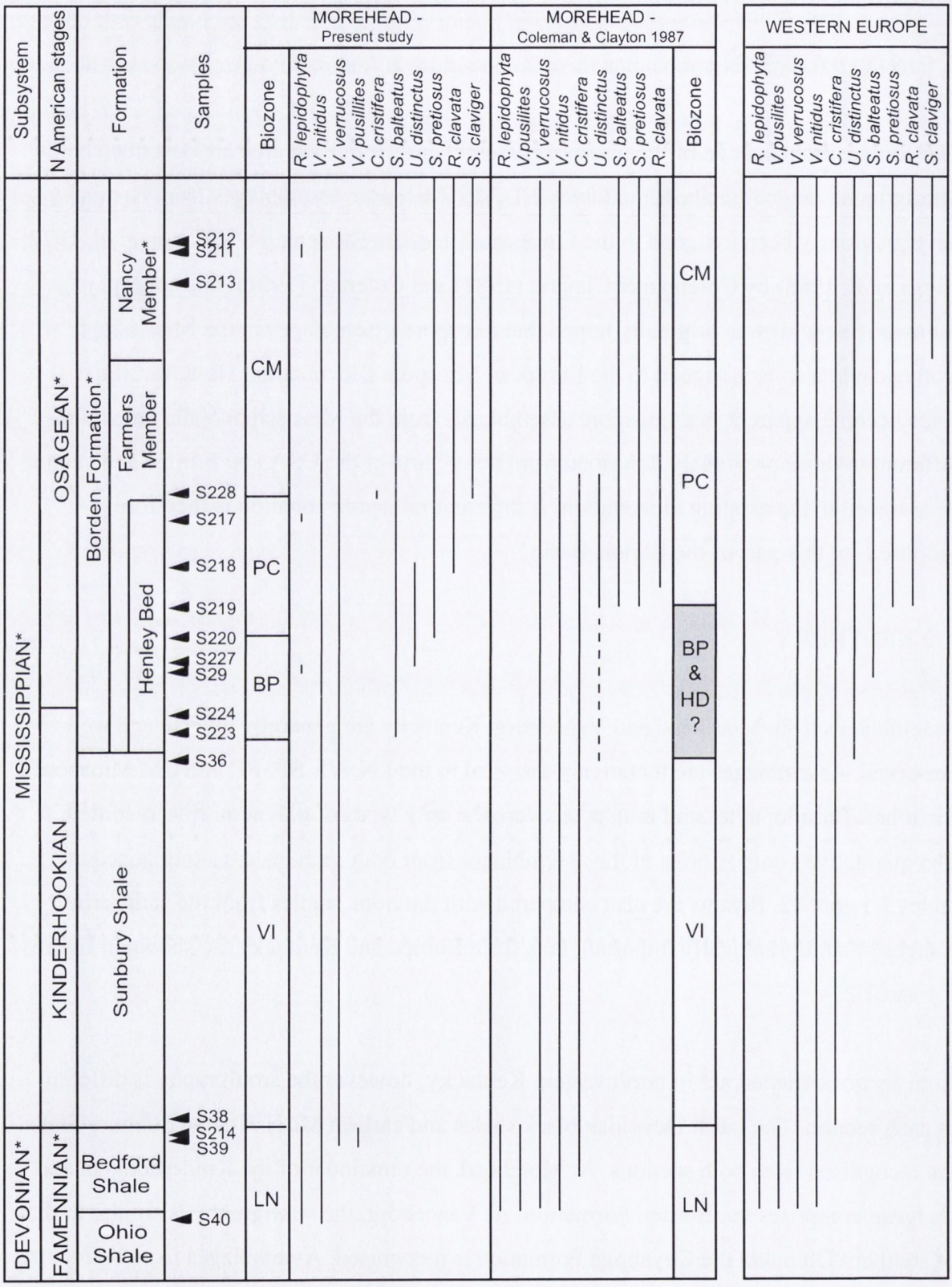


Figure 7.1 Comparison of the stratigraphic ranges of selected miospore taxa from Morehead in Kentucky and Western Europe (*in part). Stratigraphic units not to scale.

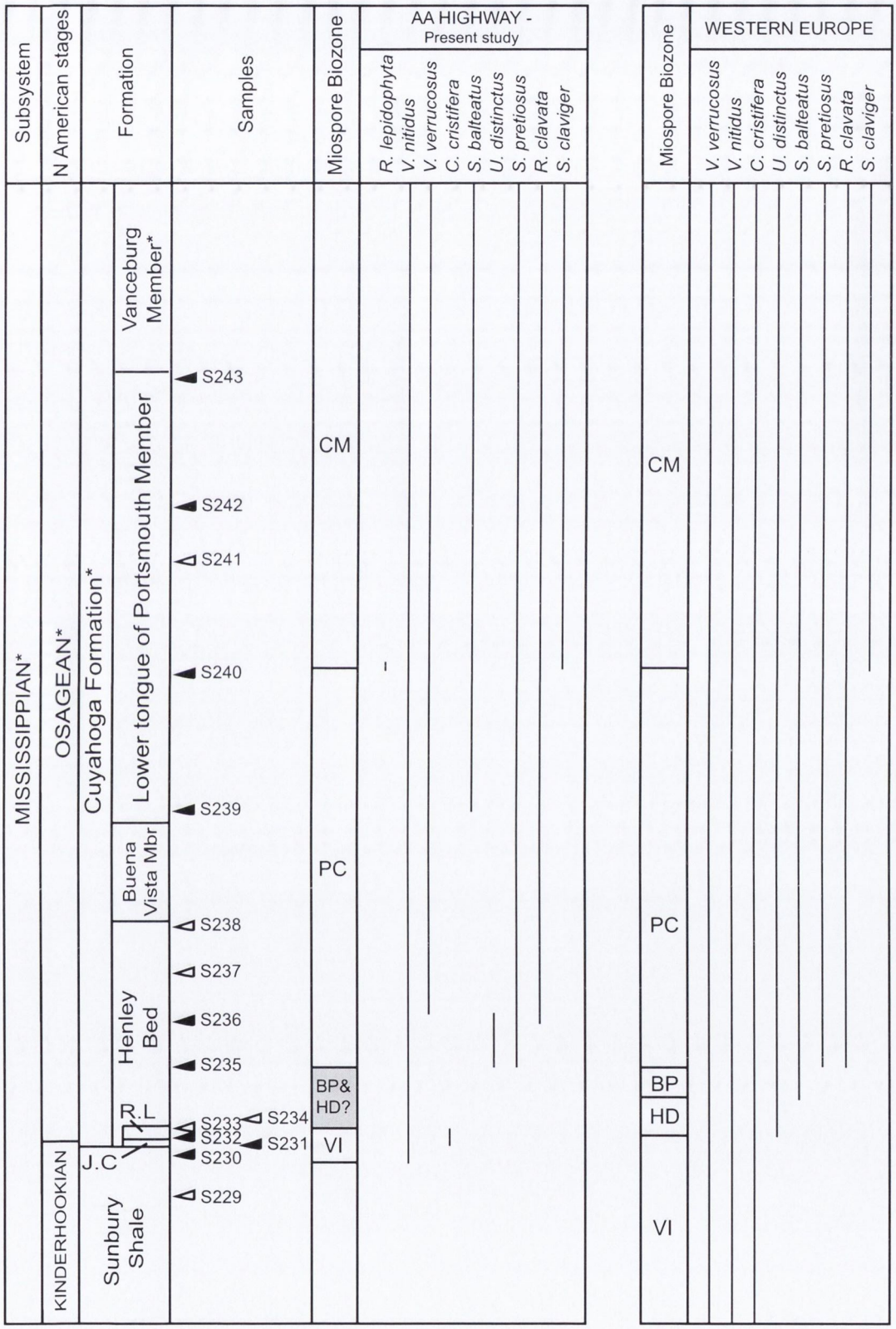


Figure 7.2 Comparison of the stratigraphic ranges of selected miospore taxa from the AA Highway section, Vanceburg, Kentucky and Western Europe (*in part). Stratigraphic units not to scale.

7. 2. 1 LN BIOZONE – Ohio Shale and Bedford Shale

COMPOSITION OF ASSEMBLAGES

Diverse and well-preserved assemblages were recovered from the Cleveland Member of the Ohio Shale and Bedford Shale at Morehead (Table 7.1). An especially diverse sample (S39) was recovered from the top of the Bedford Shale. No equivalent age material was obtained from Vanceburg. Very few species of acritarchs and prasinophytes are present, and only six taxa are recorded. *Gorgonisphaeridium furcillatum* Wicander & Playford, *Michrystridium ampliatum* Wicander & Playford and *Michrystridium stellatum* Deflandre are the most abundant and *Dictyotidium* sp., *Cymatiosphaera* cf. *C. ambotrocha* and *Lophosphaeridium segregum* Playford comprise a very minor component.

The miospore assemblage is diverse. Common taxa include *Auroraspora macra, Calamospora pallida*, *Indotriradites explanatus*, *Punctatisporites planus* Hacquebard, *Retispora lepidophyta*, *Retusotriletes incohatus*, *Vallatisporites pusillites* and *Verrucosisporites nitidus*. Other taxa present include *Apiculiretusispora fructicosa*, *Calamospora microrugosa* (Ibrahim) Schopf, Wilson & Bentall, *Calamospora parva* Guennel, *Convolutispora vermiformis*, *Cordylosporites marciae*, *Emphanisporites rotatus*, *Knoxisporites literatus*, *Pustulatisporites dolbii* Higgs, Clayton & Keegan, *Raistrickia macrura* (Luber) Dolby & Neves, *Rugospora flexuosa* and *Vallatisporites verrucosus*.

AGE OF ASSEMBLAGES

The base of the Western European LN Biozone is defined by the first appearance of *Verrucosisporites nitidus* together with *Vallatisporites verrucosus* and *Tumulispora triangularis*. *Retispora lepidophyta* is a common component, as is *Rugospora flexuosa* and *Vallatisporites pusillites*, and assemblages are typically very diverse. The base of the overlying VI Biozone coincides with the Devonian - Carboniferous boundary and is marked by the disappearance of *Retispora lepidophyta* along with many other Late Devonian taxa. A general drop in diversity is recorded at the boundary relative to Late Devonian assemblages.

Miospore assemblages from the Cleveland Member of the Ohio Shale and Bedford Shale are similar in composition to those typical of the European LN Biozone. *Retispora*

Table 7.1 - Stratigraphic ranges of taxa from the I-64 section, Morehead, Kentucky



lepidophyta is very common throughout. *Verrucosisporites nitidus* is recorded from the Cleveland Member and *Rugospora flexuosa*, *Vallatisporites pusillites* and *Vallatisporites verrucosus* occur within the Bedford Shale. The assemblages are therefore correlated with the LN Miospore Biozone.

These miospore assemblages resemble those recorded by Coleman in her 1991 thesis, and published by Coleman & Clayton (1987). Coleman recovered three productive samples from the Bedford Shale, and recognised assemblages which she assigned to the LN Biozone.

In the present study, *Retispora lepidophyta* is also recorded from the Mississippian but in greatly reduced numbers. In most Late Devonian assemblages *Retispora lepidophyta* is typically dominant or at least very abundant. Therefore, these younger occurrences are interpreted as an effect of reworking (see section 7.3.1 for further discussion).

7. 2. 2 VI BIOZONE – Sunbury Shale, Jacobs Chapel and Rockford Limestone.

COMPOSITION OF ASSEMBLAGES

Assemblages recorded from the Sunbury Shale at Morehead, and the Sunbury Shale, Jacobs Chapel and base of the Rockford Limestone equivalent at Vanceburg are compositionally very similar to each other (tables 7.1 and 7.2). A decrease in diversity compared to the underlying Late Devonian assemblages is recorded in both sections. No new acritarch and prasinophyte taxa are recorded; a few specimens of the acanthomorph taxa *Micrhystridium ampliatum* and *Micrhystridium stellatum* are present in the Morehead section. No acritarchs and prasinophytes are recorded from the Sunbury Shale at Vanceburg. The Jacobs Chapel and Rockford Limestone yield a few specimens of *Michrystridium stellatum* together with *Cymatiosphaera chelina* Wicander & Loeblich and *Multiplicisphaeridium* sp.

Miospore assemblages from the Sunbury Shale, Jacobs Chapel and Rockford Limestone are dominated by taxa ranging from the Late Devonian. At Morehead, just three new taxa occur in the Sunbury Shale, and assemblages are much lower in diversity than those recoded from the Late Devonian. Common taxa include *Apiculiretusipora fructicosa*, *Auroraspora macra*, *Calamospora microrugosa*, *Calamospora pallida* (Loose 1932)

Schopf, Wilson & Bentall, *Punctatisporites planus*, *Retusotriletes incohatus* and *Verrucosisporites nitidus*. Other taxa include *Calamospora parva*, *Emphanisporites rotatus, Geminospora* sp. A, *Retispora lepidophyta*, *Retusotriletes communis* Naumova, *Retusotriletes famenensis* Naumova, *Vallatisporites vallatus* and *Vallatisporites verrucosus.* At Vanceburg, additional taxa are recorded from the Jacobs Chapel and Rockford Limestone - *Acanthotriletes* sp. A, *Cyclogranisporites commodus* Playford, *Cyrtospora cristifera*, *Geminospora spongiata*, *Knoxisporites concentricus* (Byvscheva) Playford & McGregor and *Raistrickia variabilis*. Species disappearing at the top of the underlying unit include *Cordylosporites marciae*, *Knoxisporites literatus* and *Vallatisporites hystricosus*.

AGE OF ASSEMBLAGES

The acritarch assemblages recorded from the Sunbury Shale, Jacobs Chapel and Rockford Limestone consist of taxa common in the Late Devonian, and are therefore of little stratigraphic significance. Blooms of *Micrhystridium* are occasionally recognised after mass extinction events such as those recorded at the Devonian-Carboniferous and Permian-Triassic boundary (Riegel 2008). The assemblage is interpreted as representative of the 'survival phase' in the early Carboniferous following the Late Devonian mass extinction.

Miospore assemblages from the Sunbury Shale, Jacobs Chapel and Rockford Limestone closely resemble those assigned to the European VI Miospore Biozone. Coleman & Clayton (1987) recorded very similar miospore assemblages from the Sunbury Shale at Morehead which they also assigned to the VI Biozone. The base of the biozone is defined by the disappearance of *Retispora lepidophyta* together with many other Late Devonian taxa. These include *Cordylosporites marciae* and *Vallatisporites hystricosus*. A worldwide drop in diversity is recognised after the Late Devonian mass extinction event and the biozone is characterised by Late Devonian survivor taxa (Clayton 1996; Clayton *et al.* 1998). *Retispora lepidophyta* is not identified in the basal Carboniferous Sunbury Shale, Jacobs Chapel and Rockford Limestone. Isolated specimens of *Retispora lepidophyta* are recorded from slightly younger samples, but these are poorly preserved and are interpreted as reworked.

The VI Biozone in Western Europe is overlain by strata representing the HD, BP and PC biozones, defined by the first occurrences of *Umbonatisporites distinctus*, *Spelaeotriletes*

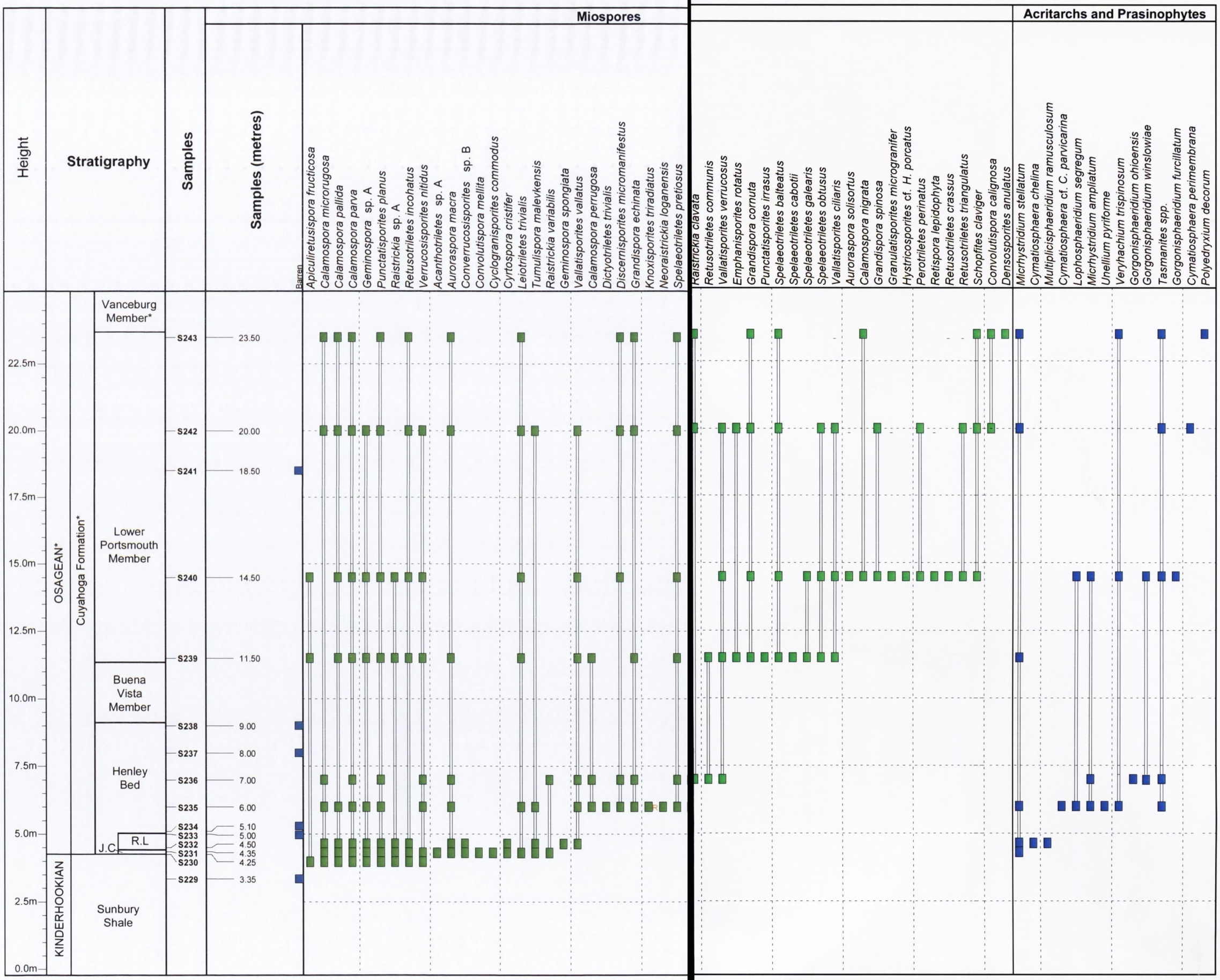


Table 7.2 - Stratigraphic ranges of taxa from the AA Highway section, Vanceburg, Kentucky (*in Part). Abbreviations: J.C - Jacobs Chapel, R.L - Rockford Limestone

balteatus and *Spelaeotriletes pretiosus* respectively. The HD and BP biozones were not previously recognised by Coleman (1991) and a condensed sequence in the lower part of the overlying Henley Bed was interpreted as representing the HD and BP biozones. In the present study, *Spelaeotriletes balteatus* is recorded from the lower part of the overlying Henley Bed at Morehead defining the base of the BP Biozone. *Umbonatisporites distinctus* is first recorded from the upper part of the Henley Bed and, therefore, the HD Biozone cannot be identified. At Vanceburg, *Spelaeotriletes pretiosus* appears together with *Umbonatisporites distinctus* in the Henley Bed defining the base of the PC Biozone. *Spelaeotriletes balteatus* is recorded from the overlying Portsmouth Member. The HD and BP biozones are not recognised at Vanceburg.

Conodonts from the base of the Henley Bed at Morehead are characteristic of the Upper *crenulata* Zone (Figure 7.3a), and place it in the upper part of the Kinderhookian (Work & Mason 2005). This suggests that the Sunbury Shale is no younger than the upper Kinderhookian. In Western Europe this conodont fauna correlates to the Hastarian Stage which spans the upper part of the BP Biozone and lower part of the PC Biozone (Higgs *et al.* 1992). This suggests that the interval representing the HD Biozone is either absent in northeastern Kentucky, or that the Sunbury Shale may be equivalent to both the VI and HD biozones.

Conodonts were recorded from the Sunbury Shale, Jacobs Chapel and Rockford Limestone at Vanceburg (Figure 7.3b) (Sandberg *et al.* 2002). The lower part of the Sunbury Shale is assigned to the Upper *duplicata* Zone indicating an early Kinderhookian age, consistent with the VI Biozone. The upper part of the Sunbury Shale and Jacobs Chapel are assigned to the Lower *crenulata* Zone, and the Rockford Limestone is assigned to the Upper *crenulata-isosticha* to Lower *typicus* (*communis carinus* of Lane & Brenckle 2005) zones. These faunas are correlated to the middle and upper parts of the Hastarian, and possibly the lowermost Ivorian stages of Western Europe, and suggest correlation of the Sunbury Shale and Jacobs Chapel to the uppermost HD and base of the BP biozones, and the Rockford Limestone to the BP and base of the PC biozones (Higgs *et al.* 1992). These correlations are shown in Figure 7.3b. These conodont-based correlations suggest that the index taxa of the overlying HD, BP and PC biozones appear slightly later in Kentucky than in Western Europe.

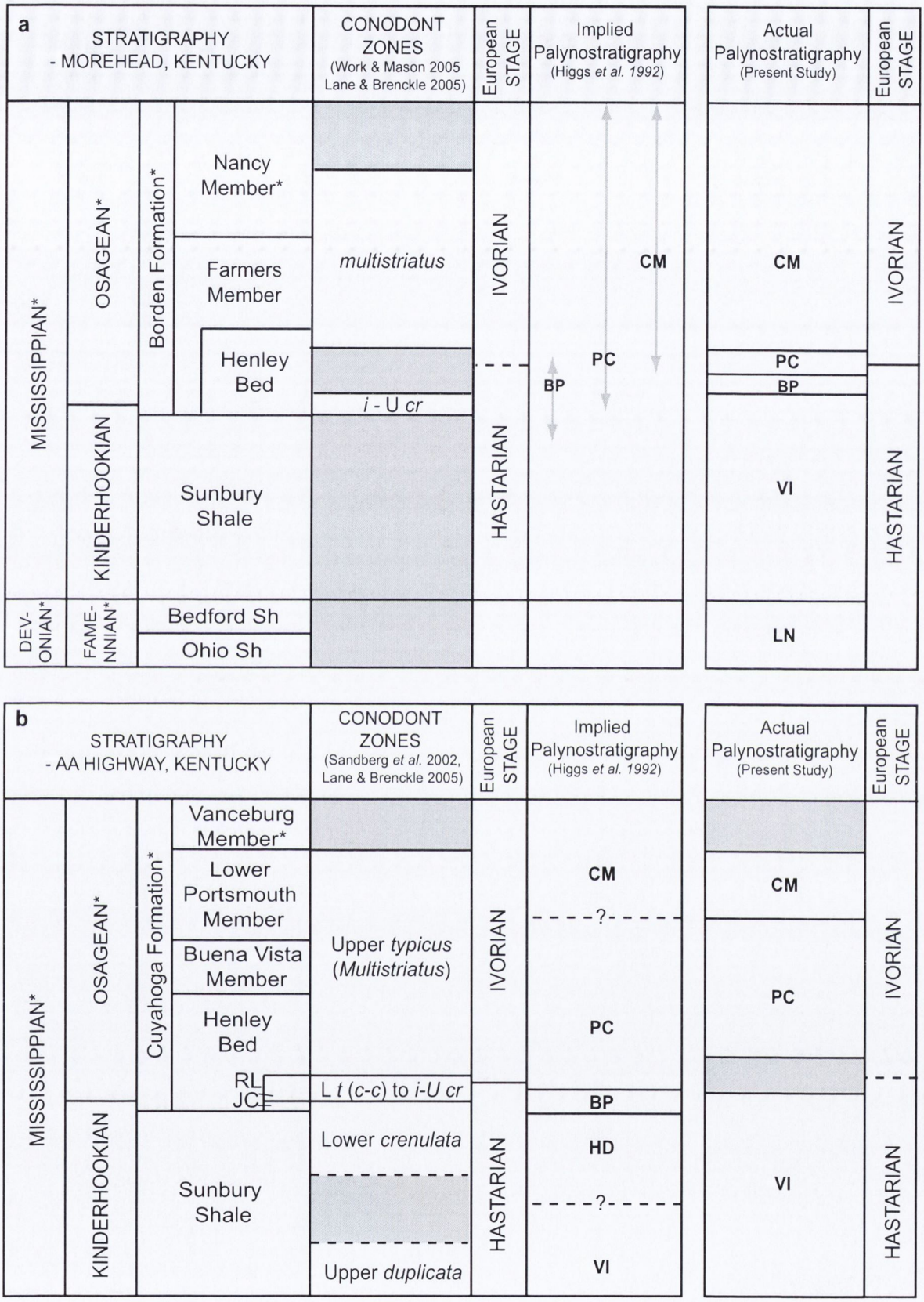


Figure 7.3 Comparison of conodont zones, implied palynostratigraphy and actual palynostratigraphy (*in part). Stratigraphic units are not to scale. **a**) Morehead section, Kentucky. Conodont zones are those of Lane & Brenckle (2005). Arrows indicate possible ranges of miospore biozones. Abbreviations are as follows: *i*-U *cr* - *isosticha*-Upper *crenulata*. **b)** AA Highway section, Vanceburg, Kentucky. Conodont zones are defined by Sandberg *et al.* (2002) after the zonation of Sandberg *et al.* (1978) and Lane & Ormiston (1982). Equivalent conodont zones of Lane and Brenckle (2005) are given in brackets. Abbreviations are as follows: JC - Jacobs Chapel, RL - Rockford Limestone, L *t* (*c-c*) to *i*-U *cr* - Lower *typicus* (*communis-carinus*) to *isosticha*-Upper *crenulata*.

It should be noted that conodont correlations between Kentucky and Western Europe are, in the most part, tentative. Although conodonts have been recovered from the Kinderhookian and Osagean strata at Morehead (Mason pers. comm. 2006), the intensive reworking of sediments within the Henley Bed and sparse conodont faunas throughout the rest of the section have resulted in only one conodont zone, the *multistriatus* zone, being recognised (Work & Mason 2005). Conodont faunas from the AA Highway Section, Vanceburg, are more diverse and common. Five conodont zones are published from this section (Sandberg *et al.* 2002).

The distribution of conodont taxa is depth and facies related. *Siphonodellid* conodonts are typically indicative of deeper marine facies (Varker & Sevastopulo 1985). The *Siphonodellid* conodont zonation defined from North America by Sandberg *et al.* (1978) is therefore applicable in deeper marine sediments, but may be more tentative in shallower marine sediments. Correlations of shallow marine deposits can be made, for example Higgs *et al.* (1992) interpreted the presence of Siphonodellid conodonts in shallow marine deposits of the upper Hastarian of the Namur Syclinorium, as resulting from episodic storm wave activity (tempestites), and correlated the palynostratigraphy with these faunas. However, the correlation of conodonts faunas from typically shallow European facies and deeper Kentucky facies should be viewed cautiously as differences in conodont assemblages may be due to differences in palaeoenvironments.

7. 2. 3 BP BIOZONE – Lower part of Henley Bed, Borden Formation

COMPOSITION OF ASSEBLAGES

Two samples (S223 and S224) from the lower part of the Henley Bed at Morehead yield moderately well-preserved, low diversity assemblages. The higher of the two (S224), is particularly low in diversity with only three miospore and four acritarch taxa recorded. This sample is of little stratigraphic significance. The lower sample yields a higher diversity assemblage (although still relatively low diversity). Two samples (S29 and S227) from the middle part of the Henley Bed yield similar spores but higher diversity assemblages, with some new miospore taxa appearing. Acritarch assemblages are dominated by acanthomorph forms such as *Michrystridium ampliatum*, *Michrystridium stellatum* and *Gorgonisphaeridium furcillatum*, but more elaborately ornamented forms are recorded from the lower part of the Henley Bed. These include *Multiplicisphaeridium* sp.,

Oppilatala sp. Wicander and Playford and *Ozotobrachion furcillatus* (Deunff) Playford. Other acritarch and prasinophyte taxa recognised are *Cymatiosphaera* cf. *C. ambotrocha*, *Dictyotidium* sp., *Veryhachium trispinosum* (Eisenack) Deunff and *Stellinium comptum* Wicander & Loeblich.

Common miospore taxa from the lower part of the Henley Bed include *Calamospora parva*, *Calamospora pallida*, *Geminospora* sp. A, *Retusotriletes incohatus* and *Verrucosisporites nitidus*. *Emphanisporites rotatus*, *Punctatisporites irrasus*, *Punctatisporites minutus*, *Spelaeotriletes obtusus*, *Speleotriletes balteatus* and *Vallatisporites* sp. A are also present. Specimens in the lower part of the Henley Bed are generally of small size and the larger species of *Calamospora* (*Calamospora microrugosa* and *Calamospora perrugosa* (Loose 1934) Schopf, Wilson & Bentall) are not recorded.

In the middle part of the Henley Bed, a more diverse and well-preserved miospore assemblage is recorded. This includes the taxa identified in the lower Henley Bed as well as taxa ranging from the Late Devonian such as *Auroraspora macra*, *Punctatisporites planus*, *Pustulatisporites dolbii*, *Grandispora echinata* Hacquebard, *Retusotriletes communis* and *Vallatisporites vallatus*. Larger taxa such as *Calamospora microrugosa* and *Calamospora perrugosa* are also recorded. This suggests that assemblages from the lower part of the Henley Bed have undergone significant transport and an increased amount of sorting compared to those from the middle of the Henley; differences between the lower and middle Henley assemblages could therefore be a possible effect of sorting. However, some new species occur in the middle part of the Henley Bed. These include *Auroraspora solisorta* Hoffmeister, Staplin & Malloy, *Granulatisporites microgranifer*, *Raistrickia variabilis*, *Rugospora* cf. *R. polyptycha* and *Umbonatisporites distinctus*.

AGE OF ASSEMBLAGES

Assemblages from the lower and middle part of the Henley Bed at Morehead closely resemble those from the European BP Miospore Biozone. The base of the BP Biozone is marked by the first appearance of *Spelaeotriletes balteatus*. Other taxa appearing at the base of the biozone include *Lophozonotriletes tuberosus* and *Vallatisporites vallatus*. *Rugospora polyptycha*, *Spelaeotriletes obtusus* and *Vallatisporites verrucosus* are common components. The base of the overlying PC Biozone is marked by the appearance of *Spelaeotriletes pretiosus*. *Vallatisporites vallatus* typically appears earlier in the Kentucky

sections. *Spelaeotriletes balteatus* and *Spelaeotriletes obtusus* are both very common within the lower part of the Henley Bed. A single specimen of *Rugospora* cf. *R. polyptycha* is recorded from the middle part of the Henley. *Granulatisporites microgranifer* typically appears in the overlying PC Biozone, but is occasionally associated with BP assemblages (Higgs pers. comm. 2006).

The BP Miospore Biozone has not previously been recognised from Kentucky. It has recently been recorded from the Coldwater Shale in the Michigan Basin (Richardson 2006). Coleman (1991) and Coleman & Clayton (1987) did not recover any productive samples from the lower and middle part of the Henley Bed nor did they record assemblages representative of the BP Biozone.

Independent conodont age data from Morehead places the lowermost part of the Henley Bed in the Upper *crenulata* Zone of Lane & Brenckle (2005) (Work & Mason 2005). At Vanceburg, the same zone is recognised from the lower part of the Rockford Limestone equivalent (Sandberg *et al.* 2002). This conodont fauna correlates to the upper part of the Hastarian Substage in Western Europe and spans the upper part of the BP Biozone (figures 7.3a & 7.4) (Higgs *et al.* 1992).

Conodonts from the upper part of the Henley Bed at Morehead place it within the *multistriatus* Zone (Work & Mason 2005). This conodont fauna has been correlated to the Ivorian Substage in the upper Tournaisian Stage of Western Europe (Work & Mason 2005). In Europe, this interval correlates to the upper part of the PC Biozone (Higgs *et al.* 1992) and the CM Biozone (figures 7.3a & 7.4). Conodont data from Morehead, therefore, suggests that assemblages representative of the BP Miospore biozones appear in slightly younger age strata in the Morehead succession than in Europe, and that spores typical of the European PC and CM miospore biozones appear at similar levels in Europe and the Mississippi Valley.

The relatively small and regular size of specimens within the lower part of the Henley Bed suggests that sediments are well-sorted, and implies that assemblages were transported a relatively long distance from their source. Although this may seem inconsistent with the interpreted palaeoenvironment of a highly proximal shelf or basin (see Chapter 9), it is consistent with the interpretation of the Henley Bed as the oldest unit in the Borden delta sequence. These prodelta sediments were fairly proximal to the palaeo-shoreline

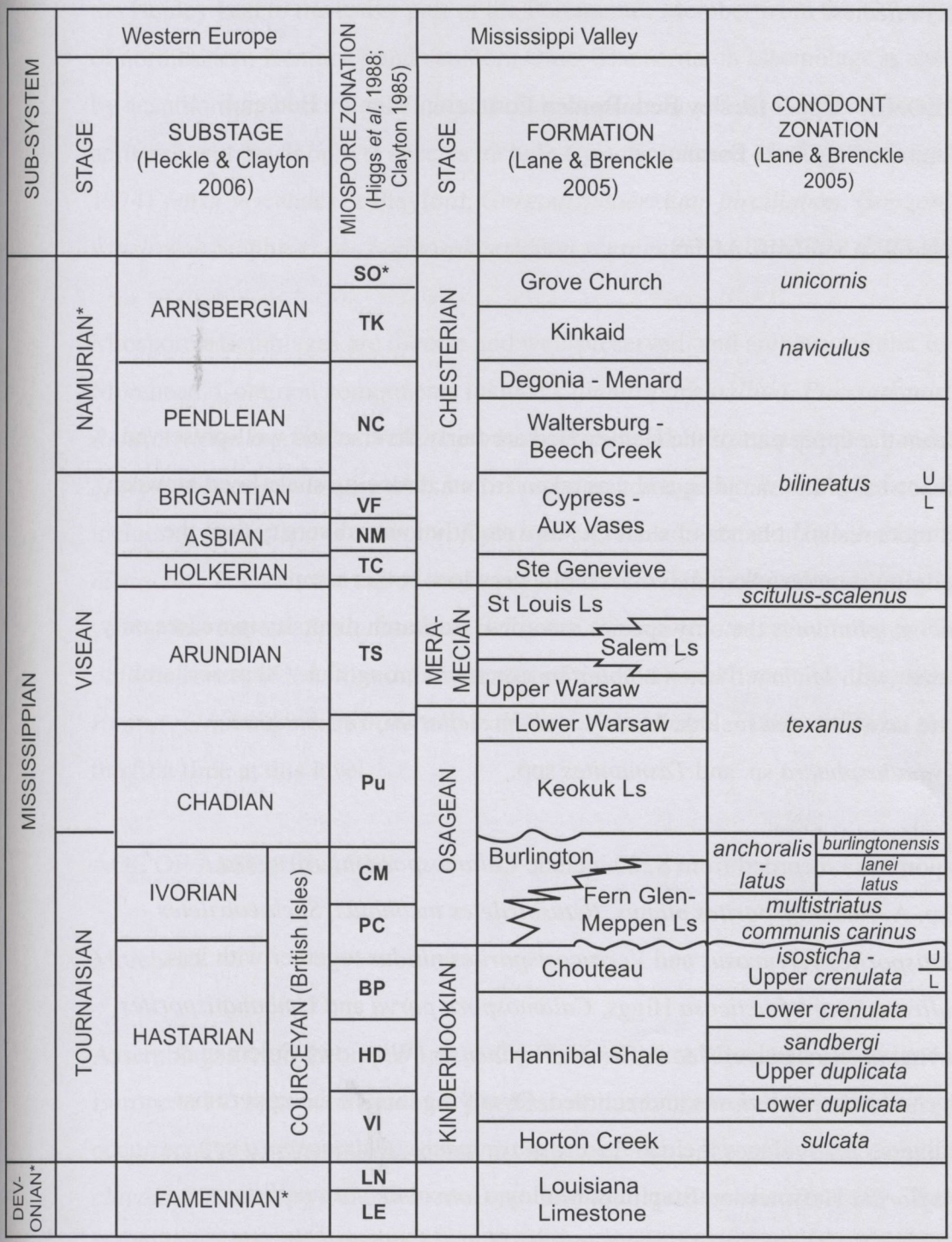


Figure 7.4 Type Mississippian stratigraphic units and conodont zonation and possible correlation with European stratigraphy and miospore biozones (after Lane & Brenckle 2005; Higgs *et al.* 1992; Higgs 1996). Stratigraphic units are not to scale.

(Sable & Dever 1990) but may have been transported a long way from the landward side of the delta. Furthermore, conodont faunas indicate a significant amount of reworking within the Henley Bed. Similar reworking of organic matter within the Henley may have also affected the palynofacies.

7. 2. 4 PC BIOZONE – Upper Henley Bed, Borden Formation; Henley Bed and Portsmouth Member, Cuyahoga Formation

COMPOSITION OF ASSEMBLAGES

Morehead

Assemblages from the upper part of the Henley Bed are fairly diverse and well-preserved. Sample S220 is lowest of the samples, and was taken from a dark silty shale layer between two lighter and more resistant bands of shale; it has a slightly lower diversity than the under- and overlying samples. Acritarch diversity is very low in this sample; *Michrystriudium ampliatum* is the only species recorded. Acritarch diversity increases only slightly above this, with *Michrystridium ampliatum* common throughout. Other acritarch and prasinophyte taxa recorded include *Michrystridium stellatum*, *Veryhachium trispinosum*, *Cymatiosphaera* sp. and *Tasmanites* spp.

Common miospore taxa recorded from S220 include *Calamospora microrugosa*, *Geminospora* sp. A, *Punctatisporites planus*, *Retusotriletes incohatus*, *Spelaeotriletes balteatus*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus* together with less common *Apiculiretusispora fructicosa* Higgs, *Calamospora parva* and *Umbonatisporites distinctus*. The first occurrences of *Neoraistrickia loganensis* (Winslow) Coleman & Clayton and *Spelaeotriletes pretiosus* are recorded. Overlying this, in the uppermost Henley, more diverse assemblages include *Auroraspora macra*, *Calamospora* spp., *Convolutispora florida* Hoffmeister, Staplin & Malloy, *Convolutispora mellita* Hoffmeister, Staplin & Malloy, *Grandispora cornuta* Higgs, *Retusotriletes* spp., *Vallatisporites vallatus* and *Spelaeotriletes obtusus*. First occurrences of *Discernisporites micromanifestus* (Hacquebard 1957) Sabry & Neves, *Raistrickia clavata*, *Retusotriletes crassus*, *Retusotriletes triangularis* Streel (Streel) and *Kraeuselisporites mitratus* are recorded.

Vanceburg

A slightly more diverse, but essentially similar assemblage is recorded from the middle of the Henley Bed to the lower part of the Portsmouth Member from the Cuyahoga Formation of northeastern Kentucky and southern Ohio. The acritarch assemblage is again dominated by acanthomorph taxa e.g. *Michrystridium ampliatum* and *Michrystridium stellatum*. Other acritarch and prasinophyte species include *Cymatiosphaera* cf. *C. parvicarina* (Wicander 1974) *sensu* Wicander & Playford, *Gorgonisphaeridium furcillatum*, *Gongonisphaeridium winslowae* Staplin *et al.*, *Lophosphaeridium segregum* and *Unellium pyriforme* Rauscher.

Miospore assemblages are diverse and well-preserved, and are very similar to those seen at Morehead. Common components include *Calamospora pallida*, *Punctatisporites planus*, *Retusotriletes incohatus*, *Vallatisporites vallatus* and *Verrucosisporites nitidus*. *Spelaeotriletes pretiosus* makes its first appearance together with a number of other taxa including *Grandispora echinata*, *Knoxisporites triradiatus* and *Umbonatisporites distinctus*. Towards the top of the Henley Bed *Raistrickia clavata* and *Vallatisporites verrucosus* appear. *Spelaeotriletes balteatus*, *Spelaeotriletes cabotii* and *Spelaeotriletes obtusus* are recorded from the lower part of the Portsmouth member. *Emphanisporites rotatus*, *Grandispora cornuta* and *Vallatisporites ciliaris* (Luber) Sullivan also appear for the first time at this level.

AGE OF ASSEMBLAGES

Morehead

Assemblages from the upper part of the Henley Bed at Morehead are assigned to the European PC Miospore Biozone. The base of this biozone is defined in Europe by the first occurrence of *Spelaeotriletes pretiosus* together with a few other taxa including *Raistrickia clavata*, *Kraeuselisporites mitratus* and *Granulatisporites microgranifer*. This assemblage is typically very diverse. The base of the overlying CM Biozone is recognised by the first occurrence of *Schopfites claviger*. Assemblages recorded from Morehead are of relatively lower diversity, but contain some of the key zonal taxa. *Kraeuselisporite mitratus* and *Raistrickia clavata* appear in the upper part of the assemblage. *Granulatisporites microgranifer* is present in the underlying BP Biozone, but has recently been recorded from this lower level in Europe (Higgs pers. comm. 2006).

The PC Miospore Biozone has previously been recognised from the upper part of the Henley Bed by Coleman (1991) and Coleman & Clayton (1987). The PC Biozone was the highest miospore biozone that Coleman (1991) was able to identify at Morehead. This study recognises the base of the PC Biozone at a slightly lower level than Coleman. However, the miospore assemblages recorded are very similar.

As previously mentioned, conodonts from the upper part of the Henley Bed are assigned to the *multistriatus* Zone of Lane and Brenckle (2005) (Work & Mason 2005). This suggests that assemblages assigned to the PC Biozone in Kentucky are equivalent in age to those assigned to the PC Biozone in Europe (Figure 7.3a).

Vanceburg

Assemblages from the Henley Bed and lower part of the Portsmouth Member at Vanceburg are tentatively assigned to the Western European PC Miospore Biozone. Although assemblages from Vanceburg are similar to those from Morehead some key taxa have noticeably later first appearances. In particular, the first appearance of *Spelaeotriletes balteatus* and *Spelaeotriletes cabotii* are much later than that of *Spelaeotriletes pretiosus*. Assemblages are diverse and well-preserved, suggesting that this late occurrence is a true event rather than an effect of preservation. The underling BP Biozone is not recognised from Vanceburg. The first appearance of *Spelaeotriletes cabotii* is recorded from the BP Biozone of Western Europe (Brittain & Higgs 2007). However, it has a later first appearance in Canada within assemblages correlated to the PC Biozone (Utting *et al.* 1989).

Conodont assemblages recorded from the Henley Bed and Portsmouth Member are assigned to the Upper *typicus* Zone (*multistiatus* Zone of Lane & Brenckle 2005) (Sandberg *et al.* 2002). This places the Henley Bed within the lower Osagean and correlation with the Ivorian Substage of Western Europe and the upper part of the PC and CM miospore biozones are suggested (Figure 7.3b). As noted above, this suggests that assemblages assigned to the PC Miospore Biozone in Kentucky are coeval with those of Western Europe.

7. 2. 5 CM BIOZONE – Farmers Member, Nancy Member, Borden Formation; Portsmouth Member, Cuyahoga Formation

COMPOSITION OF ASSEMBLAGES

Morehead

Palynomorph assemblages from the Farmers Member and Nancy Member at Morehead are diverse and well-preserved. Acritarchs and prasinophytes are a minor component within assemblages, again dominated by *Michrystridium ampliatum*, with rare occurrences of *Multiplicisphaeridium ramusculosum* (Deflandre 1945) Lister, *Cymatiosphaera* spp. and *Polyedryxium* sp.

Miospore assemblages are relatively diverse. A single sample (S228) from the base of the Farmers Member yields common *Convolutispora* spp., *Geminospora* sp. A, *Punctatisporites planus*, *Spelaeotriletes balteatus*, *Spelaeotriletes pretiosus, Vallatisporites vallatus* and *Vallatisporites verrucosus*. *Schopfites claviger* is first recorded from this sample together with *Convolutispora* cf. *C. usitata* Playford; Smith & Butterworth and *Cyrtospora cristifera*. The remainder of the Farmers Member comprises light-coloured and well-consolidated sandstones and was not sampled for palynology. The next productive samples were obtained from the overlying Nancy Member. This assemblage is slightly more diverse than the one recorded from the Farmers Member. Common taxa are similar to those from sample S228 and additionally include *Auroraspora macra*, *Auroraspora solisorta*, *Raistrickia clavata* and *Retusotriletes incohatus*.

Vanceburg

Palynomorph assemblages from the Portsmouth Member at Vanceburg are well-preserved and diverse, and closely resemble those from the Nancy Member. A slightly more diverse acritarch and prasinophyte assemblage is recorded from Vanceburg than at Morehead. *Michrystridium* is notably absent from the upper part of the Portsmouth Member. Assemblages comprise of rare occurrences of taxa including *Lophosphaeridium segregum*, *Veryhachium trispinosum*, *Gorgonisphaeridium* spp., *Cymatiosphaera* spp. and *Polyedryxium decorum* Deunff.

Miospore assemblages from the middle part of the Portsmouth Member are characterised by long ranging taxa from the underlying assemblages such as *Calamospora* spp., *Retusotriletes incohatus* and *Spelaeotriletes pretiosus* and *Vallatisporites vallatus*, as well as a suite of new taxa including *Auroraspora solisorta*, *Grandispora spinosa*, *Hystricosporites* cf. *H. porcatus* and *Schopfites claviger*. *Convolutispora caliginosa* and *Densosporites anulatus* (Loose) Potonié & Kremp are recorded from the upper part of the Portsmouth Member. Notably absent in the highest sample (S243, just below the base of the Vanceburg Member), are *Knoxisporites concentricus*, *Vallatisporites vallatus*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus*.

AGE OF ASSEMBLAGES

Assemblages from the Farmers Member, Nancy Member and Portsmouth Member are assigned to the European CM Miospore Biozone. In Europe, the base of this biozone is marked by the first occurrence of *Schopfites claviger*. This taxon is recorded from both Morehead and Vanceburg. Other characteristic taxa include *Anaplanisporites baccatus*, *Auroraspora macra*, *Colatisporites decorus*, *Colatisporites denticulatus*, *Crassispora trychera*, *Baculatisporites fusticulus*, *Lophozonotriletes triangularis*, *Plicatispora scolecophora*, *Raistrickia corynoges* and *Retusotriletes incohatus*. Most of these taxa are not recorded from the Kentucky assemblages; only the long-ranging taxa *Auroraspora macra* and *Retusotriletes incohatus* are recorded. This suggests that either a large proportion of the assemblage is not preserved within the samples or that there are marked differences between ranges of certain taxa from Kentucky and Europe. The former is unlikely due to the observation of well-preserved assemblages within the Kentucky successions. The latter explanation is preferred, as the associated taxa listed above have been found within much younger age rocks from the Mississippi Valley (see Section 7.3).

Independent conodont age data from Morehead and Vanceburg place the above assemblages in the *multistriatus* Zone (Sandberg *et al.* 2002; Work & Mason 2005). These zones are no older than the late Tournaisian of Western Europe, suggesting correlation with the upper PC and CM miospore biozones (figures 7.3a & 7.3b). A distinctive ammonoid assemblage was recorded from both the lower Nancy Member at Morehead and the basal part of the Portsmouth Member at Vanceburg (Sandberg *et al.* 2002; Work & Mason 2005). This assemblage, known as the Cave Run Lake Fauna, comprises *Kazakhstania mangeri* Work & Mason, *Muensteroceras* cf. *M. oweni* (Hall) Work &

Mason and *Masonoceras kentuckiensis* Work & Manger, and was recorded from the same level as conodonts indicative of the *multistriatus* Zone. A robust correlation between the two Kentucky sections is suggested at this level.

7. 3 MISSISSIPPI VALLEY

As previously discussed, miospore assemblages from the Mississippi Valley region cannot be easily correlated to the Western European miospore biozones. Assemblages will, therefore, be described in ascending stratigraphic order and tentatively assigned to biozones. Sampling was restricted to shale-rich, clastic units. As a result the bases and tops of many spore ranges are a result of facies change rather than true occurrences and disappearances. However, this preliminary zonation will allow palynological correlation at a local level and provides a base for future palynostratigraphical studies within the type Mississippian.

Assemblages from the Kinderhookian show very little, if any, change in composition and a single biozone is proposed for this stage. Sampling was especially restricted throughout Osagean and Meramecian strata due to thick limestone units such as the Burlington, Keokuk, Salem and St Louis limestones (Chapter 4, Figure 4.2). Again, a single assemblage is described and biozone proposed. The frequency and number of clastic dominated units increase in the Chesterian, and the composition of assemblages changes throughout the stage. Seven miospore biozones are proposed for the Mississippian. In ascending order these are the *Cyclogranisporites commodus* Biozone; *Spelaeotriletes obtusus* Biozone; *Prolycospora rugulosa* Biozone, *Crassispora aculeata* Biozone, *Cingulizonates bialatus* Biozone, *Crassispora maculosa* Biozone and the *Cirratriradites annuliformis* Biozone (Figure 7.5).

7. 3. 1 KINDERHOOKIAN - Hannibal Shale, Chattanooga Shale, Bachelor Formation, Northview Shale, McCraney Limestone & Prospect Hill Siltstone.

COMPOSITION OF ASSEMBLAGES

Samples from the Hannibal type section and Clarence Cannon Dam localities have previously been analysed in a paper by Heal & Clayton (2008). The results of this study are discussed below and compared with additional data from equivalent age core material.

The composition and preservation of miospore assemblages within the Hannibal Shale are similar throughout the Hannibal and Clarence Cannon Dam successions in Missouri and core C14859 from Illinois. Preservation varies from good to very good. Similar assemblages are recognised from the Chattanooga Shale, Bachelor and Northview Shale formations of southwest Missouri (cores LS21, NS2 and NS3), and the McCraney and Prospect Hill formations of southern Iowa (core H29). A slightly different assemblage is recorded from the Hannibal Shale from core 59-Mi close to the Hannibal type area in northeastern Missouri. Preservation within the core samples ranges from poor to good. The palynomorphs include acritarchs, miospores, prasinophytes and scolecodonts. The qualitative compositions of the assemblages from the Hannibal section are summarised in Table 7.3. Palynomorph assemblages from the Clarence Cannon Dam core section closely resemble those from the Hannibal section (Table 7.4). Assemblages from the core sections are summarised in Tables 7.5 - 7.9. All assemblages are dominated by acanthomorph acritarchs. The most abundant species is *Micrhystridium stellatum,* with *Gorgonisphaeridium winslowiae*, *Micrhystridium ampliatum,* and *Unellium pyriforme* also common throughout.

The miospore assemblages are similar throughout both Hannibal and Clarence Cannon Dam successions. Diversity is consistently low, and marginally increases in sample S54 (towards the top of the Hannibal section), CC8 and CC11 (middle of the core section) and CC15 (near the top of the core section). Common miospores include *Apiculiretusispora fructicosa, Calamospora parva*, *Calamospora perrugosa, Cyclogranisporites commodus*, *Geminospora* sp. A, *Leiotriletes trivialis* Naumova, *Punctatisporites planus*, *Retusotriletes incohatus* and *Verrucosisporites nitidus*. Other taxa present include *Auroraspora macra*, *Converrucosisporites* sp., *Convolutispora florida*, *Discernisporites micromanifestus*, *Grandispora echinata*, *Velamisporites* cf. *V. magnus*, *Pustulatisporites dolbii*, *Retusotriletes communis* and *Retusotriletes famenensis*.

Similar, but much less diverse assemblages are recorded from the Chattanooga Shale in core LS21 (Table 7.5), and the Bachelor Formation in core NS2 (Table 7.6). A poorly preserved and low diversity miospore assemblage is recorded from the Northview Shale in core NS3 with only nine taxa recorded (Table 7.7). A slightly higher (but still relatively low) diversity assemblage is recorded from the Northview Shale in core NS2. Assemblages from these cores closely resemble those from the Hannibal Shale; *Geminospora spongiata*, *Microreticulatisporites araneum* Higgs, Clayton & Keegan and *Punctatisporites irrasus*

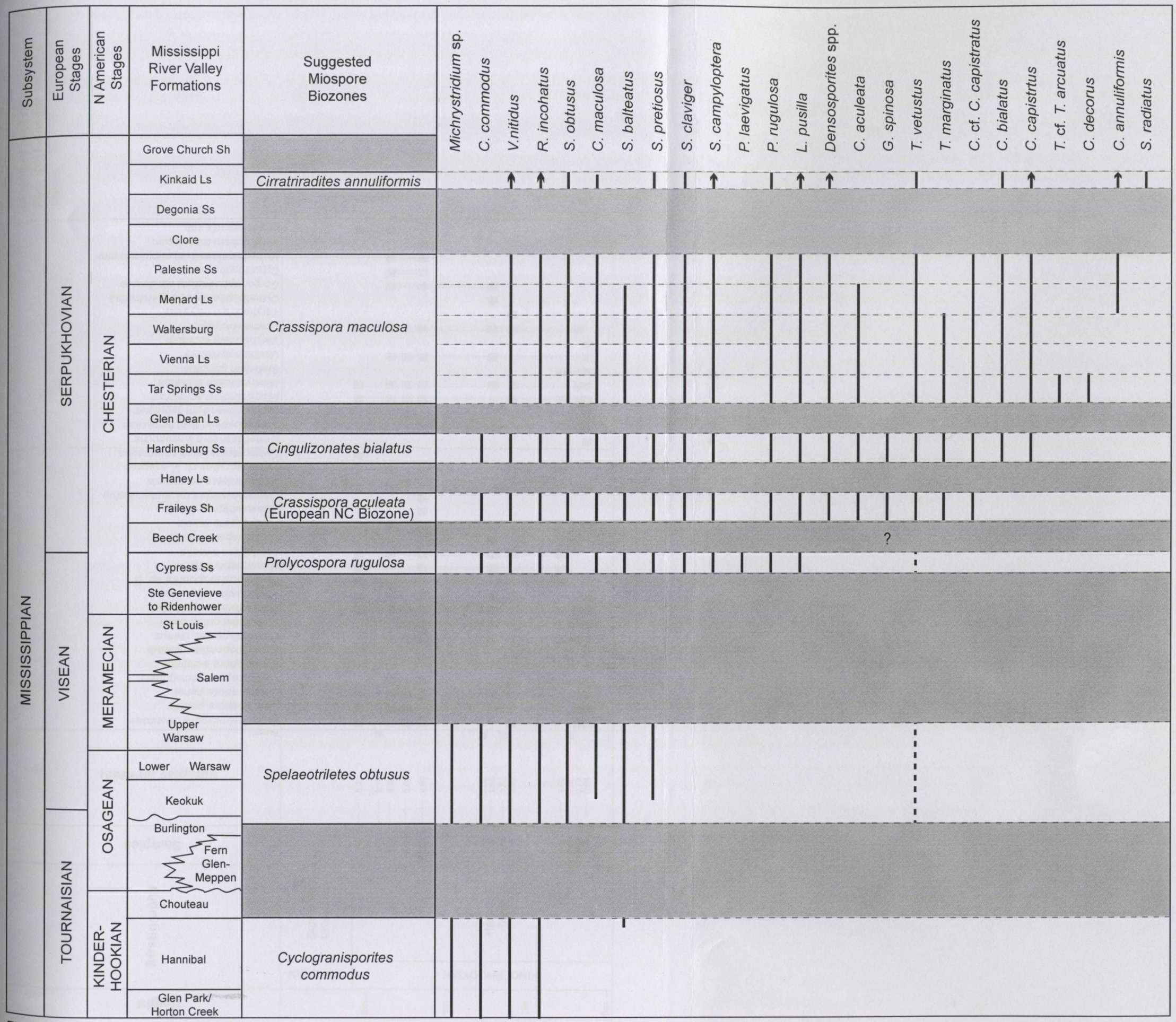


Figure 7.5 Ranges of stratigraphically important taxa in the Mississippi Valley and suggested miospore biozonation

Table 7.3 - Stratigraphic ranges of taxa recorded from the Hannibal section, Illinois.

Table 7.4 - Stratigraphic ranges of taxa recorded from the Clarence Cannon Dam section, Illinois.

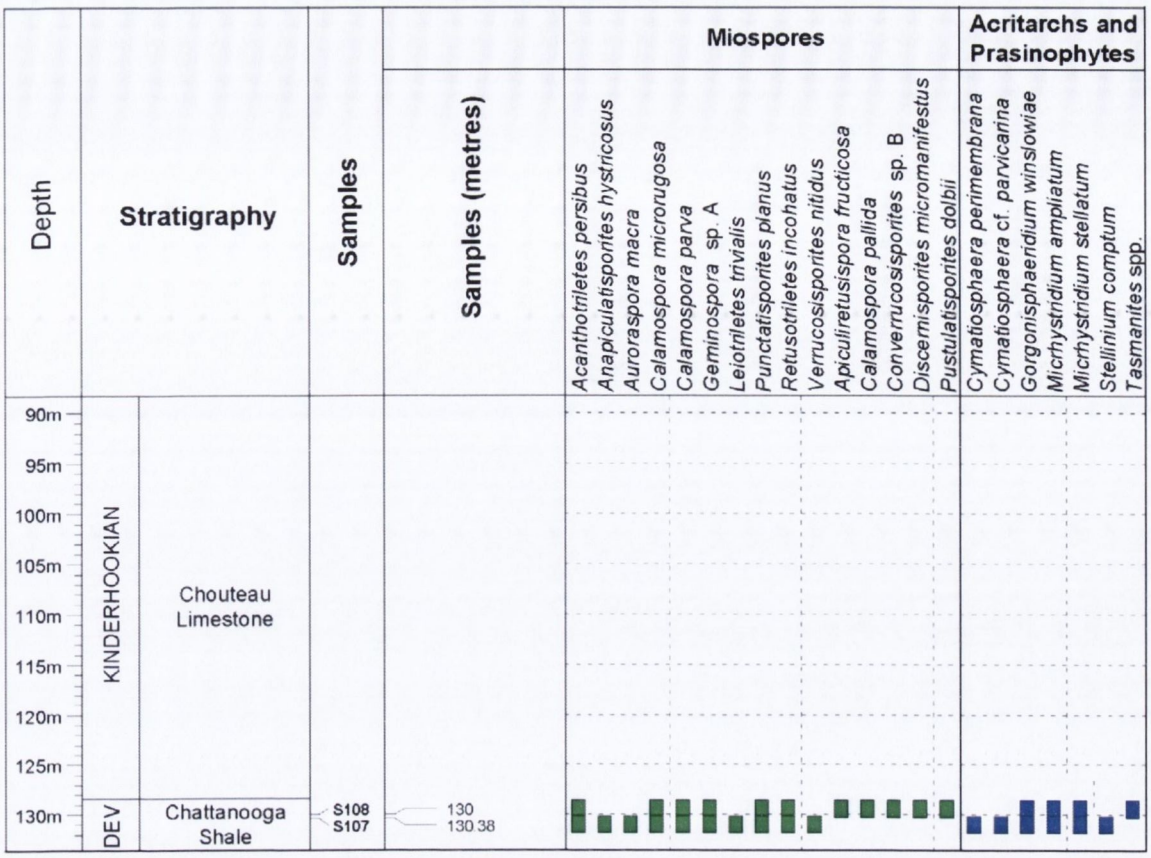


Table 7.5 - Stratigraphic ranges of taxa recorded from core LS-21, Randolph County, Missouri.

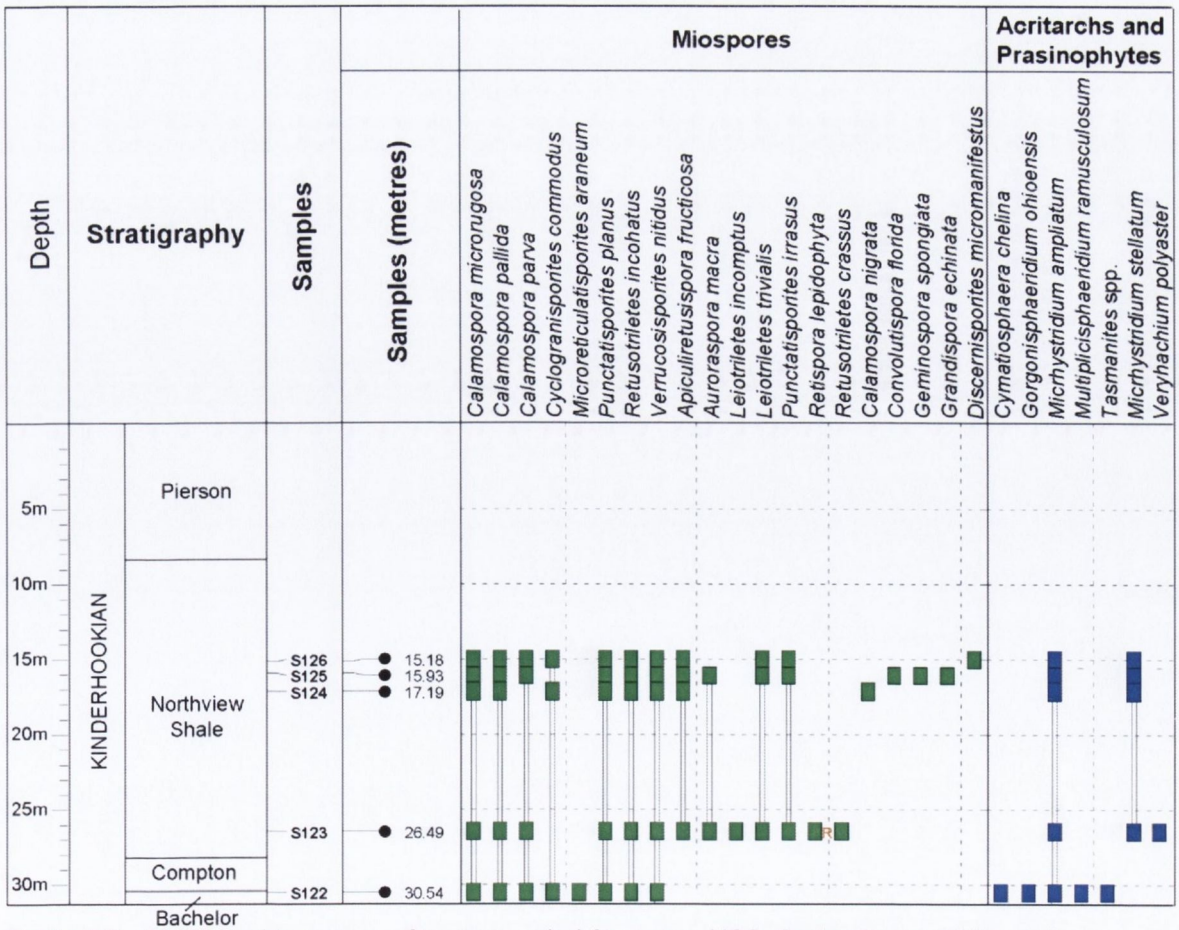


Table 7.6 - Stratigraphic ranges of taxa recorded from core NS2, Cedar County, Missouri.

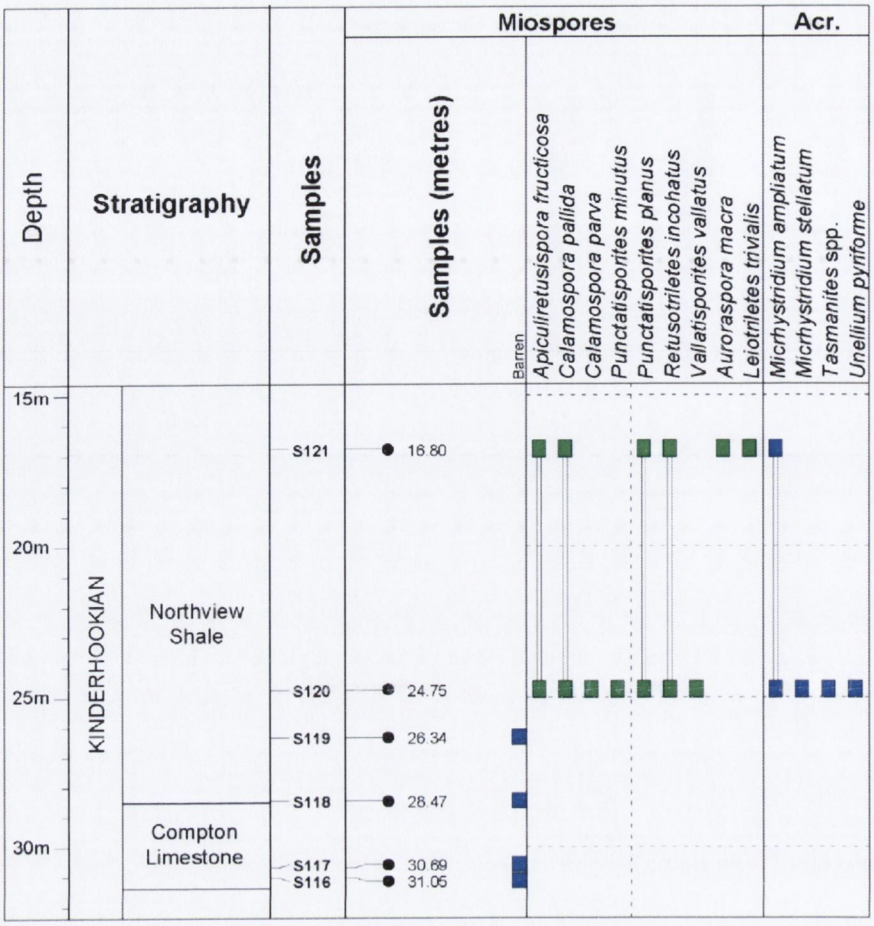


Table 7.7 - Stratigraphic ranges of taxa recorded from core NS3, Dade County, Missouri. (Acr. - Acritarchs and Prasinophytes).

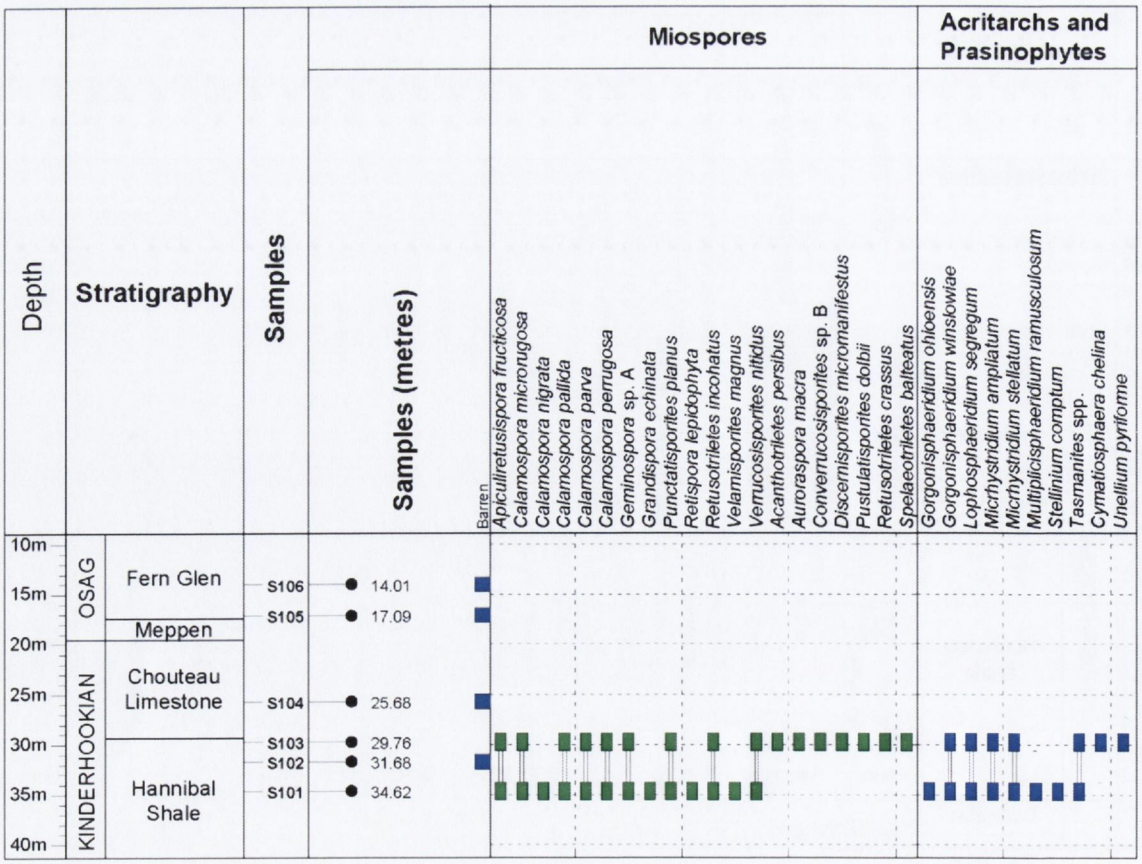


Table 7.8 - Stratigraphic ranges of taxa recorded from core C14859, Jersey County, Illinois.

are additionally recorded. Fairly diverse assemblages are recorded from the McCraney Limestone and Prospect Hill formations and also consist mainly of taxa seen in the Hannibal and Clarence Cannon Dam sections. Additional taxa recorded include *Discernisporites sullivani* Higgs & Clayton and *Knoxisporites literatus*.

Miospores from the Hannibal Shale from core C14859 are very similar to those from the Hannibal type area but also include *Spelaeotriletes balteatus* (Table 7.8). Miospores from a single sample of the Hannibal Shale from core 59-Mi are low diversity but include *Spelaeotriletes balteatus* and *Vallatisporites* sp. B (Table 7.9).

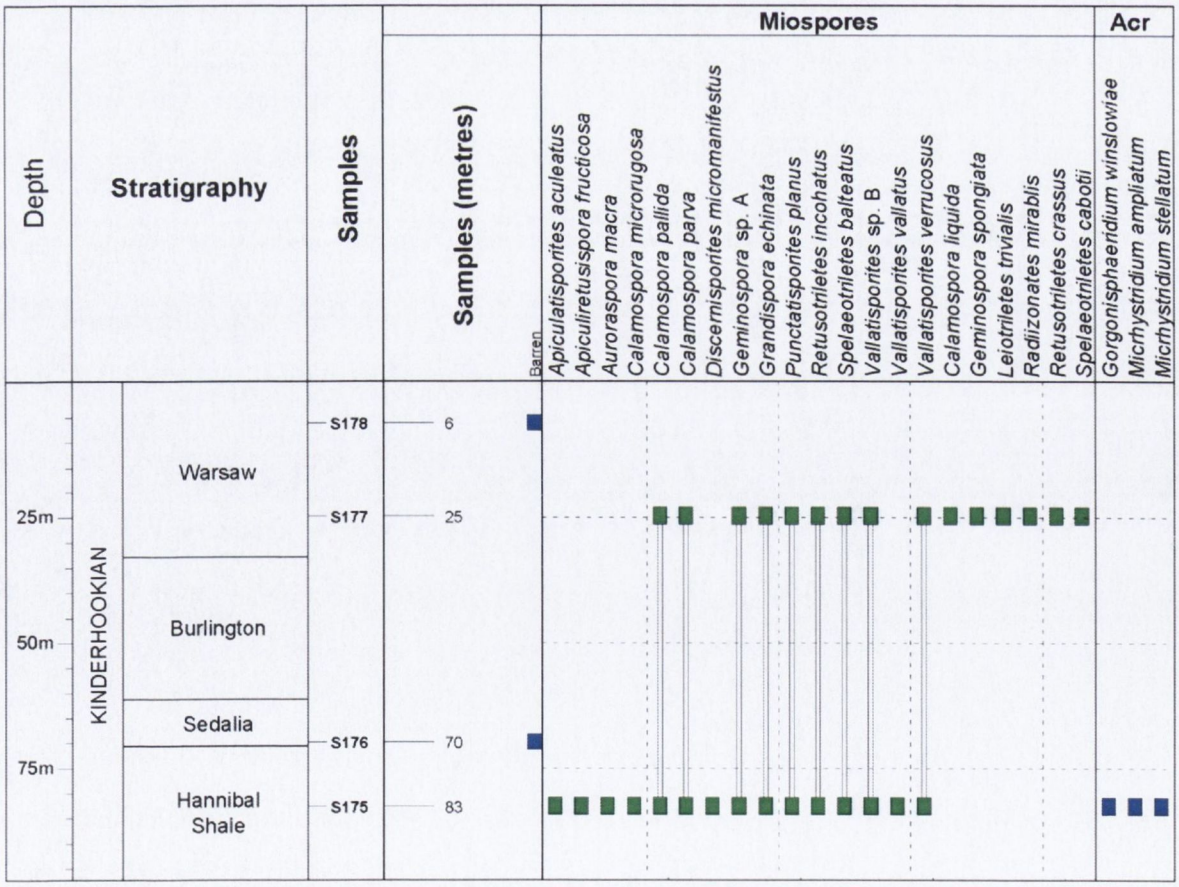


Table 7.9 - Stratigraphic ranges of palynomorphs recorded from core 59-Mi, Clark County, Missouri. (Acr - Arcritarchs)

AGE OF THE PALYNOMORPH ASSEMBLAGES

Hannibal type section and Clarence Cannon Dam

Acritarchs and prasinophyte abundance and diversity both declined rapidly during the Early Mississippian (Tappan, 1980). The acritarch assemblage from the Hannibal Shale resembles assemblages previously described from the earliest Mississippian of Kentucky. The assemblage includes many species that are common in the Late Devonian, but which persist into the Early Carboniferous and are therefore of limited stratigraphic significance. These include *Micrhystridium stellatum*, *Multiplicisphaeridium ramusculosum*, *Stellinium comptum*, *Stellinium micropolygonale* (Stockmans & Willière) Playford, *Unellium pyriforme*, *Veryhachium polyaster* Staplin and *Veryhachium trispinosum*.

The Hannibal Shale miospores closely resemble assemblages from the Sunbury Shale, Jacobs Chapel and Rockford Limestone, and are typical of the Western European VI Miospore Biozone. In Europe, this biozone is earliest Carboniferous in age. The base is defined by the top of the range of *Retispora lepidophyta*, with numerous other latest Devonian miospores disappearing at the same level. Biozone VI assemblages are typically of relatively low diversity, containing only survivor taxa from the latest Devonian.

In Western Europe, the bases of the Tournaisian HD, BP, and PC miospore biozones which succeed the VI zone are defined by *Cristatisporites hibernicus*, *Spelaeotriletes balteatus,* and *Spelaeotriletes pretiosus* respectively (Figure 7.6). The absence of these three taxa, together with the absence of *Retispora lepidophyta,* suggests that the Hannibal assemblage should be assigned to the VI Biozone.

Miospore assemblages referable to the European VI Biozone are recognised from Morehead and Vanceburg (Section 7.2 above) and have previously been described from several other sections in the USA. These include the Sunbury Shale of Michigan (Richardson 2006) and Ohio (Winslow 1962), and the Pocono Formation of Pennsylvania (Warg & Traverse 1973; Streel & Traverse 1978), from the Michigan and Appalachian Basins. However, Hannibal is located on the western edge of the Eastern Interior Basin (Sable & Dever 1990), further west than any of these sections, and the palynofacies of the Hannibal Shale suggests much less terrestrial influence. Caution should therefore be

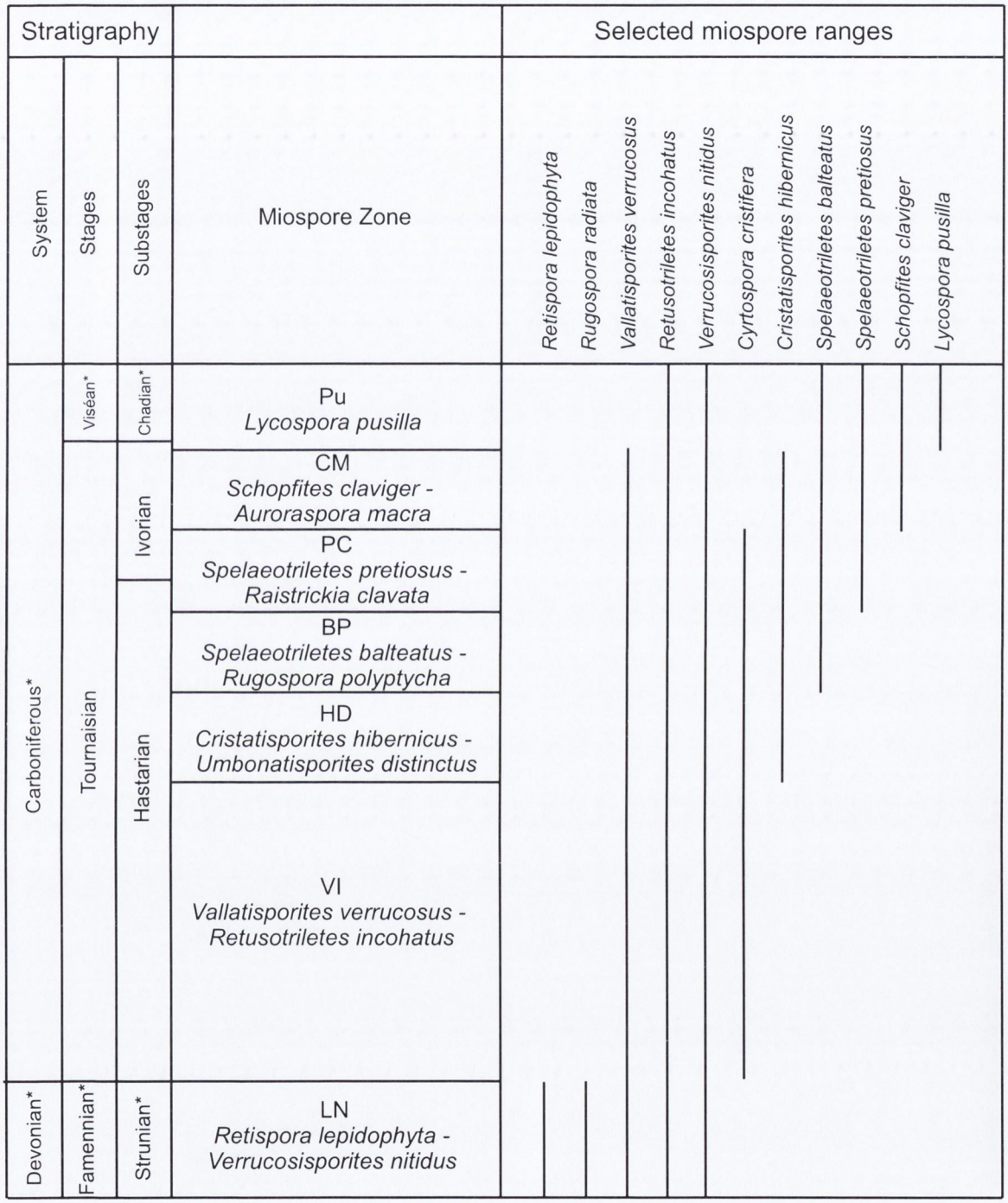


Figure 7.6 Ranges of stratigraphically important miospore species throughout the Tournaisian of Western Europe (* in part).

exercised in interpreting the age of the Hannibal miospore assemblages on negative evidence.

Independent conodont data from Clarence Cannon Dam shows that the Hannibal Shale encompasses the Lower *Siphonodella duplicata* through Lower *Siphonodella crenulata* zones (Work et al., 1988; Lane & Brenckle, 2005). This suggests that the Hannibal Shale is Hastarian in terms of the European regional chronostratigraphy. In Belgium, the Hastarian Substage contains the *Vallatisporites verrucosus-Retusotriletes incohatus* (VI), the *Cristatisporites hibernicus-Umbonatisporites distinctus* (HD), and possibly the lowermost part of the *Spelaeotriletes balteatus-Rugospora polyptycha* (BP) European miospore biozones (Higgs et al. 1992; Higgs 1996). Coeval Early Mississippian assemblages from the Appalachian Basin of Kentucky have previously been assigned to the VI and BP miospore biozones (Coleman & Clayton 1987). However, in the Mississippi Valley, this interval is represented by impoverished miospore assemblages tentatively assigned to the basal Mississippian VI Miospore Biozone. Assemblages representing both the HD and BP miospore biozones are notably absent. This may indicate a longer interval between the Late Devonian mass extinction, and the first appearance of new miospore taxa in the Mississippi Valley, compared with the rest of North America and Europe, and may be a result of facies control on the distribution of the parent plants. Assemblages from the Hannibal shale are therefore assigned to the ***Cyclogranisporites commodus* Biozone** (Figure 7.5).

Core Sections

Assemblages recorded from the Bachelor Formation and Northview Shale of southwest Missouri and the McCraney and Prospect Hill Siltstone of Iowa are very similar to those from Hannibal and are also assigned to the *Cyclogranisporites commodus* Biozone (Figure 7.5). The upper part of the Northview Shale is equivalent to the Chouteau Limestone of northeast Missouri and is youngest Kinderhookian in age. This suggests the entire Kinderhookian of the Mississippi Valley region should be assigned to the *Cyclogranisporites commodus* Biozone.

Palynomorph assemblages recovered from the top of the Chattanooga Shale from Missouri core LS21 have a very similar composition to those from Hannibal and Clarence Cannon Dam and resemble assemblages from the European VI Miospore Biozone. However, the

Chattanooga Shale is considered to be Late Devonian (Thompson 1986). As previously mentioned, Late Devonian miospore assemblages are typically of high diversity and dominated by *Retispora lepidophtya*. Both the low diversity assemblage and absence of *Retispora lepidophyta* suggest that at least the uppermost part of the Chattanooga Shale should be tentatively assigned to the Carboniferous rather than the Devonian. However, the low diversity and the lack of *Retispora lepidophyta* could be attributed to poor preservation in the Chattanooga Shale strata, and further research is required to determine the exact age of this unit. In the present study Chattanooga Shale assemblages are tentatively assigned to the *Cyclogranisporites commodus* Biozone.

Miospore assemblages from the Hannibal Shale from core C14859 are also assigned to the *Cyclogranisporites commodus* Biozone. A single, poorly preserved specimen of *Spelaeotriletes balteatus* is recorded from sample S103 (approximately 60cm/2ft below the Hannibal Shale - Chouteau Limestone contact). As mentioned above, the first occurrence of this taxon defines the base of the BP Biozone in Western Europe. However, this is the only *in-situ* specimen of *Spelaeotriletes balteatus* recorded from the Hannibal Shale and as such its biostratigraphic significance is limited. *Spelaeotriletes balteatus* is also recorded in sample S175 from core 59-Mi. Samples from this core are cuttings and *Spelaeotriletes balteatus* occurs as a single specimen. *Vallatisporites* sp. B is also recorded from this sample. Both these taxa are commonly recorded in the overlying Lower Warsaw and therefore their occurrence in the Hannibal Shale is interpreted as a result of caving.

The occurrence of *Retispora lepidophyta* in earliest Carboniferous assemblages has been previously attributed to either reworking, or the later extinction of the parent plant in certain areas (Playford & McGregor 1993). In Missouri, *Retispora lepidophyta* is abundant in assemblages from the Late Devonian (Famennian) Saverton Shale Formation (Sandberg *et al.* 1972). In the present study, sporadic occurrences of *Retispora lepidophyta* are recorded throughout the early Mississippian. This supports the conclusion of Playford and McGregor (1993) that reworking is the most likely cause of the occasional appearance of *Retispora lepidophyta* in Carboniferous assemblages.

7. 3. 2 OSAGEAN-MERAMECIAN – Burlington, Keokuk, Lower Warsaw and Upper Warsaw

Most of the samples from the Osagean - Meramecian boundary level in the Mississippi Valley are taken from the shale-rich units - predominantly the Lower and Upper Warsaw formations. Shaley partings within the underlying Keokuk and Burlington limestones have also been sampled. Very similar palynomorph assemblages are recovered from all the units. A slightly different assemblage is obtained from the Burlington Limestone as outlined below. However, only two samples are obtained from the Burlington and differences in assemblage composition may be a result of facies change. The assemblage is therefore assigned to a single biozone.

COMPOSITION OF ASSEMBLAGES

Burlington Limestone

Palynomorph assemblages from the Burlington Limestone are obtained from two samples in Iowa core H29, close to the Burlington type region (Table 7.10). Assemblages are relatively diverse and palynomorphs are well preserved. Acritarchs and prasinophytes are rare and much less diverse than in the underlying Prospect Hill and McCraney formations (Hannibal Shale equivalents). *Michrystridium ampliatum* is the most common taxa along with rare occurrences of *Cymatiosphaera perimembrana* Staplin, *Gorgonisphaeridium* spp. and *Stellinium comptum.*

The Burlington yields a diverse miospore assemblage. The most common components within the assemblage are taxa ranging from the underlying *Cyclogranisporites commodus* Biozone such as *Calamospora pallida*, *Punctatisporites planus*, *Pustulatisporites dolbii* and *Retusotriletes incohatus*. A number of taxa have first appearances recorded within the Burlington Limestone. These include *Acanthotriletes falcatus* (Knox) Potonié & Kremp, *Densosporites intermedius*, *Neoraistrickia loganensis*, *Rugospora polyptycha*, *Spelaeotriletes balteatus*, *Spelaeotriletes obtusus*, *Tripartites vetustus*, *Vallatisporites ciliaris* and *Vallatisporites vallatus.*

Keokuk, Lower Warsaw and Upper Warsaw

Samples are obtained from the Lower Warsaw type section at Geode Glen (principally geodiferous dolomite and interbedded shale) and from a more distal palaeoenvironment at Cragwold Road (predominantly limestones and interbedded shale). Preservation and diversity varies between the two assemblages, but the assemblages are essentially very similar. A number of core sections from Illinois and Iowa have also been studied. The qualitative compositions of the assemblages are summarised in tables 7.10-7.15.

Palynomorph assemblages are similar throughout the Keokuk, Lower Warsaw and Upper Warsaw. Preservation is generally good to very good and diversity is high in all samples. The Lower Warsaw yields the highest diversity assemblages and the highest proportion of productive samples, a reflection of its highly proximal/terrestrial palaeoenvironment. Acritarchs and prasinophytes are rare to completely absent, with sporadic occurrences of *Cymatiosphaera perimembrana* and *Lophosphaeridium segregum* from the Keokuk and *Michrystidium stellatum* from the Lower Warsaw.

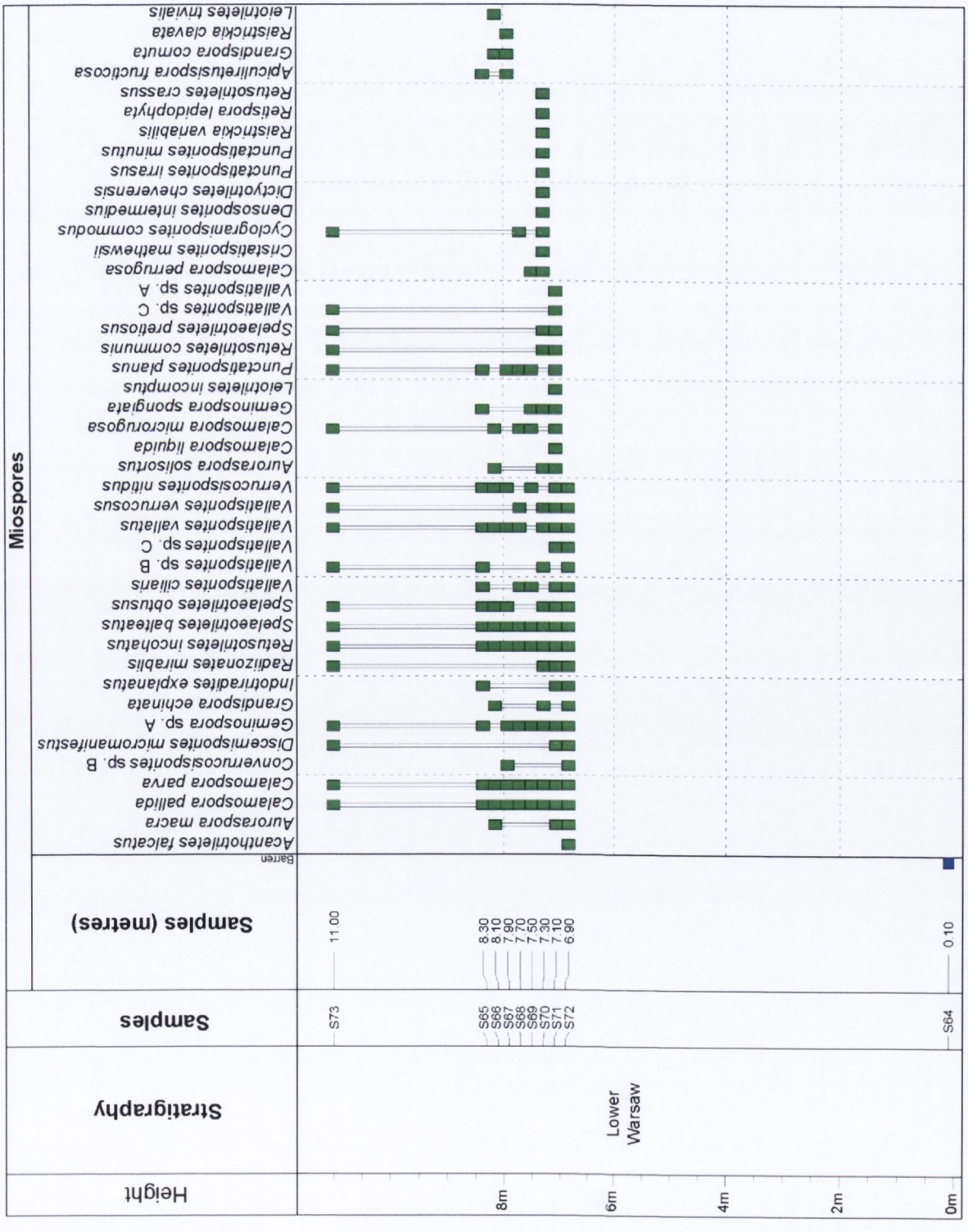
Miospore assemblages contain a high proportion of species which range from the underlying biozones. Common taxa include *Auroraspora macra*, *Calamospora* spp., *Geminospora* sp. A, *Punctatisporites planus*, *Retusotriletes incohatus*, *Spelaeotriletes balteatus*, *Spelaeotriletes obtusus*, *Vallatisporites ciliaris* and *Vallatisporites vallatus*, together with *Apiculiretusispora fructicosa*, *Cyclogranulisporites commodus*, *Grandispora echinata*, *Pustulatisporites dolbii* and *Verrucosisporites nitidus*. New taxa appearing in the Keokuk, Lower Warsaw and Upper Warsaw include *Cristatisporites menendezii* (Menéndez & Azcuy) Playford, *Densosporites anulatus*, *Grandispora spinosa*, *Radiizonates mirabilis* and *Spelaeotriletes pretiosus*. A number of small species of *Vallatisporites* are commonly recorded from the Lower Warsaw, these are termed *Vallatisporites* sp. A, *Vallatisporites* sp. B and *Vallatisporites* sp. C (Plate 16, figures 10-16).

AGE OF ASSEMBLAGES

The acritarch assemblage comprises very few taxa, all of which are present in the underlying units, and are of little biostratigraphic significance. The miospore assemblage from the Burlington Limestone resembles the European BP Miospore Biozone, but is of

Table 7.10 - Stratigraphic ranges of taxa from core H29, Lee County, Iowa.

Table 7.11 - Stratigraphic ranges of taxa from the Geode Glen section, Hancock County, Illinois.



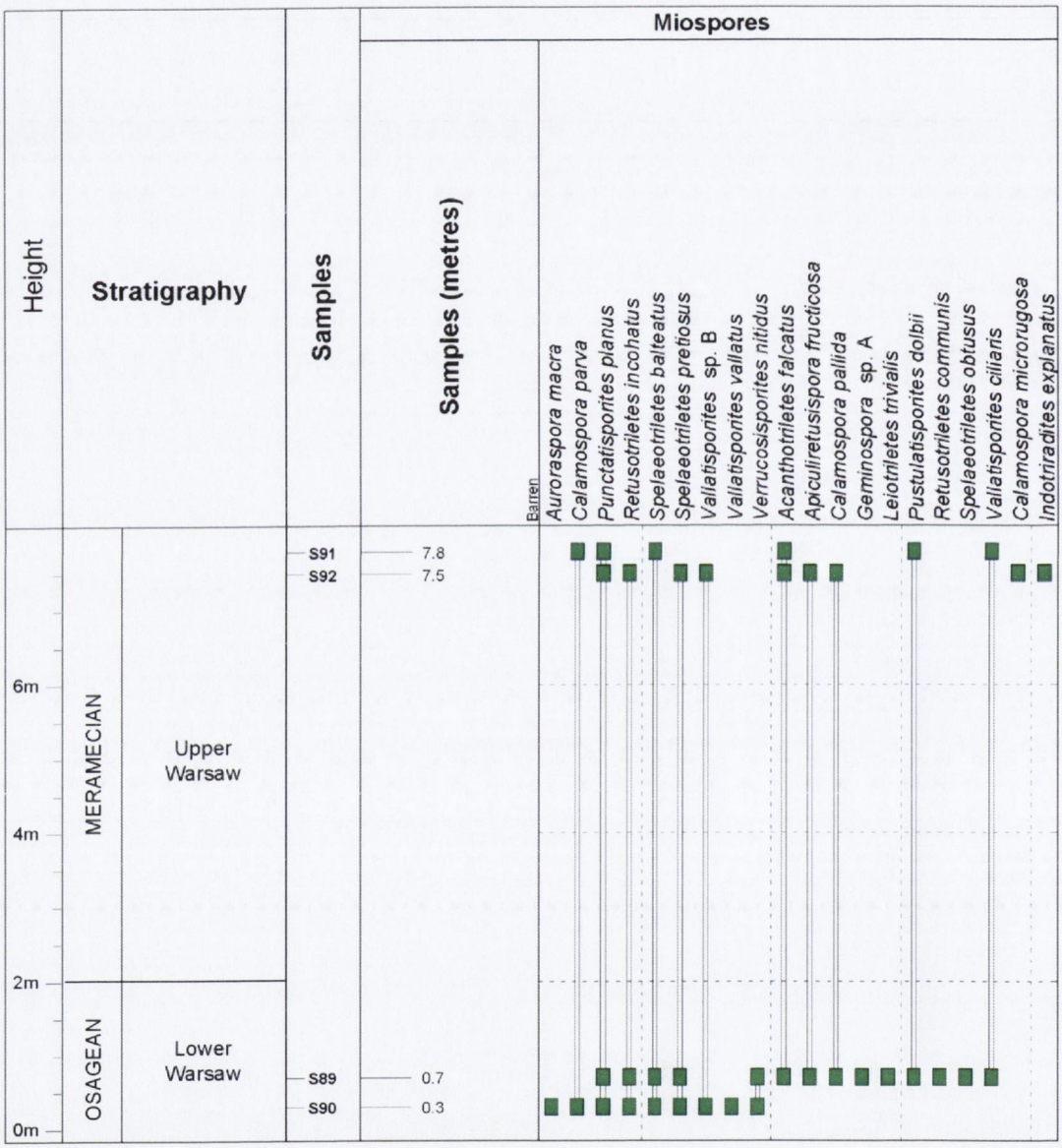


Table 7.12 - Stratigraphic ranges of taxa from the Cragwold Road section, St Louis County, Missouri.

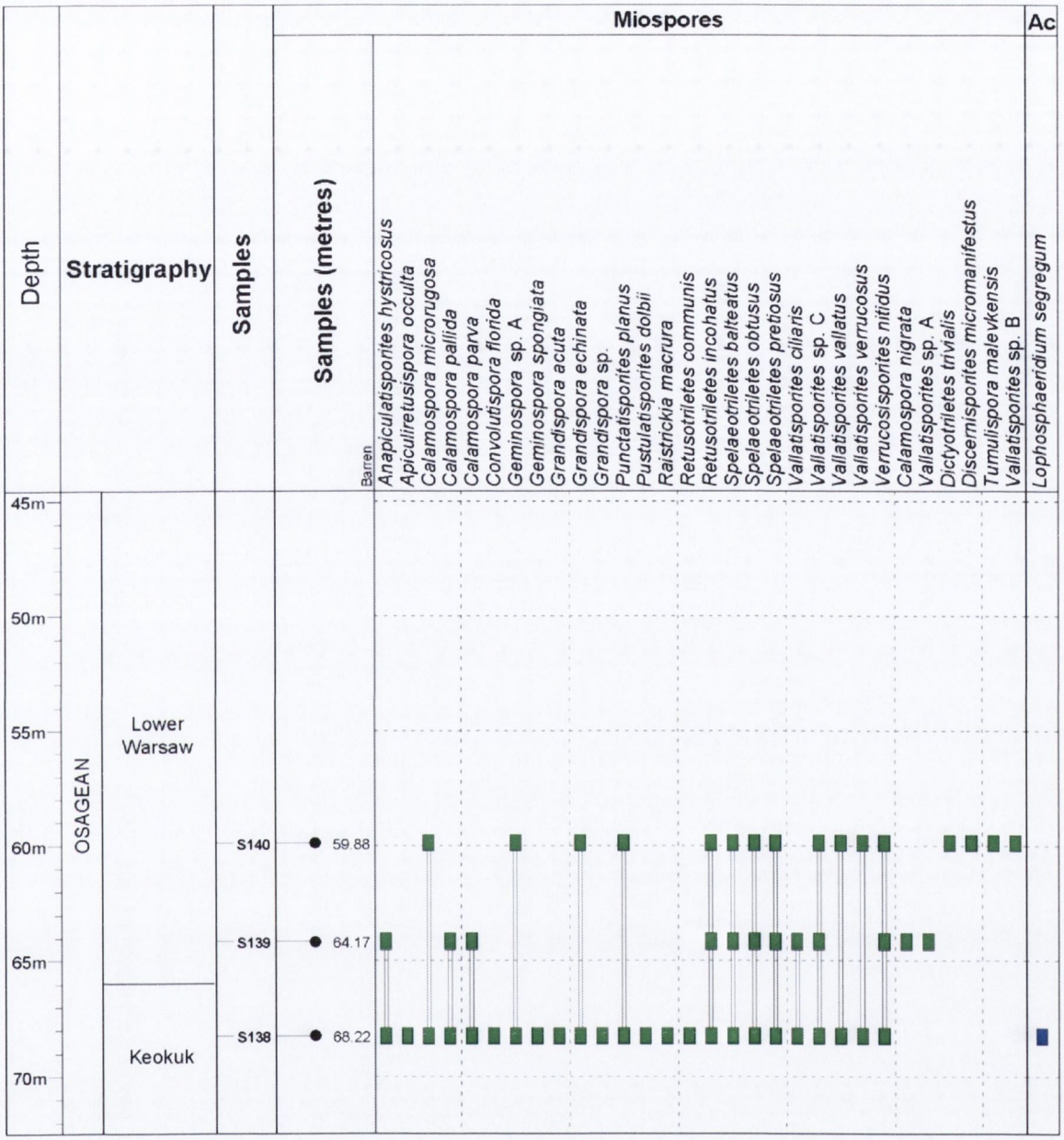


Table 7.13 - Stratigraphic ranges of taxa from core C14715, St Clair County, Illinois.
Ac - Acritarchs and Prasinophytes.

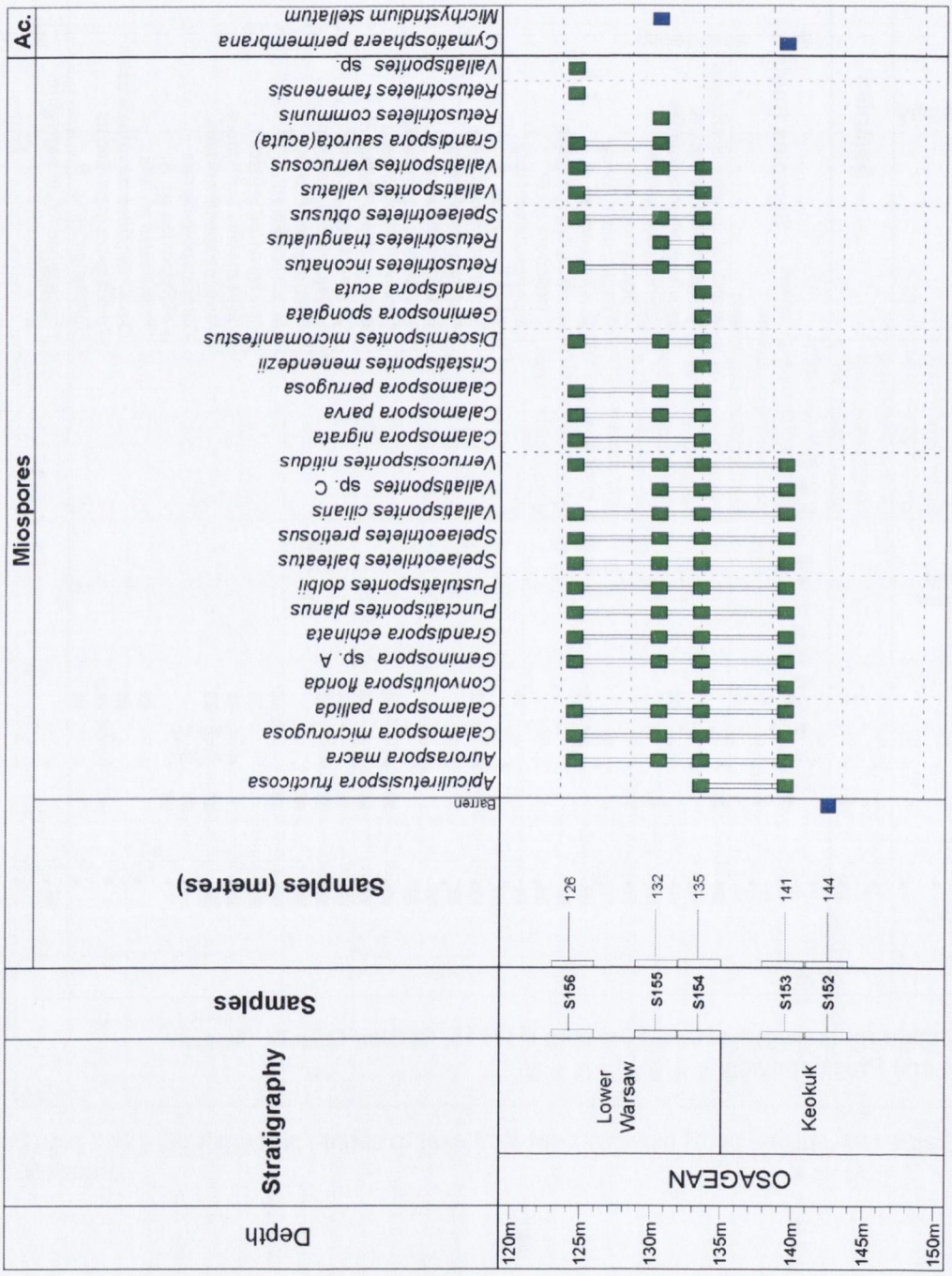


Table 7.14 - Stratigraphic ranges of taxa from core S69127, Monroe County, Illinois. Ac. - Acritarchs

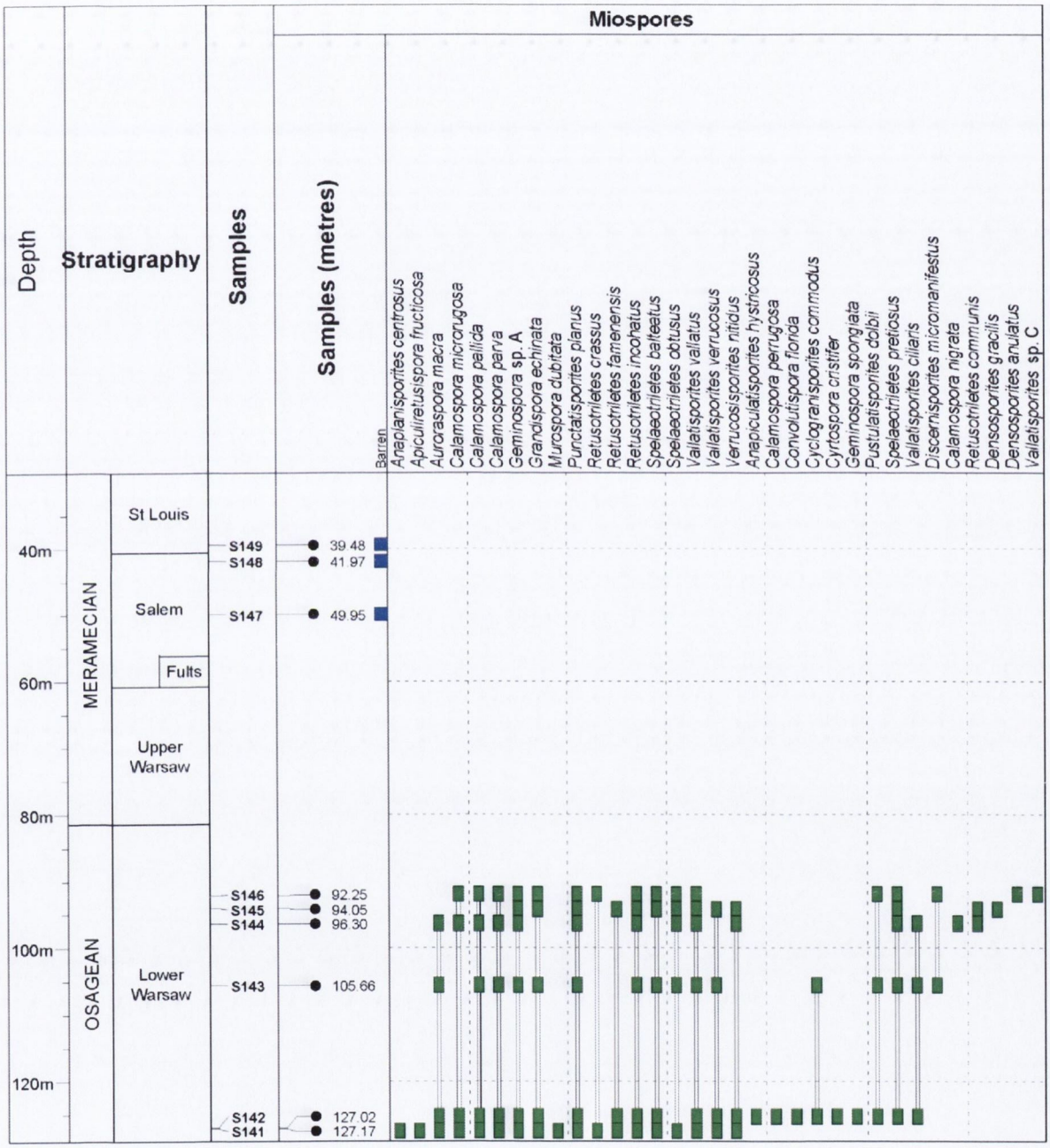


Table 7.15 - Stratigraphic ranges of taxa from core C15223, Monroe County, Illinois.

relatively low diversity. In Europe, this biozone is Early Carboniferous in age. The base is defined by the first appearance of *Spelaeotriletes balteatus*. *Vallatisporites vallatus* also appears at or near the base of the biozone and *Rugospora polyptycha* appears infrequently in the underlying HD Biozone, and becomes common in the BP. BP Biozone assemblages are typically diverse. The base of the overlying PC Biozone is marked by the first appearance of *Spelaeotriletes pretiosus*. Miospore assemblages from the overlying Keokuk, Lower Warsaw and Upper Warsaw are typical of the lower part of the European PC Miospore Biozone. In Europe the base is defined by the first appearance of *Spelaeotriletes pretiosus*. *Raistrickia clavata* and *Kraeuselisporites mitratus* also appear close to the base of the PC Biozone and the base of the overlying CM Biozone is marked by the first appearance of *Schopfites claviger*.

Assemblages representative of the European BP and PC biozones are recognised from Morehead and Vanceburg as well as from previous studies of the Borden delta in Kentucky and Indiana (Coleman & Clayton 1987; Coleman 1991; Richardson and Ausich 2004), the Marshall Sandstone and Coldwater Shale of Michigan (Richardson 2006) and the Cuyahoga and Logan Formations of northeastern Ohio (Clayton *et al.* 1998). However, in a similar situation to the Hannibal Shale (Section 7.3.1), the Burlington, Keokuk and Lower and Upper Warsaw formations are all located in the Mississippi Valley on the western edge of the Eastern Interior Basin (Sable & Dever 1990). Assemblages may be influenced by different sources of terrestrial material.

Independent biostratigraphic evidence places the North American Osagean – Meramecian boundary at the Lower – Upper Warsaw contact (Kammer *et al.* 1990). The section at Geode Glen is of particular interest as it is the type section for the Warsaw Formation. As a result it has been rigorously studied in terms of brachiopods, echinoderms and foraminifera (Kammer *et al.* 1990), as well as preliminary palynology (Leonard Eames, pers. comm. 2005), and is correlated to the early-mid Viséan Stage of Western Europe (Kammer *et al.* 1990; Menning *et al.* 2006). The placement of the Tournaisian – Viséan Boundary in the Midwest USA has also been the focus of many studies (see discussion in Chapter 2). Foraminiferal and conodont evidence places the boundary within the uppermost Burlington Limestone and place the Keokuk within the early Viséan. In Western Europe, the uppermost Tournaisian to mid Viséan comprises the Belgian Ivorian, Moliniacian and Livian substages (British Chadian, Arundian and Holkerian substages), and this interval is represented by the CM, Pu and TS miospore biozones (Clayton *et al.* 1977; Higgs *et al.*

1988), the bases of which are respectively defined by *Schopfites claviger*, *Lycospora pusilla* and *Knoxisporites stephanephorus*. *Lycospora pusilla* appears just below the base of the Viséan in Europe and is generally very abundant within many early Viséan European assemblages. *Densosporites* spp. are also a common component of Viséan assemblages in Europe. However, *Schopfites claviger*, *Lycospora pusilla*, *Knoxisporites stephanephorus* and *Densospoites* spp. are not recorded in assemblages from the Keokuk, Lower Warsaw and Upper Warsaw in the Mississippi Valley. Assemblages from the Burlington, Keokuk, Lower Warsaw and Upper Warsaw are therefore assigned to the Mississippi Valley ***Spelaeotriletes obtusus* Biozone** (Figure 7.5).

A single specimen of the typically late Viséan (Brigantian) taxa *Tripartites vetustus* is recorded from the Burlington Limestone (Table 7.10). In Europe this species commonly occurs at the base of the VF Biozone. *Tripartites vetustus* is commonly recorded from the much younger Fraileys Shale and Tar Springs Formations in the Chesterian of the Mississippi Valley, however, the appearance of a single specimen in the Burlington is not regarded as stratigraphically significant.

Previous biostratigraphic studies of the Osagean - Meramacian boundary in the Mississippi Valley have identified significant faunal change at the boundary (Kammer *et al.* 1990; Hirt 1991). However, no similar change is observed within miospore assemblages at this level. This is most likely a result of increased carbonate deposition within the early Meramecian resulting in unsuitable facies for palynological analysis. Only two samples (S91 and S92) were gained from the Upper Warsaw at Cragwold Road. Both samples are of very low diversity, poorly preserved and are interpreted as a distal palynofacies (Chapter 9) and are therefore of limited stratigraphic value. No well preserved diverse assemblages were obtained form the earliest Meramecian.

7. 3. 3 CHESTERIAN – Ste Genevieve to Cypress Formations

COMPOSITION OF ASSEMBLAGES

As previously discussed, the Chesterian of the Mississippi Valley region comprises numerous alternating clastic and limestone units, which vary in their potential for palynological analysis. Miospores are the only recorded palynomorphs. Prasinophytes and scolecodonts are not recovered from the Chesterian. Miospore assemblages vary

enormously in terms of diversity (from low to high) and level of preservation (poorly to very well-preserved).

A very low diversity assemblage is recorded at the base of the Chesterian from the Ste Genevieve Limestone. Shaley partings in the limestone yield a single productive sample (S204) which contains a very low diversity, poorly preserved miospore assemblage (Table 7.16). Only five taxa were recorded, *Apiculiretusispora fructicosa*, *Calamospora pallida*, *Calamospora parva* and *Discernisporites micromanifestus* range from the latest Devonian and early Carboniferous, and *Convolutispora* cf. *C. usitata* is first recorded here at the base of the Chesterian.

No productive samples were obtained from the Aux Vases Sandstone, the Paoli Formation, the Renault Limestone, the Yankeetown Sandstone or the Downies Bluff Limestone. A slightly higher diversity assemblage is recorded from the Cypress Sandstone than is recorded from the Ste Genevieve. Five productive samples were obtained from three cores - C13076, C141 and C13619, all from Illinois (Tables 7.17 – 7.19). Assemblages from all three cores are similar, all are of low diversity, and comprise a high proportion of taxa from the underlying biozones. Species such as *Auroraspora macra*, *Auroraspora solisorta*, *Calamospora pallida*, *Calamospora parva, Discernisporites micromanifestus*, *Punctatisporites planus* and *Verrucosisporites nitidus* are all very common in the Cypress Formation. A number of taxa have first recorded occurrences within this unit. A sample from the base of the Cypress (S207) yields common *Prolycospora rugulosa* (Butterworth & Spinner) Turnau and *Schulzospora campyloptera* together with less common *Lycospora pusilla* and *Convolutispora florida*. These taxa are also recorded from samples S133 and S203 within the upper part of the Cypress. *Auroraspora bateola* Sullivan, *Microreticulatisporites hortonensis* Playford, *Velamisporites tessellatus*, *Proprisporites laevigatus* Neves, *Schopfites claviger* and *Schulzospora rara* Kosanke are all recorded from the upper part of the Cypress Sandstone.

AGE OF THE ASSEMBLAGES

The Meramecian is dominated by large intervals of carbonate deposition. As a result, the first recorded appearances of spores within the Ste Genevieve (at the base of the Chesterian Stage) and the Cypress Formation (as the first relatively diverse Chesterian assemblage) may be much later than their true first occurrences within the Mississippi Valley.

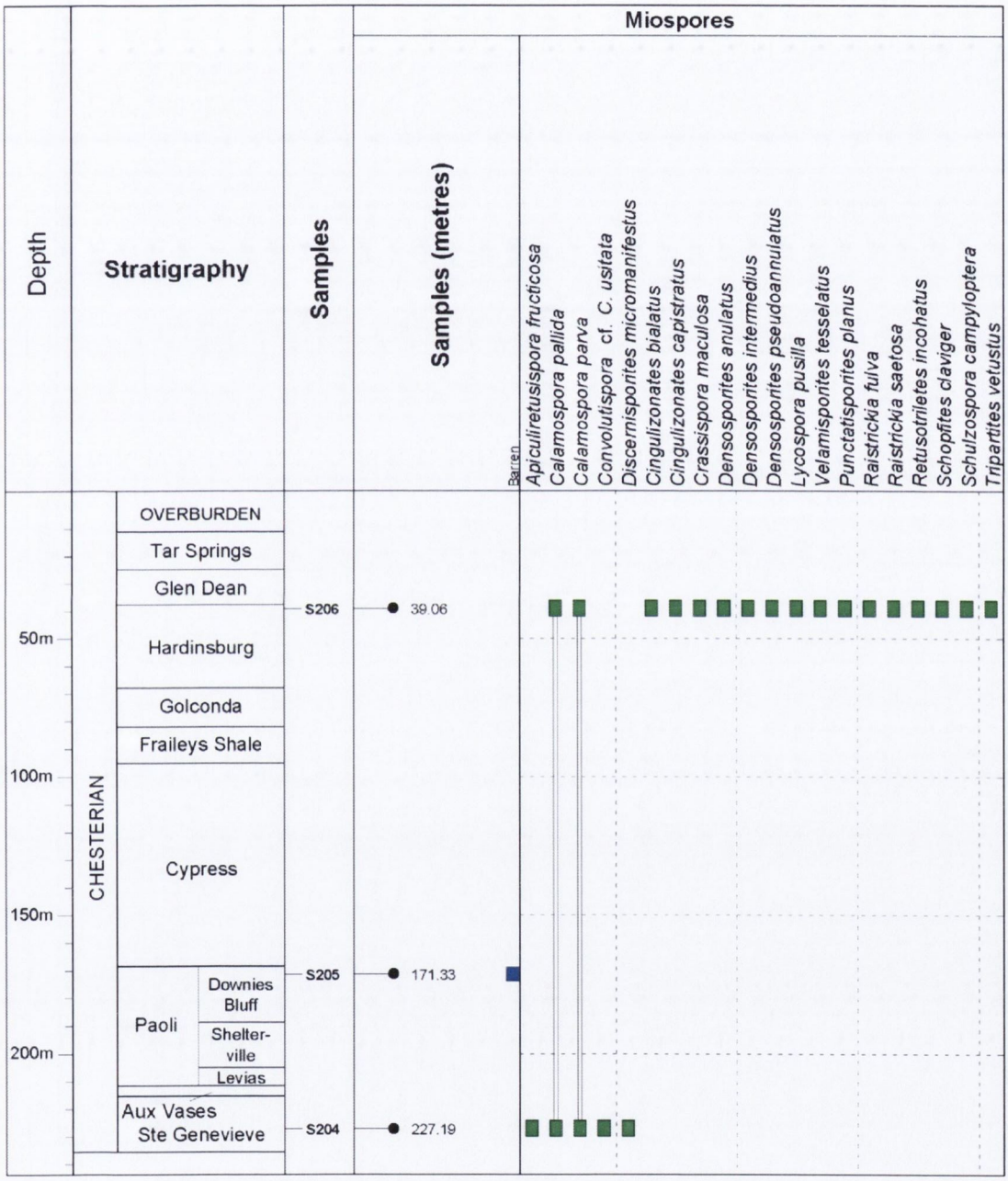


Table 7.16 - Stratigraphic ranges of taxa from core C46, Pope County, Illinois.

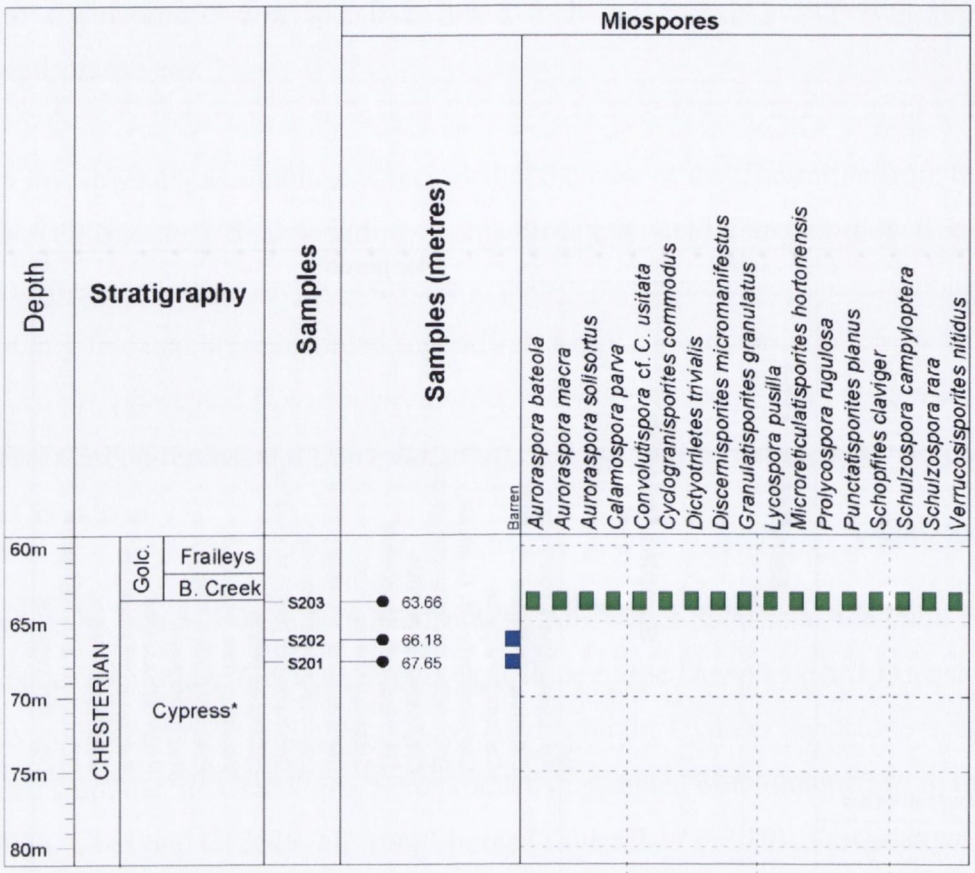


Table 7.17 - Stratigraphic ranges of taxa from core C13076, Pope County, Illinois (*in part). Abbreviations: Golc. - Golconda.

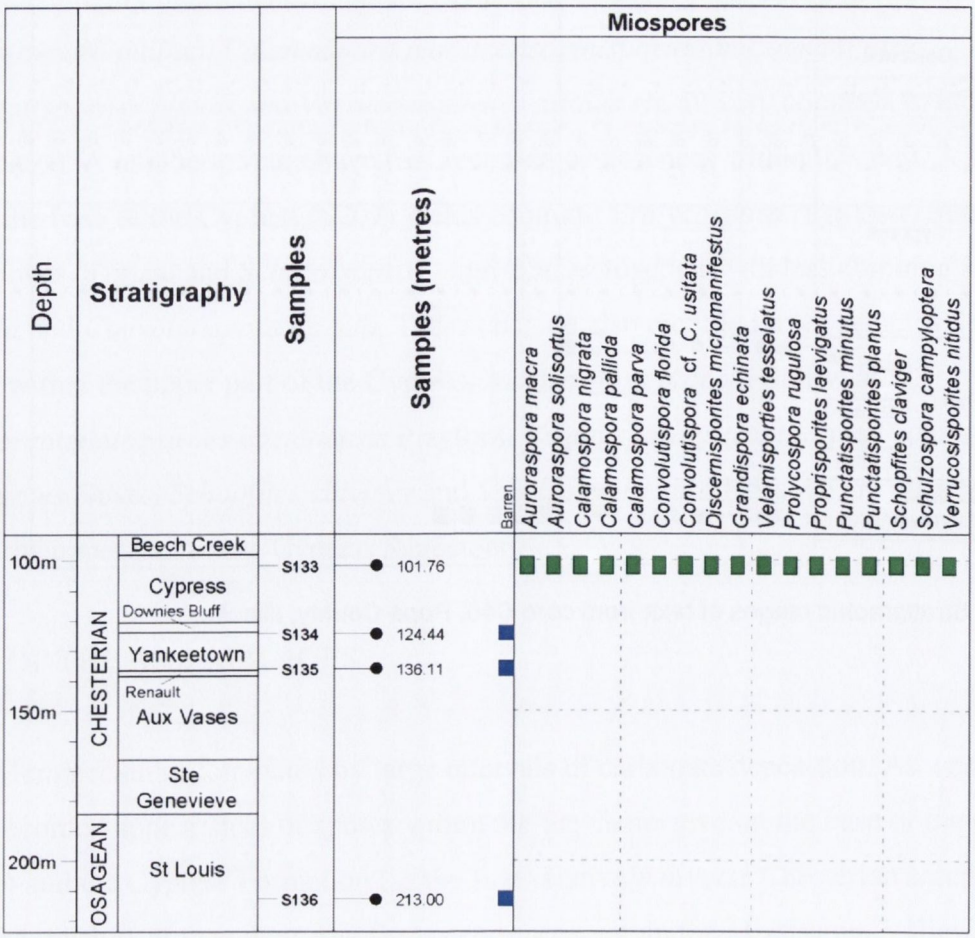


Table 7.18 - Stratigraphic ranges of taxa from core C141, Madison County, Illinois.

Table 7.19 - Stratigraphic ranges of taxa from core C13619, Union County, Illinois.

The miospore assemblage from the Ste Genevieve Limestone is dominated by taxa common in both the underlying and overlying assemblages. The very low diversity and poor preservation of the assemblage suggest it is of little stratigraphic significance. The appearance of a single new 'Chesterian' taxon suggests assignment of the Ste Genevieve to a separate biozone than the underlying strata, but more palynological data are needed to reliably assign the Ste Genevieve to a miospore biozone.

Independent conodont and foraminiferal data correlate the base of the Ste Genevieve to the British Holkerian and Belgian Livian substages in the mid Viséan Stage of Europe (Lane & Brenckle 2005; Menning *et al.* 2006). This interval is represented by the TS and TC miospore biozones (*Knoxisporites stephanephorus* and *Schulzospora campyloptera* biozones) in Western Europe (Figure 7.4) (Clayton *et al.* 1977; 2003).

Assemblages from the Cypress Formation yield European zonal taxa from the mid Viséan CM, Pu and TC miospore biozones. In Europe, the bases of these biozones are marked respectively by the first appearances of *Schopfites claviger*, *Lycospora pusilla* and *Schulzospora campyloptera*; all three taxa are recorded from the Cypress Formation. In European assemblages, *Schopfites claviger* typically does not range higher than the base of the TC Miospore Biozone and is not usually recorded from TC biozonal assemblages. However, it is recorded together with *Schulzospora* spp. from upper Viséan and Namurian strata in Canada (Neves & Belt 1970; Utting 1987). This suggests the Mississippian assemblages may have some affinity with those recorded from Canada (see Chapter 9). *Proprisporites laevigatus* is typically recognised from much younger strata in Western Europe where it has a first occurrence in the Namurian, although earlier occurrences of this species have been recorded from the Viséan of Portugal (Pereira 1999). The age ranges of stratigraphically significant Viséan taxa therefore appear to differ between Europe and the Mississippi Valley, and Mississippian assemblages show affinities with assemblages from other regions outside of Europe.

In Europe, *Lycospora pusilla* appears just below the base of the Viséan and this species is typically abundant within Viséan assemblages (Clayton *et al.* 1977; Higgs *et al.* 1988). *Densosporites* spp. are also common in Viséan assemblages from Western Europe. However, *Densosporites* spp. are not recorded from the Cypress Formation of the Mississippi Valley and although *Lycospora pusilla* is present within the Cypress Sandstone, assemblages are dominated by *Prolycospora rugulosa*. Both *Lycospora* and

Prolycospora are associated with a Lycopsid parent plant (Bek & Opluštil 2006), and *Prolycospora* commonly occurs just before *Lycospora* in most European successions (e.g. Higgs *et al.* 1988; Loboziac *et al.* 1994). *Lycospora pusilla* clearly has a much later first occurrence and is generally much less common in Mississippi Valley assemblages than those of equivalent age in Western Europe.

Conodont and foraminiferal assemblages both provide independent biostratigraphic data for the Cypress Sandstone. Chesterian conodont assemblages generally show less faunal turnover than those in the Kinderhookian, Osagean and Meramecian and as a result, the conodont zonation is of much lower resolution. Conodonts have not been recorded from the cores but independent conodont age data places the Cypress in the Upper *bilineatus* Zone (Collinson *et al.* 1971; Lane & Brenckle 2005). This zone spans the Asbian, Brigantian and lower Pendleian substages of Western Europe and encompasses the NM, VF and lowermost NC miospore biozones (Clayton *et al.* 2003; Lane & Brenckle 2005) (Figure 7.4).

Foraminiferal assemblages from the Chesterian show a much greater faunal turnover than the conodont faunas. Assemblages recently recorded from the overlying Beech Creek Limestone place the Tournaisian – Viséan boundary at the base of the Beech Creek (Kulagina *et al.* 2008). This suggests that the Cypress Sandstone is latest Viséan in age, an interval represented by the VF and NC biozones in Western Europe (Figure 7.4).

Assemblages from the Cypress Sandstone are, therefore, quite different to coeval assemblages recorded from Western Europe. In the present study the Cypress Sandstone is assigned to the ***Prolycospora rugulosa* Biozone** (Figure 7.5).

7. 3. 4 CHESTERIAN – Fraileys Shale

COMPOSITION OF ASSEMBLAGES

A single productive sample (S208) is obtained from the Fraileys Shale in core C13619, Illinois. The Beech Creek Limestone, which underlies the Fraileys Shale, is unsuitable for palynological analysis. The miospore assemblage recorded from the Fraileys is fairly diverse and very well preserved (Table 7.19). Common taxa ranging from the underlying *Prolycospora rugulosa* Biozone include *Auroraspora macra*, *Calamospora nigrata*

(Naumova) Allen, *Convolutispora* cf. *C. usitata*, *Discernisporites micromanifestus*, *Prolycospora rugulosa*, *Schopfites claviger* and *Schulzospora campyloptera*, together with *Densosporites intermedius*, *Grandispora echinata* and *Radiizonates mirablis*. New taxa appearing in the Fraileys Shale include *Cingulizonates* cf. *C. capistratus*, *Crassispora aculeata* Neville, *Grandispora spinosa*, *Tripartites vetustus* and *Triquitrites marginatus*.

AGE OF ASSEMBLAGES

The miospore assemblage from the Fraileys Shale yields several taxa representative of the European VF and NC biozones of latest Viséan age. In Europe the base of the VF Miospore Biozone is marked by the first occurrence of *Tripartites vetustus* together with a large group of species including *Crassispora maculosa* and *Grandispora spinosa*. The base of the overlying European NC Miospore Biozone is marked by the first appearance of *Cingulizonates* cf. *C. capistratus* as well as *Bellispores nitidus*, and comprises many of the taxa from the underlying VF Biozone, e.g. *Raistrickia nigra*, *Tripartites vetustus*, *Crassispora maculosa*, *Grandispora spinosa*, *Spelaeotriletes arenaceus* and *Kraeuselisporites echinatus*.

Independent conodont data again places the Fraileys Shale within the long-ranging Upper *bilineatus* Zone (Lane & Brenckle 2005). As discussed in Section 7.3.3 this correlates with a relatively long interval from the late Viséan to early Namurian of Western Europe. Foraminiferal assemblages from the underlying Beech Creek Limestone are identified as earliest Serpukhovian/Namurian and suggest correlation of the Fraileys Shale with the NC Biozone of Western Europe (Kulagina *et al.* 2008).

Therefore, the miospore assemblage from the Fraileys Shale appears to share several common taxa with that of the coeval European NC Miospore Biozone, and the first appearance of the zonal taxa *Cingulizonates* cf. *C. capistratus* is recorded from a similar level in the Mississippi Valley. In the present study this assemblage is assigned to the ***Crassispora aculeata* Biozone** equivalent to the European NC Biozone (Figure 7.5).

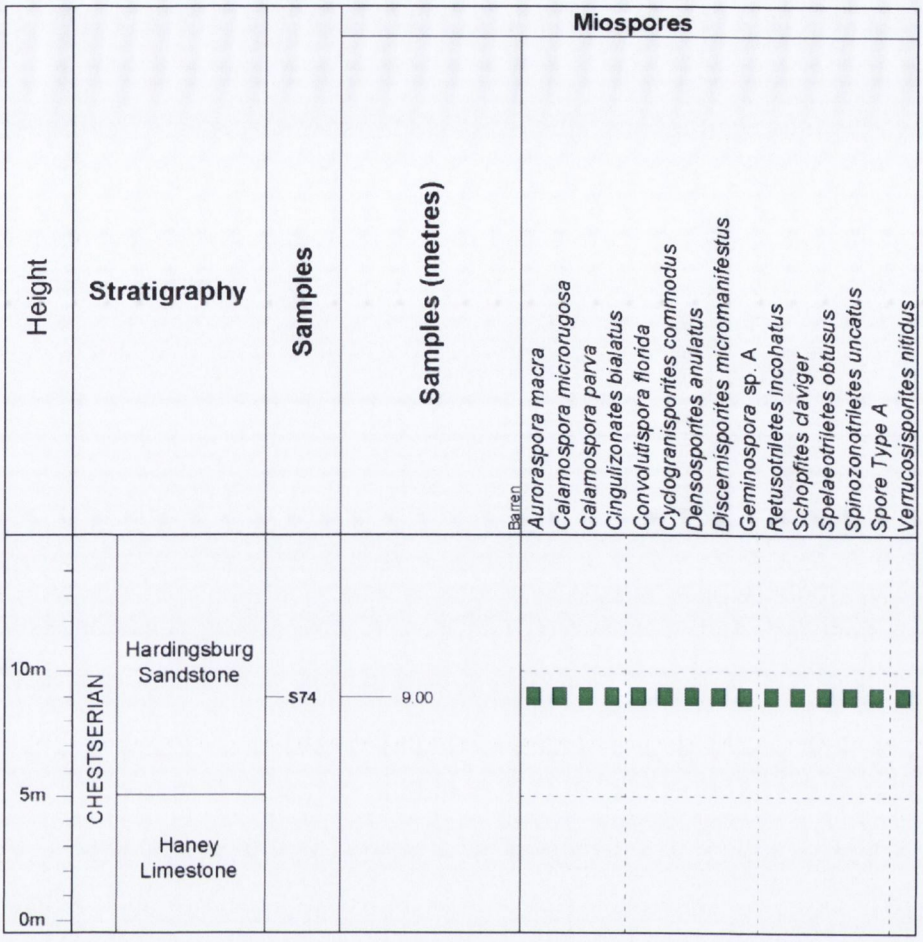


Table 7.20 - Stratigraphic ranges of taxa from the Old Randolph Stone Company Quarry section, Johnson County, Illinois.

7. 3. 5 CHESTERIAN – Hardinsburg Sandstone

COMPOSITION OF ASSEMBLAGES

Two samples are obtained from the Hardinsburg Sandstone, the composition of each is shown in tables 7.20 and 7.16. The first (S74), from the Old Randolph Stone Company Quarry, Illinois is of low diversity and comprises poorly preserved spores. The second (S206) is from the uppermost Hardinsburg from core C46, Illinois and comprises a well preserved, although still fairly low diversity assemblage.

Common miospores from the Hardinsburg Sandstone include long-ranging *Auroraspora macra*, *Calamospora parva*, *Calamospora pallida*, *Discernisporites micromanifestus*, *Retusotriletes incohatus* and *Verrucosisporites nitidus*. These taxa dominate sample S74. A single taxon, *Cingulizonates bialatus* (Waltz) Smith & Butterworth, has its first appearance

in this assemblage. *Densosporites anulatus*, *Densosporites intermedius* and *Schulzospora campyloptera* are common in the assemblage from the top of the Hardinsburg (S206). Other less common taxa recorded in this assemblage include *Convolutispora* cf. *C. usitata*, *Convolutispora florida*, *Lycospora pusilla*, *Velamisporites tessellatus*, *Schopfites claviger*, *Spelaeotriletes obtusus*, *Spinozonotriletes uncatus* and *Tripartites vetustus*. *Cingulizonates bialatus*, *Cingulizonates capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jansonius, *Crassispora maculosa*, *Raistrickia fulva* Artüz and *Raistrickia saetosa* (Loose) Schopf, Wilson & Bentall appear within the top of the Hardinsburg Sandstone.

AGE OF ASSEMBLAGES

The miospore assemblage recorded from sample S74 within the Hardinsburg Sandstone is dominated by relatively long ranging taxa commonly occurring throughout the Tournaisian and Viséan of Western Europe. Apart from the appearance of *Cingulizonates bialatus*, the assemblage is of little stratigraphic significance. The assemblage recorded from sample S206 comprises a greater proportion of taxa commonly occurring in younger strata and taxa ranging from the *Crassispora aculeata* Biozone of the underlying Fraileys Shale. The occurrence of *Tripartites vetustus* marks the base of the *Crassispora aculeata* Biozone in the Mississippi Valley and the base of the VF Biozone in Western Europe. The miospore assemblage from sample S206 is dominated by species of the genera *Cingulizonates* and *Densoporites,* and several species – *Cingulizonates bialatus*, *Cinglizonates capistratus* and *Densosporites pseudoannulatus* – have their first appearances in the Hardinsburg Sandstone. This suggests this assemblage should be assigned to a separate miospore biozone than that of the underlying Fraileys Shale.

The Hardinsburg Sandstone and adjacent units, yield very similar conodont and foraminiferal faunas to those of the Fraileys Shale (Kulagina *et al.* 2008). Independent conodont age data places the Hardinsburg in the same zone (Upper *bilineatus*) as the Fraileys Shale and Cypress Sandstone (Lane & Brenckle 2005). Again, this zone correlates to a relatively long interval within the Chesterian and is correlated with the late Viséan and early Namurian of Western Europe. Kulagina *et al.* (2008) correlate foraminiferal assemblages from the underlying Haney and overlying Glen Dean Limestones with the early Serpukhovian/Namurian of the Russian Platform and Europe. This suggest the Hardinsburg Sandstone can be correlated to the Pendleian Substage of Western Europe, which spans the European NC Biozone.

In the present study, the Hardinsburg Sandstone is assigned to the ***Cingulizonates bialatus* Biozone** (Figure 7.5).

A diverse assemblage was previously recovered from the Hardinsburg Sandstone of Illinois and Kentucky by Hoffmeister *et al.* (1955). Many of the miospores identified in sample S206 are also recorded from this assemblage. A few of the spores in the present study resemble specimens illustrated and described by Hoffmeister *et al.* (1955) and possible synomony is suggested (Chapter 9). However, no revision of this material has been published and the original specimens are unavailable for re-examination.

7. 3. 6 CHESTERIAN – Tar Springs Sandstone, Waltersburg Formation, Menard Limestone and Palestine Sandstone

COMPOSITION OF ASSEMBLAGES

Four samples from the Tar Springs Sandstone yield relatively diverse and well-preserved assemblages. Two samples (S209 and S210) are from core C13619, Illinois and two samples (S75 and S78) are from an exposure of the Tar Springs at Coles Mill, Illinois. The qualitative compositions of the assemblages are summarised in Tables 7.19 and 7.21. The composition of these miospore assemblages is similar in all four samples. Long-ranging early Mississippian taxa such as *Calamospora parva*, *Calamospora pallida*, *Grandispora echinata* and *Punctatisporites planus* are present within assemblages but are much less common than in the underlying units (e.g. Cypress Sandstone and Hardinsburg Sandstone). Assemblages from the Tar Springs Sandstone are dominated by *Densosporites anulatus*, *Densosporites intermedius*, *Densosporites spinifer* Hoffmeister, Staplin & Malloy, *Lycospora pusilla* and *Schulzospora campyloptera*. *Lycospora pusilla* is abundant within assemblages. *Cingulizonates capistratus*, *Cingulizonates* cf. *C. capistratus*, *Convolutispora florida*, *Crassispora maculosa*, *Schopfites claviger*, *Tripartites vetustus* and *Triquitrites marginatus* are also all relatively common. Taxa appearing within the Tar Springs Sandstone include *Colatisporites decorus*, *Densosporites* cf. *D. crassigranifer* and *Tricidarisporites* cf. *T. arcuatus* Neville.

The overlying Vienna Limestone was not suitable for palynological analysis, but samples from the proceeding Waltersburg Sandstone (S88, Grantsburg Northeast Railroad), Menard

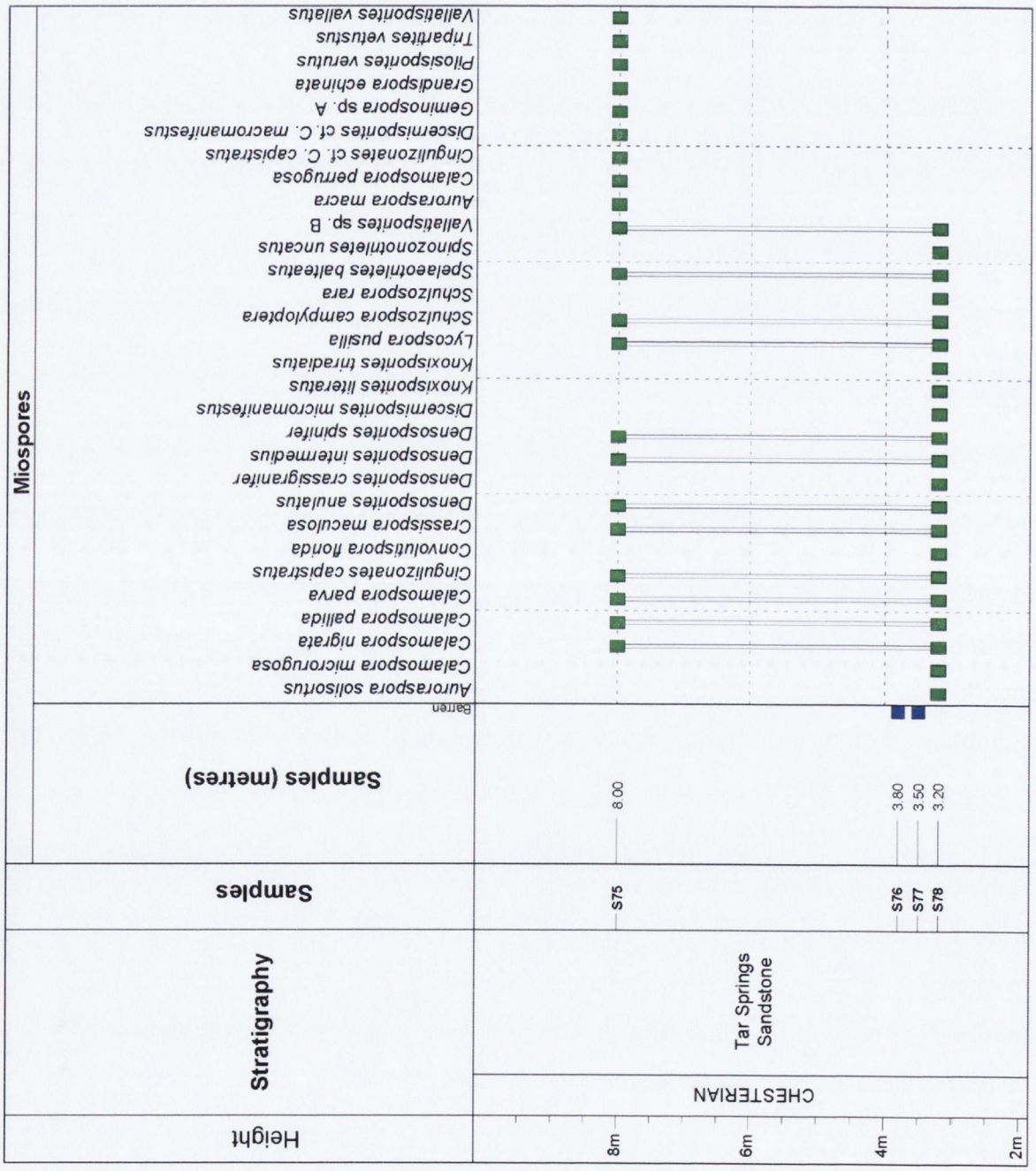


Table 7.21 - Stratigraphic ranges of taxa from the Coles Mill section, Chester, Randolph County, Illinois.

Limestone and Palestine Sandstone (S82, S83, S86 and S87, Flatwoods-Kerley Railroad) all yield assemblages with a similar miospore composition to those recorded from the Tar Springs Sandstone. Assemblages from these outcrops are shown in tables 7.22-7.23. Diversity within the assemblage from the Waltersburg is relatively low, and increases throughout the Menard and Palestine. Common taxa recorded from the railroad sections include *Aurospora solisorta*, *Calamospora* spp., *Cingulizonates bialatus*, *Cingulizonates capistratus*, *Crassispora maculosa*, *Densosporites* spp., *Discernisporites micromanifestus*, *Lycospora pusilla*, *Prolycospora rugulosa* and *Schulzospora campyloptera*.

AGE OF ASSEMBLAGES

Assemblages from the Tar Springs Sandstone, Waltersburg Formation, Menard Limestone and Palestine Sandstone are dominated by typical European early to mid Viséan taxa, e.g. D*ensosporites* spp., *Lycospora pusilla* and *Schulzospora* spp. *Lycospora pusilla* is very abundant in the Tar Springs, resembling levels of abundance typically recorded throughout European Viséan assemblages. Assemblages also yield taxa common in the upper Viséan and Namurian such as *Cingulizonates* spp., *Crassispora maculosa*, *Tripartites vetustus* and *Triquitrites marginatus*. In Europe, these taxa are typical of the early Namurian NC Miospore Biozone. The base of the overlying TK Biozone is marked by the first appearances of *Mooreisporites trigallerus* as well as *Stenozonotriletes triangulus*.

Independant conodont data from the Vienna Limestone places the underlying Tar Springs and overlying Waltersburg within the Upper *bilineatus* Zone. A change in conodont faunas is recognised in assemblages from the Menard Limestone and places the Menard and Palestine Sandstone within the *naviculus* Zone. This fauna is correlated with the Pendleian and lower part of the Arnsbergian of Europe (Lane & Brenckle 2005) (Figure 7.4).

Foraminiferal assemblages from the Vienna Limestone and Menard Limestone are correlated with the middle and upper parts of the Serpukhovian of the Donets Basin respectively (Kulagina *et al.* 2008). This suggests correlation of the Vienna Limestone to the upper Pendleian and lower Arsnbergian substages of Western Europe, spanning the upper part of the NC and lower part of the TK biozones. The Menard can be correlated with the Arnsbergian Substage spanning the upper TK to the basal SO miospore biozones (Figure 7.4).

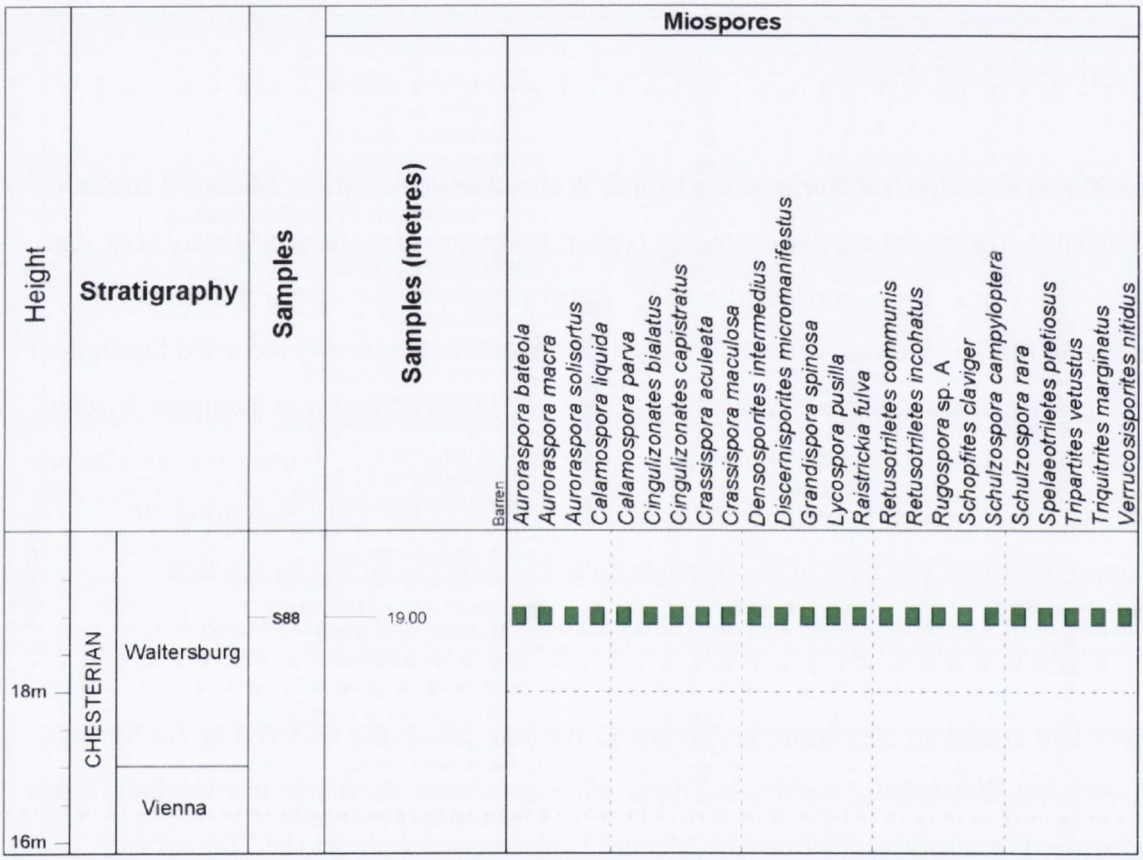


Table 7.22 - Stratigraphic ranges of taxa from Grantsburg Northeast Railroad cut, Johnson County, Illinois.

Table 7.23 - Stratigraphic ranges of taxa from Flatwoods-Kerley Cemetery Railroad cut, Johnson County, Illinois.

Although typical European NC Biozonal taxa are recorded within coeval assemblages from the Mississippi Valley, typical TK biozonal taxa are not recorded. In the present study, assemblages from the Tar Springs to Palestine Sandstone are assigned to the ***Crassispora maculosa* Biozone** (Figure 7.5). The base of this biozone is marked by the first appearance of *Colatisporites decorus* together with abundant *Crassispora maculosa*.

7. 3. 7 CHESTERIAN – Kinkaid Limestone

COMPOSITION OF ASSEMBLAGES

Miospore assemblages from the Kinkaid Limestone are the youngest obtained from the Mississippi Valley in the present study. Three productive samples are recovered from the Cave Hill Shale Member in the middle part of the Kinkaid Limestone – Sample S79 from an outcrop at the Southern Illinois Stone Company Quarry, and samples S198 and S199 from Illinois core C4883. All three samples contain well-preserved and relatively diverse miospore assemblages compared with the underlying Menard Limestone and Palestine Sandstone (Tables 7.24 and 7.25).

Assemblages recorded from C4883 comprise taxa commonly recorded from the underlying *Tripartites vetustus*, *Cingulizonates bialatus* and *Crassispora maculosa* biozones, as well as some long-range Tournaisian species. Common taxa include *Auroraspora macra*, *Auroraspora solisorta*, *Calamospora* spp., *Cingulizonates bialatus*, *Crassispora maculosa*, *Densosporites* spp. *Lycospora pusilla*, *Schopfites claviger* and *Schulzospora campyloptera*, together with less common *Prolycospora rugulosa*, *Retusotriletes incohatus*, *Tripartites vetustus* and *Verrucosisporites nitidus*. The first appearances of *Cirratriradites annuliformis* Kosanke & Brokaw and *Spencerisporites radiatus* are recorded from S79.

Although this study focuses on the Mississippian units of the Mississippi Valley region, two productive samples were taken from the Pennsylvanian Caseyville Formation, where it unconformably overlies the Kinkaid Limestone at the Southern Illinois Stone Company Quarry locality. Preliminary analysis of these samples has identified a diverse, well preserved assemblage dominated by typical Late Mississippian and earliest Pennsylvanian taxa, including *Cirratriradites annuliformis*, *Knoxisporites stephanephorus*, *Stenozonotriletes triangularis* and *Crassispora kosankei* (Table 7.24).

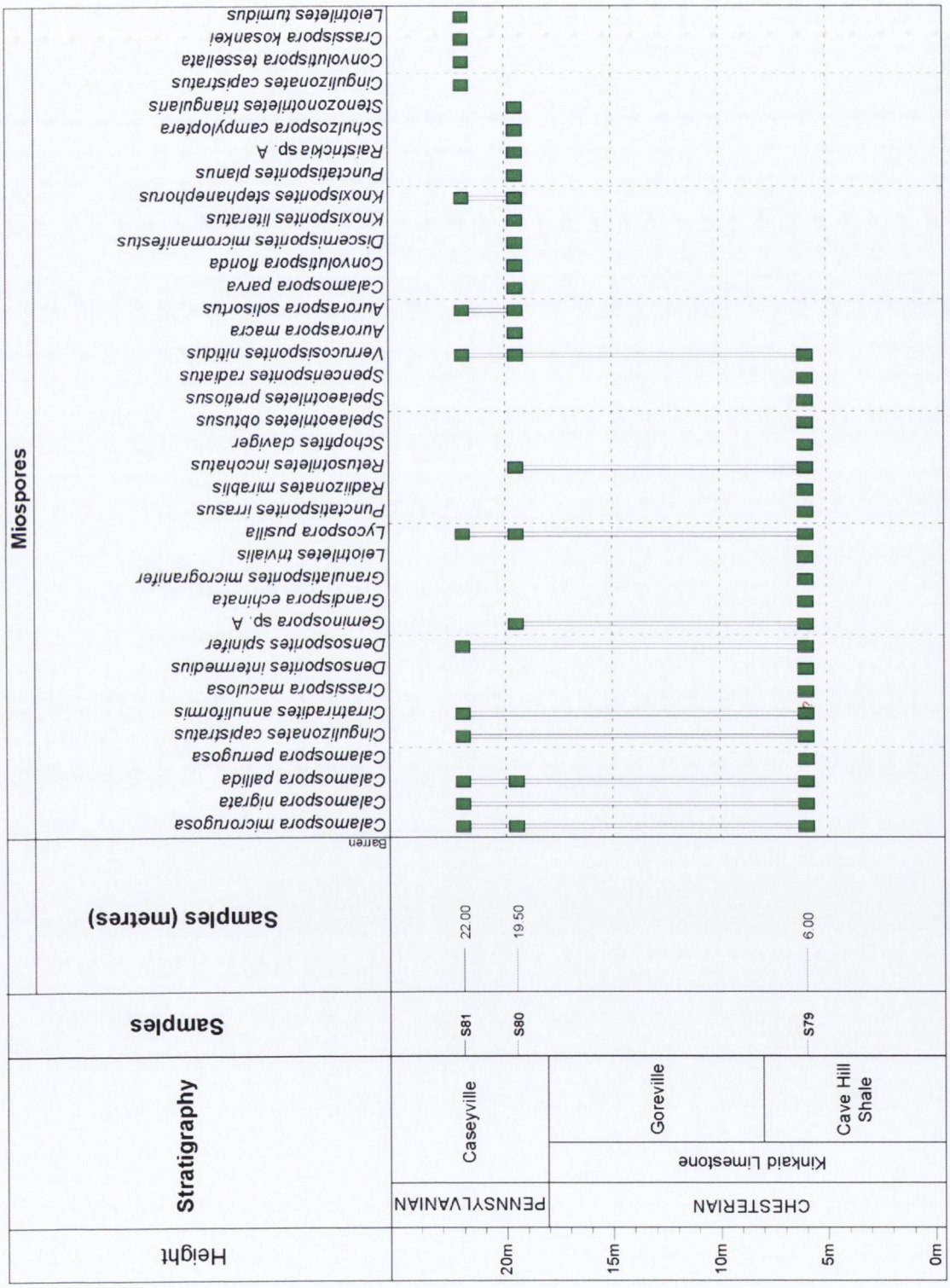


Table 7.24 - Stratigraphic ranges of taxa from the Southern Illinois Stone Company Quarry section, Johnson County, Illinois.

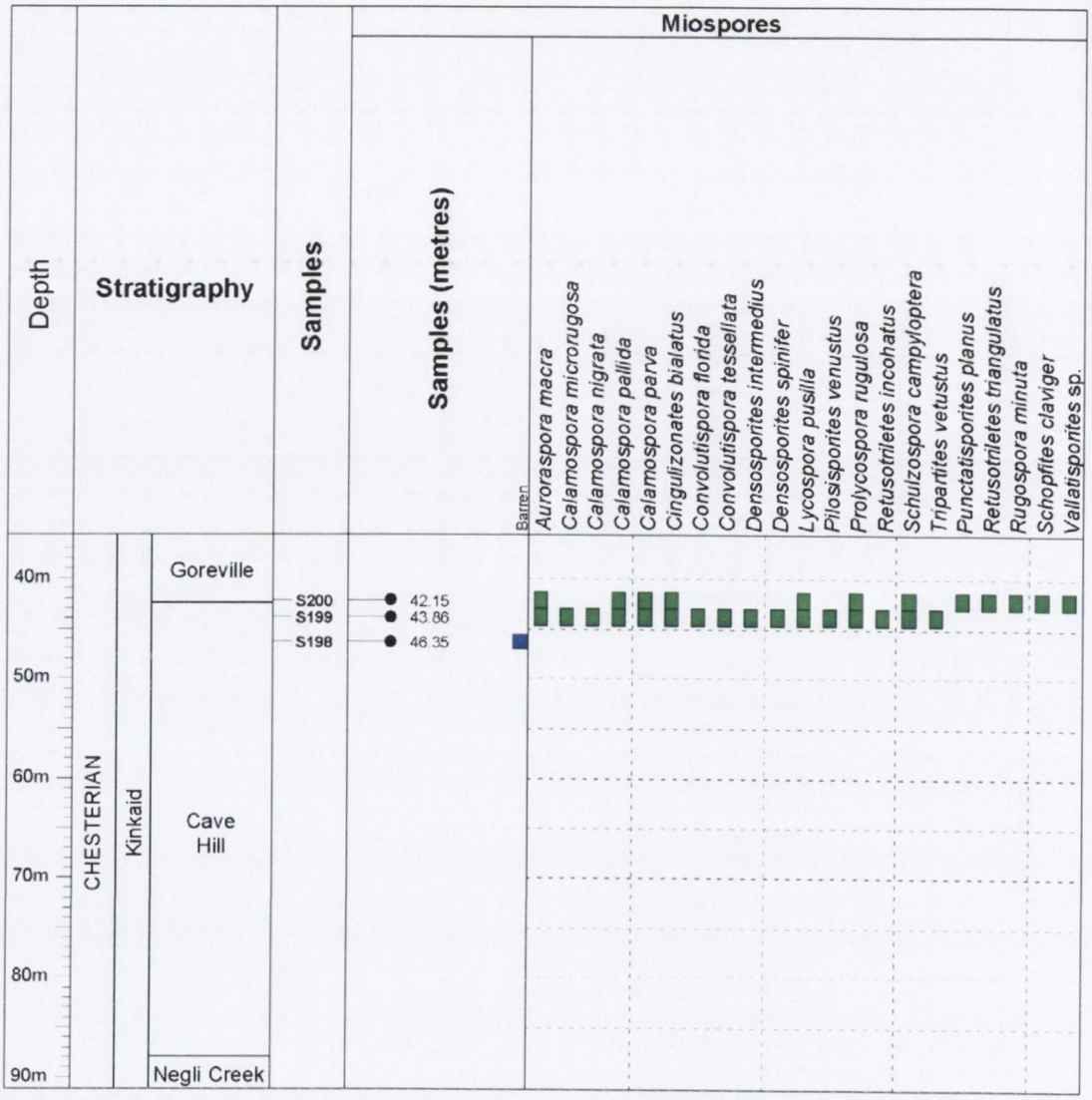


Table 7.25 - Stratigraphic ranges of taxa from core C4883, Gallatin County, Illinois.

AGE OF ASSEMBLAGES

Miospore assemblages recorded from the Kinkaid Limestone comprise a number of taxa typically recorded from the mid-upper Viséan Stage of Western Europe. These include *Cingulizonates bialatus*, *Lycospora pusilla*, *Schulzospora campyloptera* and *Tripartites vetustus*. This assemblage is typical of the Western European VF Biozone. The Namurian of Western Europe is characterised by a suite of taxa including *Bellispores nitidus*, *Cingulizonates* cf. *C. capistratus*, *Mooreisporites trigallerus*, *Stenozonotriletes triangulus* and *Verrucosisporites morulatus*. However, none of these taxa are recorded from equivalent age strata within the Mississippi Valley. *Schopfites claviger* is recorded from the Cave Hill Shale Member. In Europe, this species typically does not range above the base of the mid Viséan TC Biozone. However, *Schopfites claviger* has been recorded from younger Namurian strata in Canada by Utting (e.g. Utting 1987).

Triquitrites marginatus, *Triquitrites trivalvis* and *Tripartites vetustus* disappear just below the top of the Mississippian at the base of the SO Biozone in Europe (Clayton *et al.*1977). *Tripartites vetustus* is recorded from sample S199 in the upper part of the Cave Hill Shale Member but is not recorded from the top of this member or from the overlying Pennsylvanian. In Western Europe, the ranges of *Crassispora maculosa* and *Schulzospora campyloptera* extend to the mid SO Biozone. *Crassispora maculosa* is present within the Cave Hill Shale Member, but is not recorded from the top of the Cave Hill Shale, and rare specimens of *Schulzospora campyloptera* are recorded from both the Cave Hill Shale and the overlying Pennsylvanian.

Independent age data from both conodonts and foraminifera place the Kinkaid Limestone within the upper Serpukhovian. Conodont faunas from the Kinkaid place it within the *naviculus* Zone, similar to the Menard Limestone and Palestine Sandstone (Lane & Brenckle 2005). Foraminiferal assemblages suggest the Kinkaid Limestone correlates to the uppermost Serpukhovian of the Russian Platform and Donets Basin (Brenckle *et al.* 2005; Kulagina *et al.* 2008).

Assemblages from the Cave Hill Shale Member of the Kinkaid Limestone are assigned to the ***Cirratriradites annuliformis* Biozone**. This is the youngest biozone recognised from miospore assemblages within the Mississippian of the Mississippi Valley.

CHAPTER 8
CORRELATION

8. 1 INTRODUCTION

The present day positions of the areas referred to in this chapter are shown in Figure 8.1. The palaeogeographic locations are shown in Figure 8.2.

8. 2 CORRELATION OF ASSEMBLAGES FROM KENTUCKY AND THE MISSISSIPPI VALLEY

Miospore assemblages have been obtained and analysed from the Kinderhookian and lower part of the Osagean stages of Kentucky and the Mississippi Valley. Comparisons of the miospore biozonations between these two areas are illustrated in Figure 8.3. As previously mentioned, the depositional environment of the Kentucky strata was more suitable for preservation of organic material than that of the Mississippi Valley. Productive samples have been obtained from coeval assemblages in both areas. However, productive strata from the Mississippi Valley are less extensive than in Kentucky.

Assemblages from the Hannibal Shale in the Mississippi Valley are assigned to the *Cyclogranisporites commodus* Biozone. This biozone spans the lower-mid part of the Kinderhookian. *Cyclogranisporites commodus* Biozone assemblages comprise similar taxa to the European VI Biozone assemblages recognised from the Sunbury Shale of Kentucky. Independent age data show the top of the *Cyclogranisporites commodus* Biozone is younger than the top of the VI Biozone and can be correlated with the European VI, HD and lower part of the BP Biozone (Higgs *et al.* 1992). These biozones are recognised from the Sunbury Shale and lower part of the Henley Bed (Borden Formation) of Morehead and the Sunbury Shale, Jacobs Chapel, Rockford Limestone and Henley Bed (Cuyahoga Formation) of Vanceburg. Therefore, spore assemblages are shown to be very different in Kentucky and the Mississippi Valley and correlations between these two areas are tentative.

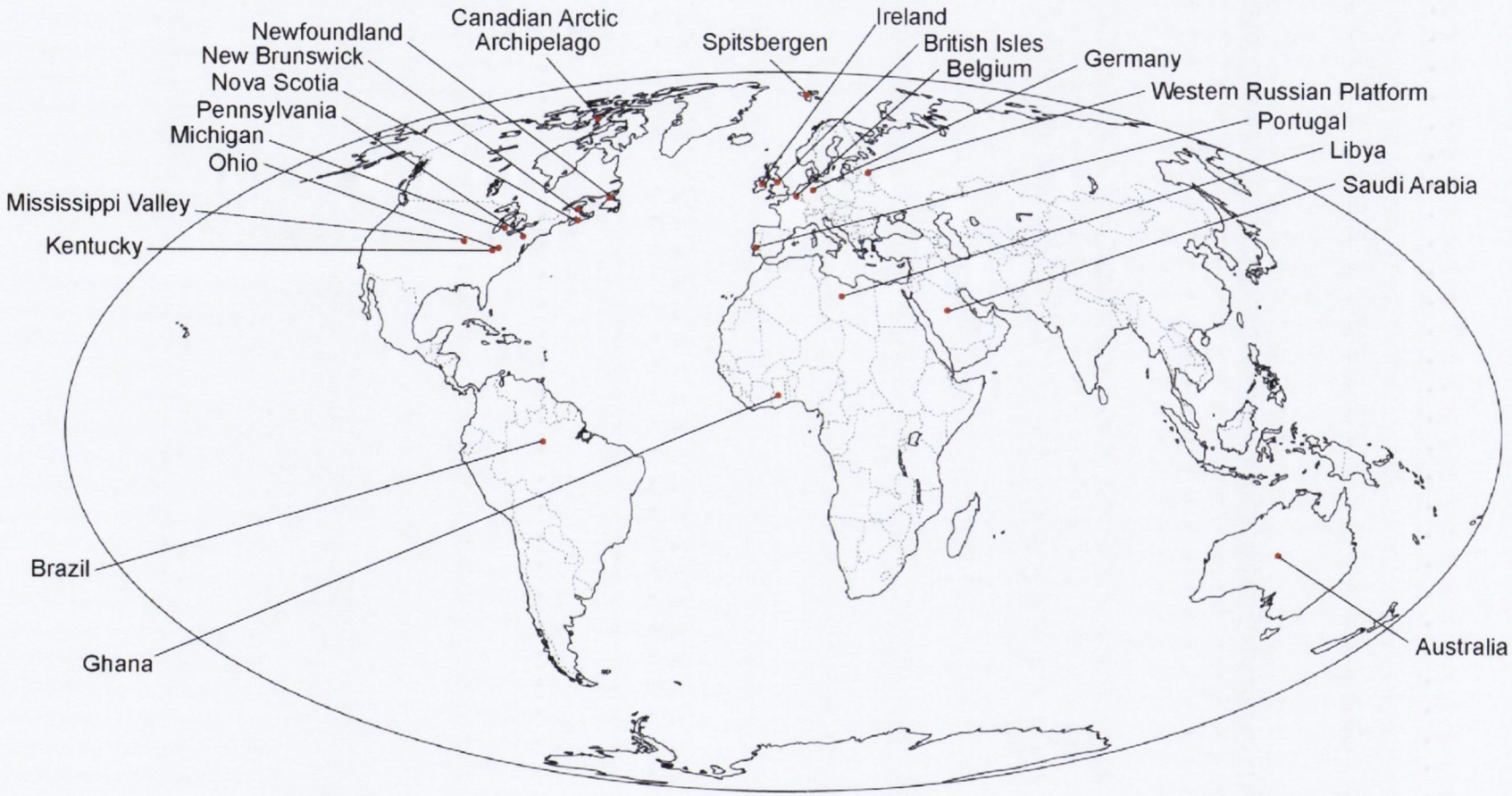


Figure 8.1 Present day positions of localities referred to in this chapter.

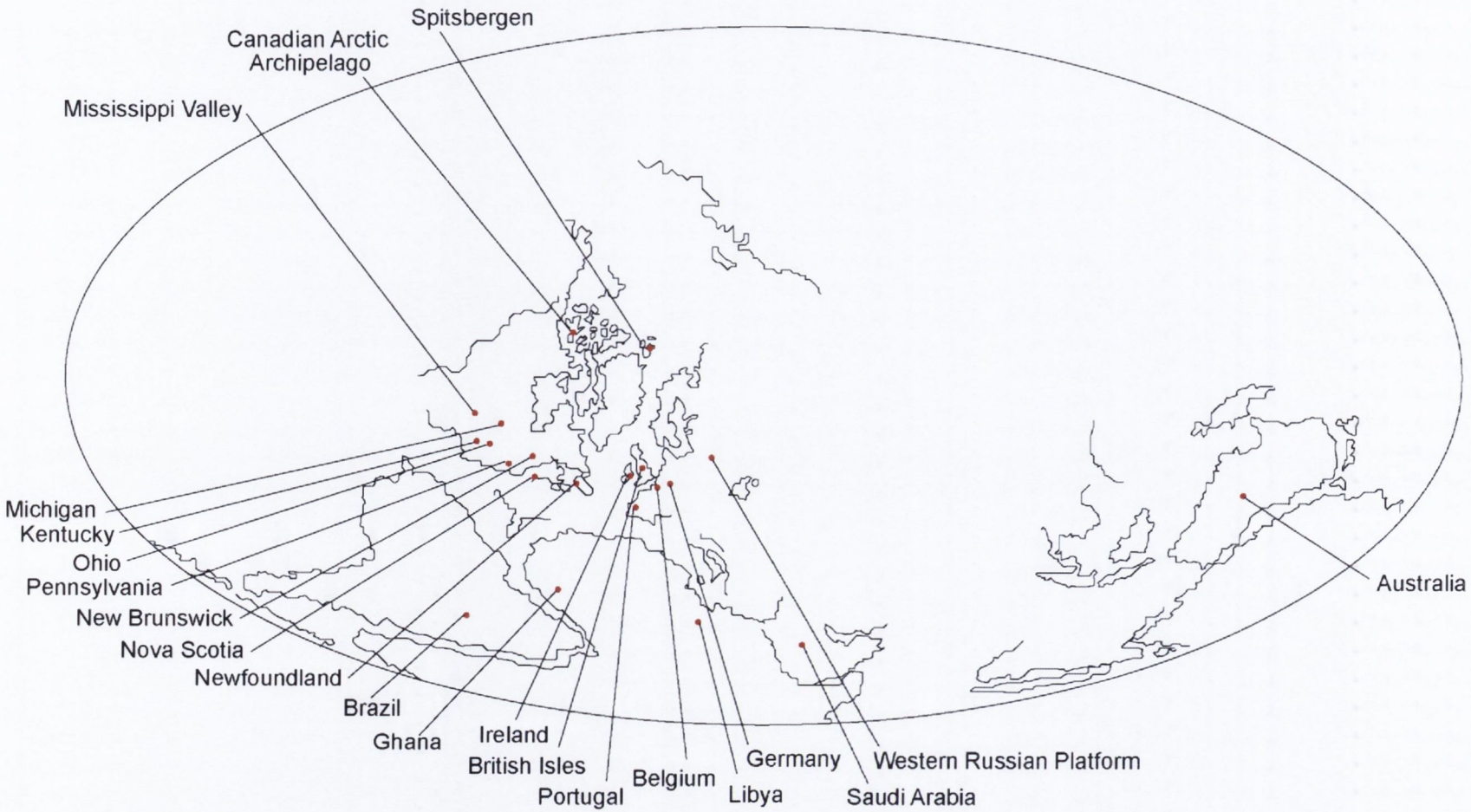


Figure 8.2 Positions of localities in the Early Mississippian referred to in this chapter. Base map after Clayton (1985).

8. 3 PREVIOUSLY DESCRIBED MIOSPORE ASSEMBLAGES FROM KENTUCKY AND THE MISSISSIPPI VALLEY

8. 3. 1 Coleman & Clayton 1987

Coleman studied the Morehead section from Kentucky as part of her PhD thesis (1991) and Coleman & Clayton (1987) published assemblages from it. Both of these studies are referred to throughout the present work, and comparisons with Coleman's assemblages have been made in Chapter 7. A summary of these comparisons is given below and shown in Figure 8.4.

Bedford Shale

Coleman & Clayton (1987) recorded a diverse assemblage from the Bedford Shale comprising common *Retispora lepidophyta*, together with *Rugospora flexuosa*, *Vallatisporites pusilites*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus*. These taxa are all recorded from the present study of the Bedford Shale. A very similar assemblage is also recorded from the underlying Cleveland Member of the Ohio Shale. Assemblages from the study of Coleman & Clayton (1987) and the present study are assigned to the Western European VI Miospore Biozone.

Sunbury Shale

Assemblages recorded from the present study of the Sunbury closely resemble those described by Coleman & Clayton (1987). Assemblages are of low diversity and are dominated by acamerate, laevigate spores. Taxa common to both of these studies include *Auroraspora* spp., *Punctatisporites planus*, *Retusotriletes communis*, *Retusotriletes incohatus*, *Retusotriletes famenensis*, *Vallatisporites verrucosus* and *Verrucosisporites nitidus*. Coleman also recorded common *Cyrtospora cristifera*. In the present study, this species is not recorded from the Sunbury Shale, but it is recorded from the Jacobs Chapel and Rockford Limestone which overlie the Sunbury Shale at Vanceburg. Coleman & Clayton's (1987) Sunbury Shale assemblages and assemblages from the Sunbury, Jacobs Chapel and Rockford Limestone within the present study share many common taxa with the VI Miospore Biozone of Europe. Both studies recorded the presence of *Retispora lepidophyta* within the Sunbury Shale, just above the base of the Carboniferous. However,

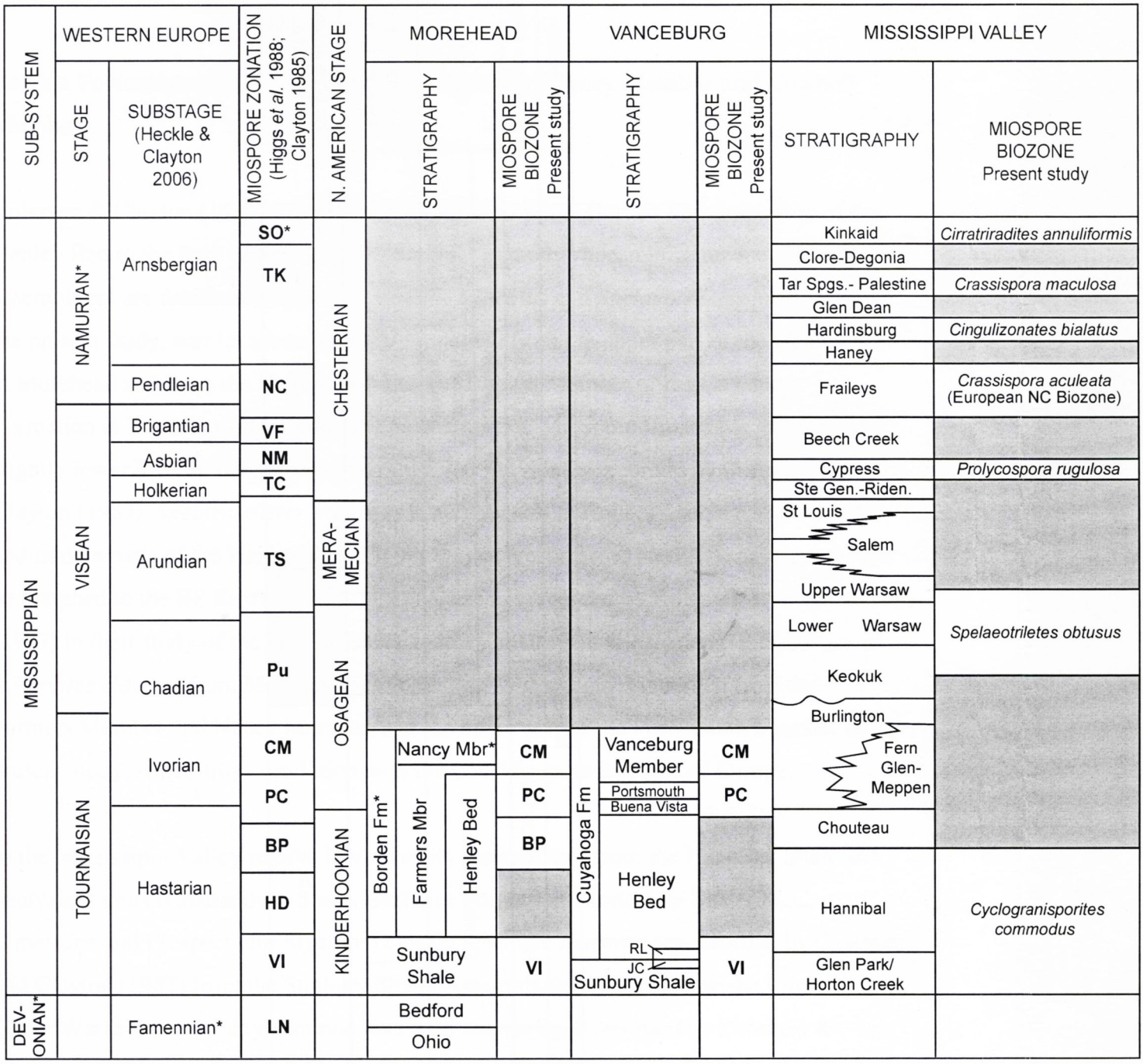


Figure 8.3 The miospore zonal scheme of Western Europe and comparisons with Kentucky and the Mississippi Valley (*in part). Stratigraphic units not to scale. Abbreviations are as follows - Fm - formation, Mbr - member, JC - Jacobs Chapel, RL - Rockford Limestone, Ste Gen. - Ste Genevieve, Riden. - Ridenhower, Tar Spgs. - Tar Springs.

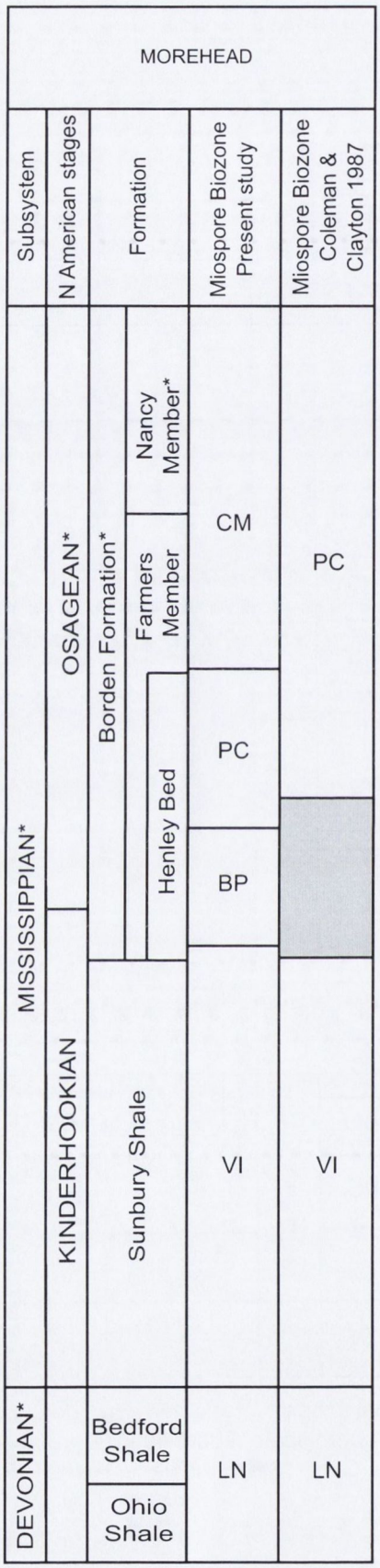


Figure 8.4 The miospore zonal scheme of Morehead, Kentucky (*in part). Stratigraphic units not to scale.

occurrences of *Retispora lepidophyta* in the earliest Carboniferous are very sporadic (compared with abundant/dominant *Retispora lepidophyta* in latest Devonian assemblages), and in both cases its presence is interpreted as a result of reworking.

Borden Formation - Henley Bed, Farmers Member, Nancy Member and Cowbell Member

Coleman & Clayton (1987) assigned assemblages from the Borden Formation (top of the Henley Bed to the base of the Cowbell Member) to the European PC Biozone. These assemblages are dominated by *Spelaeotriletes balteatus* and *Spelaeotriletes pretiosus*. In the present study, similar assemblages are recorded from the upper part of the Henley Bed at Morehead and from the Henley Bed and Portsmouth Member of the Cuyahoga Formation at Vanceburg. However, the base of the PC Miospore Biozone is recorded at a slightly lower level in the present study than was previously recorded by Coleman & Clayton (1987). *Spelaeotriletes pretiosus* is notably absent from assemblages in the lower and middle parts of the Henley Bed (Figure 6.1) suggesting that these assemblages should be assigned to the BP Biozone. This biozone was not recorded by Coleman & Clayton (1987) in their study of the Henley Bed. Coleman & Clayton (1987) noted the absence of *Schopfites claviger* from Morehead assemblages. This species is recorded from the Farmers Member and Nancy Member, and the upper part of the Portsmouth Member in the present study, suggesting correlation with the CM Miospore Biozone of Europe.

In the Mississippi Valley region, low diversity assemblages from the Hannibal Shale and equivalent units (Chattanooga Shale, Bachelor Formation, Northview Shale, McCraney Limestone and Prospect Hill Siltstone) closely resemble assemblages recorded by Coleman and Clayton (1987) from the Sunbury Shale. Assemblages recorded from the Lower and Upper Warsaw share many common taxa with assemblages recorded by Coleman & Clayton (1987) from the upper Henley Bed, Farmers Member and Nancy Member. Independent biostratigraphic evidence suggests the assemblage from the Hannibal Shale is of a similar age to that of the Sunbury Shale (Work 2002, Mason pers. comm. 2006). However, assemblages from the Lower and Upper Warsaw are of Osagean/Meramecian age (Kammer *et al.* 1990) and much younger than those from the Henley, Farmers and Nancy.

8. 3. 2 Richardson & Ausich 2004

Richardson & Ausich (2004) studied assemblages from the Borden Delta in Kentucky and Indiana. These authors divided the Borden Delta into three regions based on lithology and sequence stratigraphy – BA-I (northwestern Kentucky), BA-II (south central Kentucky) and BA-III (south central Indiana).

Assemblages recorded from BA-I are recovered from the Henley Bed, Farmers Member, Nancy Member and the Cowbell Member. Assemblages are dominated by *Punctatisporites* and *Retusotriletes*, with common *Calamospora*, *Grandispora*, *Neoraistrickia*, *Vallatisporites*, *Verrucosisporites* and *Umbonatisporites*, and less common *Discernisporites* and *Geminospora*. Richardson & Ausich (2004) recorded *Spelaeotriletes pretiosus* from the upper part of the Henley Bed and throughout the overlying Farmers, Nancy and Cowbell Members, and suggest correlation with the PC European Miospore Biozone. All these taxa are present in the Morehead and Vanceburg sections, although *Neoraistrickia* and *Umbonatisporites* are rare in the present study. Richardson & Ausich did not record *Schopfites claviger* from BA-I. This species is recorded from the Farmers Member and Nancy Member in the present study.

The BA-II region encompasses the Maury Shale and Fort Payne Formation in its western extent and the Maury Shale, Nancy Member and Muldraugh Member in the east. The western part of the region yielded sparse miospores and prasinophytes. *Spelaeotriletes pretiosus* and *Vallatisporites* are recovered throughout the section. Richardson & Ausich (2004) recorded a more diverse and abundant miospore assemblage from the eastern part of the region. An assemblage from the lower part of the Nancy Member is dominated by *Punctatisporites* and *Retusotriletes* together with common *Spelaeotriletes pretiosus*, *Calamospora microrugosa* and *Verrucosisporites nitidus*, and the authors correlated this with the Nancy Member of BA-I. *Schopfites claviger* was identified in the upper part of the Nancy Member in BA-II. The authors suggested correlation of the upper part of the Nancy Member with the CM Miospore Biozone and that the Nancy of BA-II is younger than that of BA-I. However, in the present study, *Schopfites claviger* is recorded from the Nancy Member of Eastern Kentucky suggesting that the Nancy Member is a similar age throughout Kentucky.

Slightly different miospore assemblages are recorded from Indiana (BA-III). Richardson & Ausich (2004) noted a low diversity assemblage from the New Providence Shale comprising *Calamospora microrugosa*, *Cristatisporites menendezii* and several species of *Vallatisporites*. The overlying Spickert Knob Formation contains an assemblage dominated by *Vallatisporites* with abundant *Punctatisporites minutus*, *Retusotriletes famenensis* and *Retusotriletes planus*, common *Spelaeotriletes pretiosus* and rare *Schopfites claviger* and *Auroraspora macra*. In the present study, this assemblage shares several taxa in common with the Nancy Member of Morehead and the Portsmouth Member of Vanceburg. Assemblages recorded from the Osagean/Meramecian boundary at Geode Glen also contain abundant *Vallatisporites* and *Spelaeotriletes*, although *Schopfites claviger* is not present in the Geode Glen assemblages.

Richardson & Ausich (2004) recorded several specimens of *Lycospora pusilla* from the overlying Floyds Knob Bed in the base of the Edwardsville Formation, and suggested a late Tournaisian/early Viséan age. However, the designation of the figured specimen (Richardson & Ausich 2004, pl. 2, fig. 12) to *Lycospora pusilla* is rejected by the present author. In the present study, the first occurrence of *Lycospora pusilla* is recorded from much younger strata within the Mississippi Valley, suggesting that this species has very different age ranges in Midwest America and Western Europe.

In summary, assemblages recorded by Richardson & Ausich (2004) from Kentucky comprise taxa commonly occurring in the European PC and CM Miospore Biozones, and can be correlated with assemblages from the Henley Bed, Farmers Member, and Nancy Member of Morehead and the Henley Bed and Portsmouth Member of Kentucky in the present study. Assemblages from Indiana share taxa in common with assemblages from the Nancy Member of Morehead, the Portsmouth Member of Vanceburg and the upper Osagean of the Mississippi Valley. Correlation in this area is less certain.

8. 3. 3 Hoffmeister, Staplin & Malloy 1955

Hoffmeister *et al.* (1955) studied material from the Hardinsburg Formation in southeastern Illinois and western Kentucky. The clastic-dominated Hardinsburg is a widely traceable unit in this region and is interpreted as a shallow marine, deltaic deposit sandwiched between equally widely traceable limestone units. As such, spore assemblages are expected to be essentially similar throughout the unit.

Hoffmeister *et al.* (1955) recorded a diverse assemblage from the Hardinsburg Formation. They identified 19 genera dominated by *Cirratriradites*, together with abundant *Punctatisporites*, *Densosporites*, *Granulatisporites* and *Schulzospora*. *Cirratriradites uber* Hoffmeister, Staplin & Malloy was the most abundant species; this species is regarded herein as a synonym of *Lycospora pusilla* (as is the commonly recorded species, *Cirratriradites pseudoannulatus* (Kosanke) Hoffmeister, Staplin & Malloy). *Schulzospora* cf. *S. rara* Kosanke was the most common species of *Schulzospora* recorded by Hoffmeister *et al.* (1955). However, the description, dimensions and figured specimen appear to more closely resemble *Schulzospora campyloptera* than *Schulzospora rara*.

Hoffmeister *et al.* (1955) also assigned a number of species to the genus *Punctatisporites* Kosanke as defined by Schopf *et al.* (1944) including forms with various ornamentation of the exine. The redefinition of *Punctatisporites* (Kosanke) by Potonié & Kremp (1954) excluded ornamented forms, and some of the specimens of Hoffmeister *et al.* (1955) have been reassigned to the genera *Verrucosisporites* and *Anaplanisporites* (Smith & Butterworth 1967). *Densosporites capistratus* Hoffmeister, Staplin & Malloy was reassigned to the genus *Cingulizonates* by Staplin & Jansonius (1964). *Densosporites parvus* Hoffmeister, Staplin & Malloy has two distinct bands on the equatorial region, also suggesting its inclusion in the genus *Cingulizonates*. Specimens identified as *Calamospora* cf. *C. straminea* Wilson & Kosanke by Hoffmeister *et al.* (1955) are herein regarded as specimens of *Calamospora parva* due to their relatively thin exine and small size. *Calamospora* type A of Hoffmeister *et al.* appears to resemble *Calamospora pallida*.

Given the number of possible synonymous taxa, and the unavailability of original material for re-examination, correlation with this early material is somewhat tentative. However, a few comparisons can be made with assemblages from the Hardinsburg Sandstone recorded in the present study. *Calamospora parva*, *Calamospora pallida*, *Cingulizonates* spp., *Convolutispora florida*, *Densosporites* spp, *Lycospora pusilla*, *Schulzospora campyloptera* and *Tripartites vetustus* are recorded from both assemblages. *Auroraspora macra* and *Discernisporites micromanifestus*, both commonly recorded from assemblages in the present study may be respectively synonymous with *Endosporites minutus* Hoffmeister, Staplin and Malloy and *Cirratriradites praetergranulatus* Hoffmeister, Staplin and Malloy.

Therefore, assemblages from the Hardinsburg within the Mississippi Valley and Kentucky comprise very similar taxa. This suggests that the Hardinsburg is of a similar age throughout Midwest America.

8. 3. 4 Sandberg, Streel & Scott 1972

Conodont and miospore assemblages have been recorded previously from Devonian-Carboniferous boundary sections in Illinois as well as Utah and Montana by Sandberg *et al.* (1972). *Retispora lepidophyta* was recognised from the upper Devonian Saverton Shale of Illinois and the Sappington Member of Montana together with *Baculatisporites fusticulus*, *Cristatisporites echinatus*, *Cyrtospora cristifera*, *Dictyotriletes trivialis*, *Emphanisporites rotatus*, *Grandispora echinata*, *Hystricosporites mutifurcatus* (Winslow) Mortimer & Chaloner, *Raistrickia macrura*, *Retusotriletes incohatus*, *Tumulispora rarituberculata*, *Vallatisporites pusillites*, *Vallatisporites verrucosus* and *Velamisporites* cf. *V. perinatus*. Basal Carboniferous occurrences of *Retispora lepidophyta* were interpreted as being reworked or the strata being misdated (Sandberg *et al.* 1972). The ages of the assemblages were constrained using the independent conodont biostratigraphy, and correlated with Devonian-Carboniferous boundary sections within Europe (Ardenno-Rhine region, British Isles and Russian Platform). These assemblages are similar to those recorded from the Bedford Shale in the present study, and are typical of the western European LN Biozone assemblages.

8. 4 MIOSPORE ASSEMBLAGES FROM ELSEWHERE IN THE USA

Ohio

8. 4. 1 Winslow 1962

Winslow (1962) studied miospore assemblages throughout the Late Devonian and Early Carboniferous of Ohio, recording more than 80 species and describing 31 new taxa. This work was one of the first major studies of palynostratigraphy in the Midwest region, and is commonly cited in Mississippian palynological literature. Many of the taxa identified by Winslow have since undergone taxonomic revision and have been reassigned to different species or genera. Those relevant to the present study are listed below together with the taxa to which they are now assigned:

Cirratriradites hystricosus	*Vallatisporites hystricosus*
***Cirratriradites* sp. A**	*Vallatisporites hystricosus*
***Cirratriradites* sp. B**	*Vallatisporites hystricosus*
Convolutispora tuberosa	*Verrucosisporites nitidus*
Cyrtospora clavigera	*Cyrtospora cristifera*
Dicrospora porcatus	*Hystricosporites porcatus* (Winslow) Allen
Endosporites lacunosus	*Retispora lepidophyta*
Granulatisporites logani	*Neoraistrickia loganesis*
***Lycospora* sp. A**	*Vallatisporites verrucosus*
Punctatisporites logani	*Spelaeotriletes balteatus*
Radforthia radiata	*Emphanisporites rotatus*
Reticulatisporites? fimbriatus	*Cordylosporites marciae*
Hystricosphaeridium ohioensis	*Gorgonisphaeridium ohioensis*
Hystricosphaeridium trispinosum	*Veryhachium trispinosum*

Ohio & Bedford Shale

Winslow (1962) obtained spore assemblages from the Ohio Shale and Bedford Shale. Assemblages from the Ohio Shale contained common *Hystricosporites* spp., *Endosporites chagrinensis* Winslow (*Auroraspora sp?*), *Vallatisporites hystricosus* and *Emphanisporites rotatus*, as well as *Calamospora* spp., *Grandispora* spp. and *Gorgonispora crassa* (Winslow) Higgs, Clayton & Keegan. *Retispora lepidophyta* was recorded as abundant in the Cleveland Member (upper member of the Ohio Shale in southern Ohio) together with *Cordylosporites marciae*, *Gorgonispora crassa*, *Emphanisporites rotatus*, *Vallatisporites hystricosus* and *Veryhachium* spp. (Winslow 1962).

Winslow (1962) recorded a similar assemblage from the Bedford Shale including *Retispora lepidophyta*, *Vallatisporites verrucosus*, *Verrucosisporites nitidus*, *Gorgonispora crassa*, *Cordylosporites marciae* and *Cyrtospora cristifera*. The assemblages recorded by Winslow (1962) from the Ohio Shale and Bedford Shale of Ohio share many common taxa with assemblages recorded from the Ohio Shale and Bedford Shale at Morehead within the present study, and are typical of LN Biozone assemblages of Western Europe.

Sunbury Shale

Winslow (1962) noted the absence of *Retispora lepidophyta* and *Hystricosporites* spp. in the overlying Sunbury Shale, and recorded low diversity assemblages comprising *Cyrtospora cristifera*, *Emphanisporites rotatus*, *Vallatisporites hystrichosus* and *Verrucosisporites nitidus*. This assemblage closely resembles that of the Sunbury Shale from Morehead and Vanceburg in the present study and is typical of VI Biozone assemblages from Europe.

Cuyahoga Formation & Logan Formation

The Cuyahoga Formation contains common *Cyrtospora cristifera*, together with many of the taxa from the underlying units. *Retispora lepidophyta* was recorded from the Cuyahoga, but Winslow (1962) considered it to be reworked. *Neoraistrickia loganensis* was recorded in the upper part of the Cuyahoga together with *Endosporites? crassispinosus* Winslow and *Vallatisporites pusillites*. *Spelaeotriletes balteatus* appears in the overlying Logan Formation. *Umbonatisporites distinctus*, *Raistrickia clavata* and *Spelaeotriletes pretiosus* were not recorded (Winslow 1962). The spore assemblages from the lower part of the Cuyahoga Formation are typical of the European VI Biozone, although Coleman (1991) suggest the first appearance of the taxa *Neoraistrickia loganensis*, may indicate an age younger than VI. The presence of *Spelaeotriletes balteatus* in the Logan Formation suggests possible correlation with the BP Biozone (Coleman 1991).

Assemblages from the Cuyahoga Formation of Ohio are similar to those from the Sunbury Shale at Morehead and the Sunbury Shale, Jacobs Chapel and Rockford Limestone at Vanceburg. In the present study, *Neoraistrickia loganensis* is recorded together with *Spelaeotriletes balteatus* from the middle of the Henley Bed. This suggests correlation with the upper Cuyahoga and lower Logan formations of Ohio. *Neoraistrickia loganensis* is not recorded from assemblages from Vanceburg, where *Spelaeotriletes balteatus* appears together with *Spelaeotriletes pretiosus*, *Vallatisporites vallatus* and *Raistrickia clavata* in the Henley Bed. This suggests possible correlation with the PC Biozone. Therefore, the Cuyahoga Formation of northern Kentucky may be younger than the Cuyahoga and Logan formations of Ohio.

8. 4. 2 Eames 1974

Eames (1974) studied the Bedford Shale, Berea Sandstone and Cuyahoga Group of northeastern Ohio, which he correlated with the Upper Famennian and Lower Tournaisian of Western Europe. Assemblages described from the Bedford Shale and overlying Berea Sandstone are dominated by *Retispora lepidophyta*. Assemblages comprise similar taxa to those recorded from the Bedford Shale by Winslow (1962) in central and southern Ohio, and from the Cleveland Member of the Ohio Shale and Bedford Shale of northeastern Kentucky within the present study.

In northeastern Ohio, the Sunbury Shale is absent and the Cuyahoga Group lies directly on the Berea Sandstone. The Cuyahoga Group comprises the Orangeville Shale, Sharpsville Sandstone and Meadville Shale. Eames (1974) recorded diverse assemblages from these formations which comprised many of the same taxa as were recorded from the Sunbury Shale and Cuyahoga Formations of central Ohio (Winslow 1962), and the Sunbury Shale and lower part of the Borden Formation of Kentucky (present study).

8. 4. 3 Molyneux, Manger & Owens 1984

Miospore assemblages collected by Molyneux *et al.* (1984) from the Bedford Shale and Berea Sandstone of central Ohio, are dominated by *Retispora lepidophyta* together with *Apiculiretusisporites multiseta* (Luber) Butterworth & Spinner, *Calamospora microrugosa*, *Cordylosporites marciae*, *Indotriradites explanatus*, *Rugospora flexuosa*, *Vallatisporites pusillites* and *Verrucosisporites nitidus*. The authors assigned this assemblage to the Late Devonian.

Again, this assemblage is very similar to those recorded from the Bedford Shale at Morehead, where assemblages are dominated by *Retispora lepidophyta*, and contain the typically Late Devonian taxa *Cordylosporites marciae*, *Rugospora flexuosa* and *Vallatisporites hystricosus*. A robust correlation can be made between the Bedford Shale and Berea Sandstone of central Ohio and the Bedford Shale of northeastern Kentucky.

8. 4. 4 Clayton, Manger & Owens 1998

Clayton *et al.* (1998) described assemblages from the Cuyahoga and Logan formations of northeastern Ohio. These assemblages are dominated by *Vallatisporites* spp. and *Spelaeotriletes* spp, and also contain common *Auroraspora macra*, *Discernisporites micromanifestus*, *Knoxisporites literatus*, *Spelaeotriletes balteatus*, *Spelaeotriletes pretiosus*, *Tumulispora malevkensis*, *Vallatisporites pusillites* and *Verrucosisporites nitidus* and less common *Granulatisporites microgranifer*, *Neoraistrickia cymosa*, *Neoraistrickia loganensis?*, *Raistrickia clavata*, *Retispora lepidophyta* and *Rugospora flexuosa*. The authors noted that the typically Late Devonian taxa present in the assemblages (e.g. *Retispora lepidophyta* and *Vallatisporites pusillites*) are probably reworked, and concluded that the upper Cuyahoga and Logan assemblages are mid Tournaisian (PC Biozone) in age (Clayton *et al.* 1998).

Assemblages described by Clayton *et al.* (1998) are from sections situated in Wayne County approximately 150 miles northeast of the AA Highway section at Vanceburg, Kentucky (5 miles south of the Kentucky/Ohio state boundary). The assemblages described by Clayton *et al.* (1998) closely resemble those from the upper Henley Bed of Morehead, and the Henley Bed and the lower part of the Portsmouth Member of northeastern Ohio. *Spelaeotriletes balteatus*, *Spelaeotriletes pretiosus* and *Vallatisporites* spp. are present in both sections. Reworked specimens of Late Devonian taxa are present within both the Henley Bed and the Portsmouth Member, but appearances are more sporadic and fewer specimens are found in these units than recorded from the Cuyahoga Formation of Ohio.

Miospore assemblages from the upper part of the Cuyahoga Formation and overlying Logan Formation in Ohio are slightly different to those from the upper part of the Cuyahoga Formation at Vanceburg, where the appearance of *Schopfites claviger* suggests correlation with the European CM Biozone. However, the Cuyahoga is interpreted as a deltaic complex characterised by prodeltaic, interdistributary and channel deposits and numerous members have been proposed (Collins 1979; Clayton *et al.* 1998). Large lateral fluctuations in thickness occur within members, and an unconformity exists between the Cuyahoga and the overlying Logan Formation. Therefore, lateral relationships between the members of the Cuyahoga and Logan formations must be viewed tentatively, and the upper part of the Cuyahoga may be diachronous in Kentucky and Ohio.

Michigan

8. 4. 5 Richardson 2006

Richardson (2006) studied miospore assemblages from the Michigan Basin in central and southern Michigan. In this area, the Sunbury Shale lies at the base of the Mississippian and is overlain by the Coldwater Shale and Marshall Sandstone. Two moderately diverse miospore assemblages are recorded from the Coldwater Shale and the Marshall Sandstone. The assemblage from the Coldwater Shale is dominated by *Punctatisporites minutus* and *Punctatisporites planus*, and contains common *Discernisporites micromanifestus*, *Retusotriletes communis*, *Spelaeotriletes crustatus*, *Vallatisporites vallatus* and *Vallatisporites verrucosus*. Richardson (2006) correlated this assemblage with the BP Biozone of Western Europe and the uppermost Kinderhookian.

The assemblage recorded from the Marshall Sandstone also contains common *Punctatisporites minutus*, *Punctatisporites planus* and *Vallatisporites vallatus* together with *Spelaeotriletes pretiosus*, *Neoraistrickia loganensis*, *Convolutispora major*, *Raistrickia clavata* and *Knoxisporites literatus* (Richardson 2006). This assemblage is correlated with the PC Biozone of Western Europe and the lowermost Osagean.

The Michigan Basin study localities are located approximately 550 km (350 miles) to the northwest of the Morehead and Vanceburg localities. Assemblages from the Coldwater Shale closely resemble assemblages from the lower and middle parts of the Henley Bed of the present study. The assemblage recorded from the Marshall Sandstone shares some common taxa with assemblages recorded from the upper part of the Henley Bed of Morehead and the Henley Bed and Portsmouth Member of Vanceburg. Notably, *Spelaeotriletes pretiosus* is common to both assemblages, as is *Convolutispora* sp., *Neoraistrickia loganensis* and *Raistrickia clavata*. Correlation is, therefore, suggested between the lower and middle parts of the Henley Bed of eastern Kentucky and the Coldwater Shale, and the uppermost Henley Bed of eastern Kentucky and the Henley Bed and Portsmouth Member of northeastern Kentucky, with the Marshall Sandstone.

Pennsylvania

8. 4. 6 Warg & Traverse 1973

Warg & Traverse (1973) recorded assemblages from the Catskill Formation of Pennsylvania that were dominated by *Retispora lepidophyta*, *Rugospora flexuosa* and *Vallatisporites pusillites*. *Retispora lepidophyta* decreased in abundance throughout the section and was absent at the top of the section. *Vallatisporites pusillites* was common throughout the section. The authors interpret these sediments as uppermost Devonian (Warg & Traverse 1973). However, the disappearance of *Retispora lepidophyta* is now recognised as a marker for the Devonian-Carboniferous boundary (Clayton *et al.* 1977; Higgs *et al.* 1988), and the section is reinterpreted as uppermost Devonian - lowermost Carboniferous.

These assemblages can be correlated with assemblages from the Bedford Shale-Sunbury Shale at Morehead of the present study. *Retispora lepidophyta* is recorded from the Bedford Shale, but is not recorded from the overlying Sunbury Shale. *Vallatisporites pusillites* is recorded from the Sunbury Shale. No similar assemblages are recorded from the Mississippi Valley; assemblages from the upper Devonian Chattanooga Shale and lowest Kinderhookian Hannibal Shale and equivalents contain very infrequent occurrences of *Retispora lepidophyta* but these specimens are interpreted as reworked; *Vallatisporites pusillites* and *Rugospora flexuosa* are not recorded from the Mississippi Valley.

8. 4. 7 Streel & Traverse 1978

Streel & Traverse (1978) recorded two spore assemblages from the Catskill and Pocono formations of Pennsylvania; the lower dominated by *Vallatisporites hystricosus* and *Retusotriletes lepidophyta* and the upper one dominated by *Indotriradites explanatus* and *Vallatisporites pusillites*. These assemblages are correlated with the uppermost Devonian and the Devonian-Carboniferous boundary respectively (Streel & Traverse 1978).

The lower assemblage closely resembles assemblages from the Bedford Shale; the upper assemblage resembles that of the Sunbury shale. No similar assemblages are recorded from the Mississippi Valley.

8. 5 CANADA - NOVA SCOTIA AND NEW BRUNSWICK

Studies of Early Mississippian miospore assemblages from Nova Scotia and New Brunswick were undertaken by Hacquebard (1957) and Playford (1964). Playford (1964) recognised two separate microfloras, one within the Horton Bluff Formation and undifferentiated Horton Group, and the other within the Cheverie Formation. These assemblages do not closely resemble lower Carboniferous assemblages from Europe, Russia, and Spitsbergen (Playford 1964). Hacquebard (1972) summarised palynological assemblages from this area and assigned the Horton Bluff and Cheverie Formations to spore zone 'g', which contains *Spelaeotriletes pretiosus* and *Vallatisporites vallatus*. This zone encompasses the Tournaisian-Viséan boundary.

8. 5. 1 Neves & Belt 1970

Neves & Belt (1970) compared late Viséan and Namurian miospore assemblages from the Antigosh Basin and Cape Breton Island of Nova Scotia with those described from Britain (Neves & Owens 1966). Neves & Belt (1970) noted that these assemblages were different from those recorded from the British succession, with many key taxa rare or absent, most notably *Lycospora* spp., *Densosporites* spp., *Tricidarisporites* spp., *Tripartites* spp. and *Crassispora maculosa*. Taxa present in Nova Scotia are typically common in the *Grandispora* Suite of Europe and Russia. In the Mississippi Valley, *Lycospora* is absent throughout most of the Viséan, appearing in the uppermost Viséan Cypress Sandstone (Kulagina *et al.* 2008) and becoming common in the mid Namurian Tar Springs Sandstone (*Crassispora maculosa* Biozone). Similarly, *Densosporites* is rare in Mississippi Valley assemblages until the mid Namurian (*Cingulizonates bialatus* Biozone). Spore assemblages from the late Viséan and Namurian of Nova Scotia are tentatively correlated with the *Spelaeotriletes obtusus* Biozone and possibly the *Prolycospora rugulosa* and *Crassispora aculeata* biozones of the present study.

8. 5. 2 Utting 1977, 1978

Utting (1977; 1978) carried out preliminary studies on the palynological assemblages of the Windsor Group of Cape Breton and Port Hood Islands and recognised two assemblage zones (I and II). Assemblage Zone I is comprised of *Auroraspora macra*, *Discernisporites micromanifestus*, *Lycospora noctuina* Butterworth & Williams var. *noctuina* Somers,

Punctatisporites spp., *Rugospora minuta* Neves & Ioannides, *Retusotriletes incohatus* and *Schopfites claviger*. Assemblage Zone II includes taxa from Zone I as well as *Acanthotriletes* sp. A Utting, *Discernisporites* sp. D Utting, *Knoxisporites triradiatus* and *Schopfipollenites ellipsoides* (Ibrahim) Potonié & Kremp (Utting 1978). Utting (1978) suggested the Lower Windsor is no older than the upper part of the European Pu Biozone (Arundian or Holkerian), and the Upper Windsor is no older than the European VF Biozone (Asbian or Brigantian).

8. 5. 3 Utting, Keppie & Giles 1989

Utting *et al.* (1989) named four palynological assemblage zones from the Horton Bluff Formation, Cheverie Formation, Wilkie Brook Formation and Coldstream Formation of Nova Scotia. In ascending stratigraphical order these are the *Emphanisporites rotatus – Indotriradites explanatus*, *Vallatisporites vallatus*, *Spelaeotriletes pretiosus* var. *pretiosus* and *Colatisporites decorus – Schopfites claviger* assemblage zones. The authors correlated these zones with the European HD to CM Miospore Biozones, equivalent to the middle of the Tournaisian Stage (upper Hastarian) to the Tournaisian - Viséan boundary (Ivorian – Chadian substages).

In an earlier report, Utting (1978) recognised two palynological assemblage zones from the Windsor Group of Nova Scotia – Assemblage zone I and Assemblage zone II (see above). Three concurrent range zones were later recognised from the Windsor Group; the *Lycospora noctuina* var. *noctuina – Knoxisporites stephanephorus* (NS) Zone, the *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Zone and the *Grandispora spinosa – Ibrahimispores magnificus* (SM) Zone (Utting 1987, detailed in section 8.5.4 below).

The Windsor Group variably conformably/unconformably overlies the Coldstream Formation (uppermost unit of the Horton Group in its type area), and the NS Zone is correlated to the European TS Miospore Biozone and the Holkerian Substage (Utting *et al.* 1989).

Tournaisian assemblages from the Horton Group type sections in the Windsor Basin, the Rights River Formation of the Antigosh Basin and the Diamond Brook Formation in the Cumberland Basin all comprise similar taxa to each other (Utting *et al.* 1989; Martel *et al.*

1993). Similar assemblages were also obtained from the Albert Formation of New Brunswick, dominated by *Punctatisporites irrasus* and *Punctatisporites planus* with common *Spelaeotriletes pretiosus* in the upper Hiram Brook Member (Utting 1987b). These assemblages were correlated with the Horton Bluff Formation and possibly the European PC Biozone.

The assemblage zones of Nova Scotia and suggested correlation of Utting *et al.* (1989) are shown in Figure 8.5. Comparisons with the material in the present study are made below.

***Emphanisporites rotatus – Indotriradites explanatus* Assemblage Zone**

Utting *et al.* (1989) noted the following species are characteristic of this assemblage zone: *Emphanisporites rotatus*, *Retusotriletes incohatus*, *Retusotriletes triangulatus*, *Retusotriletes crassus*, *Grandispora acuta* (Kedo) Byvscheva, *Verrucosisporites nitidus*, *Raistrickia corynoges*, *Indotriradites explanatus*, *Tumulispora malevkensis*, *Umbonatisporites abstrusus* and *Umbonatisporites distinctus*.

This assemblage does not closely resemble any of the assemblages recorded within the present study. Utting *et al.* (1989) correlated this assemblage with the HD Miospore Biozone of Europe, but, as previously discussed (Chapter 7. 2), this biozone does not appear to be represented in Kentucky. *Emphanisporites rotatus*, *Indotriradites explanatus*, *Retusotriletes crassus*, *Retusotriletes incohatus*, *Retusotriletes triangulatus*, *Tumulispora malevkensis*, *Umbonatisporites distinctus* and *Verrucosisporites nitidus* are all recorded from the Henley Bed in Kentucky, but typically occur with common *Spelaeotriletes* spp. and *Vallatisporites* spp. *Grandispora acuta* and *Raistrickia corynoges* and are not recorded from Kentucky.

Indotriradites explanatus, *Grandispora acuta*, *Retusotriletes crassus*, *Retusotriletes incohatus*, *Retusotriletes triangulatus* and *Verrucosisporites nitidus* are recorded from the Keokuk and Lower Warsaw Formations of the Mississippi Valley. However, this assemblage is dominated by *Vallatisporites* sp. B, *Vallatisporites* sp. C and *Spelaeotriletes balteatus*. *Emphanisporites rotatus*, *Raistrickia corynoges, Tumulispora malevkensis*, *Umbonatisporites abstrusus* and *Umbonatisporites distinctus* are not recorded in the Mississippi Valley. Correlation of these assemblages is questionable due to the much younger age of the Geode Glen sediments suggested by independant biostratigraphy

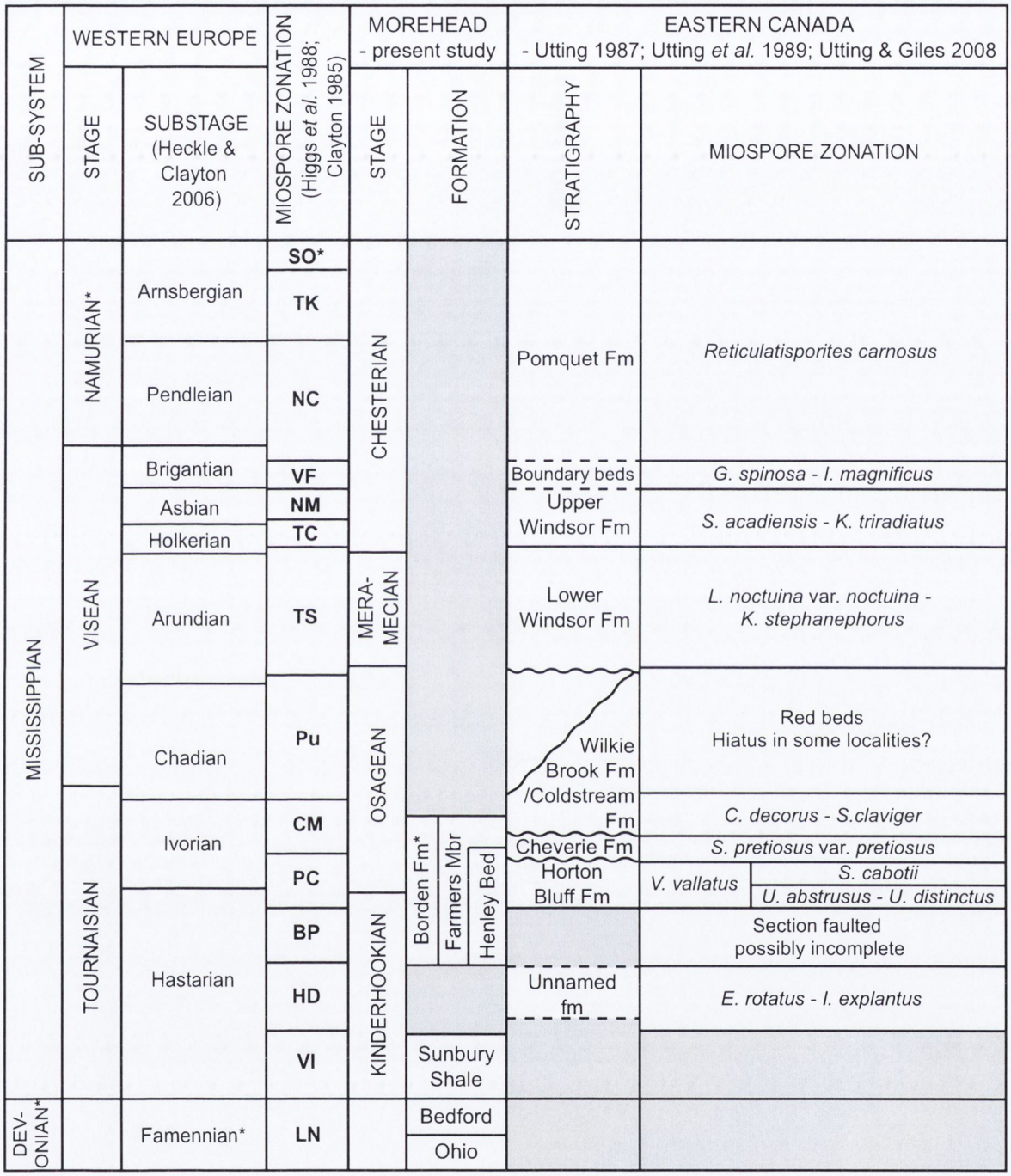


Figure 8.5 The miospore zonal scheme of Eastern Canada and comparisons with Western Europe and Morehead, Kentucky (*in part). Stratigraphic units not to scale. Abbreviations are as follows - Fm - formation, Mbr - member.

(Kammer *et al.* 1990). Coeval assemblages recorded from the Hannibal Shale (based on conodont biostratigraphy e.g. Higgs *et al.* 1992; Work 2002) bear no resemblance to the *Emphanisporites rotatus – Indotriradites explanatus* Assemblage Zone.

Vallatisporites vallatus Assemblage Zone

Utting *et al.* (1989) divided this zone into two subzones – the *Umbonatisporites abstrusus – Umbonatisporites distinctus* Assemblage Subzone and the *Spelaeotriletes cabotii* Assemblage Subzone.

a. *Umbonatisporites abstrusus – Umbonatisporites distinctus* Assemblage Subzone

This subzone comprises many taxa from the underlying zone, but *Indotriradites explanatus*, *Emphanisporites rotatus*, *Retusotriletes crassus* and *Tumulispora malevkensis* were not recorded (Utting *et al.* 1989). Additional characteristic species include *Auroraspora macra*, *Dictyotriletes trivialis*, *Punctatisporites irrasus*, *Rugospora polyptycha*, *Raistrickia clavata*, *Spelaeotriletes cabotii*, *Spelaeotriletes echinatus* (Hacquebard) Utting, rare *Spelaeotriletes pretiosus* var. *pretiosus*, *Vallatisporites vallatus* and *Vallatisporites verrucosus*.

Utting *et al.* (1989) correlated this subzone to the European PC Biozone. In the present study assemblages typical of this biozone are recognised from the Portsmouth Member of Kentucky. Assemblages from these units do not closely resemble those from the *Umbonatisporites abstrusus – Umbonatisporites distinctus* Subzone (*Indotriradites explanatus*, *Emphanisporites rotatus* and *Retusotriletes crassus* are all present within the Portsmouth Member), but many common taxa are recorded from both areas e.g. *Spelaeotriletes* spp. and *Vallatisporites* spp.

b. *Spelaeotriletes cabotii* Assemblage Subzone

This subzone is similar to the underlying subzone, but is recognised by the absence of *Umbonatisporites* spp. and the presence of abundant *Vallatisporites vallatus* and *Spelaeotriletes cabotii*. Rare specimens of *Schopfites claviger* and *Crassispora trychera* are also recorded. The *Spelaeotriletes cabotii* Assemblage Subzone is correlated with the upper part of the European PC and possibly lowermost CM biozones (Utting *et al.* 1989).

Given the rare occurrence of *Umbonatisporites distinctus* in assemblages from Kentucky and the absence of *Crassispora trychera* in all samples this subzone is not recognised in the present study. The presence of *Schopfites claviger* and *Spelaeotriletes cabotii* may suggest correlation with the Farmers Member, Nancy Member and Portsmouth Member of Kentucky. In the Mississippi Valley, no assemblages were obtained from equivalent age strata. *Schopfites claviger* has a much younger recorded first appearance in the Chesterian (upper Viséan) of the Mississippi Valley.

Spelaeotriletes pretiosus var. *pretiosus* Assemblage Zone

Assemblages assigned to this zone share many common taxa with those of the underlying *Vallatisporites vallatus* Assemblage Zone. *Vallatisporites vallatus* is notably absent and assemblages are dominated by *Spelaeotriletes pretiosus* var. *pretiosus* which comprises around 90% of the recorded taxa (Utting *et al.* 1989). This assemblage zone was again correlated with the upper part of the European PC and possibly lowermost CM biozones (Utting *et al.* 1989).

In the present study, no similar dominance of *Spelaeotriletes pretiosus* var. *pretiosus* is recorded from assemblages in Kentucky or the Mississippi Valley. As with the previous assemblage zone, tentative correlation is suggested with the Henley Bed or the Farmers, Nancy and Portsmouth Members of Kentucky, based on the occurrence of *Schopfites claviger* and *Spelaeotriletes* spp.

Crassispora trychera – Colatisporites decorus Assemblage Zone

This assemblage zone comprises many taxa from the underlying zone (Utting *et al.* 1989), however, *Spelaeotriletes pretiosus* var. *pretiosus* is rare. Common components of the assemblage include *Auroraspora macra*, *Colatisporites decorus*, *Punctatisporites glaber* (Naumova) Playford and *Punctatisporites irrasus* together with less abundant *Crassispora trychera*, *Schopfites claviger* and *Verrucosisporites nitidus*. Utting *et al.* (1989) noted the absence of *Lycospora* spp. and *Knoxisporites stephanephorus* - taxa associated with the *Lycospora noctuina – Knoxisporites stephanephorus* (NS) Assemblage Zone from the Windsor Group of Nova Scotia (Utting 1987); these two species are characteristic of the

European Pu and TS biozones. Correlation of this assemblage with the European CM Biozone is suggested (Utting *et al.* 1989).

This assemblage shares some common taxa – *Auroraspora macra*, *Punctatisporites* spp., *Schopfites claviger*, and *Verrucosisporites nitidus* – with assemblages recorded from the Farmers and Nancy members of Morehead and the Portsmouth Member of Vanceburg, Kentucky. However the two zonal taxa, *Crassispora trychera* and *Colatisporites decorus*, are not present and correlation of miospore assemblages is tentative.

The first occurrence of *Colatisporites decorus* in the Mississippi Valley is in the Tar Springs Formation, where it appears together with *Auroraspora macra*, *Punctatisporites* spp., *Schopfites claviger* and *Verrucosisporites nitidus*. Also common in the Tar Springs assemblages are abundant *Lycospora pusilla*, common *Densosporites* spp. and *Schulzospora* spp., and *Cingulizonates* spp., *Crassispora maculosa*, *Tripartites vetustus* and *Triquitrites marginatus*. These typically Viséan and Namurian taxa are not recorded from the *Crassispora trychera – Colatisporites decorus* Assemblage Zone of Utting *et al.* (1989). *Crassispora trychera* is not recorded from any of the samples in the present study.

Utting *et al.* (1989) also noted the presence of the *Lycospora noctuina – Knoxisporites stephanephorus* Assemblage Zone from the Windsor Group of the Windsor Basin and throughout Atlantic Canada. This assemblage zone was first outlined by Utting in 1987 from a study of the Windsor Group of Nova Scotia (section 8. 5. 4 below). Utting *et al.* (1989) noted the occurrence of *Lycospora pusilla*, *Lycospora noctuina, Knoxisporites stephanephorus* and *Vallatisporites ciliaris* within assemblages of a similar level throughout Atlantic Canada. This assemblage is correlated to the European TS Biozone (Utting 1987, Utting *et al.* 1989).

In the present study, *Lycospora pusilla* is commonly recorded throughout the Chesterian of the Mississippi Valley and *Vallatisporites ciliaris* is recorded from the Osagean to middle Chesterian. The association of these two taxa in the early to middle Chesterian may suggest correlation of this level with the Windsor Group. However, *Lycospora noctuina* is not recorded from the Mississippi Valley and *Knoxisporites stephanephorus* is recorded from much younger Pennsylvanian sediments. Furthermore, *Convolutispora florida*, *Prolycospora rugulosa* and *Schulzospora campyloptera* are common components of the

Mississippi Valley assemblage and are not present in the Windsor Group. Therefore, correlation between these assemblages is tentative.

8. 5. 4 Utting 1987

Utting (1987) established three concurrent range zones for the Windsor Group throughout Nova Scotia, Quebec, New Brunswick and Newfoundland. In ascending order these are the *Lycospora noctuina* var. *noctuina – Knoxisporites stephanephorus* (NS) Zone, the *Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Zone and the *Grandispora spinosa – Ibrahimispores magnificus* (SM) Zone (Figure 8.5). These zones were correlated with the upper part of the Pu Biozone to the VF Biozone (Arundian to Brigantian) and belong to the *Vallatisporites* Microflora. Similar assemblages are recorded from Euramerica (i.e. eastern Canada, Ireland, Great Britain and Denmark) (Utting 1987). Assemblages are of relatively low diversity and are dominated throughout by *Crassispora trychera* and *Rugospora minuta*. In general, assemblages recorded by Utting (1987) do not closely resemble those from the present study.

***Lycospora noctuina* var. *noctuina – Knoxisporites stephanephorus* (NS) Zone**

This zone was recognised in the lower part of the Windsor Group and comprises a low diversity assemblage dominated by *Crassispora trychera*, *Punctatisporites planus*, *Retusotriletes incohatus* and *Rugospora minuta*. Also common are *Knoxisporites stephanephorus*, *Lycospora noctuina* and *Vallatisporites ciliaris*. *Densosporites* spp. and *Lycospora pusilla* are both rare (Utting 1987). Utting (1987) correlated this zone to the upper part of the Pu Biozone and the Holkerian and possibly the Arundian substages. Correlation of this assemblage with assemblages from the Mississippi Valley is tentative (see section 8. 5. 3 above).

***Schopfipollenites acadiensis – Knoxisporites triradiatus* (AT) Zone**

This zone was recognised in the upper part of the Windsor Group and is characterised by similar taxa recorded from the underlying NS Zone, e.g. *Crassispora*, *Lycospora noctuina*, *Retusotriletes* and *Rugospora* as well as the first appearances of *Knoxisporites triradiatus*, *Raistrickia magdalena* Utting, *Rugospora corporata* Neves & Owens var. *verrucosa* Neville and *Schopfipollenites acadiensis* Utting. This zone was correlated to the European

TC and NM biozones and the Asbian to lowermost Brigantian substages (Utting 1987). Most of the characteristic taxa of this assemblage zone are not recorded from the present study of the Mississippi Valley, although *Knoxisporites triradiatus* is recorded from the Tar Springs Formation. Precise correlation with the Mississippi Valley assemblages is therefore very difficult.

***Grandispora spinosa – Ibrahimispores magnificus* (SM) Zone**

This zone was recognised from the Windsor-Canso Group boundary beds. Assemblages from the SM Zone share many taxa with the underlying NS and AT zones, and are characterised by the first appearances of *Grandispora spinosa*, *Ibrahimispores magnificus* Neves, *Raistrickia nigra*, *Schulzospora bilunata* Utting and *Tricidarisporities arcuatus* Neville. This assemblage was correlated with the European VF Biozone and possibly the uppermost Asbian to Brigantian substages (Utting 1987).

Correlation of the Windsor Group of Nova Scotia with assemblages from the present study is tentative. Rare occurrences of the common Viséan taxa *Lycospora pusilla* and *Densosporites* sp. are noted from Osagean-Meramecian boundary assemblages at Geode Glen (*Spelaeotriletes obtusus* Biozone), however many of the other common components of the Canadian assemblages are not recognised from Geode Glen assemblages. *Knoxisporites stephanephorus* is first recorded from the Pennsylvanian. *Grandispora spinosa* and *Schulzospora* appear in the early Viséan. *Knoxisporites triradiatus* appears in younger sediments within the Namurian. *Schopfites claviger* appears to range into much younger strata in eastern Canada and the Mississippi Valley than in Western Europe. In Europe, it is typically not recorded from sediments younger than mid Viséan, however, in Canada it is recorded in the late Viséan (Utting 1987) and in the Mississippi Valley it ranges into the mid to late Namurian.

8. 6 CANADA - NEWFOUNDLAND

8. 6. 1 Utting & Giles 2008

Utting & Giles (2008) studied miospore assemblages from the Upper Codroy Group and Barachois Group (upper Mississippian) of southwestern Newfoundland. Assemblages are similar to those recorded from the upper part of the Windsor Group and Mabou Group of

Nova Scotia, and were assigned to the *Schopfipollenites acadiensis – Knoxisporites triradiatus* Zone, *Crassispora maculosa – Spelaeotriletes arenaceus* palynofacies and the *Grandispora spinosa – Ibrahimisporites magnificus* Zone of Utting (1987). Utting & Giles (2008) also recognised a new zone – the *Reticulatisporites carnosus* Assemblage Zone (Figure 8.5). These zones are correlated with the upper Viséan and Serpukhovian stages and the Brigantian to Arnsbergian substages of Western Europe.

***Reticulatisporites carnosus* Assemblage Zone**

This zone is characterised by a number of first appearances of taxa including *Anapiculatisporites baccatus* (Hoffmeister, Staplin and Malloy) Smith & Butterworth, *Corrugitriletes radiatus* Turner & Spinner, *Crassispora kosankei*, *Cribrosporites cribellatus* Sullivan, *Florinites pumicosus* (Ibrahim) Schopf, Wilson & Bentall, *Granulatipsorites microgranifer*, *Grumosisporites verrucosus* (Butterworth & Williams) Smith & Butterworth, *Potonieisporites elegans*, *Reticulatisporites carnosus*, *Savitrisporites nux* and *Waltzispora planiangulata*. *Crassispora maculosa*, *Grandispora spinosa* and *Lycospora pusilla* are also present (Utting & Giles 2008). The first appearance of monosaccate pollen (*Florinites* spp. and *Potonieisporites elegans*) is recorded from the lower Namurian/Serpukhovian of Western Europe and throughout the *Grandispora*, *Monilospora* and *Aratrisporites saharaensis* microfloras (e.g. Felix & Burbridge 1967; Owens *et al.* 1978; Clayton *et al.* 1990). Utting & Giles (2008) correlated the *Reticulatisporites carnosus* Zone to the Western European Pendleian and Arnsbergian substages.

Miospore assemblages from the *Reticulatisporites carnosus* Zone do not closely resemble coeval assemblages from the present study of the Mississippi Valley. Monosaccate pollen have not been recorded from the Mississippian of the Mississippi Valley, and none of the taxa listed as having first appearances within the *Reticulatisporites carnosus* Zone have similar first appearances within the Mississippi Valley. Therefore, provincialism of assemblages is suggested within the uppermost Mississippian assemblages of North America.

8. 7 CANADA - CANADIAN ARCTIC ARCHIPELAGO

8. 7. 1 Utting, Jachowicz & Jachowicz 1989; Utting 1989

Utting *et al.* (1989) studied miospore assemblages from the Emma Fjord Formation of the Canadian Archipelago, and correlated them with material from Western Canada. These assemblages belong to a different floral province than those of Western Europe However, some similarities can be recognised and correlation was suggested between the Emma Fjord assemblages and typical European late Viséan NM and VF assemblages (Utting *et al.* 1989). Assemblages comprise common *Calamospora*, *Colatisporites*, *Densosporites*, *Lycospora* and *Punctatisporites*, as well as the stratigraphically significant taxa *Cingulizonates bialatus*, *Colatisporites decorus*, *Diatomozonotriletes saetosus* (Hacquebard & Barss) Hughes & Playford, *Knoxisporites stephanephorus*, *Knoxisporites triradiatus*, *Lycospora pusilla*, *Murospora aurita* (Waltz) Playford, *Velamisporites tessellatus*, *Rotaspora fracta* and *Waltzispora planiangulata* (Utting *et al.* 1989).

This assemblage was later defined as the *Murospora aurita – Diatomozonotriletes saetosus* Assemblage Zone (Utting 1989). Although the assemblage shares some common taxa with assemblages from the Mississippi Valley, neither of the nominal zonal taxa are recorded in the present study. Possible correlation with the *Cingulizonates bialatus* Biozone or the *Crassispora maculosa* Biozone is suggested.

8. 8 SPITSBERGEN

Miospore assemblages recorded from Spitsbergen belong to the *Lophozonotriletes* Microflora and succeeding *Murospora* Microflora, and are similar to those recorded from western Canada, Bear Island, northern Poland and northwestern Russia (Hughes & Playford 1961; Playford 1962; Playford 1963; Clayton 1985; Clayton *et al.* 1990). Major work on the area was undertaken in the 1960s by Hughes and Playford, who described many new taxa from this area.

8. 8. 1 Hughes & Playford 1961

Hughes & Playford (1961) gave a preliminary account of miospore assemblages from the Tournaisian, Viséan and lowermost Namurian of the Billefjorden Sandstones of Spitsbergen. These authors noted that assemblages from Spitsbergen share many taxa with those previously recorded from the coal basins of Russia, Canada and Scotland. *Densosporites* spp., *Lycospora* spp. and *Triquitrites* spp. were all commonly recorded from the upper part of the Billefjorden Sandstones, and these assemblages were correlated with the Viséan and possibly lower Namurian (Hughes & Playford 1961).

8. 8. 2 Playford 1962; 1963

In a paper published in two parts, Playford (1962, 1963) described the Billefjorden assemblages from three localities in Spitsbergen, and compared them with assemblages previously recorded from Russia, the British Isles and Canada. The assemblages were correlated with the Tournaisian to upper Viséan or lowermost Namurian of Europe and the Kinderhookian to lower Chesterian of America (Playford 1962).

Playford (1963) identified two assemblages, the Rarituberculatus Assemblage from the lower part of the succession and the Aurita Assemblage from the upper part. The Rarituberculatus Assemblage is characterised by abundant *Tumulispora rarituberculata* together with a large group of taxa including *Convolutispora vermiformis* Hughes & Playford, *Knoxisporites* spp., *Densosporites* spp., *Tholisporites foveolatus* Playford and *Spinozonotriletes uncatus*. The Aurita Assemblage is named after the species *Murospora aurita* and is characterised by zonate forms such as *Cirratriradites* and *Diatomozonotriletes*, as well as *Anapiculatisporites*, *Cingulizonates*, *Convolutispora*, *Densosporites, Lycospora, Murospora* and *Waltzispora*. Playford (1963) correlated the Rarituberculatus Assemblage with the Tournaisian and the Aurita Assemblage with the Viséan and possibly lowest Namurian.

Several of the taxa recorded from the Billefjorden assemblages are also recorded from the present study of the Mississippi Valley. However, assemblages from the Mississippi Valley are generally much less diverse and many of the characteristic Spitsbergen taxa are not recorded. *Tumulispora rarituberculosa* is not recorded in the present study. *Tumulispora malevkensis* is very similar and has been suggested as synonymous with

Tumulispora rarituberculosa (Playford & McGregor 1993). This species is recorded in the Jacobs Chapel and Henley Bed in Kentucky which are assigned to the European VI and BP miospore biozones, indicative of a Tournaisian age. It is also recorded from the Lower Warsaw of the Mississippi Valley. *Spinozonotriletes* appears later in the Mississippi Valley within the early Namurian Fraileys Shale and Tar Springs Sandstone; *Densosporites* appears in the Lower Warsaw but does not become abundant until the Tar Springs.

Murospora aurita and other species of *Murospora* are absent or very rare in the present study. Other zonate forms that characterise the upper Spitsbergen assemblages become common in the Viséan and Namurian of the Mississippi Valley. *Lycospora* appears in the late Viséan of the Mississippi Valley in the *Prolycospora rugulosa* Biozone, *Cingulizonates bialatus* appears in the early Namurian in the *Cingulizonates bialatus* Biozone, and *Waltzispora polita* is first recorded from the middle Namurian *Crassispora maculosa* Biozone. This suggests that many taxa have a much later first occurrence in the Mississippi Valley than they do in Spitsbergen.

8. 9 WESTERN EUROPE

Western Europe has been extensively studied in terms of palynology and the miospore biozonation for this region is well established. This biozonation is described in detail in Chapter 3. Important contributions include studies based on assemblages from the British Isles, Belgium, Germany, Ireland and the North Sea (Clayton *et al.* 1977; Clayton *et al.* 1978; Turnau 1978; Higgs *et al.* 1988; Clayton *et al.* 2003; Owens *et al.* 2004). Comparisons between the European Miospore Zonation and the proposed zonation for the Mississippi Valley are shown in Figure 8.3.

8. 9. 1 Clayton, Coquel, Doubinger, Gueinn, Loboziak, Owens & Streel 1977

The standard miospore biozonation for Western Europe was described and illustrated by Clayton *et al.* (1977). The scheme has since undergone revisions e.g. Higgs *et al.* (1988), Clayton *et al.* (2003). The Late Devonian and Tournaisian parts of the biozonation have been redefined from Ireland (Higgs *et al.* 1988) and comparisons with the present study are detailed in section 8. 11. The Viséan and Namurian biozones are have been refined from sections from the British Isles (Clayton *et al.* 1978; Clayton 1985) and from numerous section in Western Europe (Clayton *et al.* 2003) and are discussed in section 8. 9. 2.

8. 9. 2 Clayton, McLean & Owens 2003

Clayton *et al.* (2003) presented a preliminary version of the updated Western European Miospore Biozone at the XVth International Congress on Carboniferous and Permian Stratigraphy, Utrecht (2003). Although this updated scheme is yet to be published, it recognises some important refinements to the existing European Miospore Biozonation of Clayton *et al.* (1977).

Pu (*Lycospora pusilla*) Biozone

The Pu Biozone is recognised throughout Western Europe by the first occurrence of *Lycospora pusilla* slightly below the base of the Viséan Stage. This species is typically rare in the lowermost Pu, but becomes common to abundant in the lower Viséan and dominates most assemblages throughout the Viséan of Western Europe (Clayton *et al.* 1977). In the present study, *Lycospora pusilla* is first recorded in the Cypress Sandstone, and becomes abundant in assemblages younger than the Tar Springs Sandstone of the Mississippi Valley. However, the Cypress Sandstone is mid Viséan in age and the Tar Springs Sandstone is Namurian (Kulagina *et al.* 2008). This suggests a later first appearance and establishment of *Lycospora pusilla* within the Mississippi Valley. The Pu Miospore Biozone is correlated with the *Spelaeotriletes obtusus* Biozone of the Mississippi Valley.

Miospore assemblages recorded from Kentucky in the present study do not contain *Lycospora pusilla* and independent age data suggests that these sections are no younger than Tournaisian age (Coleman & Clayton 1987; Sandberg *et al.* 2002; Work & Mason 2005).

TS (*Knoxisporites stephanephorus*) Biozone

Clayton (1985) defined the base of the TS Biozone by the first occurrences of *Knoxisporites triradiatus* and *Knoxisporites stephanephorus*. These two taxa are recorded from the Namurian Tar Springs Sandstone and the Pennsylvanian Caseyville Formation respectively - much later than their first occurrences in Western Europe. In the Mississippi Valley the TS Miospore Biozone is correlated with the *Spelaeotriletes obtusus* Biozone.

TC (*Schulzospora campyloptera*) Biozone

The base of the TC Biozone in Western Europe was defined by Clayton *et al.* (1977) at the first appearance of the genus *Schulzospora* in the Early Viséan. In the present study, this genus is commonly recorded in assemblages from the Cypress Sandstone and ranges into the Pennsylvanian. *Schulzospora campyloptera* is the dominant species. The first occurrence of *Schulzospora campyloptera* within the Mississippi Valley is, therefore, later than recorded from Western Europe. Other taxa recorded from the Cypress Sandstone include *Schopfites claviger*, a species typically disappearing at the top of the TS Biozone and *Proprisporties laevigatus*, a species typically recorded from the Namurian (Clayton *et al.* 1977). This illustrates the differences between the ranges of many of the key European zonal taxa in Western Europe and the Mississippi Valley. Using independent biostratigraphic evidence (Kammer *et al.* 1990; Kulagina *et al.* 2008), correlation is suggested between the TC Biozone and the upper part of the *Spelaeotriletes obtusus* and lower part of the *Prolycospora rugulosa* biozones of the Mississippi Valley.

NM (*Raistrickia nigra*) Biozone

The base of the NM Biozone is defined in Western Europe by the first appearance of *Raistrickia nigra*, together with a group of taxa comprising *Murospora* sp., *Monilospora* sp., *Spelaeotriletes arenaceus* and *Kraeuselisporites echinatus* (Clayton *et al.* 1977). These characteristic taxa have not been recorded from the Mississippi Valley and the NM Biozone. In the Mississippi Valley the NM Biozone probably correlates with the *Spelaeotriletes* spp. and possibly the lower part of the *Prolycospora rugulosa* biozones.

VF (*Tripartites vetustus*) Biozone

The base of the VF Biozone is defined by the first appearances of the species *Tripartites vetustus* and *Rotaspora fracta* Clayton *et al.* (1977). In the present study *Tripartites vetustus* is first recorded from the Fraileys Shale of the Mississippi Valley, *Rotaspora fracta* is not recorded. Also occurring at this level is *Cingulizonates* cf. *C. capistratus* whose first occurrence marks the base of the NC Biozone of Western Europe. The VF Biozone is tentatively correlated with the upper part of the *Prolycospora rugulosa* and the lower part of the *Crassispora aculeata* biozones.

NC (*Cingulizonates* cf. *C. capistratus*) Biozone

The base of the NC Biozone is marked by the first appearance of *Cingulizonates* cf. *C. capistratus* (Clayton *et al.* 1977). In the Mississippi Valley, this species is first recorded within the Fraileys Shale together with other characteristic NC Biozone taxa. Independent biostratigraphy suggest that European NC Biozone assemblages and those recorded from the Fraileys Shale are coeval in age, and the NC Biozone can be correlated with the *Crassispora aculeata* Biozone.

TK (*Mooreisporites trigallerus*) and SO (*Lycospora subtriquetra*) biozones

In Western Europe the bases of the TK and SO biozones are respectively defined by the first occurrences of *Mooreisporites trigallerus* and *Lycospora subtriquetra* (Clayton *et al.* 1977; Clayton *et al.* 2003). Many of the taxa commonly recognised from these biozones are not recorded from the present study of the Mississippi Valley and correlation of miospore biozones is difficult. The species *Tripartites vetustus* typically disappears at the top of the TK Biozone within Western Europe. This taxon is recorded from the highest Mississippian sample within the Mississippi Valley and suggests correlation between the TK Biozone and the youngest Mississippi Valley biozones – the *Cingulizonates bialatus* and the *Crassispora maculosa* biozones.

8. 10 WESTERN EUROPE – BRITISH ISLES

Carboniferous palynological assemblages have been studied extensively throughout the British Isles. Many early studies focused on the Carboniferous and Pennsylvanian coal measures of the Midlands, northern England and Scotland (e.g. Sullivan 1964; Sullivan & Marshall 1966; Butterworth & Spinner 1967; Smith & Butterworth 1967). More recent studies have focused on the correlation of assemblages from the British Isles with the Western European Biozonation and the establishment and refinement of this zonation (Clayton *et al.* 1978; Clayton 1985; Clayton *et al.* 2003; Owens *et al.* 2004).

8. 10. 1 Butterworth & Spinner 1967

Butterworth & Spinner (1967) recorded palynological assemblages from the Viséan of Cumberland, northwest England. Assemblages comprise of typical European taxa such as

Calamospora spp., *Convolutispora* spp., *Lycospora* spp., *Prolycospora rugulosa* and *Schulzospora campyloptera*. These assemblages closely resemble those from the Cypress Formation of the Mississippi Valley within the present study. However, *Lycospora* spp., the dominant taxa recorded within the English assemblages (Sullivan 1964; Butterworth & Spinner 1967), is recorded sporadically within the Cypress Formation and is absent in some samples.

8. 10. 2 Smith & Butterworth 1967

Smith & Butterworth (1967) produced a detailed account of spore assemblages from the Viséan, Namurian and Westphalian coal seams of Great Britain. Three assemblages were identified within the upper Viséan and Namurian – the *Grumosisporites verrucosus* Assemblage I, the *Diatomozonotriletes saetosus* Assemblage II and the *Rotaspora knoxi* Assemblage III.

Assemblage I is of mid-late Viséan age and comprises common *Lycospora*, *Calamospora* and *Granulatisporites*. This assemblage can be tentatively correlated with the *Prolycospora rugulosa* Biozone of the Mississippi Valley (present study), However, as previously mentioned, *Lycospora* spp. is notably less common within the Mississippi Valley assemblages than those from Great Britain.

Assemblage II is of late Viséan age and comprises common *Tripartites*, *Rotaspora* and *Diatomozonotriletes* as well as *Cingulizonates* cf. *C. capistratus*. This assemblage is tentatively correlated with the *Crassispora aculeata* Biozone of the Mississippi Valley. *Rotaspora* and *Diamtomozonotriletes* are not recorded from assemblages of the Mississippi Valley strata within the present study. Independant correlation suggests that the *Crassispora aculeata* Biozone is of late Viséan age (Kulagina *et al.* 2008).

Assemblage III spans the Viséan-Namurian boundary and lower Namurian and comprises common *Grumosisporites*, *Microreticulatisporites*, *Convolutispora*, *Cingulizonates*, *Densosporites* and *Tholisporites*. This assemblage is tentatively correlated with the *Cingulizonates bialatus*, *Crassispora maculosa* and *Cirratriradites annuliformis* biozones of the Mississippi Valley.

8. 11 WESTERN EUROPE - IRELAND

A number of studies were carried out during the 1970s and 1980s describing miospore assemblages throughout Ireland, e.g. Clayton *et al.* (1980; 1982), Higgs (1975; 1975b), Keegan (1981), MacCarthy *et al.* (1978), Van Veen (1981), Van der Zwan & Van Veen (1978). These assemblages have been widely used in the construction and refinement of the Western European Miospore Biozonation and a synthesis of this work was provided by Higgs *et al.* (1988). More recently, refinements to the European Miospore Biozonation have been suggested by Brittain & Higgs (2008).

8. 11. 1 Higgs, Clayton & Keegan 1988

Miospore assemblages from the Tournaisian of Ireland were recorded and analysed in a comprehensive study by Higgs *et al.* (1988). Assemblages were assigned to the European Miospore Biozonation, and refinements to this scheme were made. The authors noted that the zonation was robust in terms of sedimentary facies, and applicable to rock sequences of similar age throughout Britain and Western Europe. As such, this study has formed the basis of many correlations of Early Carboniferous assemblages to the Western Europe biozonation scheme. The composition of assemblages is detailed in Chapter 3.

As noted throughout this chapter, the Western European biozonation has provided a standard for correlation of assemblages worldwide. Assemblages from Morehead and Vanceburg show similarities with those described from Ireland, both in the present study as well as in previous studies (e.g. Coleman & Clayton 1987; Coleman 1991).

LN Biozone

Miospore assemblages from the Bedford Shale of Kentucky suggest correlation with the LN Biozone in Ireland (Higgs *et al.* 1988). The disappearance of *Retispora lepidophyta* places the Devonian-Carboniferous boundary at the Bedford Shale/Sunbury Shale contact, although sporadic appearances are recorded from the early Mississippian assemblages of Kentucky. Other typical LN taxa which are present in the Bedford shale and absent in the overlying Sunbury Shale include *Rugospora flexuosa* and *Vallatisporites hystricosus*. *Emphanisporites rotatus*, *Verrucosisporites nitidus* and *Knoxisporites literatus* are recorded from both the Late Devonian and the Early Mississippian in both the Mississippi

Valley and Ireland. However, some characteristic taxa appear later in Kentucky than in the Irish sections. These include *Indotriradites explanatus*, *Tumulispora malevkensis*, *Vallatisporites pusillites* and *Vallatisporites verrucosus*.

VI Biozone

Assemblages from the Sunbury Shale closely resemble those assigned to the VI Biozone in Ireland. As previously noted, assemblages are dominated by taxa from the underlying LN Biozone. Taxa common in earliest Mississippian assemblages from both Kentucky and Ireland include *Calamospora* spp., *Punctatisporites planus*, *Retusotriletes incohatus* and *Verrucosisporites nitidus*. Although similar in composition, assemblages recorded from Kentucky are less diverse than those recorded from Ireland and many common components of the Irish sections are absent in the Sunbury Shale. However, assemblages from the Sunbury Shale are poorly preserved - a result of deposition within a distal basin environment (see Chapter 9). Furthermore, very few samples were studied from the Sunbury Shale compared to extensive sampling from numerous localities in the study of Higgs *et al.* (1988). Many of the differences in assemblage composition between the two areas may, therefore, be a result of preservation or sampling bias.

HD Biozone

This Biozone is recognised in Western Europe by the first occurrences of *Cristatisporites hibernicus* and *Umbonatisporites distinctus*. *Cristatisporites hibernicus* is not recorded from Kentucky. The first occurrence of *Umbonatisporites distinctus* is recorded from the upper part of the Henley Bed together with *Spelaeotriletes balteatus* and *Spelaeotriletes pretiosus* in assemblages assigned to the PC Biozone. This suggests that *Umbonatisporites distinctus* has a later first occurrence in Kentucky than it does in Ireland and the HD Biozone cannot be recognised from Kentucky. However, the lowermost part of the Henley Bed is barren and is interpreted as representing a period of extremely slow sedimentation in the deepest part of the basin (Chaplin 1982; Coleman & Clayton 1987). The HD Biozone may equate with this barren level.

BP Biozone

Assemblages from the lower part of the Henley Bed at Morehead, Kentucky resemble those from the European BP Biozone. As seen in the Sunbury Shale, assemblages recorded in the present study are slightly less diverse than those recorded by Higgs *et al.* (1988). The occurrence of *Spelaeotriletes balteatus* suggests correlation with the BP Biozone recorded from Ireland, as does the absence of taxa typical of the overlying PC and CM biozones. The first occurrence of *Rugospora* cf. *R. polyptycha* is recorded from this level in Kentucky, as well as *Granulatisporites microgranifer*. Higgs *et al.* (1988) recorded *Granulatisporites microgranifer* from the base of the overlying PC Biozone, but its range in Europe has recently been extended down to the BP Biozone (Higgs pers. comm. 2006)

PC Biozone

Assemblages from the upper part of the Henley Bed at Morehead and the Henley Bed and lower part of the Portsmouth Member at Vanceburg are similar in composition to assemblages typical of the PC Biozone in Ireland (Coleman & Clayton 1987; Higgs *et al.* 1988). *Spelaeotriletes pretiosus* is recorded from the Kentucky sections, together with *Raistrickia clavata*.

CM Biozone

Schopfites claviger is recorded from the Farmers Member and Nancy Member of Morehead and the Portsmouth Member of Vanceburg. The first appearance of this species defines the base of the CM Biozone in Ireland and its recognition in the Kentucky successions suggest correlation between these two areas.

8. 11. 2 Brittain & Higgs 2008

Brittain & Higgs (2008) examined the *Spelaeotriletes balteatus – Spelaeotriletes pretiosus* miospore complex from the Tournaisian of southern Ireland, and used it to provide a more precise definition of the base of the PC Biozone. The authors recorded a trend in diversification of ornament and increased spore size over time. In addition to the respective

first appearances of *Spelaeotriletes balteatus* and *Spelaeotriletes pretiosus* at the bases of the BP and PC miospore biozones, *Spelaeotriletes cabotii* is recorded from the middle part of the BP Biozone, and *Spelaeotriletes galearis* is recorded from the lower part of the PC Biozone (Brittain & Higgs 2008).

A slightly different *Spelaeotriletes* succession is recorded from Kentucky and the Mississippi Valley of the present study to that recorded from Ireland. *Spelaeotriletes cabotii* is recorded as appearing in slightly younger sediments than *Spelaeotriletes pretiosus* in both Kentucky and the Mississippi Valley. This later occurrence of *Spelaeotriletes cabotii* is similar to its first appearance in Nova Scotia (see section 8. 5. 1 above, Utting *et al.* 1989). *Spelaeotriletes galearis* also appears in slightly younger sediments than *Spelaeotriletes pretiosus* in the Kentucky section at a similar level to its first appearance in Ireland.

8. 12 PORTUGAL

Palynological assemblages from the southwest region of Portugal, have been studied in detail by Pereira (1999) and Pereira *et al.* (1996; 1998; 2003). Assemblages are very similar to and have been reliably correlated with those from the rest of Western Europe.

8. 12. 1 Pereira 1999

Pereira (1999) examined palynomorph assemblages from the late Strunian to the Westphalian of the South Portuguese Zone, and correlated them with the European Biozonation (Figure 8.6).

Terecenas Formation

Assemblages from the lower part of the Terecenas Formation comprise common *Verrucosisporites nitidus* together with *Tumulispora rarituberculata*, *Retispora lepidophyta*, *Densosporites spitsbergensis*, *Cordylosporites marciae*, *Knoxisporites concentricus*, *Retusotriletes crassus*, *Rugospora flexuosa* and *Vallatisporites pusillites*. In the upper part, *Retispora lepidophyta*, *Vallatisporites pusillites* and *Rugospora flexuosa* are

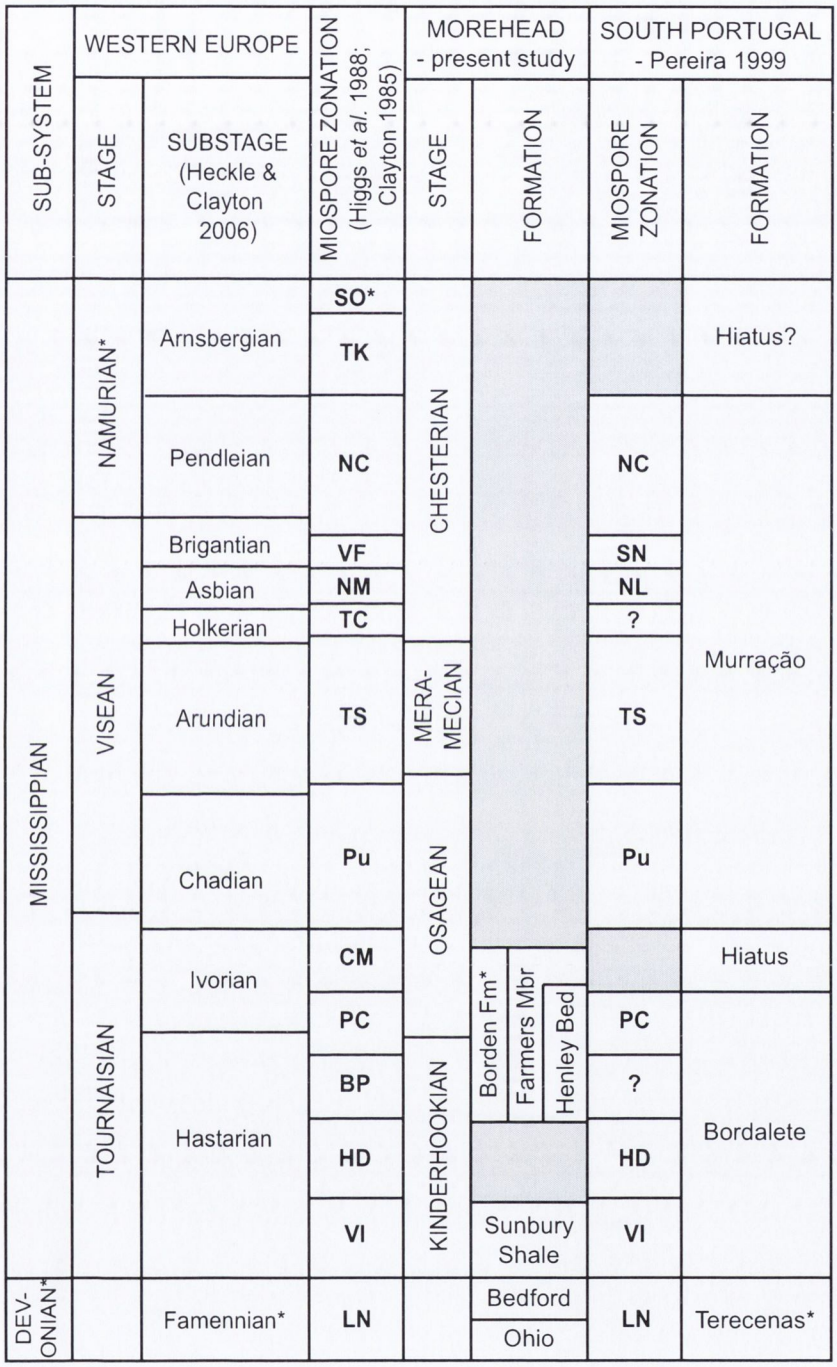


Figure 8.6 The miospore zonal scheme of Southern Portugal and comparisons with Western Europe and Morehead, Kentucky (*in part). Stratigraphic units not to scale. Abbreviations are as follows - Fm - formation, Mbr - member.

notably absent. These assemblages are respectively assigned to the LN and VI biozones (Pereira 1999).

The Portuguese assemblages closely resemble those from the Bedford Shale and Sunbury Shale of Morehead and Vanceburg, Kentucky and share many common taxa with assemblages from the Hannibal Shale of the Mississippi Valley. *Tumulispora* sp., *Knoxisporites concentricus* and *Vallatisporites pusillites* appear later in the Mississippi Valley and Kentucky than in the Portuguese assemblages. Pereira (1999) and Pereira *et al.* (2003) also recorded a characteristic Late Devonian acritarch assemblage from the Terecenas Formation. A similar assemblage is recorded from the Hannibal Shale of the present study.

Bordalete Formation

Assemblages from the Bordalete Formation were assigned to the VI, HD and PC biozones (Pereira 1999). The BP and CM biozones have not been recognised from southern Portugal. VI Biozone assemblages are comprised of *Vallatisporites verrucosus*, *Retusotriletes incohatus*, *Cyrtospora cristifera* and *Tumulispora malevkensis*. The base of the overlying HD Biozone is marked by the first occurrences of *Umbonatisporites distinctus* and *Neoraistrickia cymosa*. The PC Biozone is marked by the first appearances of the two index species together with *Granulatisporites microgranifer*, *Neoraistrickia loganensis*, *Spelaeotriletes balteatus* and *Vallatisporites vallatus* (Pereira 1999).

Within the present study, the Portuguese assemblages can be closely correlated with those recorded from Kentucky. *Umbonatisporites distinctus* is recognised from coeval assemblages within the lower part of the Henley Bed, and a similar absence of BP Biozone assemblages is noted. *Neoraistrickia loganensis* appears together with *Spelaeotriletes pretiosus* in the upper part of the Henley Bed. Correlation of assemblages from the Bordalete Formation with those of the Mississippi Valley is less certain and tentative correlation with the Burlington, Keokuk and Warsaw formations is suggested.

Murração Formation

Pereira (1999) assigned assemblages from the Murração Formation to the Pu, TS, NL (*Raistrickia nigra-Proprisporites laevigatus*), SN (Savitrisporites nux) and NC biozones.

The TC Biozone was not recorded and the interval represented by the NM Biozone throughout most of Europe was assigned to the NL Biozone in Portugal (Pereira 1999). Although many of the taxa characterising these zones in Europe are recorded from the Mississippi Valley, the ranges of many of the taxa are quite different. For example, the much younger late Viséan first appearance of *Lycospora pusilla*, and the mid and upper Serpukhovian first appearances of *Knoxisporites triradiatus* and *Knoxisporites stephanephorus*.

The first appearance of *Proprisporites laevigatus* is recorded from most Western European successions in the Namurian NC Biozone (Clayton *et al.* 1977). Pereira (1999) recorded common *Proprisporites laevigatus* within the Viséan of southern Portugal. Rare specimens of this taxon are also found within the Viséan *Prolycospora rugulosa* Biozone recognised from the Mississippi Valley. Within the present study of the Mississippi Valley, *Schulzospora* spp. is a very common component of Viséan and Namurian assemblages. However, this taxon was not recorded from Portugal by Pereira (1999). *Crassispora maculosa* has a first recorded appearance within the Portuguese SN (*Savitrisporites nux*) Biozone – equivalent to the VF assemblages recorded from other parts of Western Europe (Pereira 1999; Pereira *et al.* 2003). This species typically appears throughout the Tournaisian and Viséan of Western Europe, but has a similar later first appearance within the *Crassispora aculeata* Biozone of the Mississippi Valley.

8. 13 RUSSIA – BYELORUSSIA, RUSSIAN PLATFORM & URALS

8. 13. 1 Avchimovitch, Byvscheva, Higgs, Streel & Umnova 1988

The western, or European, part of Russia encompasses Byelorussia, the Russian Platform and the Urals. This part of Russia has been the focus of many taxonomic studies, for example, Luber (1938), Luber & Waltz (1938; 1941), Kedo (1957; 1963), Naumova (1953), Byvscheva (1976) and Byvscheva et *al.* (1984). Many of the species named within the early Russian literature were synonymous with those named from Western Europe and North America (Hughes & Playford 1961; Playford 1962; Playford 1963) and this has caused certain taxonomic problems (Avchimovitch *et al.* 1988). Avchimovitch *et al.* (1988) reassessed the taxonomy of many of the Late Devonian-Early Carboniferous miospores, and in doing so allowed a more accurate correlation between the European part of Russia and Western Europe.

Avchimovitch *et al.* (1988) discussed correlation of the miospore zonation schemes for Devonian-Carboniferous boundary sections from the Pripyat Depression in Byelorussia and the eastern and central Russian Platform with the miospore zonation schemes for western Germany (Higgs & Streel 1984) and southern Ireland (Higgs *et al.* 1988). This study is useful in that it provided a summary of the Russian schemes, originally published in Russian.

The Late Devonian of the central and eastern part of the Russian Platform comprises two zones (*Retispora lepidophyta* (L) Zone and *Vallatisporites pusillites* (P) Zone) split into five subzones (Avchimovitch *et al.* 1988). The lower part of the Tournaisian comprises the *Tumulispora malevkensis* (M) Zone. The *Retispora lepidophyta* Zone is correlated to the Western European LV, LL and LN biozones and is older than the age range of the present study. This zone will not be discussed further. The *Vallatisporites pusillites* and the *Tumulispora malevkensis* zones are discussed below.

***Vallatisporites pusillites* Zone**

The lower part of the *Vallatisporites pusillites* Zone is represented by the PLE (*Vallatisporites pusillites – Retispora lepidophyta – Hymenozonotriletes explanatus*) Subzone, the middle part is represented by the PM (*Vallatisporites pusillites – Tumulispora malevkensis*) Subzone and the upper part is represented by the PMi (*Vallatisporites pusillites – Bascaudispora mischkinensis*) Subzone. Avchimovitch *et al.* (1988) correlated the *Vallatisporites pusillites* Zone with the LN Miospore Biozone of Western Europe. *Retispora lepidophyta* is present throughout the *Vallatisporites pusillites* Zone; however, in the Russian assemblages this species gradually diminishes through the Late Devonian and disappears at the top of this zone. In the central part of the Russian Platform, the PMi subzone is characterised by a complete absence of *Retispora lepidophyta* and has been correlated with the European VI Biozone (Avchimovitch *et al.* 1988).

Assemblages from the Bedford Shale of Kentucky can be correlated with those from the P Zone and the PLE and PM subzones of Byelorussia and the Russian Platform. In the present study *Retispora lepidophyta* is abundant in samples from just below the Devonian–

Carboniferous boundary, and there is no evidence of a gradual decrease in abundance within North American sections.

Tumulispora malevkensis Zone

The *Tumulispora malevkensis* Zone is defined from the central and eastern parts of the Russian Platform. In the Ural Mountains, an additional underlying ML (*Tumulispora malevkensis – Retispora lepidophyta*) Zone is recognised and this is correlated with the upper part of the PM Zone in Byelorussia and the Russian Platform and the top of the European LN Biozone. The M (*Tumulispora malevkensis*) Zone is correlated with the European VI Biozone, and in Byelorussia, the HD Biozone (Avchimovitch *et al.* 1988).

Assemblages from the Sunbury Shale of Kentucky and the Hannibal Shale of Illinois and Missouri are similar to those recorded from the Russian M Zone (Byvscheva *et al.* 1984; Avchimovitch *et al.* 1988).

8. 14 GONDWANA - AUSTRALIA

In Carboniferous times, Australia formed part of the Gondwana palaeocontinent situated in the Southern Hemisphere, and was separated from Euramerica by the Rheic and Paleotethys oceans (Figure 1.1). As such, miospore assemblages recorded from this region are very different from those recorded from Kentucky and the Mississippi Valley, and belong to the *Vallatisporites* Microflora (Sullivan 1965; Sullivan 1967; Clayton 1985) and the *Granulatisporites frustulentus* Microflora (Kemp *et al.* 1977; Clayton 1985; Avchimovitch *et al.* 1988). However, some taxa may be useful in global correlations.

8. 14. 1 Playford 1990

Playford (1990) provided a summary of stratigraphically useful taxa from both Gondwana and Euramerica. Playford (1990) noted that the exit of *Retispora lepidophyta* appears to be a global event, marking the Devonian-Carboniferous boundary in both Northern and Southern hemispheres. Other taxa of possible global significance include *Schopfites claviger*, *Tricidarisporites* spp., *Tumulispora rarituberculata*, *Umbonatisporites distinctus* and *Waltzispora polita* (Playford 1990). *Schopfites claviger* appears at the Tournaisian-Viséan boundary, slightly later than its first appearance in Europe and North America.

Tricidarisporites spp. appears in the mid to late Viséan of Australia, much later than its first recorded appearance in the early Viséan of Western Europe (Playford 1990). Within the Mississippi Valley *Tricidarisporites* is rare and is first recorded from the late Chesterian (Namurian) Tar Springs Sandstone. *Tumulispora rarituberculata* has a similar range in both Australia and Western Europe, and disappears within the lower Viséan (Playford 1990). In the present study, the range of *Tumulispora* appears to be restricted to the mid Tournaisian. *Umbonatisporites distinctus* occurs slightly later in Australia than in parts of the Northern Hemisphere (Playford 1990). In the present study this species is only recorded from Kentucky, and appears to have a slightly later first appearance than in the rest of Euramerica. *Waltzispora polita* appears in the late Viséan of Australia, similar to its first appearance in Europe; a slightly later, early-mid Namurian appearance is recorded from the Mississippi Valley within the present study. In summary, correlation between the Mississippian of Australia and coeval strata from the present study is poorly constrained by the miospore assemblages, but specific taxa may be useful at certain levels.

8. 15 GONDWANA –AFRICA & THE MIDDLE EAST

Miospore assemblages from the Mississippian of Northern Africa are similar in composition to those from Australia and the rest of Gondwana (Loboziak & Clayton 1988). Two miospore biozones span the early Viséan to Serpukhovian – the *Aratrisporites saharaensis – Radiizonates genuinus* (SG) Biozone, comprising the *Vallatisporites vallatus – Spelaeotriletes pretiosus* (VP) Sub-Biozone, the *Spelaeotriletes pretiosus – Spelaeotriletes owensi* (PO) Sub-Biozone and the *Spelaeotriletes owensi – Vallatisporites agadesi* (OA) Sub-Biozone, and the *Prolycospora rugulosa – Spelaeotriletes triangulus* (RT) Biozone (Loboziak & Clayton 1988). These biozones are mainly defined on the first appearances of exclusively Gondwanan taxa. The appearances of a few cosmopolitan species such as *Spelaeotriletes pretiosus* and *Prolycospora rugulosa* allow tentative correlation with assemblages from the present study, however, the ranges of many of these taxa differ between Gondwana and Euramerica.

Assemblages from the Mississippian of Saudi Arabia can be correlated with those of Northern Africa. Tournaisian assemblages are dominated by geographically widespread taxa such as *Indotriradites explanatus* and *Auroraspora macra*. Viséan and Namurian assemblages are more diverse and *Aratrisporites saharaensis* Loboziak, Clayton & Owens, *Spelaeotriletes owensi* Loboziak & Alpern and *Vallatisporites agadesi* Loboziak & Alpern

are all present (Clayton 1995). These assemblages closely resemble those of the *Aratrisporites saharaensis* Microflora (Clayton *et al.* 1990; Clayton 1995) and cannot be closely correlated with assemblages within the present study.

8. 15. 1 Atta-Peters 1996

Atta-Peters studied Late Devonian and Early Carboniferous assemblages from the Takoradi Shale of Ghana, Western Africa (Anan-Yorke & Atta-Peters 1996; Atta-Peters 1996; Atta-Peters & Anan-Yorke 2003). Miospore assemblages closely resemble those from Western Europe and were assigned to the European LE, LN and VI biozones. The Devonian-Carboniferous boundary was placed within the lower part of the Takoradi Formation (Atta-Peters 1996). *Retispora lepidophyta* was recorded from the lower part of the Takoradi Formation, but is absent in the upper part of the formation. Atta-Peters recorded abundant muronate taxa from the Late Devonian assemblages and noted the similarity of the Ghanaian assemblages to those from the Pocono Formation of Pennsylvania (Warg & Traverse 1973; Atta-Peters 1996). A moderately diverse acritarch assemblage was also recognised from the latest Devonian (Atta-Peters 1999) which included several species present in the earliest Mississippian strata of the Mississippi Valley, e.g. *Multiplicisphaeridium ramusculosum*, *Veryhachium* cf. *V. polyaster* and *Umbellasphaeridium saharicum*. In the present study, assemblages from Ghana are similar to those recorded from the Ohio, Bedford and Sunbury Shale of Kentucky, and the Devonian-Carboniferous boundary is defined in both areas by the disappearance of *Retispora lepidophyta*.

8. 16 GONDWANA - SOUTH AMERICA

In Early Carboniferous times, South America was situated in the southwestern part of Gondwana (Loboziak & Melo 2000; Scotese 2006). Miospore assemblages from the Late Devonian and Early Carboniferous of Brazil have been the focus of numerous studies including Loboziak *et al.* (1991; 1992; 1997), Loboziak & Melo (2000) and Melo & Loboziak (2003), and similarities with Australian, African and European assemblages have been noted (Loboziak *et al.* 1991; Clayton 1996).

Latest Devonian assemblages from the Amazonas, Parnaíba and Paraná basins comprise cosmopolitan taxa such as *Indotriradites explanatus*, *Retispora lepidophyta*, *Tumulispora*

malevkensis, *Vallatisporites verrucosus*, *Verrucosisporites nitidus* as well as typically Gondwanan taxa e.g. *Aratrisporites saharaensis* and *Granulatisporites frustulensis* (Loboziak *et al.* 1991; 1992; Loboziak & Melo 2000). These assemblages are quite different to those recorded from the Bedford Shale within the present study. As expected, typical Gondwanan taxa are not recognised from Kentucky assemblages and *Indotriradites explanatus*, *Tumulispora malevkensis* and *Vallatisporites verrucosus* appear slightly later within the earliest Carboniferous. However, *Retispora lepidophyta* and *Verrucosisporites nitidus* are both present within the Bedford Shale, and suggest placement within the Late Devonian and correlation with the South American assemblages.

The disappearance of *Retispora lepidophyta* is recorded at the top of the Longá Formation of the Parnaíba Basin and within the Oriximina Formation of the Amazonas Basin (Loboziak *et al.* 1991; 1992). This suggests correlation with the Bedford Shale-Sunbury Shale contact of Morehead, Kentucky.

Earliest Carboniferous assemblages from Brazil, like their European equivalents, are typically of low diversity. *Spelaeotriletes pretiosus*, *Raistrickia clavata*, *Colatisporites decorus* and *Neoraistrickia loganensis* all appear within the Lower Carboniferous, and have been correlated with the middle to late Tournaisian PC Miospore Biozone (Loboziak *et al.* 1992; Playford & Melo 2009). Early Mississippian assemblages from Kentucky and the Mississippi Valley within the present study are quite different to those from South America. However, a few common species are recognised from both areas and suggest correlation with the Henley Bed and Portsmouth Members of Kentucky, and possibly the Warsaw Formation of the Mississippi Valley.

8. 16. 1 Melo & Loboziak 2003

Melo & Loboziak (2003) proposed a miospore biozonation for the Devonian and Mississippian of the Amazon Basin. Large intervals of the middle and upper parts of the Mississippian are represented by sandy sediments or breaks in deposition. However five zones have been identified from the latest Devonian to the Upper Mississippian.

The ***Retusotriletes lepidophyta–Vallatisporites vallatus*** (LVa) Interval Zone is recognised from the uppermost Devonian and is characterised by common *Retusotriletes lepidophyta*, *Indotriradites explanatus*, *Vallatisporites hystricosus*, *Cordylosporites marciae* and

Rugospora flexuosa. These taxa are commonly recorded in the uppermost Devonian of Euramerica and are correlated with the European LN Biozone (Melo & Loboziak 2003) and the Bedford Shale of Kentucky.

In the earliest Tournaisian Oriximina Formation, Melo & Loboziak (2003) recorded the disappearance of a large group of taxa all common within the latest Devonian. The authors noted sparse appearances of some of these taxa in the Tournaisian (Melo & Loboziak 2003), most notably the occurrence of *Retispora lepidophyta* above the Devonian-Carboniferous boundary. Similar occurrences are recorded in Kinderhookian and Osagean strata in Kentucky and the Mississippi Valley. The species *Radiizonates arcuatus* Loboziak, Playford & Melo, *Waltzispora lanzonii* Daemon and *Rugospora minuta* are all recorded as appearing in the early Tournaisian. Diversity increases during the Tournaisian and an increase in *Densosporites* as well as reticulate and apiculate forms is observed. Melo & Loboziak (2003) named this assemblage the ***Radiizonates arcuatus-Waltzispora lanzonii*** (AL) Interval Zone and correlated it with the VI and HD biozones of Western Europe.

The ***Spelaeotriletes balteatus-Neoraistrickia loganensis*** (BL) and ***Spelaeotriletes pretiosus-Colatisporites decorus*** (PD) interval zones have been recognised from the upper part of the Oriximina Formation. Assemblages are similar to those from Western Europe and have been respectively correlated with the BP and PC miospore biozones (Melo & Loboziak 2003).

Melo & Loboziak (2003) recognised a single zone from the middle and upper part of the Mississippian – the ***Cordylosporites magnidictyus*** (mag) Interval Zone. Strata are restricted to the Viséan Faro Formation - a mostly sandy unit with some argillaceous deposits yielding miospore assemblages. The index taxa - *Cordylosporites magnidictyus* (Playford and Helby) Loboziak & Melo has not been recorded from assemblages within the present study. However, other common taxa from the Faro Formation, including *Apiculiretusispora*, *Convolutispora*, *Densosporites*, *Radiizonates*, *Retusotriletes* and *Vallatisporites*, are all recorded from the Osagean and Chesterian of the Mississippi Valley. *Velamisporites tessellatus* is relatively common and Melo & Loboziak (2003) suggest correlation with the European TC-NM miospore biozones. Melo & Loboziak (2003) also note that *Lycospora* spp. is surprisingly rare in the Amazon Basin. This is similar to its sparsely recorded occurrences in the present study of the Mississippi Valley.

CHAPTER 9
PALYNOFACIES

9. 1 DEFINITION OF TERMS

Facies

"A facies is a body of rock with specified characteristics... A facies should ideally be a distinctive rock that forms under certain conditions of sedimentation, reflecting a particular process or environment" (Reading 1996).

Palynofacies

A palynofacies can be defined as "a body of sediment containing a distinct assemblage of palynological organic matter thought to reflect a specific set of environmental conditions, or to be associated with a characteristic range of hydrocarbon-generating potential" (Tyson 1995). Organic matter comprises all HF and HCl resistant components within a rock or sediment; chitin, sporopollenin and cutin.

Palynofacies Analysis

Palynofacies analysis can be defined as "the palynological study of depositional environments and hydrocarbon source rock potential based upon the total assemblage of particulate organic matter" (Tyson 1995).

9. 2 INTRODUCTION

Palynofacies analysis is a relatively new field of study only becoming popular with the increased availability of hydrofluoric acid in the second half of the twentieth century. Previous to this, the bulk of organic matter within sediments was completely ignored and palynological studies focused solely on the morphology and biostratigraphy of the organic–walled microfossils. Once the different components of organic matter were recognised, their usefulness became apparent, and palynofacies analysis became a widely used tool in defining palaeoenvironments and hydrocarbon potential (Tyson 1995).

Palynofacies analysis can be used in most palynological studies with a variable degree of precision, depending on the aims of the study (e.g. palaeoenvironmental analysis and assessment of hydrocarbon source rock potential) and the time and means available. It is used herein as a means for identifying palaeoenvironment. It is hoped that this will help to explain the distribution and content of spore assemblages by providing an indication of degradation and transport; processes which may disrupt the presence or absence of species. Quantitative palynofacies analysis (using a *Lycopodium* spore 'spike') is the most accurate method for comparing proportions of the different components within an assemblage. However, this method requires reprocessing of each sample, and is beyond the scope of this project. The method used will give a general guide to palaeoenvironment, and will be used in a comparative sense i.e. 'Locality A' is situated more distally / has lower oxygen levels than 'Locality B'. Although this is a relatively crude analysis, it will provide a useful overview of the depositional environments in the Mississippi Valley and adjacent areas, and leaves the way open for more detailed, future analyses.

9. 3 LIMITATIONS OF PALYNOFACIES ANALYSIS

As previously mentioned, palynofacies analysis can be as detailed or as vague as is required. However, even in the most detailed studies, there are still limitations which apply to the use of palynofacies analysis as a tool for interpretation and care must be taken not to rely too heavily on the outcomes.

The organic matter preserved within a rock is only a small proportion of the total organic material produced – estimates put it at less than 1% (Brooks 1981; Tyson 1995), and most of this is at least partly decayed (Batten 1996). Chitin, sporopollenin and cutin are all relatively resistant to weathering (in comparison to soft tissue), but can still be removed or recycled by transportation, predation and decay. The production of organic matter in terrestrial ecosystems is dependant on many factors such as the climate, type of soil, and available nutrients. Preservation is dependant on the accumulation of this material in lacustrine and fluvial systems, the degree of transportation, oxygen levels and biological degradation (Batten 1996). Most organic matter is preserved in anoxic environments (e.g. dark grey and black shales) and can be concentrated by turbidites and winnowing (Tyson 1995; Batten 1996).

The methods of extraction will also have an effect on the final observed organic matter. Care needs to be taken when using certain palynological processing methods. Amorphous organic matter (AOM) may be lost during palynological preparation, especially sieving where up to 100% of the total AOM may be lost (Tyson 1995). Oxidation of the samples will alter and eventually destroy organic matter, so residues must be unoxidised.

9. 4 CLASSIFICATION SCHEMES OF ORGANIC MATTER USED IN PALYNOFACIES ANALYSIS

The term 'palynofacies' was introduced by Combaz (1964) to describe the, "*total microscopic image of the organic components*", that is, the total acid-resistant palynological organic matter (POM, also referred to as kerogen) recovered from sedimentary rocks. The type and preservational state of this organic matter can be used to reconstruct the palaeoenvironment in which the sediments were deposited. Numerous authors have since used palynofacies analysis as a tool for reconstruction (for examples see Bujak *et al.* 1977; Hart 1986; Tyson 1995; Batten 1996; Smith 1996). However, no official classification of organic matter exists and analyses are generally tailored to the needs of the particular study. As a result, a wide variety of classifications have been used. These are dependant on many factors including the maturity and age of the material, the range of facies represented and the objectives of the authors (Tyson 1995).

For a detailed analysis of POM, Tyson (1995) cites the following variables which should be considered – the biological provenance of the particles, ecological groupings of the particles, preservational state, variations in size/morphology, hydrocarbon generating potential and differences in the geological age and/or organic maturation. The different types of POM have been categorised in many ways; commonly into phytoclasts, palynomorphs and amorphous organic matter (AOM) (Tyson 1995), and phyrogen, hylogen, melanogen and amorphogen (Bujak *et al.* 1977), with numerous subdivisions of each.

Selected classification schemes of organic matter applicable to this study are outlined in detail below and comparisons are drawn in Figure 9.1.

9. 4. 1 Burgess 1974

Burgess (1974) divided organic matter into amorphous, finely disseminated O. M. (organic matter), herbaceous plant debris, woody plant debris, coaly fragments and algal debris. These categories have since been abbreviated to single words – amorphous, herbaceous, woody, coaly and algal (Tyson 1995). A drawback to this classification is that the use of some of these names can be misleading or vague, mixing botanical terms (e.g. herbaceous) with ones that are essentially petrographic (e.g. coaly). An advantage of the scheme is that algal material is separated out, although the author gives no clear definition of exact usage of the term (Tyson 1995).

9. 4. 2 Bujak *et al.* 1977

Bujak *et al.* (1977) presented a similar classification to that of Burgess (1974), the major difference being the use of morphological category names in place of the original botanical terms. The terms amorphogen, phyrogen, hylogen and melanogen replace the names amorphous, herbaceous, woody and coaly respectively. These terms avoid any botanical connotations and have since been used in various publications such as those by the British Geological Survey e.g. Davies *et al.* (1991), Coleman and Clayton (1987), McPhilemy (McPhilemy 1988; McPhilemy 1989) and Connolly (2002), as well as some Scandinavian workers. However, they have not been widely adopted and are generally unfamiliar to many palynofacies workers (Tyson 1995), so have not been adopted here.

9. 4. 3 Hart 1986

Hart (1986) based his classification on 'maceral clasts' (organic particles), dividing them into phytoclasts (plant derived), protistoclasts (algae, dinocysts, acritarchs and microforaminiferal linings), scleratoclasts (fungal spores and hyphae), zooclasts (arthropod, graptolites and chitinozoans), receptoclasts (artifacts of sample preparation), and indeterminate clasts. The scheme also distinguishes five preservational categories. However, these categories are subjective and the inclusion of the terms 'amorphous structured' and 'amorphous non-structured' for the most poorly preserved phytoclasts is confusing as well as contradictory to other classification systems.

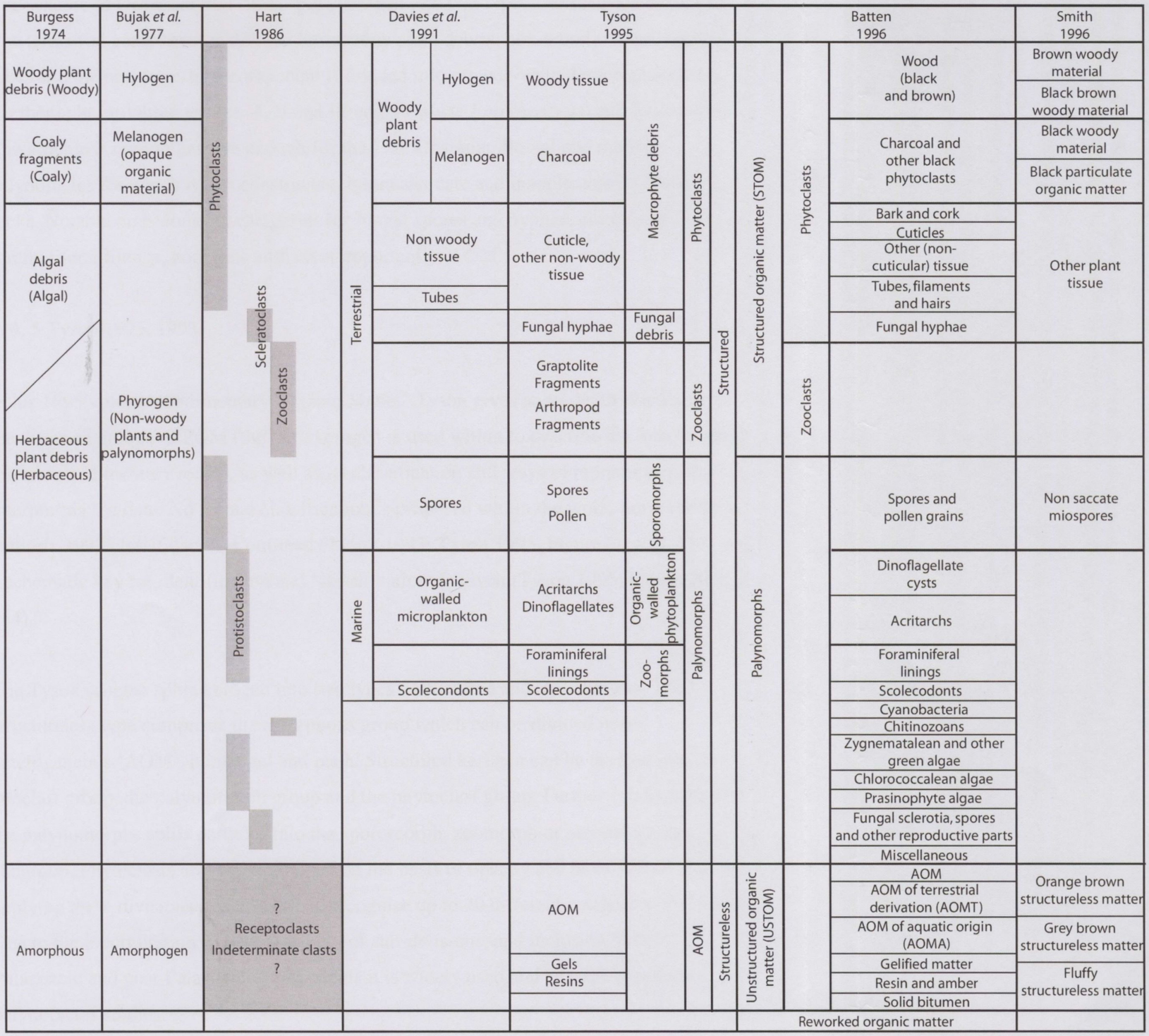


Figure 9.1 Classification schemes of organic matter used in palynofacies analysis

9. 4. 4 Davies *et al.* 1991

The scheme of Davies *et al.* (1991) splits kerogen into two types – terrestrial and marine. The terrestrial component is divided into woody plant debris, non-woody tissue, spores and tubes and the non-terrestrial component is divided into organic-walled microplankton (further split into three groups –I, II and III and the algae *Botryococcus*) and scolecodonts. The scheme is comprehensive enough for the Late Devonian fluvial and marine palynofacies for which it was constructed, but inadequate and inapplicable to younger rocks. Notable omissions are categories for fungal spores and hyphae, chitinozoa, foraminiferal linings, zooclasts and, most importantly, AOM.

9. 4. 5 Tyson 1995, 1993

In his 1995 volume 'Sedimentary Organic Matter' Tyson gives an in-depth discussion of the different groups of POM (the term kerogen is used within to describe the fossil organic matter in sedimentary rocks), as well as its classification and ways of representing and interpreting the data. No formal classification is proposed within the work, however the author's 1993 classification is outlined (Tyson 1993; Tyson 1995, Figure 20.1, p. 334), and a schematic key for identification and 'classification' is given (Tyson 1995, Figure 20.5, p. 354).

The Tyson scheme splits kerogen into two types - structured and structureless. The structureless type comprises the amorphous group which can be divided into heterogeneous 'AOM', humic gel and resin. Structured kerogen can be divided into the zooclast group, the palynomorph group and the phytoclast group. Further subdivision of the palynomorphs splits particles into the sporomorph, zoomorph or phytoplankton subgroup. Phytoclasts are further divided on the basis of opacity and biostructure. By applying these divisions it is possible to recognise up to 20 different categories of kerogen. Due to the incorporation of a wide variety of sub-divisions, and inclusion of both Palaeozoic and post-Palaeozoic components it is widely used and adaptable to most palynofacies studies.

9. 4. 6 Batten 1996

Batten (1996) provides a classification of palynological matter (PM) dividing it into four main categories; palynomorphs (including spores, acritarchs, algae, foraminifera, chitinozoa and scolecodonts), structured organic matter (STOM) (subdivided into phytoclasts and zooclasts), unstructured organic matter (USTOM) (including terrestrial and aquatic AOM, gel and resin) and reworked organic matter. This scheme is unsuitable for the current study due to the complications of recognising different types of AOM and reworked organic matter.

9. 4. 7 Smith 1996

The classification of Smith (1996) follows the Amsterdam Palynological Organic Matter Classification, 2nd edition, as defined at Aix-en-Provence, France in September 1992. This classification was an attempt to establish an internationally recognised palynofacies analysis scheme. However, the scheme has never been published and is not readily accessible. Therefore, it has not been widely accepted.

9. 4. 8 CLASSIFICATION SCHEME USED IN THIS STUDY

For the current study a modified version of the Tyson (1995) scheme has been used. As previously mentioned, the scheme is widely applicable depending on the categories chosen. Obviously for Palaeozoic palynology, certain Mesozoic and Cenozoic categories will be inappropriate e.g. dinoflagellates, and are omitted. Also the zooclast group and foraminiferal linings category are omitted as they have not been recognised in the samples. A separate '*Tasmanites*' category has been included, and the woody tissue and charcoal groups have been slightly modified following Batten (1996) (Figure 9.2).

The major groupings – phytoclasts, palynomorphs and AOM, are used to construct ternary 'AOM'-phytoclast-palynomorph kerogen plots (Figure 9.3). These plots were originally defined using Late Jurassic sediments, but have since been successfully applied throughout the Mesozoic and Cenozoic (Tyson 1995) and Palaeozoic (e.g. Connelly 2002; James 2003; Jäger & McLean 2008). A drawback of using ternary plots is they do not differentiate between the different types of palynomorphs, namely the marine and non-

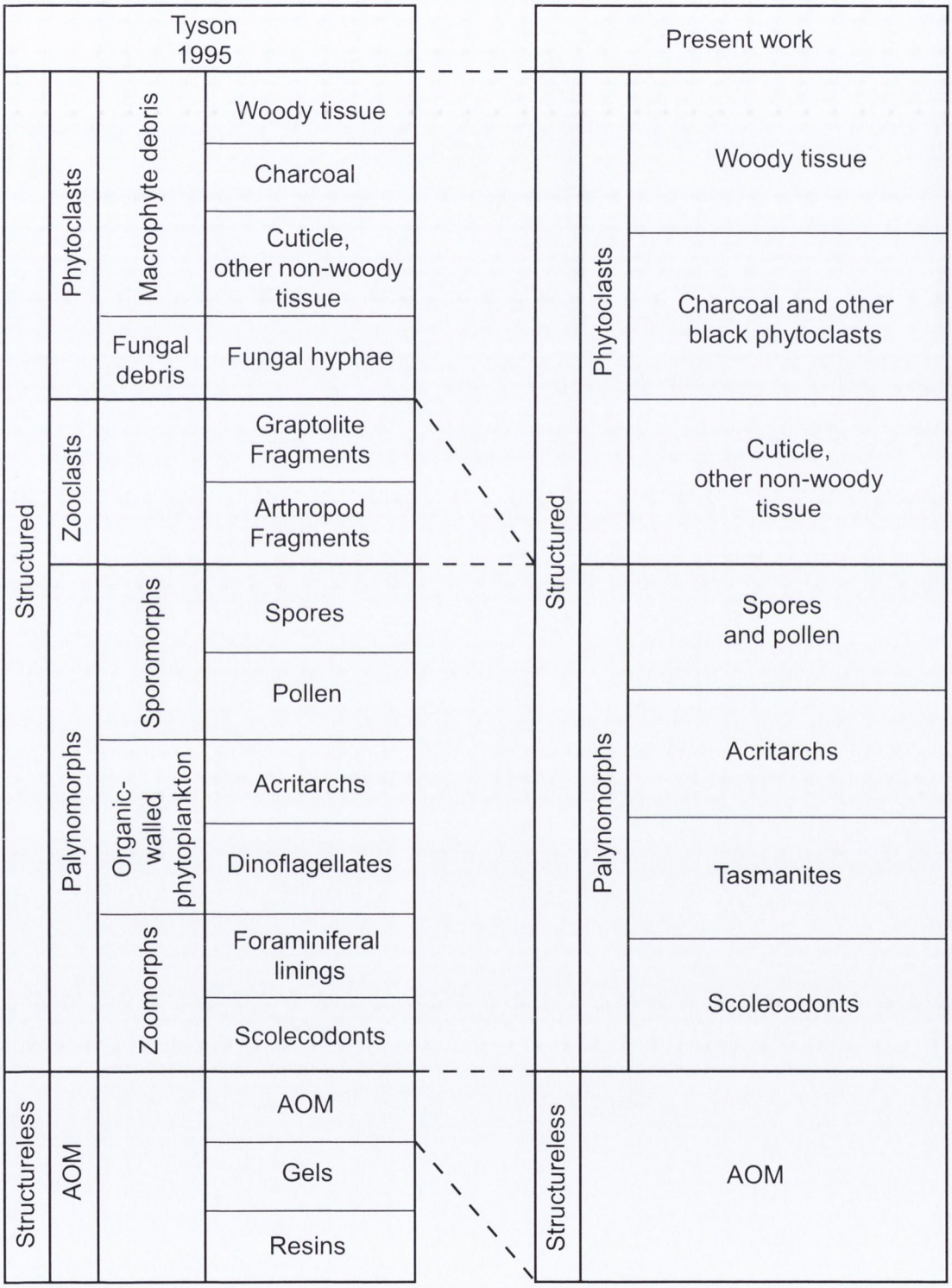


Figure 9.2 Palynofacies classification scheme used in the present work

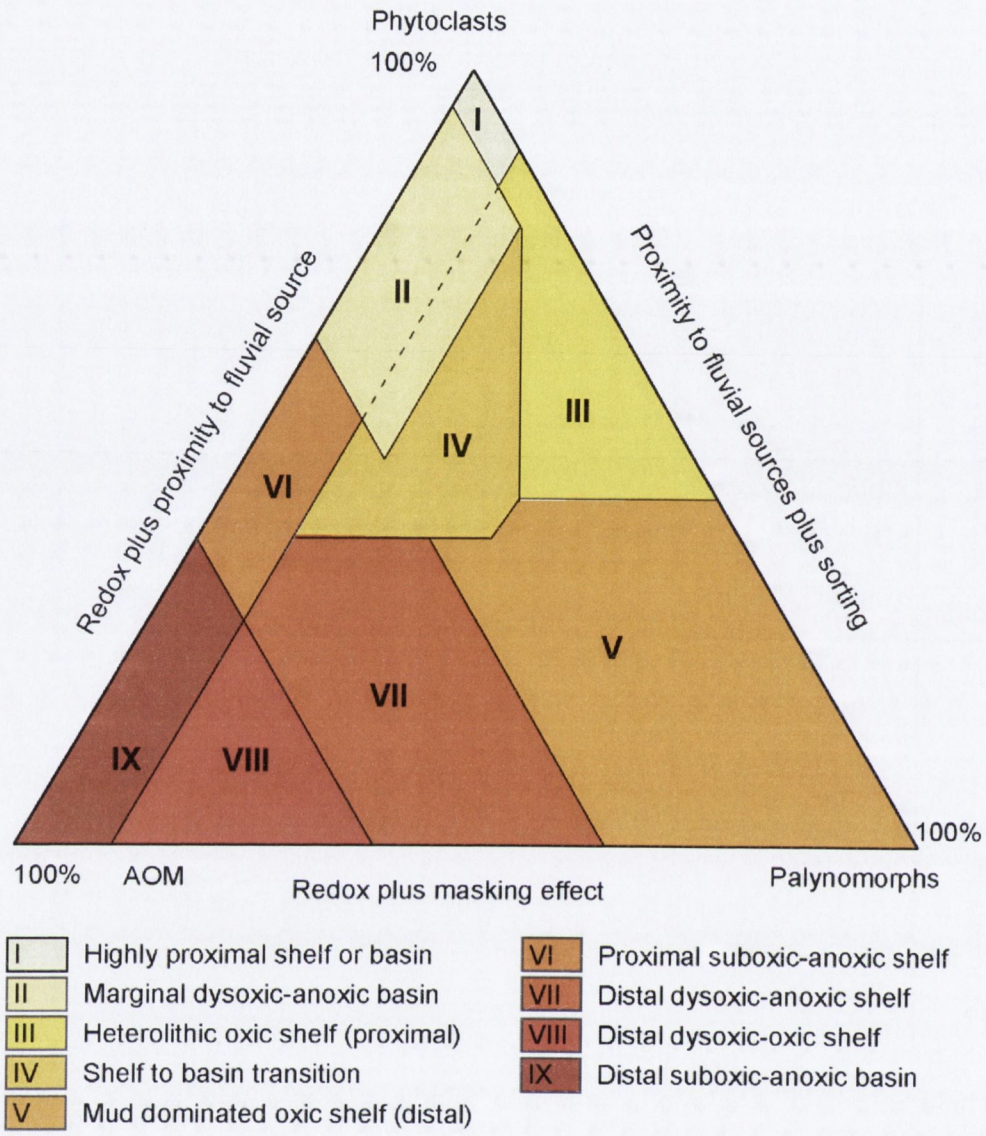


Figure 9.3 Ternary 'AOM'-phytoclast-palynomorph kerogen plot (after Tyson 1993; 1995)

marine components. Another possible problem is the use of relative abundance data as opposed to absolute abundances. A relative decline in the amount of particles in one group may either be a true decline or simply the effect of a large increase in one of the other groups e.g. a phytoplankton bloom. This must be kept in mind when interpreting the data.

9. 5 CLASSIFICATION OF ORGANIC PARTICLES

Usage of terms differs depending on the classification scheme being used. For example, Tyson (1995) and Batten (1996) include fungal hyphae within the phytoclast group and classify fungal sclerotia and spores as palynomorphs. However, Hart (1986) places all

fungal material in a separate 'scleratoclasts' group. Definitions of the different categories of organic particles as used in the current scheme are therefore given below.

In the present scheme palynological organic particles are divided into two major groups, 'structured' and 'stuctureless'. The structured group is split into a further two sub-groups and seven categories. The structureless group comprises the sub-group AOM (Figure 9.2).

STRUCTURED

Three kinds of organic particles fall into this group, those with a well-defined morphological structure, fragments which contain or at least partially contain some original botanical features, and angular or irregular particles with a distinct outline, structure or shape which is indicative of botanical origin (Tyson 1995).

Phytoclasts

The term 'phytoclast' was originally used to describe particles of plant matter originally derived from land plants, and included coal-like organic matter with relic plant structures such as plant spores and pollen, cuticles and other structured fragments. 'Floccules', recognised as algal debris or liptinite, were also included (Bostick 1971). The term was therefore defined as encompassing all particles of plant-derived kerogen (Tyson 1995). Subsequent definitions used the term in a narrower sense, literally 'phyto' (the Greek term for plant) 'clast' (from the Greek term *klastos* – meaning broken) (Alpern 1980; Hart 1986; Tyson 1995). This latter definition excludes palynomorphs and AOM and is used herein.

Woody Tissue

Woody tissue, sometimes referred to as hylogen (Coleman & Clayton 1987), is a common component of the preserved palynological organic matter within sediments. These particles have a high preservation potential due to their characteristic lignin content – a hydrophobic and therefore highly stable and decay resistant compound (Tyson 1995). The most commonly observed structures are the heavily lignified support and vascular tissues or 'xylem', e.g. tracheids and vessels (Plate 20, figures 6-8). This type of tissue is present in modern gymnosperms and angiosperms, but would also have been present in extinct early

vascular plants. Tracheids can be recognised by their distinctive pits and pores, which allow for intercellular transport (Tyson 1995; Batten 1996).

In the present work woody tissue refers to all phytoclasts with recognizable woody structures (Plate 20, figures 1-8), very dark brown material may be difficult to distinguish from true opaque material but care is taken in defining the presence or absence of woody structures, and whether the edge of the particles are opaque (classed as charcoal) or translucent (classed as woody tissue).

Charcoal and other black phytoclasts

Most of the opaque organic matter (also known as melanogen) within an assemblage can be identified as charcoal – defined as terrestrial plant material which has undergone intense heating in oxygen starved conditions (Cope 1981; Chaloner 1989). Tyson (1995) notes that a continuous range of oxidized and charred plant material can be identified, so that clasts exhibiting true opacity may be difficult to distinguish from those which are very dark brown. Pyrite is also opaque under transmitted light but is usually distinguished by its framboidal shape.

The term charcoal has previously been used to describe all opaque or semi opaque matter regardless of origin (Masran & Pocock 1981). However, the term is used herein in its more specific sense. Other black phytoclasts included in this category are most likely oxidized land plant tissues which are generally of a more degraded appearance with less structural preservation (Tyson 1995) (Plate 21, figures 1 & 2).

Cuticle and other non-woody tissue

Cuticular material is derived from the outer epidermis of higher plants that do not show secondary growth, e.g. unlignified tissue. In modern assemblages this cuticle is relatively thin (<0.1μm – 3μm) (Mauseth 1988) and commonly comes from the leaf epidermis. Carboniferous cuticle material from coal assemblages has a wider range of thicknesses from <1μm to >10μm (Tyson 1995), possibly due to the wider variety and increased dominance of non-vascular plants at this time. Cuticles can be recognised by their generally thin and 'flimsy' appearance and rectangular, rounded, hexagonal, pentagonal or tetragonal cell pattern (e.g. Plate 21, Figure 6).

Other plant tissues and phytoclasts included in this category are those in which no cell structure is recognisable but a definite organised internal structure or fabric can be seen (Plate 21, figures 3-5). These clasts are generally variable in colour, size and thickness. Also included are tubes (possibly fungal hyphae) (Plate 21, figures 8 & 9), fibres (Plate 21, Figure 7) and bundles of fibres, these are generally dark in colour and are easily distinguishable from the more sheet-like cuticles and other clasts.

This material falls into the phyrogen category of earlier classification schemes (e.g. Bujak *et al.* 1977) a group which includes palynomorphs and algal material. In the present study this category includes cuticle material as is defined above as well as other phytoclasts which cannot be assigned to the 'woody' or 'charcoal' categories.

Palynomorphs

The term 'palynomorph' (Tschudy & Scott 1969) refers to all discrete acid-resistant, organic-walled microfossils that may be encountered in a palynological preparation (Batten 1996).

In the zonal scheme of Tyson (1995) the palynomorph group is split into three subgroups; sporomorphs (spores, pollen and fungal spores), phytoplankton and zoomorphs (animal derived palynomorphs including foraminiferal linings, Chintinozoa and scolecodonts). In the present study these subgroups have not been included due to the lack of diversity within the palynomorph group, therefore four categories are recognised; spores and pollen (sporomorphs), acritarchs (phytoplankton), *Tasmanites* (phytoplankton) and scolecodonts (zoomorphs).

Spores and pollen (Plates 1-17; Plate 22, figures 1-4)

The term 'spore' is defined as the "durable reproductive cell of bryophytes and free-sporing pteridophytic vascular plants" (Playford & Dettmann 1996) i.e. the reproductive cells of early land plants. Pollen refers to the "free living gametophyte generation of seed plants" (Jarzen & Nichols 1996) i.e. the reproductive cells of seed-producing land plants. The term miospore is widely used to refer to small spores and pollen in a collective sense, and encompasses homospores (where all spores are the same size for a given species),

male microspores of heterosporous plants, and pre-pollen or pollen of primitive seed plants less than 200μm (Kosanke 1969). Spores became an increasingly important component of palynological assemblages from the Middle Palaeozoic onwards, with pollen appearing in the Late Palaeozoic. Spores and pollen are generally the dominant components of the palynomorph group; however distribution can be affected by transportation (dominantly water, rather than wind-borne), distribution of the parent plant, and degradation by bacterial grazing and pyrite overgrowth (Batten 1996). For a more detailed description of spore morphology see Chapter 5.

In Tyson's 1995 classification, spores and pollen are defined as two separate categories, belonging to the sporomorph subgroup. In the present study, spores and pollen are grouped together in a single category. This is due to the appearance of prepollen in the latest Devonian and its gradual establishment throughout the Mississippian, and the appearance of true pollen (in the form of saccate pollen) in the Middle Mississippian (Jarzen & Nichols 1996). The relative abundances of spores and pollen may therefore not be a true representation of palaeoenvironments.

Acritarchs (Plates 18-19; Plate 22, figures 5 & 6)

The term acritarch, meaning 'of uncertain origin' was first used by Evitt (1963) to refer to all palynomorphs of uncertain affinity, where the parent organism is either extinct or unknown. The group is polyphyletic, but the majority of acritarchs are generally recognised as marine phytoplankton (Tappan 1980). Classification is based on morphology and a wide variety of forms exist, with the most diverse assemblages being recorded from the Ordovician to the Late Devonian (Tyson 1995). Acritarchs are locally common in early Mississippian sediments, but diversity declines towards the end of the subsystem.

Tasmanites (Plate 22, Figure 7)

The fossil genus *Tasmanites* is classified within the prasinophyte algae and as such belongs to the phytoplankton subgroup of Tyson (1995). The prasinophytes were previously classed within the Acritarcha but are now generally recognised as the resting stages of phytoplankton e.g. cysts or phycomata (Traverse 1988; Playford 2003). *Tasmanites* is recorded as a separate category in the current classification because of its frequent

appearance within Early Palaeozoic sediments and the absence of other prasinophyte algae within samples.

Scolecodonts (Plate 22, figures 8-11)

Scolecodonts are the 'teeth-like' mouth parts ('pharyngeal jaws') of benthic annelid worms. Compositionally they are part-calcified and sclero-proteinaceous ('chitinous'). They range from Early Ordovician to Recent, with the highest abundance recorded from the Ordovician to Devonian (Traverse 1988; Tyson 1995). Most scolecodont elements occur as isolated parts, as the soft parts of the animal are easily degraded. Scolecodonts can range in size from around 100μm to over 1000μm (Brenchley 1979), and they are usually well preserved and orange brown in colour, making them easily identifiable. In the current study, the size range was between 100μm and 500μm.

Tyson (1995) assigned scolecodonts to the zooclast group, due to their animal origin. In the present study, the zooclast subgroup becomes redundant due to the lack of other members of the group.

STRUCTURELESS

The term 'structureless' is used herein to describe any organic particles with no obvious structure, shape or organised internal fabric which suggests the original state of the material (Tyson 1995). In the classification of Tyson (1995) the term includes all AOM as well as gels and resins. In the present study these latter two groups have not been recognised and therefore the term refers solely to material categorised as AOM

AOM (Plate 23, figures 1-6)

Amorphous organic matter (AOM, also referred to as amorphogen), is mainly derived from phytoplankton or bacteria, and is used in palynofacies analysis in a descriptive sense. A second source of AOM is from degraded woody tissue. It is normally recognised by a lack of internal structure with a 'fluffy' or non-definitive outline. AOM is "typically heterogeneous and consists of a truly amorphous matrix and a variety of structured or 'pseudoamorphous' inclusions that often give it a variably 'clotted' (grumose) appearance" (Tyson 1995, pg. 169). AOM ranges from brown-grey to dark brown to orange brown in

colour. The origin of AOM can be identified by use of fluorescence microscopy. AOM derived from melanogen (woody tissues) and hylogen (opaque organic matter) does not usually fluoresce. AOM of liptinitic origin (e.g. algal, spore, cuticle) fluoresces brightly, although fluorescence decreases with maturation (Van Gijzel 1967; McPhilemy 1988; McPhilemy 1989; Van Gijzel 1989). AOM of marine origin is therefore usually fluorescent, whereas AOM derived from degraded woody tissue generally does not fluoresce (McPhilemy 1988; McPhilemy 1989; Van Gijzel 1989).

9. 6 METHODS

Samples were processed for palynofacies analysis as detailed in Chapter 4. Samples were mounted at all stages of processing i.e. unsieved and sieved residues, samples cleaned by boiling in HCl, and at various oxidation intervals. Sieving residues tends to break down the AOM component, but many samples contained a large proportion of fluorite crystals and other minerals which obscured much of the organic matter. These were removed by boiling in HCl and sieving. Therefore gentle sieving of samples was undertaken and samples were examined at the stage prior to oxidation. This may have biased the sorting of the samples as the <20μm fraction was removed and some AOM particles may have become additionally fragmented.

As previously stated, oxidation alters and/or destroys certain components of the palynofacies. Batten (1996) advocated brief ultrasonic/oxidative treatment to clean residues for palynological analysis, but this was deemed unnecessary and not worth the risk of damage to samples in the present study.

Palynofacies analysis was carried out on a Nikon palynological (transmitted light) microscope. A total of 136 samples were analysed. For the present study particle counts were made as opposed to relative area counts. One possible drawback of using counts is that particle size can influence results; this is especially true in the case of larger woody clasts, sheet-like cuticle clasts and large clumps of AOM. Relative area counts are more suitable for samples comprising highly variable-sized clasts, or a large proportion of AOM. However, in the present study material is generally fairly uniform in size and where larger clasts are encountered (e.g. S215, S216, S40) they are counted as numerous particles. AOM is not commonly encountered in most samples.

Previous studies of this nature have used around 300-350 counts per sample (Coleman 1991; Connelly 2002), Tyson (1995) advocates 500 particles per sample. For the present study cumulative counts were carried out on selected samples, with previously recognised different depositional environments (Coleman 1991; Heal & Clayton 2008) – S47 from the Hannibal type section in the Mississippi Valley and S39 from Morehead in Kentucky. The former has a relatively high proportion of AOM and is interpreted as a transitional shelf to basin environment (Heal & Clayton 2008); the latter has an abundant spore assemblage and is recognised as pro-delta (Sable & Dever 1990; Coleman 1991). From these counts it was determined that a count of 300 particles per sample is sufficient. Particles were identified and categorised according to the palynofacies classification outlined above and detailed in Figure 9.2.

9. 7 RESULTS AND INTERPRETATION OF PALYNOFACIES ANALYSIS

The results of the palynofacies analysis are shown in Figures 9.4 to 9.17. For more detailed information and individual counts refer to Appendix III.

9. 7. 1 KENTUCKY

Morehead (Figure 9. 4a, b)

The oldest samples from Morehead are from the Upper Devonian Ohio Shale and Bedford Shale. The Ohio Shale is dominated by AOM with very few phytoclasts and spores, many of which were partially obscured by large clumps of AOM. The samples are clustered in field IX of the ternary plot suggesting a distal suboxic-anoxic basin environment (Figure 9.4b).

The Bedford Shale has a very different assemblage compared to the underlying and overlying units, being dominated by spores, light brown plant cuticle and dark brown woody tissue (samples S39 and S214). The palaeoenvironment is interpreted as an oxic shelf, possibly transitional between mud dominated (distal, field V) and heterolithic (proximal, field III). This assemblage is similar to the 'tasmanites – amorphogen palynofacies' recognised by Coleman & Clayton (1987), who interpret the Bedford Shale as a prodelta environment. The proportion of AOM within samples S39 and S214 (1-15%) is slightly different to that recorded by Coleman & Clayton (4.5-64%).

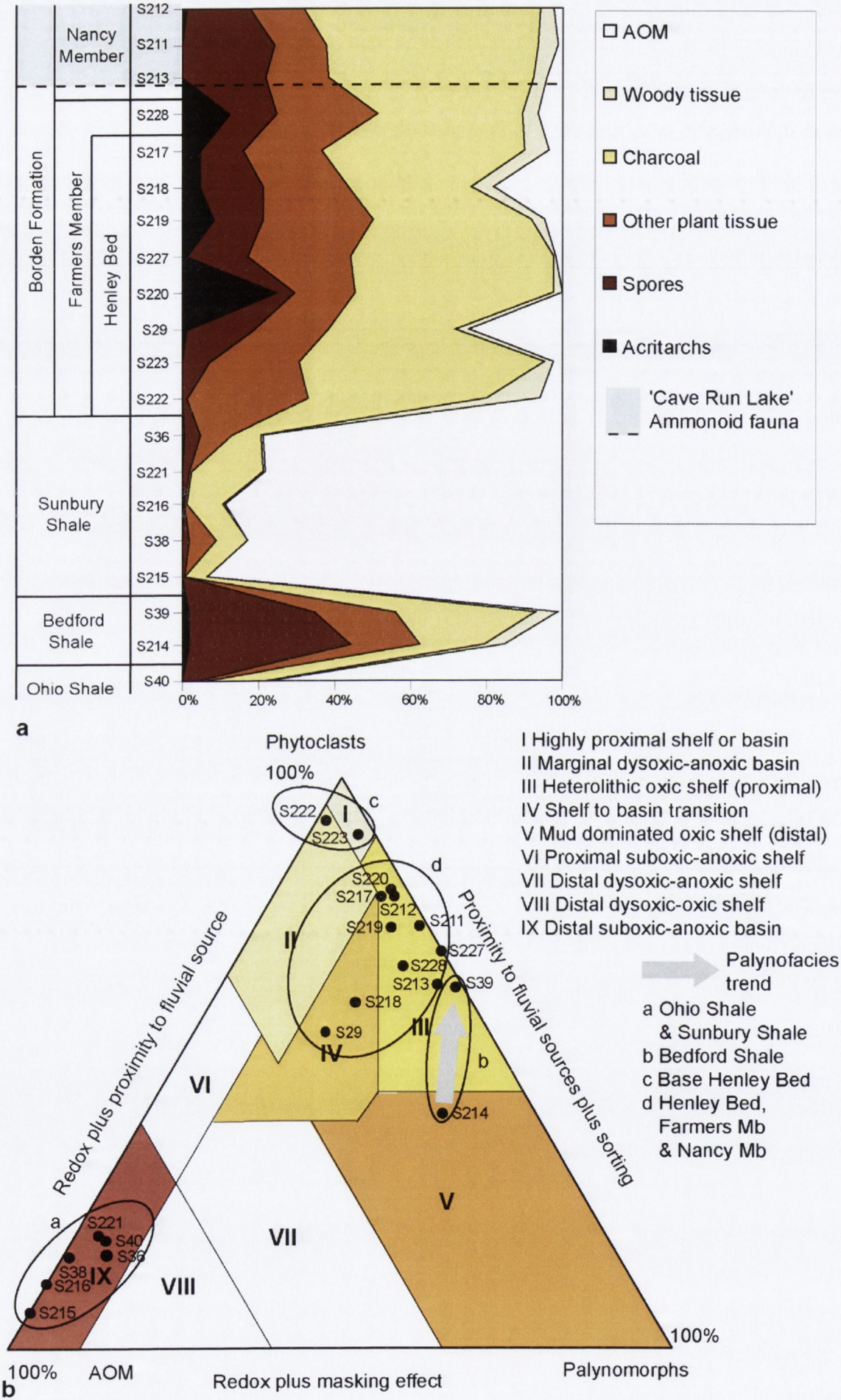


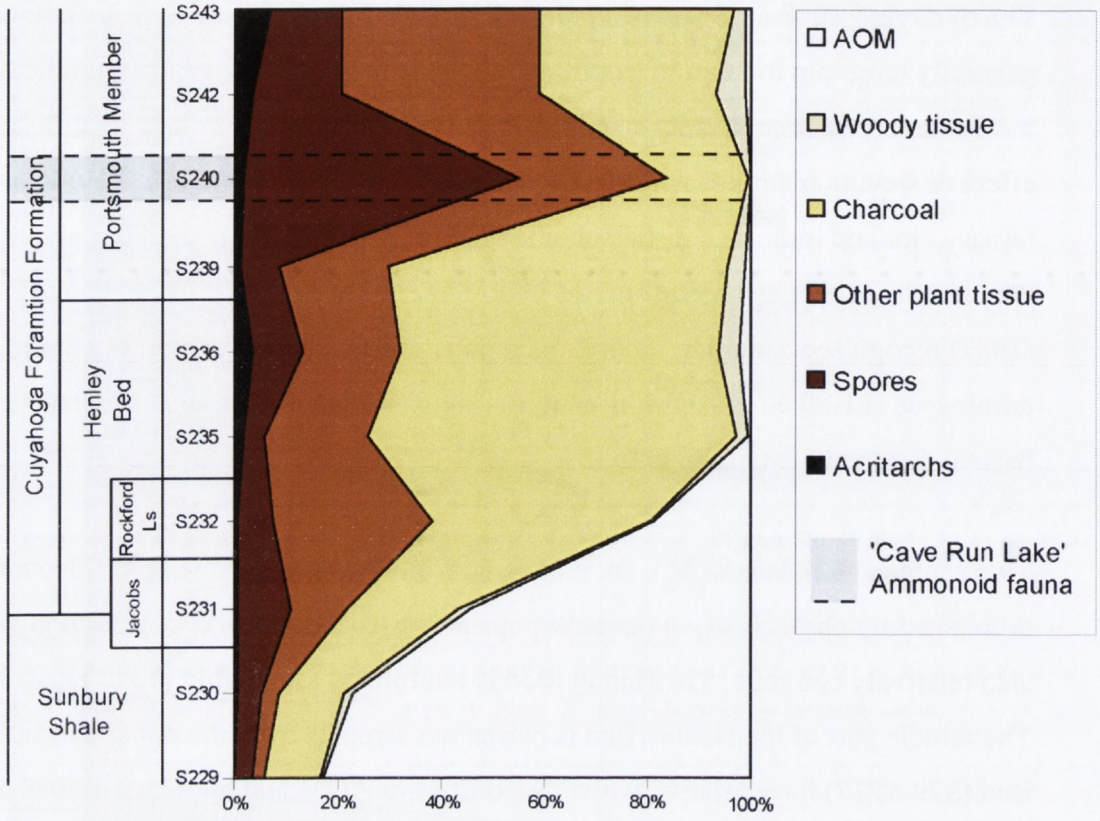
Figure 9.4 Palynofacies analysis for Morehead, Kentucky a - Palynofacies counts b - ternary plot

The overlying Sunbury Shale is dominated by AOM throughout (>78%), clasts are generally large (up to 2mm in length), although some samples from the middle of the unit have smaller, more uniformly sized particles (40 – 150μm). It is noted that this could be an effect of sieving methods. All samples from the Sunbury Shale plot in field IX of the ternary plot and indicate a distal suboxic-anoxic basin environment. The palynofacies is very similar to that recorded from the Ohio Shale at this locality. Coleman & Clayton (1987) recognised a similar 'amorphogen palynofacies' from the Sunbury Shale, noting the dominance (81-89%) of AOM in samples. They interpreted the Sunbury Shale as a quiet, basinal deposition environment.

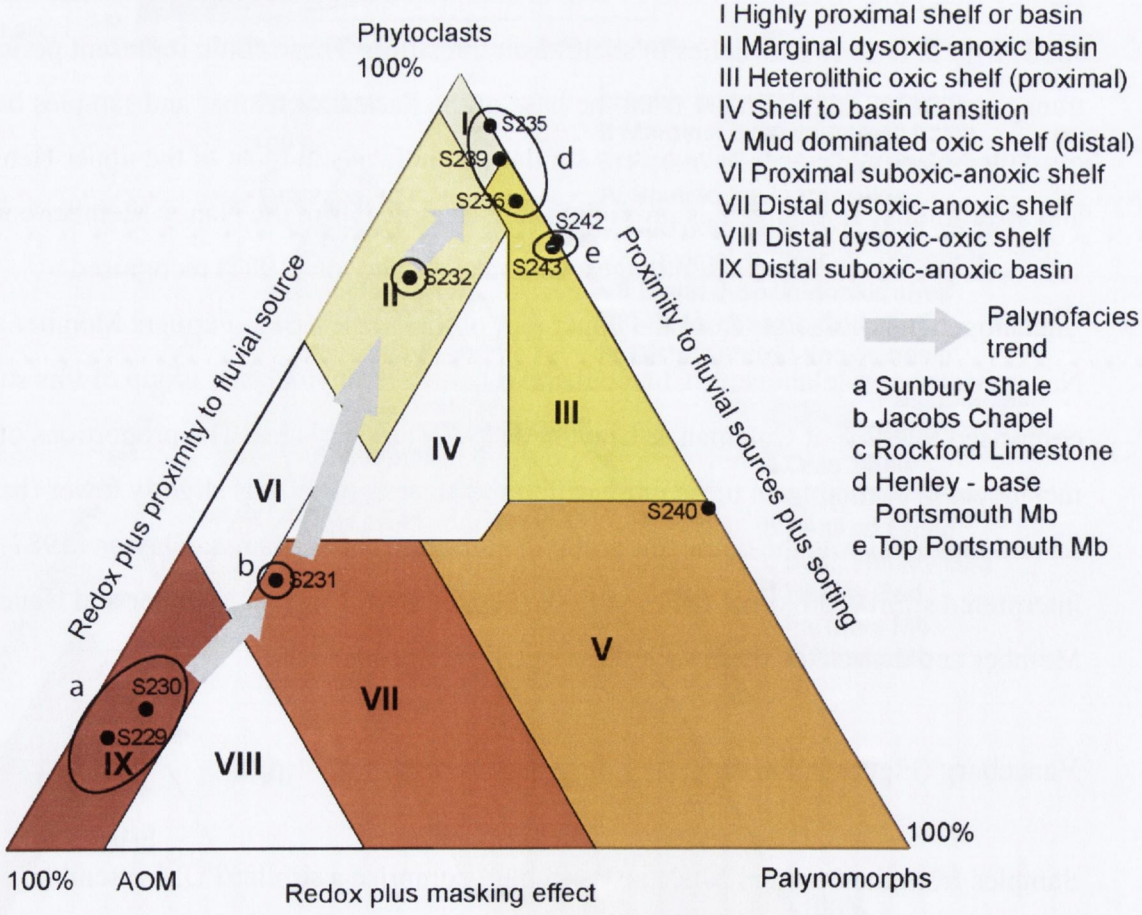
Two samples, S222 and S223, are recovered from the base of the Henley Bed and are dominated by phytoclasts, in particular opaque phytoclasts. Dark brown woody tissue is also relatively common. The Henley Bed is interpreted as a highly proximal shelf or basin. The middle part of the Henley Bed is barren but samples from the upper part of the Henley Bed (S29-S217) have relatively low proportions of AOM and high proportions of phytoclasts. Again opaque phytoclasts dominate most samples. The upper part of the Henley Bed plots in fields III and IV and is interpreted as heterolithic (proximal) oxic shelf, with at least two switches to shelf/basin transition. These could represent periods of transgression. A single sample from the base of the Farmers Member and samples from the overlying Nancy Member have a very similar palynofacies to most of the upper Henley, and are similarly interpreted as proximal shelf. Samples from the Nancy Member contain very well preserved spore assemblages. Coleman & Clayton (1987) recognised a 'melanogen palynofacies' from the upper part of the Henley Bed, Farmers Member and Nancy Member. Melanogen ('Charcoal and other black phytoclasts' group of this study) comprised 52-92% of Coleman & Clayton's (1987) assemblages. The proportions of melanogen recorded from these units within the present study was slightly lower (between 38 and 66%) but was the dominant group in all samples. Coleman & Clayton (1987) interpreted similar proximal facies with the Henley Bed, Farmers Member and Nancy Member and associated them with the prograding Borden Delta.

Vanceburg (Figure 9. 5a, b)

Samples from the Sunbury Shale at Vanceburg comprise a similar POM assemblage to those from the same unit at Morehead. The palynofacies is dominated by AOM, with clast size apparently decreasing towards the top of the unit. The proportion of AOM gradually



a



b

Figure 9.5 Palynofacies analysis for AA Highway, Kentucky a - Palynofacies counts b - ternary plot

declines through the overlying Jacobs Chapel and Rockford Limestone as proportions of opaque and dark brown cuticle material increase. Spores and acritarchs comprise a minor part of these assemblages. A shift is recognised from distal suboxic-anoxic basin (field IX) in the Sunbury Shale to distal dysoxic-oxic shelf (VII) in the Jacobs Chapel to marginal dysoxic-anoxic basin in the Rockford Limestone.

The upper part of the section (Henley Bed and Portsmouth Member) is dominated by opaque phytoclasts and plant cuticle. The proportion of AOM within these samples is generally low (<2%). Minor shifts in the palaeoenvironment are recognised between proximal and highly proximal oxic shelf, possibly representing slight fluctuations in sea level. A similar palynofacies was recorded from the upper part of the Cuyahoga Formation in northeastern Ohio, dominated by hylogen (woody tissue) and melanogen (charcoal) with <1% amorphogen (AOM) (Clayton *et al.* 1998), and was interpreted as a nearshore depositional environment. Clayton *et al.* (1998) also recorded *Botryococcus* (freshwater algae) and tasmanitids associated with fluctuating levels of salinity and typical of deltaic environments. Neither of these taxa were recorded from the Cuyahoga at Vanceburg.

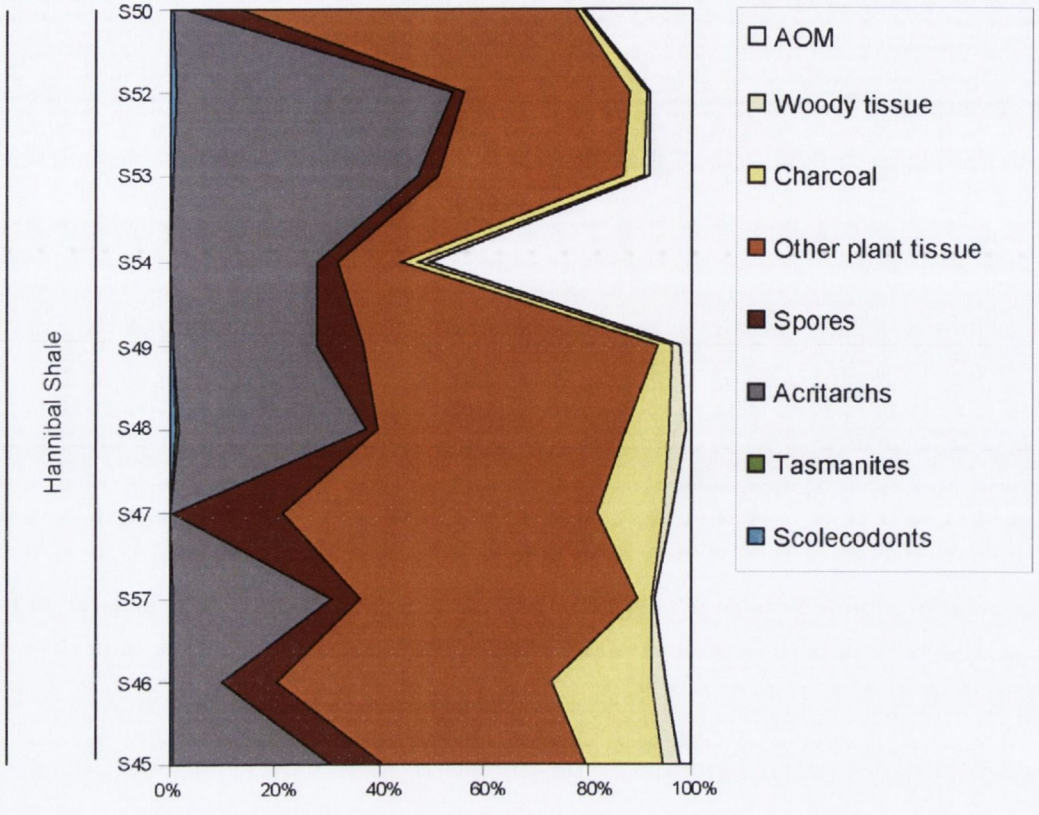
A single sample from the middle part of the Portsmouth Member yields a palynofacies with a high proportion of palynomorphs (56%) dominated by spores. This appears to indicate a shift towards a distal oxic shelf palaeoenvironment. This level can be correlated to a similar level in the upper part of the Farmers Member at Morehead by identification of a similar ammonoid fauna (the 'Cave Run Lake' fauna). No similar shift in palaeoenvironment is observed from a similar level within the Morehead section.

9. 7. 2 MISSISSIPPI VALLEY OUTCROPS

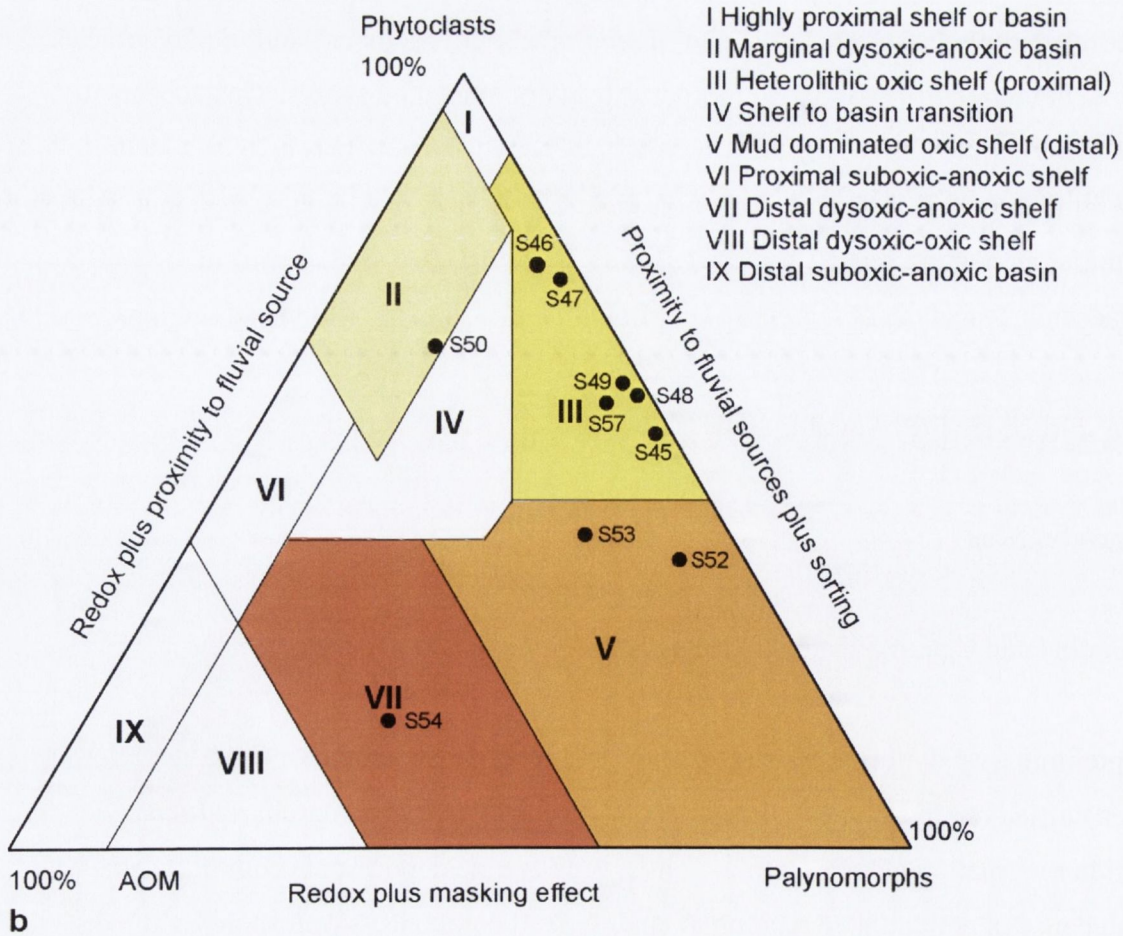
Kinderhookian

Hannibal and Clarence Cannon Dam (Figures 9. 6a, b and 9. 7a, b)

A preliminary palynofacies analysis of the Hannibal Shale at both of these localities has been carried out by Heal & Clayton (2008). The presence of acritarchs and scolecodonts within the Hannibal Shale samples confirms its marine depositional environment. The abundance of acritarchs in relation to land-derived components (miospores and

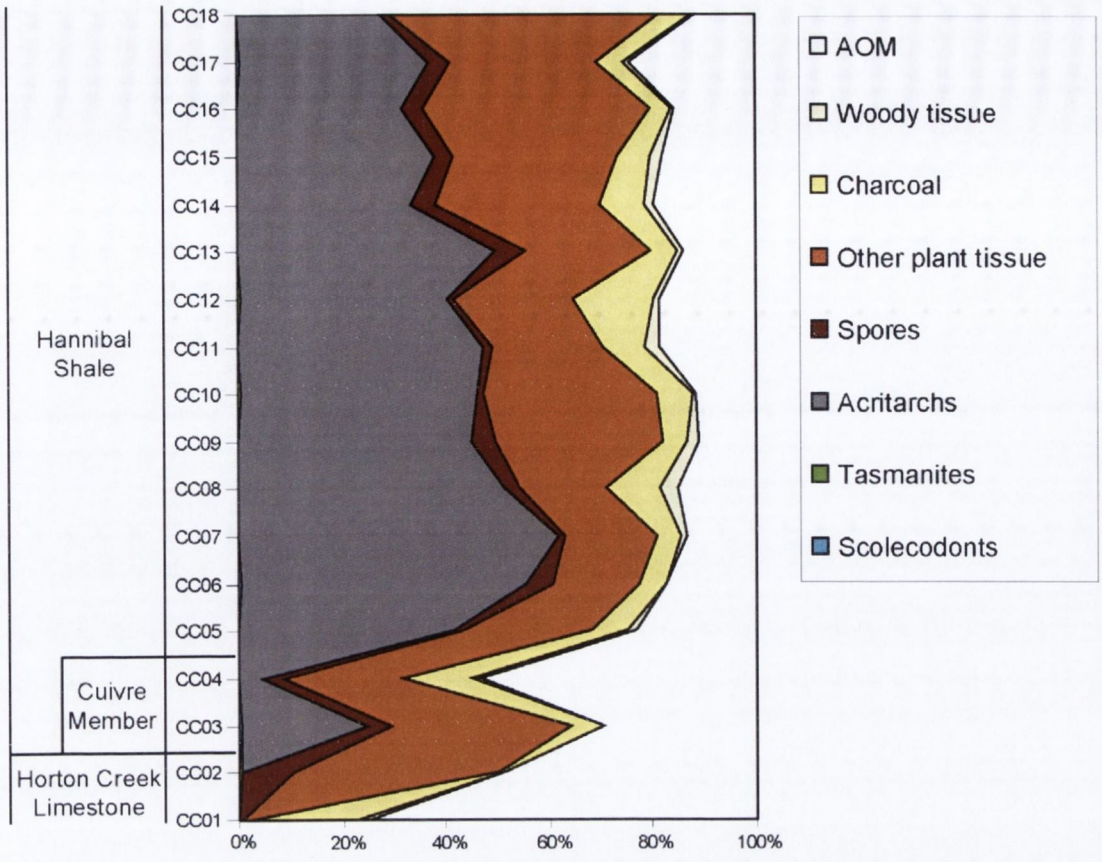


a

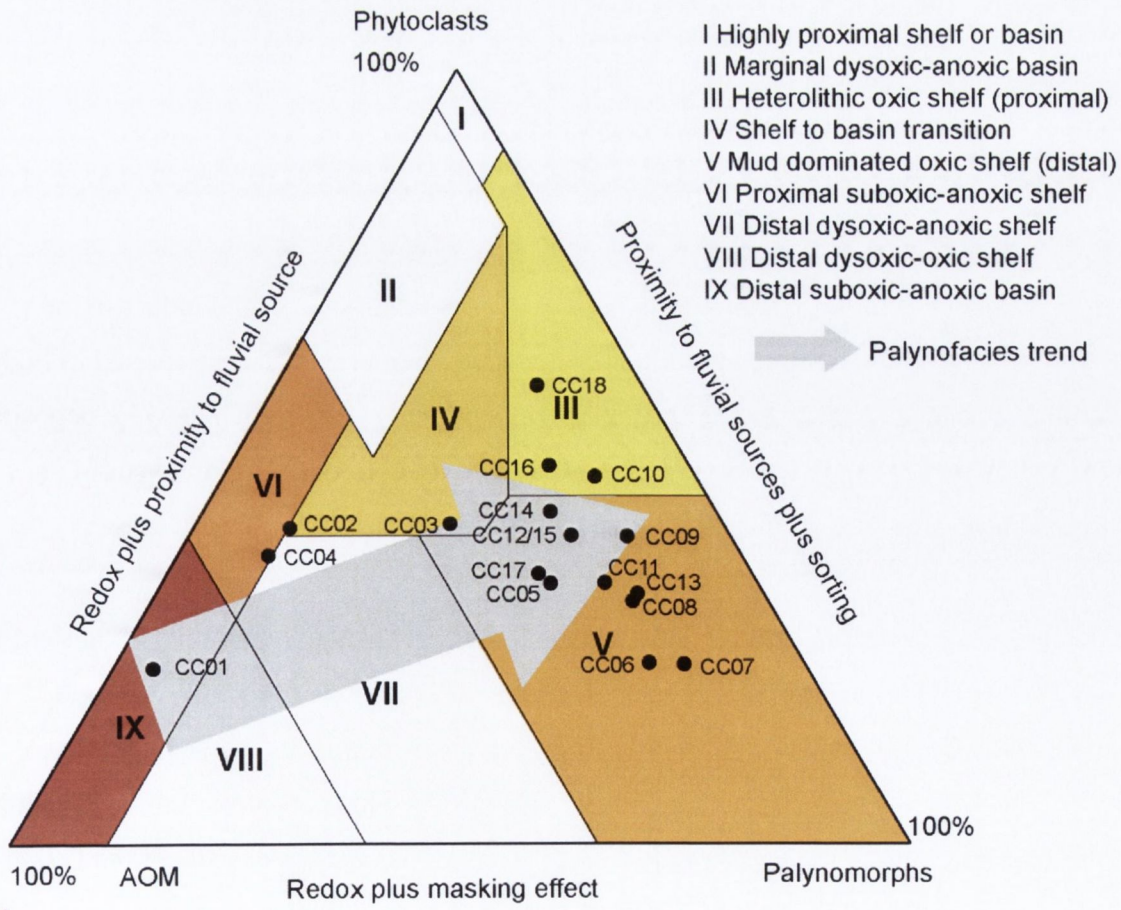


b

Figure 9.6 Palynofacies analysis for Hannibal, Missouri a - Palynofacies counts b - ternary plot



a



b

Figure 9.7 Palynofacies analysis for Clarence Cannon Dam, Missouri a - Palynofacies counts b - ternary plot

phytoclasts) suggests that the site of deposition was relatively distal in terms of the nearest terrestrial vegetation. Two samples from the Hannibal section (S50 and S54) and four samples from the base of the Clarence Cannon Dam core (CC01, CC02, CC03 and CC04) are relatively rich in AOM.

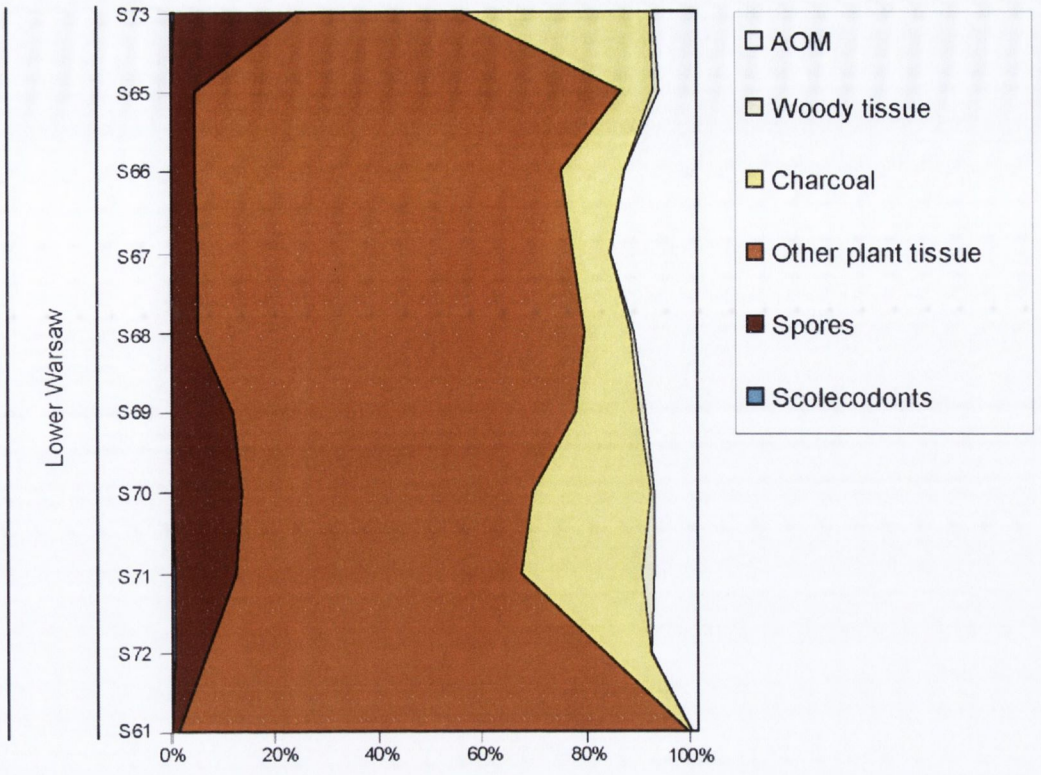
At Hannibal, the data mainly plot in fields III and V indicating oxic proximal shelf and distal shelf in terms of depositional environments (Figure 9.6b). The two outlying samples with increased proportions of AOM (S54 and S50), plot in fields VII and II. This indicates a shift to dysoxic-anoxic conditions on the shelf and basin margins. At Clarence Cannon Dam, a palynofacies shift is observed from fields IV, VI and IX, thereby indicating anoxic shelf to basin depositional environments in the lower part of the section to fields III and V, indicating a proximal to distal oxic shelf depositional environment in the mid-upper part (Figure 9.7b). Brenckle *et al.* (2005) suggested a slightly different palaeoenvironment for the Hannibal Shale, and interpreted it as a dysoxic marine environment, with a large amount of quartz silt. This fits with the current interpretation as only the shale-rich units were sampled herein; the silty layers were not sampled. Slightly lower oxygen levels are suggested from the shales with a higher silt content (S54 and S50).

Osagean-Meramecian boundary

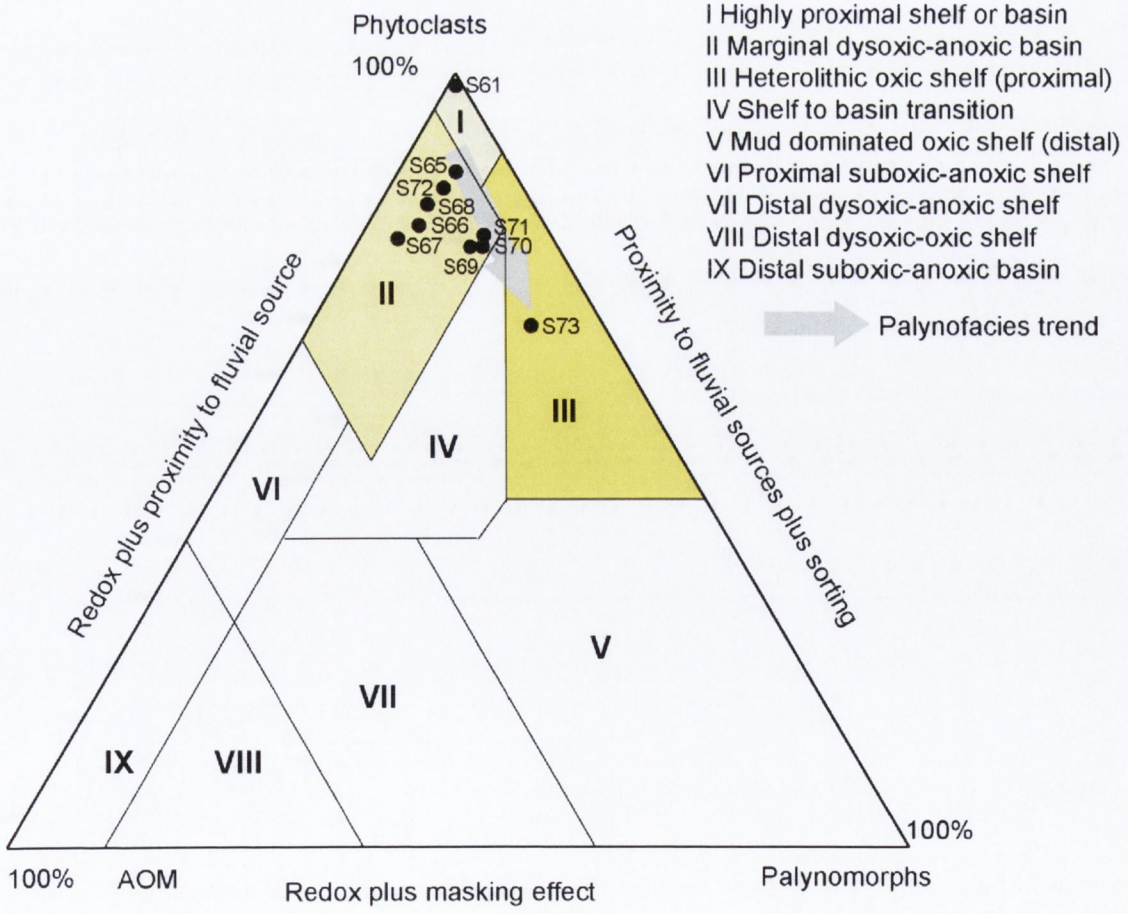
Geode Glen and Cragwold Road (Figures 9. 8a, b and 9. 9a, b)

Sections from both of these localities cover the Osagean-Meramecian boundary in the Mississippi Valley. Sediments from Geode Glen have been previously interpreted as highly proximal marine sediments and palaeosols (on lithological evidence) which were deposited in the Osagean regressive phase. Cragwold Road was interpreted as a more distal palaeoenvironment (Brenckle *et al.* 2005).

In the current study a trend from highly proximal shelf or basin to heterolithic oxic shelf is recognised from the lower part to the uppermost part of the Lower Warsaw. A single sample (S61) from the lower part of the Lower Warsaw is dominated by light brown phytoclasts, possibly cuticle material (Plate 21, Figure 5). This part of the Lower Warsaw plots in field I – highly proximal shelf or basin. The middle and upper parts of the Lower Warsaw yield darker organic matter which required further oxidation for spore identification. A cluster of samples from the middle part of the Lower Warsaw contain

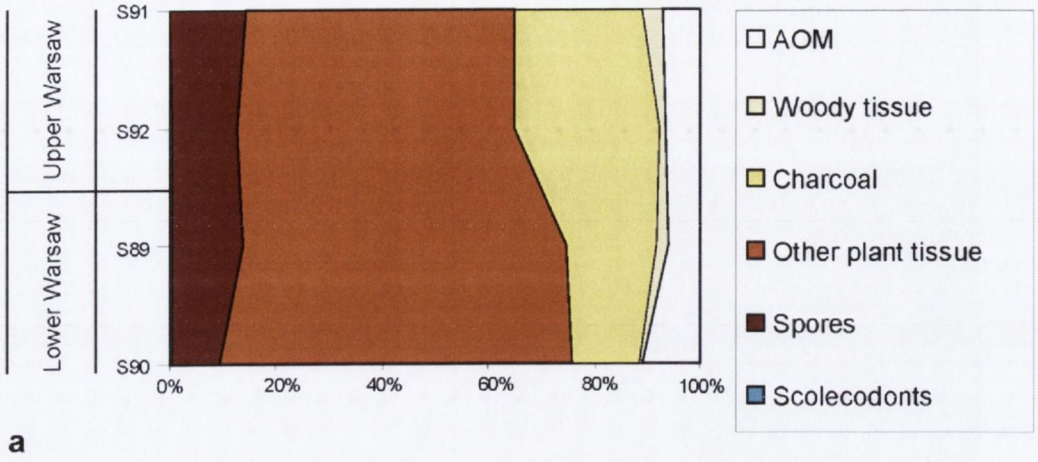


a

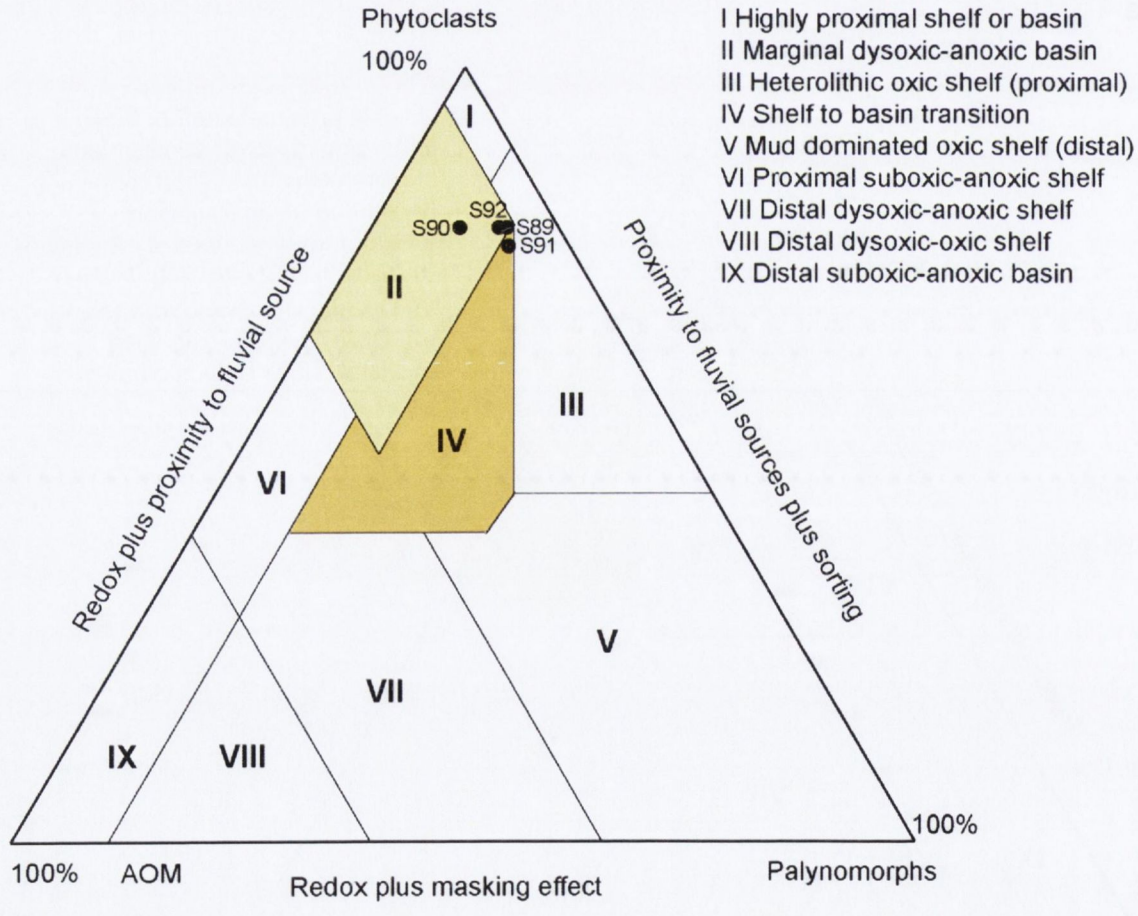


b

Figure 9.8 Palynofacies analysis for Geode Glen, Illinois a - Palynofacies counts b - ternary plot



a



b

Figure 9.9 Palynofacies analysis for Cragwold Road, Missouri a - Palynofacies counts b - ternary plot

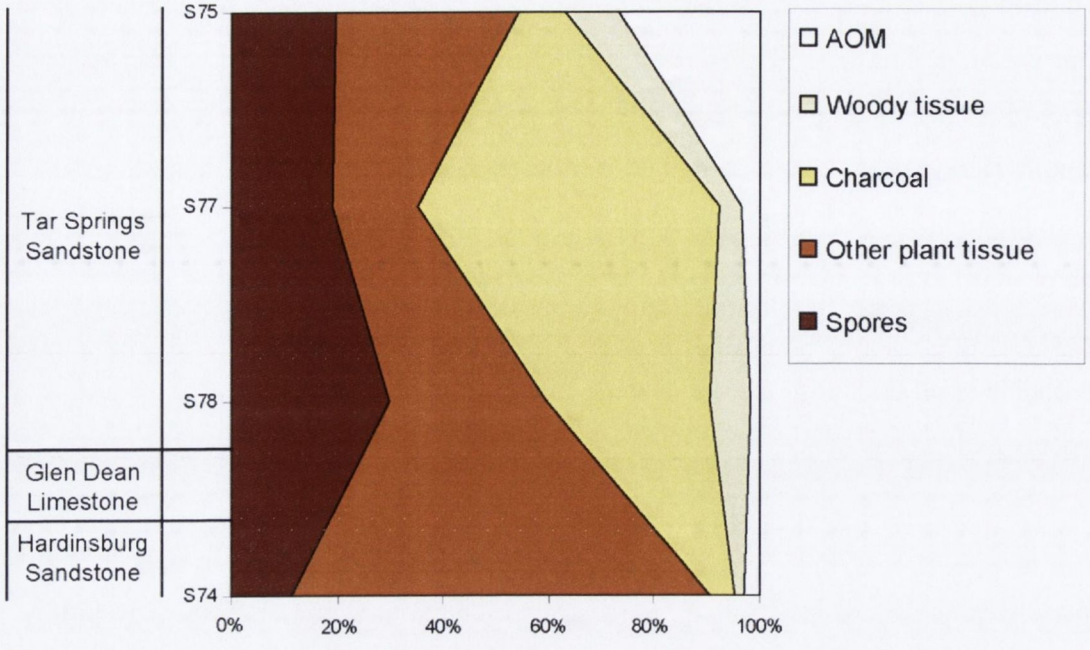
increased proportions of both AOM and palynomorphs. Phytoclast material is generally poorly preserved, and much of the AOM may be highly degraded phytoclasts. This section plots in field II – marginal dysoxic-anoxic basin. In the upper part of the Lower Warsaw a single sample (S73) shows an increase in the proportion of palynomorphs, charcoal and dark brown phytoclasts, and suggests a heterolithic oxic shelf depositional environment. This high proportion of terrestrial material agrees with previous analyses suggesting the Lower Warsaw was deposited during the regressive phase of the Osagean sedimentary cycle (Brenckle *et al.* 2005), and is represented by proximal to highly proximal marine environments and palaeosols.

Samples from Cragwold Road span the Lower/Upper Warsaw boundary. Analysis shows no notable difference in palynofacies across the formation boundary, as samples are tightly clustered in fields II and IV. This illustrates a marginal basin – shelf to basin transitional palaeoenvironment. However, samples from Cragwold Road generally contain slightly higher proportions of palynomorphs and increased pyrite overgrowth compared to those from Geode Glen, and the interpreted palaeoenvironment is more distal (marginal basin compared to proximal shelf). This supports previous lithological studies which suggested that sediments at Cragwold Road were deposited in a more distal palaeoenvironment than those at Geode Glen (Brenckle *et al.* 2005).

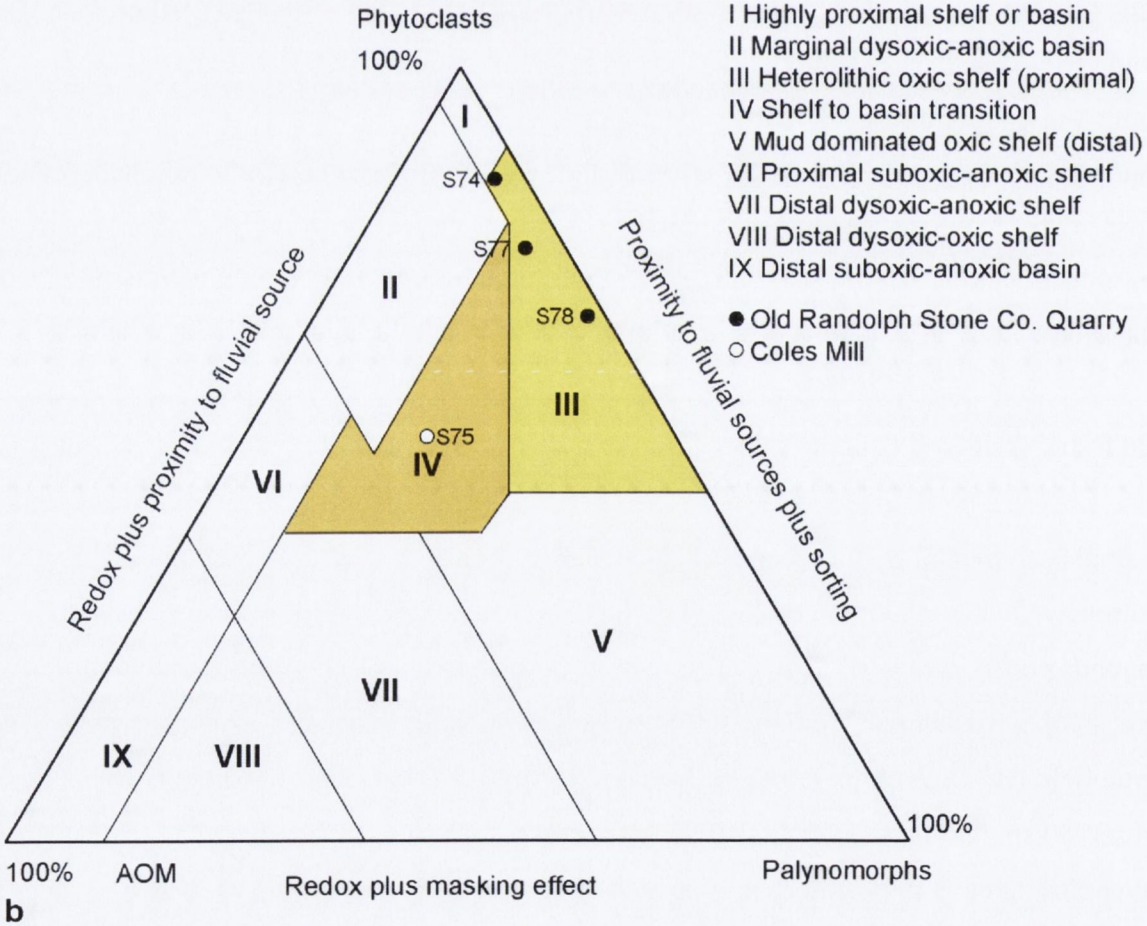
Chesterian

Old Randolph Stone Company and Coles Mill (Figure 9. 10a, b)

A single sample (S74) from the Hardinsburg Sandstone at the Old Randolph Stone Company Quarry is dominated by light brown phytoclasts (possibly cuticle material), and contains poorly preserved spores. This sample plots in field III representing a heterolithic oxic shelf. Two samples from the Tar Springs Sandstone (S77 and S78) both plot in the same field (III) but comprise an increased proportion of woody tissue and much better preserved spores. This suggests that the source of organic matter was different between the two units, and that palynomorphs deposited in the Hardinsburg interval may have undergone increased degradation due to increased transportation. This interpretation is highly likely given that the Hardinsburg and the Tar Springs are separated by an interval of carbonate deposition, and that both were transported by the Michigan River and deposited in a constantly changing deltaic system (Atherton 1975). Sample S75, from the upper part



a



b

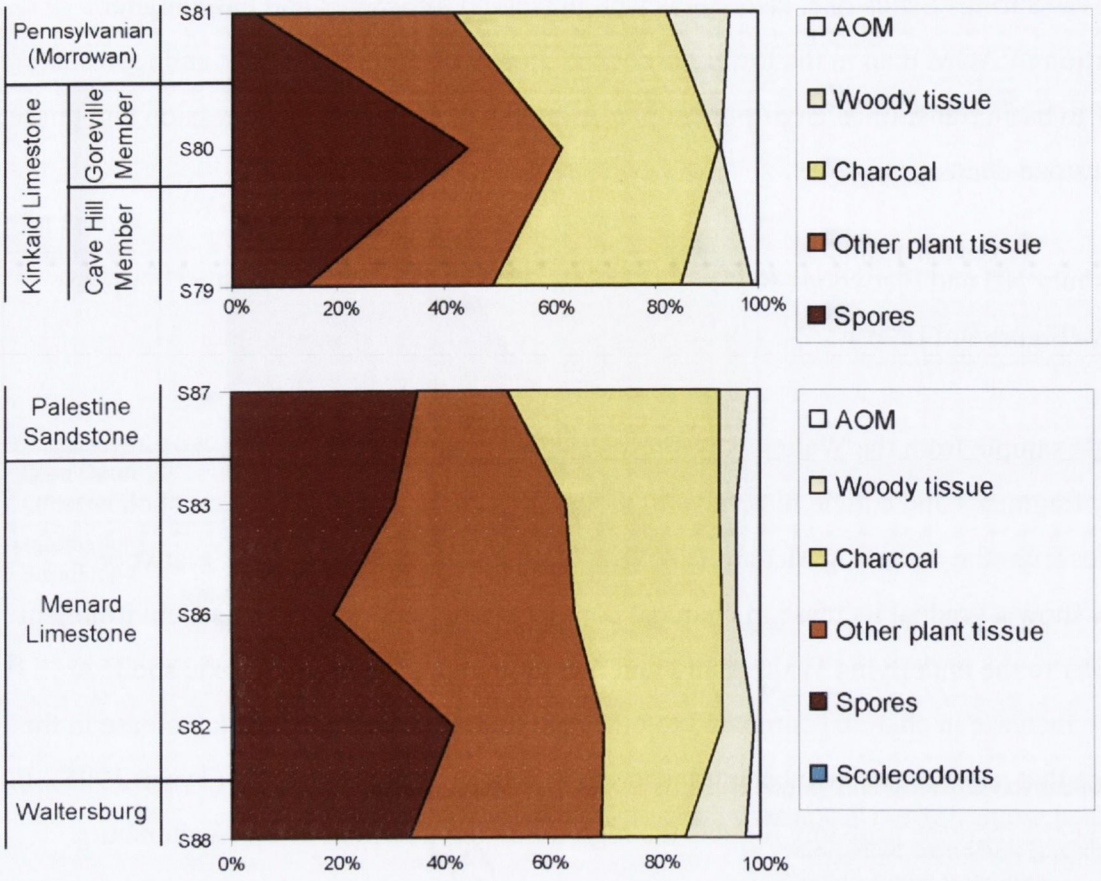
Figure 9.10 Palynofacies analysis for the Old Randolph Stone Company Quarry, and Coles Mill, Illinois a - Palynofacies counts b - ternary plot

of the Tar Springs Sandstone, also yields well preserved miospores and has a higher proportion of AOM than in the lower part of the unit. This plots in field IV and represents a shelf to basin transitional environment preceding the next marine transgression and phase of limestone deposition.

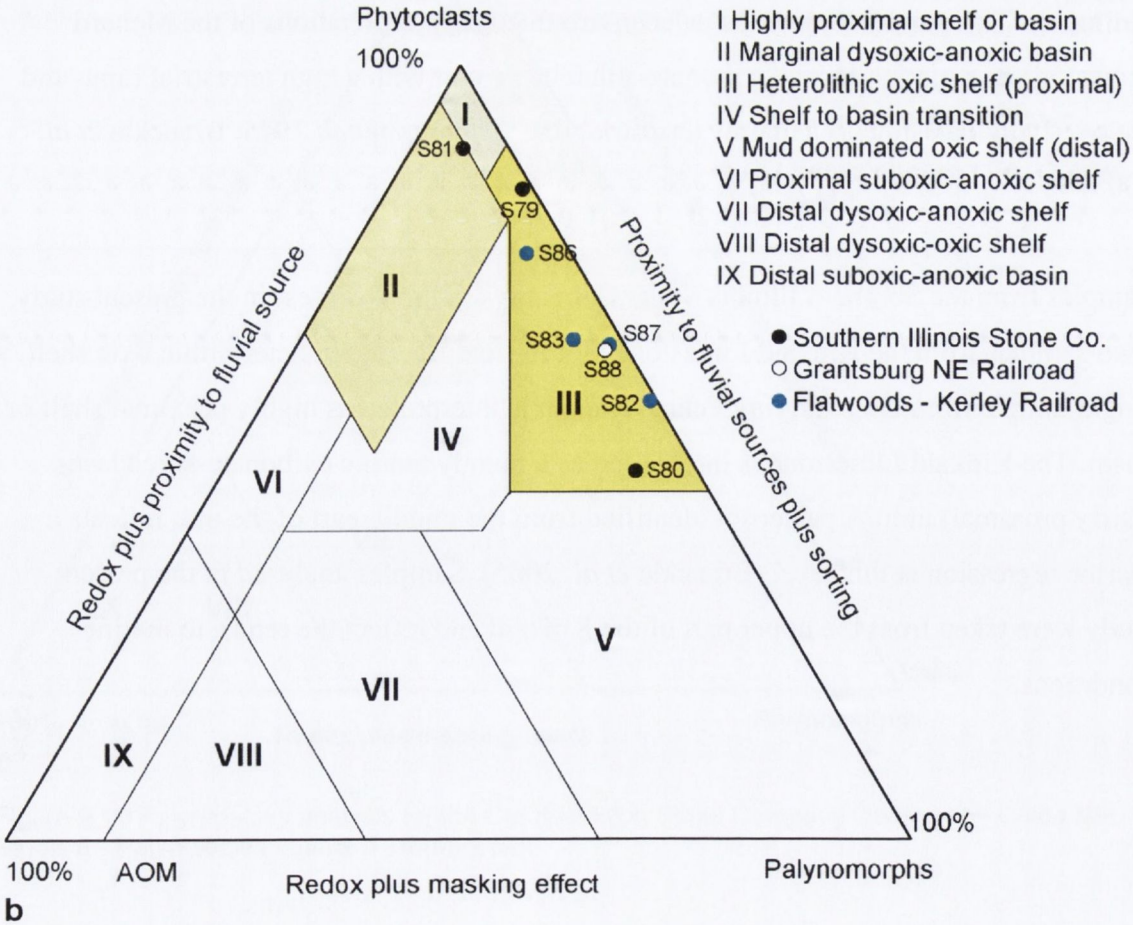
Grantsburg NE and Flatwoods-Kerley Railroads, and Southern Illinois Stone Company Quarry (Figure 9. 11a, b)

A single sample from the Waltersburg Formation at Grantsburg NE, yields dark spores, woody fragments and cuticle material and plots in field III – heterolithic oxic shelf. Samples from the overlying Menard Limestone and Palestine Sandstone at Flatwoods-Kerley show a gradual increase in charcoal content up the section. The palaeoenvironment is similar to the underlying Waltersburg and is interpreted as heterolithic oxic shelf. A relative increase in charcoal compared to other phytoclasts usually means a increase in the distance that phytoclasts have been transported in oxidising environments (Tyson 1995). In this case the increase probably reflects the high oxidation potential of the Waltersburg depositional environment, or may suggest some oxidation within sandy subaerial sediments. This supports previous paleoenvironmental interpretations of the Menard Limestone as a marine mixed carbonate-siliciclastic unit with a high terrestrial input and the overlying Palestine as a mainly terrestrial unit (Atherton *et al,* 1975; Brenckle *et al.* 2005).

Samples from the Southern Illinois Stone Company are the youngest in the present study. Two samples from the Kinkaid Limestone plot in field III – again heterolithic oxic shelf. A single sample from the overlying Pennsylvanian is interpreted as highly proximal shelf or basin. The Kinkaid Limestone is interpreted as a mainly marine carbonate-siliciclastic (fairly proximal) unit. A palaeosol identified from the middle part of the unit reflects a marine regression at this level (Brenckle *et al.* 2005). Samples analysed in the present study were taken from the upper part of the Kinkaid and reflect the return to marine conditions.



a



b

Figure 9.11 Palynofacies analysis for Southern Illinois Stone Company Quarry, Grantsburg NE railroad and Flatwoods-Kerley railroad, Illinois a - Palynofacies counts b - ternary plot

9. 7. 3 MISSISSIPPI VALLEY CORE SECTIONS

3.1. Illinois

Kinderhookian, Osagean-Meramecian Cores - C14589, C14715, S69127, C15223, C14703 (Figures 9. 12 and 9. 13)

Two samples were obtained from the Hannibal Shale in the St. Louis area, around 100km south of its type area. The older of the two (S101) at the base of the Hannibal, is dominated by AOM and plots in field VII – distal suboxic-anoxic shelf, the younger is dominated by thin, light coloured phytoclasts and has a large proportion of acanthomorph acritarchs. The palynofacies here is similar to that from the Hannibal Shale in its type region and plots in the same field, indicating heterolithic oxic shelf conditions.

No further samples were gained from the Kinderhookian of Illinois, but a number of samples from the Osagean-Meramecian boundary have been collected from this area. Three samples from the Keokuk are dominated by dark brown phytoclasts, with a large amount of pyrite present throughout the samples. These plot in field II and the Keokuk is interpreted as marginal dysoxic-anoxic basin. This fits with previous interpretations of the Keokuk as being deposited in a relatively deep-water, mid-shelf environment (Brenckle *et al.* 2005). Above this a number of samples have been collected from the Lower Warsaw close to the Cragwold Road outcrop. The palynofacies of the Lower Warsaw is similar to that of the Keokuk; samples are dominated by phytoclasts – mostly cuticle type tissue. Two samples (S139 and S140) near the base of the Lower Warsaw contain very little AOM and plot in field III – proximal oxic shelf, throughout the rest of the Lower Warsaw AOM is more relatively more abundant and the palaeoenvironment is again interpreted as marginal dysoxic basin.

The Meramecian Salem and St. Louis Limestones yielded very few samples suitable for palynofacies analysis. Two samples from the Salem Limestone are dominated by AOM and phytoclasts, with less than 5% palynomorphs. The palaeoenvironment is interpreted as distal suboxic-anoxic basin. A single sample from the St. Louis has a slightly higher proportion of phytoclasts and plots between fields IX and VI – distal suboxic-anoxic basin and proximal suboxic-anoxic shelf. This fits with previous studies which suggested the Salem was deposited in an open marine environment (reflected by massive, cross-bedded

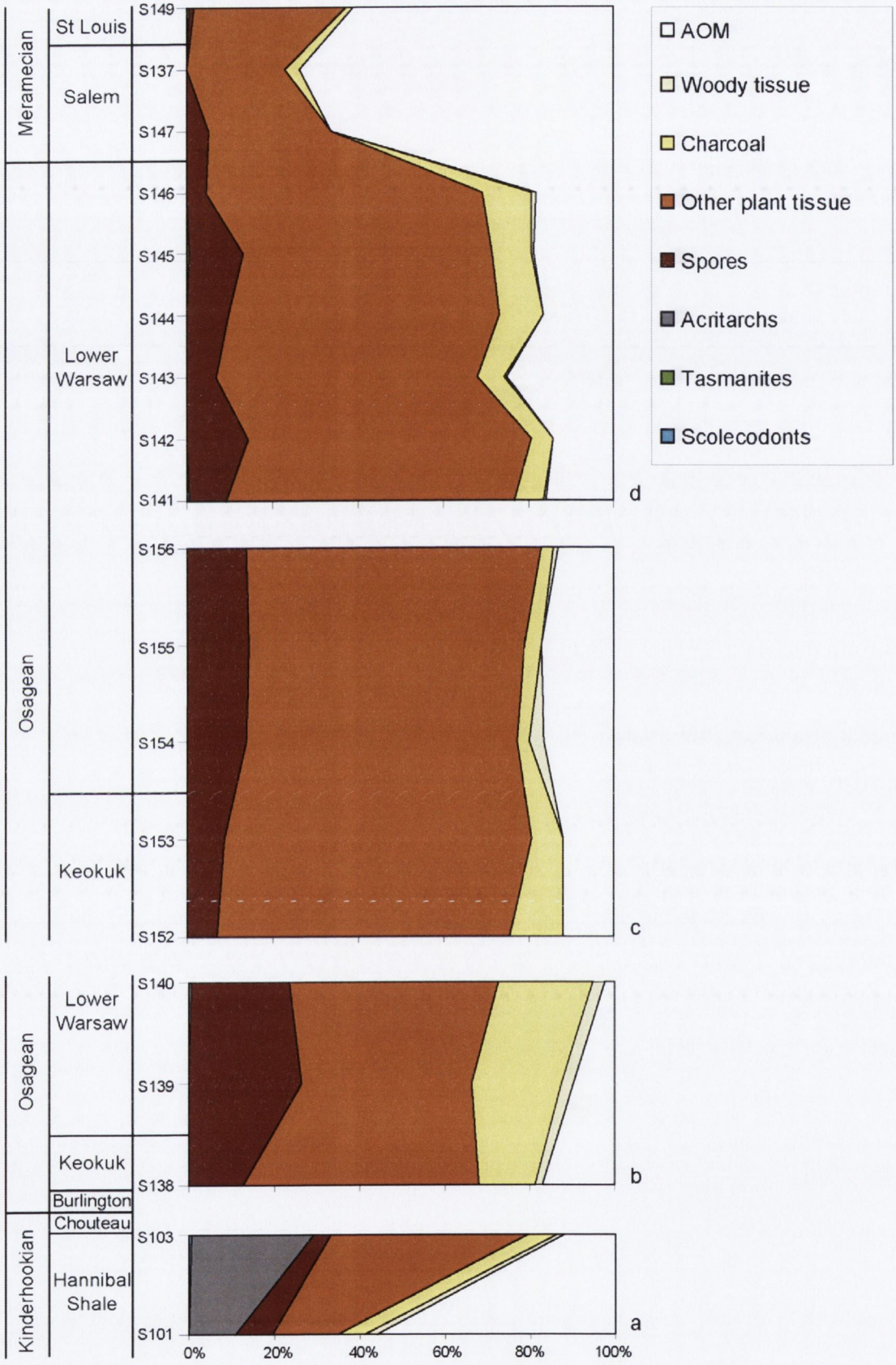


Figure 9.12 Palynofacies category counts for the Kinderhookian - Osagean / Meramecian boundary, Illinois a - Core C14859, b - Core C14715, c - Cuttings S69127, d - Core C15223 (Sample S137 from C14703)

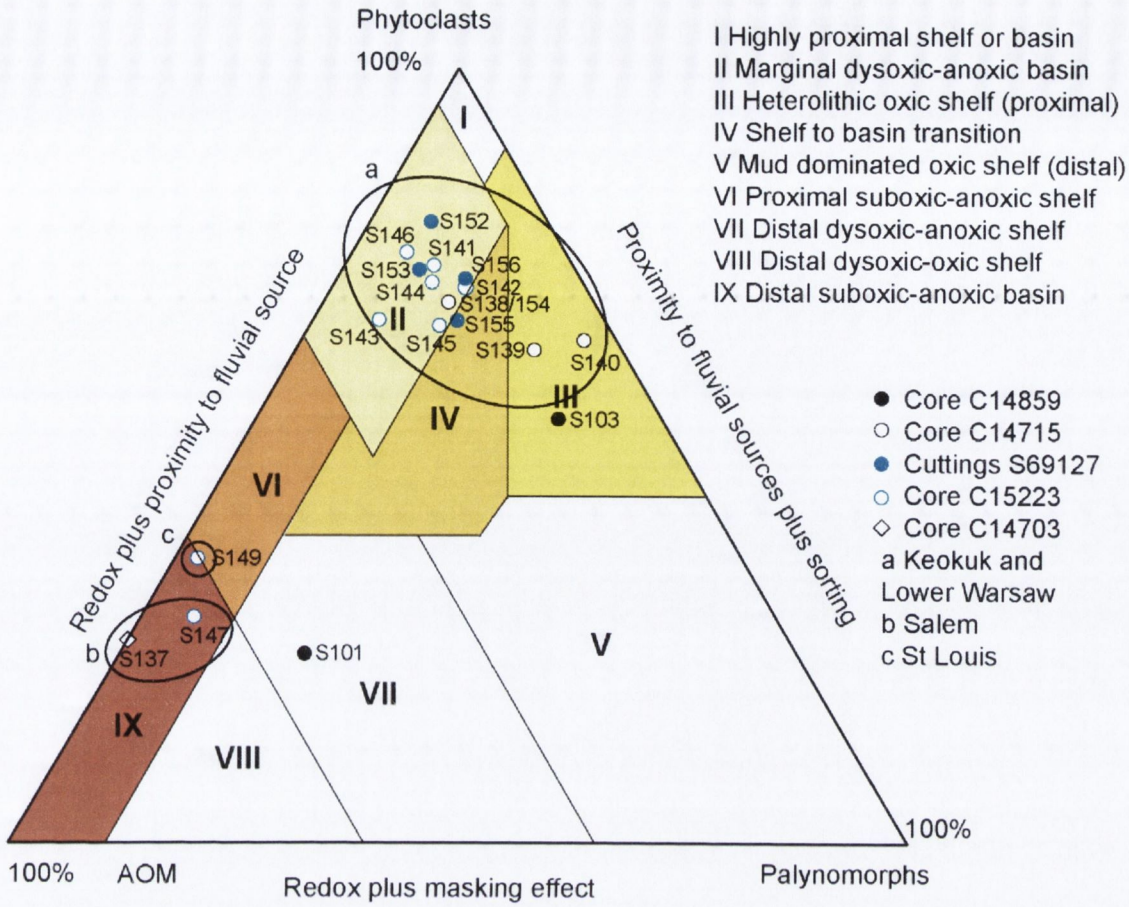


Figure 9.13 Ternary plot for Kinderhookian and Osagean / Meramecian boundary samples, Illinois

biocalcarenires) and the St. Louis as slightly shallower and more restricted (reflected by cyclical, fine-grained wackestones and packestones, stromatolites and, in the most shoreward areas, desiccation cracks) (Brenckle *et al.* 2005).

Chesterian Cores – Field Samples 1-2, C141, C13897, C4884, C13076, C46, C13619 (Figure 9. 14a, b)

Palynofacies analysis from cores taken throughout the Chesterian of Illinois show fairly major fluctuations in depositional environments throughout the stage. In the Mississippi Valley, Chesterian sediments were transported from the northeast by the Michigan River and deposited in a deltaic environment. The fluctuations reflect shifts of the relative positions of the river mouth and shoreline, and are recorded by clastic/limestone alterations within the sediments (Atherton *et al.* 1975). The Ste Genevieve Limestone is interpreted as representing a transgressive interval at the base of the Chesterian (Brenckle *et al.* 2005).

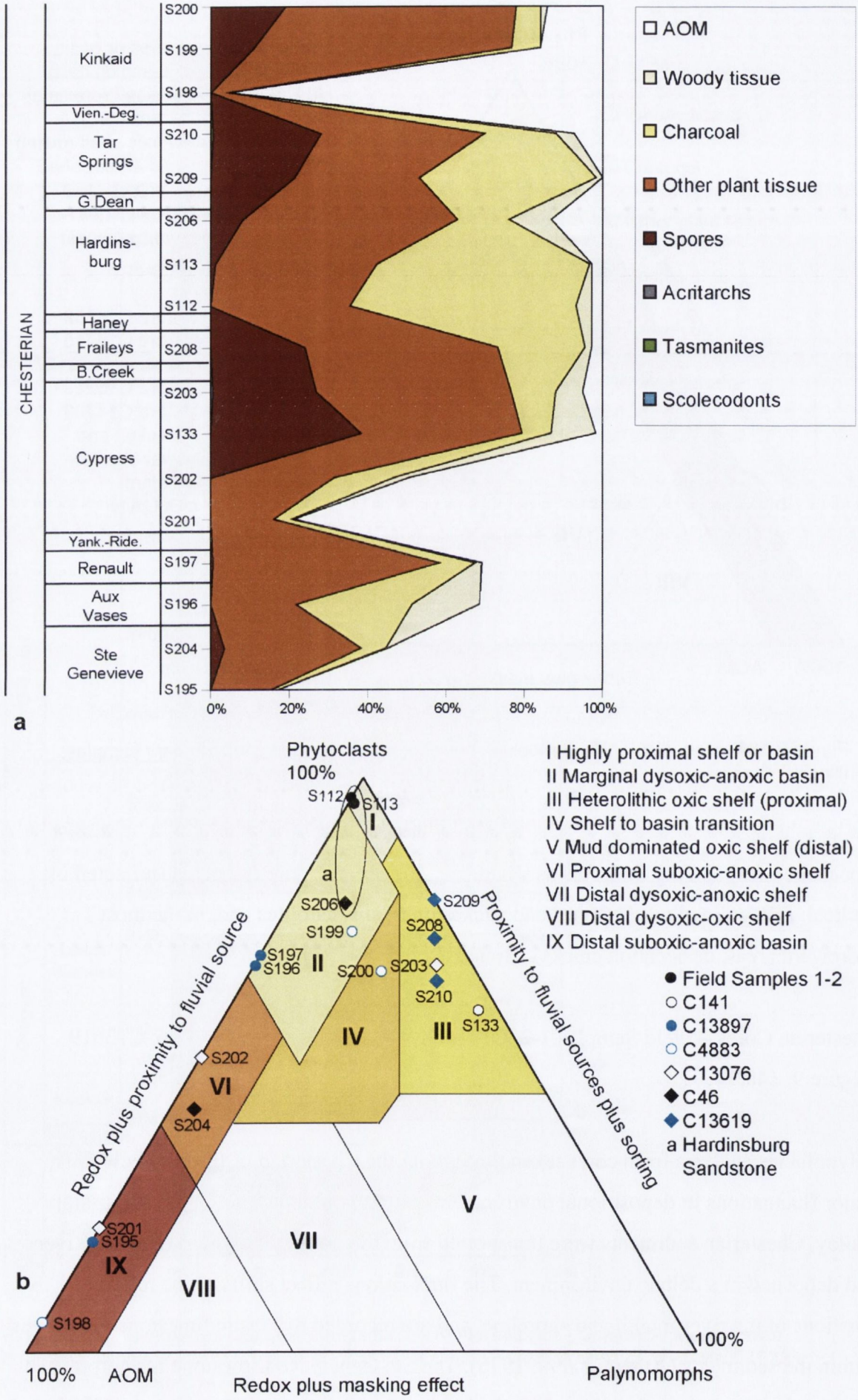


Figure 9.14 Palynofacies analysis for Chesterian Cores, Illinois a - Palynofacies counts b - ternary plot.

Two samples from near the top of the Ste Genevieve are dominated by grey/brown AOM and degraded plant material. The data plot in fields IX and VI showing a shift from suboxic-anoxic distal basin to proximal shelf at the top of the Ste Genevieve. Above this the overlying Aux Vases Sandstone and Renault Limestone contain an increased proportion of phytoclasts and plot in field II (marginal dysoxic-anoxic basin), reflecting their more proximal depositional environment. It can be noted that the types of phytoclasts differ between the two units, with the Aux Vases Sandstone containing a higher proportion of wood and charcoal and less cuticle than the Renault Limestone.

Above this the Cypress Sandstone shows a shift from an AOM dominated palynofacies in its lowermost part to phytoclast dominated in the mid to upper part. Palynomorphs are absent in the lower part of the Cypress but become common in the upper part. A regressive phase is recognised throughout the unit from distal suboxic-anoxic basin to proximal suboxic-anoxic shelf to proximal oxic shelf. This reflects shifts in the position of the palaeo-shoreline at the mouth of the Michigan River (Atherton *et al.* 1975). A single sample (S208) from the Fraileys Shale shows the continuation of this oxic shelf palaeoenvironment.

The next youngest unit is the Hardinsburg Sandstone. Samples from the type section of the Hardinsburg are rich in coal and yield a very small proportion of both AOM and palynomorphs (< 3%) (Plate 21, Figure 1). As such, these are interpreted as being highly proximal shelf or basin. The top of the Hardinsburg Sandstone is more like a true sandstone and comprises all three components, although phytoclasts still dominate the palynofacies. This plots in field II and shows a brief switch back to dysoxic-anoxic conditions. Above this, samples from the Tar Springs Sandstone contain an increased proportion of palynomorphs and a decrease in AOM, illustrating a return to an oxic proximal shelf palaeoenvironment.

Samples from the youngest part of the Chesterian are obtained from the Kinkaid Limestone. At its base (S198) the Kinkaid is dominated by large dark brown clasts of AOM (<1.5mm) (Plate 23, figures 5 & 6) suggesting a distal suboxic-anoxic basin. In the upper part of the section, cuticle material dominates the palynofacies and palynomorphs increase in abundance suggesting a shift to marginal dysoxic-anoxic basin and shelf basin transition. This basinal palaeoenvironment represents a more distal situation than seen in the underlying sandstones, further from the mouth of the Michigan River. The shift to

proximal oxic shelf as observed from the uppermost Kinkaid at the Southern Illinois Stone Co. is not recognised from the core material.

Missouri

Kinderhookian, Osagean-Meramecian Cores – LS21, NS2, NS3, 59-Mi (Figures 9. 15 and 9. 16)

Samples from the Late Devonian Chattanooga Shale (equivalent to the Bedford Shale of Kentucky) contain fairly equal amounts of all three types of organic matter. Of these, the palynomorphs and AOM are slightly more abundant than phytoclasts and assemblages are dominated by acanthomorph acritarchs. The data plot in fields V and VII, and indicate a distal shelf environment, with oxygen levels increasing in the younger sample (S108). Samples from the Hannibal Shale in western Illinois both contain similar acanthomorph acritarchs.

A single sample from the Bachelor Formation (Hannibal equivalent in southwest Missouri) is dominated by phytoclasts and AOM, and plots in field II. Slightly younger samples from the Northview Shale all have a similar composition and are dominated by phytoclasts. Data from the Northview Shale plot in fields I, II and III. This suggests a marginal basin environment in the Bachelor becoming more proximal in the Northview Shale. This reflects a more distal palaeoenvironment in southwest Missouri than the Mississippi Valley, an effect of its situation further from the margins of the Illinois Basin.

A single sample (S176) was obtained from the Sedalia Limestone which overlies the Bachelor and underlies the Northview Shale in parts of southwestern and central Missouri. The Sedalia is dominated by plant tissue and plots in field VI – proximal suboxic-anoxic shelf. This sample originates from a core (59-Mi) from northeast Missouri – therefore it is at the northeastern most extent of the Sedalia, but again a slightly more distal situation is recorded than in the Hannibal Shale. Two samples from the Lower Warsaw are obtained from the same core (59-Mi). These plot in a similar field to Lower Warsaw samples from Illinois (see above), indicating a marginal dysoxic-suboxic basin.



Figure 9.15 Palynofacies category counts for the Kinderhookian - Osagean / Meramecian boundary, Missouri a - Core LS21, b - Core NS2, c - Core NS3, d - Core 59-Mi

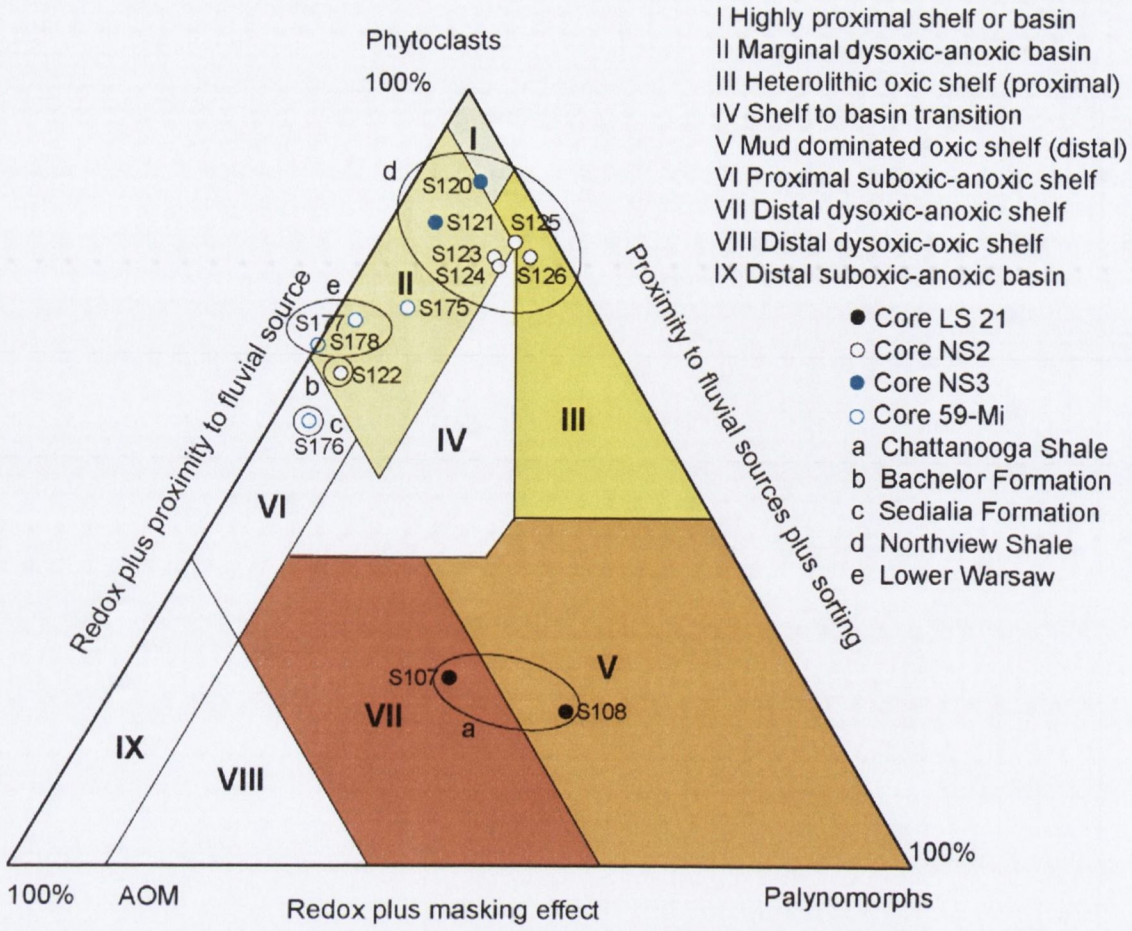


Figure 9.16 Ternary plot for Kinderhookian and Osagean / Meramecian boundary samples, Missouri

Iowa

Core H29 (Figure 9. 17a, b)

Mississippian stratigraphy from the Mississippi Valley in Iowa is limited to the southeast corner of the state. A single core has been obtained from this region, around 30 km north of localities in western Illinois (e.g. Geode Glen) and northern Missouri (e.g. core 59 Mi).

The oldest samples obtained from core H29 are from the McCraney Limestone, equivalent to the uppermost part of the Hannibal Shale. Samples are dominated by poorly preserved plant material (mostly cuticle) and some AOM, a very small percentage of palynomorphs (0-3%) is recorded. Samples plot in field II – marginal dysoxic-anoxic basin. This is noticeably different from equivalent age rocks in northern Missouri, where the Hannibal Shale was deposited in more proximal oxic conditions.

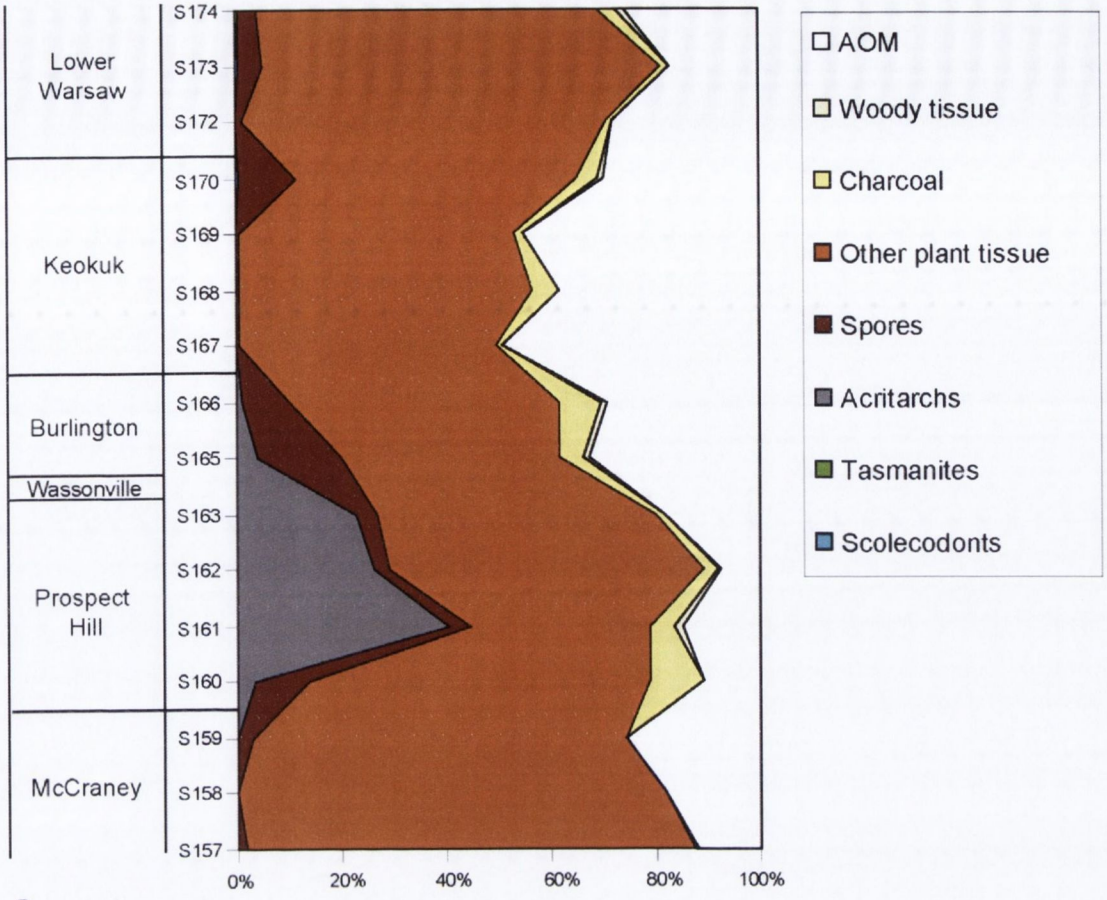


Figure 9.17 Palynofacies analysis for H29, Iowa a - Palynofacies counts b - ternary plot

Overlying the McCraney, the Prospect Hill Siltstone is the equivalent to the uppermost Hannibal Shale and the Chouteau Limestone of northern Missouri. Spores and acritarchs increase in the middle part of the Prospect Hill suggesting transport and increased sorting of organic matter. This is recorded by a shift from field II to field III (proximal shelf) and V (distal shelf), and is similar to the depositional environment recorded from the Hannibal Shale. Analysis of a single sample from the top of the Prospect Hill records a shift to shelf-basin transition.

The older of the samples from the Burlington Limestone (S165) plots in a similar field to the underlying siltstone. Samples from the upper part of the Burlington and the overlying Keokuk show an increase in AOM and record a shift from field II (Marginal dysoxic-anoxic basin) in the upper part of the Burlington to field VI (proximal suboxic-anoxic shelf) in the Keokuk. The upper part of the Keokuk and Lower Warsaw show a decrease in the amount of AOM, and a subsequent switch back to a marginal dysoxic-anoxic basin, similar to that seen in the middle part of the Lower Warsaw at Geode Glen.

Witzke *et al.* (1990) provided a detailed discussion of facies change and relative sea level change throughout the Mississippian of Iowa based on sequence stratigraphy. The base of the McCraney is interpreted as being deposited in an open marine setting, becoming shallower and restricted towards the top of the unit. This fits with the above interpretation of a marginal basin setting in a dysoxic environment. The Prospect Hill Siltstone was interpreted by Witzke *et al.* (1990) as representing a transgressive-regressive cycle, from very shallow in the lowermost part, to shallow open marine in the middle part, and a general coarsening upwards sequence through the middle and upper part. This supports the above palynofacies interpretation of a switch from proximal to distal shelf in the middle part of the Prospect Hill, although the regression in the upper part of the Prospect Hill is not recorded. The top of the Burlington through the lower part of the Keokuk reflects a shallowing trend and this is reflected in the above palynofacies analysis. Witzke *et al.* (1990) record little sea level change through the Keokuk and Lower Warsaw in Iowa and an upwards shallowing trend is suggested throughout the two units. This disagrees with the interpretation of a switch from shelf to basin in the lower to middle part of the Warsaw. However, Witzke *et al.* (1990) noted that similarities in the Keokuk and Warsaw strata hinder sequence stratigraphical interpretation. In addition, the frequency of sampling in the present study is not sufficient to track detailed palynofacies changes and only general trends are recognised herein.

CHAPTER 10
CONCLUSIONS

Miospore assemblages from the Late Devonian to Early Mississippian in northeast Kentucky correlate well with those from Western Europe. Assemblages can be assigned to the Western European Miospore Biozonation. Five of the European biozones are recognised:

1. Assemblages from the Cleveland Member of the Ohio Shale and the Bedford Shale are assigned to the latest Devonian LN Biozone.
2. Assemblages from the Sunbury Shale, Jacobs Chapel and Rockford Limestone are assigned to the oldest Mississippian (early Tournaisian) VI Biozone.
3. Assemblages from the lower part of Henley Bed of the Borden Formation are assigned to the mid Tournaisian BP Biozone.
4. Assemblages from the upper Henley Bed of the Borden Formation, and the Henley Bed and Portsmouth Member of the Cuyahoga Formation are assigned to the mid to late Tournaisian PC Biozone.
5. Assemblages from the Farmers Member and Nancy Member of the Borden Formation and the upper part of the Portsmouth Member of the Cuyahoga Formation are assigned to the late Tournaisian CM Biozone. The Nancy Member is the same age throughout Kentucky (and not diachronous, as previously suggested).

The palynostratigraphic interpretation of the Kentucky succession supports that of the independent conodont and ammonoid data.

Miospore assemblages from the Mississippian of the Mississippi Valley are very different from those of Kentucky, the rest of the Midwest USA and Western Europe.

An independent miospore biozonation is proposed for the Mississippian of the Mississippi Valley. The miospore succession within the Mississippi Valley strata is discontinuous and sporadic. Biozones are tentative, but provide a framework for the development of the miospore biozonation within the type Mississippian.

Seven miospore biozones are proposed for the Mississippian. In ascending order these are the *Cyclogranisporites commodus* Biozone, *Spelaeotriletes obtusus* Biozone, *Prolycospora rugulosa* Biozone, *Crassispora aculeata* Biozone, *Cingulizonates bialatus* Biozone, *Crassispora maculosa* Biozone and the *Cirratriradites annuliformis* Biozone.

1. The Hannibal Shale yields an impoverished miospore assemblage, dominated by survivor taxa from the latest Devonian mass extinction. These assemblages are assigned to the early to mid Tournaisian *Cyclogranisporites commodus* Biozone.

Palynomorph assemblages from the Hannibal Shale and equivalent units in the Mississippi Valley are dominated by acanthomorph acritarchs.

2. Assemblages from the Burlington, Keokuk, Lower Warsaw and Upper Warsaw are assigned to the early Viséan *Spelaeotriletes obtusus* Biozone.

3. Cypress Formation assemblages are assigned to the late Viséan *Prolycospora rugulosa* Biozone.

4. Fraileys Shale assemblages are assigned to the early Serpukhovian *Crassispora aculeata* Biozone.

5. Hardinsburg Sandstone assemblages are assigned to the early to mid Serpukhovian *Cingulizonates bialatus* Biozone.

6. Assemblages from the Tar Springs Sandstone, Waltersburg Formation, Menard Limestone and Palestine Sandstone are assigned to the mid Serpukhovian *Crassispora maculosa* Biozone.

7. Kinkaid Limestone assemblages are assigned to the mid to late Serpukhovian *Cirratriradites annuliformis* Biozone.

The first appearance and establishment of *Lycospora pusilla* is much later in the Mississippian of the Mississippi Valley than in Western Europe. In the Mississippi Valley, *Lycospora pusilla* first appears in the late Viséan Cypress Sandstone and is common to abundant above the mid Serpukhovian Tar Springs Sandstone.

Reworked Early to Late Devonian acritarchs were identified from the Kinderhookian and Osagean of Kentucky and the Mississippi Valley.

Palynofacies analysis of the Ohio Shale, Bedford Shale and Sunbury Shale indicates a distal suboxic-anoxic basin environment consistent with the interpretation of these strata as prodeltaic deposits. This supports the palaeogeographic position of Kentucky in the Early Carboniferous.

Palynofacies analysis of the Borden Formation and Cuyahoga Formation indicates a highly proximal environment consistent with the interpretation of these strata as deltaic deposits.

Palynofacies analysis of the Kinderhookian of the Mississippi Valley indicates a shelf to basin environment consistent with the palaeogeographical position of the Mississippi Valley in the Early Carboniferous.

The depositional environment of the Lower Warsaw is interpreted as a highly proximal shelf environment reflecting the regressive phase of the Osagean sedimentary cycle.

Sediments at Cragwold Road were deposited in a more distal palaeoenvironment than those at Geode Glen.

Palynofacies analyses of the Chesterian strata of the Mississippi Valley indicate a high terrestrial input and fluctuations from a proximal basin to shelf environment. This reflects shifts in the position of the palaeo-shoreline at the mouth of the Michigan River, northeast of the Mississippi Valley.

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APPENDIX I

LOCALITY AND SAMPLING DATA

APPENDIX I.I Field sample collection data

APPENDIX I.II Core sample collection data

APPENDIX I.III Photographs of outcrops

Sample No.	State	County	Locality	Locality No.	Collected	GPS No.	Postion N	Position W	Remarks	TCD No.
S26	Kentucky	Rowan Co.	Mile post 135 Interstate 64	2.2	23/09/2005	27	3811.168'	08331.242'	Mounted, Barren	TCD 59049
S27	Kentucky	Rowan Co.	Mile post 135 Interstate 64	2.2	23/09/2005	27	3811.168'	08331.242'	Mounted, Barren	TCD 59050
S28	Kentucky	Rowan Co.	Mile post 135 Interstate 64	2.2	23/09/2005	27	3811.168'	08331.242'	Mounted, Barren	TCD 59051
S29	Kentucky	Rowan Co.	Mile post 135 Interstate 64	2.2	23/09/2005	27	3811.168'	08331.242'	Mounted	TCD 59052
S30	Kentucky	Rowan Co.	Mile post 135 Interstate 64	2.2	23/09/2005	27	3811.168'	08331.242'	Mounted, Barren	TCD 59053
S31	Kentucky	Rowan Co.	Mile post 135 Interstate 64	2.2	23/09/2005	27	3811.168'	08331.242'	Mounted, Barren	TCD 59054
S32	Kentucky	Rowan Co.	Mile post 135 Interstate 64	2.2	23/09/2005	27	3811.168'	08331.242'	Mounted, Barren	TCD 59055
S33	Kentucky	Rowan Co.	Mile post 135 Interstate 64	2.2	23/09/2005	27	3811.168'	08331.242'	Mounted, Barren	TCD 59056
S34	Kentucky	Rowan Co.	Junction Interstate 64/801	2.3	23/09/2005	29	3810.963'	08333.740'	Mounted, Barren	TCD 59057
S35	Kentucky	Rowan Co.	Junction Interstate 64/801	2.3	23/09/2005	29	3810.963'	08333.740'	Mounted, Barren	TCD 59058
S36	Kentucky	Rowan Co.	Junction Interstate 64/801	2.3	23/09/2005	29	3810.963'	08333.740'	Mounted	TCD 59059
S37	Kentucky	Rowan Co.	Junction Interstate 64/801	2.3	23/09/2005	30	3810.957'	08333.742'	Mounted, Barren	TCD 59060
S38	Kentucky	Rowan Co.	Junction Interstate 64/801	2.3	23/09/2005	31	3810.954'	08333.778'	Mounted	TCD 59061
S39	Kentucky	Rowan Co.	Junction Interstate 64/801	2.3	23/09/2005	31	3810.954'	08333.778'	Mounted	TCD 59062
S40	Kentucky	Rowan Co.	Junction Interstate 64/801	2.3	23/09/2005	32	3810.816'	08334.081'	Mounted	TCD 59063
S45	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	36	3942.163'	09120.929'	Mounted	TCD 59097
S46	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	36	3942.163'	09120.929'	Mounted	TCD 59022
S47	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	36	3942.163'	09120.929'	Mounted	TCD 59023
S48	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	36	3942.163'	09120.929'	Mounted	TCD 59024
S49	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	36	3942.163'	09120.929'	Mounted	TCD 59025
S50	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	39	3942.177'	09120.934'	Mounted	TCD 59098
S51	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	39	3942.177'	09120.934'	Mounted, Barren	TCD 59026
S52	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	39	3942.177'	09120.934'	Mounted	TCD 59099
S53	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	39	3942.177'	09120.934'	Mounted	TCD 59027
S54	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	39	3942.177'	09120.934'	Mounted	TCD 59021
S55	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	39	3942.177'	09120.934'	Mounted, Barren	TCD 59028
S56	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	39	3942.177'	09120.934'	Mounted, Barren	TCD 59029
S57	Missouri	Marion Co.	Highway 79	4.1	25/09/2005	40	3942.176'	09120.937'	Mounted, Barren	TCD 59030
S58	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	41	4021.733'	09125.926'	Mounted, Barren	TCD 59100
S59	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	41	4021.733'	09125.926'	Mounted, Barren	TCD 59101
S60	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	41	4021.733'	09125.926'	Mounted, Barren	TCD 59102
S61	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	41	4021.733'	09125.926'	Mounted, Barren	TCD 59103

Appendix I.I Field sample collection data

Sample No.	State	County	Locality	Locality No.	Collected	GPS No.	Postion N	Position W	Remarks	TCD No.
S62	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	41	4021.733'	09125.926'	Mounted, Barren	TCD 59104
S63	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	42	4021.640'	09125.893'	Mounted, Barren	TCD 59105
S64	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	43	4021.661'	09125.795'	Mounted, Barren	TCD 59106
S65	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	44	4021.665'	09125.785'	Mounted	TCD 59107
S66	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	44	4021.665'	09125.785'	Mounted	TCD 59108
S67	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	44	4021.665'	09125.785'	Mounted	TCD 59109
S68	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	44	4021.665'	09125.785'	Mounted	TCD 59110
S69	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	44	4021.665'	09125.785'	Mounted	TCD 59111
S70	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	44	4021.665'	09125.785'	Mounted	TCD 59112
S71	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	44	4021.665'	09125.785'	Mounted	TCD 59113
S72	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	44	4021.665'	09125.785'	Mounted	TCD 59114
S73	Illinois	Hancock Co.	Geode Glen	4.2	25/09/2005	45	4021.562'	09125.697'	Mounted	TCD 59115
S74	Illinois	Randolph Co.	Old Randolph Stone Co.	5.1	26/09/2005				Mounted	TCD 59116
S75	Illinois	Randolph Co.	Coles Mill	5.2	26/09/2005				Mounted	TCD 59117
S76	Illinois	Randolph Co.	Coles Mill	5.2	26/09/2005				Mounted, Barren	TCD 59118
S77	Illinois	Randolph Co.	Coles Mill	5.2	26/09/2005				Mounted	TCD 59119
S78	Illinois	Randolph Co.	Coles Mill	5.2	26/09/2005				Mounted	TCD 59120
S79	Illinois	Johnson Co.	Southern Illinois Stone Company Quarry	6.1	27/09/2005	47	3729.373'	08858.067'	Mounted	TCD 59121
S80	Illinois	Johnson Co.	Southern Illinois Stone Company Quarry	6.1	27/09/2005	48	3729.358'	08858.136'	Mounted	TCD 59122
S81	Illinois	Johnson Co.	Southern Illinois Stone Company Quarry	6.1	27/09/2005	49	3729.276'	08858.137'	Mounted	TCD 59123
S82	Illinois	Johnson Co.	Flatwoods - kerley railroad	6.2	27/09/2005				Mounted	TCD 59124
S83	Illinois	Johnson Co.	Flatwoods - kerley railroad	6.2	27/09/2005				Mounted	TCD 59125
S84	Illinois	Johnson Co.	Flatwoods - kerley railroad	6.2	27/09/2005				Mounted, Barren	TCD 59126
S85	Illinois	Johnson Co.	Flatwoods - kerley railroad	6.2	27/09/2005				Mounted, Barren	TCD 59127
S86	Illinois	Johnson Co.	Flatwoods - kerley railroad	6.2	27/09/2005				Mounted	TCD 59128
S87	Illinois	Johnson Co.	Flatwoods - kerley railroad	6.2	27/09/2005	50	3725.138'	08843.168'	Mounted	TCD 59129
S88	Illinois	Johnson Co.	Grantsburg NE railroad	6.3	27/09/2005	51	3723.946'	08843.108'	Mounted	TCD 59130
S89	Missouri	St Loius Co.	Cragwold Road	6.4	27/09/2005	52	3833.146'	09025.734'	Mounted	TCD 59131
S90	Missouri	St Loius Co.	Cragwold Road	6.4	27/09/2005	52	3833.146'	09025.734'	Mounted	TCD 59132

Appendix I.I Field sample collection data

Sample No.	State	County	Locality	Locality No.	Collected	GPS No.	Postion N	Position W	Remarks	TCD No.
S91	Missouri	St Loius Co.	Cragwold Road	6.4	27/09/2005	53	3833.122'	09025.959'	Mounted	TCD 59133
S92	Missouri	St Loius Co.	Cragwold Road	6.4	27/09/2005	53	3833.122'	09025.959'	Mounted	TCD 59134
S211	Kentucky	Rowan Co.	Morehead Interstate 64	1	18/10/2006				Mounted	TCD 59064
S212	Kentucky	Rowan Co.	Morehead Interstate 64	1	18/10/2006				Mounted	TCD 59065
S213	Kentucky	Rowan Co.	Morehead Interstate 64	1	18/10/2006				Mounted	TCD 59066
S214	Kentucky	Rowan Co.	Morehead Interstate 64	1b	18/10/2006				Mounted	TCD 59067
S215	Kentucky	Rowan Co.	Morehead Interstate 64	1b	18/10/2006				Barren	TCD 59068
S216	Kentucky	Rowan Co.	Morehead Interstate 64	2a	19/10/2006				Barren	TCD 59069
S217	Kentucky	Rowan Co.	Morehead Interstate 64	2b	19/10/2006				Mounted	TCD 59070
S218	Kentucky	Rowan Co.	Morehead Interstate 64	2b	19/10/2006				Mounted	TCD 59071
S219	Kentucky	Rowan Co.	Morehead Interstate 64	2b	19/10/2006				Mounted	TCD 59072
S220	Kentucky	Rowan Co.	Morehead Interstate 64	2b	19/10/2006				Mounted	TCD 59073
S221	Kentucky	Rowan Co.	Morehead Interstate 64	2c	19/10/2006				Barren	TCD 59074
S222	Kentucky	Rowan Co.	Morehead Interstate 64	2c	19/10/2006				Mounted	TCD 59075
S223	Kentucky	Rowan Co.	Morehead Interstate 64	2c	19/10/2006				Mounted	TCD 59076
S224	Kentucky	Rowan Co.	Morehead Interstate 64	2c	19/10/2006				Barren	TCD 59077
S225	Kentucky	Rowan Co.	Morehead Interstate 64	2c	19/10/2006				Barren	TCD 59078
S226	Kentucky	Rowan Co.	Morehead Interstate 64	2c	19/10/2006				Barren	TCD 59079
S227	Kentucky	Rowan Co.	Morehead Interstate 64	2c	19/10/2006				Mounted	TCD 59080
S228	Kentucky	Rowan Co.	Morehead Interstate 64	2d	19/10/2006				Mounted	TCD 59081
S229	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Barren, Palynofacies	TCD 59082
S230	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59083
S231	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59084
S232	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59085
S233	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Barren	TCD 59086

Appendix I.I Field sample collection data

Sample No.	State	County	Locality	Locality No.	Collected	GPS No.	Postion N	Position W	Remarks	TCD No.
S234	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Barren	TCD 59087
S235	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59088
S236	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59089
S237	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Barren, Palynofacies	TCD 59090
S238	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Barren, Palynofacies	TCD 59091
S239	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59092
S240	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59093
S241	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Barren, Palynofacies	TCD 59094
S242	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59095
S243	Kentucky	Lewis Co.	Brightman Cemetery, AA Highway	2e	19/10/2006				Mounted	TCD 59096

Appendix I.I Field sample collection data

Sample No.	Survey	Core Name/No.	County	Stratigraphic Unit	Level (ft)	Collected	Remarks	TCD No.
CC01	Missouri DNR	516-C	Ralls Co.	Horton Creek Limestone	179.2 - 179.8	01/2007	Mounted	TCD 59031
CC02	Missouri DNR	516-C	Ralls Co.	Horton Creek Limestone	177.5 - 178.1	01/2007	Mounted	TCD 59032
CC03	Missouri DNR	516-C	Ralls Co.	Cuivre Member	175.9 - 176.5	01/2007	Mounted	TCD 59033
CC04	Missouri DNR	516-C	Ralls Co.	Cuivre Member	173.85 - 173.25	01/2007	Mounted	TCD 59034
CC05	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	166.3 - 166.8	01/2007	Mounted	TCD 59035
CC06	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	159.9 - 160.5	01/2007	Mounted	TCD 59036
CC07	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	153.9 - 153.3	01/2007	Mounted	TCD 59037
CC08	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	146.7 - 147.3	01/2007	Mounted	TCD 59038
CC09	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	139.4 - 140.0	01/2007	Mounted	TCD 59039
CC10	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	133.6 - 134.2	01/2007	Mounted	TCD 59040
CC11	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	127.1 - 127.7	01/2007	Mounted	TCD 59041
CC12	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	120.4 - 121.0	01/2007	Mounted	TCD 59042
CC13	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	114.0 - 114.6	01/2007	Mounted	TCD 59043
CC14	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	107.4 - 108.0	01/2007	Mounted	TCD 59044
CC15	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	100.8 - 101.4	01/2007	Mounted	TCD 59045
CC16	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	97.8 - 98.4	01/2007	Mounted	TCD 59046
CC17	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	96.2 - 96.8	01/2007	Mounted	TCD 59047
CC18	Missouri DNR	516-C	Ralls Co.	Hannibal Shale	94.5 - 95.1	01/2007	Mounted	TCD 59048
S101	Illinois SGS	C 14859	Jersey Co.	Hannibal	115.3 - 115.4	20/07/2006	Mounted	TCD 59135
S102	Illinois SGS	C 14859	Jersey Co.	Hannibal	105.5 - 105.6	20/07/2006	Mounted, Barren	TCD 59136
S103	Illinois SGS	C 14859	Jersey Co.	Hannibal	99.1 - 99.2	20/07/2006	Mounted	TCD 59137
S104	Illinois SGS	C 14859	Jersey Co.	Chouteau	85.4 - 85.6	20/07/2006	Mounted, Barren	TCD 59138
S105	Illinois SGS	C 14859	Jersey Co.	Burlington	56.7 - 56.9	20/07/2006	Mounted, Barren	TCD 59139
S106	Illinois SGS	C 14859	Jersey Co.	Burlington	46.5 - 46.7	20/07/2006	Mounted, Barren	TCD 59140
S107	Missouri DNR	LS21	Randolph Co.	Chattanooga	434.6	26/07/2006	Mounted	TCD 59141
S108	Missouri DNR	LS21	Randolph Co.	Chattanooga	433.4	26/07/2006	Mounted	TCD 59142
S109	Missouri DNR	660K - 3	Delaware Co., Oklahoma	Late Devonian St Peter	341.4	26/07/2006	Microwaved, Barren	TCD 59143
S110	Missouri DNR	660K - 3	Delaware Co., Oklahoma	Chattanooga	303	26/07/2006	Mounted, Barren	TCD 59144

Appendix I.II Core sample collection data. Abbreviations are as follows: DNR - Department of Natural Resources, SGS - State Geological Survey, GS - Geological Survey

Sample No.	Survey	Core Name/No.	County	Stratigraphic Unit	Level (ft)	Collected	Remarks	TCD No.
S111	Missouri DNR	660K - 3	Delaware Co., Oklahoma	Chattanooga	276.4	26/07/2006	Microwaved, Barren	TCD 59145
S112	Illinois SGS	Field sample 1	Mermet, Massac Co.	Hardinsburg underclay	N/A	21/07/2006	Mounted, Barren	TCD 59146
S113	Illinois SGS	Field sample 2	Mermet, Massac Co.	Hardinsburg coal	N/A	21/07/2006	Mounted, Barren	TCD 59147
S114	Illinois SGS	Field sample 3	State Pond, Jonesboro, Union Co.	Springville Shale	N/A	21/07/2006	Microwaved, Barren	TCD 59148
S115	Illinois SGS	Field sample 4	State Pond, Jonesboro, Union Co.	Springville Shale	N/A	21/07/2006	Microwaved, Barren	TCD 59149
S116	Missouri DNR	NS 3	Dade Co.	Compton Ls	103.5	26/07/2006	Barren	TCD 59150
S117	Missouri DNR	NS 3	Dade Co.	Compton Ls	102.3	26/07/2006	Barren	TCD 59151
S118	Missouri DNR	NS 3	Dade Co.	Northview	94.9	26/07/2006	Barren	TCD 59152
S119	Missouri DNR	NS 3	Dade Co.	Northview	87.8	26/07/2006	Barren	TCD 59153
S120	Missouri DNR	NS 3	Dade Co.	Northview	82.5	26/07/2006	Mounted	TCD 59154
S121	Missouri DNR	NS 3	Dade Co.	Northview	56	26/07/2006	Mounted	TCD 59155
S122	Missouri DNR	NS 2	Cedar Co.	Bachelor	101.7	26/07/2006	Mounted	TCD 59156
S123	Missouri DNR	NS 2	Cedar Co.	Northview	88.2	26/07/2006	Mounted	TCD 59157
S124	Missouri DNR	NS 2	Cedar Co.	Northview	57.2	26/07/2006	Mounted	TCD 59158
S125	Missouri DNR	NS 2	Cedar Co.	Northview	53	26/07/2006	Mounted	TCD 59159
S126	Missouri DNR	NS 2	Cedar Co.	Northview	50.5	26/07/2006	Mounted	TCD 59160
S133	Illinois SGS	C 141	Madison Co.	Cypress Ss	339 - 339.2	20/07/2006	Mounted	TCD 59161
S134	Illinois SGS	C 141	Madison Co.	Yankeetown Ss	414.6 - 414.8	20/07/2006	Mounted, Barren	TCD 59162
S135	Illinois SGS	C 141	Madison Co.	Yankeetown Ss	453.5 - 453.7	20/07/2006	Mounted, Barren	TCD 59163
S136	Illinois SGS	C 141	Madison Co.	St Genevieve	709.7 -710.0	20/07/2006	Mounted, Barren	TCD 59164
S137	Illinois SGS	C 14703	Monroe Co.	Salem	177.9 - 178.1	20/07/2006	Mounted, Barren	TCD 59165
S138	Illinois SGS	C 14715	St Clair Co.	Keokuk	227.2 - 227.4	20/07/2006	Mounted	TCD 59166
S139	Illinois SGS	C 14715	St Clair Co.	L. Warsaw	213.7 - 213.9	20/07/2006	Mounted	TCD 59167
S140	Illinois SGS	C 14715	St Clair Co.	L. Warsaw	199.4 - 199.6	20/07/2006	Mounted	TCD 59168
S141	Illinois SGS	C 15223	Monroe Co.	L. Warsaw	423.6 - 423.8	20/07/2006	Mounted	TCD 59169
S142	Illinois SGS	C 15223	Monroe Co.	L. Warsaw	423.2 - 423.4	20/07/2006	Mounted	TCD 59170

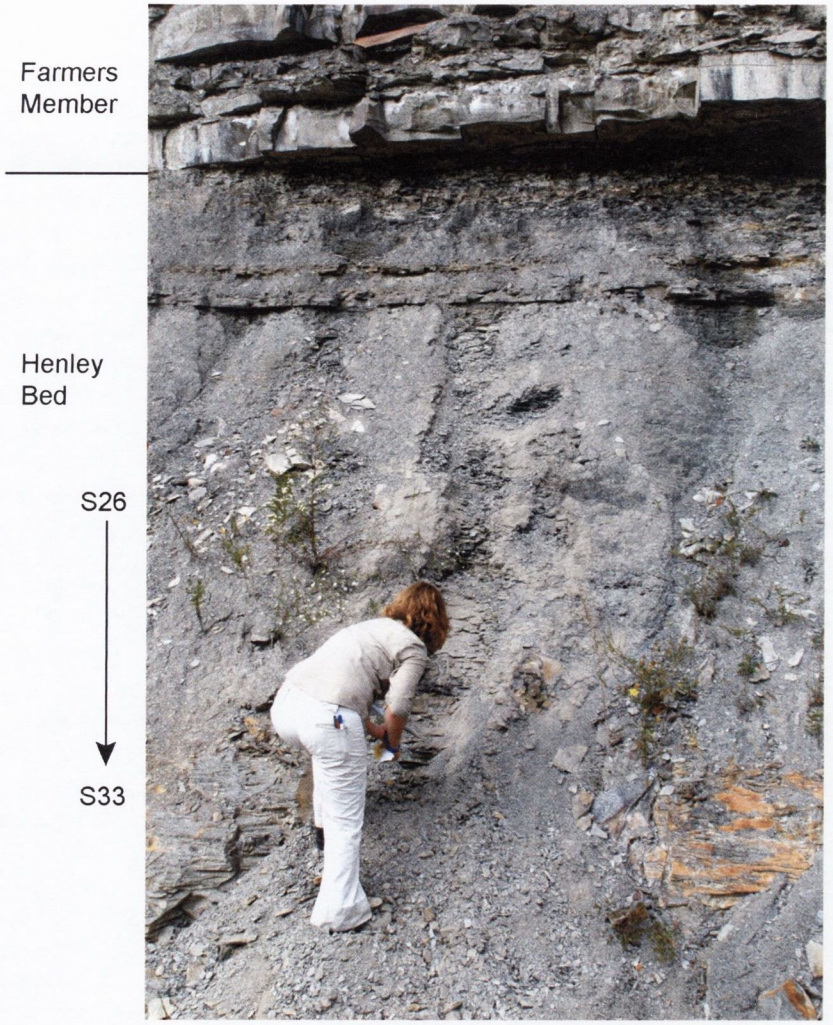
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Sample No.	Survey	Core Name/No.	County	Stratigraphic Unit	Level (ft)	Collected	Remarks	TCD No.
S143	Illinois SGS	C 15223	Monroe Co.	L. Warsaw	352.1 - 352.2	20/07/2006	Mounted	TCD 59171
S144	Illinois SGS	C 15223	Monroe Co.	L. Warsaw	320.8 - 321	20/07/2006	Mounted	TCD 59172
S145	Illinois SGS	C 15223	Monroe Co.	L. Warsaw	313.3 - 313.5	20/07/2006	Mounted	TCD 59173
S146	Illinois SGS	C 15223	Monroe Co.	L. Warsaw	307.3 - 307.5	20/07/2006	Mounted	TCD 59174
S147	Illinois SGS	C 15223	Monroe Co.	Salem	166.4 - 166.5	20/07/2006	Mounted, Barren	TCD 59175
S148	Illinois SGS	C 15223	Monroe Co.	Salem	139.7 - 139.9	20/07/2006	Mounted, Barren	TCD 59176
S149	Illinois SGS	C 15223	Monroe Co.	St Louis	131.4 - 131.6	20/07/2006	Mounted, Barren	TCD 59177
S150	Illinois SGS	C 15100	St Clair Co.	St Louis	196.4	20/07/2006	Mounted, Barren	TCD 59178
S151	Illinois SGS	C 15100	St Clair Co.	St Louis	196.2	20/07/2006	Mounted, Barren	TCD 59179
S152	Illinois SGS	S 69127 (Well Cuttings)	Monroe Co.	Keokuk	470 - 480	21/07/2006	Barren, palynofacies	TCD 59180
S153	Illinois SGS	S 69127 (Well Cuttings)	Monroe Co.	Keokuk	460 - 470	21/07/2006	Mounted	TCD 59181
S154	Illinois SGS	S 69127 (Well Cuttings)	Monroe Co.	L. Warsaw	440 - 450	21/07/2006	Mounted	TCD 59182
S155	Illinois SGS	S 69127 (Well Cuttings)	Monroe Co.	L. Warsaw	430 - 440	21/07/2006	Mounted	TCD 59183
S156	Illinois SGS	S 69127 (Well Cuttings)	Monroe Co.	L. Warsaw	410 - 420	21/07/2006	Mounted	TCD 59184
S157	Iowa GS	H29	Lee Co.	McCraney	320.2 - 320.4	28/07/2006	Mounted	TCD 59185
S158	Iowa GS	H29	Lee Co.	McCraney	315.4 - 315.5	28/07/2006	Barren, palynofacies	TCD 59186
S159	Iowa GS	H29	Lee Co.	McCraney	309.3 - 309.4	28/07/2006	Mounted	TCD 59187
S160	Iowa GS	H29	Lee Co.	Prospect Hill	294.8 - 294.9	28/07/2006	Mounted	TCD 59188
S161	Iowa GS	H29	Lee Co.	Prospect Hill	282.8 - 282.9	28/07/2006	Mounted	TCD 59189
S162	Iowa GS	H29	Lee Co.	Prospect Hill	256.6 -256.7	28/07/2006	Mounted	TCD 59190
S163	Iowa GS	H29	Lee Co.	Prospect Hill	248.4 - 248.6	28/07/2006	Mounted	TCD 59191
S164	Iowa GS	H29	Lee Co.	Wassonville Fm	236 - 236.1	28/07/2006	Mounted, Barren	TCD 59192
S165	Iowa GS	H29	Lee Co.	Burlington	206- 206.1	28/07/2006	Mounted	TCD 59193
S166	Iowa GS	H29	Lee Co.	Burlington	205.6 - 205.7	28/07/2006	Mounted	TCD 59194
S167	Iowa GS	H29	Lee Co.	Keokuk	133.4 - 133.5	28/07/2006	Barren, palynofacies	TCD 59195
S168	Iowa GS	H29	Lee Co.	Keokuk	130 - 130.1	28/07/2006	Barren, palynofacies	TCD 59196
S169	Iowa GS	H29	Lee Co.	Keokuk	121.7-121.9	28/07/2006	Barren, palynofacies	TCD 59197
S170	Iowa GS	H29	Lee Co.	Keokuk	103 - 103.1	28/07/2006	Mounted	TCD 59198
S171	Iowa GS	H29	Lee Co.	Keokuk	84.5 - 84.7	28/07/2006	Mounted, Barren	TCD 59199
S172	Iowa GS	H29	Lee Co.	Lower Warsaw	77.5 - 77.7	28/07/2006	Barren, palynofacies	TCD 59200
S173	Iowa GS	H29	Lee Co.	Lower Warsaw	61.2 - 61.4	28/07/2006	Mounted	TCD 59201

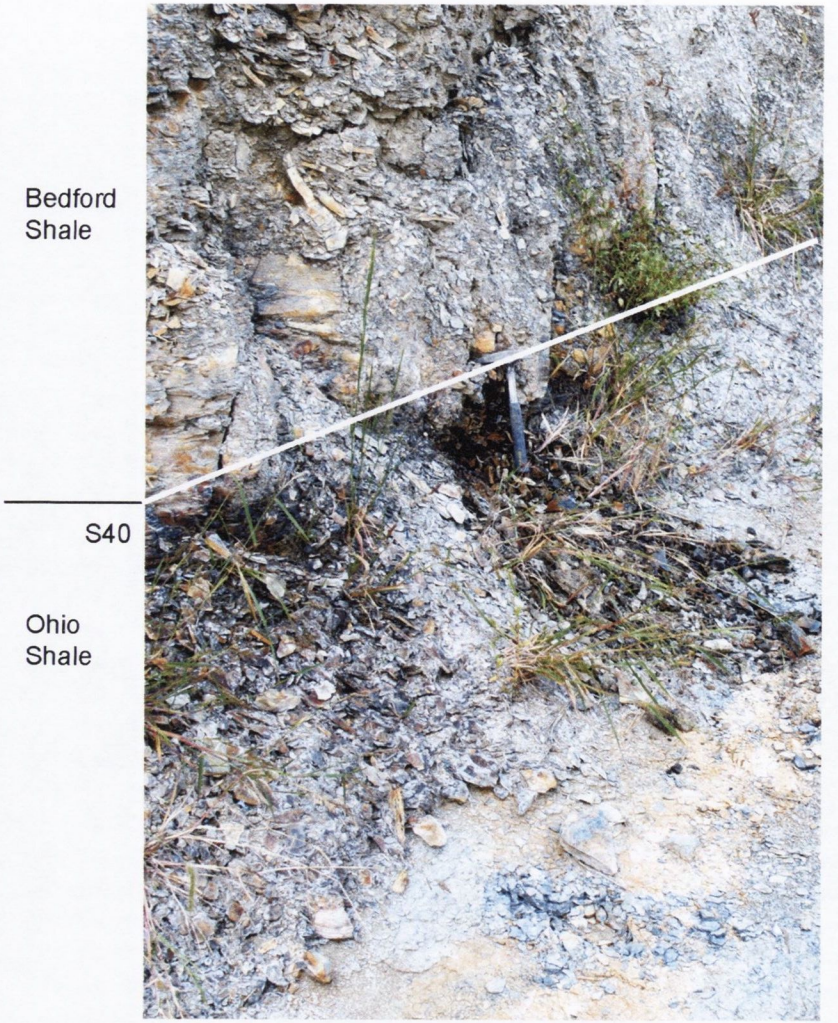
Appendix I.II Core sample collection data. Abbreviations are as follows: DNR - Department of Natural Resources, SGS - State Geological Survey, GS - Geological Survey

Sample No.	Survey	Core Name/No.	County	Stratigraphic Unit	Level (ft)	Collected	Remarks	TCD No.
S174	Iowa GS	H29	Lee Co.	Lower Warsaw	54.2 - 54.4	28/07/2006	Mounted	TCD 59202
S175	Missouri DNR	59 MI (Well Cuttings)	Clark Co.	Hannibal	264-275	26/07/2006	Mounted, Barren	TCD 59203
S176	Missouri DNR	59 MI (Well Cuttings)	Clark Co.	Sedalia	232	26/07/2006	Mounted, Barren	TCD 59204
S177	Missouri DNR	59 MI (Well Cuttings)	Clark Co.	U. Warsaw	82	26/07/2006	Mounted	TCD 59205
S178	Missouri DNR	59 MI (Well Cuttings)	Clark Co.	U. Warsaw	15 - 20	26/07/2006	Mounted, Barren	TCD 59206
S195	Illinois SGS	C 13897	Hardin	St Genevieve	704.2 - 704.4	21/07/2006	Barren, palynofacies	TCD 59207
S196	Illinois SGS	C 13897	Hardin	Aux Vases Ss	667.2 - 667.4	21/07/2006	Barren, palynofacies	TCD 59208
S197	Illinois SGS	C 13897	Hardin	Renault LS	621.7 - 621.8	21/07/2006	Barren, palynofacies	TCD 59209
S198	Illinois SGS	C 4883	Gallatin Co.	Kinkaid Ls	154.3 - 154.5	21/07/2006	Barren, palynofacies	TCD 59210
S199	Illinois SGS	C 4883	Gallatin Co.	Kinkaid Ls	146.0 - 146.2	21/07/2006	Mounted	TCD 59211
S200	Illinois SGS	C 4883	Gallatin Co.	Kinkaid Ls	140.3 - 140.5	21/07/2006	Mounted	TCD 59212
S201	Illinois SGS	C 13076	Pope Co.	Cypress Ss	225.5 - 225.6	21/07/2006	Barren, palynofacies	TCD 59213
S202	Illinois SGS	C 13076	Pope Co.	Cypress Ss	220.4 - 220.6	21/07/2006	Barren, palynofacies	TCD 59214
S203	Illinois SGS	C 13076	Pope Co.	Cypress Ss	212.0 - 212.2	21/07/2006	Mounted	TCD 59215
S204	Illinois SGS	C 46	Pope Co.	St Genevieve	757.2 - 757.3	21/07/2006	Mounted	TCD 59216
S205	Illinois SGS	C 46	Pope Co.	Downies Bluff	570.0 - 570.1	21/07/2006	Mounted, Barren	TCD 59217
S206	Illinois SGS	C 46	Pope Co.	Hardinsburg Ss	130.0 - 130.2	21/07/2006	Mounted	TCD 59218
S207	Illinois SGS	C 13619	Union Co.	Bethel Ss?	567.1 - 567.2	21/07/2006	Mounted	TCD 59219
S208	Illinois SGS	C 13619	Union Co.	Fraileys	293.5 - 293.7	21/07/2006	Mounted	TCD 59220
S209	Illinois SGS	C 13619	Union Co.	Tar Springs Ss	76.5 - 76.7	21/07/2006	Mounted	TCD 59221
S210	Illinois SGS	C 13619	Union Co.	Tar Springs Ss	19.3 - 19.4	21/07/2006	Mounted	TCD 59222

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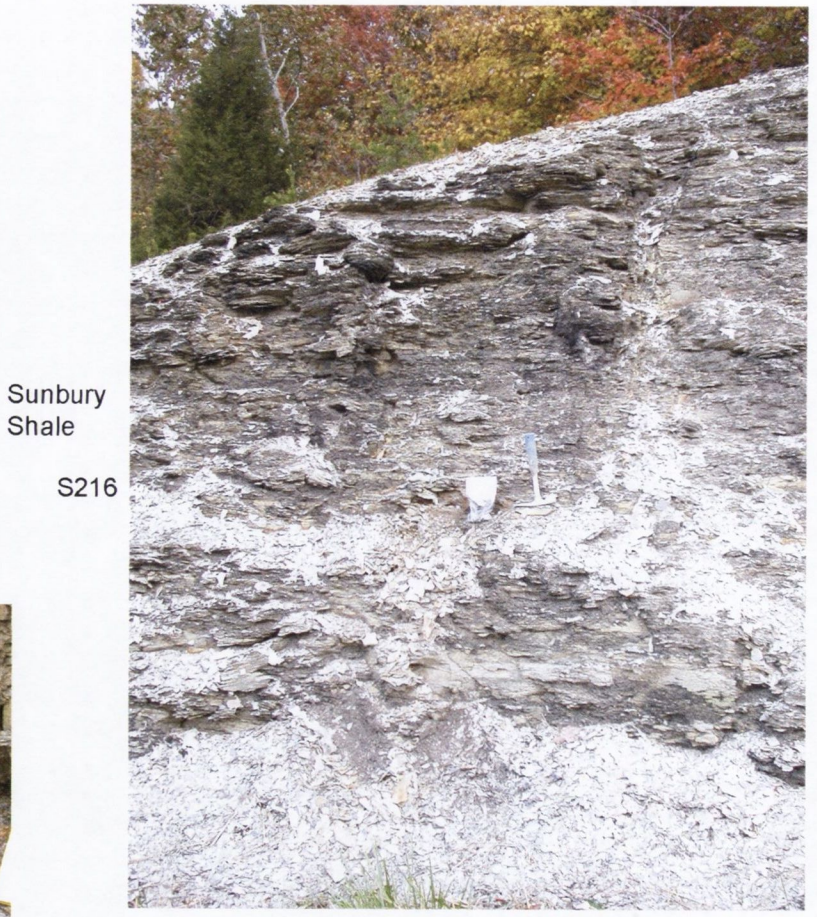
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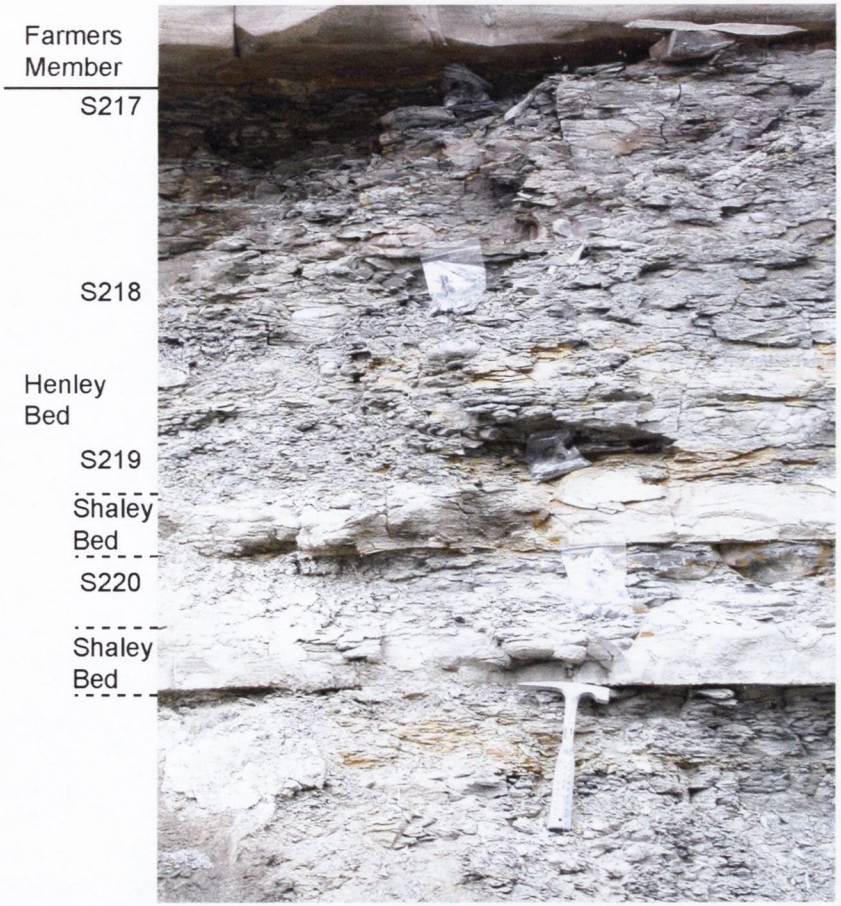
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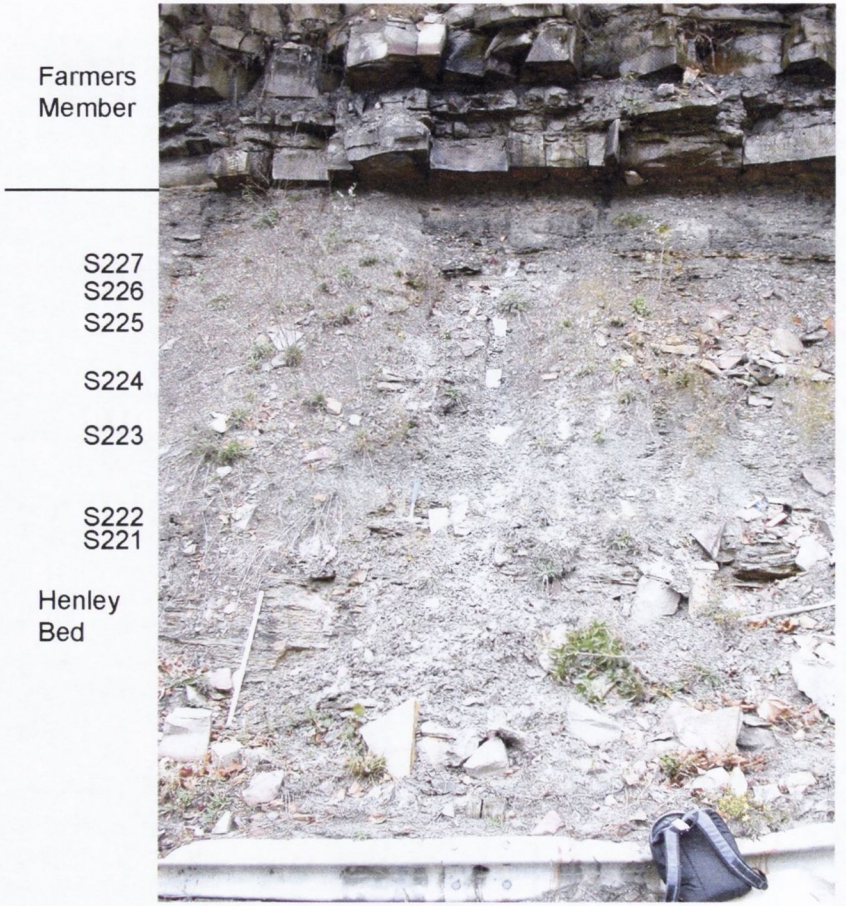
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INTERSTATE 64, Milepost 135, Morehead, Kentucky



INTERSTATE 64, Milepost 135, Morehead, Kentucky



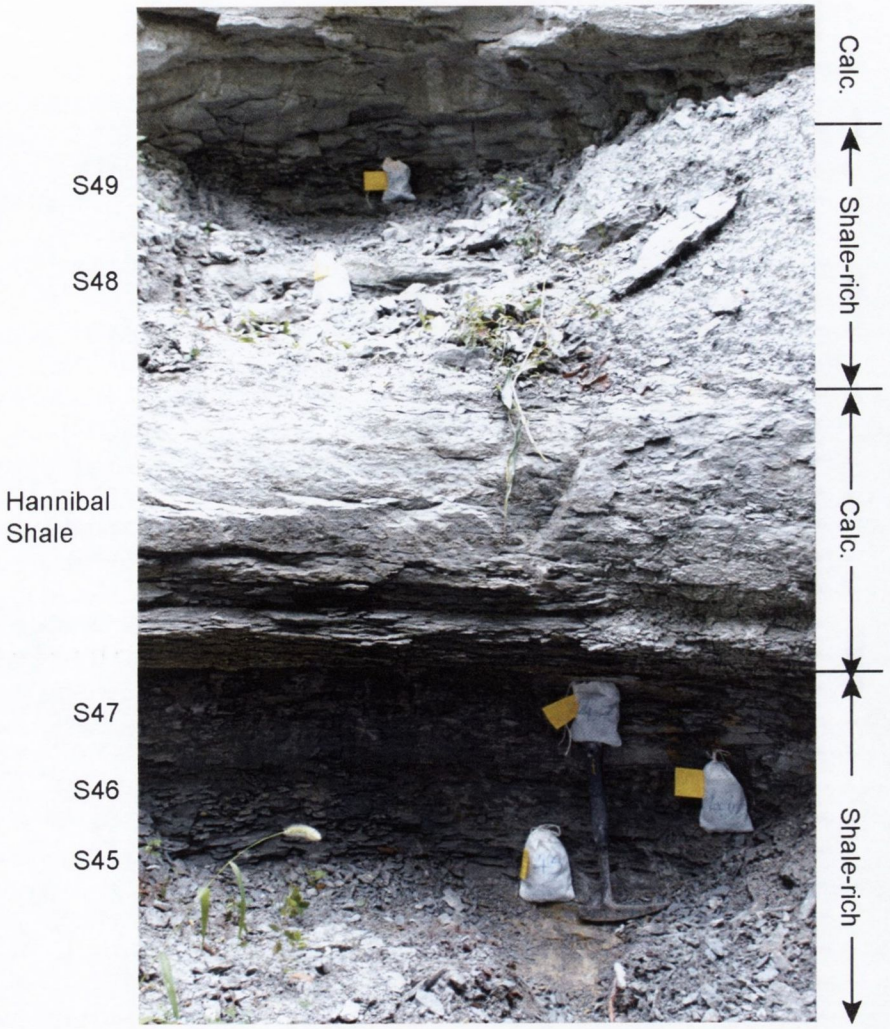
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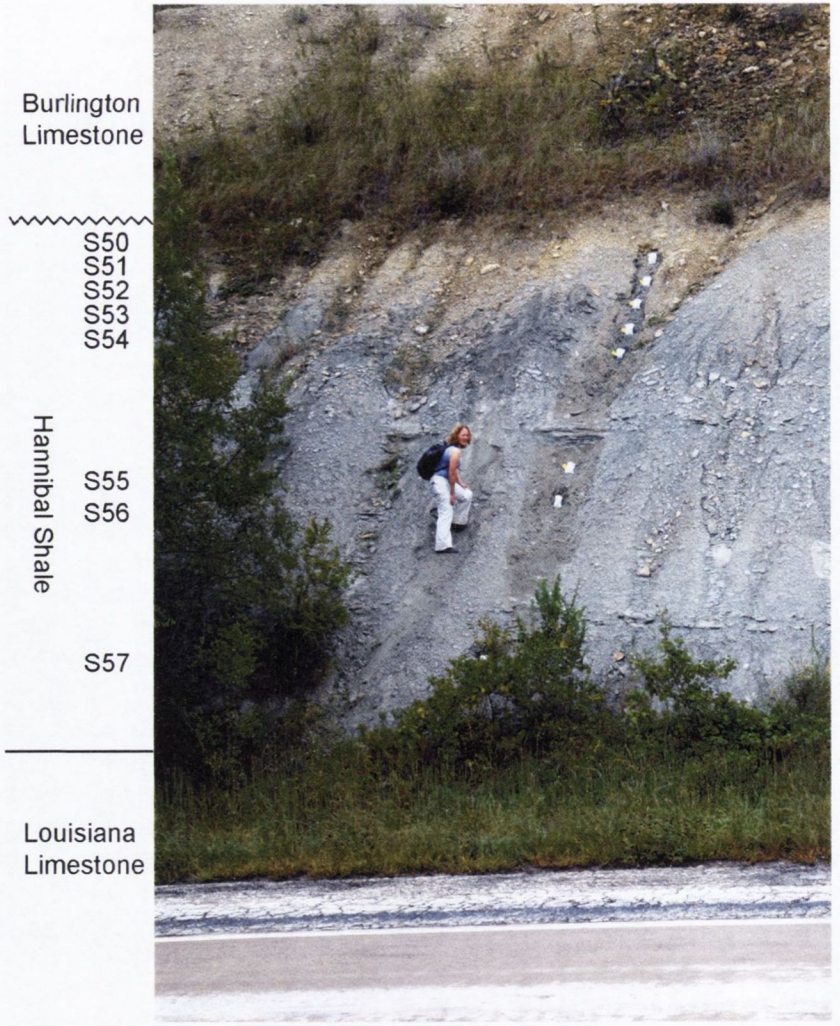
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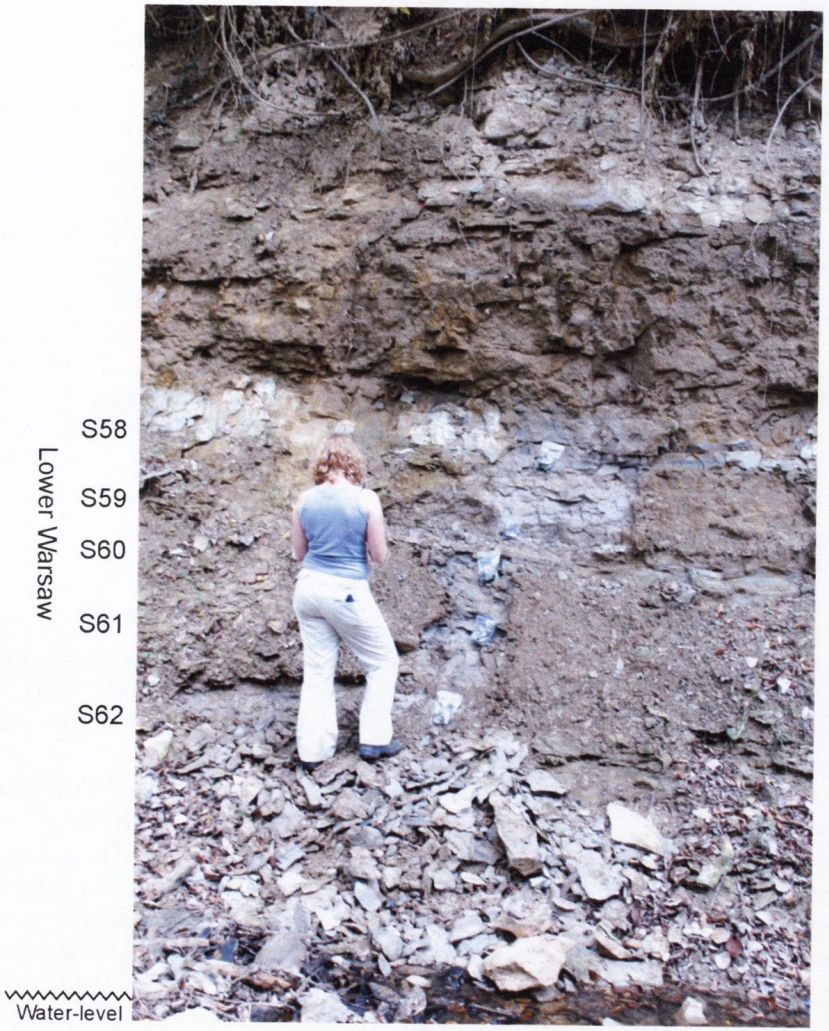
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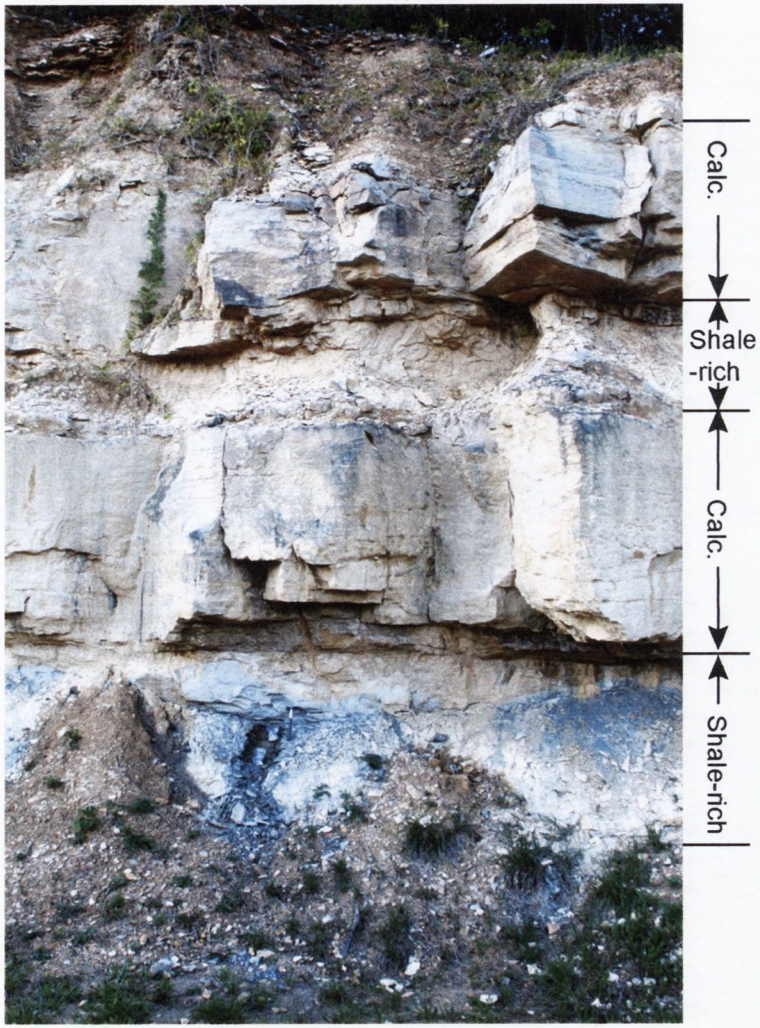
HANNIBAL, Highway 79, Marion County, Illinois



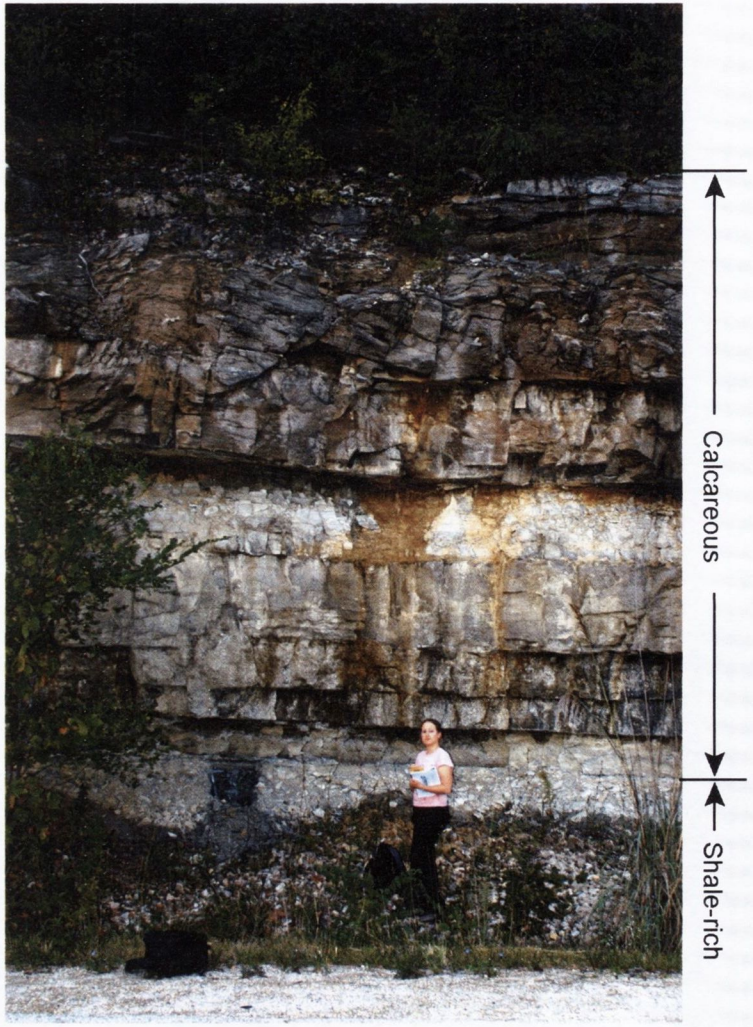
GEODE GLEN, Hancock County, Illinois



GEODE GLEN, Hancock County, Illinois



CRAGWOLD ROAD, St Louis, Illinois



CRAGWOLD ROAD, St Louis, Illinois

Palestine Sandstone

S82

Menard Limestone



FLATWOODS-KERLEY CEMETERY RAILROAD, Johnson County, Illinois

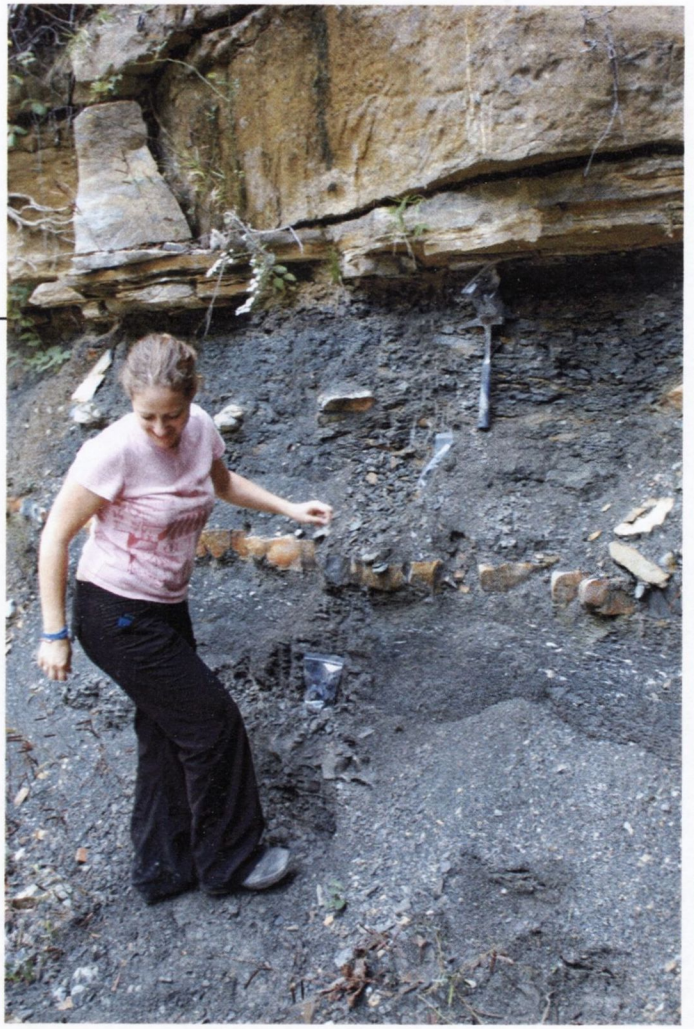
Palestine Sandstone

S83

S84

S85

Menard Limestone



FLATWOODS-KERLEY CEMETERY RAILROAD, Johnson County, Illinois

S87

Palestine Sandstone



FLATWOODS-KERLEY CEMETERY RAILROAD, Johnson County, Illinois

Waltersburg Sandstone

S88

Vienna Limestone



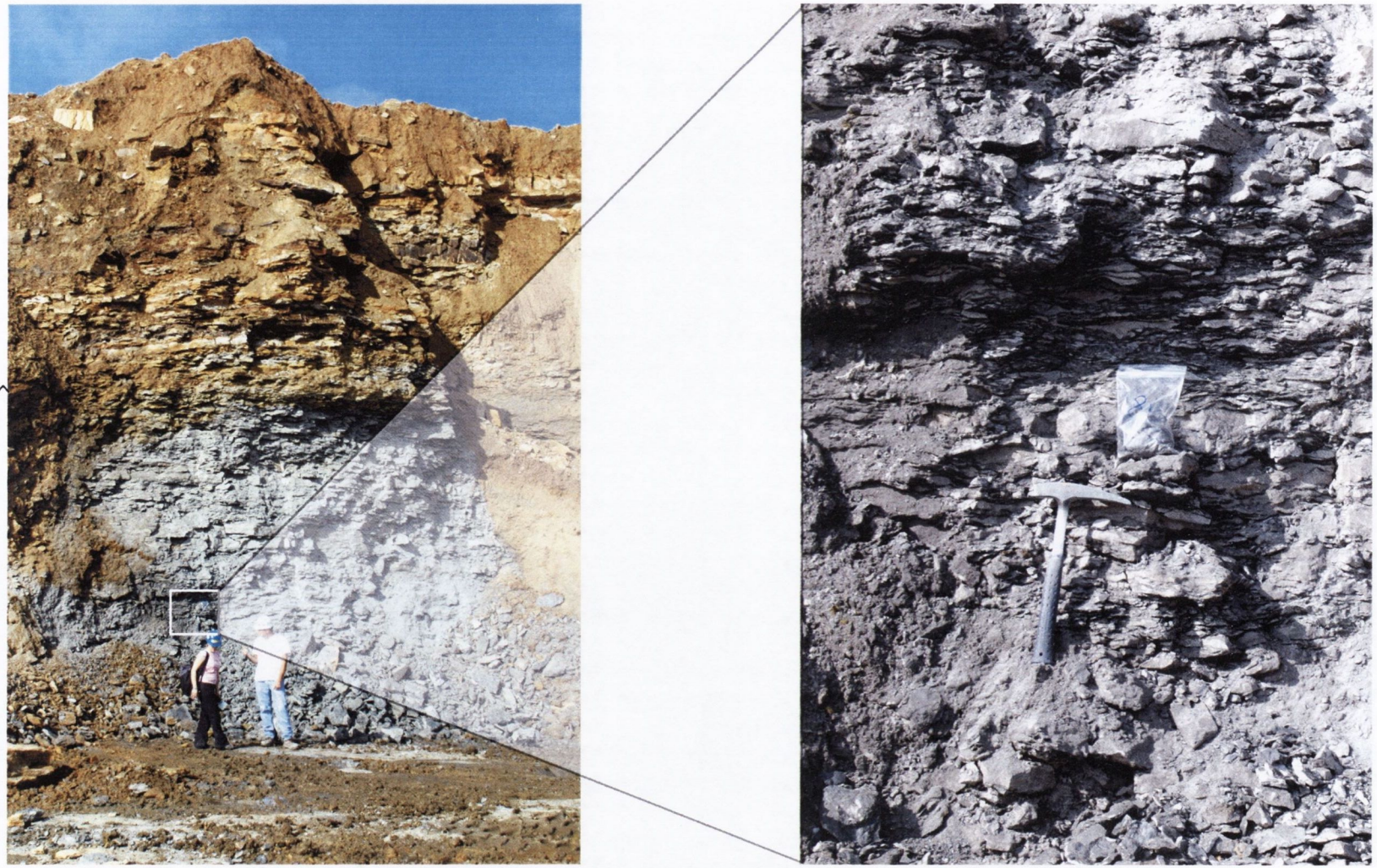
GRANTSBURG NE RAILROAD, Johnson County, Illinois



SOUTHERN ILLINOIS STONE CO., Johnson County, Illinois



SOUTHERN ILLINOIS STONE CO., Johnson County, Illinois



SOUTHERN ILLINOIS STONE CO., Johnson County, Illinois

Sample S81

APPENDIX II

PLATES

The sample number (prefixed S), England Finder co-ordinates, and museum catalogue number (prefixed TCD) are given as appropriate. All figures are Nomarski interference contrast images, illustrated at x750 magnification unless specified. The figured specimens are curated in the Geological Museum of Trinity College Dublin, Dublin, Ireland.

PLATE 1

Figure 1 *Calamospora perrugosa* (Loose) Schopf, Wilson & Bentall x 500. S139(1), E37/1. TCD 59167a.

Figure 2 *Calamospora liquida* Kosanke x 500. S75(2), P37/2. TCD 59117d.

Figure 3 *Calamospora pallida* (Loose) Schopf, Wilson & Bentall x 500. S39(1), P18/2. TCD 59062a.

Figure 4 *Calamospora microrugosa* (Ibrahim) Schopf, Wilson & Bentall x 500. S61(1), V27. TCD 59103a.

Figure 5 *Calamospora nigrata* (Naumova) Allen x 500. S75(2), E34/1. TCD 59117d.

Figure 6 *Calamospora parva* Guennel x 500. S70(2), G19. TCD 59112b.

Figure 7 *Leiotriletes trivialis* Naumova. S125(1), T19/3. TCD 59159a.

Figure 8 *Leiotriletes tumidus* Butterworth & Williams. S81(3), J20/1. TCD 59123f.

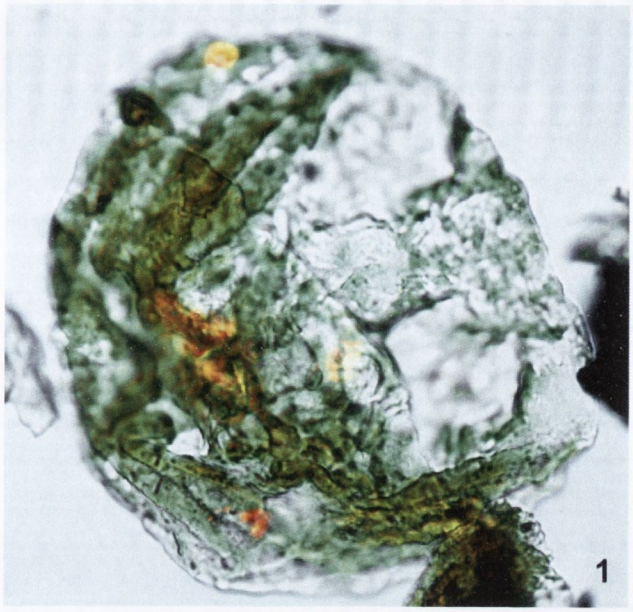
Figure 9 *Leiotriletes* sp. A *sensu* Higgs, Clayton & Keegan. S170(1), D41. TCD 59198a.

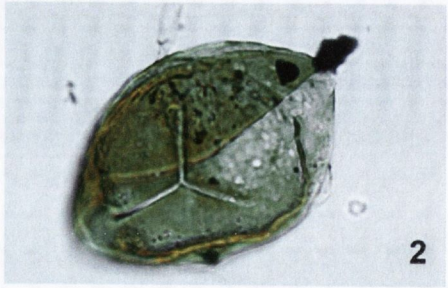
Figure 10 *Punctatisporites irrasus* Hacquebard x 500. S70(2), Q33/3. TCD 59112b.

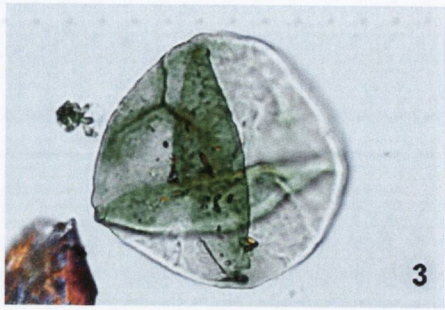
Figure 11 *Punctatisporites planus* Hacquebard. S140(1), T13/2. TCD 59168a.

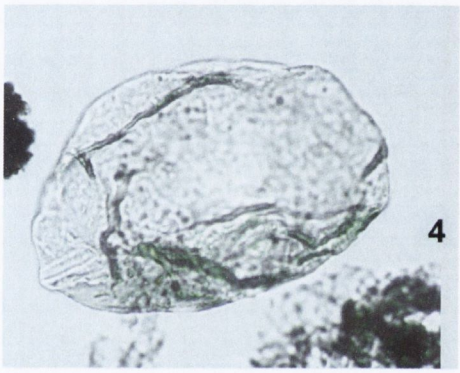
Figure 12 *Punctatisporites minutus* (Kosanke) Peppers. S133(1), G26/2. TCD 59161a.

PLATE 1


1

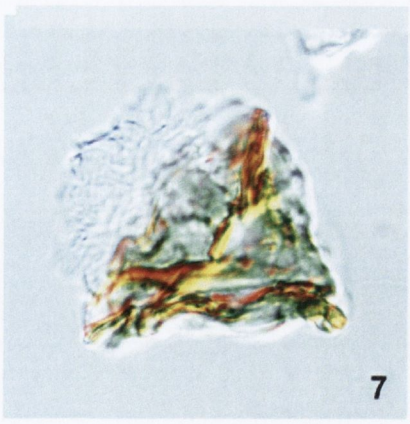

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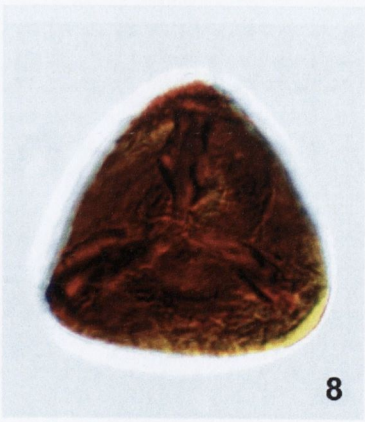

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12

PLATE 2

Figure 1 *Waltzispora polita* Hoffmeister, Staplin & Malloy. S87(1), U20/2. TCD 59129a.

Figure 2 *Retusotriletes communis* Naumova. S140(1), G33. TCD 59169b.

Figure 3 *Retusotriletes crassus* Clayton, Johnston, Sevastopulo & Smith. S70(2), M41/4. TCD 59112b.

Figure 4 *Retusotriletes incohatus* Sullivan. S45(1), K64/1. TCD 59012.

Figure 5 *Retusotriletes triangulatus* (Streel) Streel. S242, N7/2. TCD 59095a.

Figure 6 *Retusotriletes crassus* Clayton, Johnston, Sevastopulo & Smith. S78(1), G18/3. TCD 59120a.

Figure 7 *Retusotriletes famenensis* Naumova.S107(1), S23/3. TCD 59141c.

Figure 8 *Retusotriletes famenensis* Naumova S70(2), F28. TCD 59112b.

Figure 9 *Acanthotriletes falcatus* (Knox) Potonié & Kremp. S165(2), O21/1. TCD 59193b.

Figure 10 *Acanthotriletes persibus* Higgs 1975. S75(2), Q36/4. TCD 59117d.

Figure 11 *Acanthotriletes persibus* Higgs 1975. S203(1), E31/3. TCD 59215a.

Figure 12 *Acanthotriletes* sp. A. S231(1), F28. TCD 59084a.

PLATE 2

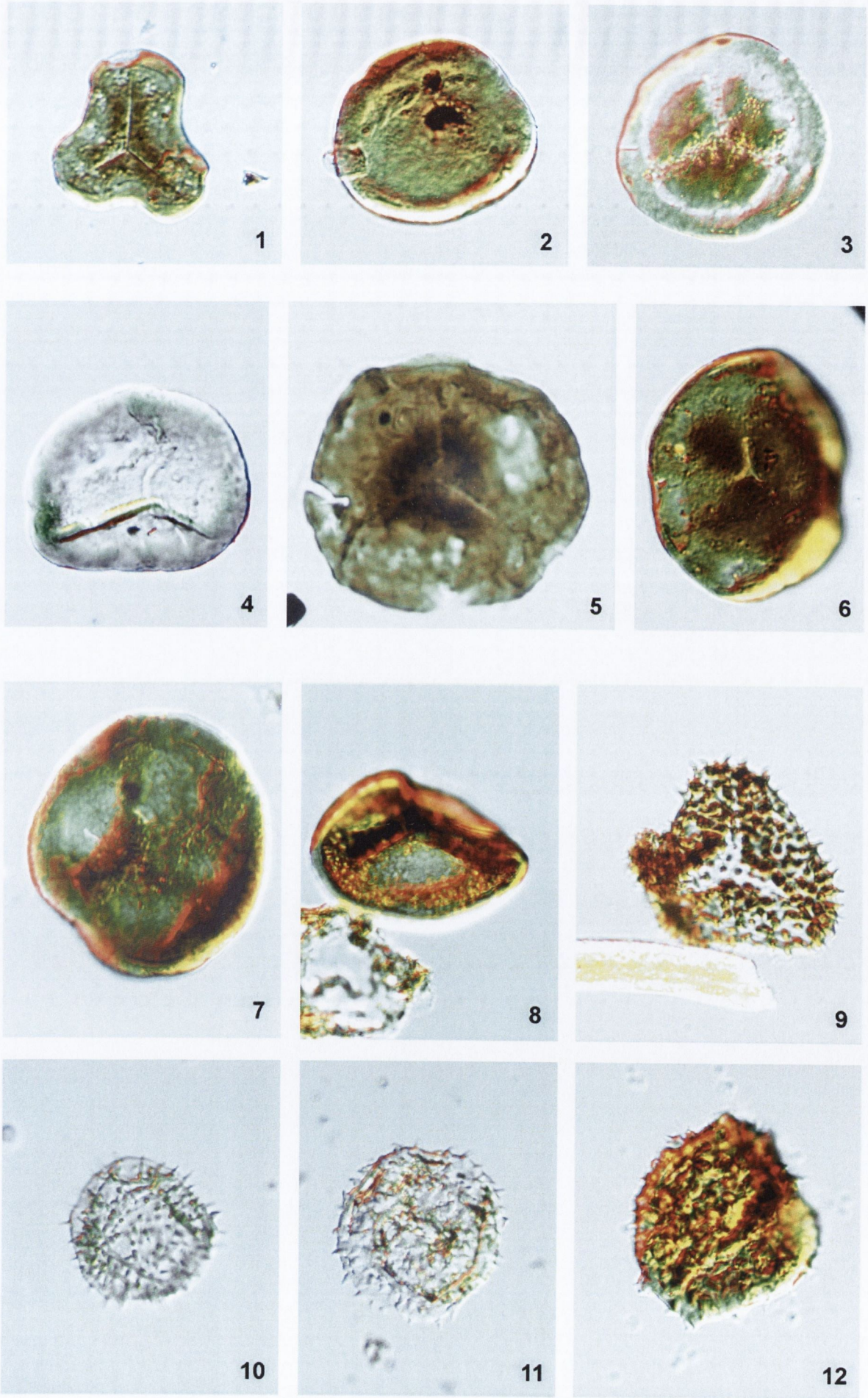


PLATE 3

Figure 1 *Anaplanisporites centrosus* Higgs, Clayton & Keegan. S73(2), S41/3. TCD 59115c.

Figure 2 *Anapiculatisporites hystricosus* Playford. S174(1), J24/4. TCD 59202a.

Figure 3 *Apiculatisporites* sp. A. S162(1), Q17/3. TCD 59190a.

Figure 4 *Apiculiretusispora fructicosa* Higgs. S83(3), Q21. TCD 59125f.

Figure 5 *Apiculiretusispora occulta* Turnau (Coleman). S72(1), J9/4. TCD 59114b.

Figure 6 *Apiculiretusispora occulta* Turnau (Coleman). S126(1), P12/2. TCD 59159a.

Figure 7 *Crassispora aculeata* Neville x 500. S82(3), G24/3. TCD 59124f.

Figure 8 *Crassispora kosankei* (Potonié & Kremp) Bharadwaj. S82(3) E38/2. TCD 59124f.

Figure 9 *Converrucosisporites* sp. A. S214(1), R16/1. TCD 59067a.

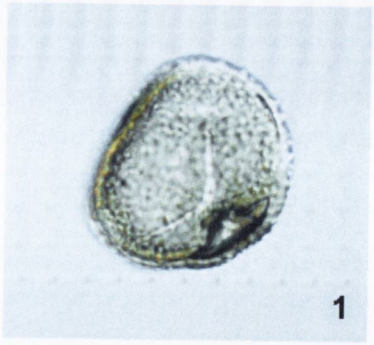
Figure 10 *Converrucosisporites* cf. *sulcatus* (Wilson & Kosanke) Potonie & Kremp. S214(1), U25. TCD 59067a.

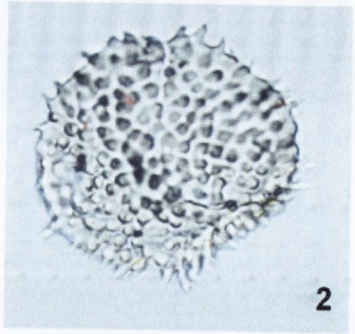
Figure 11 *Crassispora maculosa* (Knox) Sullivan x 500. S88(1), H31/3. TCD59130c.

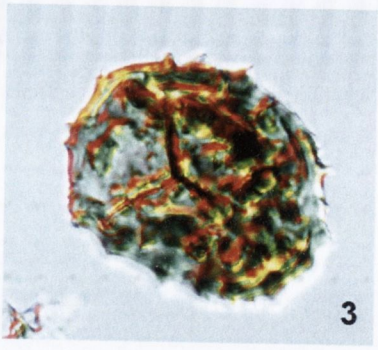
Figure 12 *Crassispora maculosa* (Knox) Sullivan x 500. S75(2), L36. TCD 59117d.

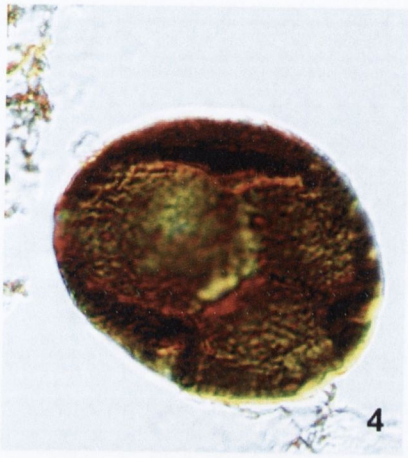
Figure 13 *Cyclogranisporites commodus* Playford. S50(1), J56/0. TCD 59017.

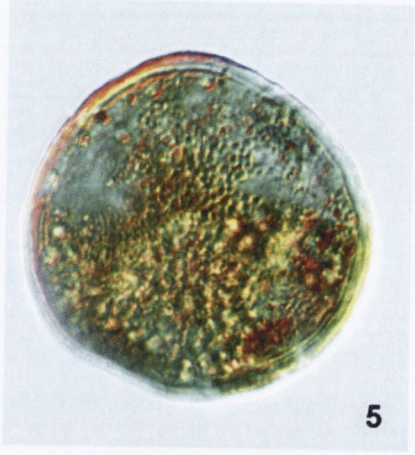
PLATE 3

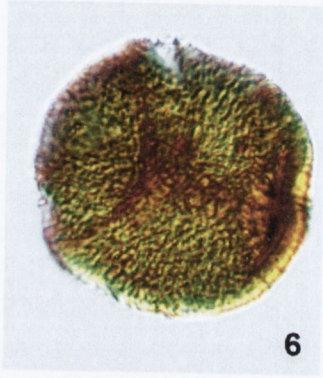


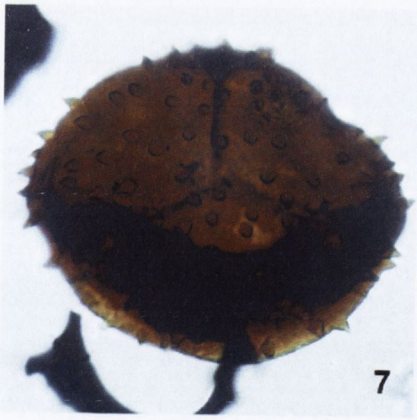














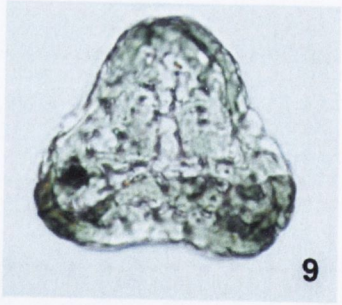










PLATE 4

Figure 1 *Granulatisporites granulatus* Ibrahim. S87(1), M39/4. TCD 59129c.

Figure 2 *Granulatisporites microgranifer* Ibrahim. S82(3), M21/2. TCD 59124f.

Figure 3 *Neoraistickia loganensis* (Winslow) Coleman & Clayton. S208(1), C19/3. TCD 59220a.

Figure 4 *Neoraistickia loganensis* (Winslow) Coleman & Clayton. S221(1), G17/3. TCD 59074a.

Figure 5 *Pilosisporites verutus* Sullivan & Marshall. S75(2), N38-1. TCD 59117d.

Figure 6 *Pustulatisporites dolbii* Higgs, Clayton & Keegan. S146(1), Q19. TCD 59174.

Figure 7 *Raistrickia clavata* Hacquebard emend. Playford. S29(1). TCD 59052a.

Figure 8 *Raistrickia clavata* Hacquebard emend. Playford. S227, N27/1. TCD 59080.

Figure 9 *Raistrickia* sp. A *sensu* Higgs, Clayton & Keegan. S230(1), V34/3. TCD 59083a.

Figure 10 *Raistrickia macrura* (Luber) Dolby and Neves. S228(1), S14. TCD 59081a.

Figure 11 *Raistrickia condylosa* Higgs. S78(1), J40/2. TCD 59120a.

Figure 12 *Raistrickia saetosa* (Loose) Schopf, Wilson & Bentall. S212(1), G44/1. TCD 59065.

Figure 13 *Raistrickia macrura* (Luber) Dolby and Neves. S138(1), F48/2. TCD 59166b.

Figure 14 *Raistrickia fulva* Artüz 1957. S88(1), R27/3. TCD 59130c.

Figure 15 *Raistrickia fulva* Artüz 1957. S206(1), P33/3. TCD 59124f.

Figure 16 *Raistrickia variabilis* Dolby & Neves. S231(1), 28/2. TCD 59084a.

PLATE 4

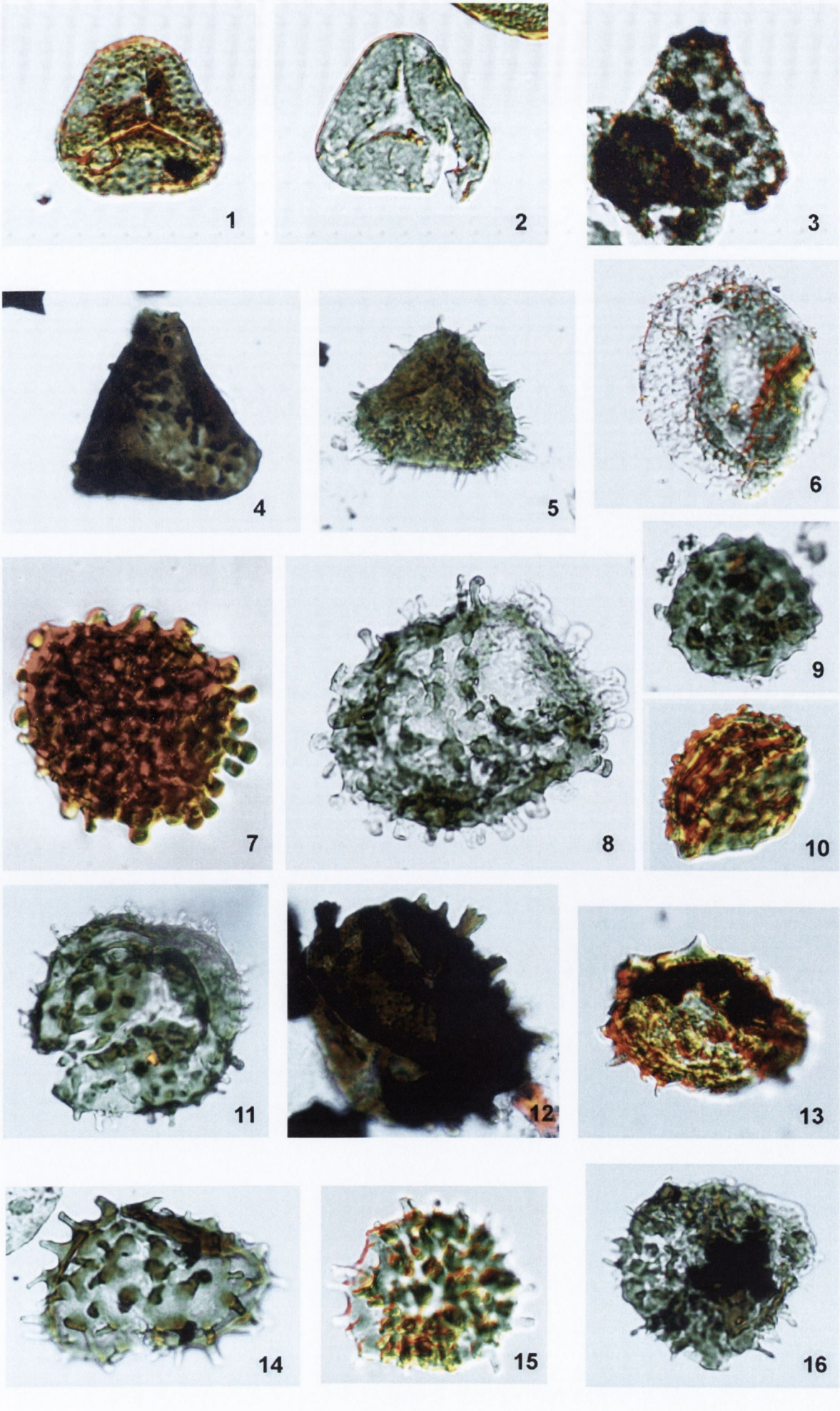


PLATE 5

Figure 1 *Raistrickia aculeata* Kosanke. S138(1), Q51/1. TCD 59166b.

Figure 2 *Schopfites claviger* Sullivan emend. Higgs, Clayton & Keegan. S82(3), P/15. TCD 59124f.

Figure 3 *Schopfites claviger* Sullivan emend. Higgs, Clayton & Keegan. S206(1), P43/2. TCD 59218a.

Figure 4 *Tricidarisporites* cf. *arcuatus* Neville in Neves *et al.* S209(1), T46/1. TCD 59221a.

Figure 5 *Umbonatisporites distinctus* Clayton x 500. S218(1), C25/4. TCD 59071.

Figure 6 *Umbonatisporites distinctus* Clayton x 500. S220, D23/3. TCD 59073.

Figure 7 *Verrucosisporites nitidus* (Naumova) Playford. S70(2), L31/3. TCD 59112b.

Figure 8 *Convolutispora caliginosa* Clayton & Keegan *in* Clayton, Keegan & Sevastopulo. S242(1), V32/2. TCD 59095a.

Figure 9 *Convolutispora florida* Hoffmeister, Staplin & Malloy. S125(1), J36/3. TCD 59159b.

Figure 10 *Convolutispora florida* Hoffmeister, Staplin & Malloy. S82(1), U25/3. TCD 59124d.

Figure 11 *Convolutispora mellita* Hoffmeister, Staplin & Malloy. S231(1), M28/3. TCD 59084a.

Figure 12 *Convolutispora permixta* Higgs, Clayton & Keegan. S228(1), V27/2. TCD 59081a.

Figure 13 *Convolutispora tessellata* Hoffmeister, Staplin & Malloy. S133(1), M23/1. TCD 59161b.

Figure 14 *Convolutispora tessellata* Hoffmeister, Staplin & Malloy. S133(1), K23/4. TCD 59161b.

Figure 15 *Convolutispora* cf. *usitata sensu* Smith & Butterworth 1967. S88(1), J30/4. TCD 59130c.

PLATE 5

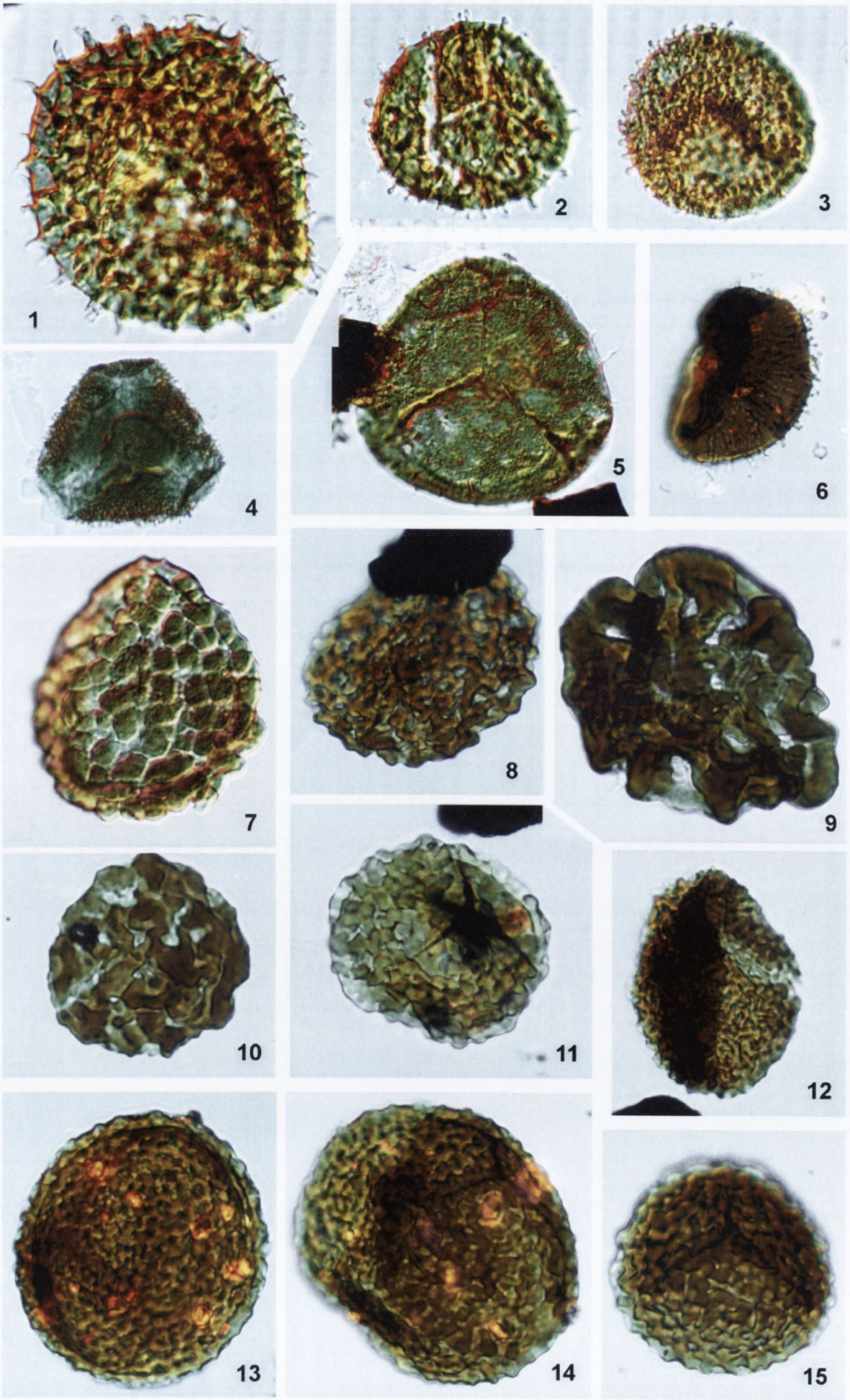


PLATE 6

Figure 1 *Dictyotriletes cheveriensis* (Playford) Bertlesen. S71(2), J22. TCD 59113b.

Figure 2 *Cordylosporites marciae* (Winslow) Playford & Satterthwait. S39(1), M39/1.

Figure 3 *Microreticulatisporites araneum* Higgs, Clayton & Keegan. S122(1), X38/3. TCD 59156a.

Figure 4 *Microreticulatisporites hortonensis* Playford. S228(1), T20/1.

Figure 5 *Dictyotriletes trivialis* Naumova in litt. Kedo. S133(1), Q43/4. TCD 59161b.

Figure 6 *Emphanisporites rotatus* (McGregor) McGregor. S39(1), N40/1.

Figure 7 *Microreticulatisporites hortonensis* Playford. S203(1), V29/1. TCD 59215a.

Figure 8 *Microreticulatisporites hortonensis* Playford. S203(2), C40/2. TCD 59215b.

Figure 9 *Emphanisporites rotatus* (McGregor) McGregor. S223(1), S35/4. TCD 59076.

Figure 10 *Tripartites vetustus* Schemel. S206(1), K24/1. TCD 59218a

Figure 11 *Tripartites vetustus* Schemel. S88(3), H10/2. TCD 59130h.

Figure 12 *Tripartites vetustus* Schemel. S165(2), R24/2. TCD 59193b.

Figure 13 Tripartites vetustus Schemel. S75(2), K33. TCD 59117d.

Figure 14 *Tripartites vetustus* Schemel. S87(1), S31/3. TCD 59129c.

Figure 15 *Triquitrites marginatus* Hoffmeister, Staplin & Malloy. S209(1), Q18/1. TCD 59221a.

Figure 16 *Triquitrites marginatus* Hoffmeister, Staplin & Malloy. S88(2), T13/3. TCD 59130d.

PLATE 6

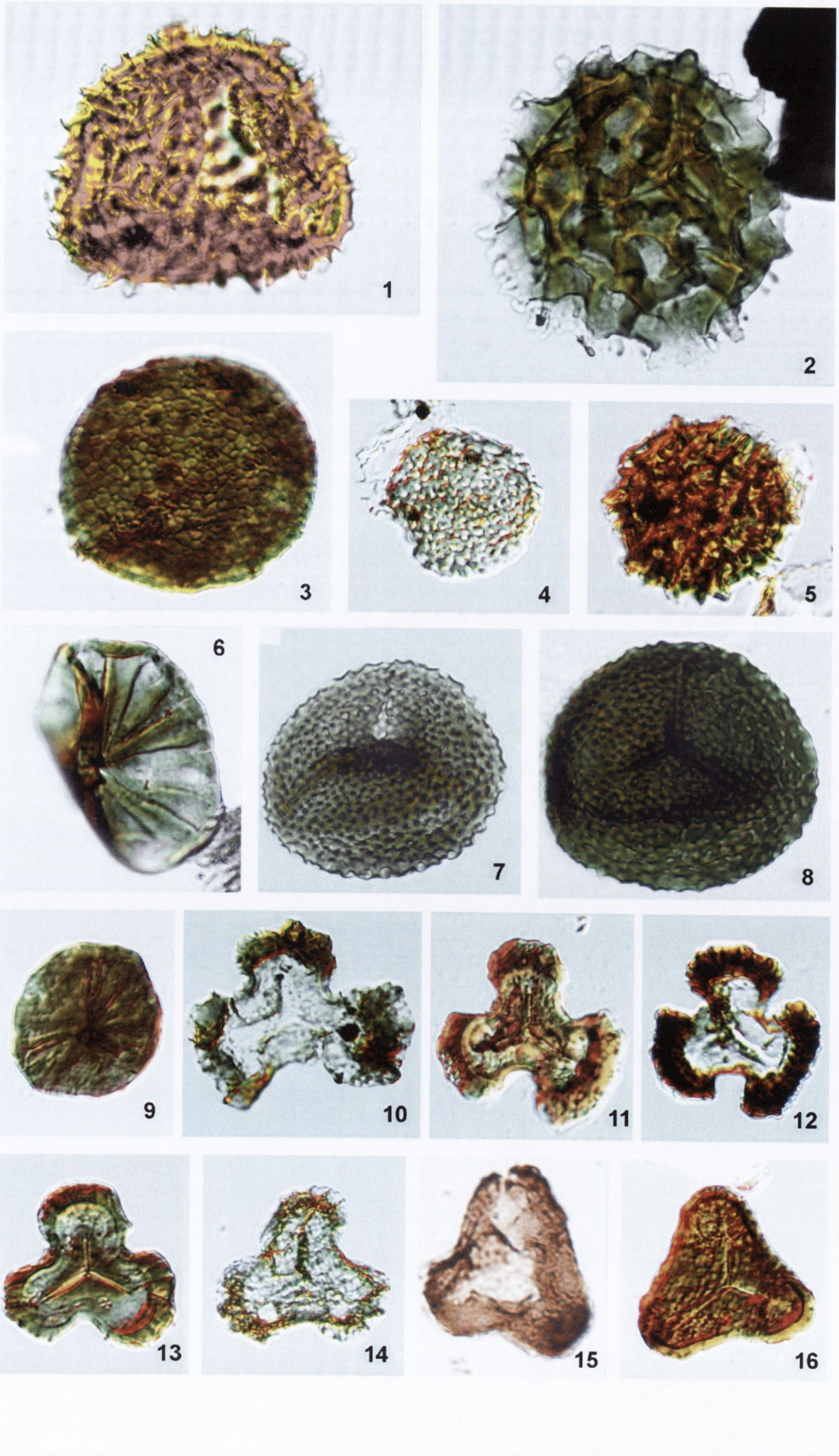


PLATE 7

Figure 1 *Knoxisporites literatus* (Waltz) Playford. S165(2),Y21/2. TCD 59193b.

Figure 2 *Knoxisporites stephanephorus* Love. S81(3), D18/2. TCD 59123f.

Figure 3 *Knoxisporites literatus* (Waltz) Playford. S80(2), R8/4. TCD 59112c.

Figure 4 *Knoxisporites triradiatus* Hoffmeister, Staplin & Malloy. S78(1), P15/1. TCD 59120a.

Figure 5 *Knoxisporites triradiatus* Hoffmeister, Staplin & Malloy. S78(1), S15/1. TCD 59120a.

Figure 6 *Murospora dubitata* Higgs. S141(1), R23/3. TCD 59169.

Figure 7 *Knoxisporites concentricus* (Byvsheva) Playford & McGregor. S83(2), G30/1. TCD 59125e.

Figure 8 *Knoxisporites concentricus* (Byvsheva) Playford & McGregor. S208(1), G28/4. TCD 59220a.

Figure 9 *Stenozonotriletes triangularis* Neves. S80(2), F6/2. TCD 59112c.

Figure 10 *Tumulispora malevkensis* (Kedo) Turnau. S140(1) G40/3. TCD 59168b.

Figure 11 *Tumulispora malevkensis* (Kedo) Turnau. S235(1), R31. TCD 59088a.

Figure 12 *Tumulispora malevkensis* (Kedo) Turnau. S232(1), J37/2. TCD 59085a.

Figure 13 *Proprisporites laevigatus* Neves. S133(1). TCD 59161b.

PLATE 7

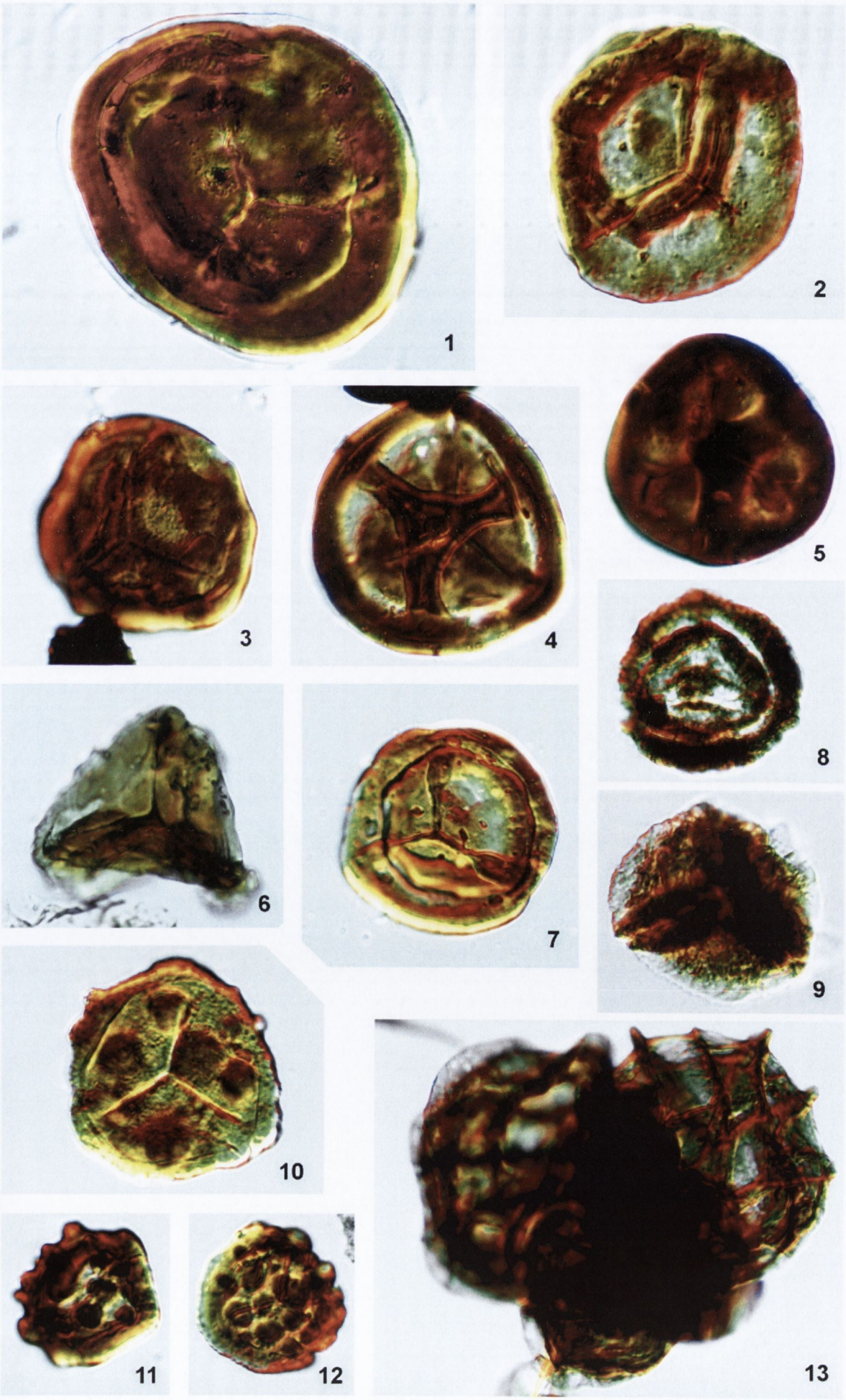


PLATE 8

Figure 1 *Cyrtospora cristifer* (Luber) emend. Van der Zwann. S232(1), L23/2. TCD 59085a.

Figure 2 *Cyrtospora cristifer* (Luber) emend. Van der Zwann. S228(1), K11. TCD 59081a.

Figure 3 *Auroraspora bateola* Sullivan. S209(1), R12. TCD 59221a.

Figure 4 *Auroraspora macra* Sullivan. S133(1), R35/3. TCD 59161b.

Figure 5 *Auroraspora macra* Sullivan. S203(2), R37. TCD 59215b.

Figure 6 *Auroraspora solisortus* Hoffmeister, Staplin & Malloy. S80(2), S8/3. TCD 59112c.

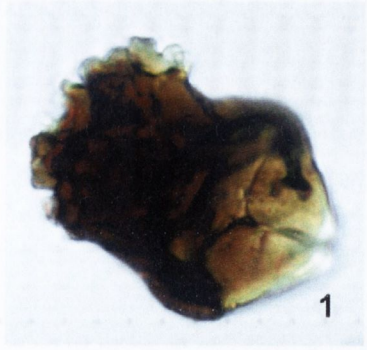
Figure 7 *Auroraspora solisortus* Hoffmeister, Staplin & Malloy. S88(2), R31. TCD 59130d.

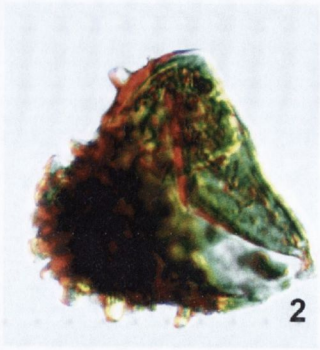
Figure 8 *Auroraspora solisortus* Hoffmeister, Staplin & Malloy. S133(1), Q12/3. TCD 59161b.

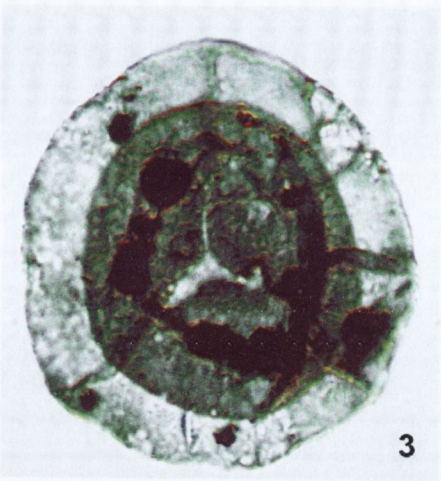
Figure 9 *Auroraspora* cf. *solisortus* x 500. S228(1), Q7/2. TCD 59081a.

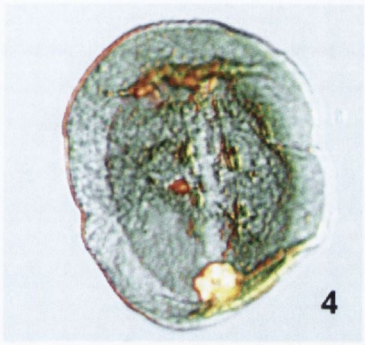
Figure 10 *Colatisporites decorus* (Bharadwaj & Venkatachala) Williams *in* Neves *et al.* S209(1), P25/4. TCD 59221a.

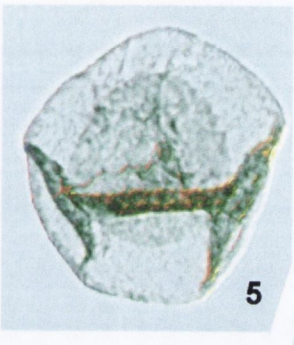
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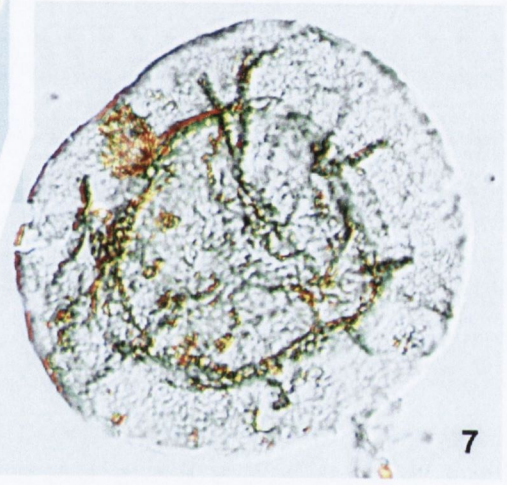

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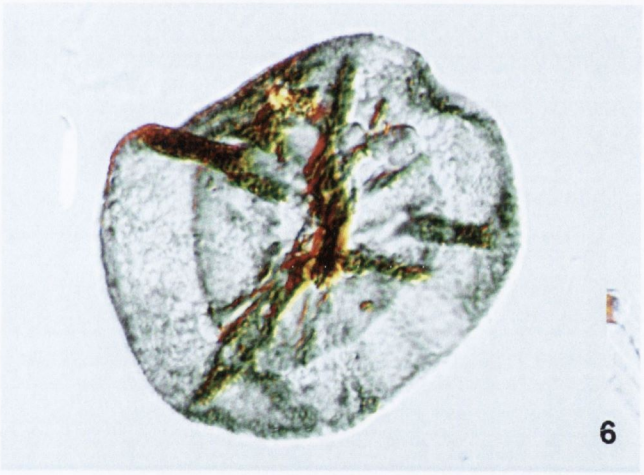

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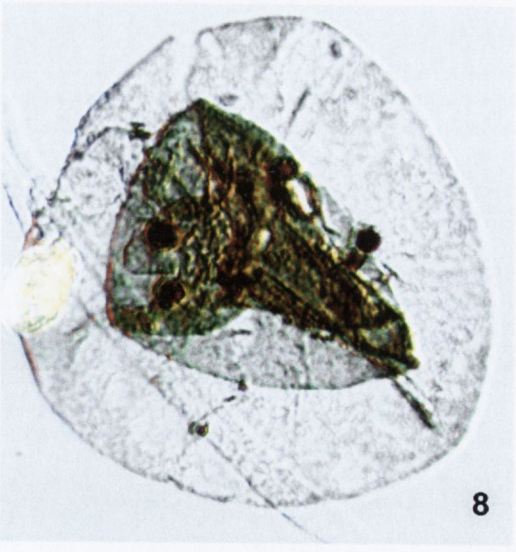

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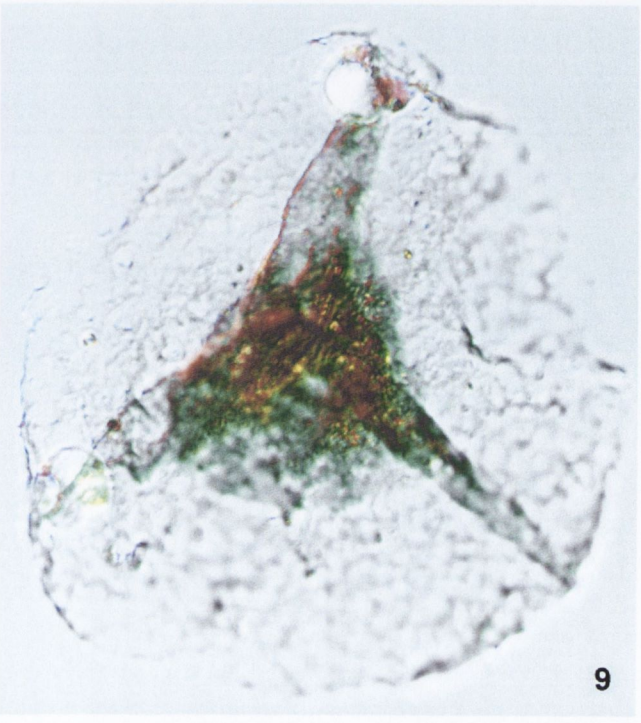

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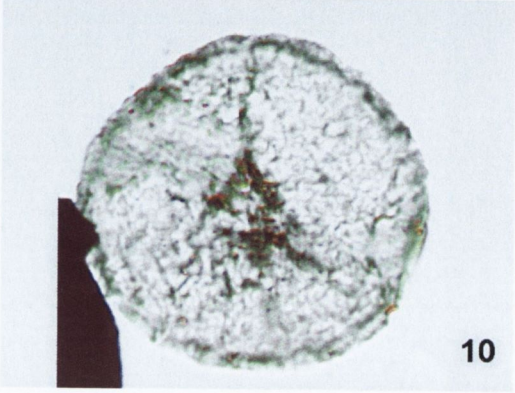

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PLATE 9

Figure 1 *Grandispora cornuta* Higgs. S242(1), R20/3. TCD 59095a.

Figure 2 *Grandispora cornuta* Higgs. S240(1), F18/4. TCD 59093a.

Figure 3 *Grandispora spinosa* Hoffmeister, Staplin & Malloy x 500. S78(1), W23/2. TCD 59120a.

Figure 4 *Grandispora spinosa* Hoffmeister, Staplin & Malloy x 500. S82(1), N30/1. TCD 59124d.

Figure 5 *Grandispora acuta* (Kedo) Byvscheva. S155(2), N27/3. TCD 59183d.

Figure 6 *Grandispora echinata* Hacquebard. S75(2), Q33/4. TCD 59117d.

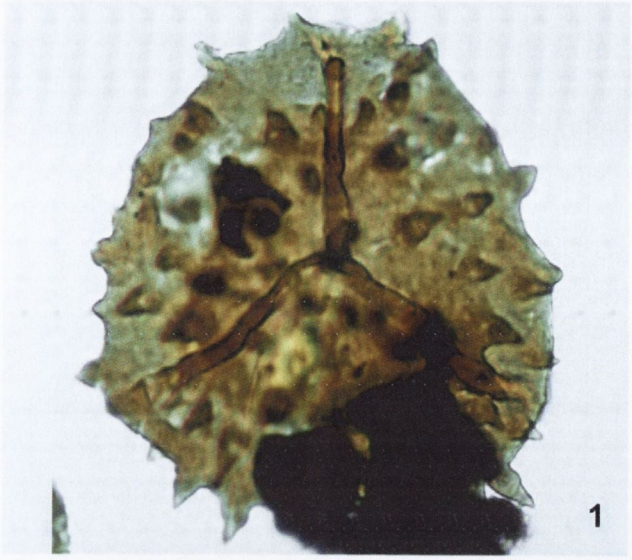
Figure 7 *Grandispora echinata* Hacquebard. S239(1), F28/2. TCD 59092a.

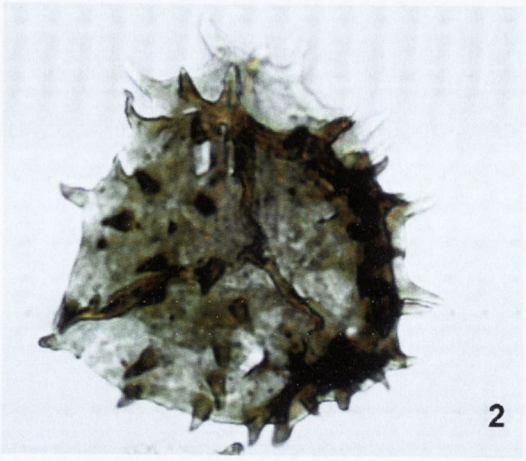
Figure 8 *Grandispora acuta* (Kedo) Byvscheva. S154(1), R35/3. TCD 59182a.

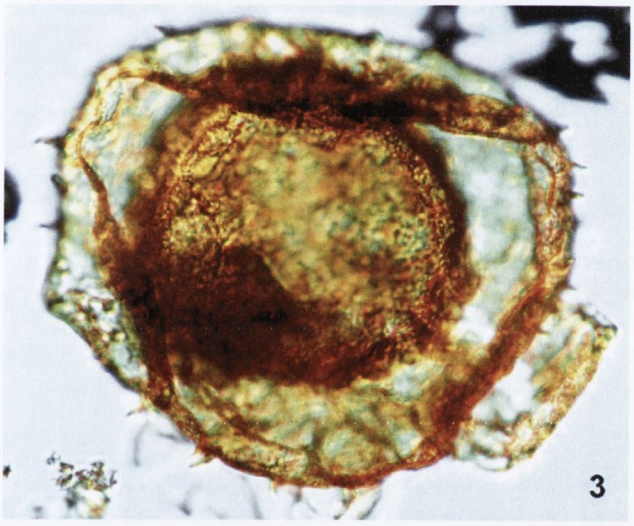
Figure 9 *Retispora lepidophyta* (Kedo) Playford. S39(3), C42/3. TCD 59062f.

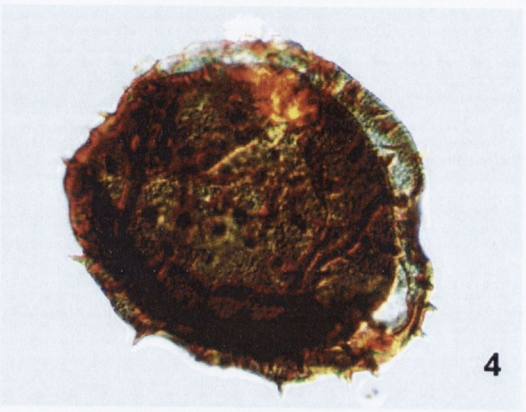
Figure 10 *Retispora lepidophyta* (Kedo) Playford. S39(4), N23/1. TCD 59062g.

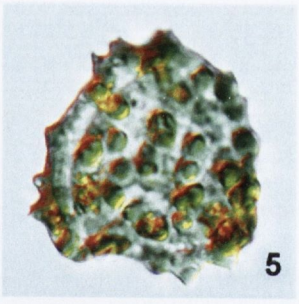
PLATE 9

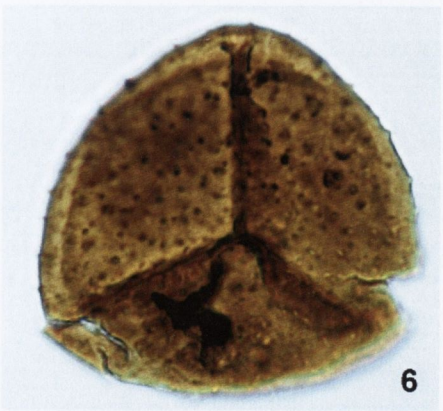

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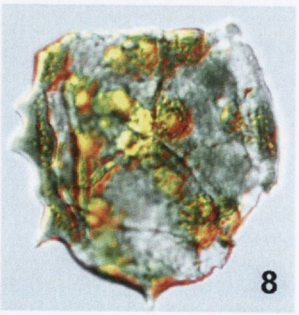

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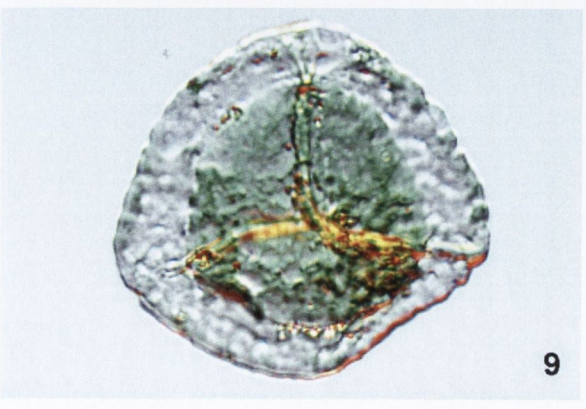

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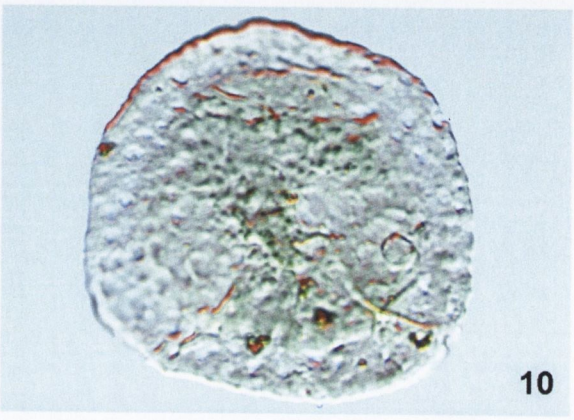

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PLATE 10

Figure 1 *Rugospora flexuosa* (Jushko) Streel. S39(2), R46. TCD 59062b.

Figure 2 *Rugospora minuta* Neves & Ioannides. S174(1), D25/2. TCD 59202a.

Figure 3 *Rugospora polyptycha* Neves & Ioannides. S124(1), D27/1. TCD 59158a.

Figure 4 *Rugospora polyptycha* Neves & Ioannides x 500. S123(1), R34/2. TCD 59157a.

Figure 5 *Rugospora lactuosa* Higgs, Clayton & Keegan. S165(2), J35. TCD 59193b.

Figure 6 *Rugospora* sp. A. S80(1), S33/3. TCD 59122a.

Figure 7 *Rugospora polyptycha* Neves & Ioannides. S82(3), G23/1. TCD 59124f.

Figure 8 *Spelaeotriletes cabotii* Utting *et al.* S177(1), V18/1. TCD 59205.

Figure 9 *Spelaeotriletes balteatus* (Playford) Higgs. S71(3), K23/1. TCD 59113d.

Figure 10 *Rugospora* cf. *polyptycha*. S29(1), H32/4. TCD 59052a.

Figure 11 *Spelaeotriletes cabotii* Utting *et al.* S239(1), S24. TCD 59092a.

Figure 12 *Spelaeotriletes balteatus* (Playford) Higgs. S207(1), J13. TCD 59219a.

PLATE 10

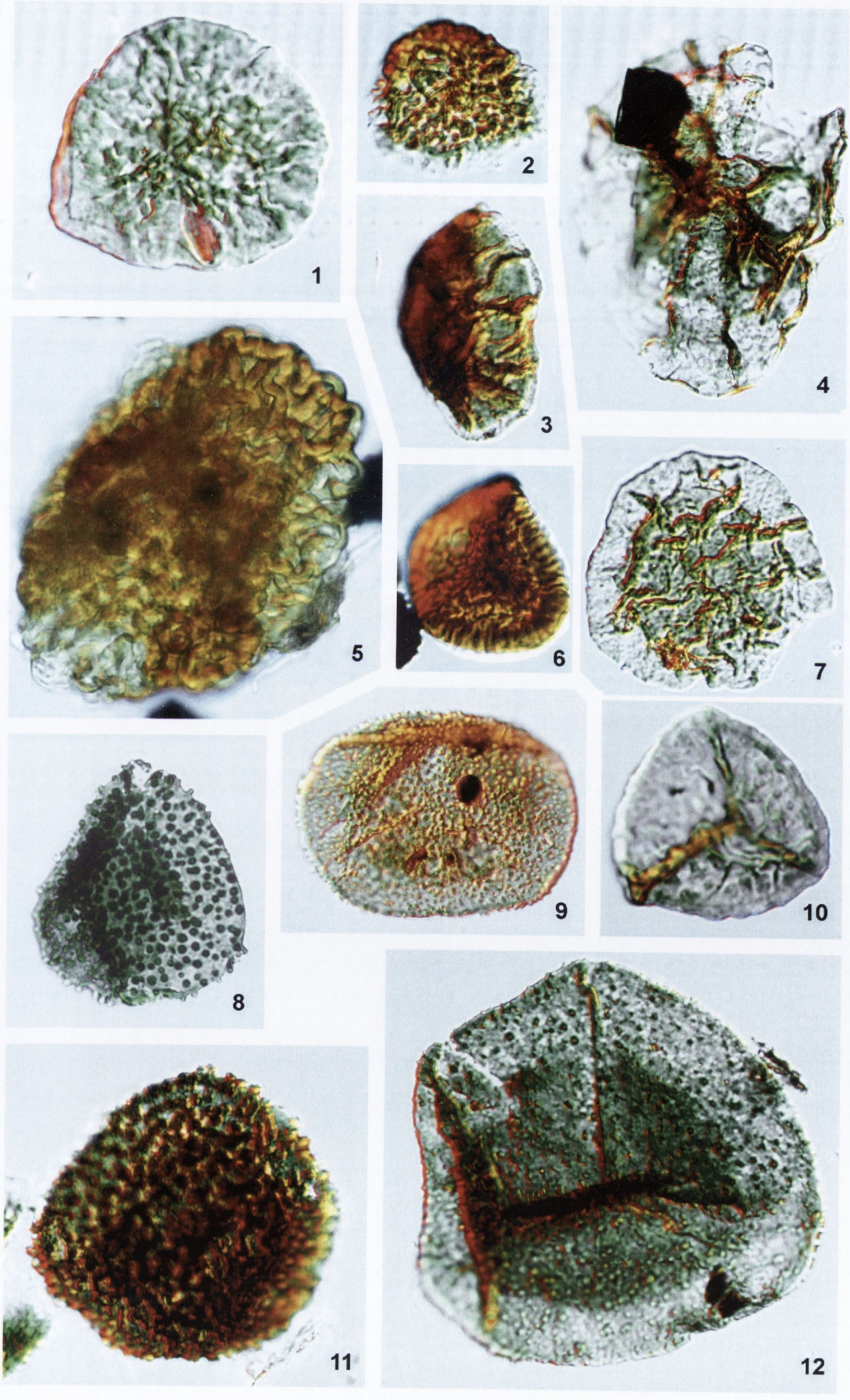


PLATE 11

Figure 1 *Spelaeotriletes crustatus* Higgs. S170(1), G45. TCD 59198a.

Figure 2 *Spelaeotriletes obtusus* Higgs. S29, E40/1. TCD 59052a.

Figure 3 *Spelaeotriletes galearis* Brittain & Higgs. S240(1), A28/4. TCD 59093a.

Figure 4 *Spelaeotriletes galearis* Brittain & Higgs. S239(1), H19/1+2. TCD 59092a.

Figure 5 *Spelaeotriletes galearis* Brittain & Higgs. S239(1), H19/1+2. TCD 59092a. Detail of galeate ornament x 1500.

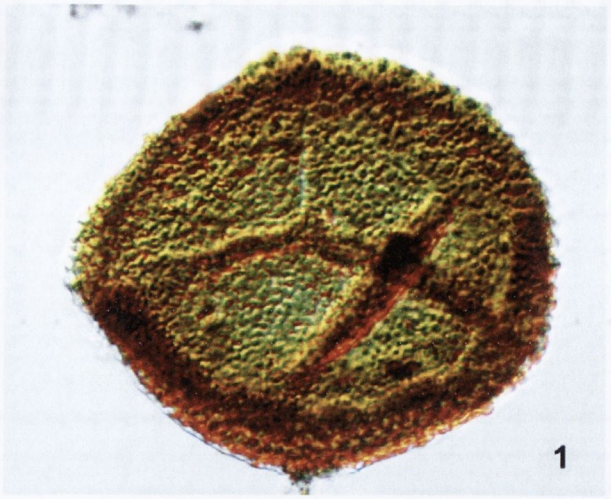
Figure 6 *Spelaeotriletes pretiosus* (Playford) Neves & Belt. S71(2), E25. TCD 59113e.

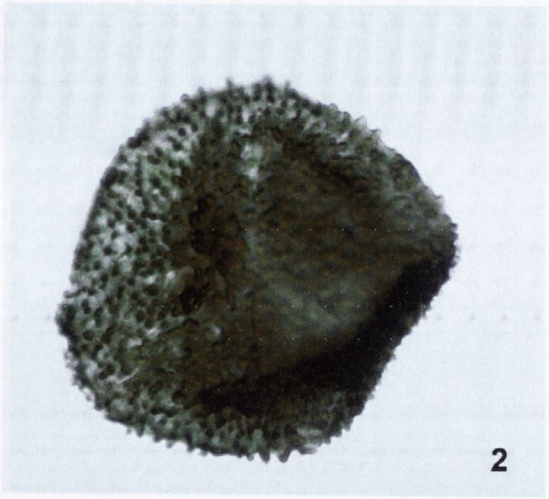
Figure 7 *Spelaeotriletes pretiosus* (Playford) Neves & Belt. S153(1), F18/1. TCD 59181a.

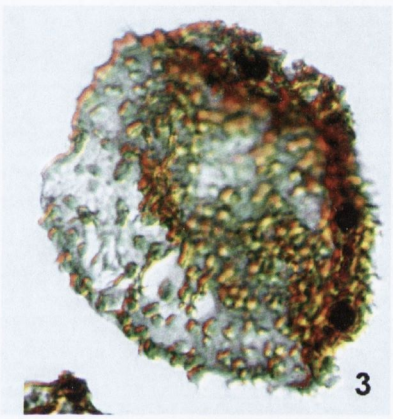
Figure 8 *Spelaeotriletes pretiosus* (Playford) Neves & Belt. S83(2), L31/2. TCD 59125e.

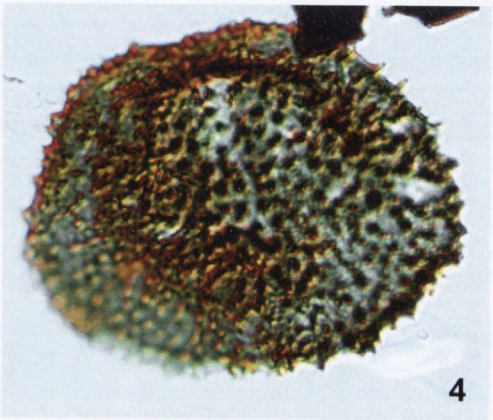
Figure 9 *Spelaeotriletes pretiosus* (Playford) Neves & Belt. S235(1) M14/3. TCD 59088a.

PLATE 11

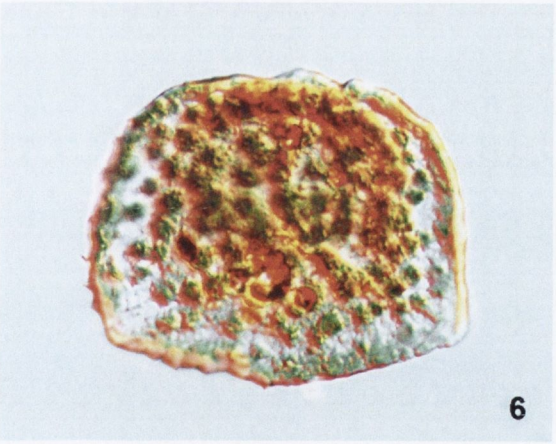

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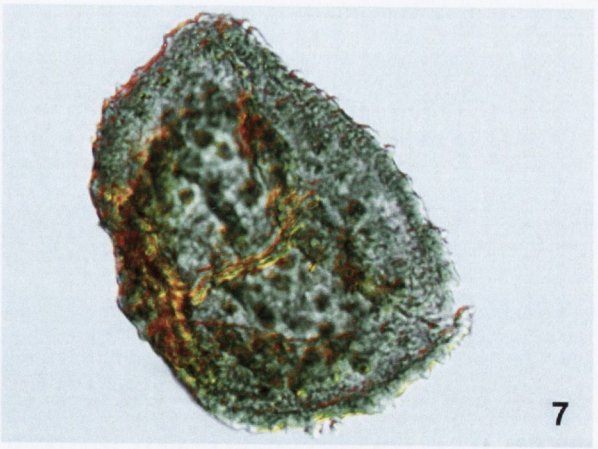

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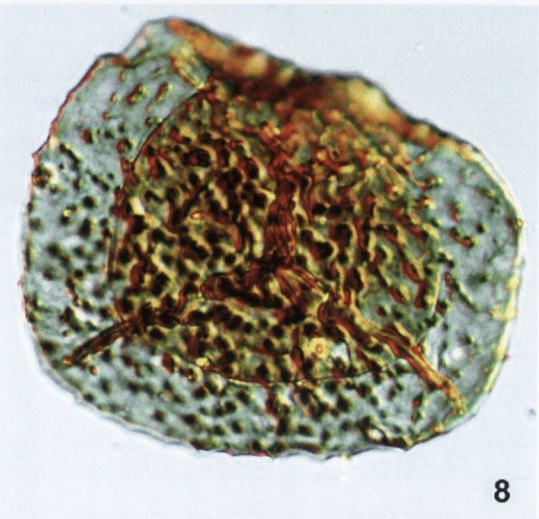

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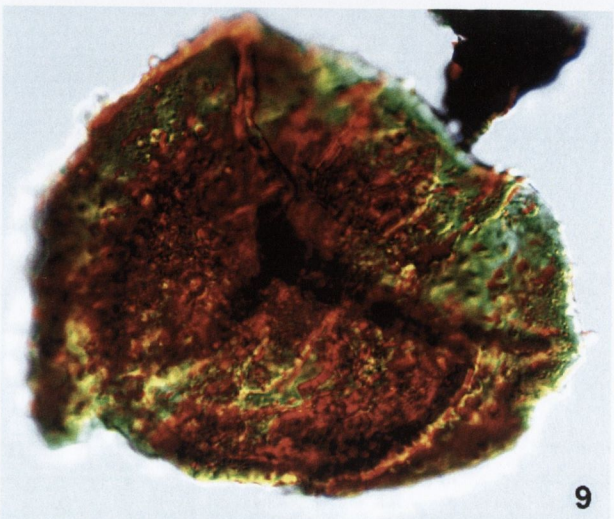

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PLATE 12

Figure 1 *Velamisporites magnus* (Hughes & Playford) Playford. S52 (1), 37/3. TCD 59099a.

Figure 2 *Velamisporites tesselatus* (Staplin) Coleman. S140(1), G30/4. TCD 59816b.

Figure 3 *Velamisporites perinatus* (Hughes & Playford) Playford. S240(1), E26/2. TCD 59093a.

Figure 4 *Velamisporites perinatus* (Hughes & Playford) Playford. S75(2), S33/2. TCD 59117d.

Figure 5 *Discernisporites micromanifestus* (Hacquebard) Sabry & Neves. S80(2), Q26/4. TCD 59112c.

Figure 6 *Discernisporites micromanifestus* (Hacquebard) Sabry & Neves. S133(1), M45/3. TCD 59161b.

Figure 7 *Discernisporites micromanifestus* (Hacquebard) Sabry & Neves. S133(1), Q43. TCD 59161b.

Figure 8 *Discernisporites* cf. *micromanifestus*. S75(2), N32. TCD 59117d.

Figure 9 *Discernisporites sullivani* Higgs & Clayton. S83(2), L31/2. TCD 59125e.

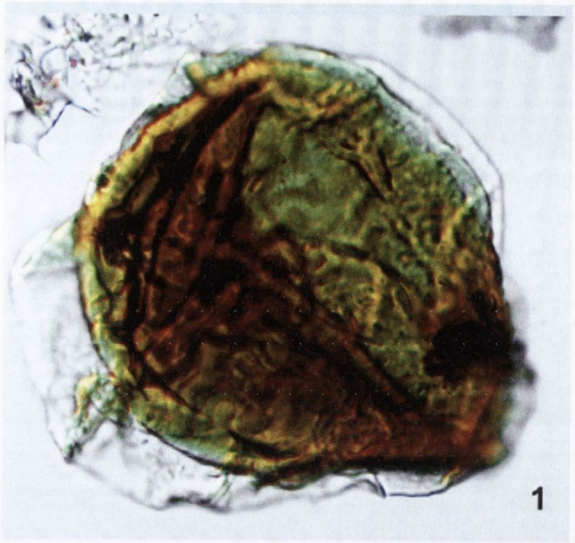
Figure 10 *Geminospora* sp. A *sensu* Higgs *et al.* S160(2), R31/4. TCD 59188d.

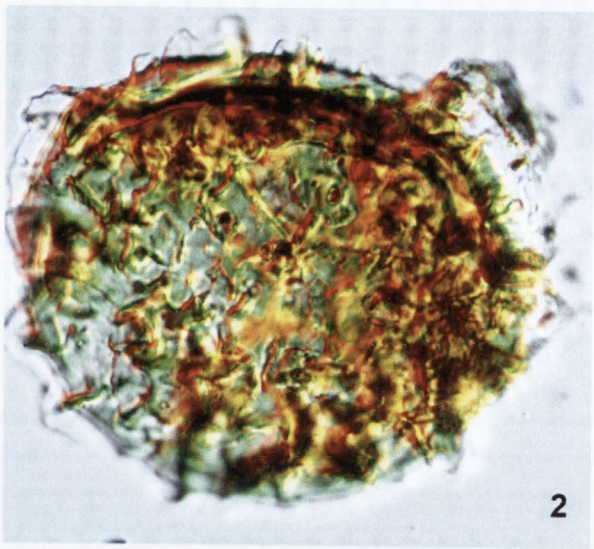
Figure 11 *Geminospora spongiata* Higgs *et al.* S213(1), O16/2. TCD 59066a.

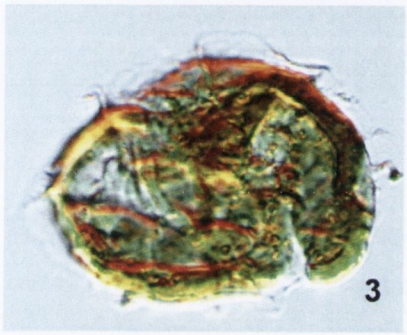
Figure 12 *Geminospora spongiata* Higgs *et al.* S170(1), J22/3. TCD 59198a.

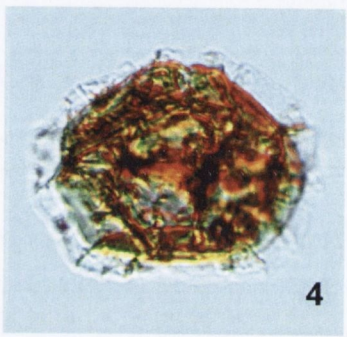
Figure 13 *Geminospora* sp. A *sensu* Higgs *et al.* S50(4), N39/4. TCD 59014. TCD 59098d.

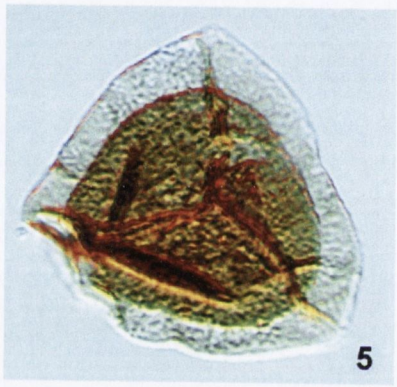
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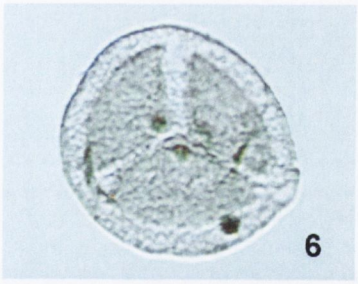

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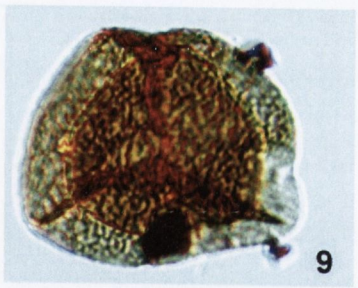

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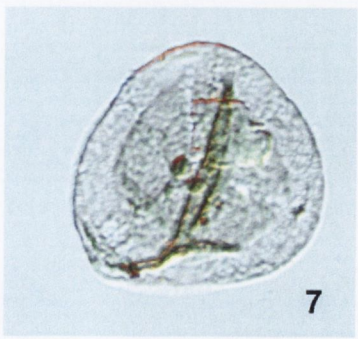

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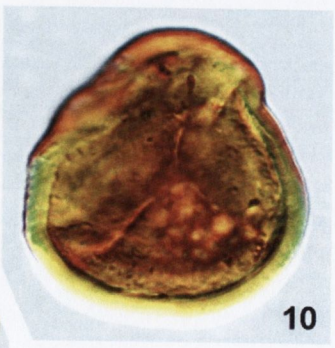

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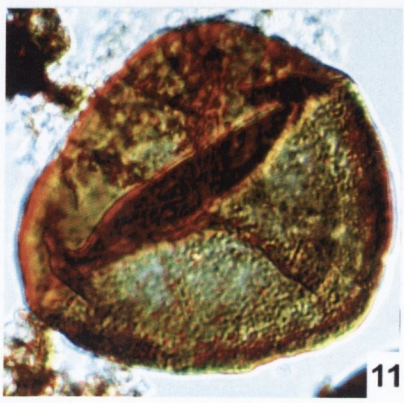

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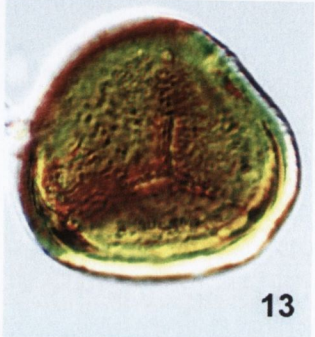

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PLATE 13

Figure 1 *Spinozonotriletes uncatus* Hacquebard 1957. S74(2), F24/2. TCD 59116d.

Figure 2 *Spinozonotriletes uncatus* Hacquebard 1957. S87(1), K21/1+3. TCD 59129c.

Figure 3 *Cingulizonates bialatus* (Waltz) Smith & Butterworth. S206(1), G34/1. TCD 59218a.

Figure 4 *Cingulizonates bialatus* (Waltz) Smith & Butterworth. S206(1), F19/3. TCD 59218a.

Figure 5 *Cingulizonates capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jansonius. S206(1), E23/3. TCD 59218a.

Figure 6 *Cingulizonates capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jansonius. S78(1), P12/3. TCD 59120a.

Figure 7 *Cingulizonates* cf. *capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jansonius. S209(1), C30/3. TCD 59221 a.

Figure 8 *Cingulizonates* cf. *capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jansonius. S87(1), O23. TCD 59129c.

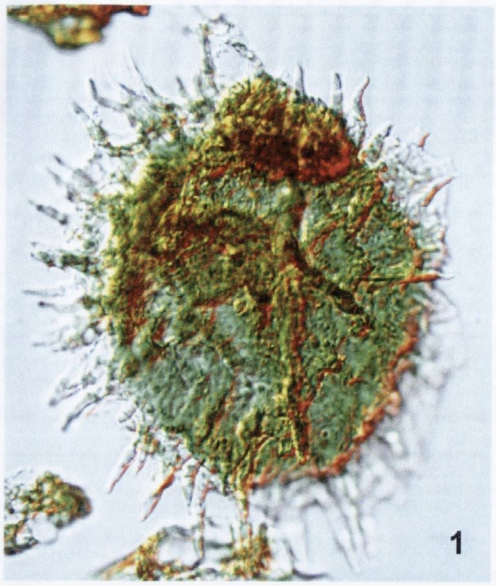
Figure 9 *Cingulizonates capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jansonius. S206(1), E23/1. TCD 59218a.

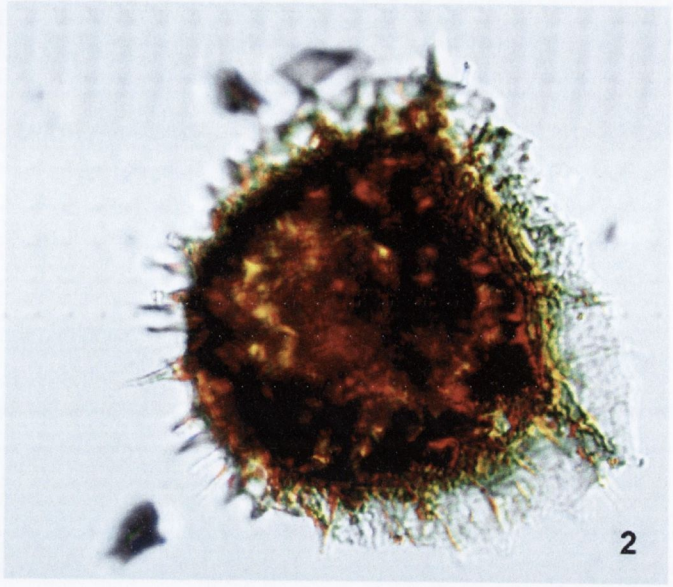
Figure 10 *Cingulizonates capistratus* (Hoffmeister, Staplin & Malloy) Staplin & Jansonius. 206(1), S33/2. TCD 59218a.

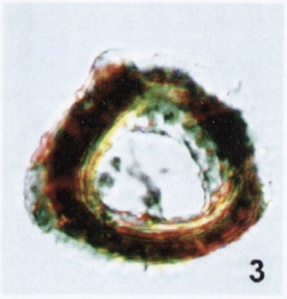
Figure 11 *Cirratriradites annuliformis* Kosanke & Brokaw (*in* Kosanke 1950). S79(3), F17. TCD 59121e.

Figure 12 *Cirratriradites annuliformis* Kosanke & Brokaw (*in* Kosanke 1950). S79(2), J33. TCD 59121c.

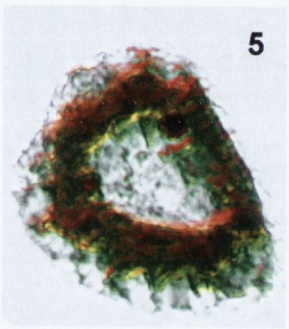
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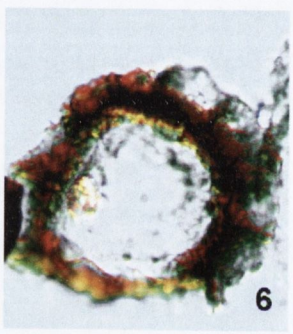

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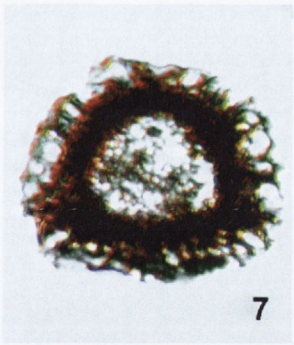

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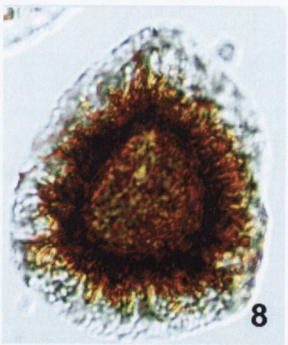

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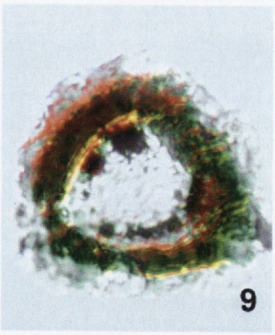

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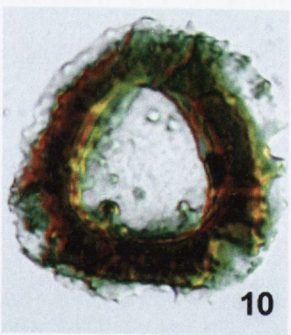

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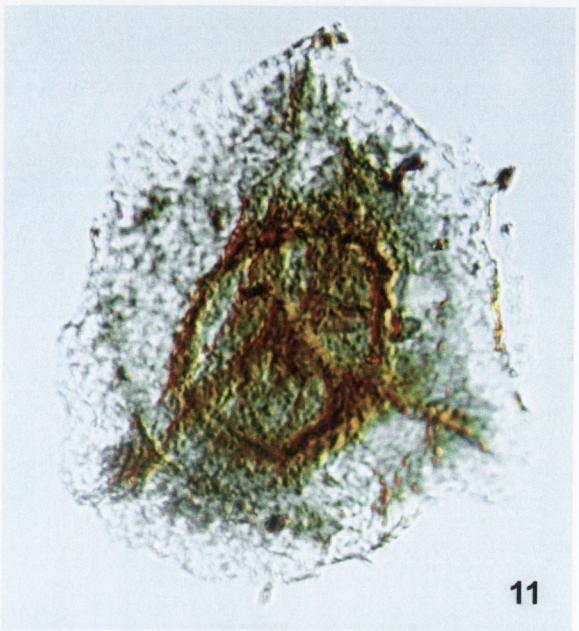

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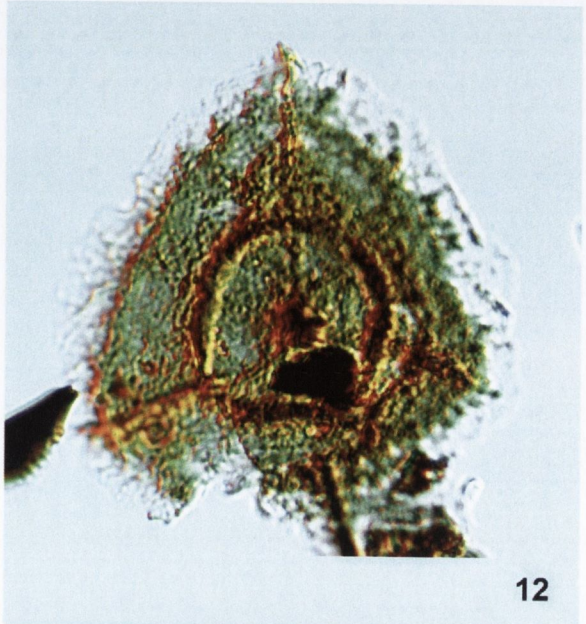

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PLATE 14

Figure 1 *Cristatisporites menendezii* (Menéndez & Azcuy) Playford. S154(1), T10. TCD 59182a.

Figure 2 *Cristatisporites menendezii* (Menéndez & Azcuy) Playford. S174(1), R34/3. TCD 59202a.

Figure 3 *Cristatisporites menendezii* (Menéndez & Azcuy) Playford. S170(1), P13. TCD 59198a.

Figure 4 *Densosporites anulatus* (Loose) Smith & Butterworth. S78(1), U35/3. TCD 59120a.

Figure 5 *Densosporites anulatus* (Loose) Smith & Butterworth. S209(1), T27/2. TCD 59221a.

Figure 6 *Densosporites anulatus* (Loose) Smith & Butterworth. S87(1), M37/4. TCD 59129a.

Figure 7 *Densosporites* cf. *crassigranifer* Artuz. S78(1), M37. TCD 59120a.

Figure 8 *Densosporites gracilis* Smith & Butterworth. S145(1), P38/4. TCD 59173.

Figure 9 *Densosporites intermedius* Butterworth & Williams. S208(1), D29/1. TCD 59220a.

Figure 10 *Densosporites intermedius* Butterworth & Williams. S75(2), H36/1. TCD 59117d.

Figure 11 *Densosporites intermedius* Butterworth & Williams. S88(1), L14/2. TCD 59130c.

Figure 12 *Densosporites psuedoannulatus* Butterworth & Williams. S208(1), G18. TCD 59220a.

Figure 13 *Densosporites psuedoannulatus* Butterworth & Williams. S208(1), D29/1. TCD 59220a.

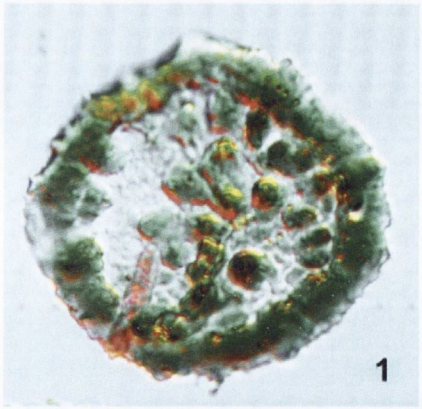
Figure 14 Densosporites *spinifer* Hoffmeister, Staplin & Malloy. S79(2), F18/4. TCD 59121c.

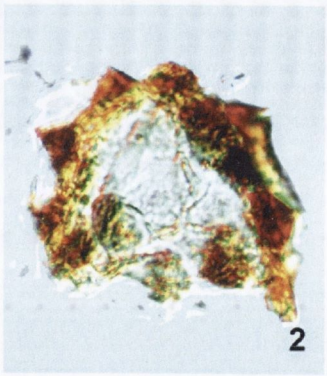
Figure 15 *Densosporites spinifer* Hoffmeister, Staplin & Malloy. S155(2), N15/3. TCD 59183d.

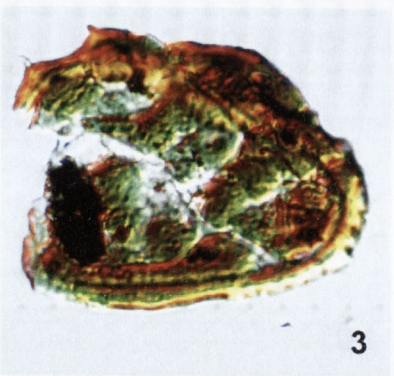
Figure 16 *Indotriradites explanatus* (Luber) Playford. S39(1), O14/4. TCD 59062a.

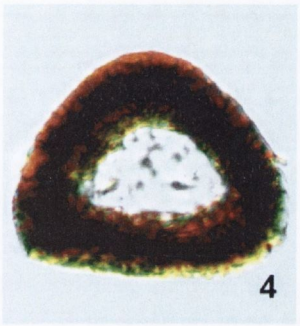
Figure 17 *Indotriradites explanatus* (Luber) Playford. S39(1), N14/2. TCD 59062a.

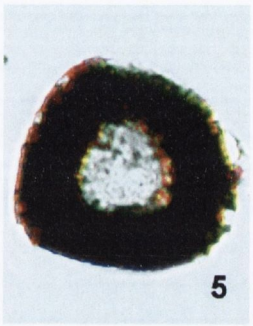
PLATE 14


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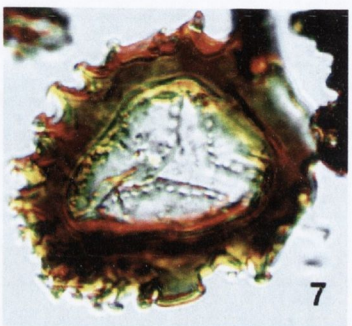

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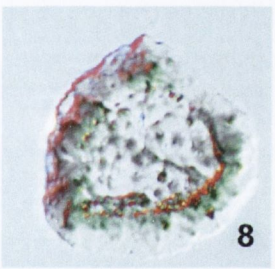

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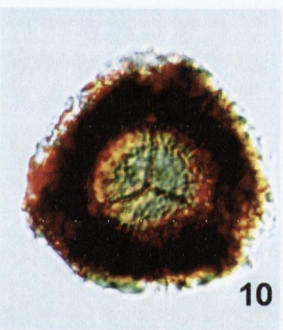

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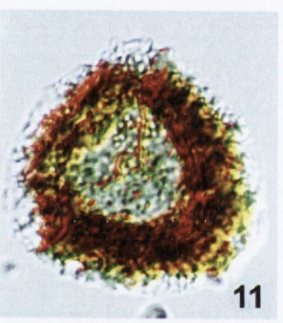

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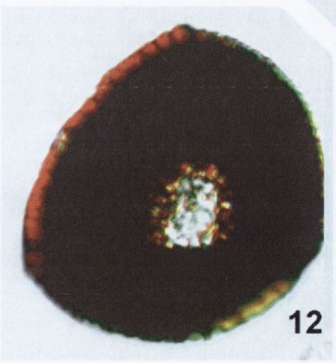

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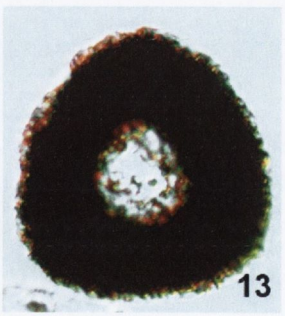

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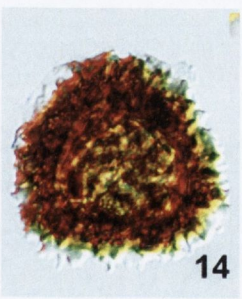

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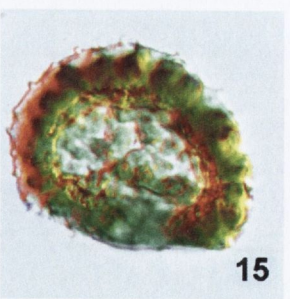

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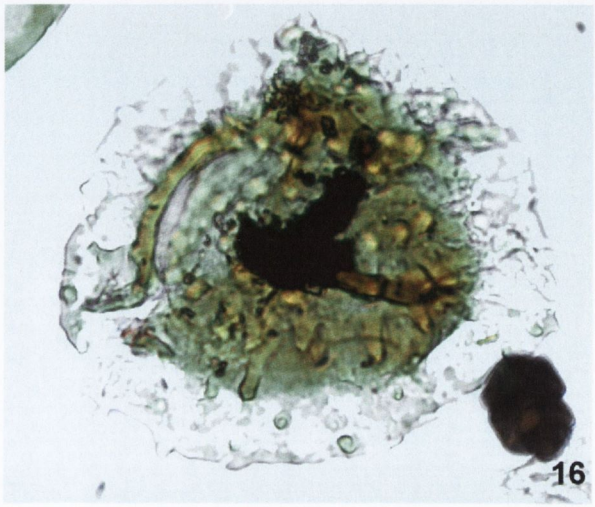

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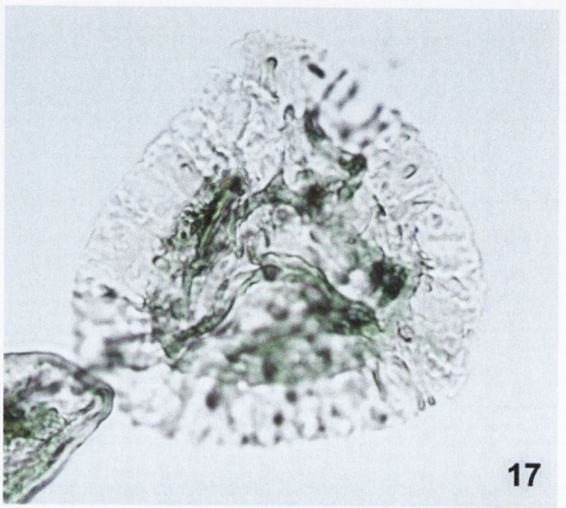

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PLATE 15

Figure 1 *Kraeuselisporites mitratus* Higgs. S120(1), K37/4. TCD 59154.

Figure 2 *Kraeuselisporites mitratus* Higgs. S120(1), V32/1. TCD 59154.

Figure 3 *Prolycospora rugulosa* (Butterworth & Spinner) Turnau. S203(2), J36. TCD 59215b.

Figure 4 *Prolycospora rugulosa* (Butterworth & Spinner) Turnau. S133(1), 027/1. TCD 59161b.

Figure 5 Cluster of *Lycospora pusilla* (Ibrahim) Somers. S133(1), K17/2. TCD 59161b.

Figure 6 *Lycospora pusilla* (Ibrahim) Somers. S203(3), N11/1. TCD 59215c.

Figure 7 *Lycospora pusilla* (Ibrahim) Somers. S75(2), M35/4. TCD 59117d.

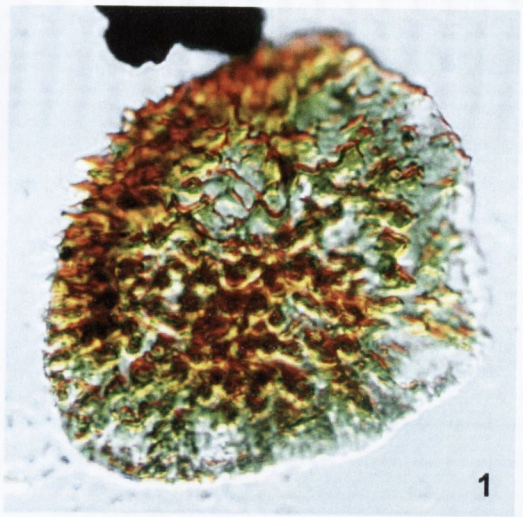
Figure 8 Cluster of *Lycospora pusilla* (Ibrahim) Somers. S79(3), G22/3. TCD 59121e.

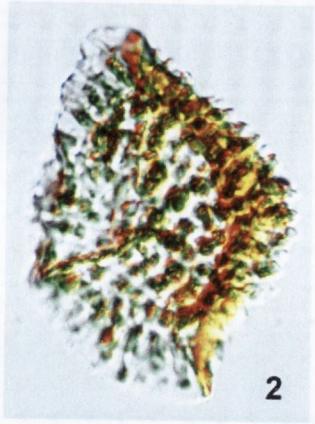
Figure 9 *Radiizonates mirabilis* Phillips & Clayton. S177, U26/1. TCD 59205.

Figure 10 *Radiizonates mirabilis* Phillips & Clayton. S70(2), W30. TCD 59112b.

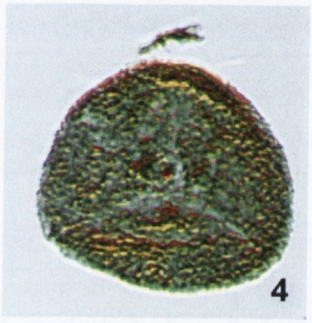
Figure 11 *Radiizonates mirabilis* Phillips & Clayton. S177, V41/4. TCD 59205.

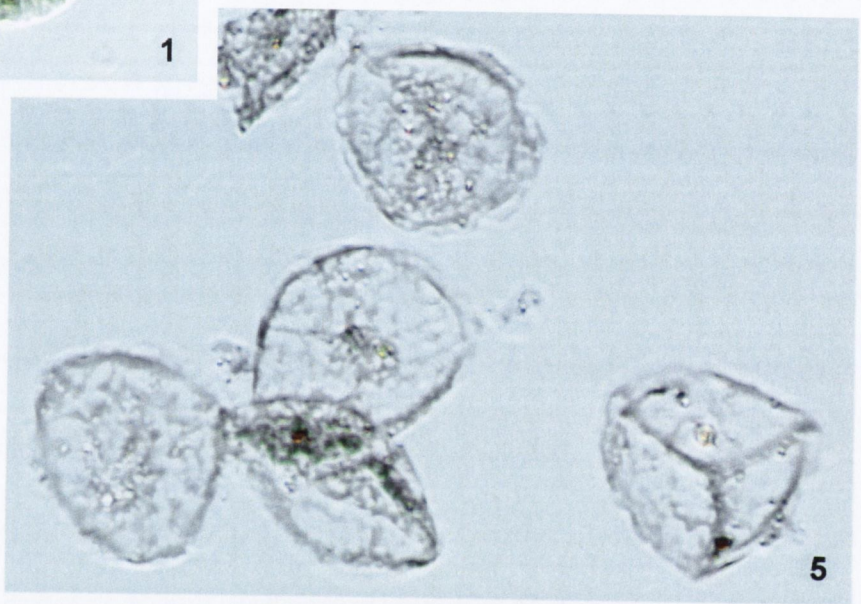
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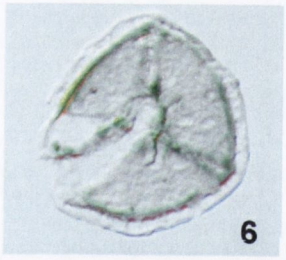

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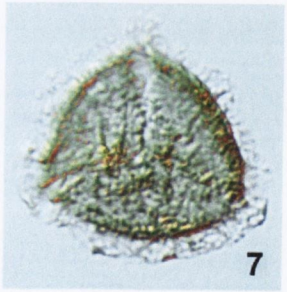

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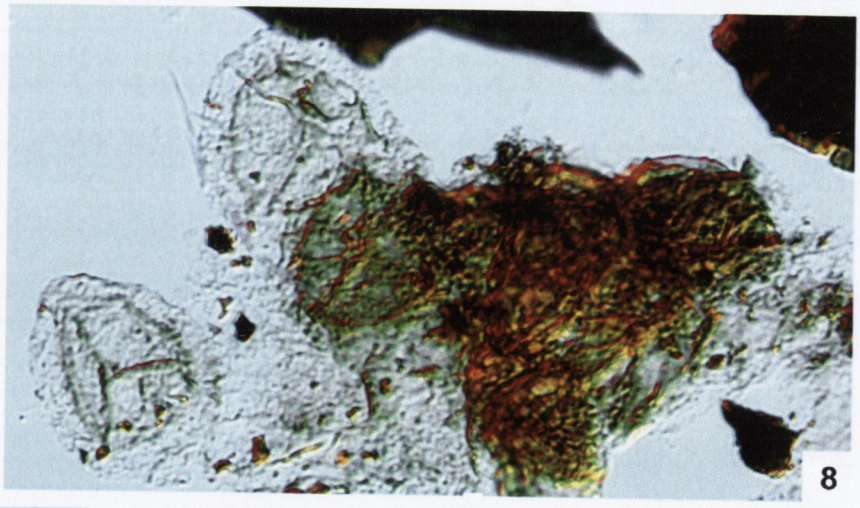

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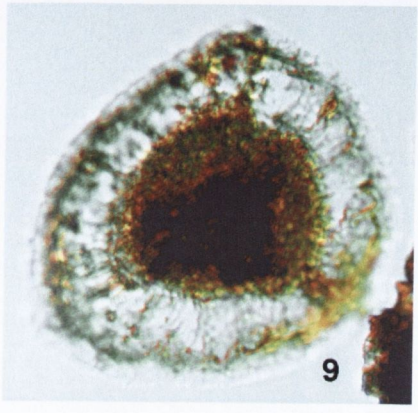

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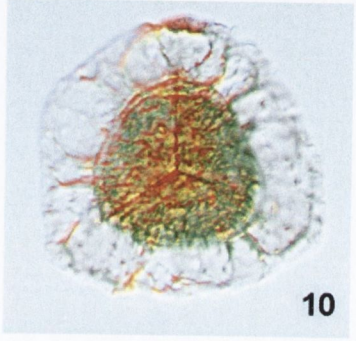

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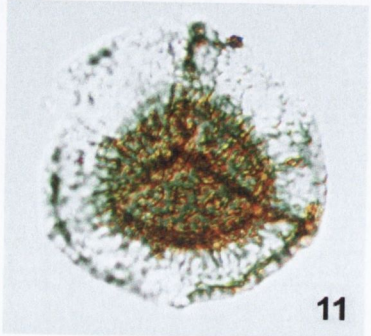

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PLATE 16

Figure 1 *Vallatisporites ciliaris* (Luber) Sullivan. S154(1), J27/3. TCD 59182a.

Figure 2 *Vallatisporites ciliaris* (Luber) Sullivan. S154(1), J18/2. TCD 59182a.

Figure 3 *Vallatisporites hystricosus* (Winslow) Byvsheva. S39(1), M47/4. TCD 59062a.

Figure 4 *Vallatisporites hystricosus* (Winslow) Byvsheva. S39(1), R46/2. TCD 59062a.

Figure 5 *Vallatisporites pusillites* (Kedo) Dolby & Neves emend. Byvscheva. S165(2), G27. TCD 59193b.

Figure 6 *Vallatisporites vallatus* Hacquebard. S154(1) T10/1. TCD 59182a.

Figure 7 *Vallatisporites verrucosus* Hacquebard. S235(1), P14/1. TCD 59088a.

Figure 8 *Vallatisporites vallatus* Hacquebard. S154(1), L10/2. TCD 59182a.

Figure 9 *Vallatisporites vallatus* Hacquebard. S165(2), U16. TCD 59193b.

Figure 10 *Vallatisporites* sp. A. S73(2), O45/3. TCD 59115c.

Figure 11 *Vallatisporites* sp. A. S174(2), P21. TCD 59202c.

Figure 12 *Vallatisporites* sp. B. S170(1), E35/2. TCD 59198a.

Figure 13 *Vallatisporites* sp. A. S175(1), D40. TCD 59203.

Figure 14 *Vallatisporites* sp. A. S177(1), W38/2. TCD 59205.

Figure 15 *Vallatisporites* sp. C. S154(1), B39/3. TCD 59182a.

Figure 16 *Vallatisporites* sp. C. S71(1), C23/3. TCD 59113b.

PLATE 16

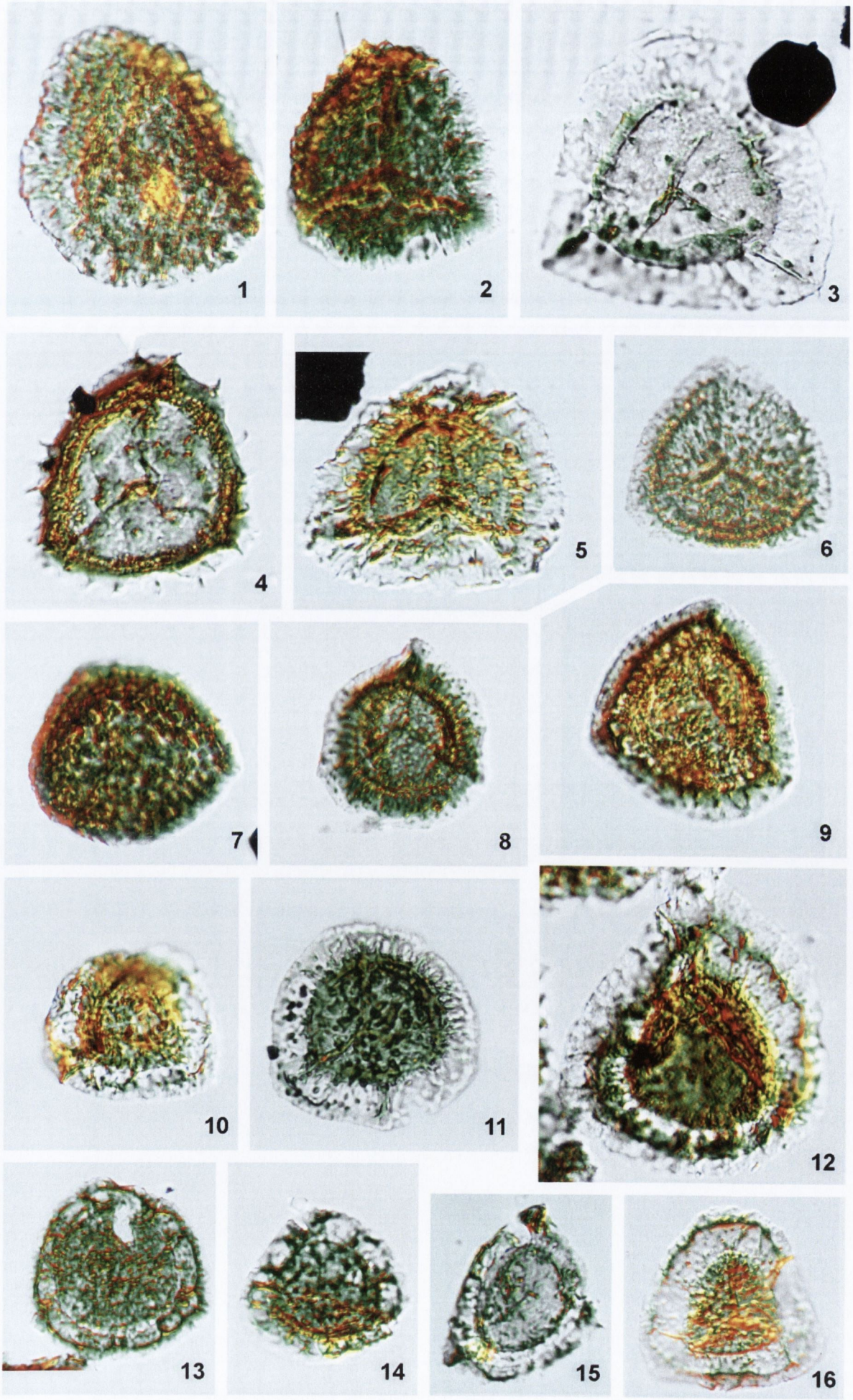


PLATE 17

Figure 1 *Schulzospora campyloptera* (Waltz) Hoffmeister, Staplin & Malloy. S203(2), L27/3. TCD 59215b.

Figure 2 *Schulzospora campyloptera* (Waltz) Hoffmeister, Staplin & Malloy. S209(1), N25. TCD 59221a.

Figure 3 *Schulzospora rara* Kosanke. S75(2), D35/3. TCD 59117d.

Figure 4 *Florinites* cf. *visendus* (Ibrahim) Schopf, Wilson & Bentall x 500. S87(1), T/35. TCD 59129c.

Figure 5 *Schulzospora rara* Kosanke. S203(1), S23/1. TCD 59215a.

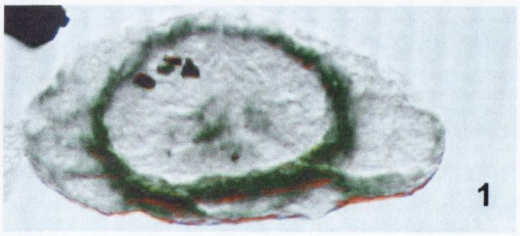
Figure 6 *Spencerisporites radiatus* (Ibrahim) Felix & Parks x 300. S79(1), B31. TCD 59121a.

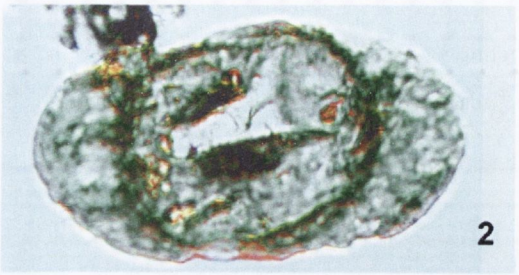
Figure 7 *Schulzospora rara* Kosanke. S209(1), N29/1. TCD 59221a.

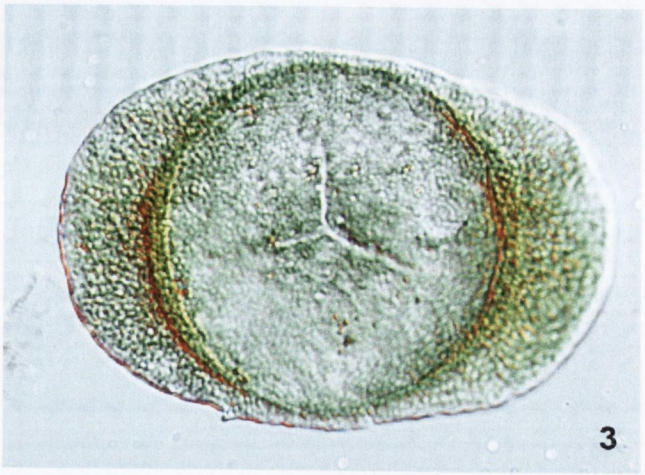
Figure 8 *Hystricosporites* cf. *porcatus* (Winslow) Allen x 500. S240(1), F20. TCD 59093a.

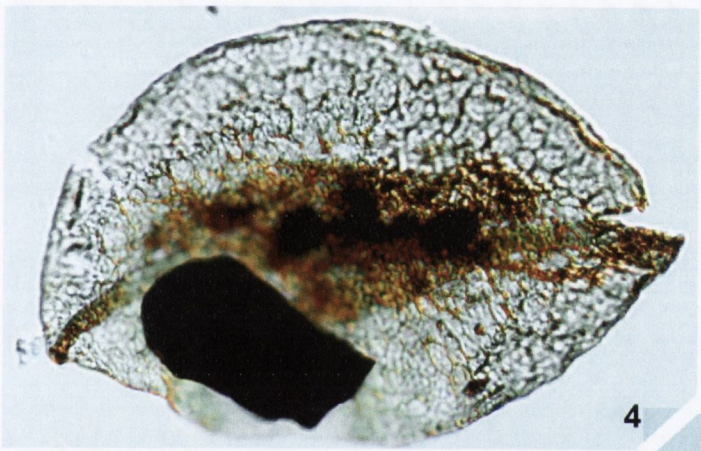
Figure 9 Spore Type A x 500. S74(2), R33/1. TCD 59116d.

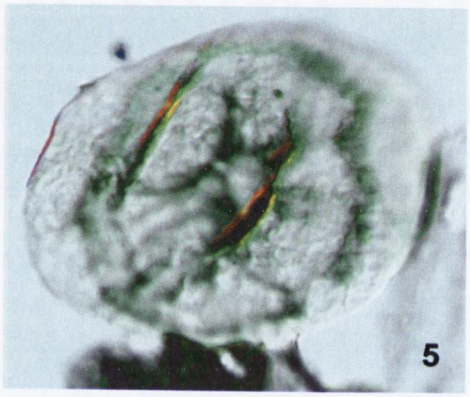
PLATE 17

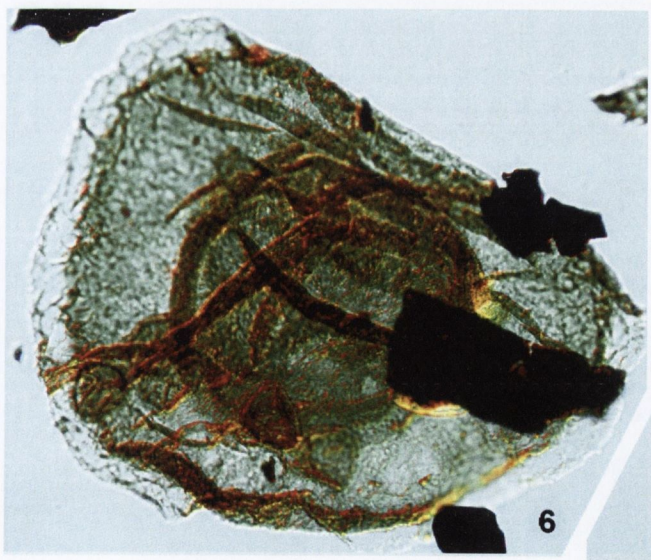


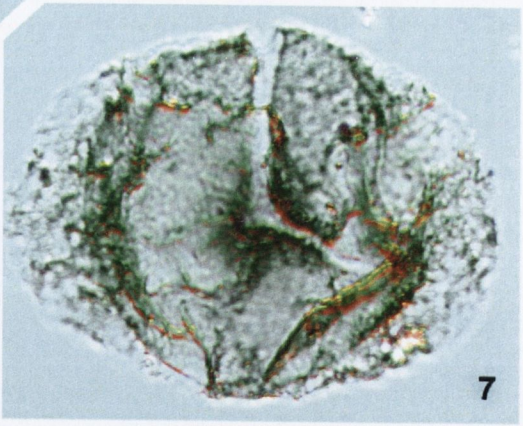


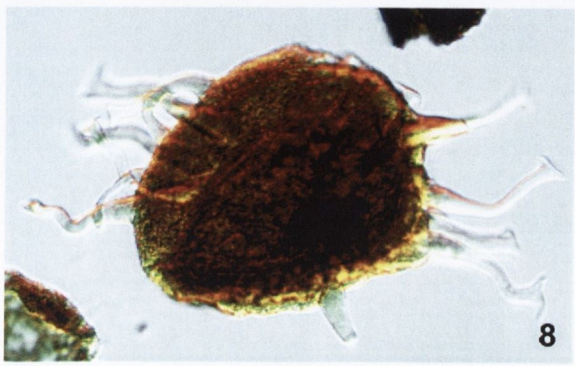












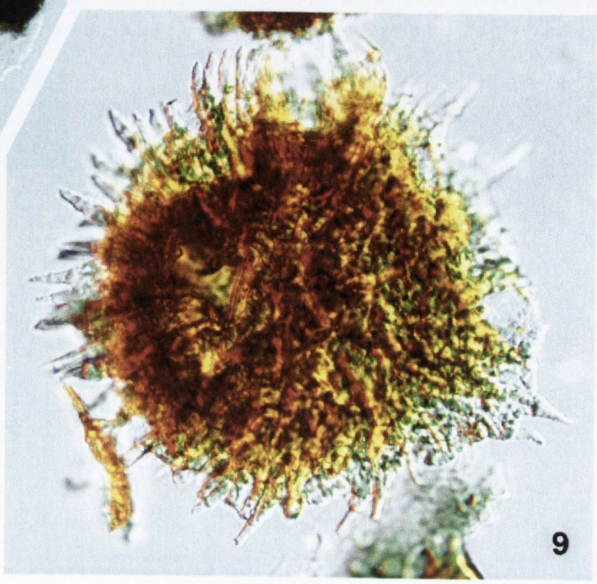


PLATE 18

Figure 1 *Cymatiosphaera ambotrocha* Wicander & Loeblich. S39(1), P21/3. TCD 59062a.

Figure 2 *Cymatiosphaera chelina* Wicander & Loeblich. S161(1), J46. TCD 59189a.

Figure 3 *Cymatiosphaera chelina* Wicander & Loeblich, showing median split. S122(1), P35. TCD 59156a.

Figure 4 *Cymatiosphaera* cf. *parvicarina sensu* Wicander & Playford. S107(1), C18/2. TCD 59141c.

Figure 5 *Cymatiosphaera perimembrana* Staplin. S242(2), D12/1. TCD 59095b.

Figure 6 *Cymatiosphaera perimembrana* Staplin. S227, N23/3. TCD 59080.

Figure 7 *Cymatiosphaera* cf. *perimembrana* x 1000. S166(1), C24/2. TCD 59194a.

Figure 8 *Dictyotidium craticulum* (Wicander & Loeblich) Wicander & Playford x 1000. S163(1), M23/4. TCD 59191a.

Figure 9 *Gorgonisphaeridium furcillatum* Wicander & Playford. S223(1), H37/24. TCD 59076.

Figure 10 *Gorgonisphaeridium winslowiae* Staplin *et al.* S236(1), H33/1. TCD 59089a.

Figure 11 *Gorgonisphaeridium ohioense* (Winslow) Wicander. S39(1), M19. TCD 59062a.

Figure 12 *Gorgonisphaeridium telum* Wicander & Playford. S161(2), E38/3. TCD 59189b.

Figure 13 *Gorgonisphaeridium telum* Wicander & Playford, showing equatorial split. S161(2), E32. TCD 59189b.

Figure 14 *Leiosphaeridia* sp. S54(2), F10. TCD 59021b.

Figure 15 *Lophosphaeridium segregum* Playford. S39(1), M19/3. TCD 59062a.

Figure 16 *Micrhystridium stellatum* Deflandre. S107(1), F44/1. TCD 59141c.

Figure 17 *Micrhystridium ampliatum* Wicander & Playford. S107(1), C35. TCD 59141c.

PLATE 18

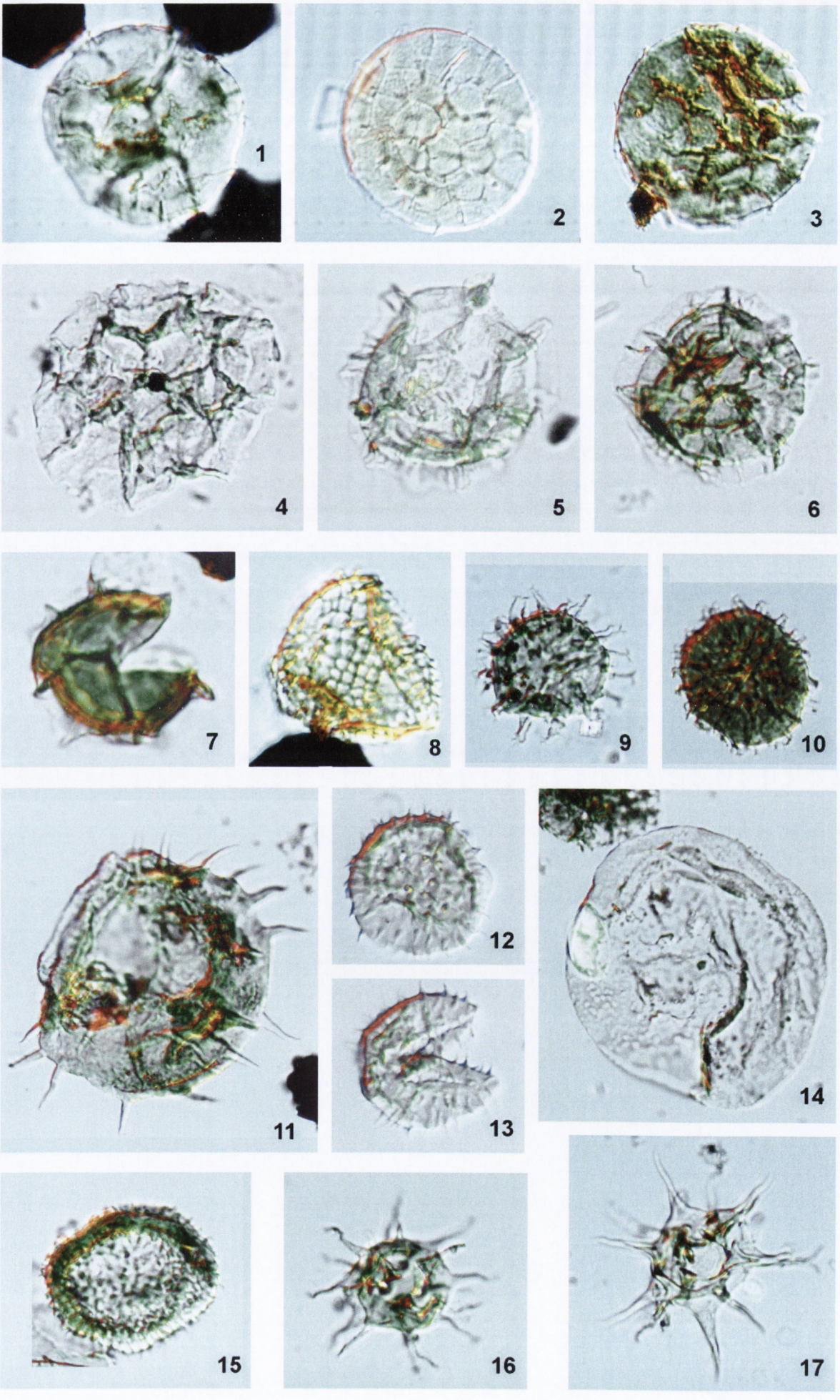


PLATE 19

Figure 1 *Multiplicisphaeridium ramusculosum* (Deflandre) Lister. S122(1), Q16/4. TCD 59156a.

Figure 2 *Oppilatala* sp. *sensu* Wicander & Playford. S224(1), N39/3. TCD 59077a.

Figure 3 *Ozotobrachion furcillatus* (Deunff) Playford. S223(1), F15/3. TCD 59076.

Figure 4 *Polyedryxium decorum* Deunff. S243(1), M14/1. TCD 59096a.

Figure 5 *Pterospermella cerebella* Loeblich and Wicander. S218(1), R12/2. TCD 59071.

Figure 6 *Stellinium comptum* Wicander & Loeblich. S162(1), G37/1. TCD 59190a.

Figure 7 *Umbellasphaeridium saharicum*. Jardiné, Combaz, Magloire, Peniguel & Vachey. S223(1), K47/2. TCD 59076.

Figure 8 *Pterospermella cerebella* Loeblich & Wicander. S224(1), S13/4. TCD 59077a.

Figure 9 *Unellium piriforme* Rauscher. S161(1), B38. TCD 59189a.

Figure 10 *Veryhachium arcarium* Wicander & Loeblich. S223(1), L47/3. TCD 59076.

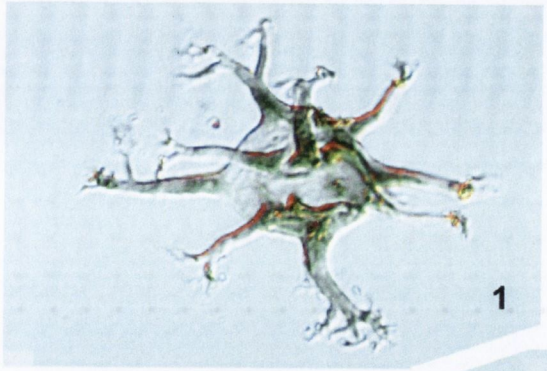
Figure 11 *Veryhachium polyaster* Staplin. S123(1), F33/1. TCD 59157a.

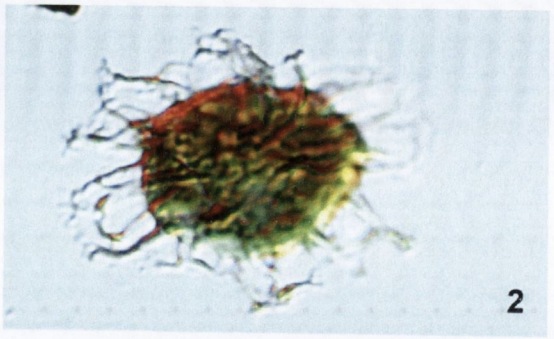
Figure 12 *Unellium winslowiae* Rauscher. S162(1), M38/2. TCD 59190a.

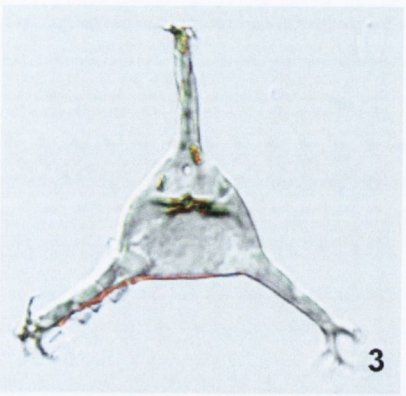
Figure 13 *Veryhachium trispinosum* (Eisenack) Deunff. S54(2), J13/2. TCD 59021b.

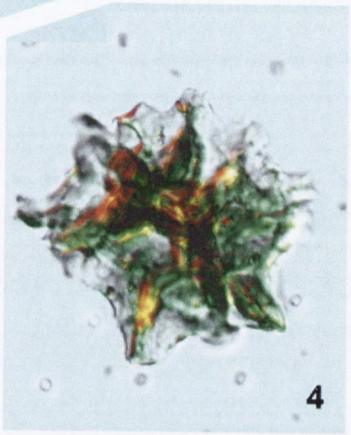
Figure 14 *Tasmanites* sp. S235(1), G26/2. TCD 59088a.

PLATE 19

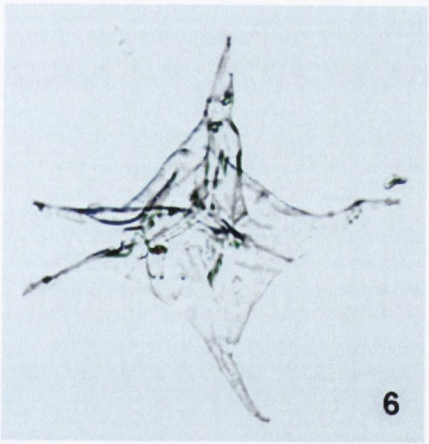

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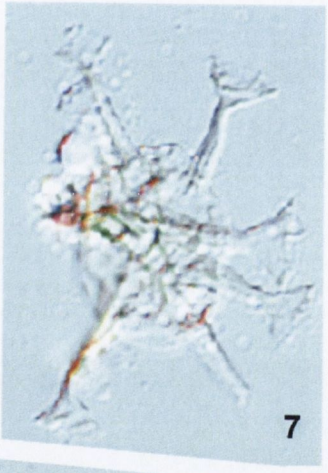

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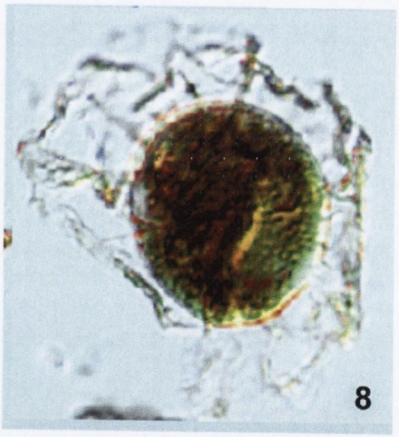

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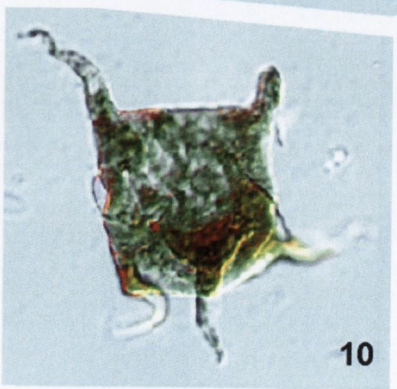

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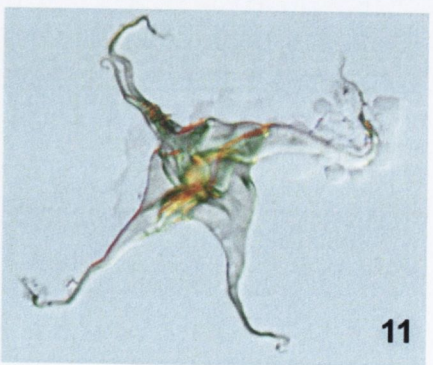

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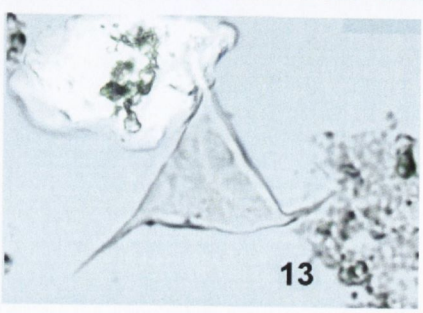

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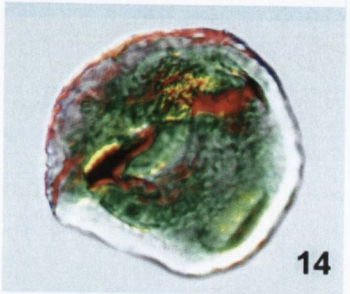

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PLATE 20

Structured - Phytoclasts (woody material)

Figure 1 Light brown woody phytoclast x 500, S207(1). TCD 59219a.

Figure 2 Medium brown woody phytoclast x 750, S203(1). TCD 59215a.

Figure 3 Medium brown woody phytoclast x 750, S81(1). TCD 59123a.

Figure 4 Dark brown woody phytoclast x 750, S87(1). TCD 59129c.

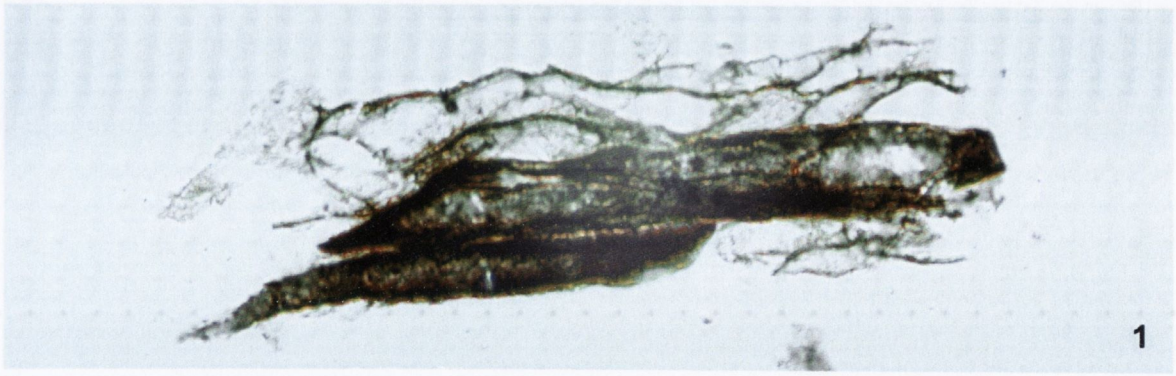
Figure 5 Nearly opaque phytoclast, note slight translucence around the margin x 750, S145(1). TCD 59173.

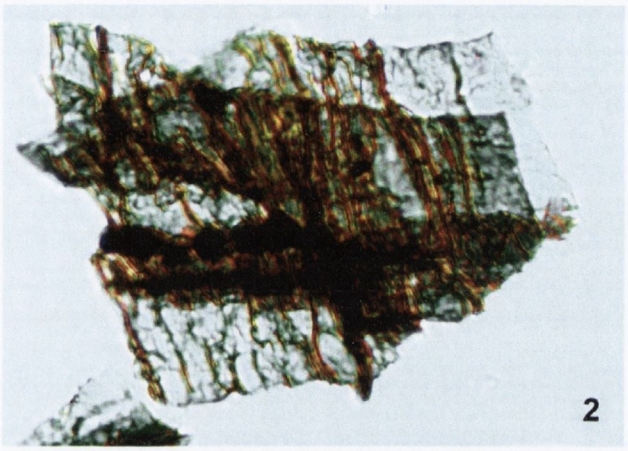
Figure 6 Phytoclast tracheids x 750, S207(1). TCD 59219a.

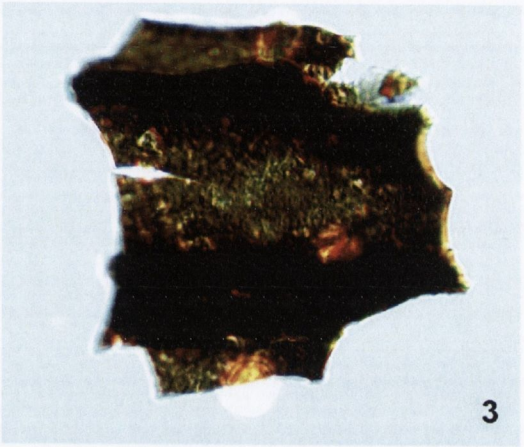
Figure 7 Tracheid showing scalariform (ladder-like) pitting x 750, S203(2). TCD 59215b.

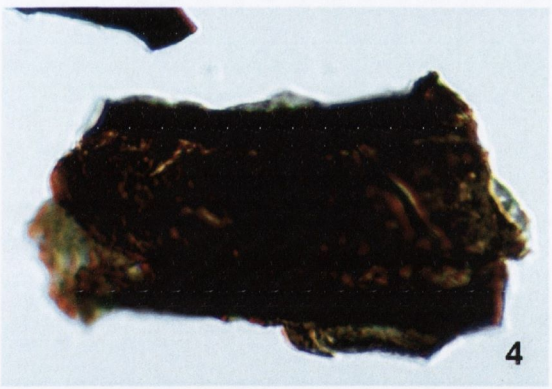
Figure 8 Opaque phytoclast composed of three adjacent tracheids x 500, S200(1). TCD 59212a.

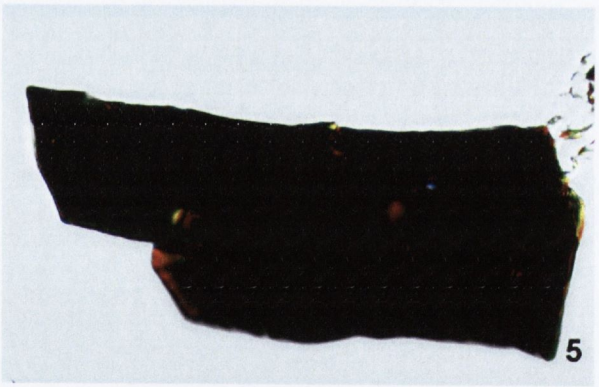
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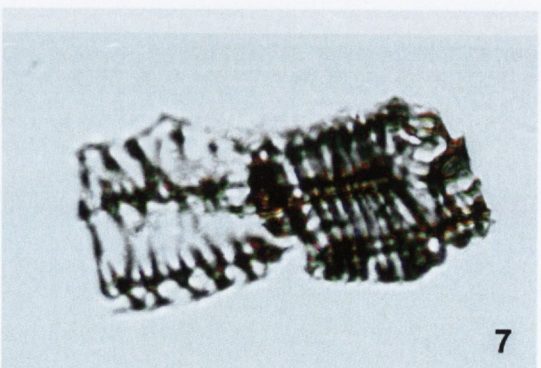

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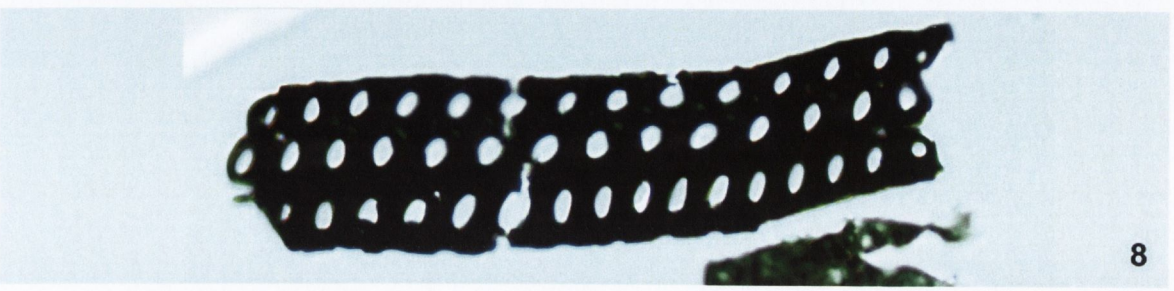

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PLATE 21

Structured - Phytoclasts (charcoal, cuticle and other plant tissue)

Figure 1 Charcoal x 400, S206(1). TCD 59218a.

Figure 2 Charcoal x 750, S80(1). TCD 59122a.

Figure 3 Plant tissue, possibly cuticle x 750, S177(1). TCD 59205.

Figure 4 Plant tissue, 'wispy' cuticle x 750, S177(1). TCD 59205.

Figure 5 Plant tissue, light brown, possibly cuticle x 750, S61(1). TCD 59103a.

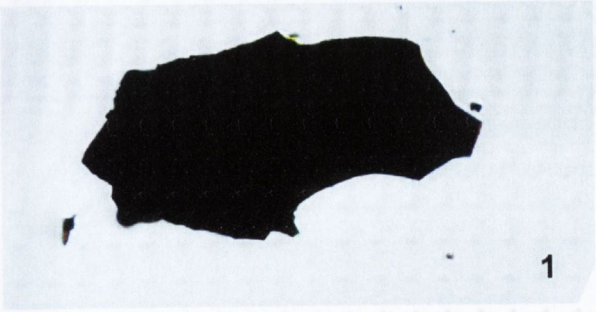
Figure 6 Leaf cuticle showing regular cell structure and stomata cells x 500, S203(2). TCD 59215b.

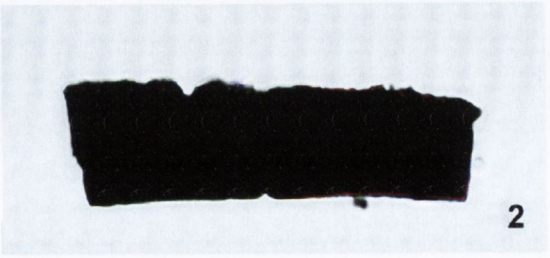
Figure 7 Plant tissue, fibre x 400, S161(1). TCD 59198a.

Figure 8 Plant tissue, tube structure x 500, S200(1). TCD 59212a.

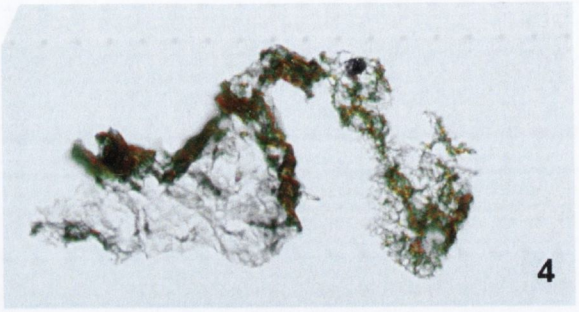
Figure 9 Plant tissue, tube structure x 500, S200(1). TCD 59212a.

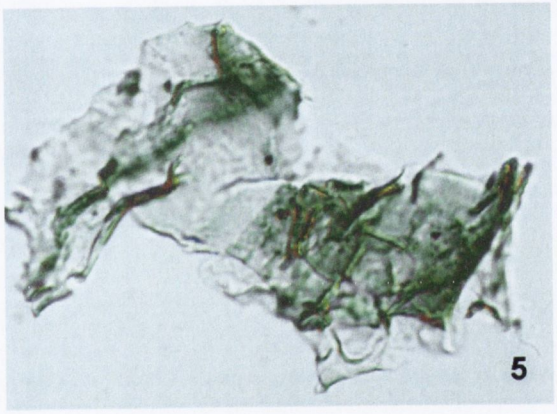
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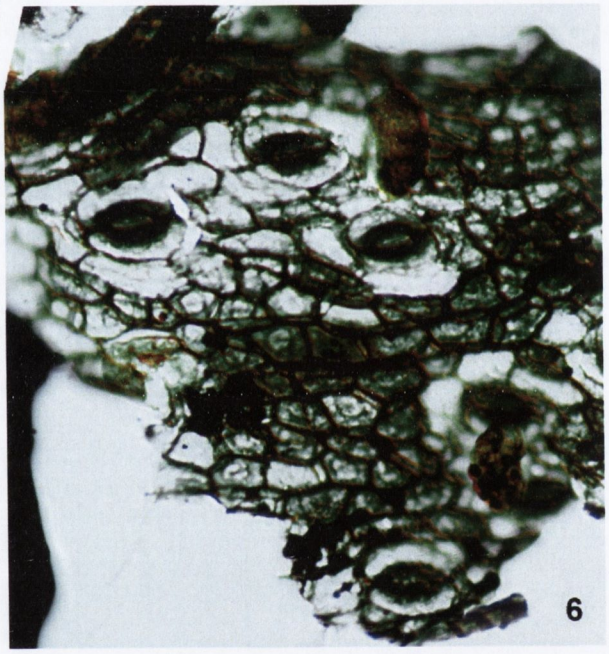

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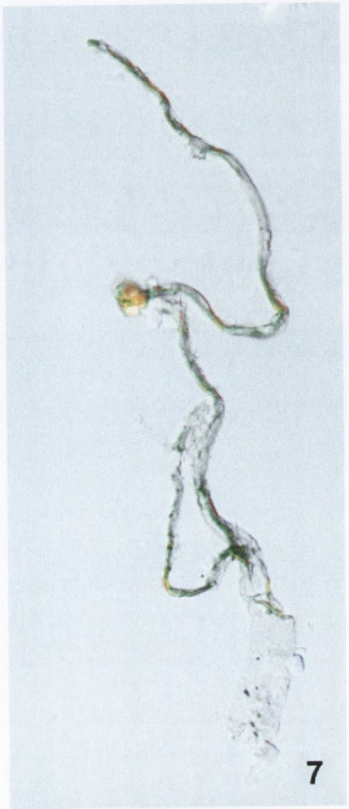

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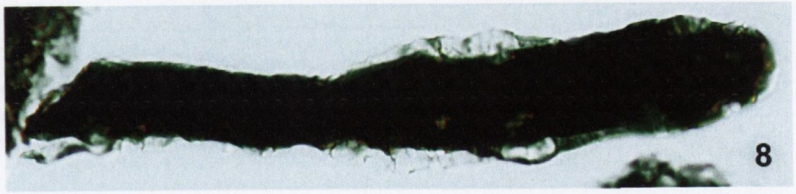

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PLATE 22

Structured - Palynomorphs (spores, acritarchs, *Tasmanites* and scolecodonts)

Figure 1 Pyratised camerate miospore x 750, S200(1). TCD 59212a.

Figure 2 Pyratised miospore *Grandispora* sp. x 750, S138(1). TCD 59166b.

Figure 3 Pyratised miospore x 750, S161(1). TCD 59189a.

Figure 4 Pale brown miospore *Calamospora* sp. x 750, S73(1). TCD 59115a.

Figure 5 Acanthomorph acritarchs - *Micrhystridium ampliatum* x 750, S227(1). TCD 59080.

Figure 6 Pyratised acanthomorph acritarchs x 750, S161(1). TCD 59189a.

Figure 7 *Tasmanites* sp. x 750, S54(2). TCD 59021b.

Figure 8 Scolecodont x 750, S165(2). TCD 59193b.

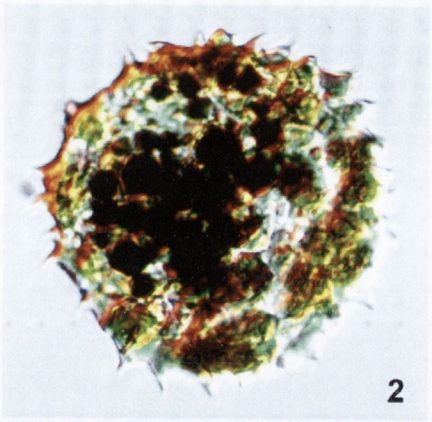
Figure 9 Scolecodont x 250, S165(2). TCD 59193b.

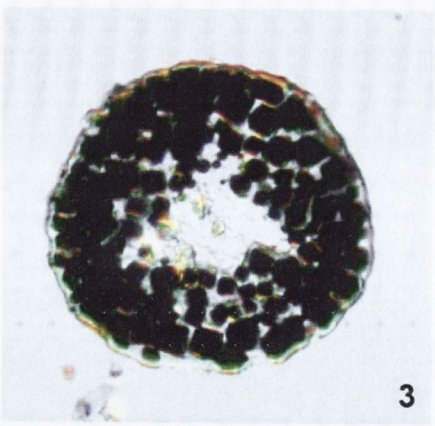
Figure 10 Scolecodont x 750, S73(1). TCD 59115a.

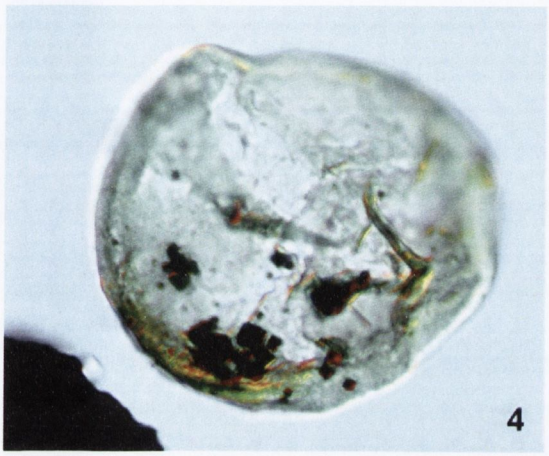
Figure 11 Scolecodont x 250, S73(1). TCD 59115a. Note the large size range of specimens within a single sample.

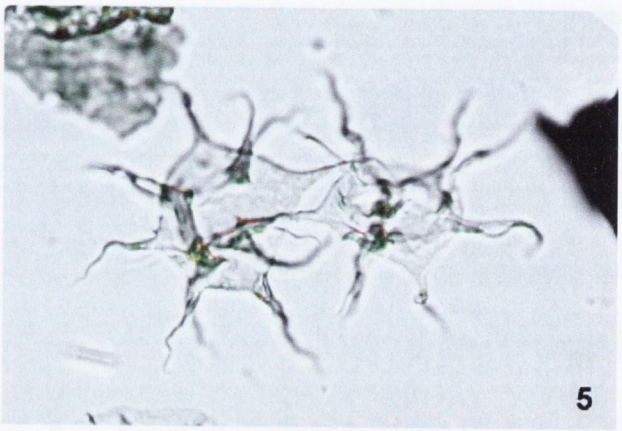
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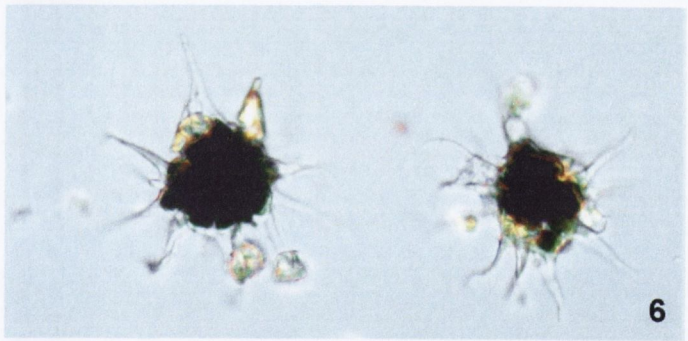

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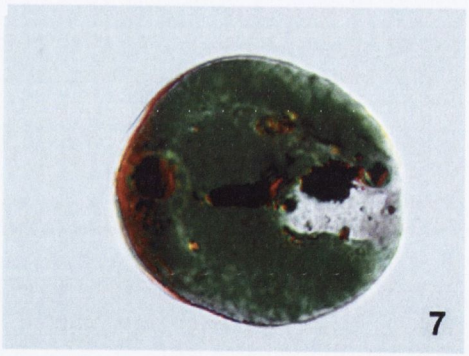

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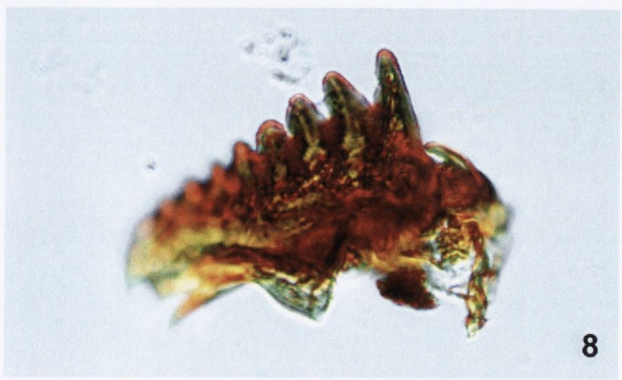

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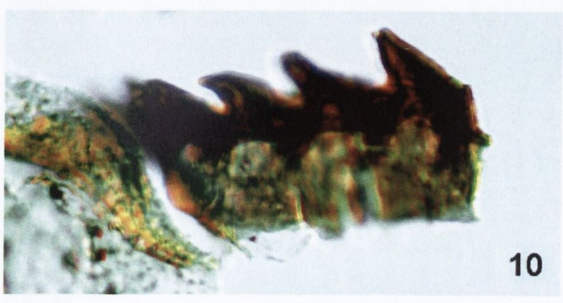

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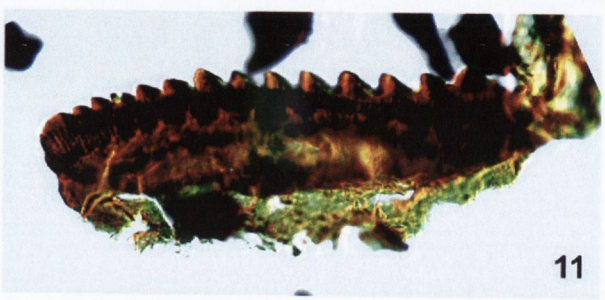

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PLATE 23

Structureless - AOM

Figure 1 AOM x 400, S38(1). TCD 59061a.

Figure 2 AOM x 500, S83(1). TCD 59125c.

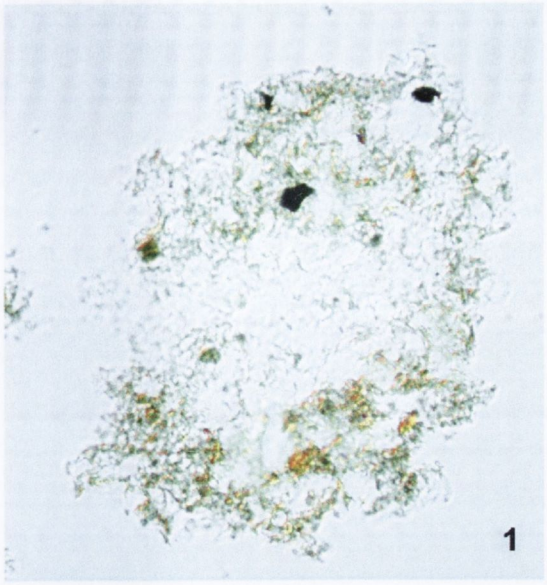
Figure 3 AOM x 750, S167(1). TCD 59195a.

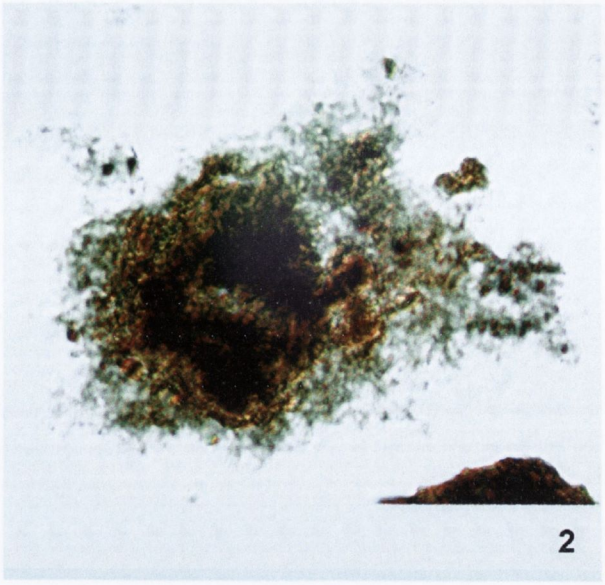
Figure 4 AOM x 500, S36(1). TCD 59059a.

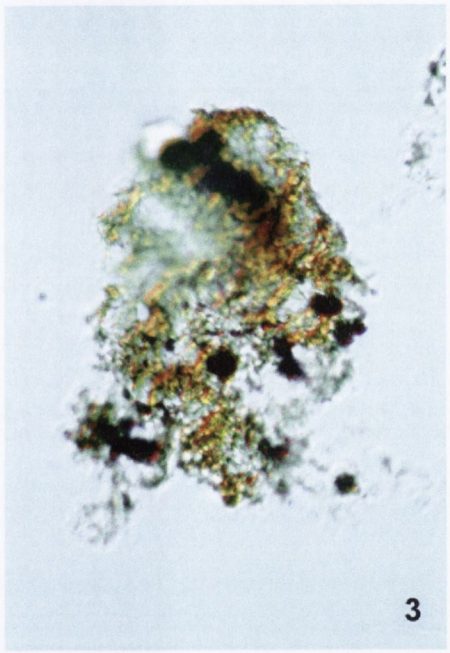
Figure 5 AOM x 750, S198(1). TCD 59210.

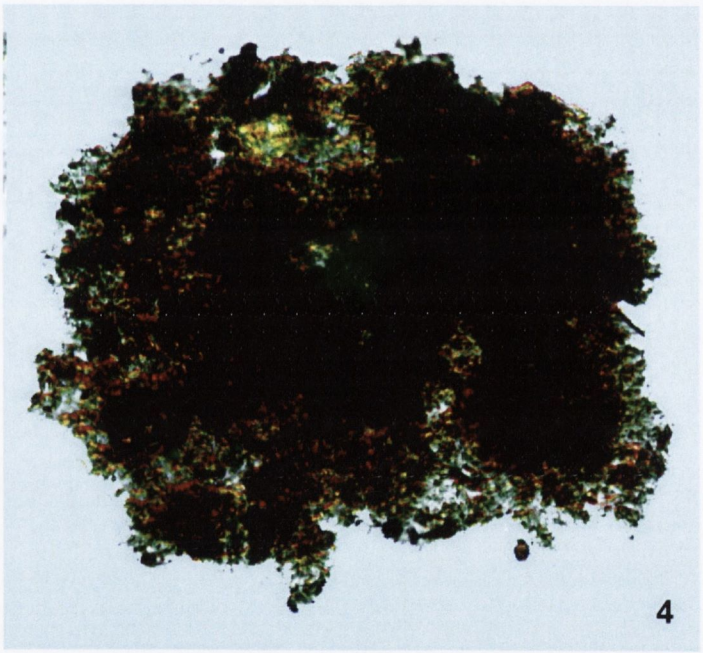
Figure 6 AOM x 250, S198(1). TCD 59210.

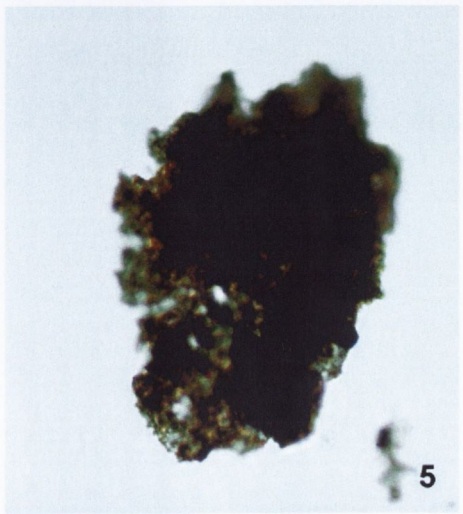
PLATE 23

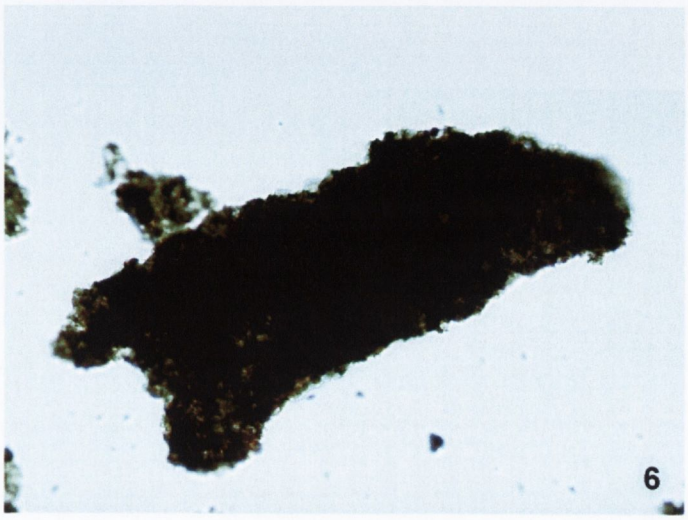

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APPENDIX III

PALYNOFACIES ANALYSIS DATA

APPENDIX III.I Palynofacies counts

APPENDIX III.II Ternary plot percentages

Sample	Unit	Futher processing	AOM	Phytoclasts			Palynomorphs				Remarks
				Woody tissue	Charcoal	Other plant tissue	Spores	Acritarchs	*Tasmanites*	Scolecodonts	
Morehead, Kentucky											
S40	Top Ohio Shale	Ultrasound	245	4	51	7	11	0	0	0	Dominated by large (up to 1mm) clumps of light – dark brown AOM. Some large fragments (<500 µm). Spores and woody material partially obscured by large fragments.
S214	Top Bedford Shale		46	15	52	55	127	5	0	0	Miospores dominant. Spores generally light brown and fragile looking. Phytoclasts comprised of dark brown woody material and light brown plant tissue. AOM light brown.
S39	Top Bedford Shale		3	19	113	66	101	5	0	0	Dominated by well-preserved light to dark brown spores, few acritarchs. Phytoclasts dominated by opaque woody fragments; woody fragments comprise a small percentage but are more common in the Bedford Shale than other units in this section.
S215	Base Sunbury Shale		281	0	17	1	1	0	0	0	Sample unproductive for palynology, the spore count being <1 %. Dominated by light brown AOM some large particles measure up to 2 mm in size. Opaque material easy to distinguish from AOM, other phytoclasts are similar colour to AOM and partially obscured by large clumps.
S38	Base Sunbury Shale		248	1	25	21	5	0	0	0	Dominated by light coloured AOM, with some small fragments of opaque woody material and plant tissue. Sparse in terms of palynomorphs. Palynomorph assemblage dominated by miospores.
S216	Mid Sunbury Shale		267	1	28	3	0	1	0	0	Barren in terms of palynology. Dominated by AOM, particles more uniformly sized than in previous sample, ranging from 40 – 150 µm. Few opaque woody fragments present, many obscured in clumps of AOM.
S37	Mid Sunbury Shale										Barren
S33	Top Sunbury Shale										Barren
S32	Top Sunbury Shale										Barren

Appendix III.I Palynofacies counts

S221	Top Sunbury Shale		265	3	63	2	6	0	0	0	Essentially barren in terms of palynology. Mostly AOM (40-200µm clasts), some larger clasts <2 mm) with a few opaque woody fragments. Spores and other lighter plant tissue similar colour to AOM and therefore harder to see. Most obscured, and very poorly preserved.
S36	Top Sunbury Shale		237	1	24	24	13	1	0	0	Dominated by light coloured AOM, with some small fragments of opaque woody material and plant tissue. Sparse in terms of palynomorphs. Palynomorph assemblage dominated by miospores.
S31	Henley Bed										Barren
S222	Base Henley Bed		17	43	142	94	4	0	0	0	Phytoclast dominated assemblage. Black charcoal most common, but dark brown woody tissue also common. Other tissue mostly cuticle – either thick or thin and degraded. Very few poorly preserved spores and less than 1% *tasmanites* .
S35	Henley Bed										Barren
S223	Lower Henley Bed		7	7	195	70	21	0	0	0	Charcoal again dominant. All elements of assemblage poorly preserved and particles are generally uniform and small (around 40µm). Mostly very dark wood and plant tissue. Palynomorphs very poorly preserved.
S34	Henley Bed										Barren
S224	Lower Henley Bed										Barren
S30	Henley Bed										Barren
S225	Lower Henley Bed										Barren
S226	Lower Henley Bed										Barren
S29	Henley Bed		76	11	104	60	56	3	0	0	Spore assemblages sparse and poorly preserved. A high proportion of blackened, opaque woody fragments were observed as well as numerous light brown cuticle material. Miospores dominate the palynomorph assemblages.
S227	Middle Henley Bed (below silty members)		0	8	158	50	14	75	0	0	Phytoclasts mainly comprise of black opaque fragments and thick, dark brown cuticle. Light coloured acanthomorph acritarchs dominate palynomorph assemblage.
S220	Henley Bed (Between 2 silty members)		6	2	165	85	48	4	0	0	Palynomorphs light and poorly preserved. Sample dominated by phytoclasts – mainly charcoal, cuticle and tube fragments.
S28	Henley Bed										Barren

Appendix III.I Palynofacies counts

S219	Henley Bed		15	11	136	92	42	27	0	0	Pyrite rich sample, pyrite preserved in 'needles' (Photo!) therefore hard to distinguish from elongate, opaque woody tissue. Palynomorphs light in colour and poorly preserved. Plant tissues comprised mainly of poorly preserved cuticle material, some more degraded cuticle hard to distinguish from AOM.
S218	Henley Bed		56	17	100	68	49	15	0	0	Spores light in colour and poor-moderate preservation observed. Phytoclasts dominated by charcoal. Plant tissues comprised mainly of poorly preserved cuticle material, some more degraded cuticle hard to distinguish from AOM.
S27	Henley Bed										Barren
S217	Top Henley Bed		12	19	169	65	35	14	0	0	Well preserved brown to light brown palynomorphs. Dominated by black opaque fragments. Dark brown woody fragments and plant material.
S26	Henley Bed										Barren
S228	Base Farmers Member		20	12	115	79	37	37	0	0	Light coloured spiny acritarchs, many pyritised. Spores well preserved and very light brown. Most plant tissue and woody fragments brown to dark brown.
S213	Nancy Member		13	10	162	50	65	0	0	0	Again dominated by opaque woody material, but higher proportions of cuticle and fibrous strands/tubes and more of this degraded to AOM. Very well preserved spore assemblage.
S211	Nancy Member		4	15	168	40	73	0	0	0	Palynomorph assemblage dominated by well-preserved miospores. Phytoclasts dominated by black opaque woody material. Dark brown woody tissue and flimsy cuticle also fairly common.
S212	Nancy Member		8	10	198	45	53	3	0	0	Some black spores, most brown/light brown. Black phytoclasts dominate again, structure fairly well preserved on plant cuticles
AA Highway, Vanceburg, Kentucky											
S229	Top Sunbury Shale		249	2	32	7	10	0	0	0	Mostly light brown AOM, fairly uniform in shape. Very few spores, mostly obscured by AOM, featureless and poorly preserved.
S230	Top Sunbury Shale		231	6	37	10	15	1	0	0	As previous but more spores and better preservation noted. Allows for identification. AOM in smaller fragments, therefore spore material easier to see.
S231	Base Jacobs Chapel		163	7	64	34	30	2	0	0	Phytoclasts mainly opaque wood or dark brown cuticle. Much of this degraded to light brown AOM. Few poorly preserved spores.
S232	Base Rockford		57	1	129	93	20	2	0	0	Few poorly preserved spores. Phytoclasts dominate and comprise mainly of charcoal and light brown cuticle. Some of the darker brown cuticle degraded to AOM and so is hard to distinguish between the two groups.
S233	Top Rockford										Barren

Appendix III.I Palynofacies counts

S234	Henley Member										Barren
S235	Henley Member		2	6	215	59	12	6	0	0	Dominated by black opaque fragments and dark plant tissue. Spiny acritarchs common.
S236	Henley Member		7	13	187	58	30	10	0	0	Acritarchs very pale, as is cuticle and fibrous material. Spores very well preserved, brown – dark brown, few black. Phytoclasts mainly dark-brown to black.
S237	Henley Member										Barren
S238	Henley Member										Barren
S239	Base Portsmouth Member (Above top		3	11	199	63	23	3	0	0	Black phytoclasts and opaque mineral dominate. A lot of light brown cuticle material present. Few spores and acritarchs but preservation good.
S240	Portsmouth Member		0	3	62	112	210	7	0	0	Lots of spores, well preserved, few pyritised. Spores dominate assemblage. Also a lot of plant tissue present, mainly thin walled cuticle.
S241	Portsmouth Member										Barren
S242	Portsmouth Member		3	18	105	118	53	10	0	0	Miospores dark and fairly well preserved, colour varies – a few much lighter and some very dark. Acritarchs are light brown – colourless. Phytoclasts mainly dark brown-opaque.
S243	Top Portsmouth Member (under base Vanceburg Member)		3	8	113	114	41	21	0	0	Spores and acritarchs very light in colour, some pyritised and very poorly preserved. Plant tissues are poorly preserved – most very dark brown or black.
Hannibal, Missouri											
S45	Base Hannibal Shale		8	11	53	140	35	110	0	1	Numerous small spiny acritarchs - genus *Michrystridium* . Cuticles and fibrous material common, generally broken up into fairly regular fragments. Some darker cuticle material.
S46	Base Hannibal Shale		15	8	57	159	32	27	0	2	Lots of black mineral, opaque phytoclasts difficult to identify – identified on shape alone. Miospores mostly light brown and poorly preserved, some black. A few light brown/colourless acritarchs present, some with pyritised central body. Plant material very sparse and broken up.
S57	Hannibal Shale		21	2	8	161	15	91	0	2	Few acritarchs, commonly overgrown with pyrite. Plant material very poorly preserved.
S47	Base Hannibal Shale		12	4	38	181	63	2	0	0	As S46, spores very badly preserved and heavily pyritised. Dark brown plant tissue.

Appendix III.I Palynofacies counts

S48	Hannibal Shale		3	11	27	155	8	116	1	4	Poorly preserved thin walled spores. Spiny acritarchs common and scolecodonts relatively common. Phytoclasts dominated by 'wispy' cuticle material (plate).
S56	Hannibal Shale										Barren
S49	Hannibal Shale	Nitric Acid 30mins	6	6	8	175	26	85	0	2	Acritarchs thin-walled as before and many pyratised. Plant tissue comprised of small fragments of thin-walled cuticle and fibres.
S55	Hannibal Shale										Barren
S54	Hannibal Shale		189	8	13	44	16	104	0	0	Hannibal Shale – Mostly light brown to brown AOM. Numerous spiny colourless acritarchs, some light brown spores. Charcoal, woody fragments and cuticle present.
S53	Hannibal Shale		26	4	13	116	12	153	0	1	Hannibal Shale - AOM grey brown in colour. Phytoclasts mainly light brown cuticle/dark brown cuticle. Very little opaque material/woody fragments.
S52	Hannibal Shale		27	3	11	107	7	177	0	3	Hannibal Shale – Dominated by acanthomorph acritarchs, some spores present generally light in colour, thin walled and broken. Most plant tissue light brown poorly preserved and fragmented, some degraded to AOM.
S51	Hannibal Shale										Barren
S50	Top? Hannibal Shale (top of Section)		63	2	3	195	30	7	0	2	Grey brown AOM. Lots of very poorly preserved cuticle and tubes, orangey-brown in colour. Pyrite and other minerals common. Spores poorly preserved and light coloured, acritarchs light in colour.
Clarence Cannon Dam, Missouri											
CC01	Horton Creek Limestone		232	8	64	6	2	0	0	0	Sample dominated by brown AOM. Few brown spores, preservation fair.
CC02	Horton Creek Limestone		162	0	3	134	32	1	1	0	Lots of brown/dark brown AOM and degraded plant tissue. Spores mostly black, some infilled with pyrite. Preservation fair.
CC03	Hannibal Shale (Cuivre Member)		89	0	19	105	13	74	0	1	Light coloured AOM, plant cuticle and fibres present. Numerous small acanthomorph acritarchs (*Michrystridium*) dominate the palynofacies.
CC04	Hannibal Shale (Cuivre Member)		174	5	44	75	14	15	0	0	Dominated by AOM, and some cuticle and fibres - brown - dark brown. Spores rare, well preserved.
CC05	Hannibal Shale		84	6	24	90	7	149	0	0	Sample dominated by acanthomorph acritarchs. AOM, brown plant tissue and fibres comprise the rest of the sample.
CC06	Hannibal Shale		59	0	17	57	16	186	0	1	Sample dominated by small light coloured, acanthomorph acritarchs, some infilled with pyrite.

Appendix III.I Palynofacies counts

CC07	Hannibal Shale		40	3	14	54	4	185	0	0	Sample dominated by small light coloured, acanthomorph acritarchs, some infilled with pyrite.
CC08	Hannibal Shale		51	11	35	56	10	171	0	0	Sample dominated by small light coloured, acanthomorph acritarchs, some infilled with pyrite. Increased proportion of opaque wood.
CC09	Hannibal Shale		38	7	17	111	15	155	0	0	Dominated again by acanthomorph acritarchs. Plant tissue light in colour and more fibres present.
CC10	Hannibal Shale		34	3	21	100	4	137	1	0	Sample dominated by small light coloured, acanthomorph acritarchs. Long single fibres and fibrous strands make up a high proportion of plant tissue.
CC11	Hannibal Shale		65	10	28	76	6	167	0	0	Sample dominated by small light coloured, acanthomorph acritarchs. Increased proportion of opaque wood.
CC12	Hannibal Shale		55	4	46	71	2	121	1	0	Sample dominated by small light coloured, acanthomorph acritarchs. Slightly higher proportion of plant tissue, poorly preserved and degrading to AOM.
CC13	Hannibal Shale		45	4	17	79	19	162	0	0	Sample dominated by small light coloured, acanthomorph acritarchs. Woody and plant tissue dark brown and poorly preserved, cuticle and fibres common.
CC14	Hannibal Shale		71	8	31	115	18	121	0	1	Sample dominated by small light coloured, acanthomorph acritarchs. Dark brown cuticle and fibres common.
CC15	Hannibal Shale		54	6	19	96	10	115	0	0	Sample dominated by small light coloured, acanthomorph acritarchs. Dark brown fibres, cuticle and tubes all fairly well preserved.
CC16	Hannibal Shale		46	2	13	131	12	96	0	0	Sparse sample. Palynomorphs still dominated by acanthomorph acritarchs, but palynofacies dominated by light coloured, poorly preserved cuticle and fibres.
CC17	Hannibal Shale		75	3	15	88	11	113	0	1	Sparse assemblage dominated by acanthomorph acritarchs and poorly preserved, light coloured cuticle, fibres and AOM.
CC18	Top Hannibal Shale		34	2	19	157	5	83	0	0	Dominated by cuticle and plant tissue, large fragments and fibres.
Geode Glen, Illinois											
S61	Lower Warsaw		4	0	2	306	4	0	0	0	Dominated by light brown fragments of cuticle, few light brown spores but preservation generally poor.
S62	Lower Warsaw										Barren
S63	Lower Warsaw										Barren
S64	Lower Warsaw										Barren
S72	Lower Warsaw		27	0	26	228	18	0	0	1	Dominated by light brown – brown cuticle material. Spores rare, well preserved and brown to dark brown.
S71	Lower Warsaw	Nitric Acid 30mins	27	6	76	175	37	0	0	2	Well preserved spores, some black. Cuticle fragments as before, not very well preserved and degrading to AOM. Charcoal increasing.

Appendix III.I Palynofacies counts

S70	Lower Warsaw	Nitric Acid 30mins	27	2	71	179	43	0	0	0	Very well preserved spores, some with a little pyrite overgrowth. Brown cuticle material and fibres degrading to AOM. Increased proportion of charcoal.
S69	Lower Warsaw		31	3	37	198	36	0	0	0	Mainly dark brown cuticle material (as in S68).
S68	Lower Warsaw		36	2	26	221	15	0	0	0	Mostly phytoclasts - dark brown cuticle material poorly preserved and degrading to AOM. Spores fairly well preserved.
S67	Lower Warsaw	Nitric Acid 30mins	51	0	22	222	15	0	0	0	Dark brown poorly preserved cuticle material making up most of the assemblage. Some charcoal present. Spores light brown – dark brown, some black, and generally well preserved.
S66	Lower Warsaw		41	1	36	208	14	0	0	0	Much of the phytoclast material degraded, therefore hard to define between plant tissue and AOM. Plant cuticles generally brown to dark brown and some opaque phytoclasts present.
S65	Lower Warsaw		23	3	20	265	15	0	0	0	Mostly light brown - dark brown cuticle and other plant tissue. Spores present but light in colour, poorly preserved and rare.
S73	Top Lower Warsaw	Nitric Acid 20mins	24	3	107	95	70	0	0	1	Spores common, well preserved, some with pyrite overgrowth. Plant tissue dark brown. Fragments of charcoal common.
Cragwold Road, Missouri											
S90	Top Lower Warsaw	Nitric Acid 20mins	33	3	38	205	27	0	0	1	Lots of pyrite overgrowth, both in spores and cuticle material. Sample dominated by orange/brown cuticle. Spores brown - light brown and well preserved.
S89	Top Lower Warsaw	Nitric Acid 20mins	19	7	51	187	41	0	0	2	Few spores, fair preservation, light coloured. Dominated by cuticle material, light brown. Pyrite common, some black spores.
S92	Upper Warsaw	Nitric Acid 20mins	21	3	86	164	39	0	0	1	Spores light brown, fairly well preserved, some pyritised. Charcoal common.
S91	Upper Warsaw	Nitric Acid 20mins	23	12	74	158	45	0	0	0	More pyrite overgrowth and crystals than other Crawold Road samples. Lots of light brown cuticle material and dark woody material present. Spore preservation fair, some pyritised spores.
Old Randolph Stone Company Quarry											
S74	Hardinsburg	Nitric Acid 20mins	9	5	16	245	36	0	0	0	Sample dominated by brown - light brown phytoclasts. Very few poorly preserved spores, mostly thin walled and broken, some black.
Coles Mill, Illinois											
S78	Base Tar Springs Sandstone	Nitric Acid 30mins	7	25	106	100	102	0	0	0	Well preserved numerous spores, some overgrown with pyrite, few black. Plant material generally dark brown in colour, with relatively high proportion woody fragments.
S77	Tar Springs Sandstone	Nitric Acid 30mins Funing nitric 10mins	13	14	194	56	64	0	0	0	Lots of black opaque woody material and dark wood fragments. Spores well preserved, dark brown to black. Cuticle present, but relativley small numbers.

Appendix III.I Palynofacies counts

S76	Tar Springs Sandstone										Barren
S75	Tar Springs Sandstone	Nitric Acid 40mins	80	30	28	103	59	0	0	0	Well preserved spores, brown to light brown. Some darker woody material and charcoal present. And small fragments of AOM.
Southern Illinois Stone Company											
S79	Kinkaid Limestone (Cave Hill)	Nitric Acid 30mins	4	40	108	107	42	0	0	0	Dark, well preserved spores. High proportion of cuticle and woody fragments (plate) and fragmented opaque material.
S80	Kinkaid Limestone (Goreville) / poss Morrowan!!	Nitric Acid 30mins	25	1	103	63	154	0	0	0	Lots of very thin cuticle material as well as dark particles and charcoal. Spores common (thin walled, featureless *Calamospora*).
S81	Pennslyvanian Morrowan	Nitric Acid 30mins	17	40	132	120	15	0	0	0	Rare, poorly preserved spores. Mostly charcoal and dark plant cuticle. Well preserved structure on woody material.
Flatwoods-Kerley Railroad Cut, Illinois											
S82	Menard Limestone	Nitric Acid 40mins	4	17	68	85	125	0	0	1	Well preserved numerous spores, some overgrown with pyrite, few black. A lot of charcoal, woody structure still apparent. Plant tissue varied in colour and type, mainly thin and thick cuticle, tubes and fibres.
S86	Menard Limestone	Nitric Acid 30mins	14	7	84	137	58	0	0	0	Spores well preserved, dark, many pyritised. Cuticle material ranges from light brown to dark brown. Fibres and tubes common.
S85	Menard Limestone										Barren
S84	Menard Limestone										Barren
S83	Top Menard Limestone	Nitric Acid 40mins	16	10	101	114	106	0	0	0	Spores well preserved and a little dark, some overgrown with pyrite. Plant cuticle mainly thin and featureless.
S87	Palestine	Nitric Acid 40mins	7	19	131	57	116	0	0	0	Well preserved spores, light to dark in colour, some black. Phytoclasts mainly comprised of charcoal and brown cuticle. Some dark brown woody material with structures preserved.
Grantsburg Northeast Railroad Cut, Illinois											
S88	Waltersburg	Nitric Acid 40mins	8	35	50	110	102	0	0	0	Very well preserved spores, some dark and overgrown with pyrite. Abundant light-dark brown cuticle material and large woody fragments.
C14859, Illinois											
S101	Hannibal Shale	Nitric Acid 20mins	186	8	22	50	30	35	0	0	Light coloured acritarchs and dark brown/black spores. Light brown AOM dominates sample. Rare thin, light coloured cuticle and thin dark fibres present.
S102	Hannibal Shale										Barren

Appendix III.I Palynofacies counts

S103	Hannibal Shale	Nitric Acid 20mins	40	7	23	157	13	98	0	1	Small acanthomorph thin walled acritarchs common as well as fibrous thin threads and light brown AOM. Cuticle degraded - hard to distinguish some cuticle from AOM. Also lots of dark brown/nearly black cuticle. Some pyritised spores.
S104	Chouteau										Barren
S105	Burlington										Barren
S106	Burlington										Barren
LS21, Missouri											
S107	Chattanooga Shale	Nitric Acid 20mins	131	0	25	57	33	85	0	0	Dominated by AOM - light colour. Some light cuticle material and fibres. Acritarchs common, spores light - dark brown/black.
S108	Chattanooga Shale	Nitric Acid 20mins	107	6	22	47	56	131	0	1	Acritarchs dominate palynomorph assemblage. Long spiny *Michrystridium* and short spined *Gorgonisphaeridium.* Some pyritised spores. Sample full of light cloured AOM.
66OK-3, Oklahoma											
S109	Late Dev, St Peter										Barren
S110	Chattanooga Shale										Barren
S111	Chattanooga Shale										Barren
Field samples, Illinois											
S112	Hardinsburg		8	12	173	107	0	0	0	0	Barren for palynomorphs. Very dark brown pyratised woody fragments. AOM dark brown - black.
S113	Hardinsburg		9	2	166	127	3	0	0	0	Larger clasts than in S112. Similar palynofacies otherwise.
S114	Burlington										Barren
S115	Burlington										Barren
NS3, Missouri											
S116	Compton Limestone										Barren
S117	Compton Limestone										Barren
S118	Northview Shale										Barren
S119	Northview Shale										Barren
S120	Northview Shale		12	0	5	261	15	5	1	1	Phytoclasts mainly comprised of whispy cuticle material, very light brown, some pyritised. Few light coloured spores, some pyritised.
S121	Northview Shale		37	0	5	247	10	6	0	0	Phytoclasts very poorly preserved, dark brown cuticle material common.

Appendix III.I Palynofacies counts

NS2, Missouri											
S122	Bachelor		95	0	16	178	11	0	0	0	Lots of featurless cuticle material and light brown AOM. Few spores, preservation not great, many pyritised.
S123	Northview Shale		25	0	11	225	36	2	0	1	Spores either pale and well preserved or black. Most phytoclasts are dark brown, poorly preserved plant tissue.
S124	Northview Shale		25	0	21	213	36	5	0	0	Spores commly black. Phytoclasts poorly preserved, dark brown and pyritised.
S125	Northview Shale		14	2	22	218	36	6	0	2	Spores commly black. Phytoclasts poorly preserved, dark brown and pyritised.
S126	Northview Shale		10	0	20	217	43	9	0	1	Most spores black, few dark brown and well preserved. Phytoclasts dominated by dark plant cuticle.
C141, Illinois											
S136	Ste Genevieve										Barren
S135	Yankeetown Ss										Barren
S134	Yankeetown Ss										Barren
S133	Cypress Ss		6	40	24	143	132	0	0	0	Well preserved spores, mostly brown - light brown, some black. Phytoclasts consist of cuticle and woody material, structures very well preserved.
C14703, Illinois											
S137	Salem		225	0	10	70	0	0	0	0	Barren for palynomorphs. Mainly comprised of AOM, light coloured. Few brown, poorly preserved fragments of cuticle.
C14715, Illinois											
S138	Keokuk	Nitric Acid 20mins	61	6	46	196	44	0	0	0	Phytoclasts dominated by plant tissue - light brown and poorly preserved, varying to dark and well preserved, pyrite comon. Spores light brown to brown, some filled with pyrite.
S139	Lower Warsaw	Nitric Acid 20mins	31	10	69	130	85	0	0	0	Lots of spores, well preserved, many pyritised. Charcoal common, plant tissue consists mainly of whispy cuticle material, brown to dark brown.
S140	Lower Warsaw	Nitric Acid 20mins	9	12	88	198	92	1	0	0	Spores well preserved , abundant, brown to dark brown in colour, mainly overgrown partially or completely with pyrite. Phytoclasts dominated by opaque woody material and well preserved fibrous cuticle.
C15223, Illinois											
S141	Lower Warsaw		48	1	21	202	27	0	0	1	Few light coloured spores, fair preservation. Sample dominated by thin, whispy cuticle.
S142	Lower Warsaw		42	0	16	199	43	0	0	0	Sample dominated by brown - dark brown cuticle, poorly preserved. Spores commonly black. Some light brown - brown.

Appendix III.I Palynofacies counts

S143	Lower Warsaw		76	1	19	184	20	0	0	0	Dominated by poorly preserved orange-brown cuticle material and AOM. Spores present, some balck.
S144	Lower Warsaw		50	0	30	191	29	0	0	0	Dominated by poorly preserved orange-brown cuticle material and AOM. Spores present, some balck.
S145	Lower Warsaw		56	3	27	175	38	1	0	0	Dominated by poorly preserved cuticle and AOM. Spore preservation poor, many pyritised.
S146	Lower Warsaw		55	3	35	193	14	0	0	0	Cuticle and AOM both contain a lot of pyrite fragments - difficult to ditinguish between the two. Few thin walled spores, poor preservation.
S147	Salem		199	0	0	86	15	0	0	0	Spores present, but fragmented, most unidentifiable. Sample dominated by light to dark brown AOM.
S148	Salem										Barren
S149	St Louis		183	0	5	106	5	1	0	0	Dominated by brown-grey AOM, lots of pyrite overgrowth. Occassional poorly preserved palynomorphs, but sample essentially barren. Plant tissue generally very degraded cuticle.
S15100, Illinois											
S150	St Louis										Barren
S151	St Louis										Barren
S69127, Illinois											
S152	Keokuk	Nitric Acid 20mins	35	0	38	204	21	0	0	2	Plant material dark brown and well preserved. Spores generally fragmented and not useful for palynology.
S153	Keokuk	Nitric Acid 15mins	34	0	20	202	24	0	0	0	Small fragments of cuticle and fibrous plant tissue. Spores moderately well preserved, some black.
S154	Lower Warsaw	Nitric Acid 20mins	51	9	9	192	42	0	0	0	Well preserved spore assemblage, light brown to dark brown. Plant tissue varies from light brown cuticle to dark brown cuticle, fibres and tubes.
S155	Lower Warsaw	Nitric Acid 20mins	52	0	11	195	44	0	0	0	Well preserved spore assemblage, light brown to dark brown. Plant tissue varies from light brown cuticle to dark brown cuticle, fibres and tubes.
S156	Lower Warsaw	Nitric Acid 20mins	40	2	9	207	42	0	0	0	Spores light brown - dark brown, sample dominated by light brown - dark brown AOM.
H29, Iowa											
S157	McCraney	Nitric Acid 20mins	36	1	0	257	6	0	0	0	Sample dominated by orange/brown cuticle, some degraded to AOM. Fragments range from 40 - 300µm.
S158	McCraney	Nitric Acid 20mins	55	0	0	245	0	0	0	0	Barren for palynology. Dominated by homogenous orange/brown plant tissue, degraded, some AOM.

Appendix III.I Palynofacies counts

S159	McCraney		77	0	0	215	8	0	0	0	Sample comprised mainly of pale, homogeneous plant tissue (cuticle?) and AOM. Few pale spores, fair preservation.
S160	Prospect Hill	Nitric Acid 10mins	37	0	35	222	34	12	0	0	Phytoclasts dominated by plant tissue, varying from very thin, almost translucent cuticle to darker cuticle and fibres. Spores and acritarchs thin walled, some overgrown with pyrite.
S161	Prospect Hill	Nitric Acid 20mins	47	5	15	107	12	127	0	0	Dominated by acanthomorph acritarchs, mainly *Michrystridium* and *Gorgonisphaeridium,* most are thin walled and filled with pyrite. Whispy cuticle and AOM common.
S162	Prospect Hill		22	3	8	184	10	80	0	0	Phytoclasts dominated by small acanthomorph acritarchs - *Michrystridium.* Few infilled with pyrite. Plant tissue common, mostly very thin, light coloured cuticle and fibres.
S163	Prospect Hill	Fuming Nitric Acid 45mins	65	1	5	190	14	81	0	0	Plant material mostly cuticle and fibres, brown - light brown. Some AOM. Acanthomorph acritachs common, many pyritised. Some spores pyritised.
S164	Wassonville Fm										Barren
S165	Burlington	Fuming Nitric Acid 45mins	105	2	15	134	52	12	0	0	Lots of pyrite crystals and overgrowth of dark brown spores. Spores well preserved, few spiny acritarchs. Phytoclasts mainly degraded cuticle and AOM.
S166	Burlington		87	4	24	154	28	3	0	0	Lots of pyrite crystals and overgrowth of spores. Spores light - dark brown, well preserved. Plant tissue orange - brown, degraded cuticle and AOM.
S167	Keokuk		152	0	5	153	1	0	0	0	Barren for palynology. Mainly poorly preserved cuticle and AOM both orange - brown. Large clasts (150-200µm). Occasional pyrite and opaque plant fragments.
S168	Keokuk		115	1	15	169	1	0	0	0	As previous but darker brown plant tissue and some fragments of charcoal, smaller clasts.
S169	Keokuk		136	0	4	159	1	0	0	0	As previous with higher percentage of AOM, plant tissue more degraded.
S170	Keokuk		89	4	11	161	33	0	0	2	Spores brown - dark brown, well preserved. Plant tissue dominated by whispy cuticle material and fibres, some charcoal.
S171	Keokuk										Barren
S172	Lower Warsaw	Nitric Acid 30 mins	88	0	3	218	3	0	0	0	Few poorly preserved spores.Common poorly preserved cuticle material, some degraded to AOM.
S173	Lower Warsaw		51	0	5	230	14	0	0	1	Dominated by cuticle material, dark brown - black, some pyrite. Spore preservation good.

Appendix III.I Palynofacies counts

S174	Lower Warsaw	Nitric Acid 30 mins	84	6	12	213	12	0	1	0	Well preserved spores, most brown - dark brown, some with pyrite overgrowth. Very common plant cuticle, dark brown - light brown.
59 MI, Missouri											
S175	Hannibal Shale		121	0	33	147	0	10	0	0	Barren for palynology. Dominated by mineral. Palynofacies dominated by dark brown poorly preserved cuticle and AOM.
S176	Sedalia		64	6	1	209	14	6	0	0	Cuticle and spores both dark brown, preservation generally poor.
S177	Upper Warsaw		85	2	3	215	7	0	0	0	Sample dominated by brown cuticle, preservation poor-fair. Few brown spores, good preservation.
S178	Upper Warsaw		96	0	14	188	0	0	0	2	Barren for palynology. Mostly dark brown cuticle and AOM.
C13897, Illinois											
S195	Ste Genevieve		281	0	5	53	0	0	0	0	Dominated by grey brown AOM. Very sparse. Some very degraded plant tissues - orange/brown present.
S196	Aux Vases Sandstone		95	51	89	65	0	0	0	0	Barren for palynomorphs, sample dominated by charcoal, dark woody tissue and grey brown AOM.
S197	Renault		95	5	28	179	1	0	0	0	Barren for palynomorphs. Sample mostly very thin featureless cuticle, degraded to AOM.
C4883, Illinois											
S198	Kinkaid		286	0	0	14	0	0	0	0	Barren for palynomorphs. Sample dominated by large dark brown clasts of AOM (up to 1.5 mm). Some plant fragments, but degraded and obscured.
S199	Kinkaid		49	0	23	205	33	0	0	0	Dominated by poorly preserved fragments of cuticle and tubes, dark colour. Spores poorly preserved.
S200	Kinkaid		49	6	21	200	64	0	0	0	Spores dark and well preserved. Phytoclasts dominated by cuticle, tubes and fibres, fairly well preserved, dark brown to black.
C13076, Illinois											
S201	Cypress Ss		242	2	14	50	0	0	0	0	Barren for palynomorphs. Dominated by brown/grey featureless AOM.
S202	Cypress Ss		151	12	48	96	0	0	0	0	Barren for palynomorphs. Dominated by dark brown/ black phytoclasts and dark brown AOM.
S203	Cypress Ss		16	23	37	162	86	1	0	0	Assemblage comprised mainly of phytoclasts - dark brown. Large black fragments of charcoal (up to 300µm). Spores well preserved, brown/dark brown.
C46, Illinois											
S204	Ste Genevieve		172	2	19	110	10	0	0	0	Sparse palynomorph assemblage, light brown, simple spores, limited diversity. Dominant AOM and degraded plant material, light/brown grey.

Appendix III.I Palynofacies counts

S205	Downies Bluff										Barren
S206	Hardinsburg		44	36	43	181	26	0	0	0	Spores well preserved, light brown. Fibrous brown - dark brown plant cuticle, charcoal and wood dominate phytoclasts, structures well preserved.
C13619, Illinois											
S207	Bethel?		0	6	14	150	20	0	0	0	Distinctive plant tissue, very well preserved. Light brown- brown fibrous cuticle material. Spores well preserved, brown - dark brown.
S208	Fraileys		8	6	67	147	72	0	0	0	Very well preserved spores. Dark and opaque wood material dominates sample. Similar structures to S207 but generally darker.
S209	Tar Springs Sandstone		0	5	135	97	63	0	0	0	Spores dark brown and well preserved, some black. Plant tissue mostly cuticle and fibrous strands.
S210	Tar Springs Sandstone		24	14	58	134	87	0	2	0	Fragmented plant tissue very common and degraded to AOM. Some woody tissue showing structures. Most phytoclasts dark to opaque. Spores well preserved, mostly brown - light brown.

Appendix III.I Palynofacies counts

Morehead	Sample No																			
	S40	S214	S39	S215	S38	S216	S221	S36	S222	S223	S29	S227	S220	S219	S218	S217	S228	S213	S211	S212
AOM	77	15	1	94	83	89	78	79	6	2	25	0	2	5	18	4	7	4	1	2
Woody material	19	41	64	6	16	11	20	16	93	91	56	70	81	75	61	80	68	74	75	80
Palynomorphs	4	44	35	0	1	0	2	5	1	7	19	30	17	20	21	16	25	22	24	18

Vanceburg	Sample No									
	S229	S230	S231	S232	S235	S236	S239	S240	S242	S243
AOM	83	77	54	19	0	2	1	0	0	1
Woody material	14	18	35	74	94	85	90	44	79	78
Palynomorphs	3	5	11	7	6	13	9	56	21	21

Hannibal	Sample No									
	S45	S46	S57	S47	S48	S49	S54	S53	S52	S50
AOM	2	5	7	4	1	2	51	8	8	21
Woody material	57	75	57	74	59	61	17	42	36	66
Palynomorphs	41	20	36	22	40	37	32	50	56	13

Clarence Cannon Dam	Sample No																	
	CC01	CC02	CC03	CC04	CC05	CC06	CC07	CC08	CC09	CC10	CC11	CC12	CC13	CC14	CC15	CC16	CC17	CC18
AOM	74	49	30	53	23	18	13	15	11	11	18	18	14	19	18	15	24	11
Woody material	23	41	41	38	34	22	24	31	40	48	33	40	32	42	40	49	35	60
Palynomorphs	3	10	29	9	43	60	63	54	49	41	49	42	54	39	42	36	41	29

Geode Glen	Sample No									
	S61	S72	S71	S70	S69	S68	S67	S66	S65	S73
AOM	1	9	8	8	10	12	17	14	7	8
Woody material	98	85	80	78	78	83	79	81	88	68
Palynomorphs	1	6	12	14	12	5	4	5	5	24

Appendix III.II Ternery plot data. Percentage of AOM-Woody material-Palynomorphs in each section

Cragwold Road	Sample No			
	S90	S89	S92	S91
AOM	11	6	7	7
Woody material	80	80	80	78
Palynomorphs	9	14	13	15

Old Randolph Stone Co. + Coles Mill	Sample No			
	S74	S78	S77	S75
AOM	3	2	4	27
Woody material	86	68	77	53
Palynomorphs	11	30	19	20

Southern Illinois Stone Co.	Sample No		
	S79	S80	S81
AOM	1	7	5
Woody material	85	48	90
Palynomorphs	14	45	5

Flatwoods + Grantsburg	Sample No				
	S88	S82	S86	S83	S87
AOM	3	1	5	5	2
Woody material	64	57	76	65	63
Palynomorphs	33	42	19	30	35

H29	Sample No															
	S157	S158	S159	S160	S161	S162	S163	S165	S166	S167	S168	S169	S170	S172	S173	S174
AOM	12	18	26	11	15	7	18	35	29	49	38	45	30	28	17	26
Woody material	86	82	71	76	40	64	55	50	61	51	62	55	58	71	78	70
Palynomorphs	2	0	3	13	45	29	27	15	10	0	0	0	12	1	5	4

Appendix III.II Ternery plot data. Percentage of AOM-Woody material-Palynomorphs in each section

Missouri-Kindehookian, Meramecian/Osagean	Sample No												
	LS21		NS2					NS3		59-Mi			
	S107	S108	S122	S123	S124	S125	S126	S120	S121	S175	S176	S177	S178
AOM	40	29	32	8	8	5	3	4	12	21	39	27	32
Woody material	24	20	64	79	78	81	79	89	83	72	58	71	68
Palynomorphs	36	51	4	13	14	14	18	7	5	7	3	2	0

Illinois - Kinderhookian, Meramecian/Osagean	Sample No																		
	C14859		C14715			S69127					C15223								
	S101	S103	S138	S139	S140	S152	S153	S154	S155	S156	S141	S142	S143	S144	S145	S146	S147	S137	S149
AOM	56	12	17	10	3	12	18	17	17	13	16	14	25	17	19	18	66	74	61
Woody material	24	55	70	64	66	81	74	70	68	73	75	72	68	73	68	77	29	26	37
Palynomorphs	20	33	13	26	31	7	8	13	15	14	9	14	7	10	13	5	5	0	2

Illinois - Chesterian	Sample No																		
	FS		141	C13897			C4883			C13076			C46		C13619				
	S112	S113	S133	S195	S196	S197	S198	S199	S200	S201	S202	S203	S204	S206	S207	S208	S209	S210	
AOM	3	3	2	81	32	31	95	16	14	79	49	5	55	13	0	3	0	7	
Woody material	97	96	60	19	68	69	5	73	67	21	51	68	42	79	93	73	79	65	
Palynomorphs	0	1	38	0	0	0	0	11	19	0	0	27	3	8	7	24	21	28	

Appendix III.II Ternery plot data. Percentage of AOM-Woody material-Palynomorphs in each section