GEOLOGICA BELGICA (2000) 3/3-4: 271-283

THE FRASNIAN-FAMENNIAN BOUNDARY SECTIONS AT HONY AND SINSIN (ARDENNE, BELGIUM): NEW INTERPRETATION BASED ON QUANTITATIVE ANALYSIS OF PALYNOMORPHS, SEQUENCE STRATIGRAPHY AND CLIMATIC INTERPRETATION

Maurice STREEL[1*], Michel VANGUESTAINE[1],
Andrés PARDO-TRUJILLO[1,2] & Eric THOMALLA[1,3]

(7 Figures, 1 Plate)

1. University of Liège, Paleontology, Sart-Tilman B 18, B-4000 LIEGE 1, Belgium
** maurice.streel@ulg.ac.be*
2. Universidad de Caldas, Departamento de Ciencias Geológicas, Calle 65 # 26-10, MANIZALES, Columbia
3. Rue des Liserons, 107, B-4000 SERAING, Belgium

ABSTRACT. In the light of recent geochemical and sedimentological investigations, the Frasnian-Famennian Boundary sections at Hony and Sinsin (eastern and central Ardenne, Belgium) are re-evaluated in terms of quantitative analysis of spiny acritarchs and miospores. It is concluded that the shaly interval separating the limestone beds dated Frasnian and Famennian by conodonts corresponds to a transgressive - regressive marine sequence. This interpretationion is supported, for the Hony section, by a quantitative analysis of two spiny acritarch groups (*Gorgonisphaeridium* gr. and *Micrhystridium* gr.) based on the relationship between their abundance and the depth of the marine environment. It is also corroborated by the frequency distribution of a Prasinophyceae (*Maranhites stockmansii*) indicative for a maximum flooding surface. A sequence stratigraphic model and the possible causes of the bathymetric changes right at the Frasnian-Famennian Boundary are briefly discussed. It is suggested that these changes are related to a short glacial phase during a "warm mode" period.

KEYWORDS: palynology, Frasnian-Famennian Boundary, Ardenne, Belgium, sequence stratigraphy, paleoclimate

1. Introduction

When the late Jos Bouckaert initiated, with Alexis Mouravieff and Willy Ziegler, the conodont research in the type Famennian of Belgium (Bouckaert *et al.* 1965, 1972), the old stratotype of the base of the Famennian at Senzeille soon appeared unsuitable for the definition of the Frasnian-Famennian Boundary (FFB). Bouckaert *et al.* (1972) supported therefore the selection of a new boundary stratotype : the Hony section described by Bouckaert & Thorez (1966). Today, the Senzeille section (Bultynck & Martin, 1995) and the Hony section (Sandberg *et al.*, 1988) have been revaluated in terms of conodont stratigraphy and the conclusion of Bouckaert *et al.* (1972) that Hony was a good reference section, remains valid. These sections also contain palynomorphs, particularly acritarchs (see Bouckaert *et al.* 1972, Vanguestaine *et al.*, 1983; Streel & Vanguestaine, 1989 and Bultynck & Martin, 1995).

The Frasnian/Famennian Global Stratotype Section and Point (GSSP) has been fixed in the Coumiac Section (Montagne Noire, southern France) at the base of the *Palmatolepis triangularis* Zone of the standard conodont zonation (Cowie *et al.* 1989). A spreading of dysoxic facies accompanying a rapid transgression followed by a strong regression right at the stage boundary (Sandberg *et al.* 1988) characterizes one of the most important extinction events of the Phanerozoic, the Upper Kellwasser Event (UKW).

Palynomorphs have been also obtained from Coumiac but are too poorly preserved for precise identification (Klapper *et al.* 1993, p. 439). Chitinozoans and Prasinophycean green algae (*Maranhites*) were found in the Montagne Noire at La Serre, 30 km from the Coumiac quarry. At La Serre, the FFB lies within interbedded anoxic dark shales and limestones. The almost complete absence of miospores and acritarchs except Prasinophyceae in these beds is probably related to the distal location of the deposition site (Paris *et al.* 1996). The major result from this section is the exceptional chitinozoan concentration in the basal-most Famennian bed (Paris *et al.* 1996, fig. 2).

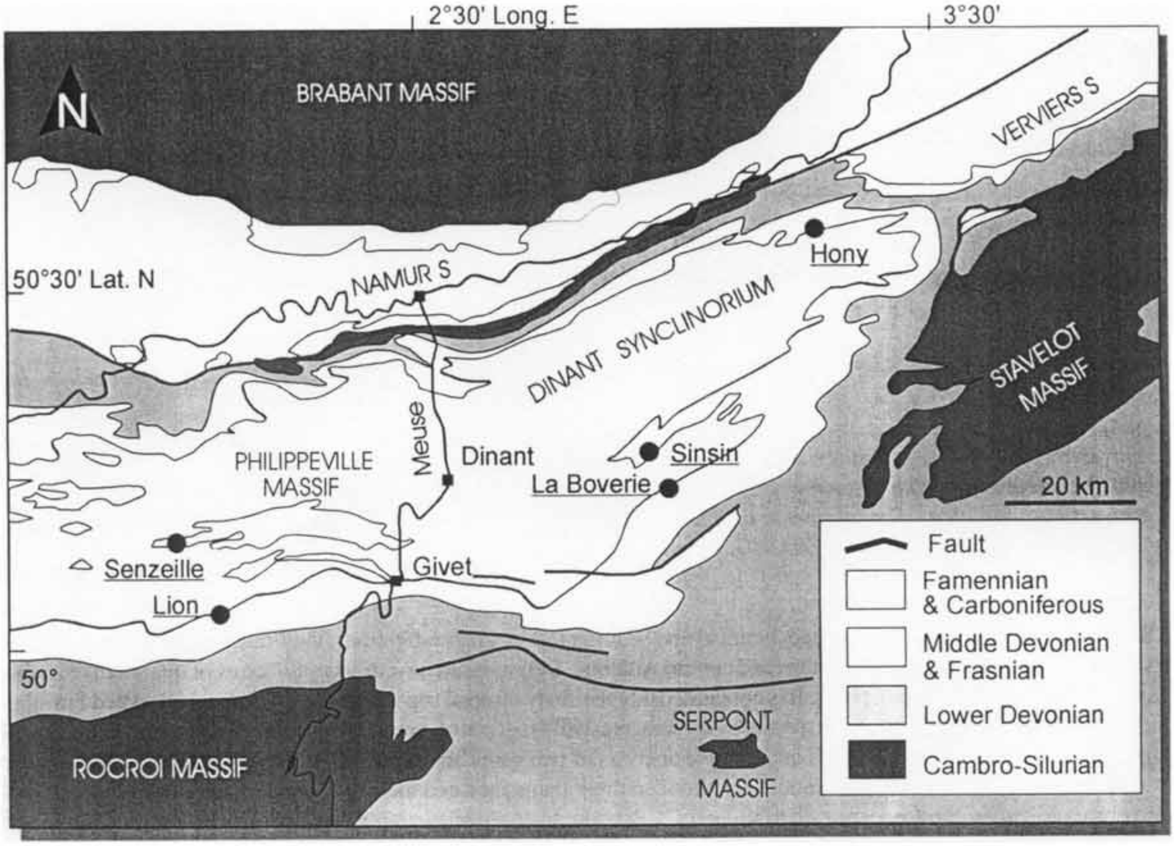

Figure 1. Location of the studied sections in the Dinant Synclinorium (NAMUR S, VERVIERS S for Namur Synclinorium and Verviers Synclinorium).

In order to observe miospores and acritarchs across the FFB, we need neritic facies that also yield conodonts to correlate with the GSSP. The former reference section of the base of the Famennian at Senzeille (southwestern Belgium) contains acritarchs but is only partly dated by conodonts (Bultynck & Martin 1995) whereas the Hony and Sinsin sections (40 km apart from each other, in southeastern Belgium, Figure1) have diagnostic conodont faunas (Sandberg *et al.* 1988) and abundant acritarchs (Vanguestaine *et al.* 1983, Streel & Vanguestaine 1989). Miospores, although present and sometimes rather abundant, are poorly preserved and surprisingly not very diverse. The UKW influence on these palynomorphs, if any, is only of quantitative character. Exceptions are the last occurrence of *V.? fecunda* and the first occurrence of *V.? occultata* (See Figs. 2 and 4) which seem to represent good markers for the transitional *linguiformis* - Early *triangularis* Zones timespan (Martin 1993, Bultynck & Martin 1995).

In a first part of the present paper, we will focus, for both Hony and Sinsin sections, on the concentration (number of specimens, not of species, per gram of sediment) of acritarchs and miospores, as fossil groups i.e. not entering in the systematic details. In a second part, quantitative variations of several taxa of acritarchs are analysed in the Hony section which can be shown to be the most complete section.

2. Acritarchs and miospores, as single fossil groups in the Hony section

The most important acritarch data related to the FFB in the Hony section were published by Vanguestaine *et al.* (1983, fig 6): a major quantitative change is shown near that boundary for 9 selected species. The time resolution is however too poor to allow evaluation of the Kellwasser Event. Low density sampling around that level doesn't allow a detailed palynological analysis. At Hony (Figure 2), 150 cm of shale separate the last Frasnian limestone bed with conodonts of the *linguiformis* Zone from the first Famennian limestone bed with conodonts of the Early *triangularis* Zone. Conodont biofacies indicates a regressive trend (abundant *Icriodus*) in both limestones (Sandberg *et al.* 1988). The shale subdivision is twofold : a lower grey unit containing coquina layers, 115 cm thick and an upper dark-grey unit, 35 cm thick (Sandberg *et al.* 1988). Olive-green shale is present below in the Frasnian and starts again above the first Famennian limestone bed.

Spiny acritarchs show a continuous decrease from 10,000 sp./gr.sed. at the base of the lower unit to nil at its top (Figure 2). They increase again in the last 10 cm of the upper unit and up to 6,000 sp./gr.sed. in the olive-green shale above the first Famennian limestone bed. Miospores

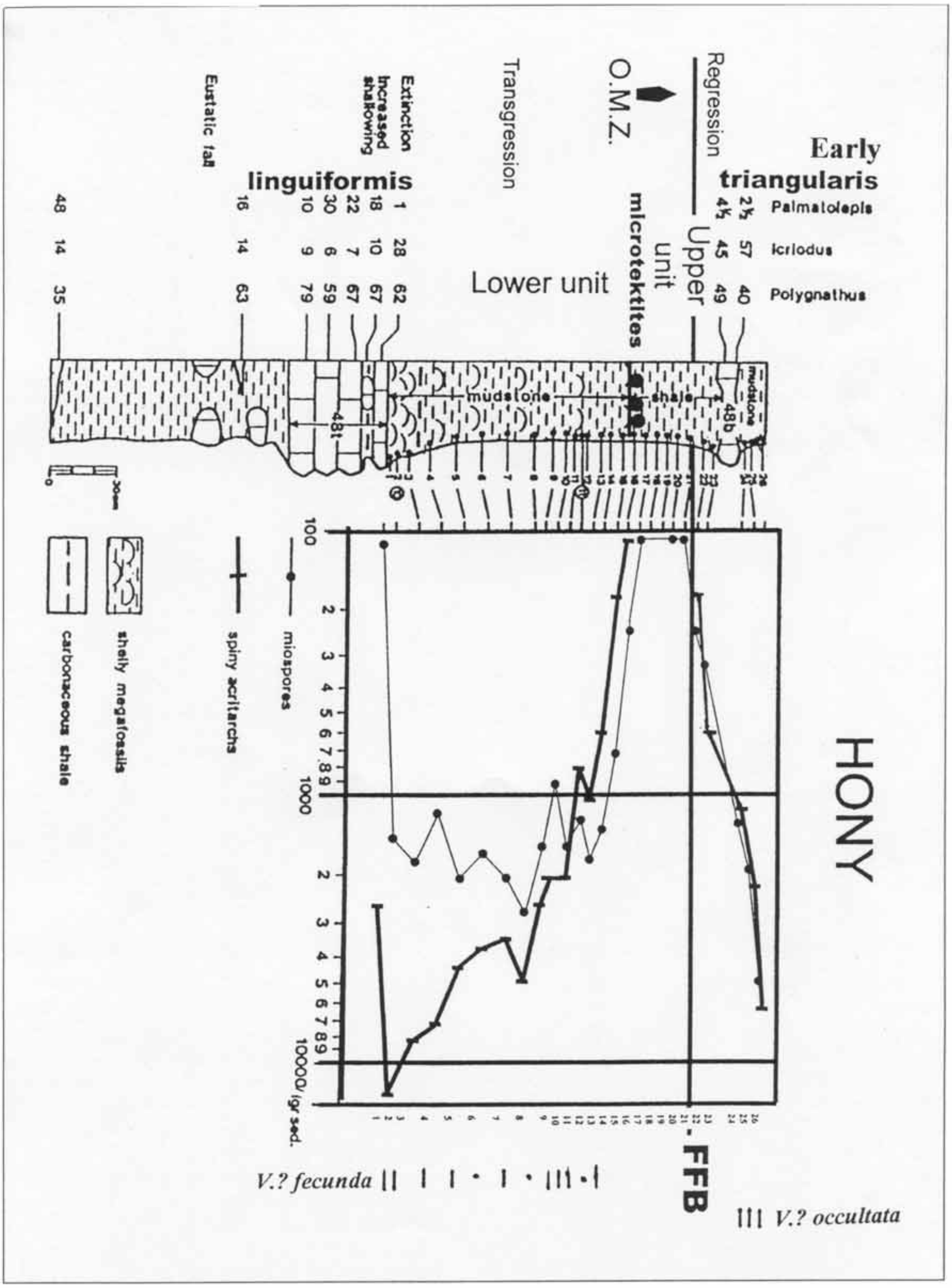

Figure 2. Palynomorph stratigraphic distribution near the FFB at Hony, after Streel & Vanguestaine (1989, fig. 2 modified). Lithology and conodont Zones and Biofacies after Sandberg *et al.* (1988, fig. 9 redrawn). Oxygen Minimum Zone (OMZ) after Claeys *et al.* (1996, fig. 7) and Herbosch *et al.* (1997).
Stratigraphic distribution of *V.? fecunda* and *V.? occultata* and quantitative data of samples 22 and 23, after Thomalla (1995).

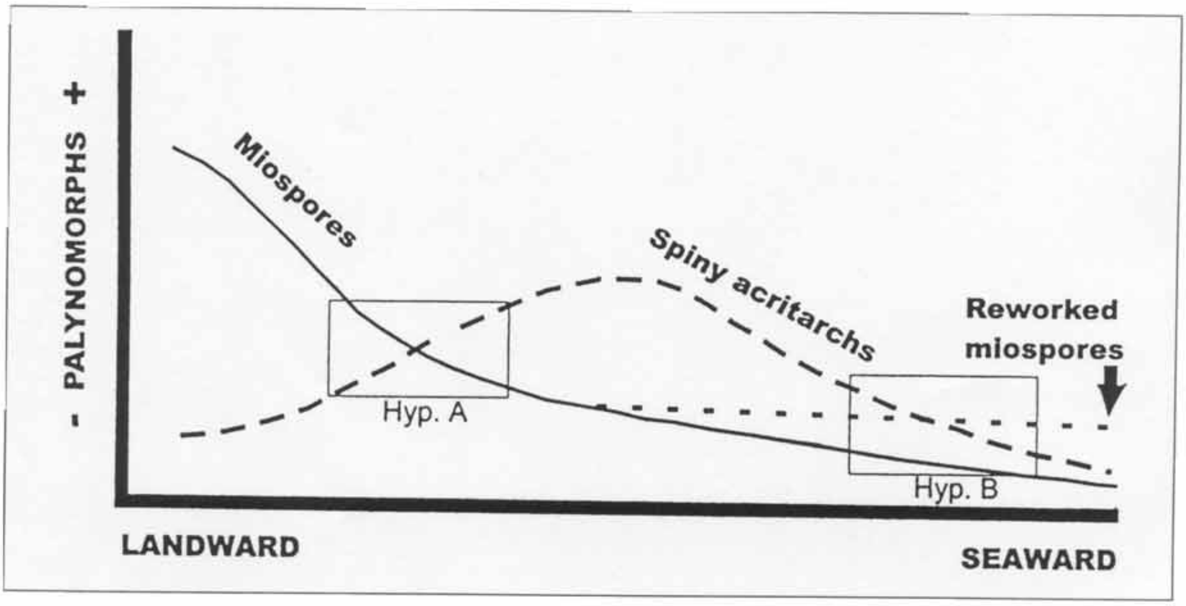

Figure 3. Hypothetical distribution of palynomorphs in sea basin. After Jekhowsky (1963), modified.

oscillate between 600 and 2,800 sp./gr.sed. in the lower unit. They almost disappear in most of the upper unit except for the last 10 cm where they increase again and become more abundant in the olive-green shale above the first Famennian limestone bed. The successive decreasing and increasing upward trends of acritarchs were interpreted by Streel & Vanguestaine (1989) as a progressive regression culminating in the deposition of the dark grey shale (the upper unit) during which a sudden acceleration of the sedimentation rate was believed to have diluted the palynomorphs, followed by a new transgression. They concluded therefore that the palynomorphs originated from that part of the shelf basin where a dominance of acritarchs was progressively replaced landward by a dominance of miospores (hypothesis A of Figure 3).

Several authors (Claeys 1993, Claeys *et al.* 1994, 1996, Herbosch *et al.*, 1996, 1997) have subsequently proposed that the upper unit probably represents a deepening of the depositional environment. Herbosch *et al.*, (1997) also demonstrated, through geochemical analyses, that chalcophile elements show an increase within this upper unit, suggesting an abrupt input of poorly oxygenated waters (Oxygen Minimum Zone or OMZ). They assume that this level must be equivalent to the UKW. Recently, a new sedimentological analysis based on microfacies study (X. Devleeschouwer, personal communication June 1999) confirms the deepening interpretation.

This alternative interpretation has some consequences for the palynomorph quantitative interpretation. In a second hypothesis (hypothesis B of Figure 3), one can accept that miospores were transported for long distances offshore by bottom return flows as a consequence of the storm waves, resulting in their poor preservation (many corroded, unidentifiable specimens). It would also explain the presence, known only in these shales, of reticulate specimens (Plate 1, figs I, J, K) formerly assigned to *Corbulispora* sp. (Loboziak & Streel 1981, Streel *et al.* 1987), and now interpreted as the mesospore wall layers of freshwater algal Zygnemataceae split along their equatorial regions (Grenfell 1995). According to this hypothesis, the non-marine palynomorphs would have been reworked from continental nearshore sediments and deposited in the distal part of the shelf basin where the abundance of acritarchs is progressively reduced seaward (hypothesis B of Figure 3).

The Hony section would record, in a small cyclic succession, a regression in the last Frasnian limestone (Sandberg *et al.* 1988, fig. 9), a transgression in most of the shaly interval, and again a regression which accounts for the uppermost part of these shales, the first Famennian limestone and the lower part of the succeeding olive-green shale.

3. Acritarchs and miospores, as single fossil groups in the Sinsin section

At Sinsin section, about 27 cm only of dark and dark-grey shale separates the last Frasnian limestone bed with conodonts of the *linguiformis* Zone from the first Famennian limestone bed with conodonts of the Early *triangularis* Zone. Conodont biofacies indicate a regressive trend (abundant *Icriodus*) in both limestones (Sandberg *et al.* 1988, fig.10). The shale is subdivided twofold: the lower

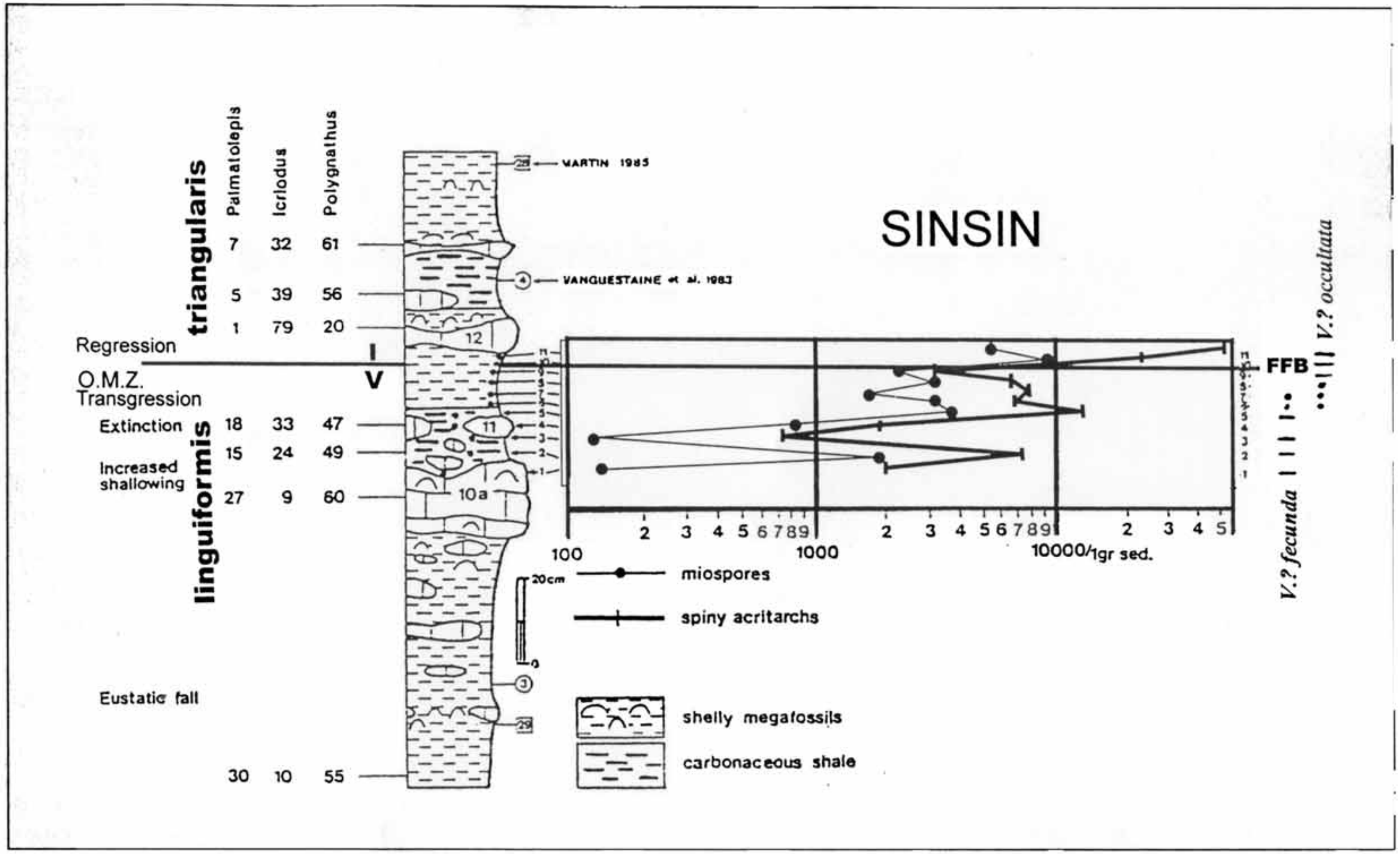

Figure 4. Palynomorph stratigraphic distribution near the FFB at Sinsin, after Streel & Vanguestaine (1989, fig. 3 modified). Lithology and conodont Zones and Biofacies, after Sandberg and others (1988, fig. 10 redrawn and modified). Oxygen Minimum Zone (OMZ) and ostracod assemblages, after Casier & Devleeschouwer (1995). I: very rich but poorly diversified ostracod fauna characteristic of semi-restricted conditions; V: Myodocopid (*Entomozoacea* and *Cypridinacea*) ostracods characteristic of dysoxic conditions.
Stratigraphic distribution of *V.? fecunda* and *V.? occultata* after Thomalla (1995).

12 cm are dark shales containing carbonate lenses, some of them yielding conodonts of the *linguiformis* Zone ; the upper 15 cm are dark-grey shales. Olive-green shale is present below in the Frasnian and higher on in the Famennian. In the lower 12 cm, acritarchs and miospores are poorly represented, except in one sample. In the upper 15 cm, acritarch abundance (spiny acritarchs) shows a continuous upward decrease from 10,000 sp./gr.sed. at the base of the dark-grey shales to 3,000 sp./gr.sed., 10 cm higher. It increases again from 8,000 sp./gr.sed. to very high values of 50,000 sp./gr.sed. in the upper 5 cm of these shales. Miospore abundance oscillates between 1,800 and 3,800 sp. gr. sed. in the lower 10 cm of the dark-grey shales and increases again up to 8,000 sp./gr.sed. in the upper 5 cm of these shales (Figure 4).

As explained for Hony, the successive decreasing and increasing upward trends of the acritarchs were interpreted by Streel & Vanguestaine (1989) as a progressive regression followed by a transgression. They also remarked that the miospore/acritarch ratio evolved in a similar fashion in both sections. They hesitated to conclude that similarity implies contemporaneity, although noting that the dark-grey shales present at Hony might be missing at Sinsin. Subsequently, Casier & Devleeschouwer (1995) discovered a very rich and well preserved ostracod fauna in the upper 5 cm of the dark-grey shales. This assemblage is indicative of a brackish-water environment with strong marine influence and clearly corresponds to a regression in that part of the shales which Streel & Vanguestaine (1989) had attributed to a transgression.

We propose therefore that, at Sinsin, palynomorphs of the upper 15 cm dark-grey shales originated from that part of the shelf basin where the abundance of acritarchs is progressively reduced seaward (hypothesis B of Figure 3).

4. Quantitative variations of some acritarch taxa in several sections of the Ardennes

The microscopic preparations used in Streel & Vanguestaine, 1989, at Hony, have been restudied to evaluate quantitatively 17 informal groups within the spiny acritarchs (Thomalla, 1995). The groups were organized in order to make possible a quantitative approach. Genera of similar morphology, often difficult and time consuming to discriminate, have been counted together. Sometimes, a group corresponded to a single species.

From this unpublished study, only the following groups are considered in the present paper (Figure 5 and Plate 1). They represent 70 to 99 % of the assemblages:

1. a *Micrhystridium* group (Plate 1, figs A to F) comprising the species of the genera *Micrhystridium* (Deflandre) Lister, 1970, *Solisphaeridium* (Staplin *et al.*) Sarjeant, 1968, *Unellium* Rauscher, 1969 and *Veryhachium* (Deunff) Turner 1984 and the species *Villosacapsula ceratioides* (Stockmans & Willière) Loeblich & Tappan,1976.

2. a *Gorgonisphaeridium* group (Plate 1, figs G and L) comprising all species of the genus and transitional forms between *Gorgonisphaeridium* (Staplin *et al.*, 1965) and *Lophosphaeridium* Timofeev *ex* Downie, 1963.

3. *Maranhites stockmansii* Martin, 1981. (Plate 1, figs H and M)

4. all other spiny acritarchs

The spiny acritarchs taken into account in Streel & Vanguestaine (1989) do not comprise *Maranhites stockmansii* which has been incorporated by these authors within the sphaeromorphs due to the mainly sphaeromorphic aspect of the species.

From the base to the top of the profile, 7 steps can be recognized :

Step 1 (sample number 1 to 4) is characterized by an increase of the *Micrhystridium* group and a correlative decrease of the *Gorgonisphaeridium* group. The two other groups demonstrate low values. At the top of this first zone, the *Micrhystridium* group reaches its highest value within the whole profile.

Step 2 (samples 5 to 14) where the ratio *Gorgonisphaeridium* group / *Micrhystridium* group is regularly increasing. The two other groups are again poorly represented. From the median part of this zone upwards, the *Gorgonisphaeridium* group is more abundant than the *Micrhystridium* group.

Step 3 (samples 15 and 16) where *Maranhites* reaches 20% to more than 40% and the *Micrhystridium* group value is low, less than 20%.

Step 4 (samples 17 to 21, which are all barren).

Step 5 (sample 22) where, above the preceeding barren interval, one can observe a dominance of *Maranhites* in only one sample but this dominance in percentage is the result of the presence of very few other acritarchs at that level. In other words, the concentration of *Maranhites* is lower here than in former step 3.

Step 6 (sample 23) where the *Gorgonisphaeridium* group is dominant (76%), *Maranhites* well represented (19%) and the *Micrhystridium* group present in very low percentage.

Step 7 (samples 24 to 26), above the 48b limestone bed, where the *Micrhystridium* group is again becoming dominant, the *Gorgonisphaeridium* group and *Maranhites* having lower values. The other spiny acritarchs are now reaching large proportions, exceeding 20%.

The observed quantitative variations are leading to the following remarks :

1. From steps 2 to 3, the successive dominance of the *Micrhystridium* group, dominance of the *Gorgonisphaeridium* group and abundance of *Maranhites*

have their counterpart above (from steps 5 to 7) the interval lacking acritarchs showing the reverse succession of abundance of *Maranhites*, dominance of the *Gorgonisphaeridium* group and dominance of the *Micrhystridium* group.

2. In the uppermost part of the profile, higher percentages are reached by the other spiny acritarchs.

Observations made in late middle Frasnian sections from nearby localities of the southern border of the Dinant Synclinorium (Vanguestaine *et al.*, 1999) offer a basis for the interpretation of the above data.

At La Boverie, a quarry near the locality of Rochefort, the Boussu-en-Fagne Member and the Neuville Formation have been interpreted by Boulvain & Herbosch (1996) and Boulvain & Coen-Aubert (1998), independently of the study of acritarchs, as an accumulation of sediments showing a transgressive system tract followed by a highstand system tract. Palynological studies, performed at La Boverie, concluded that a quick rise of sea level drowned the underlying Lion reefal mudmound, at the very base of the Boussu-en-Fagne Member and was immediately followed by a maximum flooding surface. Higher, in the Boussu-en-Fagne Member and in the Neuville Formation, observations made on organic debris (Vanguestaine *et al.*, 1999, p. 323) might imply a progressive decrease of water depth (and a more aerobic environment) in highstand conditions. During the Neuville time-equivalent, the highstand episode resulted in a new reefal activity in several parts of the basin (Vanguestaine *et al.*, 1999). An other profile, the Lion quarry (see location on Figure 1) at Frasnes, exhibits similar sedimentological features (Vanguestaine *et al.*, 1999).

In these localities (see Figure 6 for the La Boverie quarry), we have observed (Pardo-Trujillo, 1997) an increase of the *Micrhystridium* group and a correlative decrease of the *Gorgonisphaeridium* group corresponding to a progressive shallowing i.e. a regression. Therefore, if the

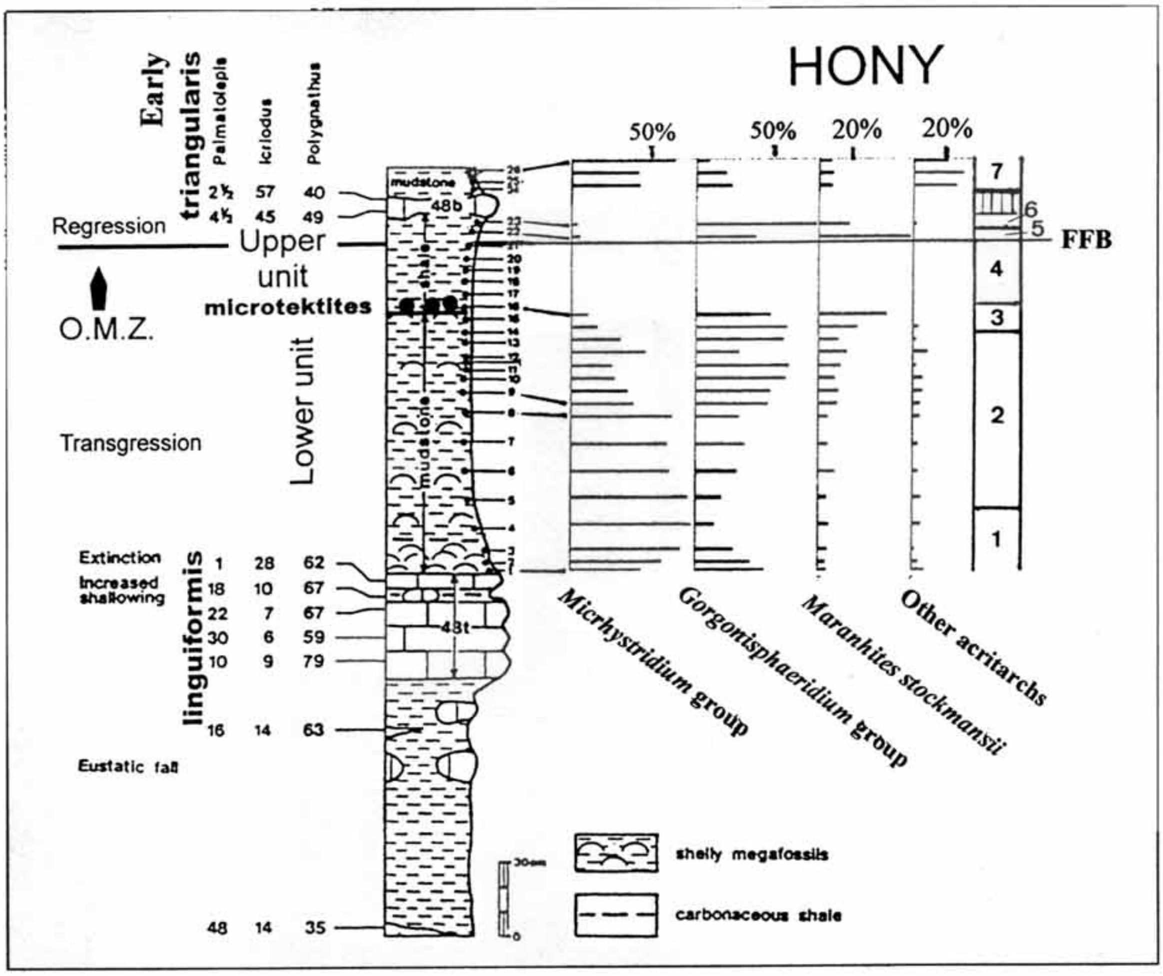

Figure 5. Quantitative acritarch distribution near the FFB at Hony, after Streel & Vanguestaine (1989, fig. 2 modified) and Thomalla (1995). Lithology and conodont Zones and Biofacies after Sandberg and others (1988, fig. 9 redrawn). Oxygen Minimum Zone (OMZ) after Claeys and others (1996, fig. 7). Steps 1 to 7 are described in the text.

increasing ratio *Micrhystridium / Gorgonisphaeridium* carries a regressive signal, then the observed profile at Hony must be interpreted from steps 2 to 7 as a transgressive-regressive cycle, the maximum of the transgression being characterized by a minimum of the *Micrhystridium / Gorgonisphaeridium* ratio, the level where the prasinophyte *Maranhites stockmansii* reaches its maximal abundance.

This last observation is in full accordance with the literature (Tyson, 1995) about the ecological meaning of Prasinophytes. Also, a recent paper (Palliani & Riding, 1999) shows a positive correlation between a dominance of *Tasmanites* (another Prasinophyte member) and the early Toarcian anoxic event in central Italy. The prasinophyte acme thus seems to correspond to a maximum flooding surface.

In conclusion, observations on quantitative variations of some acritarch groups are in full accordance with sedimentological and geochemical results (Claeys, 1993, Claeys *et al.*, 1994, 1996, Herbosch *et al.*, 1996, 1997, Devleeschouwer, personal communication). The shaly interval separating the limestone beds respectively dated Frasnian and Famennian by conodont at Hony corresponds to a transgressive marine facies which reversed subsequently into a regression.

Muchez *et al.* (1996, p. 294) place a sequence boundary near or at the top of the *linguiformis* Zone and the succeeding lowstand systems tract at the base of the *triangularis* Zone. Although they seem to consider the coquina layers of these shales, interpreted as storm deposits, as earliest Famennian deposits by analogy with another section in southwest Belgium (Muchez *et al.*, 1996, p. 292 - 293), they obviously ignore the conodont barren shaly interval. Our interpretation is different, but might well correspond to a higher order of the sequence stratigraphy model as suggested on Fig. 7.

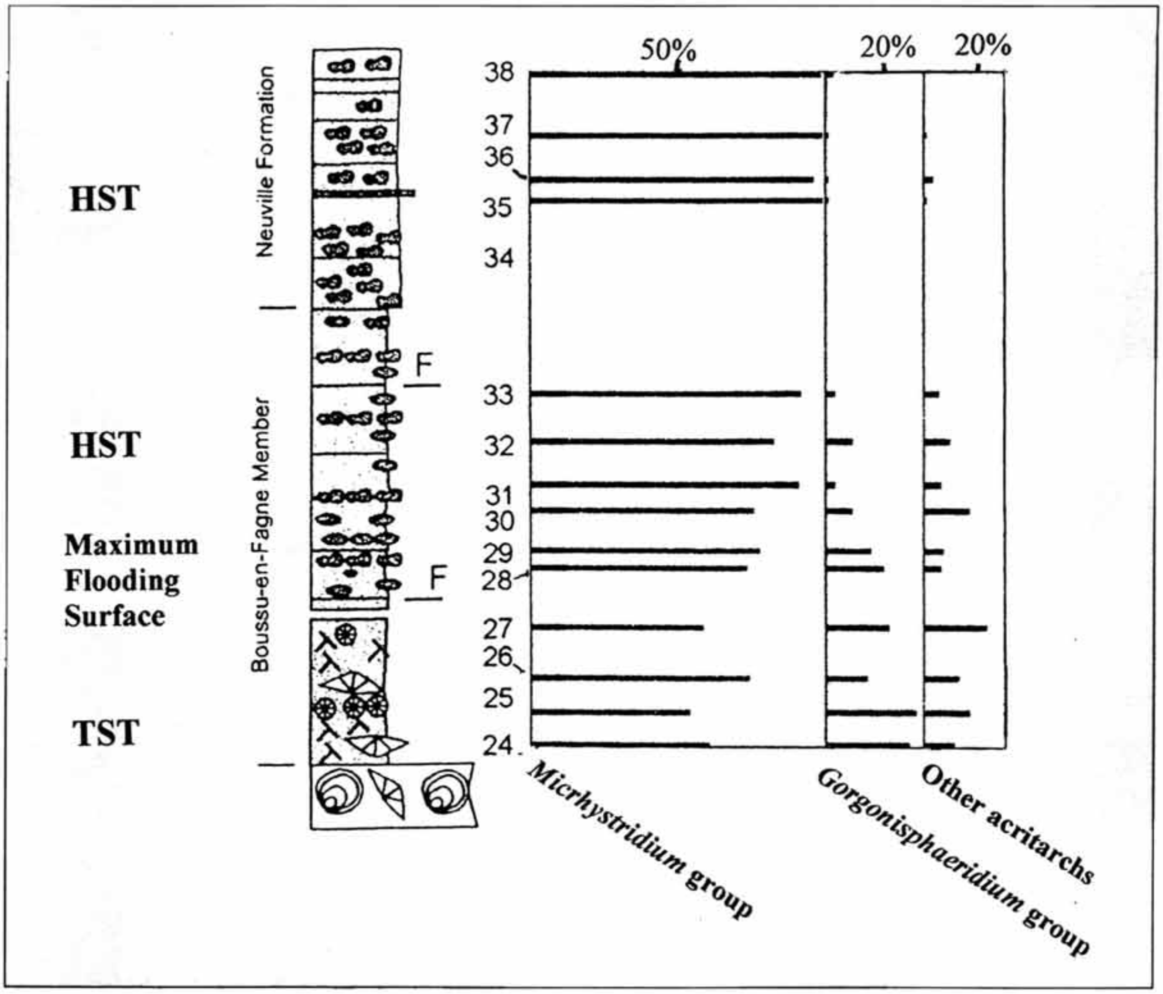

Figure 6. Quantitative acritarch distribution in late middle Frasnian at La Boverie, after Pardo-Trujillo (1997) and Vanguestaine *et al.* (1999) – [F : fault].

5. Comparison of Hony and Sinsin sections

The similarity in the concentration curves of miospores and acritarchs in both Hony and Sinsin sections is indicative of their contemporaneity. In both sections is observed successively a regression in the last Frasnian limestones or shales containing carbonate lenses (Sandberg *et al.* 1988), a transgression in most of the shaly interval culminating at Hony in the development of oxygen-poor bottom waters, and again a regression in the uppermost part of these shales, with a possible sedimentary gap at Sinsin (the equivalent of step 4 at Hony) previously suggested by Streel & Vanguestaine (1989) and by Casier & Devleeschouwer (1995). The Kellwasser Event is generally admitted, in the Rhenish regions at least, to represent a spread of dysoxic facies coinciding with a rapid transgression being reversed subsequently into a strong regression right at the stage boundary. We suggest therefore that the FFB at Hony and Sinsin should be placed near the base of the regression within the upper part of the dark-grey shales (Figs. 2, 4, 5).

It is evident that the Kellwasser Event did not affect significantly the phytoplankton. The almost complete absence of acritarchs right at the FFB may be explained by the sedimentary conditions, not necessarily by a genuine extinction.

6. Possible causes of the bathymetric changes at the Frasnian-Famennian Boundary

Sandberg *et al.* (1988, p. 297) have concluded their detailed study of the Frasnian-Famennian Boundary transitional beds in North America and Western Europe by assuming that *"Conodont biofacies demonstrate that abrupt eustatic rise and fall ... immediately preceded the mass extinction"*. They also stated that *"...a large bolid may have triggered the succession of extinction-related events..."*. They also proposed that *" changes in oceanic circulation patterns probably were the direct cause of the extinction."* and that *" the resulting changes in global climate produced a glacial episode in the Southern Hemisphere during the Famennian..."*

Microtektites have been reported from two localities of Belgium: at Senzeille (Claeys *et al.* 1992), near the uppermost part of the Early *triangularis* Zone (Bultynck & Martin 1995) and at Hony (Claeys *et al.* 1994), at the base of the dark-grey shales, i.e., immediately below the here suggested FFB (Figure 2). The absence of microtektites at Sinsin can be explained by the sedimentary gap occurring at that level. The record at Senzeille is doubtful because the glasses closely resemble the chemical composition of reflective beads used for road marking (Marini & Casier 1997). It is not the case for the Hony microtektites, which might well represent the best evidence of an impact of extraterrestrial body on Earth corresponding to the UKW, although as Walliser (1995) notes *"microtektites are found in various quantities in Palaeozoic conodont samples from many layers lacking any indication of an unusual geological or biological change "*.

The exceptional chitinozoan concentration in the basal-most Famennian bed in La Serre (Paris *et al.* 1996, fig. 2) fits rather well the global cooling hypothesis as cold water seems to have been more favourable for the proliferation of these microfossils (Paris *et al.* 1996, p. 143). Also Tyson (1995) has amply discussed the preference of Prasinophytes for cold wa-

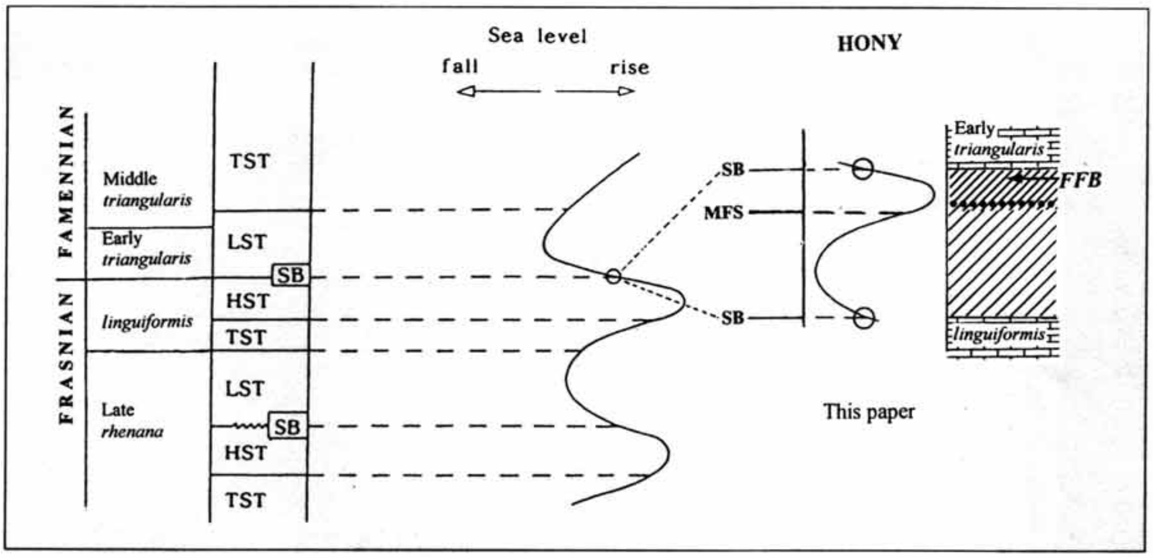

Figure 7. Sequence stratigraphy at the Frasnian-Famennian Boundary, adapted from Muchez *et al.* (1996, fig. 5).

ter. A cold episode corresponding to the maximum flooding surface might have anticipated a (very) short glaciation which would explain the sudden and short, major eustatic fall shown at the end of T-R cycle IId of Johnson *et al.* (1985). Short term glacial phases during a "warm mode" (Frakes *et al.* 1992) period are known in the Paleozoic and in the Mesozoic. Brenchley *et al.* (1994) demonstrate bathymetric and isotopic evidence for a short-lived (0.5 - 1 my) Late Ordovician glaciation in a "warm mode" period. Even in the Late Cretaceous, which is often presented as a good example of an ice-free world, isotopic and sequence stratigraphic evidence for an early Maastrichtian, very rapid (much less than 1 my) growth of an ice sheet and attendant glacio-eustatic lowering has been recently presented by Miller *et al.* (1999). The sudden growth and decay of an earliest Famennian ice sheet might have been the result of the reduction and later, increase in greenhouse capacity of the atmosphere as the consequence of sudden changes in the mode of ocean-atmosphere operation (Broecker & Denton 1989).

7. Acknowledgments

We thank the reviewers X. Devleeschouwer, P. Bultynck and M. Dusar, for constructive criticism of the manuscript

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Manuscript received on 29. .2000 and accepted for publication on 30.3.2001.

PLATE 1

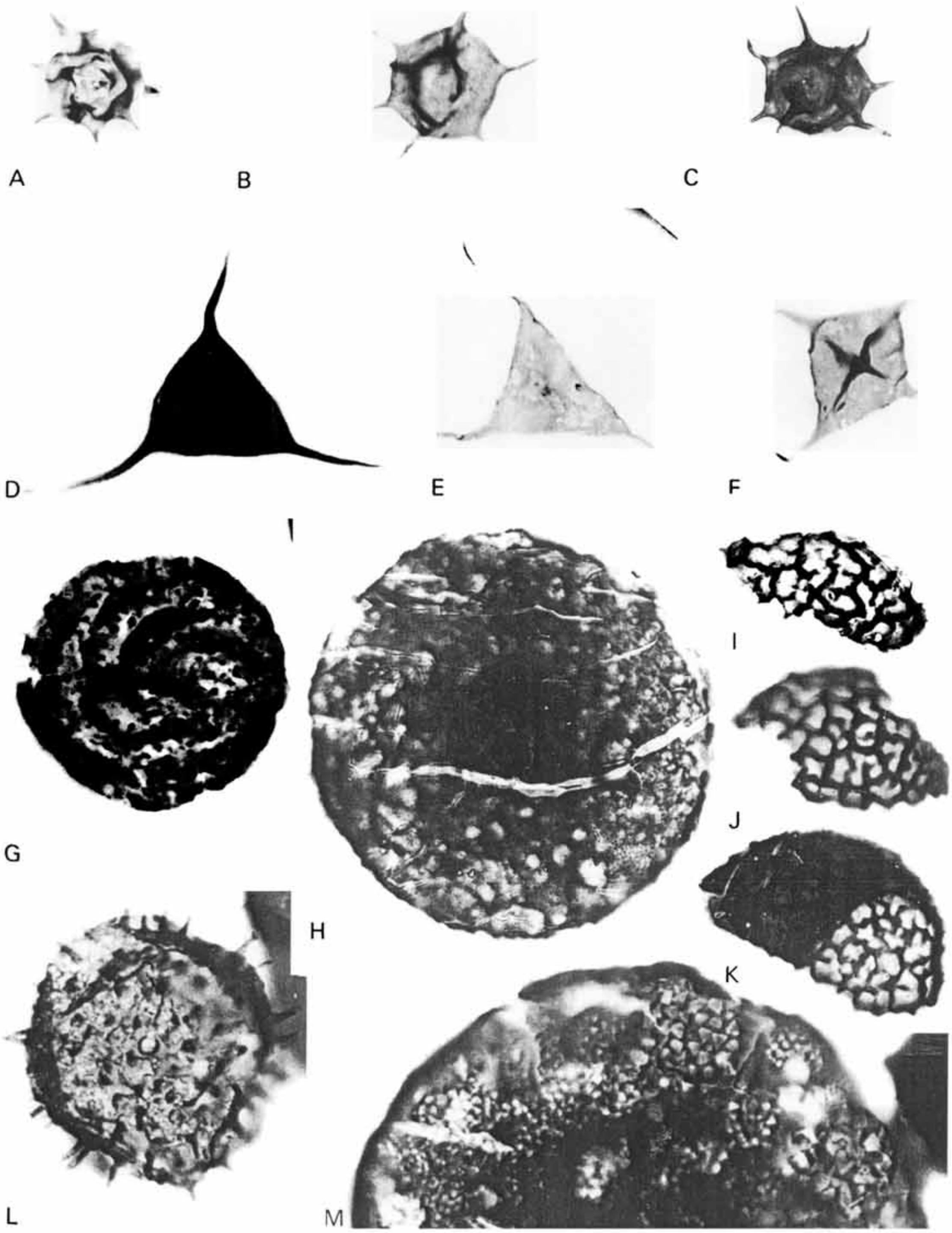
(All specimens 1000X)

A - F representatives of the *Micrhystridium* Group.
A. *Micrhystridium stellatum* Deflandre, 1945. Hony -2, 22010, K50/4.
B. *Micrhystridium* or *Solisphaeridium* sp. Hony -2, 22010, L48/1-2.
C. *Solisphaeridium* sp. with weakened distal portion of the processes. Hony -1, 22009, Z43/1
D. *Veryhachium downiei* Stockmans and Willière, 1962. Hony -25, 21712, PQ43.
E. (?) *Veryhachium* sp. with infrastriate wall surface. Hony -2, 22010, T42.
F. *Veryhachium* sp. (6 processes). Hony -2, 22010, T52-53.

G, L : representatives of the *Gorgonisphaeridium* Group.
G. *Lophosphaeridium* sp. with truncated coni (badly preserved specimen). Hony -2, 22010, Q50/1-2.
L. *Gorgonisphaeridium* sp. with divided processes (damaged specimen). Hony -2, 22010, M60/2.

H, M *Maranhites stockmansii* Martin, 1981 emend. Martin 1985.
H. Hony -12, 21728, G52 : outline ornamentation not observable; typical dark central area.
M. Hony -2, 22010, P53 pyritized specimen. Pyritisation of framboidal type.

I - K Fragments of (?) Zygnematalean fresh water algae.
I. Hony - 6, 22004
J. Hony -12, 21728
K. Hony -12, 21728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