REVIEW OF PALAEOBOTANY AND PALYNOLOGY

Observations on the establishment of a Devonian and Lower Carboniferous high-resolution miospore biostratigraphy

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Abstract

High-resolution miospore biostratigraphy depends upon accurate knowledge of taxonomy but also on the stratigraphical relationships between the miospore-based units and other biozones. Examples taken from the Devonian and Lower Carboniferous demonstrate that the Assemblage Zone concept and the lack of discrimination in evaluating the associated faunal and lithological data can lead to questionable conclusions. Suggestions are made for a more accurate definition of interval zones and related data.

1. Introduction

In geological exploration, biostratigraphical refinement is more necessary than ever, now that the chronostratigraphical approach of sequence stratigraphy is gaining impetus. However, the ultimate goal of the sequence stratigrapher, that events can be proven to be contemporaneous worldwide, is at risk. Proof of contemporaneity can only be achieved when a biostratigraphic or chronostratigraphic scale is maintained separately from any scale based on lithological or other physical "events" (Poulton, 1987).

Unfortunately, miospores are commonly used in biostratigraphy in a way that does not permit the development of a high-resolution biostratigraphy. "It is common practice to use both individual taxa and assemblages of contemporaneously occurring taxa of spores for correlation (in the Devonian)" (McGregor, 1981). Such a mixture of zonal concepts has resulted in generally poorly defined boundaries in miospore-stratigraphy. One of the consequences is that miospore-based stratig-

raphy is not considered reliable by other biostratigraphers.

This practice can only be improved by the careful separation of assemblages zones (or Oppel zones) which have, by definition, poor limits, from individual taxon ranges (or interval zones) which alone can be accurately related to other biozones.

The establishment of accurate relationships between miospore-based and other biohorizons (the limits of interval zones) and the critical evaluation of the chronostratigraphical significance of these biohorizons is an essential prerequisite for a high-resolution miospore-stratigraphy. Of course, biostratigraphy is only as good as the taxonomy used to define it. High-resolution biostratigraphy will greatly improve as taxonomic definition improves but this aspect is not the main purpose of this paper, even if most of the instances given below depend also upon a better knowledge of the taxonomy of the miospores and of the faunas.

In this paper four instances where an inadequate definition of biohorizons and the use of poorly correlated data have led to questionable conclu-

sions are reviewed. These are in stratigraphic ascending order (1) the "major break" in miospore development at the Frasnian–Famennian boundary, (2) the divergent fauna-based and miospore-based correlations in the mid-Famennian, (3) the early first occurrence of *Retispora lepidophyta* in the Famennian of Hunan (China), and (4) the belated first occurrence of *Lycospora pusilla* in the Visean of northern Africa. Subsequently, consideration is directed to attempts at a better definition of miospore horizons.

2. Miospore development at the Frasnian–Famennian boundary

McLaren (1988, p. 2), when invoking an "instantaneous event" at the Frasnian–Famennian boundary, referred to a major break in miospore development at that time. McLaren cited Richardson and McGregor (1986) in support of this view which clearly refers to the base of the *Aurorospora torquata–Grandispora gracilis* Assemblage Zone, where many species (see Richardson and McGregor, 1986, fig. 3) seem to appear at about the same time. The base is defined in the Hanover Shale Formation, West Falls Group of the Walnut Creek section, Chautauqua County, western New York State, USA. The definition of the zone base is linked to the entry of the index species at a level 9.8 m above the base of the Hanover Shale Formation. Richardson and Ahmed (1988, p. 545) mentioned that "in the strata within the basal zone spores are usually badly preserved". These authors, and Ahmed (1980), did not indicate the presence of another assemblage zone lower in that section. Richardson and McGregor (1986, p. 19) recorded the preceding *Archaeoperisaccus ovalis–Verrucosisporites bulliferus* Assemblage Zone in the Rhinestreet Shale of central New York State. This record is, however, from a level three lithostratigraphic units below the Hanover Shale, and in unpublished section(s) several tens of kilometers farther east. The limit between these two assemblage zones, therefore, lies within or between the Rhinestreet Shale and the Hanover Shale.

Faunas, though mentioned by Richardson and McGregor (1986), are not accurately located, and were possibly not found in the same sections as

the miospores, a significant factor when the strong E–W diachronism accepted for the top of the Rhinestreet Shale (Rickard, 1975) is considered.

Amongst the conodont faunas recovered, *Polygnathus asymmetricus* has been found in the base of the Rhinestreet Shale, but the middle and upper Rhinestreet Shale have been referred to the *Ancyrognathus triangularis* Zone (Rickard, 1975, p. 9), now (Ziegler and Sandberg, 1990) the *hassi* or *jamieae* Zones (Fig. 6). Klapper et al. (1971, fig. 4) referred the upper Hanover Shale to the upper *Palmatolepis triangularis* Zone (Fig. 6).

The ammonoid faunas from the uppermost Rhinestreet Shale and its equivalents mark the entry of a completely new fauna (Fauna 22 in Kirchgasser and House, 1981; *Rhynchostoma* Zone in House, 1988). This fauna, of mid-Frasnian(?) age, may range up to the lower Hanover Shale where *Manticoceras cataphractum*, a form with distinctive constrictions (Fauna 23 in Kirchgasser and House, 1981) similar to material from the Formation de Matagne (late Frasnian of Belgium), is common. Higher in the Hanover Shale, at a locality about 80 km to the northeast of the miospore locality, *Crickites holzapfeli* (Fauna 24 in Kirchgasser and House, 1981; cf. *holzapfeli* Zone in House, 1988), occurs and is also closely comparable with material from the Formation de Matagne.

The contact between faunas 23 and 24 was shown by House (1988, fig. 2) as corresponding approximately to the Frasnian–Famennian boundary now fixed between the *linguiformis* and the early *triangularis* conodont Zones. However, it is known now (Bultynck, 1993) that, if fauna 23 and 24 are really in lateral equivalence to the Formation de Matagne, they are both on the Frasnian side of the boundary (Fig. 1). It is not known, however, whether the miospore assemblage found in the Hanover Shale is younger, equivalent or older than faunas 23 and 24. Consequently, the boundary between the two miospore assemblage zones (Fig. 1) may range from the (late Frasnian) *hassi* or *jamieae* to the (Famennian) *triangularis* conodont Zones.

Fourteen miospore species are cited as characteristics in the *A. torquata–G. gracilis* Assemblage Zone, one (*Aneurospora greggsii*) first occurs well

NEW YORK STATE (U S A)   BOULONNAIS (France)   ARDENNE (Belgium)

West Falls Group

Matagne equivalent

P. triangularis
Fauna 24
Hanover Shale

Fauna 23

Pipe Creek Shale

Angola Shale

Rhinestreet Shale
Fauna 22
A. triangularis

P. asymmetricus

A. torquata–G. gracilis Ass.
A. torquata
G. gracilis
K. dedaleus
D. poljessicus
D. versabilis

A. ovalis–B. bulliferus Ass.

?

[1]   [2] ← ? km → [3]

Formation d'Hydrequent

Formation de Ferques

B. dol.

A. triangularis

Upper
P. asymmetricus

B. bulliferus–L. media Opp. Z.

V
IV

A | B | C | D | E

D. poljessicus
G. gracilis
K. dedaleus
D. versabilis
Visbysphaera? occultata

[4]   [5] ← 1 km → [6]

HONY
SINSIN

Matagne equivalent

48 b   12 Early P. triangularis

48 t   11 P. linguiformis

Visbysphaera? occultata
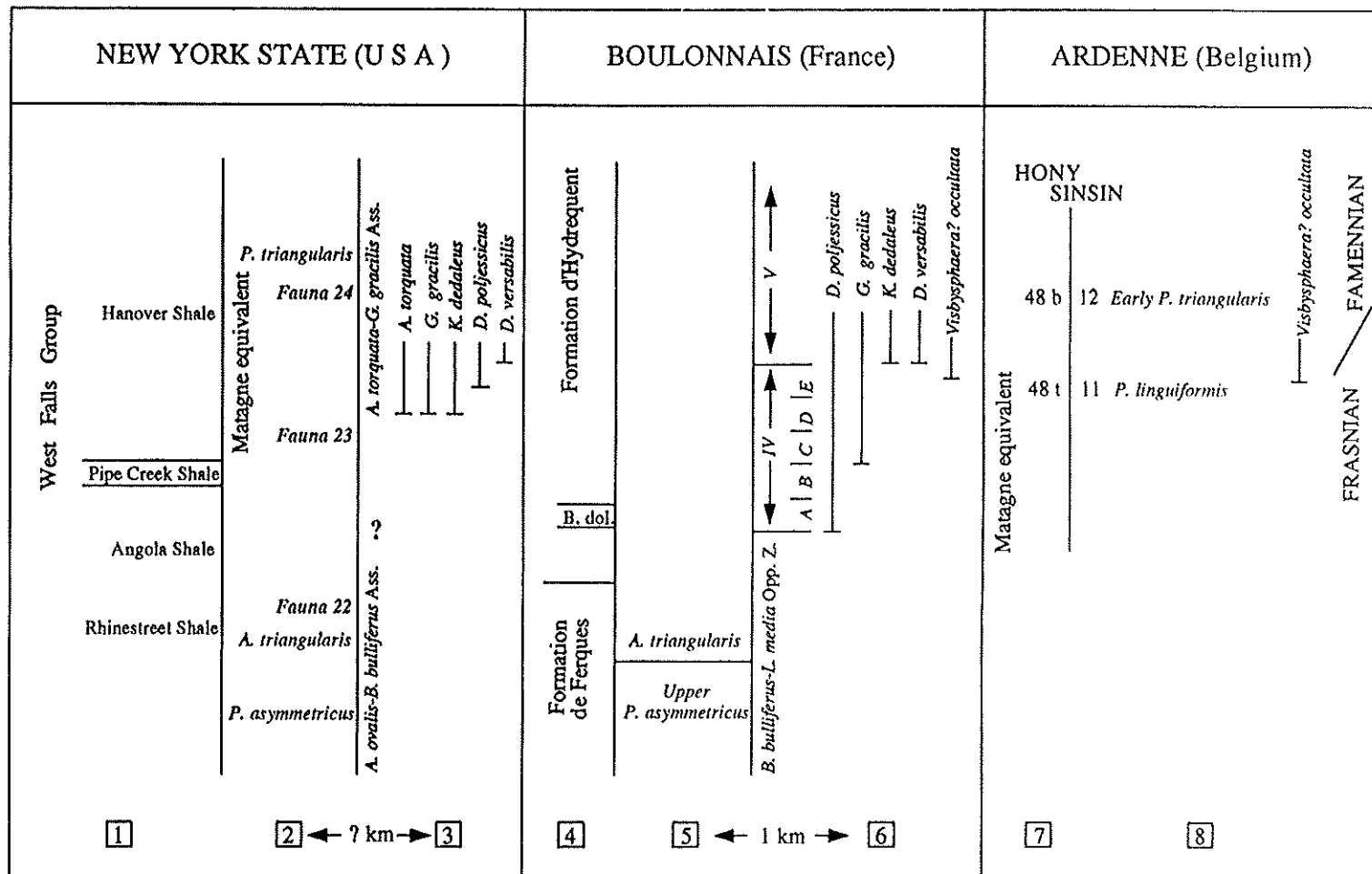
FAMENNIAN

FRASNIAN

[7]   [8]

Fig. 1. Miospores and other fossils in the Frasnian–Famennian boundary sequences in New York State (USA), the Boulonnais (France) and the Ardenne (Belgium).
New York State: [1] Lithostratigraphy after Rickard (1975); [2] Conodonts after Klapper et al. (1971), ammonoids after Kirchgasser and House, 1981; [3] Miospores after Richardson and McGregor (1986).
Boulonnais: [4] Lithostratigraphy after Brice et al. (1981); [5] Conodonts after Coen (in Brice et al., 1981), acritarchs after Vanguestaine in Loboziak et al. (1983); [6] Miospores after Loboziak et al., 1983.
Ardenne: [7] Lithostratigraphy of combined sections of Hony and Sinsin after Sandberg et al. (1988); [8] Conodonts after Sandberg et al. (1988), acritarchs after Streel and Vanguestaine (1989).

below its base, two (*Crassispora catenata* and *?Hymenozonotriletes denticulatus*) first appear slightly below the base, and the others at the base or slightly higher (?) in the Zone (Richardson and McGregor, 1986, fig. 3). Amongst these last species, four, with distinctive morphologies, are present, almost within the same time range, in the Formation d'Hydrequent (Loboziak et al., 1983) of the Boulonnais area, northern France where they are known to occur at close, but different, levels. This formation can, in turn, be correlated (Fig. 1), using acritarchs with the Hony and Sinsin sections in eastern Belgium where the new Frasnian–Famennian boundary is well documented with acritarch and conodont data (Streel and Vanguestaine, 1989). In western Europe, *Diducites poljessicus* and *Grandispora gracilis* occur below the Frasnian–Famennian boundary, probably well below the Formation de Matagne equivalent but *Knoxisporites dedaleus* and *Diducites versabilis* first appear in the Famennian. Is the succession of the first occurrence of these species really different in USA compared with western Europe or is the difference only the result of the poor definition of the base of the *A. torquata–G. gracilis* Assemblage Zone?

Which criteria have been used by Richardson and McGregor (1986, fig. 3) to draw the succession of the first occurrence of their species 140 to 154 if they were not found all in the same section?

To improve the accuracy of miospore-correlation it is necessary to obtain a better knowledge about the first entry of these miospores in the USA. Also, more specific information is required about the stratigraphical and lateral distances between the miospore and the faunal localities, and the reliability of the time correlation by lithostratigraphy over distances of several tens of kilometers in New York State. We are far from a definition of an accurate miospore-based limit at the Frasnian–Famennian boundary and a major break in miospore development at this level, suggested by McLaren (1988), is not yet demonstrated.

3. Miospore zones in the mid-Famennian

Richardson and McGregor (1986, fig. 7) have clearly illustrated an apparent discrepancy between the conodont–ammonoid and miospore correla-

tions of eastern USA with Belgium during the mid-Famennian. They compared the base of their *Rugospora flexuosa–Grandispora cornuta* Assemblage Zone in New York State with the base of the *D. versabilis–G. cornuta* (VCo) Oppel Zone in Belgium. *Grandispora cornuta*, *Rugospora radiata* and *Retusotriletes phillipsii* first occur in close succession in the Northeast Shale and Dexterville Shale and Sandstone Formations of the Canaday Creek section, south of Dunkirk, New York State (Richardson and Ahmed, 1988). The same succession was noted in the Shumla Sandstone and Northeast Shale Formations in other sections of New York State by Clendening et al. (1980). In eastern Belgium, these three species first occur at the same level in the section of La Gombe-Monfort at the base (sample 36) of the Formation d'Evieux (Bouckaert et al., 1971, fig. 6). Ten samples with miospores, but without these three key species, are known only between 50 and 180 m below sample 36, in the underlying Formation de Montfort and Formation de Comblain-la-Tour. The New York reference section is obviously better documented than the Belgian one (which also is now inaccessible).

The faunal control in both regions needs some consideration. In Belgium (Fig. 2), the conodont *Scaphignathus velifer* (first occurrence in the latest *marginifera* Zone) is known 162 m below sample 36 in the same section. *Spathognathodus bohlensianus*, recorded (Dreesen and Dusar, 1975) from Haversin, 40 km to the southwest in the Formation de Ciney, a supposed lateral equivalent of the Formation de Montfort (Thorez et al., 1977, hors-texte I) is no longer believed to provide a useful tool for subdividing the former *velifer* Zone (Dusar and Dreesen, 1985, p. 32). Therefore, the existence of the *trachytera* Zone below the miospores here concerned can no longer be demonstrated. In the same time the base of the "Fa2c" *

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* Originally such connotations in the Belgian Stratigraphic Scale were poorly defined biostratigraphically, being mostly of lithostratigraphic nature (as are still the connotations Tn1a, Tn1b, ...). In 1968 and in subsequent papers, Bouckaert et al. proposed for the first time a conodont-based boundary for the definition of Fa2a and miospore-based boundaries for the definition of Fa2b, Fa2c and Fa2d in defined reference sections, considering these subdivisions as chronozones. Later, Dusar and Dreesen (1985, p. 32) proposed to replace the miospore-based boundary of Fa2b by a conodont-based boundary.
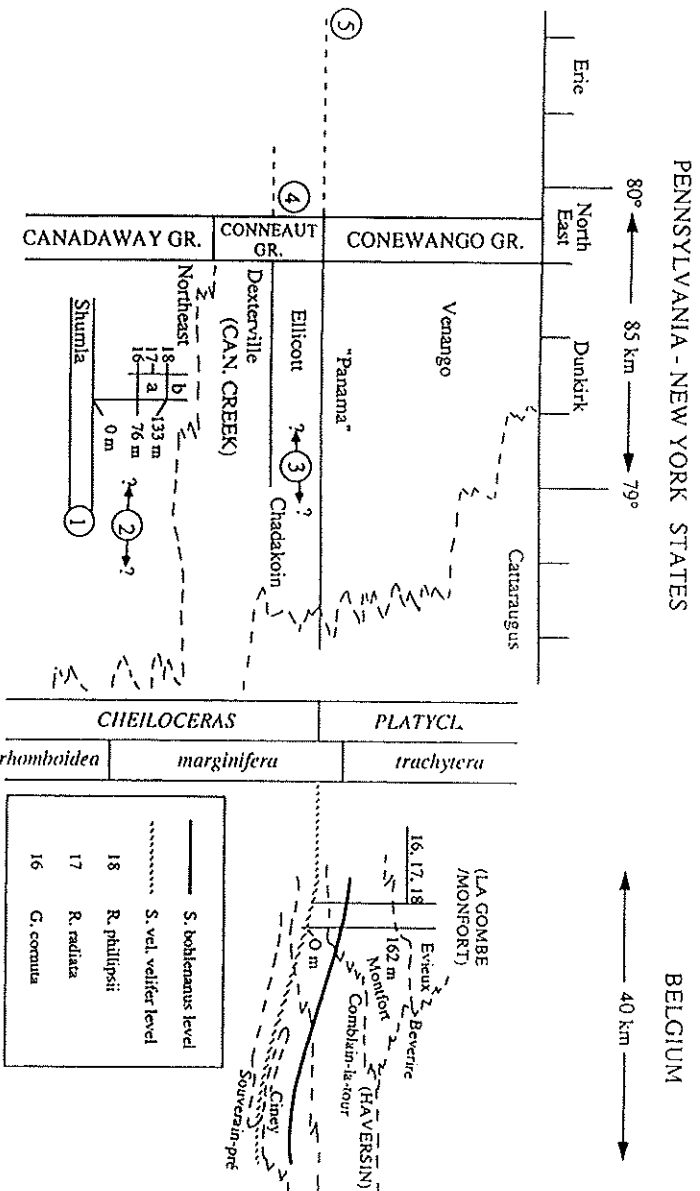
Fig. 2. Comparison of mid-Famennian bio- and lithostratigraphy in Pennsylvania/New York and Belgium. Lithology in New York State after Rickard (1975, plate 3). Spore stratigraphy in New York State after Richardson and Ahmed (1988). C.AN. CREEK = Canadaway Creek section, south of Dunkirk. Conodont stratigraphy in New York State after Klapper et al. (1971, fig. 4) and Rickard (1975). 1 = *Palmatolepis rhomboidea*, 2 = *Palmatolepis quadrantinodosa quadrantinodosa* in New York State after Klapper et al. (1971, fig. 4) and stratigraphy in Pennsylvania after Kirchgasser and House (1981, faunas 27 and 28, text-fig. 3), 3 = *Palmatolepis distorta*. Ammonoid about the middle of Ellicot Shale, 5 = *Sporadoceras milleri*, thought to be from the "Panama" Conglomerate. Note that correlations between miospores and ammonoids are based on lithologies from points at 40 and 100 km distance, respectively (Fig. 5, CQI 5 –). Lithology and correlation levels in Belgium after Thorez et al. (1977, hors-texte 1). Lithology, miospore and conodont stratigraphy in La Gombe/Montfort section in Belgium after Bouckaert et al. (1971, fig. 6).

became poorly defined in terms of the conodont succession. In the eastern USA (New York and Pennsylvania States), the datation by faunas is not better than in Belgium. Conodonts are known in the Shumla Sandstone, Northeast Shale and Ellicot Shale Formations (Klapper et al., 1971, fig. 4; Rickard, 1975). However, according to correspondence between J. Huddle and G. Klapper on the New York State conodont samples (J. Repetski and C.A. Sandberg, pers. commun., September 1990) in the Northeast Shale, the identification of *Palmatolepis quadrantinodosa quadrantinodosa* (Fig. 2, 2) is based on one single specimen in shale; in the Ellicot Shale, the fauna recovered (Fig. 2, 3) does not exclude the possibility that it is in the *velifera* Zone (now latest *marginifera* and *trachyt-*

era Zones) rather than in the *quadrantinodosa* Zone (now early and late *marginifera* Zones). The assignment of the Ellicot Shale to the Early *marginifera* Zone is not based on the conodont fauna but on the ammonoid fauna! In both cases, Huddle's samples come from probably prograding lithofacies (see Rickard, 1975, plate 3) at different, but unknown, localities. Ammonoid stratigraphy (in Pennsylvania) is given by Kirchgasser and House (1981, text-fig. 3: faunas 27 and 28). *Maeneceras* cf. *pompeckji* (Fig. 2, 4) comes from the middle of Ellicot Shale and *Sporadoceras milleri* (Fig. 2, 5) is thought to be from the "Panama" Conglomerate. The correlations between miospores and ammonoids are based on lithologies from points at 40 and 100 km distance, respectively.

The discrepancy between the conodont-ammonoid and miospore correlations of eastern USA with Belgium during the mid-Famennian is far from confirmed and more data will be necessary before it is possible to conclude that this miospore-based zone may be diachroneous.

4. The first occurrence of Retispora lepidophyta in the Famennian in Hunan

"The lower limit of the range of R. lepidophyta has been regarded as early Fa2d (early Strunian), and worldwide correlations have been based on this assumption by many authors. Nevertheless, recent evidence suggests that it may occur in slightly older rocks in some regions" (McGregor and McCutcheon, 1988). One of these regions is Central Hunan (southern China) where Hou (1982) has described a R. lepidophyta assemblage from the Oujiachong and part of the overlying Shaodong Formations in the Hsikuangshan area. R. lepidophyta assemblages were also described from the same formations in the same region by Gao (1990). However, more recent and detailed observations (Fang et al., 1993; Steemans et al., 1994) show that there are no R. lepidophyta in these formations but a closely related new monolete species named Retizonomonoletes hunanensis and that R. lepidophyta only occurs in the uppermost part of the overlying Mengongao Formation. This is certainly a case where refinement of taxonomy should precede biostratigraphical conclusions.

The absence of true R. lepidophyta in the Shaodong Formation is striking if this formation has to be of latest Famennian age. Faunas are not known from this interval in the Hsikuangshan section which has littoral characteristics. The contact between the Magunao and the Oujiachong Formations (Fig. 3) is sharp and corresponds, according to Wang (1987), to a "large magnificent regression (which) took place after the (conodont) marginifera Zone in the vast area of South China". Significant conodont assemblages were found in the lowermost part of the Shaodong Formation by Wang and Ziegler (1982), in another section where miospores were not recovered, located at
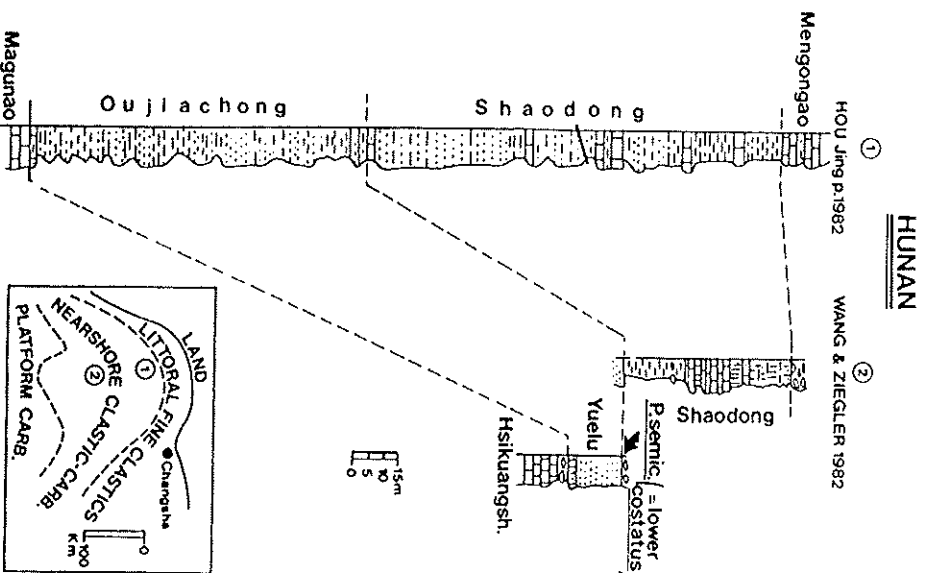
100 km distance from the miospore-bearing section. There, the lowermost Shaodong contains Polygnathus semicostatus which, based on correlations with western Europe, has its highest record approximately at the level of the incoming of R. lepidophyta, i.e. around the conodont middle and late expansa Zones. The lithostratigraphic correlation between the miospore-bearing section and the conodont-bearing section is, however, based on poor arguments. Indeed, if the sharp contact between the underlying Yuelu Sandstone and Hsikuangshan Limestone Formations has some analogy with the contact between the Oujiachong and Magunao Formations described in the distant

Fig. 3. Miospores and conodonts in the Shaodong and related formations in Hunan, China. Broken lines: lithological correlation.

HUNAN

HOU Jing p.1982 ①   WANG & ZIEGLER 1982 ②

Mengongao   Magunao   Oujiachong   Shaodong   Yuelu   Hsikuangsh.   P.semic./=lower costatus

LAND   NEARSHORE CLASTICS/CARB.   LITTORAL FINE CLASTICS/CARB.   PLATFORM CARB.   Changsha

section closer to the shoreline, this does not mean time equivalence (Fig. 3). On the contrary, the Shaodong Formation might well be a diachronous formation particularly on a direction perpendicular to the shore line. This would partly explain the different opinions about its age (see, for instance, Tan et al. 1987; Sartenaer and Xu, 1989; Xu and Ye, 1990).

This example illustrates a case where lithological correlations are not only very poor but ignore the possibility of significant non-sequences at sharp lithological contacts.

5. The first occurrence of *Lycospora pusilla* in the Visean of north Africa (Illizi and Rhadames Basins)

Lycospora pusilla first appears at, or close to, the Tournaisian–Visean boundary in many sections around the world (Clayton et al., 1990). However, in north Africa, the first appearance of this species is considered by Massa et al. (1980; and subsequent papers, see below) and more recently by Coquel and Massa (1993) to occur only in the late Visean and to be an example of the individuality of the flora of that region.

In Borehole A1-49, in western Libya (Fig. 4), the first occurrence of *L. pusilla* is in the uppermost part (l'unité à *Collenia*) of the M'rar Formation. This level is said to be dated as uppermost Visean by the presence of *Goniatites striatus* (Massa et al., 1980, fig. 4). However, Massa and Vachard (1979) explained that *G. striatus* is known only from the Illizi Basin, several hundreds of kilometers to the west and that, outside the Illizi Basin, there are no microfaunal data from the *Collenia* Horizon.

Moreover, the *Collenia* Horizon is diachronous between the area of Borehole A1-49 and the Serdeles area, a distance of approximately 300 km to the south Attar et al. (1980, p. 590) stated that the *Collenia* Horizon is rare in the Illizi Basin and only tentatively located in most boreholes. At best, therefore, if the *Collenia* Horizon is not diachronous, the first record of *L. pusilla*, marking the base of the Palynozone XV, can be placed only somewhere in the late Visean or in the early Namurian.

That this first record corresponds to the true first occurrence of *L. pusilla* in the area depends of course upon the presence of dated early and middle Visean sediments, without *L. pusilla*, below the Palynozone XV level.

Massa et al. (1980, fig. 4) showed that Palynozone XIV (which lacks *L. pusilla*) is to be dated, at the level of their cores 18-17 in Borehole A1-49, as equivalent to their "Biozone 3". The characteristic component of Biozone 3 is *Beyrichoceras hodderense* which is not known (Massa and Vachard, 1979, p. 9) from the boreholes but only, in Libya, from Tin Hieddan, a locality near the Algerian–Libyan border, on the western side of the Murzuk Basin, about 200 km south of the boreholes location. The Tin Hieddan section does not appear to have been formally documented. If we assume that the lithology there is comparable with that of the Serdeles area (150 km farther south), such correlations are too extended to be reliable (Fig. 4). The western side of the Murzuk Basin shows, at best, a very condensed sequence and even Massa and Vachard (1979, fig. 2) suggested that most of the Serdeles section below the *Collenia* Horizon might correspond only to the uppermost part of the section below that horizon in Borehole A1-49. The *Beyrichoceras* level cannot be precisely documented and compared to the miospore data in this borehole and the lithostratigraphic level adopted by Massa et al. (1980, fig. 4) is not demonstrated.

The underlying beds with Palynozone XIII (which also lacks *L. pusilla*) are considered to correspond to a "Biozone 2" devoid of any characteristic taxa (Massa et al., 1980, fig. 3).

Nevertheless, Massa and Vachard (1979, p. 9) stated that this "Intermediate Zone" might correspond to the lower and middle Visean. This assertion is of course the key to the stratigraphic interpretation of these authors but remains unproven in western Libya. Only the lower part of the M'rar Formation seems to be well dated with the presence of the ammonoid *Muensteroceras* and conodonts which suggest a late Tournaisian age (Coquel and Massa, 1993).

The approximate time-equivalent of the M'rar Formation in the Illizi Basin, in eastern Algeria, is the Issendjel Formation. In the middle (Attar et al.,
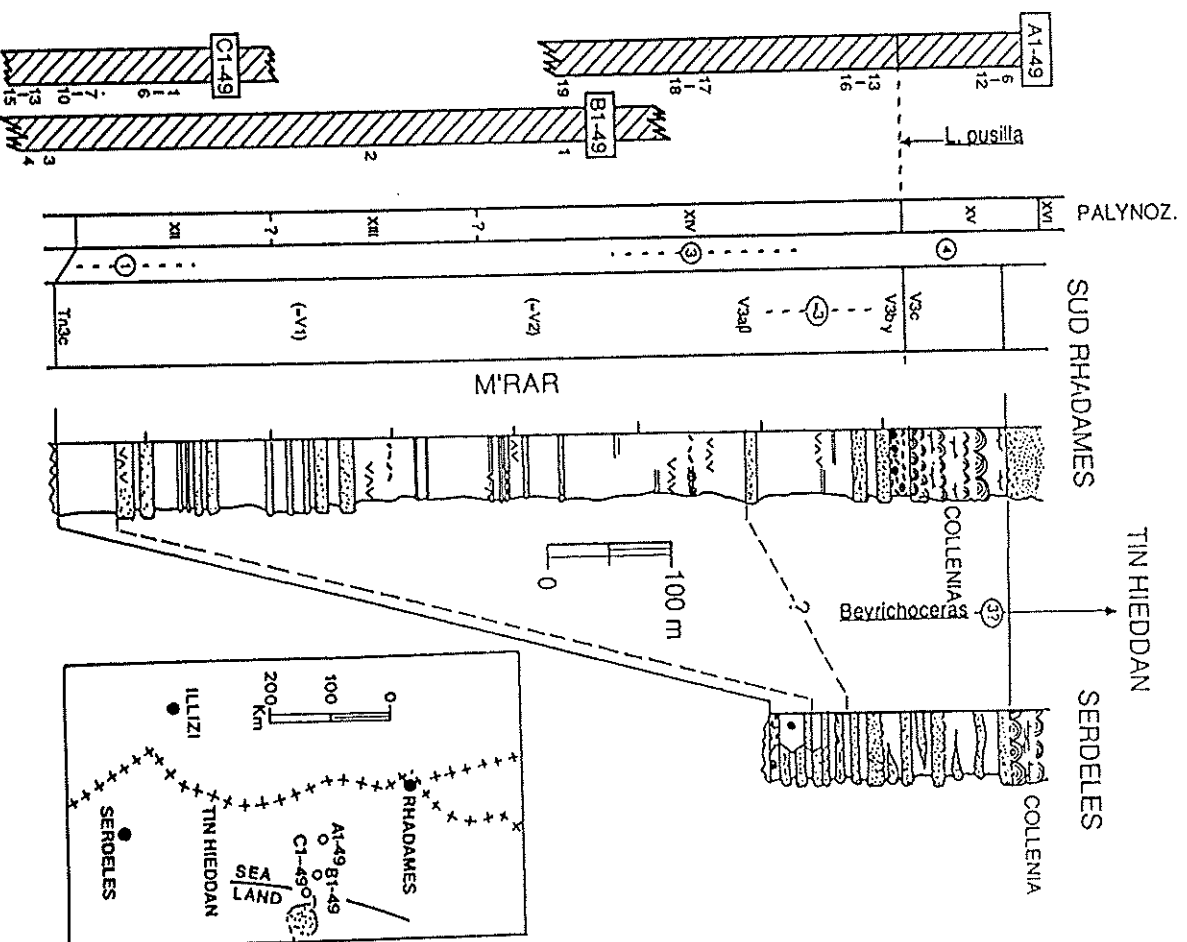
Fig. 4. Miospores and faunas in the M'rar Formation in western Libya. Data after Massa et al. (1980) and Massa and Vachard (1979).

1980, fig. 3) or the upper part (Massa and Vachard, 1979, p. 9) of this formation the genus *Beyrichoceras* is present. The palynological analysis of Attar et al. (1980) is claimed to have been based on 285 samples from 17 boreholes but no data are given on the correlation between the boreholes or on the distribution of the palyno-

morphs and faunas in each borehole. It is not even known whether any occurrences of *Beyrichoceras* can be related to any of the borehole sections. The uppermost part of the Issendjel Formation (where the lycospores occur in Palynozone V), with the *Collenia* beds, is now incorporated in the overlying Assekaifaf Formation (Coquel and Massa, 1993).
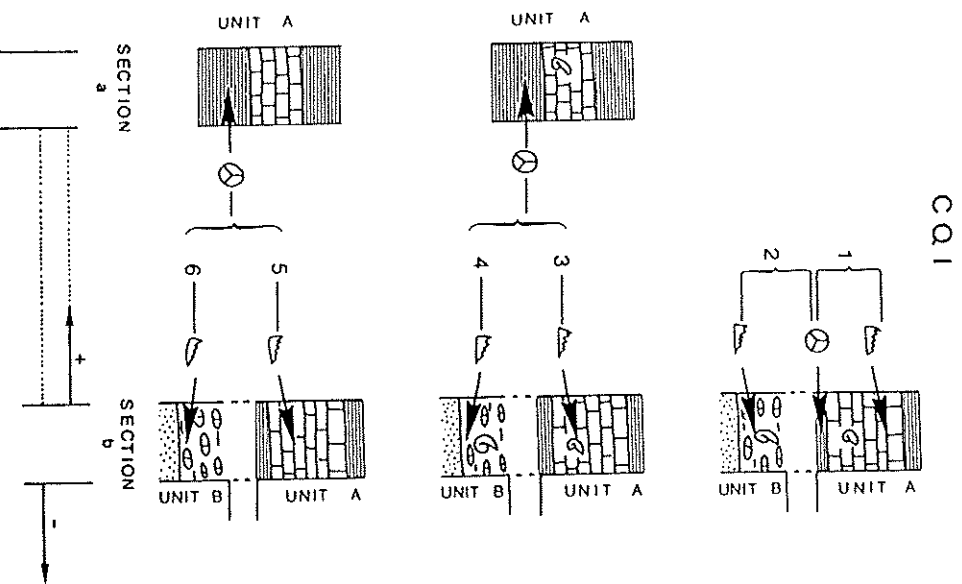
In the Illizi Basin, the horizon K known a few meters higher than the "Grès d'Issendjel" (see Coquel and Massa, 1993, fig. 2) contains *Muensteroceras subgloboosum*, *Beyrichoceras hodderense*, *B.* e.g. *obtusum*, etc., indicating (Pareyn, 1961) the lower Visean/upper Visean boundary. Riley (1990a) has recently reviewed the *Beyrichoceras* Ammonoid-Biozone. He thinks (pers. commun., 1993) that Pareyn was incorrect to assign the material referred to as *B. hodderense* to *Beyrichoceras*. Examination of the descriptions has lead Riley to believe that they may be examples of *Dzhaprakoceras*, *Bollandoceras* or *Beyrichoceratoides*. Associated to *Muensteroceras*, all these genera indicate (Riley, 1990b) a lowermost Visean (equivalent to VIa or lower part of the Moliniacian) age.

Therefore, we may conclude that Palynozones XIV and XIII in western Libya as well as Palynozone IV in eastern Algeria, all devoid of *Lycospora*, are poorly dated but that the few faunas available indicate a possible lowermost Visean age. Most of the Visean must be condensed or missing close to the *Collenia* Horizon.

The first appearance of *Lycospora* (*L. pusilla*) around the world, although known in the vicinity of the Tournaisian–Visean boundary, has never been observed in sections where this boundary can be recognized with confidence, based on the definitive guide foraminifera *Eoparastaffella* and the phased occurrence of accessory taxa above it. This first appearance of *Lycospora* might therefore be situated in the lowermost Visean. Consequently, in the absence of confirmed lower and middle Visean miospore assemblages, without *Lycospora*, a belated first occurrence of this genus in north Africa is not supported by available data.

This example illustrates not only very poor lithological correlation but emphasises that time should not be necessarily considered represented by rock when biostratigraphical evidence is inadequate to prove it. Similar conclusions were reached after careful examination of Lower and Middle Devonian sequences in western Libya (Streel et al., 1990) where, according to Massa (1988), a lycophytic megaflora should have occurred much earlier than in other regions of the world.

Fig. 5. Correlation Quality Index (CQI) between any reference faunal (here conodont) and miospore zones. From 1 to 6 decreasing in quality).

(1) Reference fauna in same section and same lithological unit as reference point of miospore zone.

(2) Reference fauna in same section but other lithological unit as reference point of miospore zone.

(3) Reference fauna in another section (3+ at short distance, 3– at long distance), but in same lithological unit containing other faunal or floral data also known in reference section of miospore zone.

(4) Reference fauna in another section (4+ at short distance, 4– at long distance), but in other lithological unit containing other faunal or floral data also known in reference section of miospore zone.

(5) Reference fauna in another section (5+ at short distance, 5– at long distance), in same lithological unit but without common faunal or floral data with reference section of miospore zone.

(6) Reference fauna in another section (6+ at short distance, 6– at long distance), in other lithological unit but without common faunal or floral data with reference section of miospore zone.

EPOCH	AGE
LOWER CARB.	
MIDDLE DEVONIAN	EIFELIAN / GIVETIAN
UPPER DEVONIAN	FRASNIAN / FAMENNIAN
LOWER DEV.	

CONODONTS		CQI	MIOSPORES
OLD ZONATION	STANDARD ZONATION		
S. sulcata	sulcata		
L. Protognathodus	praesulcata		21 R. lepidophyta LOB
U. costatus			20 H. explanatus FOB
M. costatus			19 R. lepidophyta FOB
L. costatus	expansa		16,17,18 G. cornuta, R. radiata, R. phillipsii
U. styriacus	postera		
M. styriacus			
L. styriacus	trachytera		15 R. macroreticulata
U. velifer			
M. velifer	marginifera		14 G. famenensis FOB
L. velifer			
U. marginifera	rhomboidea		
L. marginifera			13 K. dedaleus FOB NY, USA (b)
U. rhomboidea	crepida		12 G. gracilis FOB
L. rhomboidea			11 R. bricei FOB
U. crepida	triangularis		
M. crepida			10 V. bulliferus FOB
L. crepida	linguiformis		9 C. concinna FOB
U. crepida	rhenana		
U. triangularis	jamieae		8 S. triangulatus FOB
L. triangularis	hassi		7 G. lemurata FOB
M. triangularis	punctata		6 C. timanica
U. gigas	transitans		
L. gigas	falsiovalis		5 A. acanthomum, A. macrospinosus
U.* gigas	disparilis		4,5 A. acanthomum, A. macrospinosus
Ancyrognathus triangularis	herm. cristai		3 G. velata FOB
U. asymmetricus	varcus		1,2 A. apiculatus, G. protea
M. asymmetricus	ensensis		
L. asymmetricus	kockelianus		
L.* asymmetricus	australis		
	costatus		
	partitus		
	patulus		
	serotinus		
	inversus		Bohemia (a)

EIFEL REGION — BOULONNAIS REGION — ARDENNE REGION — SAUERLAND REGION

Fig. 6. Correlation between conodont zonation and miospore biohorizons in the Middle and Upper Devonian of the Ardenne–Rhine regions. Conodont zonation after Klapper and Ziegler (1979), Weddige (1984), Ziegler and Sandberg (1990, text-fig. 2). CQI=Correlation Quality Index (see Fig. 5); */** =CQI of the lowest correlation, ** =CQI of the highest correlation. FOB=first occurrence biohorizon; LOB=last occurrence biohorizon.

6. Attempts at a better definition of miospore horizons and of correlations with other fossil groups

The advantage of the interval zone concept is that it allows unequivocal correlations with interval zones based on other fossils. The quality of these correlations depends on the "distance" between the miospore data and the faunal data.

A Correlation Quality Index (CQI) is proposed here to evaluate (see also Streel and Loboziak, 1994) these "distances" which are not only geographical distances between data but also take into account the nature of the available lithological data and how they can been correlated by fossils other than miospores (Fig. 5). Of course, lithostratigraphical correlation is also subject to problems of definition, depending whether it is considered at the Group, Formation, Member or Bed level. On Fig. 5, we have purposely used the informal term unit, assuming the unit has to be defined in the context. Of course miospores are rarely found in the same lithologies as those containing conodonts or foraminifers and we realize that to incorporate a shale and a limestone in the same unit (Fig. 5, CQI 1) may be unsound, the distance in time between both horizons being uncertain. However, the Correlation Quality Index should help to evaluate correlations and consequently focus attention on those parts of the biostratigraphical scheme that need some priority for further research.

Miospore biohorizons have been defined and their correlation with the conodont standard zonation evaluated along these guidelines (Streel and Loboziak, 1994) in the Middle and Upper Devonian of the Ardenne–Rhine regions (Fig. 6). The miospores were selected on the following criteria: (1) unambiguous morphology, (2) common presence in significant sections, (3) the same sequence of first occurrences in these sections, (4) no, or little, restriction in known lateral distribution. Two kinds of biohorizons are recorded: potential and confirmed, the latter being identified by FOB (first occurrence biohorizon) or LOB (last occurrence biohorizon). The correlation quality index (CQI) is mentioned on Fig. 5. When the correlation of a biohorizon fits within one conodont zone, one CQI is given. When it ranges between two or more conodont zones, the first CQI concerns the lowest correlation, the second CQI concerns the highest correlation.

This example (Fig. 6) is given to stimulate other workers to document the proposed framework species occurrences more accurately and propose other suitable existing and/or new taxa for inclusion in a species range zonation.

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