ABHANDLUNGEN DER GEOLOGISCHEN BUNDESANSTALT
Abh. Geol. B.-A. | ISSN 0016–7800 | ISBN 3-85316-02-6 | Band 54 | S. 201–212 | Wien, Oktober 1999
North Gondwana: Mid-Paleozoic Terranes, Stratigraphy and Biota | Editors: R. Feist, J.A. Talent & A. Daurer

Quantitative Palynology of Famennian Events in the Ardenne-Rhine Regions

MAURICE STREEL*)

5 Text-Figures and 5 Tables

Belgium
Germany
Devonian
Famennian
Palynology
Sedimentology
Climatology
Events

Contents

Quantitative Palynologie famennischer Ereignisse im Ardennen-Rhein-Gebiet

Zusammenfassung

Während des späten Famenniums können auf Grund von quantitativer Palynologie vier kontinentale ökologische Nischen, drei marine Megamilieus und zwei miteinander kontrastierende Palynofazies-Typen (Sauerstoff-haltig/-frei) erkannt werden. Angewandt auf ein restriktives back-barrier-Ablagerungsmilieu zur Zeit des Maximums der Regressionskurve (Ourthetal, Ost-Belgien) lässt eine solche Analyse auf zwei Zyklentypen schließen:

1) Auftreten von nassen Klimaten, die talaufwärts Pflanzenvergesellschaftungen an Sumpfrändern entwickeln;
2) Auftreten von Meeresspiegelhochständen, die talwärts Kohlensümpfe hervorrufen.

Dies sind Zyklen sechster Ordnung, d.h. weniger als 100 ka, die keinen bedeutenden langzeitigen Wandel in der kontinentalen Vegetation verursachen. Angewandt auf eine Abfolge des späten Famenniums im Bereich des Hangenberg-Ereignisses im Sauerland, Deutschland, bei der die Meeresspiegelschwankungen bekannterweise bedeutend gewesen sind, legt dieselbe Art von Untersuchung nahe, dass hier höhere Sedimentationsraten als im Ourthetal vorliegen sowie kurze Zyklen mit Klima- und Meeresspiegelveränderungen von wahrscheinlich ebenfalls sechster Ordnung. Die kontinentale Vegetation wurde durch das Hangenberg-Ereignis s.str. (die Basis des Hangenberg-Schwarzschiefers) nicht sonderlich beeinträchtigt. Im Gegensatz dazu haben jüngere kontinentale Hangenberg-Ereignisse, die mit dem Maximum der Regression zusammenfallen und wahrscheinlich mit viel nasserem Klima assoziiert waren, die zeitgleichen talaufwärtigen und küstennahen Pflanzenvergesellschaftungen stark modifiziert. Die küstennahe Gemeinschaft hatte sich nach diesem Maximum nicht wieder erholt, vermutlich als eine Folge kälteren Klimas (BRAND, 1993).

Die Dauer der Hangenberg-Ereignisse (die mit der Miosporen-Zone LN zusammenfällt) war wahrscheinlich geringer als 100 ka, wie auch SANDBERG & ZIEGLER (1996) vorgaben. Als Konsequenz hatte auch die in Brasilien bekannte Glazialperiode, die durch dieselbe Miosporen-Zone charakterisiert ist, eine sehr kurze Dauer. Das Klima im jüngsten Famennium war in den hohen Breiten wahrscheinlich schwankend mit schnell oszillierenden kalten (oder glazialen) und gemäßigten (interglazialen) Phasen.

*) Author's address: Prof. MAURICE STREEL, University of Liège, Paleontology, Bât. B18 Sart-Tilman, B-4000 Liège 1, Belgium.

Abstract

During the late Famennian, quantitative palynology allows four continental ecological niches to be recognized, three marine megaenvironments and two kinds of contrasting palynofacies (oxic/anoxic).

Applied to a restricted marine back-barrier setting during a maximum of a regression peak (Ourthe Valley, Eastern Belgium), such analysis suggests two kinds of cycles:

1) recurrence of wet climates developing upstream swamp margin plant communities,
2) recurrence of high sea-levels developing downstream "coal" swamps.

These are 6th order cycles i.e. of less than 100 ka and do not introduce any significant long-term change in the continental vegetation.

Applied to a latest Famennian sequence around the Hangenberg Event in Sauerland, Germany, where the changes in sea-level are known to have been severe, the same kind of analysis suggests a higher rate of sedimentation than in the Ourthe Valley and short cycles involving climatic changes and sea-level changes, probably also of the 6th order. Continental vegetation has not been strongly affected by the Hangenberg Event sensu stricto (the base of the Hangenberg Black Shale). On the contrary, younger "continental Hangenberg events", corresponding to the peak of the regression, probably associated with a much wetter climate, have strongly modified the contemporaneous "upland" and "coastal" plant communities. The "coastal" one has not recovered after that peak, probably as a consequence of a colder climate (BRAND, 1993).

The duration of the Hangenberg Events (corresponding to the miospore LN Zone) was probably less than 100 ka as also suggested by SANDBERG & ZIEGLER (1996). The consequence is that the glacial episode known in Brazil, which is characterized by the same miospore Zone, had also a very short duration.

Latest Famennian climate was probably unstable with quick oscillating cold (or glacial) and temperate (or interglacial) phases in the high latitudes.

1. Introduction

Neritic shales may contain large amounts of palynomorphs but they rarely carry any information on time duration and, often, do not allow a very accurate correlation with the pelagic detailed data available for instance from conodonts and ammonoids. Sediments around the Hangenberg Event near the Devonian/Carboniferous boundary – DCB – offer opportunity to search for such correlation because it corresponds to severe changes in the sea level (BECKER, 1993b) allowing the occurrence of palynomorphs and pelagic faunas in one and the same section and because time-duration has been proposed for the relevant sequences. The ultimate goal of this paper is to study the environmental control of organic particles, including miospores, in sequences in the Sauerland, Germany, with emphasis on the Stockum trench II.

The environmental control on the key marine faunas is rather well known. See, for instance, the conodont biofacies concept (many papers of SANDBERG and collaborators cited in SANDBERG et al. [1988, p. 273]) and the effect of environmental change on Ammonoidea (HOUSE, 1993). On the contrary, the environmental interpretation based on palynomorph quantitative studies is still poorly understood in the Devonian and, therefore, needs here some preliminary statements and demonstrative applications. We have selected the late Famennian section of Esneux railway, in eastern Ardenne, for such preliminary application.

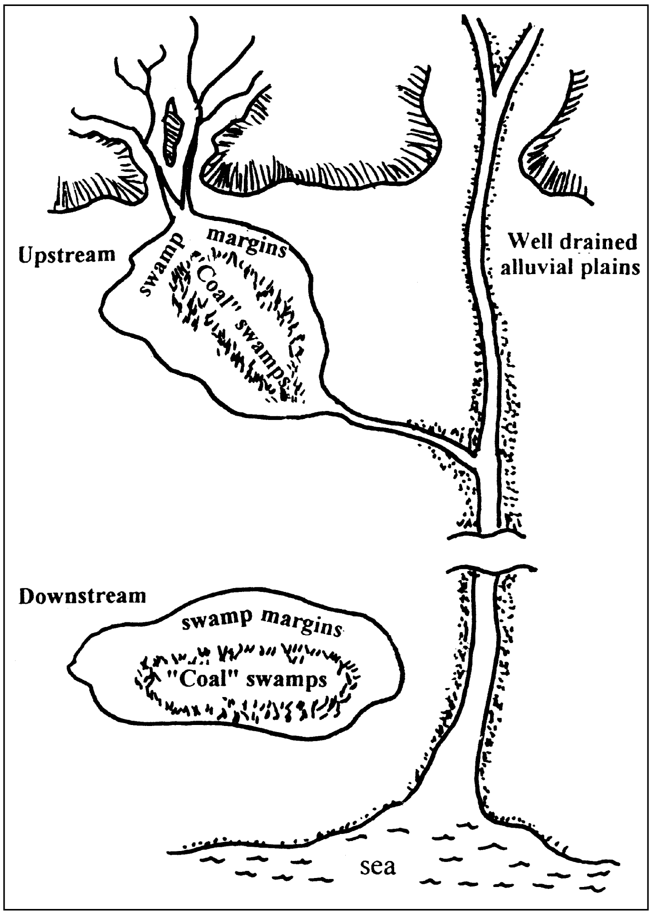
2. Paleoenvironmental Reconstruction Based on Palynomorphs and Palynodebris

We shall consider three groups of organic particles: the continentally produced miospores, the marine palynomorphs and the, most often non-marine, palynodebris corresponding to all organic particles of land plant origin, found in the organic matter residue after dissolution/sieving of the silicates.

2.1. Miospores

(Text-Fig. 1)

During the late Famennian, the most abundant miospores originated from at least four distinct continental environments (see reconstruction based on joint megaflora-miospores studies made in Virginia, USA, by STREEL & SCHECKLER [1990]). They are listed in Table 1 (See also MAZIANE [1993], STREEL & MAZIANE in DREESEN et al. [1993] and STREEL [1996]).



Text-Fig. 1.
Scheme of water distributary system with different continental environments providing miospores in the sea basin.

In the assemblage recorded so far in the late Famennian of the Ardenne, *Aneurospora greggsii* is, most often, the dominant species and should be considered to represent the dominant vegetation (*Archaeopteris*) of the well drained allu-

Table 1.
Miospores dominating a specific continental environment during the late and latest Famennian.
After STREEL & SCHECKLER (1990); JARVIS (1992); DREESEN et al. (1993).

Well drained alluvial plains	"Coal" swamps	Upstream swamp margins	Downstream swamp margins
Aneurospora greggsii (probably *Archaeopteris* microspores)	*Diducites plicabilis* - *Auroraspora varia* Complex (*Rhacophyton* isospores)	*Grandispora gracilis* *Apiculiretusispora coniferus* (*Retusotriletes* cf. *coniferus*)	*Vallatisporites hystricosus* (*V. pusillites* auctorem) *Auroraspora asperella* (*A. macra* auctorem) *Retispora lepidophyta*

vial plains which developed then, at some distance, along the sea coast. Such an environment should not have been directly affected by the short-termed variations of the sea level and therefore remains a constant in the landscape of that time. Of course, major sea transgressions or regressions might have reduced versus extended the relevant covered area.

The upstream (upland) "coal" swamp and swamp margin environments should also not have been affected by the fluctuation of the sea level. Their reduction or extension would have been first controlled by dry versus wet climates (The "VON POST effect" in CHALONER & MUIR [1964]), wet climate producing flooding episodes which, in turn, carry more upland miospores into the sea basin (The "MUIR effect" in STREEL & RICHELOT [1994]).

The downstream (coastal) "coal" swamp and swamp margin environments, on the contrary, were directly controlled by the short-termed changes in the sea level: any high sea level will induce a high fresh-water table in these environments and increase therefore their importance (their proportion) in the coastal landscape, producing more of the relevant miospores (The "NEVES effect" in CHALONER & MUIR [1964]).

2.2. Marine Palynomorphs

The continentaly produced miospores were washed, in rather great amount, into the sea basin by wind and rainfall, and water streams. In the marine sediments, miospores (thousands to hundreds of thousands per gram of sediment) are found together with more autochthonous, "marine" palynomorphs, the sphaeromorphs and acritarchs. The ratio miospores/sphaeromorphs + acritarchs provides a good tool to characterize the degree of marine influence in a sediment but also, using the "marine" palynomorphs alone, it was demonstrated (BECKER et al., 1974; MAZIANE & VANGUESTAINE, 1997), in the late Famennian that:

1) the sphaeromorphs abundance corresponds to some (here back barrier) restricted marine environment;
2) the abundance of the thin-spinned acritarch *Gorgonisphaeridium*, corresponds to intermediate marine conditions;
3) more diversified acritarchs characterize more open marine environments (see Table 2).

Table 2.
"Marine palynomorphs" dominating a specific marine environment during the late and latest Famennian.
After BECKER et al. (1974); MAZIANE & VANGUESTAINE (1997): THOMALLA et al. (1997)

Back barrier restricted marine environment	Intermediate marine environment	Offshore marine environment
Sphaeromorphs (Leiospherids)	*Gorgonisphaeridium* spp.	Abundant and diversified acritarchs

"Marine" palynomorphs offer therefore criteria to control the variability of the marine environments where miospores were trapped. They allow also to define a useful "distality index" (THOMALLA et al., 1997) measuring the inshore versus offshore character of the marine deposits.

2.3. Palynodebris

Palynodebris quantitative analyses offer criteria to evaluate the conditions of transportation, sedimentation and diagenesis of the organic particles. Nowadays, their nomenclature is rather detailed but may be reduced, for the purpose of the present study, to simple statements related to the oxic versus anoxic character of the palynofacies: permanent anoxic condition and short transport preserve palynofacies rich in thin, more or less translucid, heterogeneous debris; primary or subsequent oxic conditions and/or long transport provide palynofacies where these heterogeneous debris are destroyed and, therefore, are rich in black homogeneous debris.

A poor oxygenation of the bottom water (anoxic condition) may result from density stratification of the water column and sluggish circulation in basinal area (density stratification occurs after a reduction in surface water salinity, for instance, by river runoff). But palynomorphs are generally poorly present in deep basinal area because they originate often from a distant shoreline and, unless they were produced in very large amount, most are sorted and oxydised during transport. Relatively anoxic condition may also be present, in restricted marine environments with quiet deposits, rich in organic matter, and kept away from oxygenated waters.

3. The Late Famennian Fontin Event, at Esneux Railway (Ourthe Valley, Belgium)

3.1. Generalities

The Fontin Member of the Evieux Formation (North of the Ourthe valley) is characterized by a short-term transgressive pulse that developed in a restricted marine, back-barrier, setting, during the maximum of a Famennian regression peak, well below the Strunian transgression. The deposition of autochthonous carbonates at the climax of the late Famennian megaregressive sequence was named the Fontin Event by DREESEN & JUX (1995).

It should not be confused with the two carbonate beds occurring in the lower part of the Esneux railway section, where productive samples for conodonts have indicated the Middle *expansa* (formerly Lower *costatus*) Zone (DREESEN et al., 1993). Miospores and locally, "marine" palynomorphs, are rather abundant in this section and correspond to the VCo (*versabilis-cornuta*) Zone (MAZIANE et al., in press).

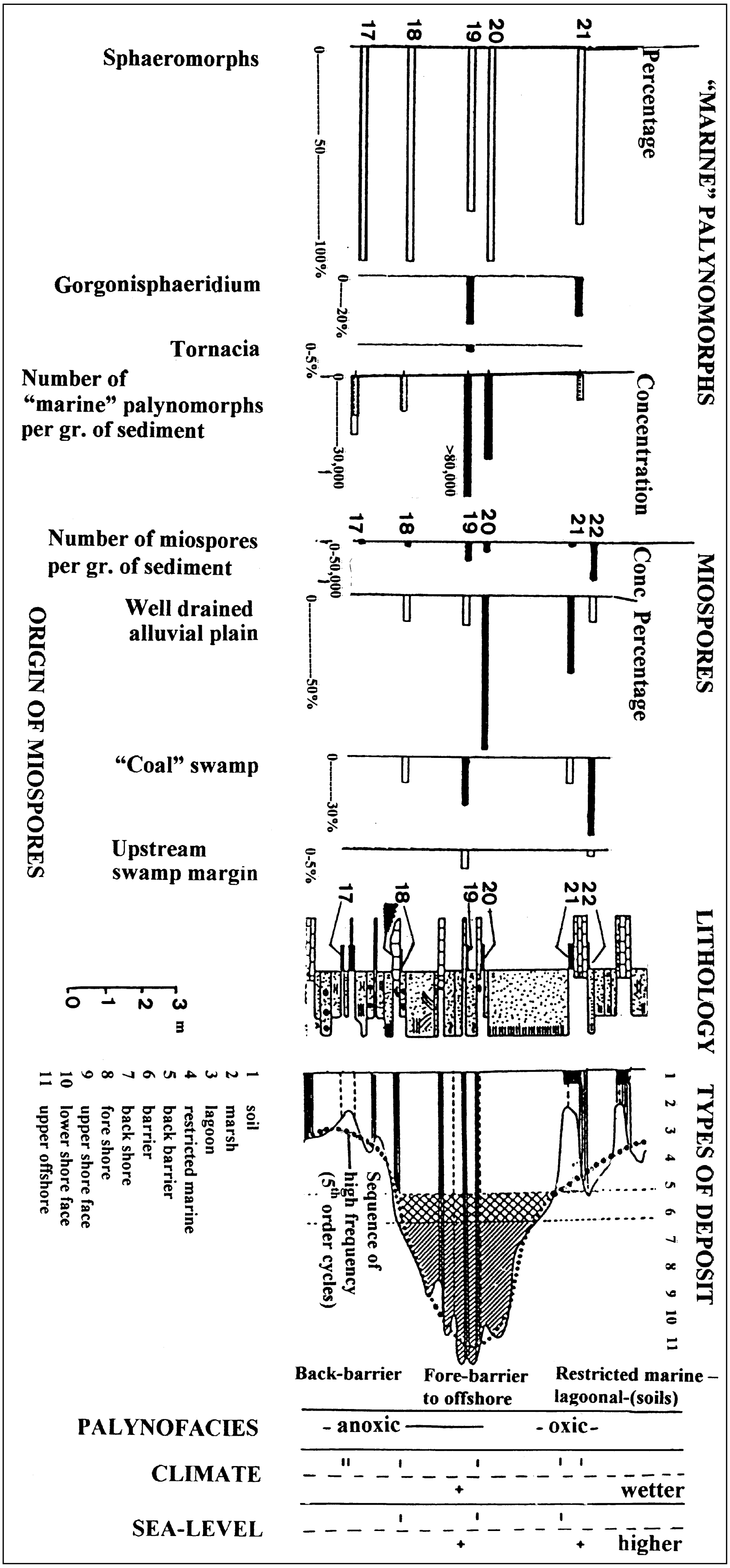
3.2. Quantitative Palynology of the Sequences

In the lower part of the section, a 9 meter-thick sequence has given palynomorph assemblages with abundant “marine” elements like sphaeromorphs, *Gorgonisphaeridium* and other acritarchs (MAZIANE, 1993). The sandy sequence is interbedded by carbonate and shaly layers and is interpreted as a succession of 3 groups of different marine environments, from the base to the top:

Back-barrier
The back-barrier environment is characterized by high percentages of sphaeromorphs and no acritarchs (samples 17, 17b, 18) which suggest restricted marine conditions. The palynofacies corresponds to rather anoxic conditions. The amount of miospores reaching such a restricted environment is rather low (less than 10,000/gr.sed.) and no miospore groups were dominant.

Fore-barrier to offshore
Samples 19 and 20, from the middle part of the sequence, correspond to the fore-barrier to offshore environments. Sample 19 has abundant *Gorgonisphaeridium* and a few other acritarchs (like *Tornacia*). Miospores are more abundant (25,000/gr.sed.) and dominated by the *D. plicabilis-A. varia* Complex. Sample 20, with sphaeromorphs only, suggests another restricted marine environment like in the lower part of the sequence (samples 17 to 18) but receiving here, high percentages of the miospore *A. greggsii*. Apparently, the two sampled shaly layers suggest a rather quick succession of

1) a high sea level corresponding to an expanded downstream “coal” swamp with their miospores trapped in some intermediate marine conditions (fore-barrier ?) and
2) a less high sea level corresponding to a reduced downstream “coal” swamp with miospores from the well drained alluvial plain



Text-Fig. 2.
Quantitative palynology in the lower part of the Esneux-railway section (Ourthe Valley, Belgium).
Sample 17 for 17 and 17b. Lithology and type of deposits after LAFLEUR (1991).

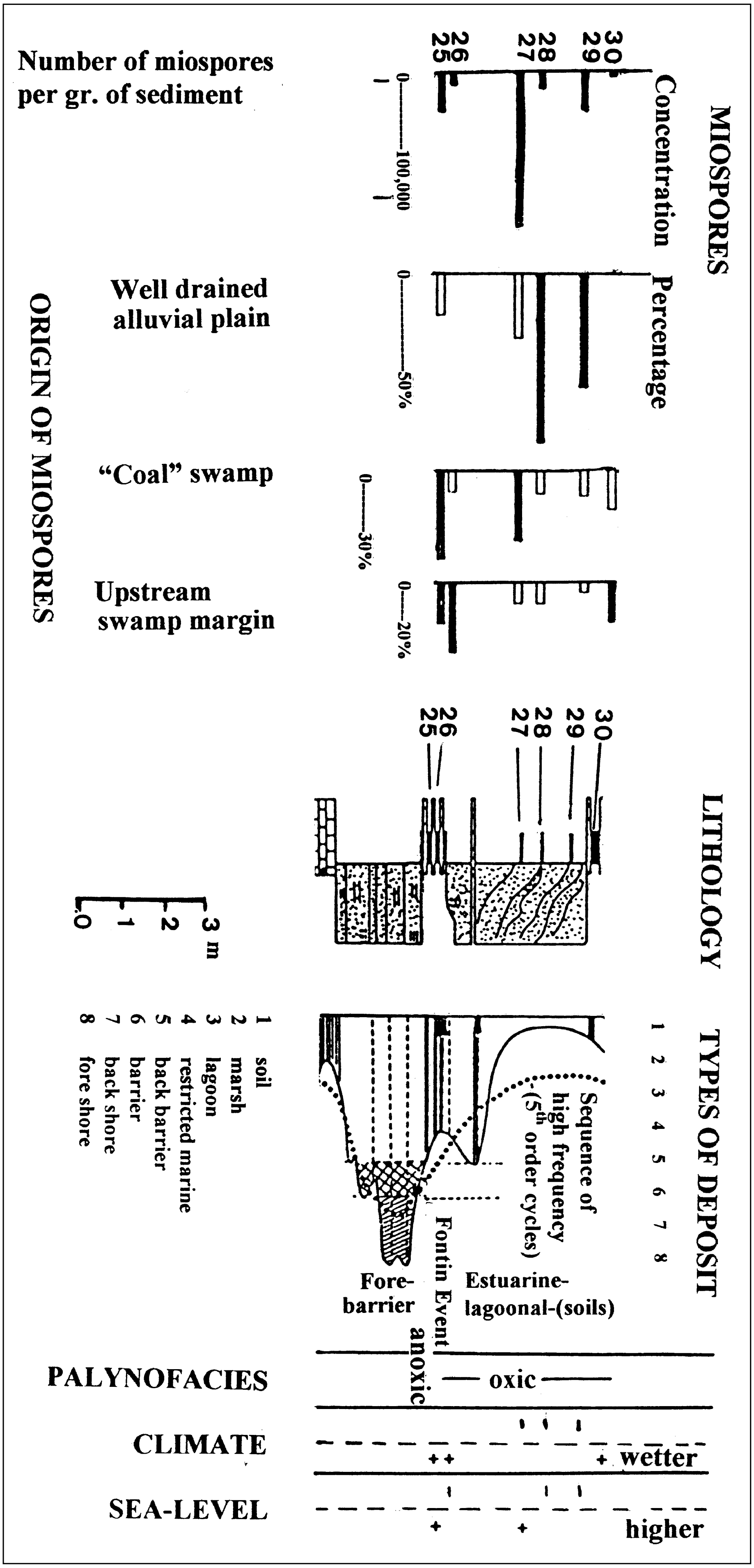
being trapped in a more restricted marine environment. Real offshore conditions are not demonstrated by these shales which carry a palynofacies corresponding to rather anoxic conditions.

Restricted marine-lagoonal and soils
(Text-Fig. 2)

The marine conditions are less restricted in the upper part of the sequence where sample 21 shows sphaeromorphs, *Gorgonisphaeridium* and *A. greggsii* co-dominant. Sample 22, with almost no "marine" palynomorphs and a more significant amount of miospores (50,000/gr.sed.) is nearer the samples of the 4-meter-thick sequence (Text-Fig. 3) studied further, particularly nearer sample 27. Both samples contain abundant miospores of the *D. plicabilis-A. varia* Complex (originating from "coal" swamps) but few *G. gracilis* (originating from upstream swamp margin). Sample 22 might correspond to another high sea level, here registered in a short-termed lagoonal episode. These samples (21 and 22) carry a palynofacies rich in black, homogeneous debris, resulting of oxic condition of transportation and/or deposition.

In the upper part of the section, at the Fontin Event, a 4 meter-thick sequence corresponds to a spectacular estuarine channel in lateral accretion bracketted by carbonate beds and a paleosoil (Text-Fig. 3) and has given interesting palynomorph assemblages (MAZIANE, 1993). "Marine" palynomorphs are poorly represented (less than 10 %) but miospores are abundant (up to 130,000/gr.sed.). The dominant *D. plicabilis-A. varia* Complex in sample 25 might either correspond to

1) an expanding downstream "coal" swamp driven by a short-termed high in the sea level, or/and to



Text-Fig. 3.
Quantitative palynology in the upper part of the Esneux-railway section (Ourthe Valley, Belgium).
Lithology and type of deposits after LAFLEUR (1991).

2) an expanding upstream "coal" swamp with miospores being washed downwards with *G. gracilis* miospores.

Unfortunately, upstream and downstream "coal" swamps cannot be discriminated by their miospore production, being dominated by the same plant type: *Rhacophyton* (SCHECKLER, 1986). However, the anoxic character of the palynofacies of this sample with thin translucid heterogeneous debris, excludes a long transport in water of all the organic particles and suggests therefore that only the first explanation is valid. This sample indicates the exact stratigraphic level of the Fontin Event. Shaly layers intercalated between the carbonate beds near the base (samples 25, 26) or near the top (sample 30) of the sequence, carry miospore assemblages characterized by abundant *G. gracilis* (from upstream swamp margin). This species might correspond to floods originating upstream. Shaly layers within the estuarine channel demonstrate miospore assemblages dominated by *D. plicabilis-A. varia* Complex (originating from "coal" swamps) in the lower half (sample 27) and by *A. greegsii* (originating from well drained alluvial plain) in the upper half (samples 28, 29). Samples 26 to 30 show a palynofacies rich in black, homogeneous debris, here probably resulting from oxic condition during transport.

Obviously the shaly layers available for palynological studies in this section are more present in the regressive parts of the sequences than in the transgressive parts (where they might have been destroyed soon after deposition). They display two kinds of possible cyclicity:

1) recurrence of high sea-levels developing downstream "coal" swamps as shown by samples 19, 22, 25 (matching the Fontin Event) and 27;
2) recurrence of wet climates developing upstream swamp margin vegetation as shown by samples 19?, 25, 26 and 30.

These potential cycles are shorter (6^{th} order cycle, THOREZ, personal communication) than the "high frequency (HF) cycles", demonstrated in this Esneux railway section by LAFLEUR (1991) who considers that her 5 HF cycles correspond more or less to one conodont zone (500 ka in SANDBERG and ZIEGLER [1996]) and that, therefore, each HF cycle had a duration of about 100 ka (5th order cycle, VAIL, 1987). Our cycles are more comparable to the Plio-Pleistocene cycles (6^{th} order cycles, 41 ka) demonstrated by NAISH & KAMP (1997).

There is no evidence of any major change in the vegetation which might allow to characterize the Fontin Event by comparison with other parts of the section of Esneux railway in the same way as it might have allowed "a short-term come-back of stromatoporoid biostromes in the Franco-Belgian Basin, possibly as a result of a post-glacial warming of the ocean waters by the end of a supposed Famennian glaciation" (DREESEN & JUX, 1995, p. 118). We shall demonstrate later that the Famennian glaciation postdated this Event which evidently did not affect the contemporaneous "upland" vegetation in the same way as we shall demonstrate it at the DCB.

4. The Latest Famennian Hangenberg Event at the Stockum Trench II (Sauerland, Germany)

4.1. Palynomorphs in Sauerland

In the Sauerland area which is characterized by pelagic facies, the miospore succession starts with the LE (*lepidophyta-explanatus*) Zone found within the highest part of the Early *praesulcata* conodont Zone, i.e. in the upper part of the Wocklum Limestone, of the Hasselbachtal section*). This zone is followed by the LN (*lepidophyta-nitidus*) Zone which starts with the Hangenberg Black Shales (HBS), on top of the Wocklum Limestone which uppermost part bears the poorly defined Middle *praesulcata* conodont Zone. The LE Zone at Hasselbachtal and the LN Zone in the HBS of several sections in Sauerland are based on rather poor assemblages with a small number of miospores of limited species diversity (HIGGS & STREEL, 1994). Acritarchs are almost absent but it is not the result of their decline at the end of the Devonian**) because they are known (WELDON, 1997) with LE-LN miospore Zones in the Riescheid section, a section where miospores are abundant, well preserved, and displaying particularly abundant *Diducites* complex, but where no Wocklum Limestone nor HBS facies is present.

At Drewer, a more offshore locality, the Drewer Sandstone in the upper part of the Wocklum Limestone, and the HBS, which are time-equivalent of part at least of the LE-LN Zones, are completely barren. The almost absence of acritarchs and the small number and bad preservation of miospores, if any, together with abundant other organic debris in the HBS of the Sauerland, is striking and will be discussed later (see 4.3.).

Above the HBS, the miospore assemblages are rich in both species and specimens (up to 68,000 miospores/gr.sed. in the Oberrödinghausen railway section, [PAPROTH & STREEL, 1982]) and correspond to the successive LN and VI (*verrucosus-incohatus*) Zones. But Hangenberg Shale sequences (not Hangenberg Sandstone!) in the Oese, Apricke and Oberrödinghausen sections, which were deposited in a somewhat isolated small basin in the immediate eastern area near the Seiler deltaic deposits (BLESS et al., 1993, Text-Fig. 3), are characterized by reworked miospores largely outnumbering those produced by the contemporaneous flora. The *Diducites* complex of miospores is here poorly present.

The adverse conditions for the deposition and the preservation of miospores are met again everywhere within the overlying Hangenberg Limestone.

Compared to the late Famennian miospore assemblages studied in the Middle and Late *expansa* conodont Zone in Belgium where *A. greggsii* is abundant, the assemblages from the Middle *praesulcata* conodont Zone in the Sauerland have few *A. greggsii* although the species and its assumed mother plant (*Archaeopteris*) are known from the stratigraphic equivalent, the Kiltorcan Beds, in Ireland (JARVIS, 1992). A morphologically related miospore, *Apiculiretusispora coniferus* (part of the *Retusotriletes incohatus* of HIGGS & STREEL 1984), is abundant in the LN and VI assemblages of the Sauerland but seems to correspond to upstream swamp margins environment rather than to well drained alluvial plains.

---

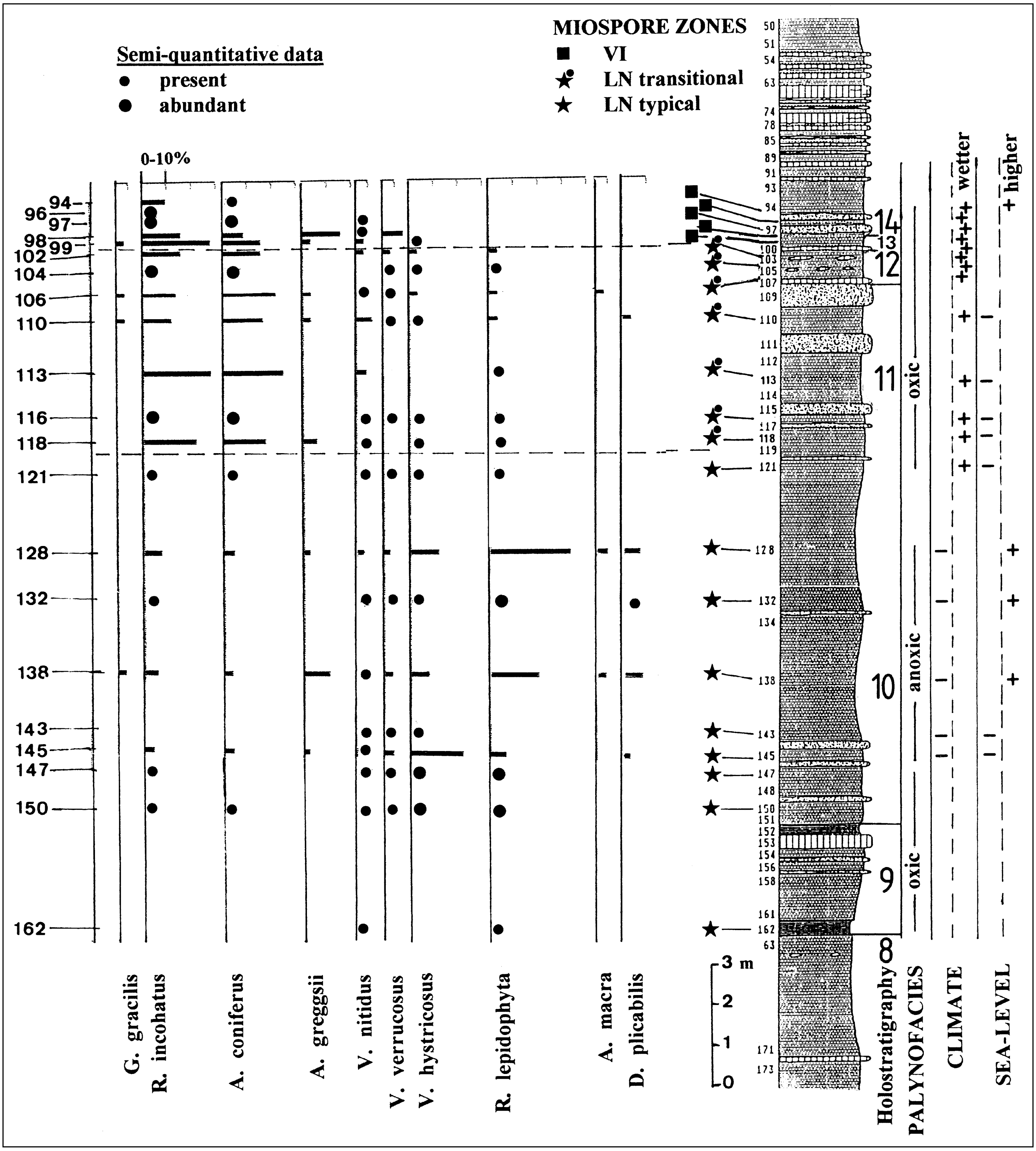
*) The base of the LE Zone is known in the Riescheid section in Sauerland (HIGGS & STREEL, 1994) and the Chanxhe I and II sections in eastern Belgium (DREESEN et al., 1993; MAZIANE et al., in print) but both localities are poorly dated at that level. An Early *praesulcata* or a Late *expansa* "age" is assumed from the occurrence of a Late *expansa* conodont fauna some 18 m below the base of the LE Zone in Chanxhe I.

**) A dramatic decline of the acritarchs at the end of the Devonian is consistently supported by all data examined thus far around the world (STROTHER, 1996). But, during the late Famennian, detailed data are rather sparse and do not establish whether the change was relatively sudden or gradual (MARTIN, 1993, p. 521).

4.2. Quantitative Palynology of the Sequences at the Stockum Trench II

The Stockum sections are situated on the northeast flank of the Ebbe anticline of the Sauerland and are composed of several outcrops and trenches located about 1 km from the village of Stockum. Trench II was described by CLAUSEN et al. (1994). It is a 28 m thick Devonian–Carboniferous sequence of clay, siltstones and sandstones with intercalated carbonates. Miospores of typical LN, transitional LN and VI Zones were recovered (See Text-Fig. 4) from the almost 17 m of sediments of Hangenberg Black Shales (HBS), Hangenberg Shales and Sandstones, and Stockum Limestone (HIGGS et al., 1993).

In the HBS (sample 162), the miospores are scarce but black homogeneous palynodebris are abundant. In the lower half of the Hangenberg Shales and Sandstones (samples 147 to 128), miospores are abundant and rather



Text-Fig. 4.
Quantitative palynology in the Stockum trench II section (Sauerland, Germany).
Miospore zones and lithology after HIGGS et al. (1993); holostratigraphy after BECKER (1996).

well preserved, palynodebris being more heterogeneous and translucid than in the HBS. Obviously the deposition of the Hangenberg Shales was very rapid, preventing the oxidation. Here, the downstream swamp margin miospores (*V. hystricosus*, *R. lepidophyta*) are abundant. Between samples 145 and 138, sandstones become exceptional and the *R. lepidophyta* dominance takes over the *V. hystricosus* dominance corresponding also to a small increase of the "coal" swamp miospore *D. plicabilis*. From these observations one can deduce that the *R. lepidophyta* mother plant should have occupied a wetter margin of the swamp than the *V. hystricosus* mother plant and that the "coal" swamp itself was not very much developed, as noted before in the Oese, Apricke and Oberrödinghausen sections by the poor presence there of the *Diducites* complex.

In the upper half of the Hangenberg Shales and Sandstones and in the Stockum Limestone (samples 121 to 94), sandstones are again more and more abundant and the palynofacies returns to oxic conditions of deposition. Coarser sediments and oxic conditions result probably from river runoff after a wetter climatic development. Indeed the upstream swamp margin miospores (*A. coniferus*) become abundant and take over the *R. lepidophyta* dominance. The strong regression of the downstream swamp margin miospores (*V. hystricosus*, *R. lepidophyta*) and the almost complete extinction of the "coal" swamp miospore, *D. plicabilis*, suggest that the new wet climatic condition matched the lowest reached sea-level. These probably adverse climatic and edaphic environmental changes strongly reduced the latest Famennian downstream swamp margin and "coal" swamp vegetation (corresponding to the *lepidophyta* assemblages).

These plant communities completely disappear immediately below the level 100 of the Stockum Limestone i.e. very near but below the DCB (See 4.5.).

At the level of sample 94, immediately above the last sandstone horizon, very abundant acritarchs suddenly occur, making 70 % of the total of the palynomorphs (miospores + acritarchs). Surprisingly, the assemblage is composed of one single "species" of *Micrhystridium*. This genus is known to characterize, with other thin-spined acritarchs, perireefal environments in Frasnian beds (VANGUESTAINE et al., 1997). Here, it seems to represent a first opportunistic blooming of one single taxon, recovering after the "latest Devonian extinction". It seems to coincide "with the basal Carboniferous eustatic rise which internationally allowed to return to the deposition of aerobic cephalopod limestones" (BECKER, 1993b) i.e. to adverse conditions for the preservation of miospores.

4.3. Holostratigraphy and Cyclicity of Deposits

It is possible to subdivide, with much detail, the different sections available in the Sauerland using time-units of sequence stratigraphy (VAN STEENWINKEL, 1993, Text-Fig. 7), units of T-R cycles (BLESS et al., 1993, Text-Fig. 4) or holostratigraphic intervals (BECKER, 1996, Tab. 2). These units (1 to 4 or 2 to 11) or intervals (8 to 15) are compared (Text-Fig. 5) within the range of the miospore assemblages available in the area. BECKER (1996, p. 27) suggests that these intervals provide an average time discrimination in the order of 200 ka i.e. 1.6 ma for the intervals 8 to 15. Combining data given by CLAUE-LONG et al. (1993, Text-Fig. 3) and SANDBERG & ZIEGLER (1996, Text-Fig. 1a), a time-range of 1.4 ma can be calculated but the last authors recommend a much shorter time range (100 ka) for intervals 8 to 11 (the Middle *praesulcata* conodont Zone), implying a much longer time-range for intervals 12 to 15 (The late *praesulcata* and part of the *sulcata* conodont Zones) (Text-Fig. 5). The LN miospore Zone and their stratigraphic most often shaly equivalents cover very different thicknesses in Sauerland and in Southern Ireland (Table 3), ranging from a few centimeters to a few hundreds of meters. Comparing three close sections in the Wocklum Limestone of the Sauerland, BECKER (1996, p. 31 and Tab. 3) concludes to surprisingly similar thicknesses of individual ammonoid zones but remarks that differences, where any, are mostly based on the development of shaly intervals. We can, in the same way, suppose that the clastic input in Sauerland and Southern Ireland, although possibly very different, covers similar time range and accept, from the conodont evidence, that this time-range was rather short (100 ka?).

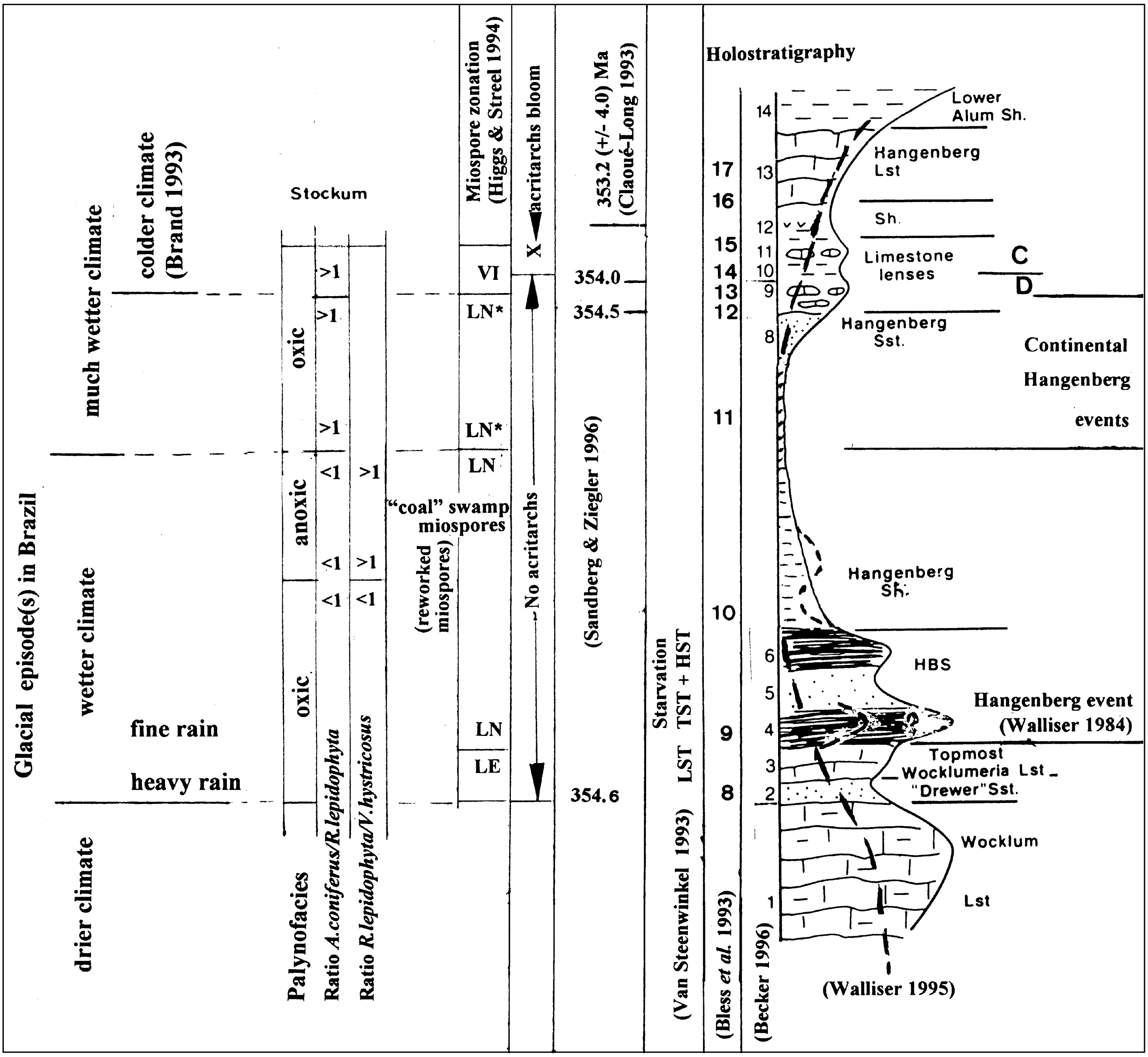
Table 3.
Thicknesses of the LN miospore Zone or holostratigraphic equivalents in the Sauerland and Southern Ireland.

Sauerland (LUPPOLD et al., 1994)		Southern Ireland (CLAYTON et al., 1986)	
Müssenberg	0.05	South Munster Basin	>250.00
Effenberg	0.40		
Wocklum	1.40		
Hasselbachtal	4.75		
Apricke	5.25		
Ober-Rödinghausen railway	6.40		
Ober-Rödinghausen road	13.90		
Stockum trench II	15.50		
Hangenberg	27.00		
Oese	29.50		

The cyclicity observed above the Hangenberg Event in the Sauerland is obviously of the same nature as the two kinds of cycles (change of sea-level and of climate) described in the late Famennian of the Esneux railway section. They probably also correspond, therefore, to 6th order cycles, adding some substantiation to SANDBERG & ZIEGLER (1996) opinion of a short time-range (100 ka) for the intervals 8 to 11 (the Middle *praesulcata* Zone). Consequently, the rate of sedimentation operating during the miospore LN Zone in the Sauerland was high compared to the rate observed during the miospore VCo Zone in the Ourthe valley (the scales of the logs on Text-Figs. 2, 3 and 4 are almost similar). Of course the rate of sedimentation might have been even much higher (one magnitude higher) in other regions like Southern Ireland (see Table 3). Higher rate of sedimentation and sandy input should correspond to wetter phases of the climate and increased river supplies during the Latest Famennian than during the Late Famennian.

Evidence of wetter climate might have started in the upper part of the Wockum Limestone with the Drewer Sandstone and this would explain the genesis of the overlying HBS. Indeed, after VAN STEENWINKEL (1993, p. 678), the HBS is a condensed unit, created by sediment starvation. It would correspond to a worldwide event*), characterized in the Sauerland area by basinal condensation during a maximum rate of eustatic sea-level rise. It most likely re-

*) VAN STEENWINKEL (1993, p. 674) proposed two scenarios: a HBS having a worldwide significance and being older than the incision event at the Seiler locality versus a HBS locally restricted, of the same age or younger than this incision event. We favor the first scenario because such major incision fits better the maximum period of regression which followed the HBS deposition.



Text-Fig. 5.
Synthesis of quantitative palynology and comparison with sedimentology and climatology in latest Famennian sections of the Sauerland (Germany. Lithology: no scale. C/D: Devonian/Carboniferous Boundary.

presents the condensed latest-Devonian Transgressive and Highstand Systems Tracts (TST + HST) of the previous sequence, the Wocklum Limestone (including the Drewer Sandstone) corresponding to the underlying Lowstand (LST). During the deposition of the upper part of the Wocklum Limestone, erosion of organic soils and vegetation probably started on the continent and rivers discharged a large amount of sand, mud and organic matter into the sea. But, except in the Riescheid nearshore area where pre-LN shaly sediments are several metres thick, this erosional material was transported by marine currents far offshore, the sand being deposited first, as on the shoal of the Drewer area (BLESS et al., 1993, Text-Fig. 3), the mud and organic matter bypassing the shoals and being deposited further into the basin to produce lowstand submarine fans (precursor of the Basin Floor Fan or BFF of VAN STEENWINKEL [1993, p. 678]). Subsequently, during the next sea-level rise (TST + HST), together with ascending of the anoxic zone, upwelling or overturn (GIRARD, 1994) might have spread the black mud everywhere in the basin, except on top of some shoal (Müssenberg) and, of course, on the nearshore area (Riescheid). The almost absence of acritarchs demonstrates that the HBS material was never deposited nearshore before the upwelling or overturn and the impoverishment of its content of miospores and the destruction of the thin, more or less translucid, heterogeneous debris (See 2.3.) prove its long transport into the sea before definitive deposition in the anoxic zone.

Heavy precipitation (thunderstorm rains), necessary to wash out the terrigeneous material, during the end of the Wocklum Limestone deposition*) might have turned into fine rains depositing mostly clays (MALEY, 1982) during the

*) Despite the fact that most sections in Sauerland and elsewhere contain blind or reduced-eyed in the topmost part of the Wocklum Limestone (R. FEIST, 1992 and personal communication, July 1998), the presence, at Hasselbachtal, in the arenitic topmost part of the Wocklum Limestone, of reduced-eyed trilobites (BECKER, 1996, p. 30) and the more recent discovery (BECKER, personal communication, August 1998) of poorly preserved tabulate coral debris suggest that this layer may well equal the Drewer Sandstone.

HBS formation. Continuous supply of rain water into the sea would explain the "contamination" of the HBS with very scarce contemporaneous miospores (like *Vallatisporites vallatus* and *Verrucosisporites nitidus*) and would contribute (ALGEO & SCHECKLER, 1998) to the stagnation of bottom water and sedimentation of the black, pelagic muds, rich in marine organic matter (sapropels), by establishing a steep vertical salinity gradient in the water column, a processus well described by ROSSIGNOL-STRICK et al. (1982) in the Quaternary of the Mediterranean Sea.

4.4. The Hangenberg Continental Events

The Hangenberg Event is defined (WALLISER, 1984, Text-Fig. 2; 1995, Text-Fig. 6) at the base of the HBS. Within the pelagic facies realm, this level is thus characterized by an abrupt lithological change which induced a strong discontinuity in the critical faunal groups.

In contrast to the pelagic environment, neritic shallow water and continental environments appear to have not been strongly affected by this event. As far as miospores are concerned, the LE/LN transition (The Hangenberg Event of WALLISER [1984, 1995]) shows only very minor changes (HIGGS & STREEL, 1994). On the contrary significant, quantitative changes occur at two higher levels (Text-Fig. 5): between the Hangenberg Shales and the Hangenberg Sandstones and also at the Stockum Limestone level i.e. very near, but below, the D/C Boundary. We name here these levels the "continental Hangenberg events". After the HBS deposition, a very quick drop of the sea-level has suddenly altered the steep vertical salinity gradient in the water column of the basin, involves the deposition of the Hangenberg Shales and allows an incision event at the Seiler locality.

Except in the area of Riescheid, *Rhacophyton* "coal" swamps were poorly developed on the continent and local erosion contributes for a large supply of reworked miospores in the Oese, Apricke and Oberrödinghausen area. In the Stockum area, local conditions or a short interruption in the sea-level drop allow the temporary reintroduction of "coal" swamps in the vicinity. A sharp change occurs then with the deposition of the Hangenberg Sandstones and equivalents. Palynofacies returns to oxic conditions. Coarser sediments and oxic conditions result probably from river runoff after a much wetter climatic development and coincided with the lowest reached sea-level of the Famennian (the Hangenberg Sandstone Lowstand).

On the contrary of what we observed in the neritic facies studied at the level of the Fontin Event in the Ourthe valley, the "continental Hangenberg events" in Sauerland strongly affected the contemporaneous "upland" and "coastal" vegetations.

4.5. Climatic Implication

Global climatic changes across the Devonian/Carboniferous limit has been investigated by geochemistry of brachiopods (POPP et al., 1986; BRAND, 1989, 1993; BRAND & LEGRAND-BLAIN, 1993). These authors note that it was not until the latest Famennian, that water temperatures started to decline. Detailed conclusions, however, are hampered by lack of biostratigraphic resolution of studied horizons. Indeed, no samples were tested which fit, without doubt, the HBS and Hangenberg Shales and Sandstones interval (They normally lack brachiopods !). The Wocklum Limestone (BRAND, 1989, 1993) is older. The Louisiana Limestone in eastern Missouri, USA (BRAND, 1993) and the "middle siliciclastic calcarenite" in the Griotte Formation at La Serre (Montagne Noire, France; BRAND & LEGRAND-BLAIN [1993]) might be slightly younger than our sequence as they are considered of Late *praesulcata* "age" (But see GIRARD, 1994). Only the shaly base of the "lower oolite" in the Griotte Formation at La Serre might be an equivalent of the Hangenberg Shales (BLESS et al., 1993; GIRARD, 1994; BECKER, 1996, p. 29). It is of some significance to note that temperature decreased significantly in the upper part of the "middle siliciclastic calcarenite" overlying the "lower oolite" (BRAND & LEGRAND-BLAIN, 1993, Text-Fig. 8) i.e. near the level where, in the Hasselbachtal section, the LN Zone definitively ended.

However, possibly the sea-level lowstand of the upper Wocklum Limestone and certainly the sea-level lowstand of the Hangenberg Sandstone are contemporaneous of the cooling episodes in high latitude as documented by glacial deposits within the Parnaiba and Amazonas basins, in Brazil (LOBOZIAK et al., 1992, 1993, 1996). These glacial deposits, at least those which seem to reach the sea-level for the first time during the Famennian, are now demonstrated to be restricted to the LE?*)–LN Zones and should correspond to an interval of time even shorter than 100 ka, assuming that the HBS transgression represent a short interglacial episode (STREEL, 1986; BLESS et al., 1993, p. 700).

We propose therefore that the change in the continental vegetation at the extreme end of the Devonian did not correspond to the so-called Hangenberg Event but postdated this event and resulted of an almost coincidence of a very low sea-level and a climatic wet phase followed by a still wet but colder phase. The time resolution of our analysis does not allow to decide between the opinion of MALEY (1976) who, in the Quaternary, has proposed that ice sheet started to develop in polar region in response to massive influx of humid tropical air (cooling of the ocean coming soon after as a consequence of the development of ice sheet reaching the sea-level) or rather the opinion of REICHART (1998, p.163) who thinks, on the contrary, that a wetter tropical climate preceded global warming and melting of the ice sheets. During the Quaternary, these contrasting climates have indeed interchanged within a few thousands years. But there is no doubt that the change in the continental vegetation at the extreme end of the Devonian can obviously be entirely explained by climatic causes.

According to the Milankovitch theory external climatic forcing results from changes in the orbital parameters of the Earth's path around the sun which affect the amount of solar radiation received at the top of the atmosphere. But the values of the orbital parameters have changed significantly in the past, the obliquity (the tilt of the Equator on Earth's elliptical orbit around the Sun) which is now of 41 ka was of 33 ka in the Devonian time (BERGER et al., 1989). This might well fit the cycles involved in the late and the latest Famennian.

We do not believe in a moderate latest Famennian regression, continued into the middle "Hangenbergian" time (WALLISER, 1995, p. 241 and Text-Fig. 6). We prefer instead the more dramatic deposition scheme of BLESS et al. (1993) which imply a rather unstable climatic system as the one demonstrated in the high latitude of the middle Miocene when it oscillated, for perhaps 1 ma, back and forth between glacial and interglacial modes (WOODRUFF

*) The LE? Zone in Brazil might well correspond to an impoverished LN Zone (MELO et al., in press).

et al., 1981). Such quick oscillating climates might reconciliate the almost coexistence, in South America, of a latest Famennian glaciation and the presence of ammonoids like the *Wocklumeria* and *Gattendorfia* faunas mentioned by BECKER (1993a) and HOUSE (1996). Latest Famennian climate was probably unstable with quick oscillating cold and temperate phases in the high latitude. Cold phases were glacial only when snow was abundant.

Acknowledgements

The author thanks R. Thomas BECKER, Raimund FEIST, Jean GALTIER and Jacques THOREZ for their invaluable help in reviewing this paper.

References

ALGEO, T.J. & SCHECKLER, S.E. (1998): Terrestrial-marine teleconnections in the Devonian: links between the evolution of land plants, weathering processes, and marine anoxic events. – Phil. Trans. R. Soc. Lond. B, **353**, 113–130, London.

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. – Meded. Rijks Geol. Dienst, NS **25** (2), 9–99, Maastricht.

BECKER, R.T. (1993a): Analysis of Ammonoid palaeogeography in relation to the global Hangenberg (terminal Devonian) and Lower Alum Shale (Middle Tournaisian) events. – Ann. Soc. Géol. Belg., **115** (2), 459–473, Liège.

BECKER, R.T. (1993b): Anoxia, eustatic changes, and Upper Devonian to lowermost Carboniferous global ammonoid diversity. – In: M.R. HOUSE (Ed.): The Ammonoidea: Environment, Ecology, and Evolutionary Change, Systematics Association Special Volume, **47**, 115–163, Clarendon Press, Oxford.

BECKER, R.T. (1996): New faunal records and holostratigraphic correlation of the Hasselbachtal D/C-Boundary Auxiliary Stratotype (Germany). – Ann. Soc. géol. Belg., **117** (1), 19–45, Liège.

BERGER, A., LOUTRE, M.F. & DEHANT, V. (1989): Pre-Quaternary Milankovitch frequencies. – Nature, **342**, 133, London.

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). – Ann. Soc. géol. Belg., **115** (2), 689–702, Liège.

BRAND, U. (1989): Global climatic changes during the Devonian–Mississippian: stable isotope biogeochemistry of brachiopods. – Palaeogeogr., Palaeoclimatol., Palaeoecol. (Global Planet. Change Sect.), **75**, 311- 329, Amsterdam.

BRAND, U. (1993): Global perspective of Famennian–Tournaisian oceanography: geochemical analysis of brachiopods. – Ann. Soc. Géol. Belg., **115** (2), 491–496, Liège.

BRAND, U. & LEGRAND-BLAIN, M. (1993): Paleoecology and biogeochemistry of brachiopods from the Devonian-Carboniferous Boundary interval of the Griotte formation, La Serre, Montagne Noire, France. – Ann. Soc. Géol. Belg., **115** (2), 497–505, Liège.

CHALONER, W.G. & MUIR, M. (1964): Spores and Floras. – In: MURCHISON & WESTOLL (Eds.): Coal and coal-bearing strata, 42–49, Edinburgh & London.

CLAOUE-LONG, J.C., JONES, P.J. & ROBERTS, J. (1993): The age of the Devonian–Carboniferous Boundary. – Ann. Soc. géol. Belg., **115** (2) (1992), 531–549, Liège.

CLAUSEN, C.-D., KORN, D., FEIST, R., LEUCHNER, K., GROOS-UFFENORDE, H., LUPPOLD, F.W., STOPPEL, D., HIGGS, K. & STREEL, M. (1994): Die Devon/Karbon-Grenze bei Stockum (Rheinisches Schiefergebirge). – Geol. Paläontol. Westf., **29**, 71–95, Krefeld.

CLAYTON, G., GRAHAM, J.R., HIGGS, K., SEVASTOPULO, G.D. & WELSH, A. (1986): Late Devonian and Early Carboniferous palaeogeography of Southern Ireland and Southwest Britain. – Ann. Soc. géol. Belg., **109** (1), 103–111, Liège.

DREESEN, R., POTY, E., STREEL, M. & THOREZ, J. (1993): Late Famennian to Namurian in the eastern Ardenne, Belgium. – I.U.G.S. Subcom. on Carb. Strat., guidebook: 60 p. Liège University.

DREESEN, R. & JUX, U. (1995): Microconchid buildups from Late Famennian peritidal-lagoonal settings (Evieux Formation, Ourthe Valley, Belgium). – N. Jb. Geol. Paläont. Abh., **198** (1/2), 107–121, Stuttgart.

FEIST, R. (1992): Trilobiten aus dem Devon/Karbon-Grenzprofil an der Grünen Schneid (Zentrale Karnische Alpen, Österreich). – Jb. Geol. B.-A., **135**, 1, 21–47, Wien.

GIRARD, C. (1994): Conodont Biofacies and Event stratigraphy across the D/C Boundary in the stratotype area (Montagne Noire, France). – Cour. Forsch.-Inst. Senckenberg, **168**, 299–309, Frankfurt am Main.

HIGGS, K. & STREEL, M. (1984): Spore stratigraphy at the Devonian-Carboniferous Boundary in the Northern “Rheinisches Schiefergebirge”, Germany. – Cour. Forsch.-Inst. Senckenberg, **67**, 157–179, Frankfurt am Main.

HIGGS, K. & STREEL, M. (1994): Palynological age for the lower part of the Hangenberg Shales in Sauerland, Germany. – Ann. Soc. géol. Belg., **116** (2) (1993), 243–247, Liège.

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 Borehole. Northern Rhenish Massif, Germany. – Ann. Soc. géol. Belg., **115** (2), 551–557, Liège.

HOUSE, M.R. (1993): Fluctuations in ammonoid evolution and possible environmental controls. – In: HOUSE (Ed.): The Ammonoidea: Environment, Ecology, and Evolutionary Change, Systematics Association Special Volume, **47**, 13–34, Clarendon Press, Oxford.

HOUSE, M.R. (1996): An Eocanites fauna from the early Carboniferous of Chile and its palaeogeographic implications. – Ann. Soc. géol. Belg., **117** (1), 95–105, Liège.

JARVIS, D.E. (1992): The stratigraphic palynology, palynofacies and sedimentology of the Devonian–Carboniferous Kiltorcan Formation of Southern Ireland. – Ph. D. Thesis, Cork, 467 p. (unpublished).

LAFLEUR, S. (1991): Contribution à l’analyse des séquences génétiques dans la partie la plus élevée de la Formation d’Evieux (Famennien supérieur) à Esneux. – Mém. Lic. Sc. géol. et min., Université de Liège, 104 p. (unpublished).

LOBOZIAK, S., MELO, J.H.G. DE, RODRIGUES, R., STREEL, M., QUADROS, L.P. & BARRILARI, I.M.R. (1996): Age and correlation of the Barreirinha Formation (Curua Group, Amazon Basin): new evidence from the miospore biostratigraphy. – An. Acad. bras. Ci., **68** (2), 207–212, Rio de Janeiro.

LOBOZIAK, S., STREEL, M., CAPUTO, M.V. & DE MELO, J.H.G. (1992): Middle Devonian to Lower Carboniferous miospore stratigraphy in the central Parnaiba Basin (Brazil). – Ann. Soc. Géol. Belg., **115** (1), 215–226, Liège.

LOBOZIAK, S., STREEL, M., CAPUTO, M.V. & DE 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. – Docum. Lab. Géol. Lyon, **125**, 277–289, Lyon.

LUPPOLD, F.W., CLAUSEN, C.-D., KORN, D. & STOPPEL, D. (1994): Devon/Karbon-Grenzprofile im Bereich von Remscheid-Altenaer Sattel, Briloner Sattel und Attendorn-Elsper Doppelmulde (Rheinisches Schiefergebirge). – Geol. Paläont. Westf., **29**, 7–69, Krefeld.

MALEY, J. (1976): Essai sur le rôle de la zone tropicale dans les changements climatiques: l’exemple africain. – C. R. Acad. Sc. Paris, **283**, 337–340, Paris.

MALEY, J. (1982): Dust, Clouds, Rain Types, and Climatic Variations in Tropical North Africa. – Quaternary Research, **18**, 1–16, Orlando.

MARTIN, F. (1993): Acritarchs: a review. – Biol. Rev., **68**, 475–538, Cambridge.

MAZIANE, N. (1993): Palynologie quantitative de la Formation d'Evieux (Famennien supérieur) à Esneux. – Mém. Maîtrise en paléontologie appliquée, Université de Liège: 54 p. + ann. (unpublished).

MAZIANE, N., HIGGS, K.T. & STREEL M. (in press): Revision of the late Famennian miospore zonation scheme in eastern Belgium. – J. Micropalaeontol.

MAZIANE, N. & VANGUESTAINE, M. (1997): Acritarchs from the Uppermost Famennian at Chanxhe and Tohogne (Eastern Belgium). – In: FATKA & SERVAIS (Eds.): Acritarcha in Praha 1996, Acta Universitatis Carolinae Geologica, **20**, 527–530, Praha.

MELO, J.H.G. DE, LOBOZIAK, S. & STREEL, M. (in press): Early to early late Carboniferous biostratigraphy of Northern Brazil; an update. – Geobios.

NAISH, T. & KAMP, P.J.J. (1997): Sequence stratigraphy of sixth-order (41 ka) Pliocene-Pleistocene cyclothems, Wanganui basin, New Zealand: A case for the regressive systems tract. – Geol. Soc. Am. Bull., **109**, 8, 978–999, Boulder

PAPROTH, E. & STREEL, M. (1982): Devonian–Carboniferous transitional beds of the northern "Rheinisches Schiefergebirge". – IUGS working group on the Dev./Carb. Boundary, August 1982, guidebook, 63 p., Liège.

POPP, B.N., ANDERSON, T.F. & SANDBERG C.A. (1986): Brachiopods as indicators of original isotopic compositions in some Paleozoic limestones. – Geol. Soc. Am. Bull., **97**, 1262–1269, Boulder.

REICHART, G.-J. (1998): Late Quaternary variability of the Arabian Sea monsoon and oxygen minimum zone. – Geologica Ultraiectina, Utrecht Universiteit, 154, 1–174.

ROSSIGNOL-STRICK, M., NESTEROFF, W.P.O. & VERGNAUD-GRAZZINI, C. (1982): After the deluge: Mediterranean stagnation and sapropel formation. – Nature, **295**, 105–110, London.

SANDBERG, C.A. & ZIEGLER, W. (1996): Devonian conodont biochronology in geologic time calibration. – Senckenbergiana lethaea, **76** (1/2), 259–265, Frankfurt am Main.

SANDBERG, C.A., ZIEGLER, W., DREESEN, R. & BUTLER, J.L. (1988): Late Frasnian mass extinction: conodont event stratigraphy, global changes, and possible causes. – Cour. Forsch.-Inst. Senckenberg, **102**, 267–307, Frankfurt am Main.

SCHECKLER, S.E. (1986): Geology, floristics and paleoecology of Late Devonian coal swamps from Appalachian Laurentia (U.S.A.). – Ann. Soc. géol. Belg., **106**, 209–222, Liège.

STREEL, M. (1996): Miospore ranges near the DC Boundary and extinction events. – Subcommission on Devonian Stratigraphy, Newsletter, **12**, 62–63, Arlington

STREEL, M. & RICHELOT, C. (1994): Wind and water transport and sedimentation of miospores along two rivers subject to major floods and entering the Mediterranean Sea at Calvi (Corsica, France). – In: TRAVERSE (Ed.): Sedimentation of organic particles, Cambridge University Press, 59–67.

STREEL, M. & SCHECKLER, S.E. (1990): Miospore lateral distribution in upper Famennian alluvial, lagoonal to tidal facies from eastern United States and Belgium. – Rev. Palaeobot. Palynol., **64**, 315–324, Amsterdam.

STROTHER, P.K. (1996): Chapter 5. Acritarchs. – In: JANSONIUS, J. & MCGREGOR, D.C. (Ed.), Palynology: principles and applications. – Amer. Ass. Strat. Palynol. Fond., **1**, 81–106, Salt Lake City.

THOMALLA, E., STREEL, M. & VANGUESTAINE, M. (1997): Any catastrophic Event at the Frasnian-Famennian Boundary? – In: FATKA & SERVAIS (Eds.): Acritarcha in Praha 1996, Acta Universitatis Carolinae Geologica, 20, 675–676, Praha.

VAIL, P. (1987): Seismic stratigraphy interpretation using sequence stratigraphy. – In: BALLY, A.W. (Ed.): Atlas of seismic stratigraphy, American Association of Petroleum Geologists, Studies in Geology, **27**, 1–10, Tulsa.

VANGUESTAINE, M., BOULVAIN, F., COEN-AUBERT, M., ROCHE, M. & OUDOIRE, T. (1997): Palynofacies in three near-to off-reef shaly deposits from Late Middle to Late Frasnian age (Upper Devonian) at Neuville and Frasnes (Dinant Synclinorium, Belgium). – In: FATKA & SERVAIS (Eds.): Acritarcha in Praha 1996, Acta Universitatis Carolinae Geologica, **20**, 681–682, Praha.

VAN STEENWINKEL, M. (1993): The Devonian-Carboniferous Boundary: comparison between the Dinant Synclinorium and the northern border of the Rhenish Slate Mountains; a sequence-stratigraphic view. – Ann. Soc. géol. Belg., **115** (2), 665–681, Liège.

WALLISER, O.H. (1984): Pleading for a natural D/C-Boundary. – Cour. Forsch.-Inst. Senckenberg, **67**, 241–246, Frankfurt am Main.

WALLISER, O.H. (1995): Global Events in the Devonian and Carboniferous. – In: O.H. WALLISER (Ed.): Global Events and Event Stratigraphy in the Phanerozoic, Springer-Verlag, Berlin, 225–250.

WELDON, S. (1997): A preliminary study of Late Devonian acritarchs from Riescheid, North Rheinish Slate Mountains, Germany. – In: FATKA & SERVAIS (Eds.): Acritarcha in Praha 1996, Acta Universitatis Carolinae Geologica, **20**, 699, Praha.

WOODRUFF, F., SAVIN, S.M. & DOUGLAS, R.G. (1981): Miocene Stable Isotop Record: A Detailed Deep Pacific Ocean Study and its Paleoclimatic Implications. – Science, **212**, 665–668, Washington.

ZIEGLER, W. & SANDBERG, C.A. (1996): Reflexions on Frasnian and Famennian Stage boundary decisions as a guide to future deliberations. – Newsl. Stratigr., **33** (3), 157–180 Tübingen.

Manuskript bei der Schriftleitung eingelangt am 2. Oktober 1998