Upper Devonian miospore and conodont zone correlation in western Europe

M. STREEL

Paleobotany, Paleopalynology, Micropaleontology Unit, Department of Geology, University of Liège, Belgium
(e-mail: Maurice.Streel@ulg.ac.be)

Abstract: The stratigraphical occurrence of 38 Upper Devonian miospore taxa is compared to some miospore and conodont zones in 28 intercalibrated levels. The accurate position of 15 miospore First Occurrence Biohorizons and one Last Occurrence Biohorizon in terms of the conodonts available in a few regions of western Europe is discussed in detail and their correlation evaluated.

Publications on the stratigraphical distribution of Devonian miospores effectively started with the classic work of Naumova (1953) on the Russian Platform. Since then, the Devonian has been zoned by various palynologists, mainly in Europe and North America, but also elsewhere around the world. Major works provide reviews and references containing detailed biostratigraphic synthesis, while illustrating most of the characteristic miospores (McGregor 1979*a*, *b*; Richardson & McGregor 1986; Richardson & Ahmed 1989; McGregor & Playford 1992; Avkhimovitch *et al.* 1993). The zonal concept used in these papers is most often the Assemblage Zone, defined, at best, by a combination of different criteria such as the appearance and disappearance of selected miospore structural or sculptural features and the first and last occurrence of selected taxa, two of them giving their name to the zone. Sometimes, the assemblages are Acme Zones (Avkhimovitch *et al.* 1993).

Streel *et al.* (1987) separated Oppel Zones and Interval Zones for the miospores of the whole Devonian in the Ardenne–Rhine regions. The Oppel Zone is difficult to define empirically because judgment may vary as to how many and which of the selected diagnostic taxa need to be present to identify the zone (Hedberg 1976). The Interval Zone is an interval between two distinctive Biohorizons. The advantage of the Interval Zone and Biohorizon concepts is that they allow unequivocal correlations with Interval Zones based on other fossils. First (or rarely last) occurrence(s) of single species (First Occurrence Biohorizon (FOB) or Last Occurrence Biohorizon (LOB) were located in continuous miospore-bearing marine sequences, preferably in uniform lithologies. The marine sequences do not normally contain the best preserved and diversified miospores because transport may have altered their morphology. But their study provides the unique possibility to obtain reliable correlation with marine faunas. The quality of these correlations depends on the distance in time and space between the miospore data on one hand and the nearest reliable faunal data (here conodonts) on the other. It depends also on the kind of stratigraphy (litho- versus bio-) used for indirect correlation.

Therefore a Correlation Quality Index (CQI: 1 to 6, best to worst) was proposed (Streel & Loboziak 1994, 1996; Streel *et al.* 2000*a*). In the present paper a simplified version of the CQI is used (CQI: A,B,C, best to worst) which characterizes the correlations between conodonts and miospores occurring in one and the same section (A) or in different but correlated sections (B), or not correlated (C) at all, by independent faunas or floras. The distance between the correlated sections may be indicated by a plus sign (+) at short distance (hundreds of metres to a few kilometres), a minus sign (−) at long distance (tens of kilometres) or two minus signs at (−−) very long distance (hundreds or more kilometres). The CQI for the biohorizons described in this paper are also indicated on Figures 1 to 5. Of course the correlation value depends also on the reliability of the reference conodont fauna itself, a subject which is not discussed here (see Johnson 1992; Bultynck 2007).

Chronostratigraphic notations refer to the *Subcommission on Devonian Stratigraphy Newsletters* 19 to 22 (2003 to 2007). As substages are not yet formally accepted, initial capital letters are avoided. Intercalibrated levels (first line on Figs 2, 4, 6, 7, 8) are intended only to help in recognizing stratigraphical steps in the western European Upper Devonian, but not to be used as a new zonation. They should replace the intercalibrated levels published by Streel *et al.* (1987). Each level is characterized by miospore-based biohorizons ($\underline{X>}$) or/and nominal taxa of Oppel Zones ($\underline{X}$) or/and changes in Conodont Zones. The occurrences of a few selected miospore taxa (X), helpful for Oppel Zones identification, are also given.

From: KÖNIGSHOF, P. (ed.) *Devonian Change: Case Studies in Palaeogeography and Palaeoecology*.
The Geological Society, London, Special Publications, **314**, 163–176.
DOI: 10.1144/SP314.9 0305-8719/09/$15.00

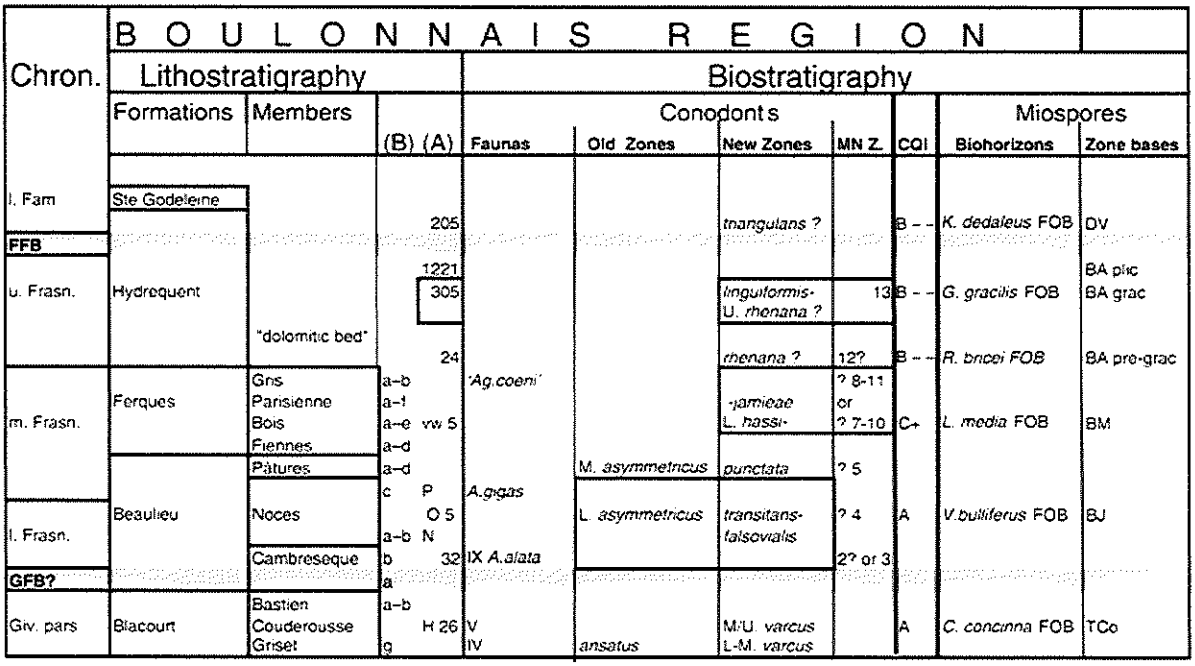

Fig. 1. Late Givetian to early Famennian in the Boulonnais region. Column headings: (A), number of samples in text; (B), subdivisions in Brice (2003). Abbreviations: FFB, Frasnian–Famennian boundary; GFB, Givetian–Frasnian boundary.

A list of the 38 miospore species is given in Table 1.

The Givetian–Frasnian boundary (384 Ma, Kaufmann 2006) and the lower and middle Frasnian (Figs 1 and 2)

Miospores occur with conodonts of the Givetian–Frasnian transitional beds in the Ferques railroad section in the Boulonnais region, northern France. They allow rather good correlation (CQI A) with the conodont zonation which was demonstrated there by Bultynck (in Brice *et al.* 1979, table III; emended by observations made by Coen in Brice *et al.* 1981). In the Couderousse Member of the Blacourt Formation, fauna V corresponds to the Mid or/and Upper *varcus* Zones (Bultynck in Brice 1988; Brice *et al.* 2002; P. Bultynck pers. comm. 2008). The basal beds of the succeeding Beaulieu Formation are not present in this section. A few metres above the first shales of the Cambresèque Member occurs fauna IX with *Ancyrodella rotundiloba alata* (Brice *et al.* 1979) which has a rather low occurrence within the 'old' *asymmetricus* Zone, now (Ziegler & Sandberg 1990) the *falsiovalis*

Intercalibrated levels:	1	2	3	4
Chronostratigraphy:	u.Givet.	l.Frasn.	m.Frasn.	m.Frasn.
New conodont zones:	dispar.-fals.	falsiovalis.	trans. to punct.	hassi to jam.
Old or alternative conodont zones:		MN 1 to 3	MN 4 to 6	MN 7 to 11
Miospore ass. zones (Rich. & McGr. 1986):	opt.-triang.	opt.-triang.	oval.-bull.	oval.-bull.
Miospore Oppel / interval zones (Streel et al. 1987):	TCo	TCo	BJ	BM
CQI for miospore biohorizon (X>)			*A*	*C+*
Diagnostic taxa of miospore zones *(nominal taxa)*				
Chelinospora concinna	X	X	X	X
Samarisporites triangulatus	X	X	X	X
Cirratriradites jekhowskyi			**X**	X
Verrucosisporites bulliferus			***X>***	**X**
Hystricosporites multifurcatus			X	X
Lophozonotriletes media				***X>***
Pustulatisporites rugulatus				X

Fig. 2. Intercalibrated levels and diagnostic miospore taxa from upper Givetian to middle Frasnian.

BOULONNAIS REGION					EIFEL REGION			
Lithostratigraphy			Biostratigraphy		Lithostrat.		Biostratigraphy	
Formation	Member	(A)	Conodonts	Miospores	Formations	(A)	Conodonts	Miospores Biohorizons
Blacourt	Couderousse	H 27	U. *varcus* M. *varcus* L. *varcus*	*S. triangulatus*			U. *varcus* M. *varcus* L. *varcus*	
					Kerpen (upper) Kerpen (lower) Cürten	44	*hemiansatus* CQI *A*	*S. triangulatus* FOB

Fig. 3. *Samarisporites triangulatus* occurrence in the Givetian of the Boulonnais and Eifel regions. (A), Number of samples cited in text.

(partim) and the *transitans* Zones or MN zones 1 to 4 of Klapper (1989). The fauna IX probably belongs to MN zone 2 or even 3 on a new finding of *A. rugosa* in the same sample 32 (P. Bultynck pers. comm. 2008). The first occurrence of *Ancyrodella gigas* noted by Coen (in Brice *et al.* 1981) in the Noces Member of the Beaulieu Formation is immediately below the base of the 'old' Middle *asymmetricus* Zone, now (Ziegler & Sandberg 1990), the mid Frasnian *punctata* Zone or MN zones 5 and 6 of Klapper (1989). Becker (2002, p. 135) suggested that the base of next higher, shaly Pâture Member correlates with the conodont MN 5.

Miospores of the late mid-Frasnian beds occur in a few quarries in the Ferques Formation of the Boulonnais region (Brice *et al.* 1981, fig. 1). In the 'La Parisienne' Quarry, *Ancyrognathus triangularis euglypheus* (now *Ag. coeni*) is present, indicating the Lower *hassi* or *jamieae* conodont Zone or MN zones 8 to 11 of Klapper (1989) (P. Bultynck pers. comm. 2008).

Four successive miospore Oppel Zones, *S. triangulatus–Ancyrospora ancyrea* var. *ancyrea* (TA), *S. triangulatus–Chelinospora concinna* (TCo), *Verrucosisporites bulliferus–Cirratriradites jekhowskyi* (BJ) and *Verrucosisporites bulliferus–Lophozonotriletes media* (BM), are present in the range of these conodont zones in the Boulonnais region. The last three are described as zones I, II and III by Loboziak & Streel (1981), being partly renamed in the same paper. The three zones are completely renamed in Streel *et al.* (1987, fig. 7).

Intercalibrated levels:	5	6	7	8
Chronostratigraphy:	u.Frasn.	u.Frasn.	u.Frasn.-l.Fam.	l.Fam.
New conodont zones:	rhenana?	U.rhen.-linguiformis?	U.rhen.-triangularis?	triang.? to u.crep.
Old or alternative conodont zones:	MN 12?	MN 13		
Miospore ass. zones (Rich. & McGr. 1986):		torq.-grac.	torq.-grac.	torq.-grac.
Miospore phases (Streel *et al.* 1987):	'IV A to B'	'IV C to D2'	'IV D3-E'	'V' - GH
New miospore Oppel/interval zones (this paper)	BA pre-grac.	BA grac.	BA plic.	DV
CQI for miospore biohorizon (X>):	*B – –*	*B – –*		*B – –*
Diagnostic taxa of miospore zones *(nominal taxa)*				
Samarisporites triangulatus	X	X	X	
Cirratriradites jekhowskyi	X	X	X	
Verrucosisporites bulliferus	X	X	X	X
Hystricosporites multifurcatus	X	X	X	X
Lophozonotriletes media	X	X	X	
Pustulatisporites rugulatus	X	X	X	
Cymbosporites acanthaceus	X	X	X	
Rugospora bricei	X>	X	X	X
Cristatisporites deliquescens	X	X	X	
Diducites poljessicus	X	X	X	X
Diducites mucronatus	X	X	X	X
Teichertospora torquata		X	X	X
Grandispora gracilis		X>	X	X
Retusotriletes planus		X	X	X
Diducites plicabilis			X	X
Retusotriletes incohatus				X
Lophozonotriletes lebedianensis				X
Diducites versabilis				X
Knoxisporites dedaleus				X>

Fig. 4. Intercalibrated levels and diagnostic miospore taxa from upper Frasnian to lower Famennian.

Chron.	ARDENNE REGION							
	Lithostratigraphy			Biostratigraphy				
	Formations	Members	(A)	Conodonts Old Zones	Conodonts New Zones	CQI	Miospores Biohorizons	Miospores Zone bases
u* Fam.	Comblain-au-Pont		111	L.-M. *costatus*	U. *expansa*	A		LE
			22			B – –	*R. lep.lepidophyta* FOB	LL
	Evieux		20'd	L. *costatus*	M. *expansa*		*V. hystricosus* FOB.	VH
		Fontin						
u. Fam.	Comblain-la-Tour		54	*styriacus* U. *velifer*	*postera* ? U. *trachytera*	C +	*G. cornuta* FOB	VCo
	Montfort	Bon-Mariage	19	M. *velifer*	? L. *trachytera*	C +	*R. macroreticulata* FOB	GF mac
			13	L. *velifer*	U* *marginifera*	A.C +	*G. microseta* FOB	GF mic
	Souverain-Pré							
m. Fam. Part	Esneux		13	L. *marginifera*	L. *marginifera*	A.C –	*G. fam.famenensis* FOB	
			4				*G. fam.minuta* FOB	GF pre-mic

Fig. 5. Middle to uppermost Famennian in the Ourthe Valley. (A), number of samples cited in text.

Richardson & McGregor (1986) described two Assemblage Zones (*Contagisporites optivus* var. *optivus–Cristatisporites* (now *Samarisporites*) *triangulatus Zone* and *Archaeoperisaccus ovalis–Verrucosisporites bulliferus* Zone) in about the same timespan. The limit between these Assemblage Zones corresponds to the lower limit of the BJ Zone (Streel *et al.* 1987, fig. 13). For that reason, the *C. optivus* var. *optivus–C. triangulatus* Zone, the base of which is characterized by the first appearance of *Samarisporites triangulatus*, includes the TA and TCo Oppel Zones. Richardson & McGregor (1986) also use the Ferques railroad section of Loboziak & Streel (1980) as a reference

Intercalibrated levels:	9	10	11	12
Chronostratigraphy:	m.Fam.	m.Fam.	u.Fam.	u.Fam.
New conodont zones:	u*.crep.to rhomb.	l. to u.marg..	u*.marg.	l.trach.?
Old or alternative conodont zones:			l.vel.	m.vel.?
Miospore ass. zones (Rich. & McGr. 1986):	torq.-grac.	(immensus ?)	?	?
Miospore Oppel / interval zones (Streel *et al.* 1987):	'V'-GH	GFl	GFm	GFu
New miospore Oppel/interval zones (this paper)	DV	GF pre-mic	GF mic	GF mac
CQI for miospore biohorizon (X>):		*A and C–*	*A and C+*	*C+*
Diagnostic taxa of miospore zones *(nominal taxa)*				
Verrucosisporites bulliferus	X	X	X	X
Hystricosporites multifurcatus	X	X	X	X
Rugospora bricei	X			
Diducites poljessicus	X	X	X	X
Diducites mucronatus	X	X	X	X
Teichertospora torquata	X	X	X	X
Grandispora gracilis	X	X	X	X
Retusotriletes planus	X	X	X	X
Diducites plicabilis	X	X	X	X
Retusotriletes incohatus	X	X	X	X
Lophozonotriletes lebedianensis	X	X	X	X
Diducites versabilis	X	X	X	X
Knoxisporites dedaleus	X	X	X	X
Grandispora famenensis var. minuta		***X>***	X	X
Grandispora famenensis var. famenensis		***X>***	X	X
Grandispora microseta			***X>***	X
Retispora macroreticulata				***X>***

Fig. 6. Intercalibrated levels and diagnostic miospore taxa from middle to upper Famennian.

Intercalibrated levels:	13	14	15	16	17	18	19
Chronostratigraphy:	u.Fam.	u.Fam.	u.Fam.	u.Fam.	u.Fam.	u.Fam.	u.Fam.
New conodont zones:	u.trach.	l.post.	u.post.	l.exp.	l.exp.	m.exp.	m.exp.
Old or alternative conodont zones:	u.vel.	l.styr.	m.styr	u.styr.	l.cost.	l.cost.	l.cost.
Miospore ass. zones (Rich. & McGr. 1986):	?	?	flex-corn	flex-corn	flex-corn	flex-corn	?
Miospore Oppel / interval zones (Streel *et al.* 1987):	GFu	GFu?	VCo	VCo	VCo	VCo	VH
New miospore Oppel/interval zones (this paper)	GF mac	GF mac?					
CQI for miospore biohorizon (X>):			*C+*				*B+*
Diagnostic taxa of miospore zones *(nominal taxa)*							
Verrucosisporites bulliferus	X	X	X	X	X	X	
Hystricosporites multifurcatus	X	X	X	X	X	X	
Diducites poljessicus	X	X	X	X	X	X	X
Diducites mucronatus	X	X	X	X	X	X	X
Teichertospora torquata	X	X	X	X	X	X	X
Grandispora gracilis	X	X	X	X	X	X	X
Retusotriletes planus	X	X	X	X	X	X	X
Diducites plicabilis	X	X	X	X	X	X	X
Retusotriletes incohatus	X	X	X	X	X	X	X
Lophozonotriletes lebedianensis	X	X	X	X	X	X	
Diducites versabilis	X	X	X	X	X	X	X
Knoxisporites dedaleus	X	X	X	X	X	X	X
Grandispora famenensis var. minuta	X	X	X	X	X	X	X
Grandispora famenensis var. famenensis	X	X	X	X	X	X	X
Grandispora microseta	X	X	X	X	X	X	X
Retispora macroreticulata	X	X	X	X	X	X	X
Retusotriletes phillipsii			X	X	X	X	
Grandispora cornuta			X>	X	X	X	X
Rugospora radiata			X	X	X	X	X
Vallatisporites hystricosus							X>
Apiculiretusispora verrucosa							X
Grandispora echinata							X

Fig. 7. Intercalibrated levels and diagnostic miospore taxa in the upper Famennian.

section for the base of their *Archaeoperisaccus ovalis–Verrucosisporites bulliferus* Zone which obviously includes both BJ and BM Oppel Zones.

Three biohorizons were selected by Streel & Loboziak (1996) and Streel *et al.* (2000*a*, fig. 3) in the TA–BJ timespan.

The *Samarisporites triangulatus* FOB (CQI A) is not present in the Boulonnais but in the Eifel region. It occurs in sample 44 in the lower part of the Kerpen Formation (Fm) at Kerpen, Hillesheim Syncline, Eifel region (Loboziak *et al.* 1991, fig. 5). Six samples from the underlying Cürten Formation, 108 to 162 m, did not contain *S. triangulatus*. The Kerpen Formation at Kerpen and the Cürten Formation are correlated with the conodont *ensensis–bipennatus* Subzone (Weddige 1984, 1988, p. 150). The base of the Kerpen Fm is now (K. Weddige, pers. comm. 2004) considered to belong to the upper part of the *hemiansatus* Zone (Fig. 3). The typical radial extensions of the zona of *S. triangulatus* in the Kerpen Fm are very short, possibly marking an early stage in the development of this species, but known also in beds occurring higher than the *C. concinna* FOB in Poland (Turnau 1996, pl. IV, fig. 6) . In the Blacourt Fm (Boulonnais region), containing the conodont Mid- and/or Upper *varcus* Zone (Fig. 3), the typical radial extensions are better developed and more conspicuous (see Loboziak & Streel 1980, pl. 2, fig. 12). Such occurrence of an 'early form' of *S. triangulatus* in the upper part of the *hemiansatus* Zone is not found by Turnau & Racki (1999) in Poland and Marshall *et al.* (2007, fig. 8) in Scotland, who place, therefore, the *S. triangulatus* FOB in the Middle–Upper *varcus* Zone, i.e. higher than their *C. concinna* FOB (see below). This discrepancy might result from these regions belonging to another phytogeographic realm (J. Marshall pers. comm. 2007).

The *Chelinospora concinna* FOB (CQI A) occurs in sample 26, unit H in the Couderousse Member of the Blacourt Fm in the Ferques railroad section (Boulonnais region, northern France; Loboziak & Streel 1988, fig. 1). Two samples from a 3 m interval below sample 26 did not contain *C. concinna*, but these samples immediately overlie a reef, 190 m thick, that lacks palynomorphs. The *C. concinna* FOB might belong to the conodont Mid *varcus* or/and Upper *varcus* Zones. However Turnau (1996) and Turnau & Racki (1999) in Poland and Marshall *et al.* (2007) in Scotland recommend a slightly lower position, i.e. the Lower or Mid *varcus*, now the transition between the *rhenanus* and *ansatus* Givetian conodont Zones.

The *V. bulliferus* FOB (CQI A) occurs in sample 05 in unit O which belongs to the Noces Member of

Intercalibrated levels:	20	21	22	23	24	25	26	27	28
Chronostratigraphy:	u.Fam.	u*.Fam	u*.Fam	u*.Fam	u*.Fam	u*.Fam	u*.Fam	u*.Fam	Carbon.
New conodont zones:	m.exp.	u.exp	u.exp	u.exp-l.praes ?	l.praes.	m.praes.	u.praes.	u.praes.	sulcata
Old or alternative conodont zones:	l.cost.	l.cost.	m.cost.	m.cost	m.cost.	u.cost	kockeli	kockeli	kuehni
Miosp. ass. zones (Rich. & McGr. 1986):	pus.-lep.	pus.-lep.	pus.-lep.	pus.-lep.	pus.-lep.	nit.-verr.	nit.-verr.	nit.-verr.	nit.-verr.
Miosp. interv./ass. zones (Streel *et al.* 1987):	LL	LL	LL	LE	LE	LN	LN	VI	VI
CQI for miospore biohorizon (X>):	*B - -*					*A*	*A*		
Diagn. taxa of miosp. Z. *(nominal taxa)*									
Diducites poljessicus	X	X	X	X	X	X	X	X	X
Diducites mucronatus	X	X	X	X	X	X	X	X	X
Teichertospora torquata	X	X	X	X	X				
Grandispora gracilis	X	X	X	X	X	X	X		
Retusotriletes planus	X	X	X	X	X	X	X	X	X
Diducites plicabilis	X	X	X	X	X	X	X		
Retusotriletes incohatus	X	X	X	X	X	X	X	X	X
Diducites versabilis	X	X	X	X	X	X	X	X	
Knoxisporites dedaleus	X	X	X	X	X	X	X		
Grandispora famenensis var. minuta	X	X	X						
Grandispora famenensis var. famenensis	X	X	X						
Grandispora microseta	X	X	X						
Retispora macroreticulata	X	X	X						
Grandispora cornuta	X	X	X	X	X	X	X	X	X
Rugospora radiata	X	X	X	X	X	X	X		
Vallatisporites hystricosus	X	X	X	X	X	X	X		
Apiculiretusispora verrucosa	X	X	X	X	X				
Grandispora echinata	X	X	X	X	X	X	X	X	X
Retispora lepidophyta	***X>***	X	X	***X***	X	***X***	*X>*		
Knoxisporites literatus	***X***	X	X	X	X	X	X	X	X
Tumulispora rarituberculatus	X	X	X	X	X	X	X	X	X
Indotriradites explanatus				***X>***	X	X	X	X	X
Vallatisporites verrucosus				X	X	X	X	X	X
Vallatisporites vallatus						X	X	***X***	X
Verrucosisporites nitidus						***X>***	X	X	X

Fig. 8. Intercalibrated levels and diagnostic miospore taxa from upper Famennian to lowermost Carboniferous.

the Beaulieu Fm in the Ferques railroad section (Loboziak & Streel 1981, fig. 1). Unit O is a shale underlying a limestone (unit P) containing the conodont *punctata* Zone and overlying a dolomitic bed (unit N). *V. bulliferus* was absent in the five samples which have been studied below, in a 45 m interval above the base of the Beaulieu Fm. The *V. bulliferus* FOB probably belongs to the upper part of the lower Frasnian conodont *transitans* Zone (MN Zone 4), i.e. to a conodont zone above the *falsiovalis* Zone where the base of the Frasnian Stage has been defined at the first occurrence of *Ancyrodella rotundiloba* (but see Bultynck 1986; Sandberg *et al.* 1989).

The TCo Oppel Zone ranges into the lower Frasnian *falsiovalis* (partim) and *transitans* Zones or MN Zones 1 to 4 of Klapper (1989). The BJ Oppel Zone and the next BM Oppel Zone are present in the middle Frasnian *punctata* Zone until the Lower *hassi* or *jamieae* Zone or MN zones 5 to 11 of Klapper (1989). Unfortunately the upper part of the Beaulieu Fm and the lower part of the Ferques Fm contain only very poor conodont faunas (Brice *et al.* 1981, fig. 2).

The *L. media* FOB (CQI C+) occurs in sample vw5 in the lower part of the Ferques Fm (Bois Member) in the 'Bois' Quarry, i.e. above the conodont *punctata* Zone known from the underlying Beaulieu Fm but below *Ancyrognathus coeni* indicating the conodont Lower *hassi* to *jamieae* Zone, near the top of the Ferques Fm in the 'La Parisienne' Quarry (Brice *et al.* 1981). R. T. Becker (pers. comm. 2007) suggests that the Bois Member fall in the middle of the interval from MN Zones 7 to 10. One sample in the Ferques Fm below vw5 and four samples in the Beaulieu Fm do not have *L. media*. The Ferques railroad section, the 'Bois' Quarry and the 'La Parisienne' Quarry are localities that are only a few kilometres apart.

The upper Frasnian to the lower Famennian and the Frasnian–Famennian boundary (376 Ma, Kaufmann 2006) (Fig. 4)

Miospores and conodonts are poorly correlated during this timespan. Upper Frasnian and Frasnian–Famennian boundary (FFB) miospore zones are best displayed in the upper part of the Hydrequent Fm in the 'Briqueterie de Beaulieu' (Boulonnais area, northern France) which does not contain any conodonts. *Ancyrognathus coeni* occurring near the top of the preceding Ferques Fm in the 'La Parisienne' Quarry (500 m north of the 'Briqueterie de Beaulieu'), and indicating the conodont Lower *hassi* or *jamieae* Zone, is about 85 m lithostratigraphically below the miospore productive part of the Hydrequent Fm. The stratigraphic

Table 1. *List of species*

Species	References
Apiculiretusispora verrucosa	(Caro-Moniez) Streel in Becker *et al.* (1974)
Chelinospora concinna	Allen (1965)*
Cirratriradites jekhowskyi	Taugourdeau-Lantz (1967)*
Corbulispora sp.	*in* Loboziak & Streel (1981, pl.1 fig. 5)
Cristatisporites deliquescens	(Naumova) Archangelskaya (1972)*
Cymbosporites acanthaceus	(Kedo) Obukhovskaya (2000)*
Diducites mucronatus	(Kedo) Van Veen (1981)*
Diducites plicabilis	Van Veen (1981)
Diducites poljessicus	(Kedo) Van Veen (1981)
Diducites versabilis	(Kedo) Van Veen (1981)
Grandispora cornuta	Higgs (1975)*
Grandispora echinata	Hacquebard (1957)*
Grandispora famenensis var. famenensis	(Naumova) Streel in Higgs *et al.* (2000)
Grandispora famenensis var. minuta	(Naumova)/(Nekriata) Streel in Higgs *et al.* (2000)
Grandispora gracilis	(Kedo) Streel in Becker *et al.* (1974)
Grandispora microseta	(Kedo) Streel in Higgs *et al.* (2000)
Hystricosporites multifurcatus	(Winslow) Mortimer & Chaloner (1967)*
Indotriradites explanatus	(Luber) Playford (1990)*
Knoxisporites dedaleus	(Naumova) Streel in Becker *et al.* (1974)
Knoxisporites literatus	(Waltz) Playford (1963)*
Lophozonotriletes lebedianensis	Naumova (1953)
Lophozonotriletes media	Taugourdeau-Lantz (1967)
Pustulatisporites rugulatus	(Taugourdeau-Lantz) Loboziak & Streel (1981)
Retispora lepidophyta	(Kedo) Playford (1976)*
Retispora macroreticulata	(Kedo) Byvsheva (1985)*
Retusotriletes incohatus	Sullivan (1964)*
Retusotriletes phillipsii	Clendening *et al.* (1980)
Retusotriletes planus	Dolby & Neves (1970)*
Rugospora bricei	Loboziak & Streel (1989)
Rugospora radiata	(Jushko) Byvsheva (1985)
Samarisporites triangulatus	Allen (1965)
Teichertospora torquata	(Higgs) McGregor & Playford (1990)*
Tumulispora rarituberculata	(Luber) Playford (1991)*
Vallatisporites hystricosus	(Winslow) Byvsheva (1985)
Vallatisporites verrucosus	Hacquebard (1957)
Vallatispotites vallatus	Hacquebard (1957)
Verrucosisporites bulliferus	Richardson & McGregor (1986)
Verrucosisporites nitidus	Playford (1964)*

*The references of these taxa can be found in the following citations in the reference list: Avkhimovitch *et al.* 1993; Loboziak & Streel 1981; Loboziak *et al.* 1983; Streel & Loboziak 1996; Streel *et al.* 1987.

position of the late *rhenana* to *triangularis* conodont zones and of the FFB in the Hydrequent Fm is known by acritarch correlation (CQI B–) with the Hony section in the Ardenne area (Streel *et al.* 2000*a*, figs 13 and 16, 2000*b*). Magnetostratigraphy susceptibility correlation of the FFB between the 'La Serre' section in southern France and the section of Hony in east Belgium is given by Crick *et al.* (2002). The obvious conclusion of this correlation is that the BA Oppel Zone *plicabilis* Interval Zone (see below) extends across the FFB.

Establishing a miospore zonation is essentially a step by step process and it is important that the zones erected at any given time reflect these steps. Loboziak & Streel (1981) used the 'phase concept' of Van der Zwan (1980) as an Oppel Zone that was not yet controlled by application in other localities and which therefore might just have local significance. Phase zones IV and V were so far the last zones unnamed (in Streel *et al.* 1987) although they have been used for correlation in other regions and even other phytogeographic areas (Avkhimovitch *et al.* 1988, 1993; Melo & Loboziak 2003).

Phase zone IV is renamed here as *Rugospora bricei–Cymbosporites acanthaceus* (BA) Oppel Zone and phase zone V as *Knoxisporites dedaleus–Diducites versabilis* (DV) Oppel Zone.

The BA Zone is subdivided in three parts by new interval zones, characterized respectively by the absence (pre-grac.) or entry of *Grandispora gracilis* (grac.) at the base of IV C and the entry of *Diducites plicabilis* (plic.) at the base of IV D3 (see Loboziak *et al.* 1983). It should be noted that the base of the *Grandispora gracilis–Samarisporites* sp. cf *Acanthotriletes hirtus* (GH) Oppel Zone was poorly defined (Streel *et al.* 1987, fig. 9, p. 221). The Oppel Zone GH is therefore withdrawn here.

Although it has a poorly defined base in the USA (Streel *et al.* 2000*a*, p. 131), the *Auroraspora torquata–Grandispora gracilis* assemblage Zone clearly starts in the upper Frasnian conodont MN zone 13 of Klapper (1989) (likely within the range of *Palmatolepis juntianensis*; J. Over pers. comm. 1998) and continues more or less at least to the middle Famennian *rhomboidea* Zone (Richardson & McGregor 1986, fig. 7).

Three biohorizons were selected by Streel & Loboziak (1996) in the BA–DV timespan of the Hydrequent Fm. Conodonts have not been found in this section.

The *Rugospora bricei* FOB (CQI B–) occurs in sample 24, immediately below the 'banc dolomitique' in the upper Hydrequent Fm of the 'Briqueterie de Beaulieu' (Loboziak *et al.* 1983, fig. 1). Two poor samples, without *R. bricei*, occur within the 2 m below the biohorizon, and another one 25 m below. According to the correlations discussed above, the R. *bricei* FOB is in the Upper *hassi, jamieae or rhenana* Zone. However, correlation with eastern Europe (the Pripyat Depression, Belarus and the Timan-Pechora Province, Russia indicates (Obukhovskaya *et al.* 2000) that this biohorizon should fit into the Upper *rhenana* Zone or the MN Zone 12. However, as these regions belong to another phytogeographic realm, this correlation is questionned.

The *Grandispora gracilis* FOB (CQI B–) occurs in sample 305 in the upper part of the Hydrequent Fm of the 'Briqueterie de Beaulieu' (Loboziak *et al.* 1983, fig. 1). Six samples in a 4.5 m interval below sample 305 above the 'banc dolomitique' do not contain *G. gracilis*. According to the correlations discussed above, the *G. gracilis* FOB should fit into the Upper *rhenana* or *linguiformis* Zone or the MN13 Zone.

The *Knoxisporites dedaleus* FOB (CQI B–) occurs in sample 205 in the uppermost Hydrequent Fm of the 'Briqueterie de Beaulieu' (Loboziak *et al.* 1983, fig. 1). Sixteen samples, rich in miospores but lacking *K. dedaleus*, have been studied in the 6 m of sediments immediately below sample 205. According to the correlations discussed for the BA Oppel Zone, the *K. dedaleus* FOB should fit into the *triangularis* zones or even higher in the Famennian.

The middle to upper Famennian transition (Figs 5 and 6)

The four Famennian substages have not yet been formally defined, therefore we refer to Streel (2005) where we have adopted the base of the Uppermost *crepida*, the base of the Uppermost *marginifera* and the base of the Upper *expansa* conodont Zones to mark respectively the bases of the middle, upper and uppermost Famennian.

Miospores are poorly represented in the lower–middle Famennian transition of western Europe and eastern North America (see the 'Lower–middle Famennian vegetation crisis' in Streel *et al.* 2000*a* and Streel 2007). This is matched by the occurrence in most of the lower–middle Famennian (from the conodont *triangularis* to the *rhomboidea* Zones at least) of the single Oppel Zone DV in western Europe and the single *Auroraspora torquata–Grandispora gracilis* assemblage Zone in eastern North America. A tentative attempt to subdivide the *torquata–gracilis* Zone into a lower part without, and an upper part with ?*Lagenicula* cf. *Hymenozonotriletes immensus*, reallocated by Turnau (2002) to the genus *Tergobulasporites*, reaching the *marginifera* conodont zone, has been published by Richardson & Ahmed (1989). However, this species might well be a megaspore, having a limited distribution range, and therefore might be unsuitable for correlation.

It is not until the *marginifera* Zone that the miospore Oppel Zone GF, *Grandispora gracilis–Grandispora famenensis* (named the GM Zone in papers older than Streel *et al.* 1987) occurs in western Europe, initiating a succession of miospore zones characterized by species of the genus *Grandispora* (Higgs *et al.* 2000). The GF Zone is subdivided in three parts by interval zones, characterized respectively by the absence (pre-mic.) or entry (mic.) of *Grandispora microseta* and by the entry of *Retispora macroreticulata* (mac.).

The *Grandispora famenensis* FOB (CQI A and C–) occurs with G. *famenensis* var. *minuta*, a variety with reduced ornamentation, in sample 4 in the Esneux Fm at the Esneux locality, Dinant Synclinorium, Ardenne region (Loboziak *et al.* 1995). G. *famenensis* var. *famenensis* occurs in sample 13, 11 m higher. Conodonts of the Lower *marginifera* Zone are known from another lithological unit (Souverain-Pré Fm) in the same section about 23 m above sample 4 (CQI A). Lithological correlation (CQI C–) suggests that the equivalent of the conodont Lower *marginifera* Zone occurs also in the upper part of the Esneux Fm, in a section studied, 25 km to the west, at Modave-Pont de Bonne (Dreesen & Thorez 1994, p. 170).

The *Grandispora microseta* FOB (CQI A and C+) and the *Retispora macroreticulata* FOB (CQI C+) occur successively and in close proximity in the lower part of the Montfort Fm of the Comblain-au-Pont 'Bon-Mariage' section, Dinant synclinorium, Ardenne region (Bouckaert *et al.* 1968, hors-texte I). Sample 13, 9 m below sample 19, is known to lack *R. macroreticulata* but have *G. microseta*. The best documented conodont faunas is given by Dreesen *et al.* (1986, fig. 1) and their correlation (CQI A) with the miospore Zones is indicated by Streel (1986, fig. 2). *G. microseta* first occurs in the Uppermost *marginifera* conodont Zone. *R. macroreticulata* probably corresponds to the next Lower *trachytera* conodont Zone. Conodonts have been restudied in a parallel section (Comblain-la-Tour) 4 km distant, by Dreesen & Thorez (1994, p. 175) demonstrating the Lower *trachytera* Zone at about the same level (CQI C+).

The upper Famennian in the Condroz Sandstones of Belgium (Fig. 7)

Dreesen *et al.* (1986, fig. 1) indicate that, due to unfavourable facies, the stratigraphic interval Upper *trachytera* to Lower *expansa* Zones in the Condroz Sandstones in Belgium lacks the characteristic conodonts of the 'standard zonation' of Ziegler & Sandberg (1990). The late GF mac Interval Zone, defined above and the Oppel Zone VCo (*Diducites versabilis–Grandispora cornuta*) cover the stratigraphic interval where characteristic conodonts are poorly present.

The base of the VCo Oppel Zone, marked by the first occurrence of *G. cornuta*, *Retusotriletes phillipsii* and *Rugospora radiata*, matches the base of the *Rugospora flexuosa* (now *radiata*)–*Grandispora cornuta* Assemblage Zone of Richardson & McGregor (1986). These authors (p. 21 and fig. 7) and also Streel & Loboziak (1994, fig. 2) have tried to evaluate the respective control by faunas of both zones. The VCo Oppel Zone base is obviously not older (CQI C+) than the Upper *trachytera* conodont Zone (See *G. cornuta* FOB). The '*flexuosa–cornuta*' Assemblage Zone, however, might well start in the middle Famennian part of the *marginifera* conodont Zone if the poor lithological correlation between a few faunas and the rich miospore assemblages in the USA is confirmed.

The *Grandispora cornuta* FOB separates the GF and VCo miospore zones.

The *Grandispora cornuta* FOB (CQI C+) was found in the now almost inaccessible locality of the lower part (sample 36) of the Evieux Fm, in the La Gombe/Montfort section, Dinant Synclinorium, Ardenne region (Bouckaert *et al.* 1971, fig. 6; Bouckaert & Streel 1974; Thorez *et al.* 1977, p. 18). Ten samples (from an interval between 50 and 180 m below sample 36) contained miospores lacking *G. cornuta*. *Scaphignathus velifer velifer* (first occurrence in the Latest *marginifera* conodont Zone) is known 162 m below sample 36 in the same section. *G. cornuta* first occurrence is also present in sample 54, above the base of the Evieux Fm in the Comblain-au-Pont 'Bon-Mariage' section at a level believed to correspond (see CQI C+ in Comblain-la-Tour section) to the *postera* conodont Zone (Streel 1986; Streel *et al.* 2003, fig. 2). These conodonts have been restudied by Dreesen & Thorez (1994, p. 175) in the parallel section of Comblain-la-Tour. They have proposed an Upper *trachytera* Zone at a lithostratigraphic level slightly below sample 54 of the Comblain-au-Pont section.

The *Vallatisporites hystricosus* FOB marks the top of the VCo Zone and the base of the *Apiculiretusispora verrucosa–Vallatisporites hystricosus* or VH Zone.

The *Vallatisporites hystricosus* FOB (CQI A) is found in sample 20'd, 10 m below the top of the Evieux Fm (Maziane *et al.* 1999, fig. 3; Streel *et al.* 2007, fig. 1). Eleven samples without *V. hystricosus* are known below this sample in the same section and the same formation. The first occurrence of the Late *expansa* conodont Zone is known (Dreesen *et al.* 1993; Streel & Hartkopf-Fröder 2005; Streel *et al.* 2007) from the Comblain-au-Pont Fm in the same section, about 28 m higher than Bed 20'd. Conodonts of the Middle *expansa* Zone occur (Dreesen *et al.* 1993, p. 23) in the underlying Evieux Fm of the Esneux railway section, 3 km from Chanxhe (CQI B+) where the Fontin Event has been traced in the VCo Oppel Zone (Streel 1999, p. 203–205). Consequently, the *V. hystricosus* FOB is in the Middle *expansa* Zone but higher than the Fontin Event (Streel & Marshall 2006, table 2, grid E6).

The uppermost Famennian and the Devonian–Carboniferous boundary (361 Ma, Kaufmann 2006) (Figs 8 and 9)

Almost all published papers recently on the Strunian as a chronostratigraphic unit refer to the old (now disused) 'Fa2d', a base being defined by the *Retispora lepidophyta* FOB at about the level of the Epinette Event. The *R. lepidophyta* FOB is an excellent marker, the species reaching, higher in the sequences, sometimes 50% of the miospore assemblages, and having a worldwide distribution in continental and neritic facies. However, it is unfortunately not matched by any well defined conodont limit. Therefore the uppermost Famennian

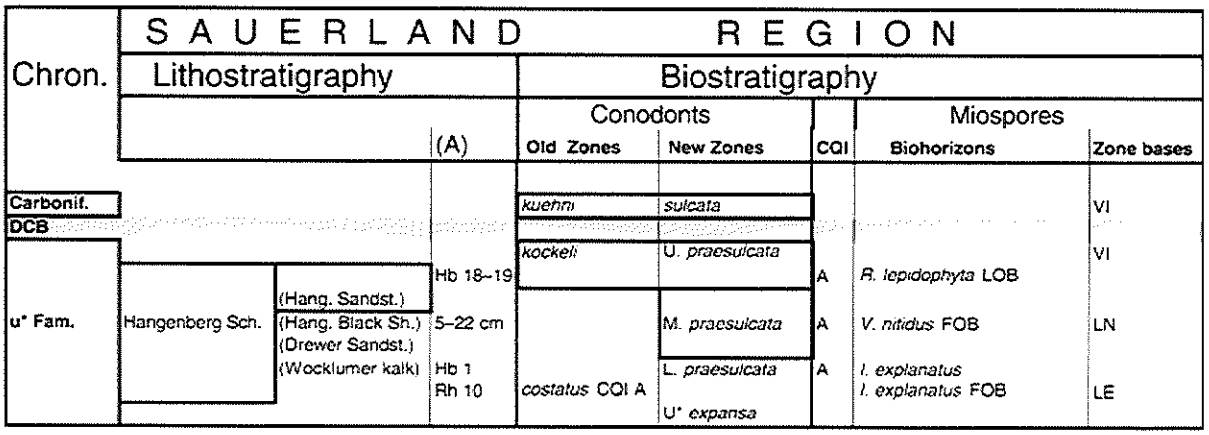

Fig. 9. Uppermost Famennian to the lowermost Carboniferous in the Sauerland region. (A), Number of samples cited in text. DCB, Devonian–Carboniferous boundary.

Substage base, at the base of the Upper *expansa* conodont Zone, and a reference section for neritic facies (Strunian) were proposed by Streel (2002, 2005) and Streel *et al.* (2003, 2005, 2006, 2007).

Richardson & Ahmed (1989, fig. 5) and Avkhimovitch & Richardson (1996) have proposed respectively to separate the lower part of the *Vallatisporites pusillites (sensu lato)–Retispora lepidophyta* Zone of Richardson & McGregor (1986) as an *Apiculiretusispora fructicosa* (now *verrucosa*)–*V. pusillites* Subzone (1988) or as a *V. pusillites–Knoxisporites literatus* PLi Zone (1996). They correlate the base of these (sub)zones with the base of the old (now disused) 'Fa2d' in Belgium (starting in the Middle *expansa* conodont Zone) but also with the base of the Cattaraugus Fm, equivalent to the Uppermost *marginifera* conodont Zone in marine sediment, after Kirchgasser & Oliver (1993, fig. 1) and Kirchgasser (2000). Such contradictions might depend on the diachronous character of the Catskill facies. As long as this situation is not clarified, these miospore zone subdivisions cannot be taken into consideration here.

The transition from the upper Famennian to the Carboniferous is covered by six conodont zones (from Middle *expansa* to *sulcata*), by three miospore Interval Zones, i.e. the *Retispora lepidophyta–Knoxisporites literatus*, *R. lepidophyta–Indotriradites explanatus*, and *R. lepidophyta–Verrucosisporites nitidus* (respectively LL, LE, LN), and by one Assemblage Zone, i.e. the *Vallatisporites vallatus–Retusotriletes incohatus* Zone (VI) which crosses the Devonian–Carboniferous boundary (DCB).

The LL Interval Zone now includes (Maziane *et al.* 1999) the former LV Zone (Streel *et al.* 1987) and could be further subdivided by the first occurrence of *Tumulispora rarituberculatus* and the sudden change in abundance from *R. lepidophyta lepidophyta* to *R. lepidophyta minor* almost at the base of the Upper *expansa* Zone (Maziane-Serraj *et al.* 2007). In the Sauerland, Germany, the extinction of *R. lepidophyta* is announced by the disappearance of peat swamps which produced *Diducites plicabilis*, followed by a strong reduction of the proportion of *R. lepidophyta* (from 30% to 1 or 2%; Higgs *et al.* 1993) suggesting also a progressive reduction of the related swamp-margin environment, which seems to disappear temporarily soon after, together with other swamp-margin environments characterized by species such as *Vallatisporites hystricosus* and *Auroraspora asperella* (Streel 1999). These miospore events partly correspond to, and immediately succeeded, the Hangenberg Event, a sedimentary cycle constituted of a transgression (the Hangenberg Black Shale) and a deep regression (the Hangenberg Sandstone and Shale) (Bless *et al.* 1993). The regression can be correlated by miospores with the glacial episode known in Western Gondwana (Streel *et al.* 2000*a*, Melo & Loboziak 2003).

The complete extinction of *Retispora lepidophyta* immediately below the base of the Carboniferous System as defined by the first occurrence of the conodont *sulcata* Zone, is well known around the world (Streel 1986; Higgs *et al.* 1993; Loboziak *et al.* 1993; Streel & Loboziak 1996). It corresponds to the change from the LN Zone to the VI Zone. The VI Assemblage Zone is poorly defined, the two nominal species being present below the top of the LN Zone. Its base corresponds to the *Retispora lepidophyta* LOB.

The *Retispora lepidophyta* FOB (CQI A and B+) is found in sample 22, 2 m below the top of the Evieux Fm in the Chanxhe section, Dinant Synclinorium, Ardenne region (Maziane *et al.* 1999, fig. 3; Streel *et al.* 2007, fig. 1). Fourteen samples without this species are known below these samples in the same section and the same formation. The first occurrence of the Late *expansa* conodont Zone is known (Dreesen *et al.* 1993;

Streel *et al.* 2007) from the Comblain-au-Pont Fm in Bed 111 of the same section (CQI A), about 20 m higher than samples 22. Conodonts of the Middle *expansa* Zone occur (Dreesen *et al.* 1993, p.23) in the underlying Evieux Fm of the Esneux railway section, 3 km from Chanxhe (CQI B+), where the Fontin Event has been traced in the VCo Oppel Zone (Streel 1999, p. 203–205). The lower part of the Comblain-au-Pont Fm contains abundant large specimens (var. *lepidophyta*) of *R. lepidophyta* (Streel 1966; Maziane *et al.* 2002) as in the Refrath 1 Borehole (Bergisch Gladbach–Paffrath Syncline, Germany) which contains a Middle *expansa* Zone (Streel & Hartkopf-Fröder 2005). Therefore, the *R. lepidophyta* FOB is in the Middle *expansa* Zone.

The *Indotriradites explanatus* FOB (CQI B−) is found in sample Rh10 in the greenish silty shales (Hangenberg Schiefer equivalent) of the Riescheid section, Remscheid Altena Anticline, Sauerland, Germany (Higgs & Streel 1984, fig. 3). Three samples in the underlying 2.5 m interval lacked *I. explanatus* (Higgs & Streel 1994). The undivided *costatus* conodont Zone (Lane & Ziegler in Paproth & Streel 1982) was found in almost the same bed (equivalent to the conodont Lower or Middle *praesulcata* Zone ?). Another, better dated sample is from 50 cm below the top of the Wocklum Kalk at Hasselbachtal (28 km east of Riescheid), in the same anticline (Higgs & Streel 1994). It is a single sample (Hb1) in the latest part of the Lower *praesulcata* conodont Zone (CQI B−), which occurs 15 cm above this sample. The Middle *praesulcata* Zone occurs 30 cm above this sample, i.e. 20 cm below the top of the Wocklum Kalk (Becker *et al.* 1984, p. 189). However, no samples with miospores are known below this single sample. Consequently, the *I. explanatus* FOB is in the late part of the Upper *expansa* Zone or in the Lower *praesulcata* Zone.

The *Verrucosisporites nitidus* FOB (CQI A) is found in a sample collected from the 5 to 22 cm interval above the base of the Hangenberg Black Shale, i.e. on top of the Wocklum Kalk, at Hasselbachtal section, Remscheid Altena Anticline, Sauerland, Germany. Two specimens of *V. nitidus* have small (3 µm) verrucate ornaments, which fall within the lower part of the morphological range of the species. The presence of the Middle *praesulcata* Zone (see *I. explanatus* FOB) 20 cm below the top of the Wocklum Kalk in the same section (CQI A) allows us to assign the *V. nitidus* FOB to the Middle *praesulcata* Zone.

The *Retispora lepidophyta* LOB (CQI A) can be observed in sample Hb 18-19 in Bed 85 of the Hangenberg Schiefer of the Hasselbachtal section, Remscheid Altena Anticline, Sauerland (Higgs & Streel 1984, figs. 5 and 6). Six samples in the overlying 14 cm did not yield *R. lepidophyta* but were dominated by simple laevigate taxa. The *sulcata* conodont zone occurs 14 cm higher than the *R. lepidophyta* LOB.

The author is indebted to J. E. A. Marshall (Southampton) and R. T. Becker (Münster) for reviewing this manuscript and for having made suggestions which led to a much improved work. P. Bultynck (Brussels) is also gratefully acknowledged for his contribution to the Givetian and Frasnian part of the conodont stratigraphy.

References

AVKHIMOVITCH, V. I. & RICHARDSON, J. B. 1996. Correlation of Late Devonian marginal marine and non-marine sediments from eastern North America, western Europe and Belorussia. *International Union of Geological Sciences, Subcommission on Devonian Stratigraphy Newsletter*, **12**, 58–61.

AVKHIMOVITCH, V. I., BYVSHEVA, T. V., HIGGS, K., STREEL, M. & UMNOVA, V. T. 1988. Miospore systematics and stratigraphic correlation of Devonian-Carboniferous boundary deposits in the European part of the USSR and Western Europe. *Courier Forschungsinstitut Senckenberg*, **100**, 169–191.

AVKHIMOVITCH, V. I., TCHIBRIKOVA, E. V. *ET AL.* 1993. Middle and Upper Devonian miospore zonation of Eastern Europe. *Bulletin Centre de Recherche Elf Exploration Production*, **17**, 79–147.

BECKER, G., BLESS, M. J. M., STREEL, M. & THOREZ, J. 1974. Palynology and ostracode distribution in the Upper Devonian and basal Dinantian of Belgium and their dependence on sedimentary facies. *Mededelingen Rijks Geologische Dienst, new serie*, **25**(2), 9–99.

BECKER, R. T. 2002. Frasnian Goniatites from the Boulonnais (France) as indicators of regional sealevel changes. *Annales de la Société géologique du Nord (Lille) 2e série*, **9**, 129–140.

BECKER, R. T., BLESS, M. J. M. *ET AL.* 1984. Hasselbachtal, the section best displaying the Devonian–Carboniferous boundary beds in the Rhenish Massif (Rheinisches Schiefergebirge). *Courier Forschungsinstitut Senckenberg*, **67**, 181–191.

BLESS, M. J. M., BECKER, R. T., HIGGS, K., PAPROTH, E. & STREEL, M. 1993. Eustatic cycles around the Devonian–Carboniferous Boundary and the sedimentary and fossil record in Sauerland (Federal Republic of Germany). *Annales de la Société géologique de Belgique*, **115**, 689–702.

BOUCKAERT, J. & STREEL, M. 1974. General information. *In*: BOUCKAERT, J. & STREEL, M. (eds) *International Symposium on Belgian Micropaleontological Limits, Namur 1974, Guidebook*. Geological Survey of Belgium, Brussels.

BOUCKAERT, J., STREEL, M. & THOREZ, J. 1968. Schéma biostratigraphique et coupes de référence du Famennien belge. Note préliminaire. *Annales de la Société géologique de Belgique*, **91**, 317–336.

BOUCKAERT, J., STREEL, M. & THOREZ, J. 1971. Le Famennien et les couches de transition Dévonien-Carbonifère dans la vallée de l'Ourthe (sud de Liège, synclinorium de Dinant). *Congrès et Colloques de l'Université de Liège*, **55**, 25–46.

BRICE, D. (ed.) 1988. *Le Dévonien de Ferques, Bas-Boulonnais (N. France)*. Université de Bretagne occidentale, Rennes, Biostratigraphie du Paléozoïque, 7.

BRICE, D. 2003. Brachiopod assemblages in the Devonian of Ferques (Boulonnais, France). Relations to palaeoenvironments and global eustatic curves. *Bulletin of Geosciences*, **78**(4), 405–417.

BRICE, D., BULTYNCK, P., DEUNFF, J., LOBOZIAK, S. & STREEL, M. 1979. Données biostratigraphiques nouvelles sur le Givétien et le Frasnien de Ferques (Boulonnais). *Annales de la Société géologique du Nord (Lille)*, **98**, 325–344.

BRICE, D., COEN, M., LOBOZIAK, S. & STREEL, M. 1981. Précisions biostratigraphiques relatives au Dévonien supérieur de Ferques (Boulonnais). *Annales de la Société géologique du Nord (Lille)*, 2^{e} *série*, **9**, 61–74.

BRICE, D., MISTIAEN, B. & ROHART, J.-C. 2002. Progrès dans la connaissance des flores et faunes dévoniennes du Boulonnais (1971–2001). *Annales de la Société géologique du Nord (Lille)*, **100**, 159–166.

BULTYNCK, P. 1986. Accuracy and reliability of conodont zones, the *Polygnathus asymmetricus* Zone and the Givetian–Frasnian boundary. *Bulletin Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre*, **56**, 269–280.

BULTYNCK, P. 2007. Limitations on the application of the Devonian standard conodont zonation. *Geological Quarterly*, **51**, 339–344.

CLENDENING, J. A., EAMES, L. E. & WOOD, G. D. 1980. *Retusotriletes phillipsii* n. sp., a potential Upper Devonian guide palynomorph. *Palynology*, **4**, 15–22.

CRICK, R. E., ELLWOOD, B. B. *ET AL.* 2002. Magnetostratigraphy susceptibility of the Frasnian/Famennian boundary. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **181**, 67–90.

DREESEN, R. & THOREZ, J. 1994. Parautochtonous – autochtonous carbonates and conodont in the Late Famennian (Uppermost Devonian) Condroz Sandstones of Belgium. *Courier Forschungsinstitut Senckenberg*, **168**, 159–182.

DREESEN, R., SANDBERG, C. A. & ZIEGLER, W. 1986. Review of Late Devonian and Early Carboniferous conodont biostratigraphy and biofacies models as applied to the Ardenne Shelf. *Annales de la Société géologique de Belgique*, **109**, 27–42.

DREESEN, R., POTY, E., STREEL, M. & THOREZ, J. 1993. *Late Famennian to Namurian in the Eastern Ardenne, Belgium*. IUGS Subcommission on Carboniferous Stratigraphy, Liège.

HEDBERG, H. H. (ed.) 1976. *International Stratigraphical Guide. A Guide to Stratigraphic Classification, Terminology, and Procedure*. International Subcommission on Stratigraphic Classification (ISSC), Wiley, Chichester.

HIGGS, K. & STREEL, M. 1984. Spore stratigraphy at the Devonian–Carboniferous boundary in the northern "Rheinisches Schiefergebirge", Germany. *Courier Forschungsinstitut Senckenberg*, **67**, 157–179.

HIGGS, K. & STREEL, M. 1994. Palynological age for the lower part of the Hangenberg Shales in Sauerland, Germany. *Annales de la Société géologique de Belgique*, **116**, 243–247.

HIGGS, K., STREEL, M., KORN, D. & PAPROTH, E. 1993. Palynological data from the Devonian–Carboniferous boundary beds in the new Stockum Trench II and the Hasselbachtal boreholes, northern Rhenish Massif, Germany. *Annales de la Société géologique de Belgique*, **115**, 551–557.

HIGGS, K., AVKHIMOVITCH, V. I., LOBOZIAK, S., MAZIANE-SERRAJ, N., STEMPIEN-SALEK, M. & STREEL, M. 2000. Systematic study and stratigraphic correlation of the *Grandispora* complex in the Famennian of northwest and eastern Europe. *Review of Palaeobotany and Palynology*, **112**, 207–228.

JOHNSON, J. G. 1992. Belief and reality in Biostratigraphic Zonation. *Newsletter on Stratigraphy*, **26**(1), 41–48.

KAUFMANN, B. 2006. Calibrating the Devonian Time Scale: A synthesis of U-Pb ID-TIMS ages and conodont stratigraphy. *Earth-Science Reviews*, **76**, 175–190.

KIRCHGASSER, W. T. 2000. Correlation of stage boundaries in the Appalachian Devonian eastern United States. *Courier Forschungsinstitut Senckenberg*, **225**, 271–284.

KIRCHGASSER, W. T. & OLIVER, W. A. JR. 1993. Correlation of stage boundaries in the Appalachian Devonian, Eastern United States. *IUGS, Subcommission on Devonian Stratigraphy Newsletter*, **10**, 5–8.

KLAPPER, G. 1989. The Montagne Noire Frasnian (Upper Devonian) conodont succession. *In*: MCMILLAN, N.-J., EMBRY, A. F. & GLASS, D. J. (eds) *Devonian of the World, Vol. 3, Paleontology, Paleoecology and Biostratigraphy*. Canadian Society of Petroleum Geologists, Memoir, **14**, 70–92.

LOBOZIAK, S. & STREEL, M. 1980. Miospores in Givetian to lower Frasnian sediments dated by conodonts from the Boulonnais, France. *Review of Palaeobotany and Palynology*, **29**, 285–299.

LOBOZIAK, S. & STREEL, M. 1981. Miospores in middle-upper Frasnian to Famennian sediments partly dated by conodonts (Boulonnais), France. *Review of Palaeobotany and Palynology*, **34**, 49–66.

LOBOZIAK, S. & STREEL, M. 1988. Synthèse palynostratigraphique de l'intervalle Givetien-Famennien du Boulonnais (France). *In*: BRICE, D. (ed.) *Le Dévonien de Ferques, Bas-Boulonnais (N. France)*. Université de Bretagne occidentale, Rennes, Biostratigraphie du Paléozoïque, 7.

LOBOZIAK, S., STREEL, M. & VANGUESTAINE, M. 1983. Miospores et acritarches de la Formation d'Hydrequent (Frasnien supérieur à Famennien inférieur, Boulonnais, France). *Annales de la Société géologique de Belgique*, **106**, 173–183.

LOBOZIAK, S., STREEL, M. & WEDDIGE, K. 1991. Miospores, the *lemurata* and *triangulatus* levels and their faunal indices near the Eifelian/Givetian boundary in the Eifel (F.R.G). *Annales de la Société géologique de Belgique*, **113**, 299–313.

LOBOZIAK, S., STREEL, M., CAPUTO, M. V. & MELO, J. H. G. 1993. Middle Devonian to Lower Carboniferous miospores from selected boreholes in Amazonas and Parnaiba Basins (Brazil): additional data, synthesis, and correlation. *Documents du Laboratoire de Géologie de Lyon*, **125**, 277–289.

LOBOZIAK, S., AVKIMOVITCH, V. I. & STREEL, M. 1995. Miospores from the type locality cf the Esneux Formation, Middle Famennian of the Ourthe valley,

eastern Belgium; *Annales de la Société géologique de Belgique*, **117**, 95–102.

MCGREGOR, D. C. 1979*a*. Spores in Devonian stratigraphical correlation. *In*: HOUSE, M. R., SCRUTTON, C. T. & BASSETT, M. G. (eds) *The Devonian System*. Special Papers in Palaeontology, **23**, The Palaeontological Association, London, 163–184.

MCGREGOR, D. C. 1979*b*. Devonian miospores of North America. *Palynology*, **3**, 31–52.

MCGREGOR, D. C. & PLAYFORD, G. 1992. Canadian and Australian Devonian spores, zonation and correlation. *Geological Survey of Canada, Bulletin*, **438**, 1–125.

MARSHALL, J. E. A., ASTIN, T. R., BROWN, J. F., MARK-KURIK, E. & LAZAUSKIENE, J. 2007. Recognizing the Kačák Event in the Devonian terrestrial environment and its implications for understanding land-sea interactions. *In*: BECKER, R. & KIRCHGASSER, W. T. (eds) *Devonian Events and Correlations*. Geological Society, London, Special Publications, **278**, 133–155.

MAZIANE, N., HIGGS, K. & STREEL, M. 1999. Revision of the late Famennian miospore zonation scheme in eastern Belgium. *Journal of Micropaleontology*, **18**, 17–25.

MAZIANE, N., HIGGS, K. & STREEL, M. 2002. Biometry and paleoenvironment of *Retispora lepidophyta* (Kedo) Playford 1976 and associated miospores in the latest Famennian nearshore marine facies, eastern Ardenne (Belgium). *Review of Palaeobotany and Palynology*, **118**, 211–226.

MAZIANE-SERRAJ, N., HARTKOPF-FRÖDER, C., STREEL, M. & THOREZ, J. 2007. Palynomorph distribution and bathymetry in the Chanxhe section (eastern Belgium), reference for the neritic late to latest Famennian transition (Late Devonian). *Geologica Belgica*, **10**(3–4), 170–175.

MELO, J. H. G. & LOBOZIAK, S. 2003. Devonian–Early Carboniferous miospore biostratigraphy of the Amazon Basin, Northern Brazil. *Review of Palaeobotany and Palynology*, **124**, 131–202.

NAUMOVA, S. N. 1953. *Spore-pollen Assemblages of the Russian Platform and their Stratigraphic Significance*. Trudy Instituta Geologicheskikh Nauk, Akademiia Nauk SSSR, 143, Geologicheskikh Seriia **60**, [in Russian].

OBUKHOVSKAYA, T. G., AVKHIMOVITCH, V. I., STREEL, M. & LOBOZIAK, S. 2000. Miospores from the Frasnian–Famennian Boundary deposits in Eastern Europe (the Pripyat Depression, Belarus and the Timan Pechora Province, Russia) and comparison with Western Europe (Northern France). *Review of Palaeobotany and Palynology*, **112**, 229–246.

PAPROTH, E. & STREEL, M. (eds) 1982. *Devonian–Carboniferous transitional beds of the Northern "Rheinisches Schiefergebirge"*. IUGS Working Group on the Devonian–Carboniferous boundary, Liège.

RICHARDSON, J. B. & AHMED, S. 1989. Miospores, zonation and correlation of Upper Devonian sequences from western New York State and Pennsylvania. *In*: MCMILLAN, N- J., EMBRY, A. F. & GLASS, D. J. (eds) *Devonian of the World, Vol. 3, Paleontology, Paleoecology and Biostratigraphy*. Canadian Society of Petroleum Geologists, Memoirs, **14**, 541–558.

RICHARDSON, J. B. & MCGREGOR, D. C. 1986. Silurian and Devonian spore zones of the Old Red Sandstone Continent and adjacent regions. *Geological Survey of Canada, Bulletin*, **364**, 1–79.

SANDBERG, C. A., POOLE, F. G. & JOHNSON, J. G. 1989. Upper Devonian of Western United States. *In*: MCMILLAN, N.-J., EMBRY, A. F. & GLASS, D. J. (eds), *Devonian of the World, Vol. 3, Paleontology, Paleoecology and Biostratigraphy*. Canadian Society Petroleum Geology, Memoirs, **14**, 183–220.

STREEL, M. 1966. Critères palynologiques pour une stratigraphie détaillée du Tnla dans les bassins ardenno-rhénans. *Annales de la Société géologique de Belgique*, **89**, 65–96.

STREEL, M. 1986. Miospore contribution to the upper Famennian–Strunian event stratigraphy. *Annales de la Société géologique de Belgique*, **109**, 75–92.

STREEL, M. 1999. Quantitative palynology of the Famennian events in the Ardenne–Rhine Regions. *Abhandlungen der Geologischen Bundesanstalt, Wien*, **54**, 201–212.

STREEL, M. 2002. The Uppermost Famennian around the World (definition, biostratigraphical and sedimentological context). *IUGS Subcommission on Devonian Stratigraphy Newsletter*, **18**, 55–61.

STREEL, M. 2005. Subdivision of the Famennian Stage into four substages and correlation with the neritic and continental miospore zonation. *IUGS Subcommission on Devonian Stratigraphy Newsletter*, **21**, 14, 16–17; **22**, 16.

STREEL, M. 2007. West Gondwanan and Euramerican climate impact on early Famennian to latest Viséan miospore assemblages. *IUGS Subcommission on Devonian Stratigraphy Newsletter*, **22**, 53–57.

STREEL, M. & HARTKOPF-FRÖDER, C. 2005. Late Famennian correlation by miospores between the Refrath 1 Borehole (Bergisch Gladbach-Paffrath Syncline, Germany) and the reference section of Chanxhe (Dinant Syncline, Belgium). *In*: STEEMANS, P. & JAVAUX, E. (eds) *Pre-Cambrian to Palaeozoic Palaeopalynology and Palaeobotany*. Carnets de Géologie/Notebooks on Geology, Brest, Memoir, **2005/02**, Abstract 10.

STREEL, M. & LOBOZIAK, S. 1994. Observations on the establishment of a Devonian and Lower Carboniferous high-resolution miospore biostratigraphy. *Review of Palaeobotany and Palynology*, **83**, 261–273.

STREEL, M. & LOBOZIAK, S. 1996. Middle and Upper Devonian miospores. *In*: JANSONIUS, J. & MCGREGOR, D. C. (eds) *Palynology: Principles and Applications*. American Association of Stratigraphic Palynologists Foundation, **2**, 575–587.

STREEL, M. & MARSHALL, J. E. A. 2006. Devonian–Carboniferous boundary global correlations and their paleogeographic implications for the assembly of Pangaea. *In*: WONG, Th. E. (ed.) *Proceedings of the XVth International Congress on Carboniferous and Permian Stratigraphy*, Utrecht, the Netherlands, 10–16 August 2003. Royal Netherlands Academy of Arts and Sciences, 481–496.

STREEL, M., HIGGS, K., LOBOZIAK, S., RIEGEL, W. & STEEMANS, P. 1987. Spore stratigraphy and correlation with faunas and floras in the type marine Devonian of the Ardenne-Rhenish regions. *Review of Palaeobotany and Palynology*, **50**, 211–229.

STREEL, M., CAPUTO, M. V., LOBOZIAK, S. & MELO, J. H. G. 2000*a*. Late Frasnian–Famennian climates based on palynomorph analyses and the question of the Late Devonian glaciations. *Earth Science Reviews*, **52**, 121–173.

STREEL, M., VANGUESTAINE, M., PARDO-TRUJILLO, A. & THOMALLA, E. 2000*b*. The Frasnian–Famennian boundary sections at Hony and Sinsin (Ardenne, Belgium): new interpretation based on quantitative analysis of palynomorphs, sequence stratigraphy and climatic interpretation. *Geologica Belgica*, **3**(3–4), 271–283.

STREEL, M., AVKHIMOVITCH, V. I. *ET AL.* 2003. Biostratigraphic correlation at the late or/and latest Famennian from Western, Central and Eastern European sections. State of the art. *IUGS Subcommission on Devonian Stratigraphy Newsletter*, **19**, 50–56.

STREEL, M., BELKA, Z. *ET AL.* 2005. Relation of the neritic microfaunas and continental microfloras with the conodont and other pelagic faunas within the latest part of the Famennian (with a few, new additional data and a synthetic correlation chart). *IUGS Subcommission on Devonian Stratigraphy Newsletter*, **21**, 17–20; **22**, 13–15.

STREEL, M., BRICE, D. & MISTIAEN, B. 2006. Strunian. *Geologica Belgica*, **9**(1–2), 105–109.

STREEL, M., MAZIANE-SERRAJ, N., MARSHALL, J. E. A. & THOREZ, J. 2007. A reference section for neritic facies at the transition Late to Latest Famennian. *IUGS Subcommission on Devonian Stratigraphy Newsletter*, **22**, 34–40.

THOREZ, J., STREEL, M., BOUCKAERT, J. & BLESS, M. J. M. 1977. Stratigraphie et paléogéographie de la partie orientale du Synclinorium de Dinant (Belgique) au Famennien supérieur: un modèle de bassin sédimentaire reconstitué par analyse pluridisciplinaire sédimentologique et micropaléontologique. *Mededelingen Rijks Geologische Dienst, new serie*, **28**, 17–32.

TURNAU, E. 1996. Miospore stratigraphy of Middle Devonian deposits from Western Pomerania. *Review of Palaeobotany and Palynology*, **93**, 107–125.

TURNAU, E. 2002. Two new spore genera from Euramerica and their stratigraphic and geographic distribution. *Review of Palaeobotany and Palynology*, **118**, 261–268.

TURNAU, E. & RACKI, G. 1999. Givetian palynostratigraphy and palynofacies: new data from the Bodzentyn Syncline (Holy Cross Mountains, central Poland). *Review of Palaeobotany and Palynology*, **106**, 237–271.

VAN DER ZWAN, C. 1980. Aspects of Late Devonian and Early Carboniferous palynology of southern Ireland. III. Palynology of Devonian–Carboniferous transition sequences with special reference to the Bantry Bay area, Co. Cork. *Review of Palaeobotany and Palynology*, **30**, 165–286.

WEDDIGE, K. 1984. Zur Stratigraphie und Paläogeographie des Devons und Karbons von NE-Iran. *Senckenbergiana lethaea*, **65**, 179–223.

WEDDIGE, K. 1988. Eifel conodonts. *Courier Forschungsinstitut Senckenberg*, **102**, 103–110, 116–118, 132–133, 140–142, 150.

ZIEGLER, W. & SANDBERG, C. A. 1990. The Late Devonian standard conodont zonation. *Courier Forschungsinstitut Senckenberg*, **121**, 1–115.