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PALAEOGEOGRAPHIC AND PALAEOENVIRONMENTAL CHARACTERISTICS OF MAJOR MARINE INCURSIONS IN NORTHWESTERN EUROPE DURING THE WESTPHALIAN C (BOLSOVIAN)

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(12 figures, 2 tables)

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ABSTRACT. The Westphalian C was a time of marked tectonic and climatic changes within the Variscan Foreland, but our understanding of these changes is hampered by a poor appreciation of large-scale palaeogeography and palaeogeographic evolution within this key stratigraphic interval. The distribution of tonsteins, marine bands and faunal occurrences related to marine incursions or the proximity of marine conditions in Britain and on the European mainland during the Westphalian C (Bolsovian) is briefly summarised. The favoured environmental conditions of some selected fossil taxa (*Lingula*, arenaceous foraminifers, *Geisina*, conchostracan faunas and *Torispora* producing tree ferns) are highlighted. A palaeogeographic model shows the relationship between major sedimentary facies belts in the Westphalian C of western Europe and the influence of major marine incursions on the distribution pattern of incursion-related faunas.

The frequent succession of transgressive-regressive faunal phases in beds with marine faunas and the close correlation between the distribution of these beds and the distribution of upper delta plain environments in the Westphalian C of northwestern Europe suggest that marine incursions were long-lived, related to glacio-eustatic events, and cannot be regarded as catastrophic « flash floods ».

KEYWORDS: Westphalian C, palaeogeography, western Europe, marine bands, tonstein, faunas, miospores

1. Introduction

The Westphalian C (or Bolsovian) of western Europe forms part of the Coal Measures deposited in the Late Carboniferous Variscan Foreland (age range 311 – 308 Ma, Menning *et al.*, 2000: Fig. 6). Syndepositional low relief deformations, related to build-up of Variscan compressional forces, led to considerable regional variations in thickness and facies distribution (Bless *et al.*, 1977; Hedemann & Teichmüller, 1971) – (thickness range 500 m, South Wales, to 1000 m, Ruhr; Menning *et al.*, 2000: Tab. 3). However, high rates of sedimentation generally maintained a depositional regime dominated by coal swamps, lakes, deltas and alluvial flood plains. Red beds are adjacent to tectonically elevated areas only. The cyclic nature of sedimentary sequences is mainly related to 3rd order glacio-eustatic sea-level fluctuations and to 5th order autocyclic controls of the delta plain/alluvial plain depositional environment. Marine transgressions supposedly invade the Variscan Foreland basin either from the marine Moscow Platform to the east or the Canadian maritime provinces to the west (Bless *et al.*, 1981; Ziegler, 1990). Recognition of flooding events in different depositional systems is necessary to establish a basin-wide stratigraphic framework.

The detailed correlation of Westphalian C or Bolsovian (Owens *et al.*, 1984) strata in western Europe is based on an intricate succession of tonsteins and bands with marine faunas or faunas related to marine incursions (Table 1, Figure 1). Only one of these, the Mansfield-Aegir Marine Band at the base of the Westphalian C (also referred to as Cefn Coed, Maurage, Petit-Buisson, Skipsey's or Rimbert Marine Band) has been traced through large parts of western Europe.

Marine bands higher up in the succession are practically unknown outside Britain, but they can be correlated with selected fossil bands on the European mainland, which have been linked to marine incursions because of their presumed

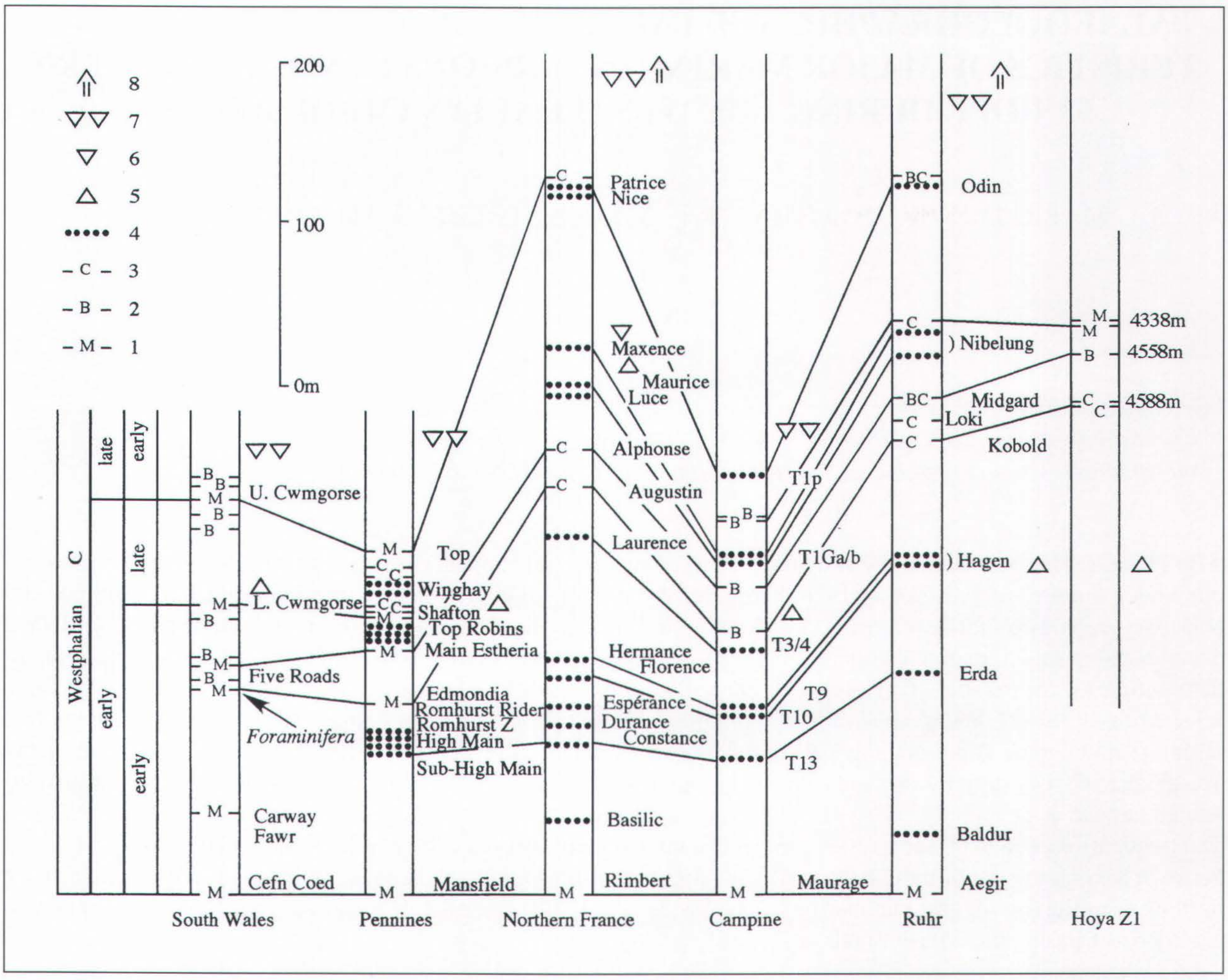


Figure 1. Correlation of tonsteins and bands with characteristic faunas related to marine incursions between some selected, composite, lower to early upper Westphalian C sections of northwestern Europe. 1: marine band (open marine/*Lingula*), 2: brackish water band (*Geisina*; arenaceous foraminifers), 3: non-marine « coolwater » band (conchostracans), 4: tonstein, 5: first appearance *Anthraconauta phillipsii*, 6: base first maximum *Torispora securis*, 7: base second maximum *Torispora securis*, 8: base common occurrence *Alethopteris grandini*.

brackish water faunas (arenaceous foraminifers and the ostracode *Geisina*) or faunas linked to marine incursions (conchostracans). Geophysical well-logs (notably gamma-ray, sonic logs and resistivity) are very useful as additional tools for the recognition of these widespread horizons (Schuster, 1968). These marine bands generally coincide with maximum flooding surfaces in 4th order sequence stratigraphic schemes (Flint *et al.*, 1995; Süss *et al.*, 2000).

Long-distance correlations in the Westphalian C also depend on tonsteins, altered volcanic ash layers, which act as widespread isochrons (Burger, 1982). Firm tonstein correlations between Germany, Belgium and northern France have become possible through the application of zircon typology (Delcambre, 1987). One tonstein has been traced from Britain (Sub-High Main) to the European mainland (Constance-Erda) by means of geochemical analysis (Spears & Kanaris-Sotirou, 1979: 421). Other tonstein correlations between Britain and the European mainland are based on their relative lithostratigraphic position.

The correlation scheme of marine bands, bands linked to marine incursions and tonsteins is supported by the quantitative distribution pattern of selected fossil taxa, such as the miospore *Torispora securis*, the seed ferns *Alethopteris corsini* and *A. grandini,* and the *adamsii-hindi-productus* non-marine bivalve assemblages. It also emphasises the partly diachronous arrival of the *Torispora securis* epibole assemblages and the non-marine bivalve *Anthraconauta phillipsii*.

The distribution of tonsteins, marine bands and bands presumably related to marine incursions or the proximity of marine conditions in Britain and on the European mainland is summarised in the following chapters. Subsequently, the favoured environmental conditions of some selected fossil taxa will be highlighted. Finally, a palaeogeographic model will show the relationship between major sedimentary regimes in the Westphalian C of western Europe and the influence of major marine incursions on the distribution pattern of incursion-related faunas.

		South Wales	***Pennines***	***Northern France***	***Campine***	***Ruhr***	***Hoya Z1***
WESTPHALIAN C	**late**	∇∇ 11%	∇∇ 4%	∇∇ 30% ↑	∇∇ 32%	∇∇ 30% ↑	
		Geisina					
		Geisina					
		U. Cwmgorse	**Top**	**Patrice**		**Odin**	
	late early	*Geisina*	conchostracans				
		Geisina	conchostracans				
			• Winghay				
			• Winghay	• Patrice	• T1p	• Odin	
			• Winghay	• Nice			
		⇑	⇑	⇑ ∇ 18%			
					Geisina		*Lingula*
		L. Cwngorse	**Shafton**		***Geisina***	**Nibelung**	***Lingula***
	early early	*Geisina*					
			• Top Robins	• Maxence	• T1Gb	• Nibelung	
			• Top Robins	• Maurice	• T1Ga	• Nibelung	
			• Top Robins	• Luce			
		Geisina					
		Five Roads	**Main Estheria**	**Alphonse**	***Geisina***	**Midgard**	**Forams**
					⇑		
		Geisina				Loki?	conchostr
		Foraminifera	**Edmondia**	**Augustin**	***Geisina***	**Kobold**	**conchostr**
				• Laurence	• T3/4		
						⇑	⇑
			• Rowhurst Rider	• Hermance	• T9	• Hagen 1	
			• Rowhurst 2	• Florence	• T10	• Hagen 4	
				• Esperance			
			• High Main	• Durance		∪	
			• Sub High Main	• Constance	• T13	• Erda	
		∪	∪			∪	
		Carway Fawr					
				• Basilic		• Baldur	
		Cefn Coed	**Mansfield**	**Rimbert**	**Maurage**	**Aegir**	

Table 1. Relative stratigraphic position of tonsteins and bands with characteristic faunas related to marine incursions in the lower to early upper Westphalian C of Europe.
Bold: major marine incursion in Northwestern Europe; • tonstein; underlined: tonstein correlation after Delcambre (1987); ∪ *adamsii-hini-productus* non-marine bivalve assemblage after Ramsbottom *et al.* (1978) and Schlepper (1971); ⇑ first appearance of *Anthraconauta phillipsii*; ∇ base first maximum of *Torispora securis* epibole assemblages with maximum % recorded; ∇∇ base second maximum of *Torispora securis* epibole assemblages with maximum % recorded; ↑ base common occurrence of *Alethopteris grandini* after Josten & Laveine (1984).

2. Marine bands and *Torispora* assemblages in Britain

The Westphalian C in Britain contains six marine bands with a wide range of fossils indicating open marine (notably goniatites, productoid brachiopods and the bivalve *Dunbarella*) to nearshore (the brachiopod *Lingula*, conodonts and some arenaceous foraminifers) conditions (Calver, 1968a-b). The complete succession of six marine bands only occurs in South Wales (cf. Bless *et al.*, 1972: Encl. 1; Ramsbottom *et al.*, 1978: Pl. 2-3). They die out or become less well developed in the strongly attenuated sequences at the eastern border of the South Wales basin (Evans *et al.*, 1971: Figs. 31, 33).

Four marine bands extend into the Pennines, where marine faunas become impoverished or even absent in marginal areas (Calver, 1968a: 49-59). Only one band (Skipsey's Marine Band at the base of the Westphalian C) is generally recognised in Scotland, where scarce records of one or two marine bands with a poor fauna higher up in the sequence emphasise the diminished marine influence towards the north (Ramsbottom *et al.*, 1978: Fig. 14).

Lancashire	Yorkshire	Nottinghamshire / Derbyshire	South Staffordshire	North Staffordshire
-----------------------	----------------	**TOP MARINE BAND**	------------------	-----------------------
				Winghay 3
				Winghay 2
				Winghay 1
-----------------------	----------------	**SHAFTON MARINE BAND**	------------------	-----------------------
			Top Robins 3	
			Top Robins 2	
			Top Robins 1	
	--- Main Estheria Band ---			
-----------------------	--------------	**EDMONDIA MARINE BAND**	----------------	-----------------------
			Bottom Robins 3	Rowhurst Rider
			Bottom Robins 2	Rowhurst 2
Worseley Four Foot	Sharlston Top	High Main	Bottom Robins 1	Rowhurst 1
Sub-Worseley Four Foot	Sharlston Muck	Sub-High Main	Supra-Wyrley Yard	Stafford
		adamsii-hindii non-marine bivalve assemblages		
-----------------------	--------------	**MANSFIELD MARINE BAND**	----------------	-----------------------

Table 2. Stratigraphic position of tonsteins in the lower Westphalian C of the Pennine Basin (after Francis, 1969: Fig. 2; Mayland & Williamson, 1970: 1167; Spears & Kanaris-Sotirou, 1979: Fig. 2).

Several horizons in between and above these marine bands have yielded conchostracans and/or the ostracode genus *Geisina*, fossils linked to the times of marine incursion, or to the proximity of marine conditions (Calver, 1968a: 157-158). One of these horizons, the Main Estheria Band of Yorkshire, Nottinghamshire-Derby and perhaps also Canonbie and Durham (cf. Ramsbottom *et al.*, 1978: Pl. 3), is inferred to match the stratigraphic position of the Five Roads Marine Band in South Wales.

Lower Westphalian C tonsteins have only been documented in the Pennines, where they occur in three intervals separated by marine bands (Table 2). The lower interval of four tonsteins occurs below the Edmondia Marine Band. The lowermost Sub-High Main Tonstein has been correlated with the Constance-Erda Tonstein of northern France, the Belgian Campine and the German Ruhr basins (Spears & Kanaris-Sotirou, 1979: 422, Fig. 2).

The middle interval with the three Top Robins tonsteins in between the stratigraphic position of the Main Estheria Band and the Shafton Marine Band is only known from South Staffordshire, whereas the upper interval with the three Winghay tonsteins in between the Shafton Marine Band and the Top Marine Band has only been observed in North Staffordshire.

Beds with the *adamsii-hindi* non-marine bivalve assemblage (also including *Naiadites* ex gr. *productus*; cf. Evans *et al.*, 1971: Fig. 14) occur below the position of the Sub-High Main Tonstein in the Pennines and above the Carway Fawr Marine Band in South Wales (Ramsbottom *et al.*, 1978: Pl. 3). The non-marine bivalve *Anthraconauta phillipsii* appears immediately above the Lower Cwmgorse Marine Band in South Wales (cf. Evans *et al.*, 1971: Fig. 14) and immediately above the Shafton Marine Band in the Pennines (Calver, 1956: Fig. 6).

The base of the epibole (interval wherein a taxon is common - more than 1% of the assemblages - or frequent; cf. Alpern, 1970: 82-85) of the miospore *Torispora securis* occurs some 30 m above the Upper Cwmgorse Marine Band (in the Nantgarw 8 Coal Seam) in South Wales, where the taxon reaches 11% of the miospore assemblage (Butterworth & Smith, 1976: 286). A maximum of 32% has been recorded some 40 m above the position of the Wilbourne (= Upper Cwmgorse) Marine Band in the nearby Bristol area (Butterworth & Smith, 1976: 286). *Torispora* rarely attains proportions of greater than 1% in the Pennines, where maximum values of 1% (some 60 m above the Top Marine Band in North Staffordshire) and 4% (some 100 m above the Top Marine Band in the Corringham borehole near Doncaster, Gainsborough Trough) have been observed (Butterworth & Smith, 1976: 284).

A large tract of the northwestern European paralic coal basin is occupied by the Southern North Sea Carboniferous Basin. No data from the North Sea are included in this study. This reflects the paucity of detailed published work on Westphalian C strata of the North Sea. Regional correlation of marine bands and their equivalents in different depositional environments requires a large data set with many exploration wells. Their stratigraphy has to be studied by combining geochemistry, frequency analysis of facies-sensitive geophysical logs and conventional biostratigraphic techniques, calibrated with recognised marine bands in cores. In the absence of such integrated approach and considering poor seismic resolution in the Carboniferous strata underneath a Permian cover, stratigraphic interpretations in the North Sea area are rather tentative (Besly, 1998: 134). Nevertheless, the facies present in the Southern North Sea Carboniferous Basin are similar to those described on the British onshore; sand-mud distribution patterns in the Westphalian A-B formations also seem to confirm the provenance data obtained from the British onshore coal fields (Rippon, 1996: Fig. 12; Besly, 1998: 123).

3. Marine bands and *Torispora* assemblages on the European mainland

The correlation of the stratigraphic subunits of the Westphalian C on the European mainland is also based on the occurrence of several widespread tonsteins, which have been traced from northern France through the Belgian Campine Basin into the German Ruhr area (Table 1; Delcambre, 1987).

Apart from a single record of a double-layered *Lingula* band in the Hoya borehole (40 km SE of Bremen; Paproth, 1962: 793; Hecht *et al.*, 1962: 1067), no marine fossils have been observed above the Aegir-Maurage-Rimbert Marine Band at the base of the Westphalian C. The stratigraphic position of the British marine bands is frequently occupied, however, by beds with arenaceous foraminifers, the ostracode *Geisina* or conchostracans (Tables 1 and 2).

Conchostracans are irregularly distributed in two or three bands, Kobold, Loki and Midgard, in between the Hagen and Nibelung tonsteins of the Ruhr area. The conchostracans are locally replaced by arenaceous foraminifers in the Midgard Band. The distinction between the Kobold and Loki bands remains problematic, since conchostracans occur either in the Kobold and Midgard bands or in the Loki and Midgard bands within a single section (Fiebig & Groscurth, 1984: 261, Pl. 1-2). The Kobold and Midgard bands have been correlated by means of geophysical well-logs (Schuster, 1968: 447-448) with, respectively, a double-layered conchostracan band and a band with arenaceous foraminifers in the Hoya borehole, and with two conchostracan bands in the Victorbur borehole (20 km NNE of Emden).

The same interval contains two *Geisina* bands (in between the T3/4 and T1Ga/b tonsteins; Figure 2; Table 1) in the Belgian Campine Basin and two conchostracan bands (St. Augustin and St. Alphonse in between the Laurence and Luce tonsteins) in northern France (Bouroz *et al.*, 1964: Fig. 1).

The Nibelung Band (immediately above the presumed position of the Nibelung tonsteins) is usually replaced by coarse-grained to sometimes conglomeratic sandstones in the Ruhr and Ibbenbüren areas. There is only one record of conchostracans in the Ruhr area (Fiebig & Groscurth, 1984: 261, 266, Pl. 1). Elsewhere, however, this horizon is represented by the undoubtedly marine, double-layered *Lingula* band of the Hoya borehole (Schuster, 1968: 447-448), and by a similarly double-layered « marine band » identified on the geophysical well-logs of Victorbur (Schuster, 1968: 447-448), Itterbeck-Halle 7 (Schuster, 1968: Fig. 17), Norddeutschland 8 (Hedemann *et al.*, 1984: Fig. 9) and Rehden 21 (Hedemann *et al.*, 1984: Fig. 9).

This double-layered « marine band » is matched by a double-layered *Geisina* band above the T1Gb tonstein in the Campine Basin (Figure 2, Table 1). No fossils have been recorded, however, from the (sandy) beds above the Maxence Tonstein in northern France.

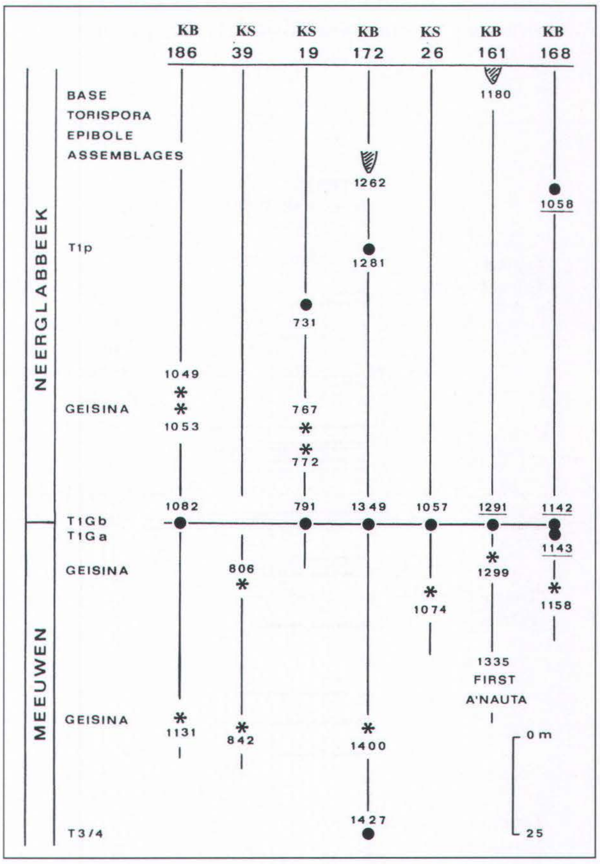


Figure 2. Stratigraphic position of tonsteins (black dots) and *Geisina* bands (asterisks) in the lower to early upper Westphalian C of the Belgian Campine area (Dusar, 1989; Dusar *et al.*, 1986 and 1987; unpublished data). The first appearance of *Anthraconauta phillipsii* (A'nauta) and the base of *Torispora* epibole assemblages are also shown. Depths in metres. Underlined depths refer to tonstein horizons recorded by Delcambre (1987: 131).

The poorly developed Odin Band (presumably on top of the stratigraphic position of the Odin Tonstein) of the Ruhr area (with a single record of arenaceous foraminifers and a single record of conchostracans; Fiebig & Groscurth, 1984: 262, Pl. 1) has no counterpart in the Campine Basin. It is correlated here, however, with the conchostracan band on top of the Patrice Tonstein in northern France (Bouroz *et al.*, 1964: Fig. 13-14).

Local records of arenaceous foraminifers, conchostracans and the marine ichnofossil *Planolites ophthalmoides* from higher horizons (Parsifal, Rübezahl, Siegfried and Tristan bands) in the upper Westphalian C of the Ruhr area (cf. Fiebig & Groscurth, 1984: 262-265, Pl. 1-2) and the Westphalian D of the Piesberg area (Knauff *et al.*, 1971) may be correlated in the future with conchostracan and *Geisina* bands in northern France, the Netherlands and Britain, or with marine faunas of Westphalian D age to the west of Ireland (Tate & Dobson, 1989). They are not considered further here.

The *productus-hindi* non-marine assemblage (the presumed counterpart of the *adamsii-hindi* assemblage with *Naiadites* ex gr. *productus* in Britain) locally occurs above the Chriemhilt (below the Erda Tonstein) and Freya (in between the Erda and Hagen tonsteins) coal seams of the Ruhr area (Schlepper, 1971: 24). This assemblage has not been recognised in the Campine Basin or northern France.

The appearance of the non-marine bivalve *Anthraconauta phillipsii* is clearly diachronous. This species appears slightly above the Hagen tonsteins in the Ruhr area (Schlepper, 1971: 25-29) and at a comparable stratigraphic position in the Hoya borehole (Paproth, 1962: 792-793). The first specimens in the Campine Basin occur somewhere in between the stratigraphic position of the two *Geisina* bands, in between the T3/4 and T1Ga/b tonsteins (Figure 2; Dusar *et al.*, 1986: 62). The species only appears above the Maxence Tonstein (on top of coal seam « 21 » in the Bruay section) in northern France (Bouroz *et al.*, 1964: Fig. 13; Bouroz *et al.*, 1969: 101).

The base of the epibole of the miospore *Torispora securis* is also clearly diachronous. The taxon reaches 5% abundance in the first coal seam (coal seam « 21 » of Bruay) above the Maxence Tonstein in northern France, and varies between 2 and 18% (mean: 12%) in the overlying

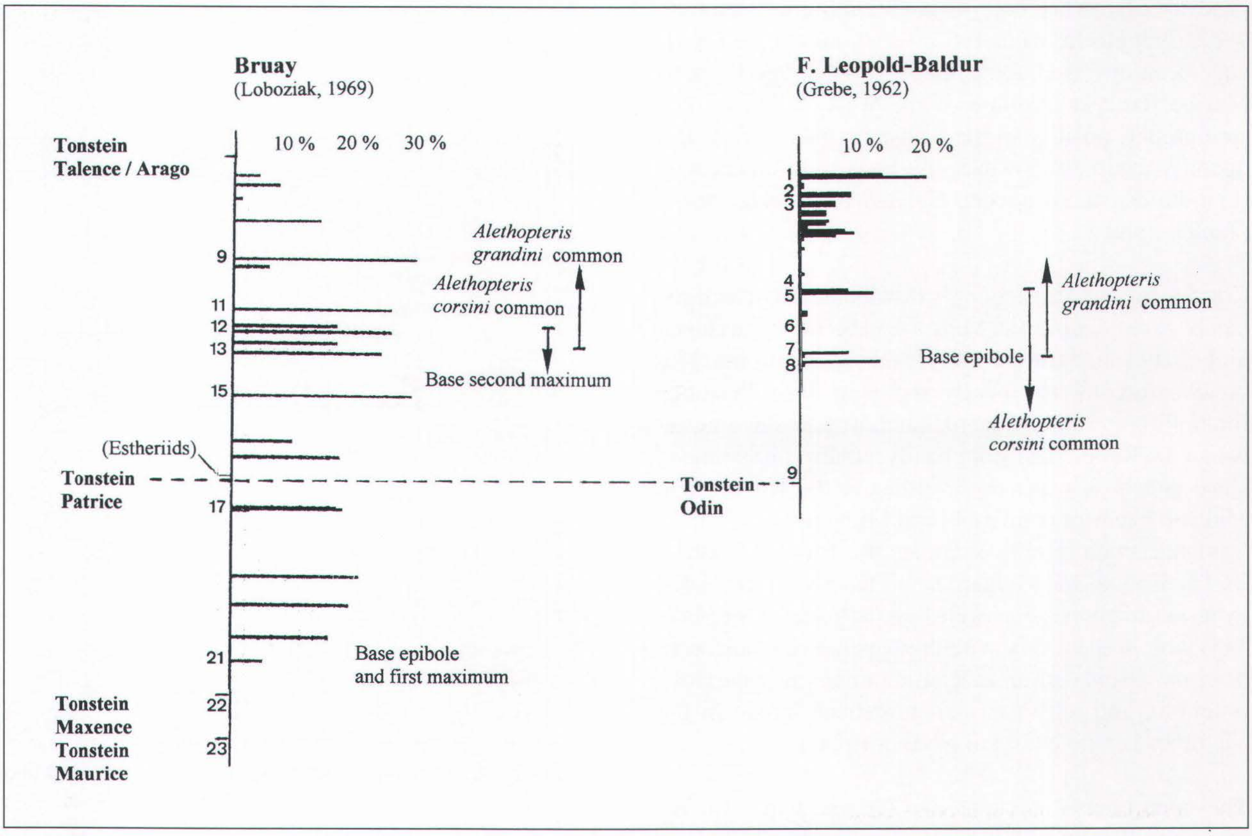


Figure 3. Quantitative distribution of *Torispora securis* in the lower to early upper Westphalian C of northern France (Bruay section; Loboziak, 1969: Tables O, R) and the Ruhr area (Borehole Abt. 04, 2.S., Fürst Leopold-Baldur; Grebe, 1962: Table 1; for stratigraphic calibration of section see Fiebig & Groscurth, 1984: Table 1), compared with the top of the common occurrence of *Alethopteris corsini* and the base of the common occurrence of *Alethopteris grandini* in the same areas (Josten & Laveine, 1984: 98-101, Fig. 4, Table 1). The stratigraphic position of the Patrice and Odin tonsteins is used here as datum line.

seams (Figure 3; Loboziak, 1969: Tables O, R). This percentage suddenly increases to values between 5 and 30% (mean 18%) some 60 m above the Patrice Tonstein. The base of this second maximum in coal seam « 15 » presumably matches the base of the epibole in the Campine Basin (some 20 m above the T1p Tonstein; Dusar *et al.*, 1987: 142, 175-176), where *Torispora* reaches 10% (Somers, 1971: 402), and in the Ruhr area (some 40 m above the Odin Band; Figure 3; Grebe, 1962: Table 1).

The correlation between the base of the epibole of *Torispora* in the Ruhr area and the base of its second maximum in northern France is supported by the distribution pattern of the seed ferns *Alethopteris corsini* and *A. grandini* (Josten & Laveine, 1984: 98-101, Figure 4, Table 1). The top of the interval, wherein *A. corsini* is common, is situated some 110 m above the Patrice Tonstein in northern France and some 90 m above the Odin Band in the Ruhr area (Figure 3). The base of the interval, wherein *A. grandini* is common, occurs some 85 m above the Patrice Tonstein in northern France and some 40 m above the Odin Band in the Ruhr area (Figure 3).

4. Palaeoecological conditions

In contrast to the laterally extensive Mansfield-Aegir Marine Band, the higher, geographically more restricted marine bands in the Westphalian C sequence are generally considered to « represent short-lived marine to brackish incursions across an 'upper delta plain' rather than the re-establishment of lower delta plain conditions» (Guion *et al.*, 1995: 51). This model is tested here by means of a detailed analysis of the distribution pattern of some selected marine, brackish water and non-marine faunas. They provide a useful tool to the understanding of the overall palaeogeography at the acme of a marine incursion. Five major faunal assemblages are briefly described. Moreover, the partly diachronous distribution of epibole assemblages of the miospore *Torispora* provides valuable gross information about the nature of the Westphalian C landscape that was invaded by the marine incursions.

4.1. Faunal assemblages related to marine incursions

Open marine faunas include goniatites, productoid brachiopods, marine bivalves and gastropods, crinoids, sponges, fishes, conodonts, endothyrid foraminifers and marine ostracodes. They occur in a wide variety of marine offshore deposits (Calver, 1968a-b).

***Lingula* faunas** are sometimes associated with arenaceous foraminifers and conodonts. Like its modern representatives, the inarticulate brachiopod *Lingula* occurred preferentially in low-energy, nearshore conditions, such as tidal flats to shallow subtidal (30-40 m) mud-flats (Craig, 1952).

Arenaceous foram assemblages « are remarkably similar to those occurring in modern coastal wetlands » (Wightman *et al.*, 1994: 200-201). The monotonous faunas consist of only one or a few species or genera of agglutinated, arenaceous foraminifers. They preferentially occur in argillaceous, greyish shales and are rare or absent in highly carbonaceous shales (Calver, 1968a: 166). They possibly preferred a wide range of brackish (frequently oligotrophic) conditions in interdistributary bays, estuaries or salt-marshes in the coastal wetlands (cf. Steineck & Bergstein, 1979; Wightman *et al.*, 1994).

***Geisina* faunas**. The filter-feeding ostracode *Geisina* preferentially occurred without other fossils or was associated with monotonous « non-marine » bivalve assemblages in black « bituminous », canneloid or carbonaceous shales, sometimes with some pyrite and/or calcareous shell material (Pollard, 1966: 668-677; Calver, 1968a: 152, 154, 156; Eagar, 1974: 224; Paproth, 1978: 98). Increased boron contents of the shales (Ernst, 1963), occasional preservation of calcareous shell material and organic-rich shales point to brackish, eutrophic ponds, which formed on the « extensive floodplain of a delta complex which was occasionally breached by the sea to allow the brackish [ostracode/bivalve] faunas to flourish for brief periods » (Barclay *et al.*, 1994: 377), or developed on « broad, very low gradient floodplains, seasonally covered by shallow lakes or marshes. Broad transition zones of this type are found in some seasonal wetland coastal plains at the present time such as the Kakadu of northern Australia. If seasonal onshore winds correspond to periods of flooding on the floodplains, very extensive transition zones, of brackish character, could develop and extend for tens of kilometres or more inland » (Wright & Marriott, 1996: 91).

Conchostracan faunas, including Estheriids and Leaiids, occur « in a variety of sediments, but are most abundant in canneloid or carbonaceous shales » (Calver, 1968a: 157). The commonly decalcified carapaces frequently reach bloom proportions in discrete beds within undoubtedly non-marine, upper Westphalian C to Permian successions (cf. Warth, 1963; Calver, 1968a; Weingardt, 1976; Kozur & Sittig, 1981; Martens, 1987). This « conflicts with the concept of a brackish water habitat that is closely linked to a marine environment » (Calver, 1968a: 158). Most likely they were non-marine organisms thriving in lacustrine environments (lakes), although they were « not part of the endemic fauna of the swamps » (Defrise-Gussenhoven & Pastiels, 1957: 57; Calver, 1968a: 158). Their characteristic presence in beds associated with major marine incursions or in beds « immediately preceding or following a marine incursion » (Calver, 1968a: 157-158) may have been caused by climatic events, such as exceptional cold spells, which were related to or induced by the marine ingressions. Perhaps the pollen-sized conchostracan eggs were introduced into the temporarily cooled waters of lakes within the tropical/subtropical belt by exceptional winds (cf. Warth, 1963: 8) blowing from higher latitudes at the onset of glacially-driven eustatic sea level changes (cf. Klein & Kupperman, 1992; DiMichele *et al.*, 1996). Increasing water temperature would have killed the conchostracans a few weeks or a few months later. The conchostracan faunas are therefore believed to represent temporarily cool water lake environments.

Non-marine bivalve faunas, in the Westphalian C only include Myalinid bivalves assigned to the genera *Anthraconaia*, *Curvirimula*, *Naiadites* and *Anthraconauta*, which presumably occurred in a wide range of fluvio-deltaic freshwater and brackish water environments (Calver, 1968a: 150-156, Fig. 2). They have not been incorporated in the present study, since the data from several areas on the European mainland may need revision.

4.2. Torispora epibole assemblages

Except for their greater length and the presence of the crassitude, the specimens of *Torispora securis*, found at the periphery of the Marattialean *Scolecopteris dispora* synangia (Lesnikowska & Willard, 1997), are identical to the interior spores which have been assigned to *Laevigatosporites globosus*. The second miospore species first occurs as *sporae dispersae* much earlier in the stratigraphic record than the first one. As the first occurrence of *Torispora* is known « worldwide » within the Westphalian C, we assume that the capacity of *Scolecopteris* to produce crassitate spores at the periphery of their synangia does represent a step in the evolution of this taxon rather than some local adaptation to ecological conditions.

Apart from the Pennines, where the species is extremely rare (one record of 1% and another of 4%; Butterworth & Smith, 1976: 284), the miospore *Torispora* is frequently common to occasionally abundant in late lower to upper Westphalian C coal seams, as emphasised by data from the Ruhr area (up to 26%; Grebe, 1962: 777, 781), Campine Basin (up to 10%; Somers, 1971: 402), northern France (up to 30%; Loboziak, 1969: Table O-P), Bristol area (up to 32%) and South Wales (up to 11%; Butterworth & Smith, 1976: 286). The species may be rare or virtually absent in shales of the same age, as emphasised by data from northern France (Coquel, 1974: Table S) and the southeastern Netherlands (Van de Laar & Fermont, 1990: 39-40, Encl. 1-3).

Torispora was also rare or virtually absent in shales from the upper Westphalian C of the Campine Basin. Only three of 111 shale samples have yielded values of more than 3% *Torispora*. One of these (9.8% *Torispora* in KB169 at 1231.25 m ; Streel, unpublished data) presumably corresponds to the late lower Westphalian C, whereas the other two (6.0% and 31.8% in KB172 at, respectively 978.30 m and 1069.00 m ; Streel, unpublished data) represent the upper Westphalian C. These extremely high percentages of *Torispora* point to an exceptional, local admixture of the spores, perhaps by the abnormal occurrence of some *Torispora* producing tree ferns near the border of the lake where the enclosing silty-clayey sediment accumulated.

The *Torispora* producing Pecopterid tree ferns (cf. Laveine, 1970; Lesnikowska & Willard, 1997) presumably favoured mineral-poor, ombrogenous, raised mire conditions, similar to those preferred by tree ferns producing the spore *Thymospora* (Mahaffy, 1988: 253-255), above the reach of (frequent) fluvial flooding. In Maritime Canada, Lyons *et al.* (1997: 45) observed that an upward increase of tree-fern spores in a coal seam was coupled with a substantial decrease in ash content (from 30 - 47% ash in the lower part to 11 - 19% ash in the upper part).

Such conditions may have been more frequently achieved in thick, clean and extensive peat within the upper alluvial plain system than in thin, impure and discontinuous peat within the lower alluvial plain system (Dreesen *et al.*, 1995: 229, Fig. 9). *Torispora* epibole assemblages are therefore believed to represent raised mire conditions, without frequent inundation of the swamps.

Figure 4. Distribution of open marine faunas (m) at the acme of the Mansfield-Aegir marine incursion in northwestern Europe. Key for figures 4 to 11: e: conchostracans, f: arenaceous foraminifers, g: *Geisina*, L: *Lingula*, m: open marine fauna, o: no characteristic faunas. 1: Grampian High, 2: Wales Massif, 3: London-Brabant Massif, 4: Variscan belt, 5: East European Platform. A: South Wales, B: Pennines, C: Northern France, D: Campine Basin, E: Ruhr area. Boreholes: Co: Corringham (Butterworth, 1976), KB: Campine Basin 168-169-172 between eastern Campine coalfield and Rur Valley Graben (Dusar *et al.*, 1987), H: Hoya (Hecht, 1962), V: Victorbur (Schuster, 1968). Question marks in Denmark refer to as yet poorly understood connection with Oslo Graben (cf. Bergström *et al.*, 1985).

Figure 5. Strongly simplified and idealised distribution of major fluvio-deltaic depositional environments in northwestern Europe during the early lower Westphalian C (partly based on Lindert, 1994: 247; Flint *et al.*, 1995: Fig. 7; Guion *et al.*, 1995: 51; Dreesen *et al.*, 1995: Fig. 12; Kockel, 1995: 15). a: upper delta plain, b: alluvial red bed facies, c: lower alluvial plain with anastomosed river systems and frequent lakes.

Figure 6. Distribution of characteristic faunas at the acme of the Edmondia-Kobold marine incursion in northwestern Europe. Key as for Figure 4.

Figure 7. Distribution of characteristic faunas at the acme of the Five Roads-Midgard marine incursion in northwestern Europe. Key as for Figure 4

Figure 4

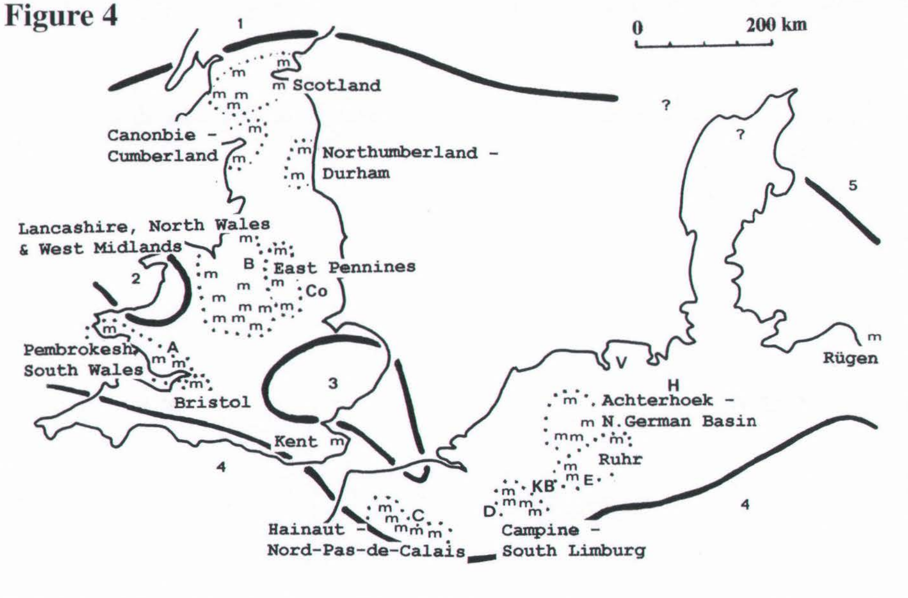


Figure 5

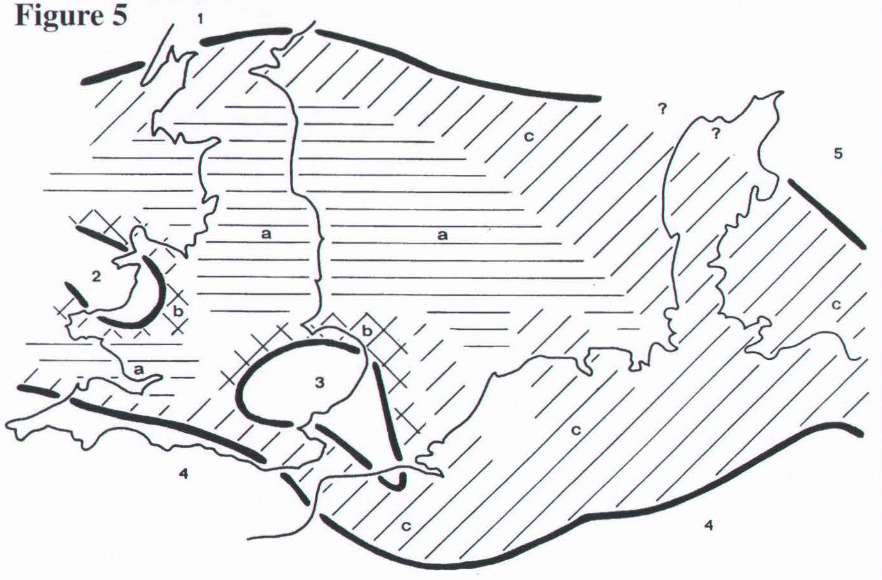


Figure 6

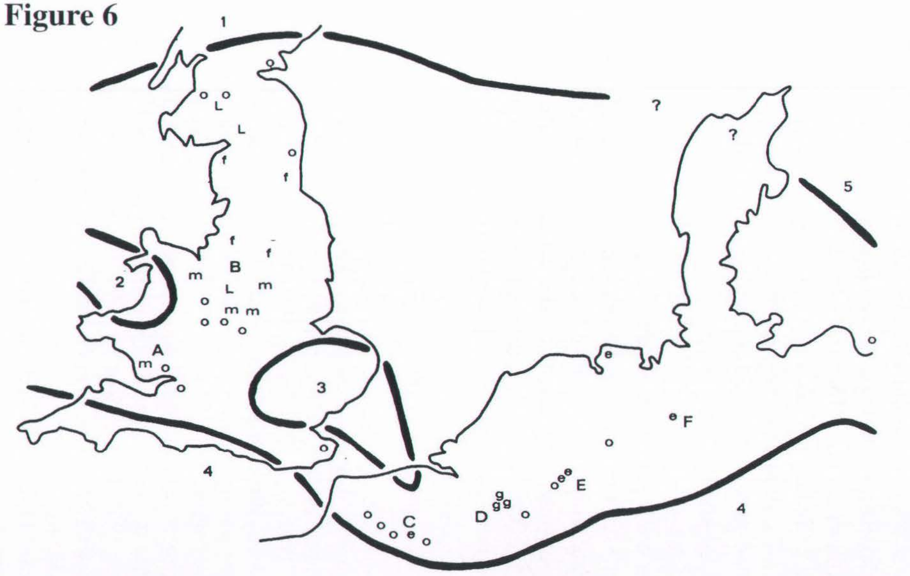
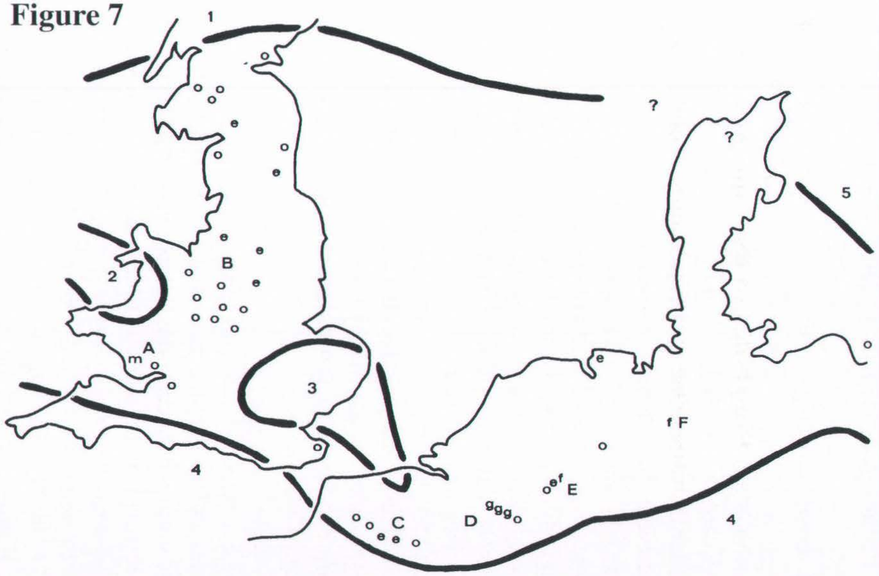


Figure 7



5. Palaeogeographic implications

5.1. Landscape successions

Northwestern Europe turned into a vast fluvio-deltaic landscape during the first half of the lower Westphalian C after the withdrawal of the sea at the end of the major Mansfield-Aegir marine incursion (Figure 4). Upper delta plain and alluvial red bed facies characterised the British lowlands to the north and to the south of the Wales and Anglo-Brabant massifs (Flint *et al.*, 1995: Fig. 7; Guion *et al.*, 1995: 51), whereas (lower) alluvial plains with an intricate network of downstream-branching, anastomosed rivers and lakes dominated the European mainland (Figure 5; Dreesen *et al.*, 1995: Fig. 12; Lindert, 1994: 247). This geographic distribution of major depositional areas was hardly affected by the ephemeral Carway Fawr marine incursion in South Wales (Table 1; Ramsbottom *et al.*, 1978: Pl. 3).

The sea extended across the upper delta plains of South Wales and the Pennines and perhaps some parts of Scotland during the succeeding Edmondia-Kobold incursion as testified by the open marine and *Lingula* faunas in these areas (Figure 6), but presumably never reached Bristol and Kent (Calver, 1968b: 51-53; Ramsbottom *et al.*, 1978: Pl. 3, Fig. 14). The impact of this incursion on the European mainland was limited to some brackish water (*Geisina*) faunas in the Campine Basin (Figure 2) and presumed cool water conchostracan assemblages in northern France (Bouroz *et al.*, 1964: Fig. 1) and Germany (Schuster, 1968: Fig. 16; Fiebig & Groscurth, 1984: Pl. 1-2). Brackish water *Geisina* faunas were also established in South Wales immediately after the retreat of the Edmondia-Kobold Sea.

The sea remained in South Wales during the less important Five Roads-Midgard incursion (Table 1, Figure 7). Brackish water conditions became locally established on the European mainland as illustrated by *Geisina* faunas in the Campine Basin (Figure 3), and arenaceous foraminifers in the Hoya borehole (Schuster, 1968: Fig. 16) and in some places of the Ruhr area (Fiebig & Groscurth, 1984: Pl. 2). Cool water conchostracan faunas occurred in the Pennines (Main Estheria Band; Table 1), at some localities in the Ruhr area (Fiebig & Groscurth, 1984: Pl. 1-2), at Victorbur (Schuster, 1968: Fig. 16), and in northern France (Bouroz *et al.*, 1964: Fig. 1). Brackish water *Geisina* faunas again occurred in South Wales immediately after the end of the Five Roads-Midgard incursion.

During the second half of the lower Westphalian C and the beginning of the upper Westphalian C the upper delta plain facies persisted in the Pennines (Flint *et al.*, 1995: Fig. 7; Guion *et al.*, 1995: Fig. 4). On the European mainland, however, upper alluvial plains gradually replaced the lower alluvial plains (Dreesen *et al.*, 1995: Fig. 12). Increasing sand content and steeper hydraulic gradients for predominantly north-flowing rivers are probably related to crustal shortening and uplift of the advancing Variscan chain to the south (Bless *et al.*, 1977; Paproth *et al.*, 1996). This shift from lower to upper alluvial plains is closely matched by the diachronic appearance of *Torispora* epibole assemblages.

The distribution pattern of *Torispora* epibole assemblages (Figure 3) suggests that raised bogs first occurred in northern France during the second half of the lower Westphalian C (Figure 8). Slightly after the beginning of the upper Westphalian C, this environment was also developed elsewhere (Figure 9) as illustrated by the repeated occurrence of *Torispora* epibole assemblages in the Ruhr area (Figure 3; Grebe, 1962: Table 1), and also – but less frequently according to the only occasionally high percentages of *Torispora* - in the Campine Basin (Somers, 1971: 402 ; Streel, unpublished data, this paper) and in Southern Britain (South Wales and Bristol ; Butterworth & Smith, 1976: 286). The meagre record of *Torispora* epibole assemblages in the upper Westphalian C of the Pennines (only two records of, respectively, 1% and 4%; Butterworth & Smith, 1976: 284) supports the interpretation of persistent upper delta plain facies in that area (Flint *et al.*, 1995: Fig. 7; Guion *et al.*, 1995: Fig. 4).

Figure 8. Strongly simplified and idealised distribution of major fluvio-deltaic depositional environments in northwestern Europe during the late lower Westphalian C (partly based on Lindert, 1994: 247; Flint *et al.*, 1995: Fig. 7; Guion *et al.*, 1995: 51; Dreesen *et al.*, 1995: Fig. 12; Kockel, 1995: 15). a: upper delta plain, b: alluvial red bed facies, c: lower alluvial plain with low-gradient anastomosed river systems, a lacustrine floodplain with thin discontinuous coals developed in frequently inundating rheotrophic mires and frequent lakes, d: upper alluvial plain with high-gradient channel belts and thick pure coals developed in ombotrophic, raised mires.

Figure 9. Strongly simplified and idealised distribution of major fluvio-deltaic depositional environments in northwestern Europe during the early upper Westphalian C (partly based on Lindert, 1994: 247; Flint *et al.*, 1995: Fig. 7; Guion *et al.*, 1995: 51; Dreesen *et al.*, 1995: Fig. 12; Kockel, 1995: 15). Key as for Figure 8.

Fig. 10. Distribution of characteristic faunas at the acme of the Shafton-Nibelung marine incursion in northwestern Europe. Key as for Figure 4.

Figure 11. Distribution of characteristic faunas at the acme of the Top-Odin marine incursion in northwestern Europe. Key as for Figure 4.

Figure 8

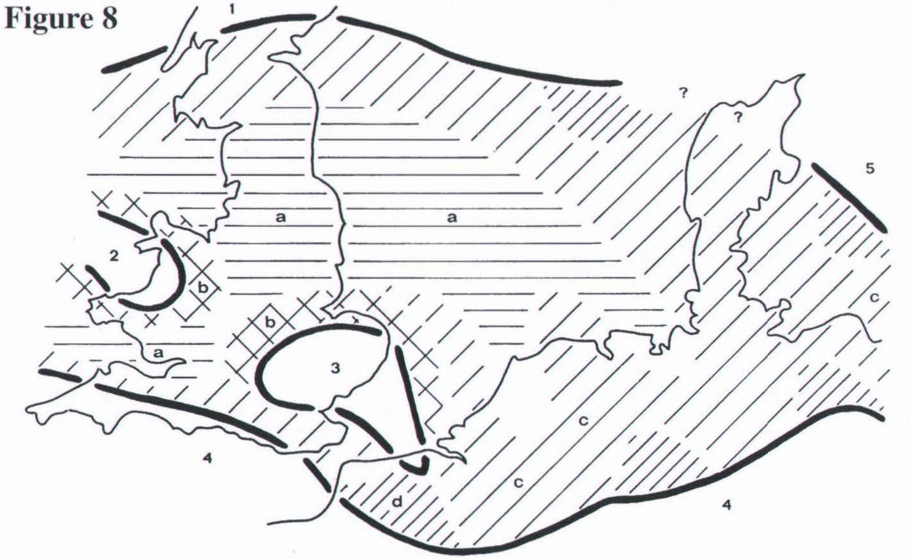


Figure 9

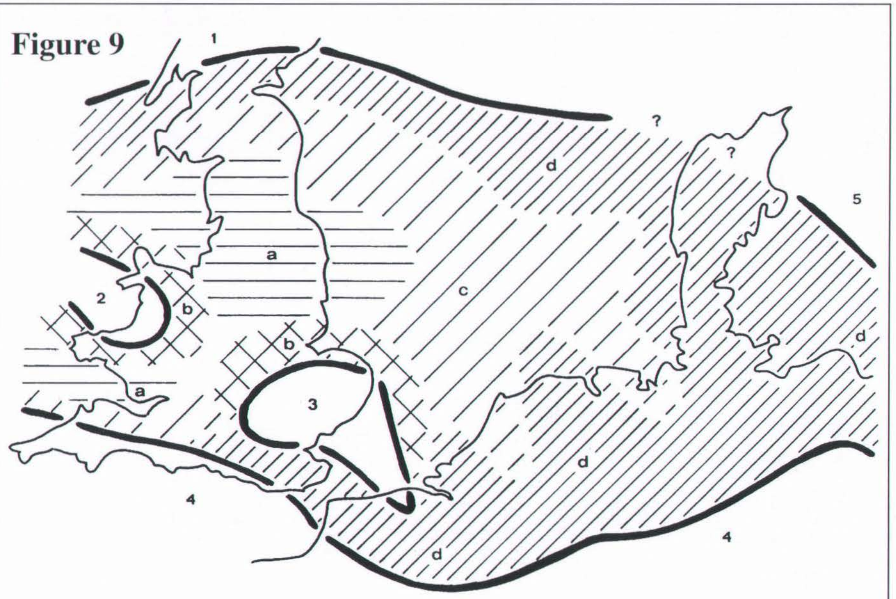


Figure 10

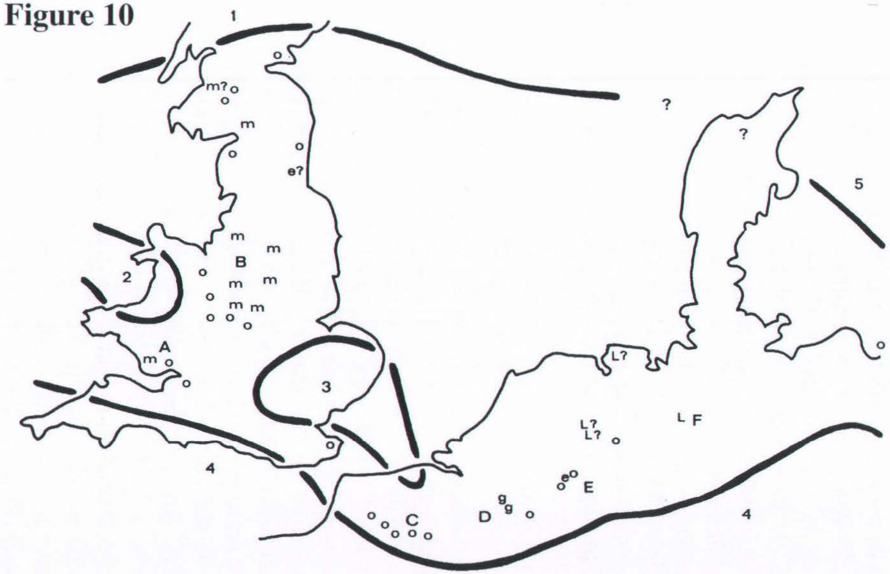
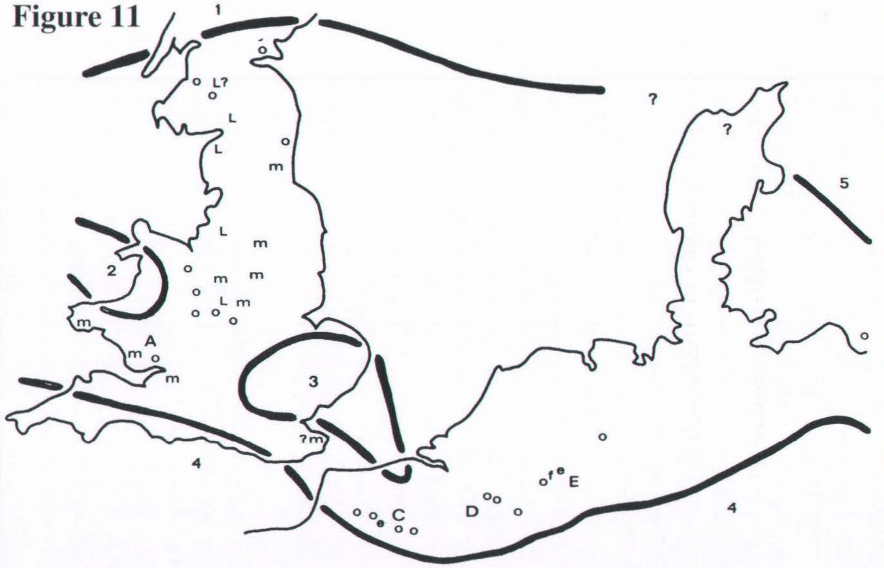


Figure 11



The Shafton-Nibelung marine incursion at the onset of the late lower Westphalian C (Figure 10) must have been more important than the preceding Five Roads-Midgard incursion. Open marine faunas occur in South Wales and the Pennines, and at some places in Scotland (Ramsbottom *et al.*, 1978: Pl. 3, Fig. 14), whereas *Lingula* assemblages have been reported from the German Hoya borehole (Schuster, 1968: Fig. 16). The presence of *Lingula* at Hoya may indicate a (temporary) eastern extension of the British upper delta plain environment (if the sea only flooded the upper delta; cf. Guion *et al.*, 1995: 51), an exceptionally low-lying lower alluvial plain, or rather a transitional zone between these major facies zones. The same holds perhaps for the Campine Basin, where brackish water *Geisina* faunas have been observed once more (Figure 3). There is only one record of conchostracans from the Ruhr area (Fiebig & Groscurth, 1984: Pl. 1-2). No characteristic faunas have been mentioned from northern France.

The Top-Odin marine incursion at the beginning of the upper Westphalian C was the last one leaving a widespread marine band with a rich and diverse fauna in South Wales, Bristol and the Pennines (Figure 11; see also Calver, 1969: Fig. 14). This incursion only left a single record of a local salt marsh (arenaceous foraminifers) environment and a single occurrence of cool water conchostracans in the Ruhr area (Fiebig & Groscurth, 1984: Pl. 1). Conchostracans have also been observed above the Patrice tonstein in northern France (Bouroz *et al.*, 1964: Fig. 13-14). No characteristic faunas are known from the Campine Basin. The scarcity of recorded faunas on the European mainland at this time may be related to the rapidly expanding high-gradient braided fluvial channel belts and stable mires, wherein lakes were less common than on the lower alluvial plain (cf. Dreesen *et al.*, 1995: Fig. 12). The Top-Odin incursion was also preceded and followed by several beds with *Geisina* or conchostracans in South Wales and the Pennines.

5.2. Tectonic control

The palaeogeographic evolution of the northwestern European paralic basin during the Westphalian C shows a gradual increase in the number and extent of upper alluvial plain systems, especially along the southern and eastern margins of the basin (facies "d" on Figures 5, 8-9). This suggests that major sediment transport routes derived from the advancing and uplifting Variscan orogenic belt replaced earlier fluvial systems supplying sediments from other, more distant or less active sourcelands. Sediment provenance and palaeocurrent studies in Westphalian C (or Bolsovian) sandstones of the Pennine basin indeed show that sediments from the Variscan orogenic belt were supplied by a fluvial system flowing from the south and southeast (Hallsworth & Chisholm, 2000). Previous fluvial systems transported sediments from a northern provenance during the Namurian to Westphalian A (or Langsettian), progressively replaced by a westerly derived system which predominated during the upper Westphalian A and the major part of the Westphalian B (or Duckmantian) (Glover *et al.*, 1996; Rippon, 1996). The transition to the E-SE-oriented fluvial system occurred abruptly with the Woolley Edge sandstone, above the Maltby Marine band in the late Westphalian B (Hallsworth & Chisholm, 2000: Fig. 8). Similar provenance and paleocurrent results were obtained for Westphalian D sandstones of the Campine Basin (Dusar *et al.*, 1987). The abrupt change in provenance during the late Westphalian B is probably linked to tectonic events in the Variscan chain to the south. Thus the Variscan orogeny apparently steered palaeoclimate changes and controlled changes in depositional environment in the Variscan Foreland (Bless *et al.*, 1984: 193; Besly, 1998: 110).

Inside the paralic basin subparallel east-west oriented drainage systems may have recurred, terminating in lacustrine deltas without connection to the sea. However, these large channels may have provided pathways for marine incursions into the Variscan Foreland, forced in east-west directions by the emerging Variscan mountain chain to the south (Rippon, 1996: 896).

6. Palaeoenvironmental conclusions

The observations discussed above have been synthesised in a palaeogeographic model showing the relationship between the major sedimentary facies zones and the influence of the marine incursions on the distribution of incursion-related faunas (Figure 12).

There is a close correlation between the distribution of beds with marine (open marine/*Lingula*) faunas and the distribution of upper delta plain environments in the Westphalian C of northwestern Europe, as already suggested by Guion *et al.* (1995: 51). The frequent succession of transgressive-regressive faunal phases in these beds suggests that the sea stayed here for a significant period during each marine incursion, so that these incursions cannot be regarded as some kind of catastrophic « flash floods ».

The recurrent presence of *Geisina* or conchostracans in beds immediately preceding or following a marine incursion within the Westphalian C upper delta plain sequences of Britain suggests that marine incursions in Britain were at least sometimes heralded by or followed by the (local) development of brackish water (*Geisina*) or cool water (conchostracans) conditions. This gradual appearance and disappearance of the « proximity of marine conditions » (cf. Calver, 1968a: 158) emphasises that these marine incursions cannot be regarded as sudden events.

	Upper delta plain	**Lower alluvial plain**	**Upper alluvial plain**
Major sedimentary regime	meandering rivers and oxbow lakes in extensive swamps	anastomosed rivers in rapidly changing landscape of shortlived lakes and swamps of limited lateral extent	major channel belts crossing extensive raised bogs with tree ferns producing *Torispora* epibole assemblages
Major marine incursion	**Major marine incursion** completely flooded by sea for longer periods as indicated by one or several transgressive-regressive faunal successions in marine bands	short-lived brackish-water environments develop in pre-existing lakes; - eutrophic conditions: *Geisina* as bottom dweller and 'non-marine' bivalves in upper freshwater levels - oligotrophic conditions: arenaceous forams in 'lower salt marsh'	- short-lived upper salt marsh conditions in pre-existing lakes are favoured by arenaceous forams - short-lived 'cool water' conditions in pre-existing lakes; severe cold spells are caused by exceptional winds blowing from higher latitudes during marine incursion, reflected by conchostracean bloom

Figure 12. Palaeogeographic model correlating the distribution of incursion-related faunas across major sedimentary facies belts in the Westphalian C of western Europe during the acme of marine incursion.

The « proximity of marine conditions » presumably resulted in the development of brackish water (*Geisina* and arenaceous foraminifers) and non-marine « cool water » (conchostracans) facies in pre-existing lakes in the fluvio-deltaic environment. These lakes were more abundant on the delta plain and on the lower alluvial plain with low-gradient anastomosed river systems than on the upper alluvial plain with high-gradient braided channels (cf. Dreesen *et al.*, 1995; Rippon, 1996: Fig. 3). This might explain the relative frequency of brackish water and «cool water » faunas in the lower alluvial plain sequences on the European mainland.

The possibly short-lived brackish-water faunas may have been introduced in these lakes by occasional (seasonal) onshore winds during the marine incursion (Barclay *et al.,* 1994; Wright & Marriott, 1996).

7. Acknowledgements

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8. References

ALPERN, B., 1970. Notes sur les concepts d'espèce et de biozone. *In*: Streel, M. & Wagner, R.H. (eds.), *Colloque sur la stratigraphie du Carbonifère*. Congrès et Colloques de l'Université de Liège, 55: 81-89.

BARCLAY, W.J., RATHBONE, P.A., WHITE, D.E. & RICHARDSON, J.B., 1994. Brackish water faunas from the St Maughans Formation: the Old Red Sandstone section at Ammons Hill, Hereford and Worcester, UK re-examined. *Geological Journal*, 29: 369-379.

BERGSTRÖM, J., BLESS, M.J.M., & PAPROTH, E., 1985. The marine Knabberud Limestone in the Oslo Graben: possible implications for the model of Silesian paleogeography. *Zeitschrift des deutschen geologischen Gesellschaft*, 136: 181-194.

BESLEY, B.M., 1998. Carboniferous. *In*: Glennie, K.W. (ed.), *Introduction to the petroleum geology of the North Sea* (4th edition). Blackwell, Oxford: 104-136.

BLESS, M.J.M., BOUCKAERT, J., CALVER, M.A., GRAULICH, J.M. & PAPROTH, E., 1977. Paleogeography of Upper Westphalian deposits in NW Europe with reference to the Westphalian C North of the mobile Variscan belt. *Mededelingen Rijks Geologische Dienst, N. S.* 28: 101-127.

BLESS, M.J.M., BOUCKAERT, J. & PAPROTH, E., 1984. Migration of facies belts as a response to continental drift during the Late Devonian and Carboniferous. *Bulletin de la Société belge de Géologie*, 93: 189-195.

BLESS, M.J.M., CALVER, M.A. & JOSTEN, K.H., 1972. Report of the working group on the Westphalian C in N.W. Europe. *C. R. 7me Congrès International de Stratigraphie et de Géologie du Carbonifère, Krefeld 1971*, 1: 223-230.

BLESS, M.J.M., PAPROTH, E. & WOLF, M., 1981. Interdependence of basin development and coal formation in the West European Carboniferous. *Bulletin Centres de Recherche Exploration-Production Elf-Aquitaine*, 5, 2: 535-553.

BOUROZ, A., BUISINE, M., CHALARD, J., DALINVAL, A. & DOLLÉ, P., 1964. Bassin houiller du Nord et du Pas-de-Calais. *C. R. 5me Congrès International de Stratigraphie et de Géologie du Carbonifère, Paris 1963*, 1: 3-33.

BOUROZ, A., CHALARD, J., CORSIN, P. & LAVEINE, J.J., 1969. Le stratotype du Westphalien C dans le bassin houiller du Nord et du Pas-de-Calais: limites et contenu paléontologique. *C. R. 6me Congrès International de Stratigraphie et de Géologie du Carbonifère, Sheffield 1967*, 1: 99-105.

BURGER, K., 1982. Kohlentonsteine als Zeitmarken, ihre Verbreitung und ihre Bedeutung für die Exploration und Exploitation von Kohlenlagerstätten. *Zeitschrift des deutschen geologischen Gesellschaft*, 133: 201-255.

BUTTERWORTH, M.A. & SMITH, A.H.V., 1976. The age of the British Upper Coal Measures with reference to their miospore content. *Review of Palaeobotany and Palynology*, 22: 281-306.

CALVER, M.A., 1956. Die stratigraphische Verbreitung der nicht-marinen Muscheln in den penninischen Kohlenfeldern Englands. *Zeitschrift des deutschen geologischen Gesellschaft*, 107: 26-39.

CALVER, M.A., 1968a. Coal Measures Invertebrate Faunas. *In*: Murchison, D.G. & Westoll, T.S. (eds.), *Coal and Coal-bearing Strata*, Oliver & Boyd, Edinburgh: 147-177.

CALVER, M.A., 1968b: Distribution of Westphalian marine faunas in northern England and adjoining areas. *Proceedings of the Yorkshire Geological Society*, 37: 1-72.

COQUEL, R., 1974. Etude palynologique de la série houillère dans l'unité de production de Valenciennes du bassin houiller du Nord de la France. Thèse de l'Université des Sciences et Techniques de Lille: 295 p.

CRAIG, T., 1952. Comparative study of the ecology and palaeoecology of *Lingula*. *Edinburgh Geological Society Transactions*, 15: 110-120.

DEFRISE-GUSSENHOVEN, E. & PASTIELS, A., 1957. Contribution à l'étude biométrique des Lioestheriidae du Westphalien supérieur. *Publications de l'Association pour l'Etude de la Paléontologie et de la Stratigraphie Houillères*, 31 (1): 71 p.

DELCAMBRE, B., 1987. Application de la typologie du zircon à la tephrostratigraphie du Westphalien C de la Belgique et des régions limitrophes. *Bulletin de la Société belge de Géologie*, 96: 129-136.

DIMICHELE, W.A., PFEFFERKORN, H.W. & PHILLIPS, T.L., 1996. Persistence of Late Carboniferous tropical vegetation during glacially driven climatic and sea-level fluctuations. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 125: 105-128.

DREESEN, R., BOSSIROY, D., DUSAR, M., FLORES, R.M. & VERKAEREN, P., 1995. Overview of the influence of syn-sedimentary tectonics and palaeo-fluvial systems on coal seam and sand body characteristics in the Westphalian C strata, Campine Basin, Belgium. *In*: Whateley, M.K.G. & Spears, D.A. (eds.), *European Coal Geology, Geological Society Special Publication*, 82: 215-232.

DUSAR, M., 1989. Non-marine lamellibranchs in the Westphalian C/D of the Campine Coalfield. *Bulletin de la Société belge de Géologie*, 98: 483-493.

DUSAR, M., BLESS, M.J.M., BURGER, K., LIE, S.F., MEYSKENS, M., PAPROTH, E., SOMERS, Y. & VOETS, R., 1986. De steenkoolverkenningsboring Opoeteren-Den Houw (Boring 168 van het Kempens Bekken). *Geological Survey of Belgium, Professional Paper*, 226: 98 p.

DUSAR, M., BLESS, M.J.M., BORREMANS, G., BURGER, K., DE LOOSE, J., FAIRON-DEMARET, M.,

FELDER, P.J., GULLENTOPS, F., LIE SUN FAN, MUCHEZ, Ph., PAPROTH, E., PIERART, P., ROSSA, H.G., SMOLDEREN, A., SOMERS, Y., STEURBAUT, E., STREEL, M., VIAENE, W., WITTE, H. & WOUTERS, L., 1987. De steenkoolverkenningsboring Gruitrode-Ophovenderheide (Boring 172 van het Kempens Bekken) Kaartblad Opoeteren , 63E 224. *Geological Survey of Belgium, Professional Paper*, 230: 235 p.

EAGAR, R.M.C., 1974. Shape of shell of *Carbonicola* in relation to burrowing. *Lethaia*, 7: 219-238.

ERNST, W., 1963. Diagnose der Salinitätfazies mit Hilfe des Bors. *Fortschritte in der Geologie von Rheinland und Westfalen*, 10: 253-266.

EVANS, W.B., GEORGE, T.N., JONES, D.G., OWEN, T.R., RAMSBOTTOM, W.H.C., SQUIRREL, H.C. & WOODLAND, A.W., 1971. Excursion 2: South Wales. *C. R. 6me Congrès International de Stratigraphie et de Géologie du Carbonifère, Sheffield 1967*, 4: 1669-1698.

FIEBIG, H. & GROSCURTH, J., 1984. Das Westfal C im nördlichen Ruhrgebiet. *Fortschritte in der Geologie von Rheinland und Westfalen*, 32: 257-267.

FLINT, S., AITKEN, J. & HAMPSON, G., 1995. Application of sequence stratigraphy to coal-bearing coastal plain successions: implications for the UK Coal Measures. *In*: Whateley, M.K.G. & Spears, D.A. (eds.), *European Coal Geology, Geological Society Special Publication*, 82: 1-16.

FRANCIS, E.H., 1969. Les tonsteins du Royaume-Uni. *Annales de la Société géologique du Nord*, 89: 209-214.

GLOVER, B.W.; LENG, M.J. & CHISHOLM, J.I., 1996. A second major fluvial sourceland for the Silesian Pennine Basin of northern England. *Journal of the Geological Society, London*, 153: 901-906.

GREBE, H., 1962. Zur Verbreitung der Sporen im oberen Westfal B und dem Westfal C des Ruhrkarbons. *Fortschritte in der Geologie von Rheinland und Westfalen*, 3: 773-786.

GUION, P.G., FULTON, I.M. & JONES, N.S., 1995. Sedimentary facies of the coal-bearing Westphalian A and B north of the Wales-Brabant High. *In*: Whateley, M.K.G. & Spears, D.A. (eds.), *European Coal Geology, Geological Society Special Publication*, 82: 45-78.

HALLSWORTH, C.R. & CHISHOLM, J.I., 2000. Stratigraphic evolution of provenance characteristics in Westphalian sandstones of the Yorkshire Coalfield. *Proceedings of the Yorkshire Geological Society*, 53: 43-72.

HECHT, F., HERING, O., KNOBLAUCH, J., KUBELLA, K. & RUEHL, W., 1962. Stratigraphie, Speichergesteins-Ausbildung und Kohlenwasserstoff-Führung im Rotliegenden und Karbon der Tiefbohrung Hoya Z1. *Fortschritte in der Geologie von Rheinland und Westfalen*, 3: 1061-1074.

HEDEMANN, H.A. & TEICHMUELLER, R., 1971. Die paläogeographische Entwicklung des Oberkarbons. *Fortschritte in der Geologie von Rheinland und Westfalen*, 19: 129-142.

HEDEMANN, H.A., SCHUSTER, A., STANCU-KRISTOFF, G. & LOESCH, J., 1984. Die Verbreitung der Kohlenflöze des Oberkarbons in Nordwestdeutschland und ihre stratigraphische Einstufung. *Fortschritte in der Geologie von Rheinland und Westfalen*, 32: 39-88.

JOSTEN, K.H. & LAVEINE, J.P., 1984. Paläobotanisch-stratigraphische Untersuchungen im Westfal C-D von Nordfrankreich und Nordwestdeutschland. *Fortschritte in der Geologie von Rheinland und Westfalen*, 32: 89-117.

KLEIN, G. DeV. & KUPPERMAN, J.B., 1992. Pennsylvanian cyclothems: methods of distinguishing tectonically induced changes in sea level from climatically induced changes. *Geological Society of America Bulletin*, 104: 166-175.

KNAUFF, W., KOEWING, K. & RABITZ, A., 1971. Der erste Nachweis von Horizonten mit Foraminiferen in Westfal D von Nordwestdeutschland. *Fortschritte in der Geologie von Rheinland und Westfalen*, 18: 257-262.

KOCKEL, F., 1995. Structural and palaeogeographical development of the German North Sea sector. Borntraeger (publ.), *Beiträge zur regionalen Geologie der Erde*, 26: 96 p.

KOZUR, H. & SITTIG, E., 1981. Das *« Estheria » tenella*-Problem und zwei neue Conchostracen-Arten aus dem Rotliegenden von Sulzbach (Senke von Baden-Baden, Nordschwarzwald). *Geologische und Paläontologische Mitteilungen Innsbruck*, 11: 1-38.

LAVEINE, J.P., 1970. Quelques Pécoptérinidées houillères à la lumière de la palynologie. (2). Implications paléobotaniques et stratigraphiques. *Pollen et spores*, 12: 235-297.

LESNIKOWSKA, A.D. & WILLARD, D.A., 1997. Two new species of *Scolecopteris* (Marattiales), sources of *Torispora securis* Balme and *Thymospora thiessenii* (Kosanke) Wilson et Venkatachala. *Review of Palaeobotany and Palynology*, 95: 211-225.

LINDERT, W., 1994. Zur Entwicklung des Oberkarbon im Untergrund von Rügen. *Zeitschrift der geologischen Wissenschaften*, 22: 241-248.

LOBOZIAK, S., 1969. Les micro- et mégaspores de la partie occidentale du Bassin Houiller du Nord de la France. Applications stratigraphiques dans l'étude de plusieurs sondages. Thèse Faculté des Sciences, Lille.

LYONS, P.C., ZODROW, E.L., MILLAY, M.A., DOLBY, G., GILLIS, K.S. & CROSS, A.T., 1997. Coal-ball floras of Maritime Canada and palynology of the Foord Seam: geologic, paleobotanical and paleoecological implications. *Review of Palaeobotany and Palynology*, 95: 31-50.

MAHAFFY, J.F., 1988. Vegetational History of the Springfield Coal (Middle Pennsylvanian of Illinois) and Distribution Patterns of a Tree-Fern Miospore, *Thymospora pseudothiessenii*, based on Miospore Profiles. *International Journal of Coal Geology*, 10: 239-260.

MARTENS, T., 1987. Conchostracan zone-succession. *In*: Lützner, H. (ed.), *Sedimentary and volcanic Rotliegendes of the Saale Depression, Excursion Guidebook Symposium Rotliegendes in Central Europe*, Zentralinstitut Physik der Erde, Potsdam.

MAYLAND, H. & WILLIAMSON, I.A., 1970. Tonstein bands in the north-western coalfields of England and Wales. *C. R. 6me Congrès International de Stratigraphie et de Géologie du Carbonifère, Sheffield 1967*, 3: 1165-1168.

MENNING, M.; WEYER, D.; DROZDZEWSKI, G.; VAN AMEROM, H.W.J. & WENDT, I., 2000. A Carboniferous Time Scale 2000: discussion and use of geological parameters as time indicators from Central and western Europe. *Geologisches Jahrbuch*, A156: 3-44.

OWENS, B., RILEY, N.J. & CALVER, M.A., 1984. Boundary stratotypes and the new stage names for the lower and middle Westphalian sequences in Britain. *C. R. 10me Congrès International de Stratigraphie et de Géologie du Carbonifère, Madrid 1983*, 4: 461-472.

PAPROTH, E., 1962. Die stratigraphische Verbreitung der nicht-marinen Muscheln im Westfal Nordwestdeutschlands. *Fortschritte in der Geologie von Rheinland und Westfalen*, 3: 787-794.

PAPROTH, E., 1978. Nicht-marine Muscheln als Spiegel der Fazies-Entwicklung im paralischen Kohlengebiet Nordwest-Europas. *Sonderveröffentlichungen des Geologischen Instituts der Universität Köln*, 33: 91-100.

PAPROTH, E.; DUSAR, M.; VERKAEREN, P. & BLESS, M.J.M., 1996 - Stratigraphy and cyclic nature of Lower Westphalian deposits in the boreholes KB174 and KB206 in the Belgian Campine. *Annales de la Société géologique de Belgique*, 117 (1994): 169-189.

POLLARD, J.E., 1966. A non-marine ostracod fauna from the Coal Measures of Durham and Northumberland. *Palaeontology*, 9: 667-697.

RAMSBOTTOM, W.H.C., CALVER, M.A., EAGAR, R.M.C., HODSON, F., HOLLIDAY, D.W., STUBBLEFIELD, C.J. & WILSON, R.B., 1978. A correlation of Silesian rocks in the British Isles. *Geological Society Special Publication*, 10: 82 p.

RIPPON, J.H., 1996. Sand body orientation, palaeoslope analysis and basin-fill implication in the Westphalian A-C of Great Britain. *Journal of the Geological Society, London*, 153: 881-900.

SCHLEPPER, H., 1971. Stratigraphisch-faunistische Untersuchungen in den Dorstener Schichten (Westfal C) des Ruhrkarbons. *Fortschritte in der Geologie von Rheinland und Westfalen*, 18: 1-32.

SCHUSTER, A., 1968. Karbonstratigraphie nach Bohrlochmessungen. *Erdöl-Erdgas Zeitschrift*, 84: 439-457.

SOMERS, Y., 1971. Etude palynologique du Westphalien du Bassin de Campine et Révision du genre *Lycospora*. Thèse Université de Liège: 469 p.

SPEARS, D.A. & KANARIS-SOTIROU, R., 1979. A geochemical and mineralogical investigation of some British and other European tonsteins. *Sedimentology*, 26: 407-425.

STEINECK, P.L. & BERGSTEIN, J., 1979. Foraminifera from Hommocks salt-marsh, Larchmont Harbor, New York. *Journal of Foraminiferal Research*, 9: 147-158.

SUESS, M.P.; DROZDZEWSKI, G. & SCHAEFER, A., 2000. Sequenzstratigraphie des kohleführenden Oberkarbons im Ruhr-Becken. *Geologisches Jahrbuch*, A156: 45-106.

TATE, M.P. & DOBSON, M.R., 1989. Pre-Mesozoic geology of the western and north-western Irish continental shelf. *Journal of the Geological Society, London*, 146: 229-240.

VAN DE LAAR, J.G.M. & FERMONT, W.J.J., 1990. On-shore Carboniferous palynology of the Netherlands. *Mededelingen Rijks Geologische Dienst*, 43: 35-73.

WARTH, M., 1963. Conchostraken (Crustacea, Phyllopoda) und Ostrakoden des saarländischen Stefans. Inaugural-Dissertation Eberhard-Karls Universität Tübingen: 121 p.

WEINGARDT, H.W., 1976. Das Oberkarbon in der Tiefbohrung Saar 1. *Geologisches Jahrbuch,* A27: 399-408.

WIGHTMAN, W.G., SCOTT, D.B., MEDIOLI, F.S. & GIBLING, M.R., 1994. Agglutinated foraminifera and thecamoebians from the Late Carboniferous Sydney coalfield, Nova Scotia: paleoecology, paleoenvironments and paleogeographical implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 106: 187-202.

WRIGHT, V.P. & MARRIOTT, S.B., 1996. Discussion of « Brackish water faunas from the St Maughans Formation: the Old Red Sandstone section at Ammons Hill, Hereford and Worcester, UK « by W.J. Barclay, P.A. Rathbone, D.E. White and J.B. Richardson. *Geological Journal*, 31: 89-94.

ZIEGLER, P.A., 1990. Geological atlas of Western and Central Europe, 2nd ed. *Shell Internationale Petroleum Maatschappij*. 239 p.

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