

MIOSPORE CONTRIBUTION TO THE UPPER FAMENNIAN-STRUNIAN EVENT STRATIGRAPHY

by

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(10 figures)

ABSTRACT. - The Northwestern European miospore zonation of the Devonian-Carboniferous transitional beds allows accurate correlations between assemblages originating from a same paleolatitudinal belt. Miospore correlations across paleolatitudes are less accurate except maybe during the late Famennian-early Strunian timespan. Palynostratigraphy demonstrates that regression-transgression events are strikingly synchronous on the Euramerica (Old Red) continent as well as in China. It is suggested that glaciation was a major cause of sea level fluctuation in the Famennian-Strunian timespan. On the contrary tectonic processes like growth of oceanic ridge systems might have been of major importance in the Tournaisian.

RESUME. - La zonation des miospores du Nord-Ouest de l'Europe dans les couches de transition dévono-carbonifère permet des corrélations précises entre des assemblages provenant d'une même ceinture latitudinale. Les corrélations par miospores entre paléolatitudes différentes apparaissent, en revanche, moins précises sauf peut-être pendant l'intervalle fini-Famennien-Strunien ancien. La palynostratigraphie montre que les régressions et transgressions sont étonnamment synchroniques sur le continent euraméricain (Old Red Continent) ainsi qu'en Chine. On suggère que des glaciations ont constitué une cause majeure de fluctuation du niveau des océans dans l'intervalle Famennien-Strunien. En revanche, des processus tectoniques comme le développement de crêtes océaniques, auraient joué un rôle plus important au Tournaisien.

1. - INTRODUCTION

Miospores are particularly abundant in the regressive-transgressive sequences of the late Famennian and Strunian of the Ardenne-Rhine area where the classical type sections also contain well known index faunas. Previous research has resulted in the intercalibration of four zonal schemes which will serve here as a biostratigraphic framework.

On an interregional scale correlations depend on paleophytogeography which in turn relies on paleoclimatology. To evaluate late Famennian-Strunian phytogeographical and climatological controls, a late Devonian-early Carboniferous timespan will be considered.

Strunian assemblages of miospores found so far around the world are so numerous that it would be beyond the scope of the present paper to review them all. Therefore, only data which seem related to "events" in a few specific areas will be considered.

2. - MIDDLE FAMENNIAN TO LATE TOURNAISIAN MIOSPORE ZONATION IN THE NORTH-WESTERN EUROPEAN REFERENCE STRATIGRAPHY

The unformal chronostratigraphic subdivisions used in the present paper are explained on fig. 1.

Miospore-zones have been defined in the type area of the middle Famennian to early Strunian in Eastern Belgium (Dinant Synclinerium) and in the late Strunian to late Tournaisian of Southern Ireland (Munster Basin).

In Belgium, the most diagnostic species are illustrated in Bouckaert, Streel *et al.*, 1969; Papproth & Streel, 1971 and more particularly in Becker, Bless *et al.*, 1974 where eight zones can be recognized (Streel *in* Becker, Bless *et al.*, 1974; enclosure II, fig. 1 : flori

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zones GH, GMi, GMm+s, VUi, VUs, PLi, PLm, PLs1). They are interval zones based on the first appearance of selected species. How they have been progressively established and applied, particularly in the Dinant Synclinorium, is explained in StreeL, 1986 (in prep.) and will not be recalled here. Nomenclatural changes have been proposed in Paproth, Conil *et al.*, 1983.

The miospore zonation of Clayton, Higgs *et al.*, 1978 for the late Devonian and early Carboniferous of Britain and Ireland has recently been modified by Higgs, Clayton & Keegan, 1986. The zonation has been successfully applied to many areas in Ireland and Britain and fully illustrated, particularly in the Munster Basin. Its independence of sedimentary facies has been demonstrated (Clayton & Higgs, 1979).

In the Dinant Synclinorium, it is not until the base of the middle Famennian (here characterized by the first occurrence of *Palmatolepis klapperi*, fig. 2 and 3) that the criteria of first occurrences of individual miospore species can be used for erecting miospore zones since below that level adverse conditions in lateral transport of spores are prevailing (Becker, Bless *et al.*, 1974). The miospore zone corresponding to the maximum of the regression is characterized by the joint first occurrence of *Grandispora cornuta*, *Rugospora flexuosa* and *Retusotriletes phillipsii* (VCo miospore zone)*. In the eastern part of the Dinant basin where miospores are abundant, the base of the Strunian seems to coincide with a new transgression and the first occurrence of *Retispora lepidophyta* and *Vallatisporites pusillites* (LV miospore zone). However there might be a gap at the base of the LV-zone because in the United States and in Northern Africa *V. pusillites* does occur below *R. lepidophyta* in an uppermost part of the late Famennian.

How the early Strunian transgression ends in the Dinant Basin is not well known. In the Etroeungt Limestone (Tn1a), less and less clastic material reaches the basin but an upward shallowing of the upper part of the sequence has been recognized by Van Steenwinkel (1984a). The abrupt lithological change occurs at the boundary between the Etroeungt Limestone and the Hastiere Limestone (Tn1b) in the central part of the Dinant Basin and may have been emphasized by some erosional process. The lowermost part of the Hastiere Limestone (a 2 m thick bed which might be of late Strunian age) has been deposited in winnowed shoal conditions. Next, a mudstone, wackestone and grainstone succession - presumably representing the lowermost part of the Hastarian (Tournaisian) local stage - was deposited below normal wave base (Van Steenwinkel, 1984a), thus marking a new deepening of the environment.

In the Namur Syncline, coarse, siliciclastic deposits with LL miospores, overlying Frasnian rocks, grade into carbonate beds upwards. An abrupt transgression occurs at the base of the Pont d'Arcole Fm (Tn2a) near the base of the HD miospore zone.

This sequence can be easily correlated with the Munster Basin in Ireland where a late Strunian very thick sequence dated by the LE and LN miospore zones would correspond, according to Mac Carthy & Gardiner (1980), to a prograding delta, overlain by a transgressive sequence dated by the VI miospore zone.

It can also be correlated with the Hangenberg Shales in the Sauerland (FRG) (Higgs & StreeL, 1984), more precisely with the late Strunian part which contains reworked spores and is shown by Keupp & Kompa (1984) to represent near-shore sediments transported over a short distance. The VI miospore zone occurring near the top of the Hangenberg Shales marks the return of a quiet environment, probably in the aphotic zone (Van Steenwinkel, 1984b), thus marking a new transgression. A more abrupt transgression occurs however at the base of the HD miospore zone, where black shales overly the Hangenberg Limestone.

In the Ardenne-Rhine area, a major lithological change occurs at the boundary between the Etroeungt Formation and the Hastiere Formation near Dinant and also between the Wocklum Limestone and the Hangenberg Shales in the Sauerland. The two miospore zonations suggest that these lithological changes - occurring above the top of the LV zone, somewhere within the LE zone - might well be more or less synchronous (the Devonian-Carboniferous event of Walliser 1984). However, clastic miospores-bearing facies only occur below the contact near Dinant (mostly early Strunian), and practically above it (late Strunian) in the Sauerland. Nowhere in Western Europe, these two zonal schemes have been identified in one rock sequence.

The middle Famennian to early Strunian part of this miospore zonation has been intercalibrated with the Conodont zonation as shown on fig. 2. But this was not possible within the interval covered by unfavourable facies for one or the other fossil group. For instance, the accurate position of the base of the VCo miospore zone is unknown within the range of the *trachytera/postera* Conodont zones; accordingly that of the Upper *praesulcata* Conodont zone is unknown within the range of the LE/VI miospore zones in the Dinant Basin. We use a sequence of numbers (the micropaleontological guide-marks or mgm of Bouckaert & StreeL, 1974 : 29 to 51) to demonstrate the sequence of interrelations between the two zonations. It is reproduced also on fig. 3 where another sequence of numbers (1 to 10) is used for correlation in the mostly late Strunian of the Sauerland. In fig. 3, these zonations are partly correlated with Foraminifer and Cephalopod zonations. They are also connected, in well documented reference sections, to chronostratigraphic subunits (Fa2b, Fa2c, Fa2d) of the Upper Famennian of Bouckaert, StreeL & Thorez, 1968, 1971 and StreeL, Bless *et al.*,

* The same zone has been recovered from a single sample taken in the Upper Old Red Sandstone of County Kerry, SW Ireland (Higgs & Russell, 1981).

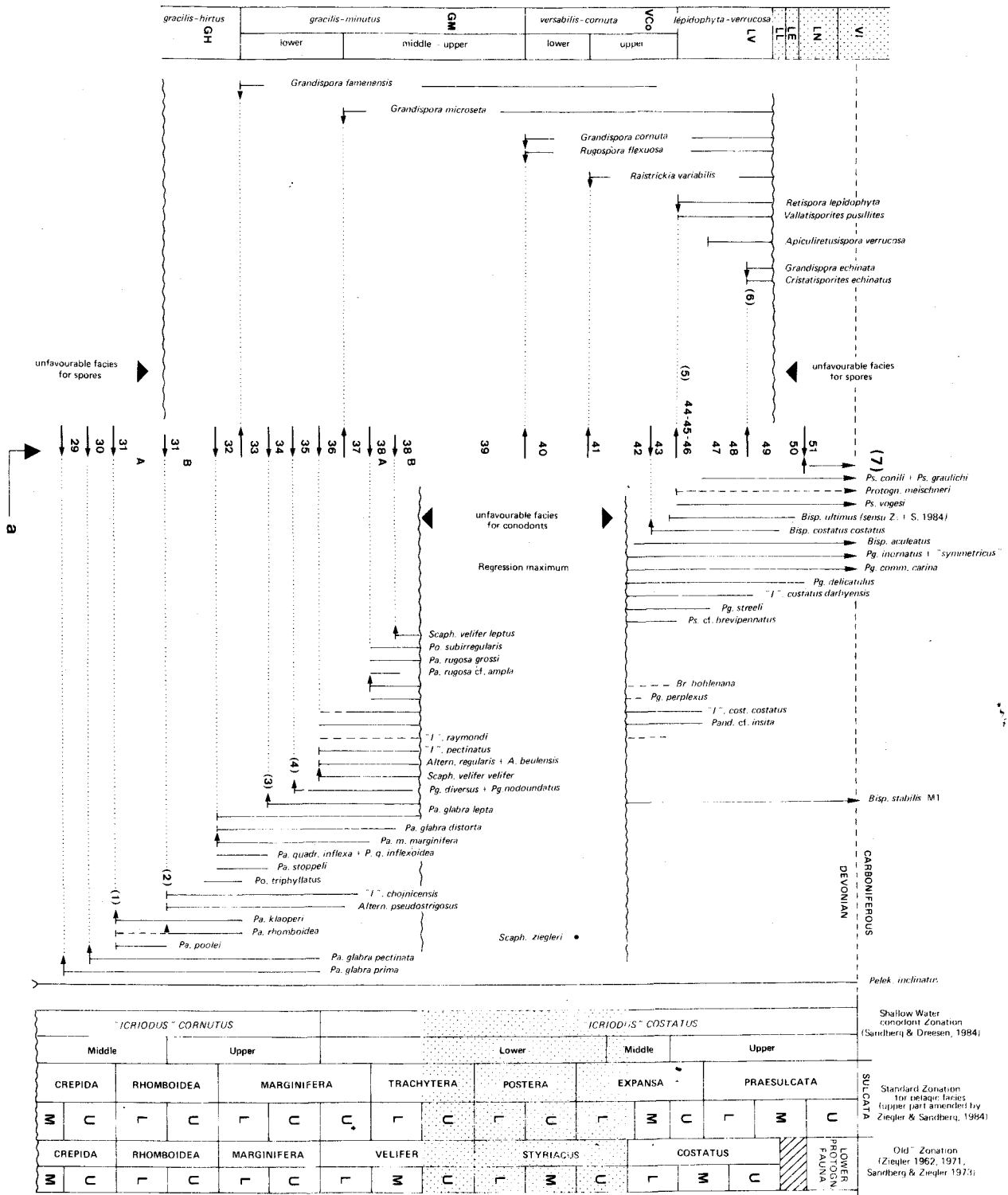


Figure 2. - Comparison of miospore and Conodont zonal schemes in the early Strunian of the Dinant Synclinorium.

a) intercalibration of the two zonal schemes, using a sequence of numbers (the micropaleontological guide-marks or mgm of Bouckaert & Streel 1974, here completed by new data from Dreesen in Dreesen, Sandberg & Ziegler, 1986.

- (1) The first appearance of *P. klapperi* is preferred over that of *P. rhomboidea* and of *P. pooleri* because of the higher frequency of the former species and the apparent "retardation" of *P. rhomboidea* due to unfavourable facies conditions.
- (2) The first occurrence of *"I" chojnicensis* marks the base of the newly proposed *"Icriodus" cornutus* Zone (shallow-water conodont zonation) and coincides with the base of the upper *P. rhomboidea* Zone. The latter zone is characterized in Belgium by the highest frequency of *P. rhomboidea*.
- (3) Because of lack of index *Palmatolepis* species it is proposed here to use the first occurrence of *Bispathodus stabilis* morphotype 1 to define the base of the upper *P. marginifera* Zone in Belgium.
- (4) *Pg. diversus* and *Pg. nodoundatus* are very common polygnathids in the highest part of the upper *P. marginifera* Zone in the Belgian section studied.
- (5) *R. lepidophyta* first appearance marks the level 44. Intercalibration of levels 45 based on Foraminifera and 46 based on Conodonts in Bouckaert & Streel (ed.) 1974, has to be reconsidered.
- (6) Among the four miopores marking the level 49 in Bouckaert & Streel (Ed.) 1974, *"V. nitidus"* is now believed to belong to another species. *G. echinata* is here designated to mark, alone, the level 49.
- (7) *Protogn. kockeli*.

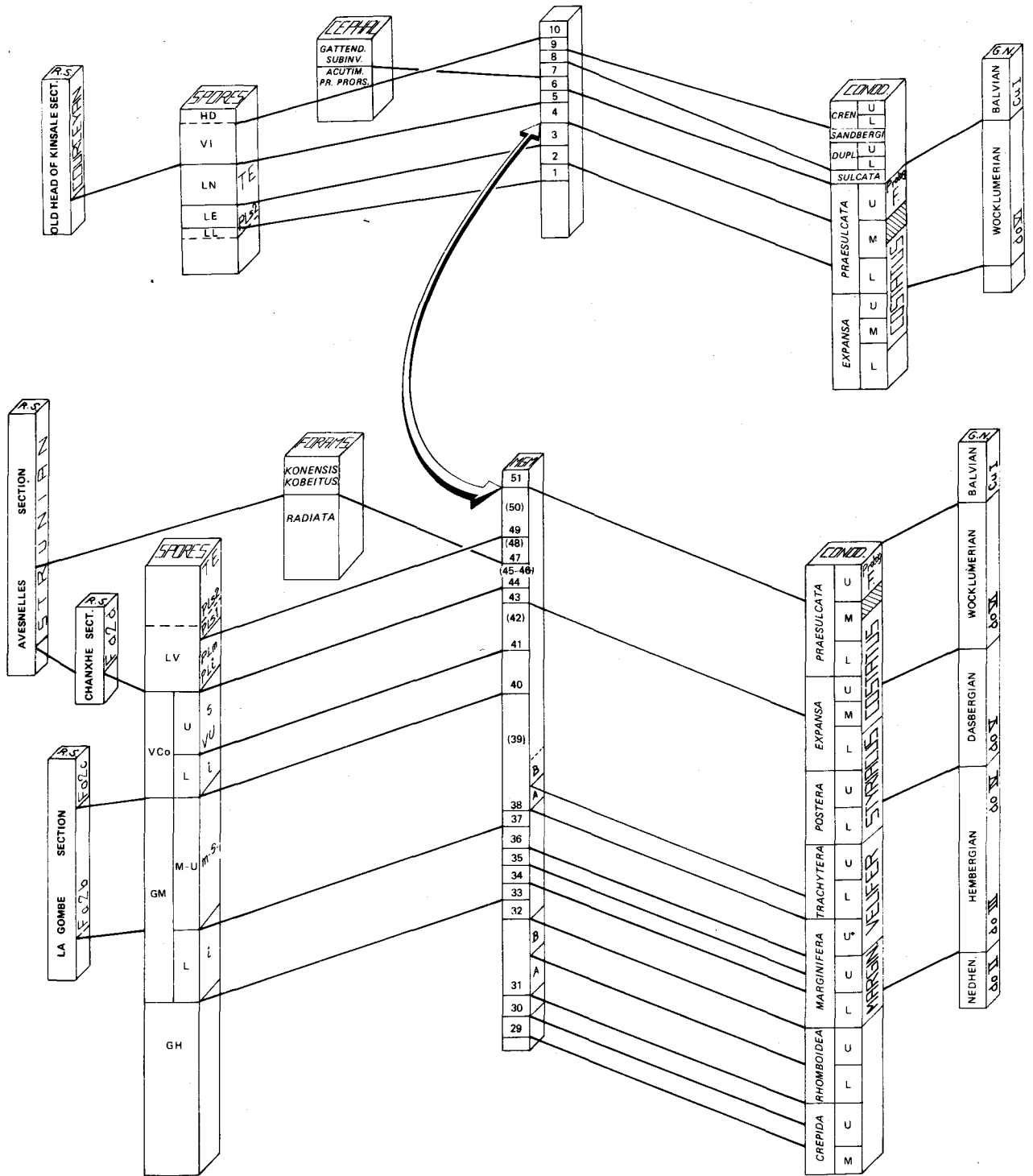


Figure 3. - Intercalibration of four zonal schemes and Reference sections (R.S.) in the Dinant Synclinorium (Belgium) and German Nomenclature (G.N.) in the Sauerland (FRG).

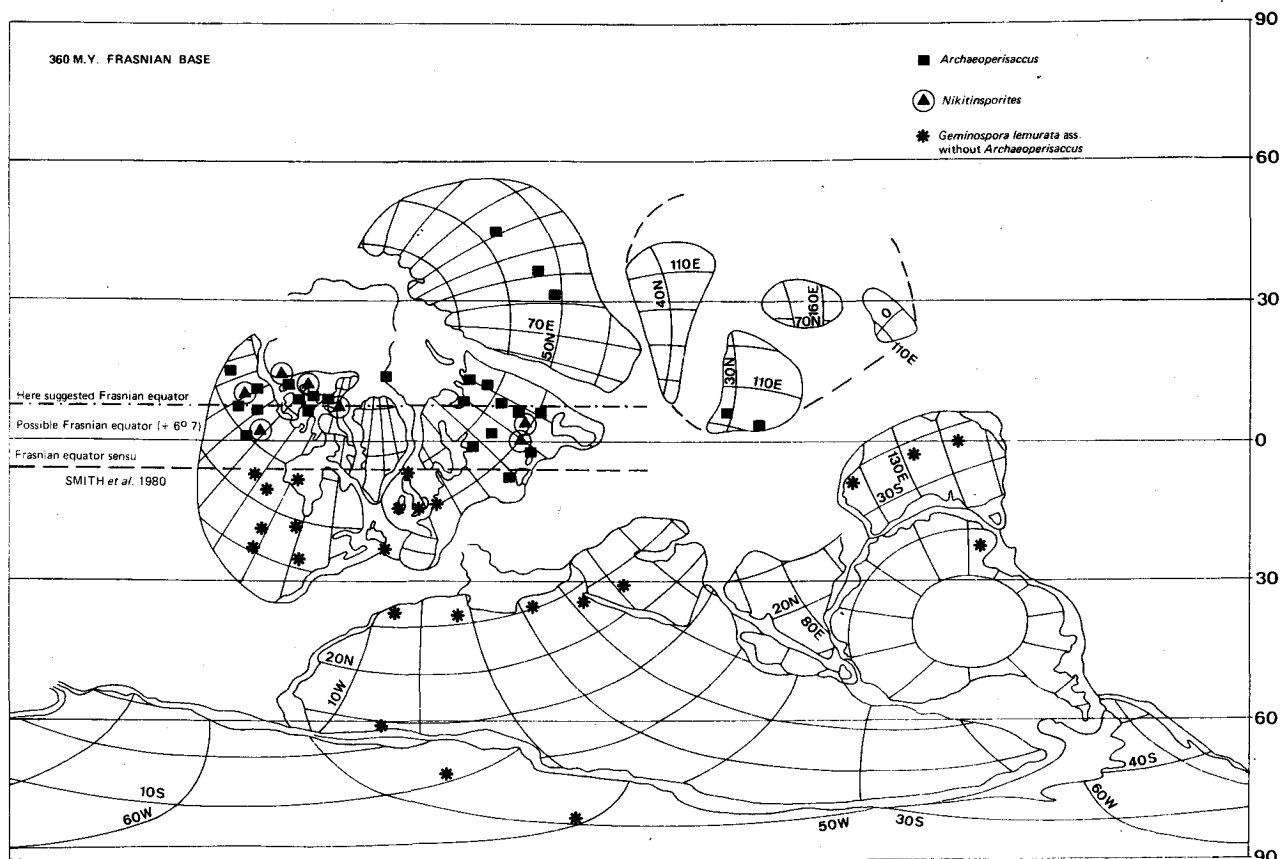


Figure 4. - Frasnian miospore assemblages
Data from McGregor 1979, Loboziak & Streel 1980, Clayton & Graham 1975, Playford 1983, etc. . .

1975 and also to the base of the Strunian of Conil & Lys, 1980.

The intercalibration of zonal schemes allows the correlation of the platform chronostratigraphic scale in the Franco-Belgian areas with its basinal equivalent in Western Germany. The base of the Strunian and the base of the Wocklumerian are here considered time-equivalent, recognized by the first occurrence of the conodont *Protognathodus meischneri* which occurs near the base of the LV (ex PL) miospore zone in the Yves-Gomezée Road Section in Belgium (Dreesen, Dusar & Groessens, 1976) and is considered by Sandberg (1979) as permitting the recognition of the base of the Middle *Bispathodus costatus* zone. The early Tournaisian is based on the first occurrence of *Siphonodella sulcata*.

3. - LATE DEVONIAN-EARLY CARBONIFEROUS PALYNOPHYTOGEOGRAPHY

During the past twenty years, several palynophytogeographic maps have been published covering the late Devonian and early Carboniferous (Sullivan, 1965, 1967; Alpern & Streel, 1972; Streel, 1974, 1980; McGregor, 1979; Van der Zwan, 1980, 1981). These maps use different projection-systems and are therefore hardly comparable. Also, the oldest ones are unreliable as the paleomagnetic records have increased

in number and precision in recent times.

To reproduce and complete the palynological data available in the relevant timespan, we have selected and slightly modified the cylindrical equidistant 360 m.y. (Frasnian) map of Smith, Hurley & Briden, 1980. This kind of projection allows the relative longitude separations of the continental fragments to be rearranged without in any way conflicting with their configuration. Assuming that former palynophytogeographic studies (i.e. Streel, 1974) have clearly demonstrated the close connections between the Euramerican and Gondwana Continents since at least the Upper Devonian, the former has been shifted as far east as possible to match the Gondwana. This was made easier by a slight latitude change of Euramerica southward within the range of evaluated errors given by Smith, Hurley & Briden, 1980. Also, fragments of an hypothetical Pacifica Continent (Zhang, 1984) have been detached from the Asian Continent, the South China Block being situated in the ideal position proposed by Hou & Wang, 1985.

This map has been used by the present author for early Carboniferous as well as for late Devonian palynophytogeographic reconstructions.

The first obvious latitudinal distribution of plant (microfossils) in the geological scale was demonstrated in the Frasnian by McGregor (1979). Plotting the distribution of *Archaeoperisaccus* (miospore) and *Niki-*

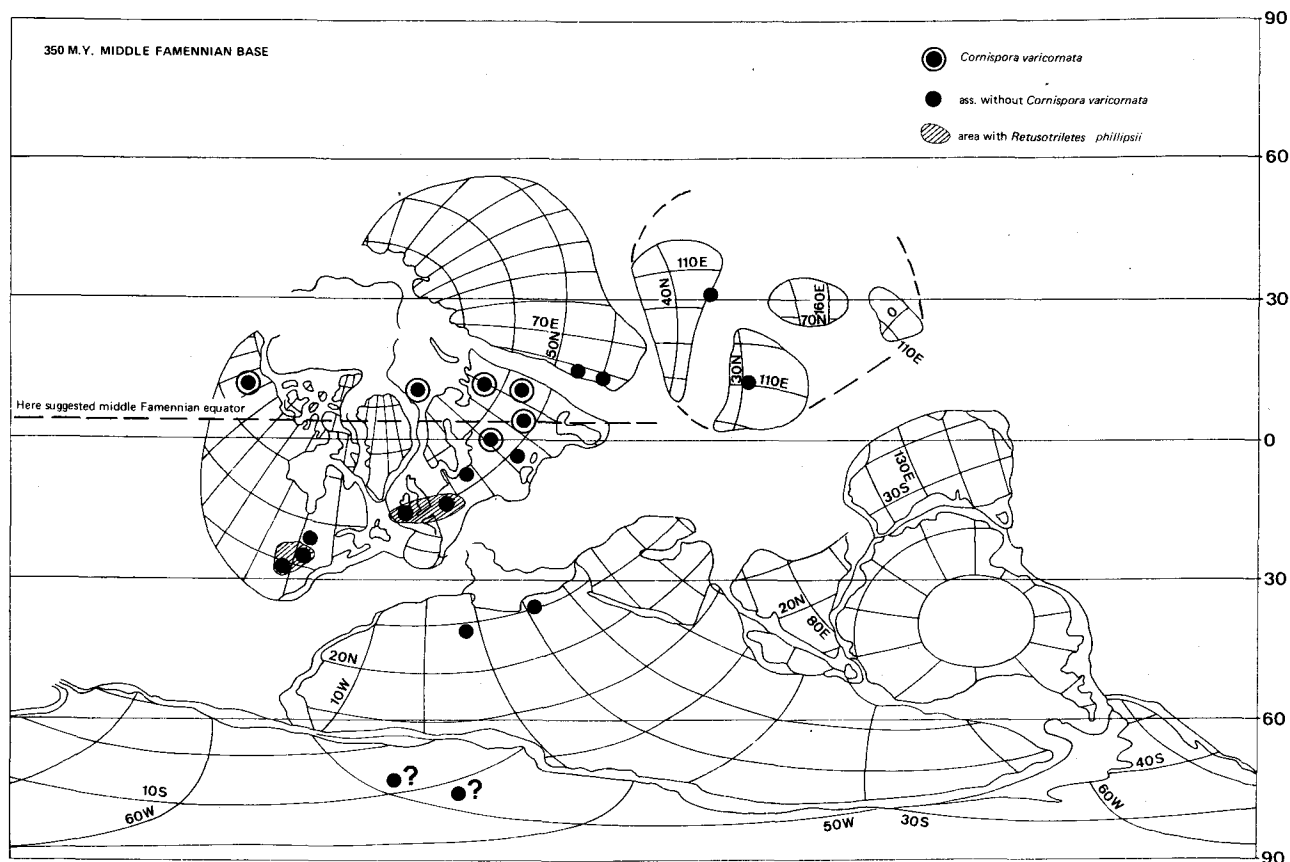


Figure 5. - Middle and late Famennian miospore assemblages.
Data from Streeel 1974, Norris 1985, Van der Zwan 1979, Van der Zwan & Walton 1981,
unpublished data on China received from Gao, etc . . .

tinsporites (megaspore), supposedly belonging to the same plant, on a paleogeographic map adapted from the generalized Middle Devonian continental assembly of Oliver (1977), he showed these plants to be abundant immediately north of the palaeoequator and virtually absent south of it. The same distribution plotted on the world map of Heckel & Witzke (1979) (Streeel, 1980) resulted in a much better fit; *Archaeoperisaccus* and *Nikitinsporites* appeared to be restricted to the equatorial belt, on each side of the equator. The same data and a few additional new records (i.e. Gao, 1981) are here (fig. 4) reproduced on the modified 360 m.y. map of Smith, Hurley & Briden, 1980. We also plotted the records of *Geminosporea lemurata* miospore assemblages which do not contain *Archaeoperisaccus* in order to prove that the distribution of the last one is not the result of a biased sampling (data from McGregor, 1979; Loboziak & Streeel, 1980; Clayton & Graham, 1975; Playford, 1983, etc. . .).

Obviously no phytogeographer would ever accept that a plant might have a distribution on one side only of the equator in the equatorial belt! Therefore we suggest the true Frasnian equator to be located 7° more to the North compared to the Euramerican continent, than the possible (+ 6°7) Frasnian equator sensu Smith, Hurley & Briden (1980), adopted on our general map.

This suggested Frasnian equator would then pass in the middle of the belt covered by the distribution of the megaspore of that plant. Such a position of the Frasnian equator can match the paleomagnetic data if we accept (as did Heckel & Witzke, 1979) that the paleomagnetic poles do not coincide always with the rotational poles of the earth. But, in his lower Carboniferous world reconstruction, Van der Zwan (1981) alternatively mentions the possibility that the paleoclimatic equator might have been situated a few degrees apart from the paleomagnetic equator, on the basis of the asymmetrical land/sea distribution per hemisphere which is so obvious in Devonian and Lower Carboniferous times.

Whatever is the true explanation, we believe that plants are probably the most reliable fossil group to reconstruct the climate and that palynology, because of the enormous amount of microfossils involved, is the best tool to provide such reconstructions.

Because of these differences in the latitudinal distribution of the Frasnian flora accurate North-South correlations are very difficult in the Euramerica Continent, i.e. between the zonation scheme of the Ardenne-Rhine type area (Boulonnais) (Loboziak & Streeel, 1986) and the rich microflora described from the Russian Platform and the Canadian North-West Territories.

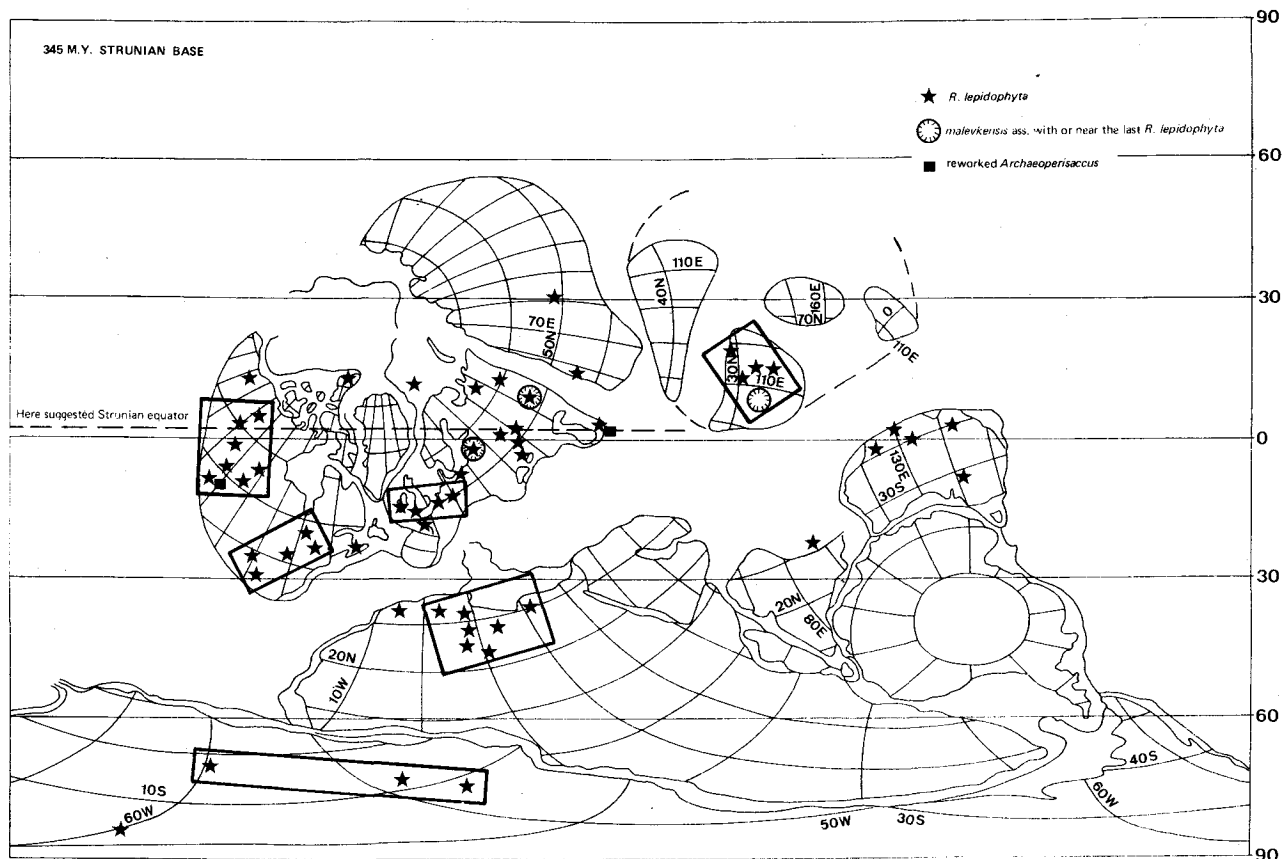


Figure 6. - Strunian miospore assemblages
Data from Streel 1974, 1980, etc. . .
The regions studied with more detail in this paper are underlined.

Is the situation similar in the middle Famennian to Strunian times ?

Records of middle and late Famennian (Fa2a-Fa2c) miospore assemblages are plotted on fig. 5 (Data from Norris, 1985; Streel, 1974; Van der Zwan, 1979; Van der Zwan & Walton, 1981, unpublished data on China received from Gao, et cetera . . .).

These records are much less abundant than the Frasnian records. Nevertheless, a sort of latitudinal zonation is perceptible on the Euramerican Continent where only the equatorial belt yields miospore assemblages with *Cornispora varicornata*. Outside this belt, *Retusotriletes phillipsii* provides a good correlation tool for the late Famennian (Clendening, Eames *et al.*, 1980; Higgs & Russell, 1981) as does the occurrence of *Rugospora flexuosa*. However, the zonal scheme, established in Belgium from Fa2a to Fa2c, based on the successive occurrence of *Grandispora* species, has not yet been recognized outside the type area. Note that the late Famennian age of the South American data (Daemon & Contreiras, 1971; Daemon, 1974 : zone VI) are doubtful (see discussion below on "South America").

All miospore assemblages characterized by the presence of *Retispora lepidophyta* belong to the Strunian (see figs 1 to 3). They are plotted on fig. 6 (Data from

Streel, 1974, 1980 supplemented by new records in nearly all continents). *R. lepidophyta* is probably one of the most widespread and abundant plant taxa of the Devonian. Its latitudinal range is exceptional, extending more than 70° south from the equator. Many species i.e. belonging to the genera *Auroraspora* and *Diducites* in the early Strunian and to the genera *Corbulispora* and *Dictyotriletes* in the late Strunian are present over almost the same wide area. All these assemblages appear very similar in composition suggesting some homogeneity of the prevailing ecological conditions around the world.

However, on the basis of the Jaccard and Simpson correlation coefficient values (Streel, 1974) a North Euramerican area and a South Euramerican-North Gondwana area might be recognized, even though the differences are small.

It is not until the upper part of the Strunian that a latitudinal zonation becomes more obvious, with the first occurrence of the *Lophozonotriletes* facies in the equatorial belt. Indeed the "Malevkensis" assemblage of the soviet authors occurs with the last *R. lepidophyta* in Bielorrussia and Udmurtia (Byvsheva, Higgs & Streel, 1984). It also occurs without *R. lepidophyta* in the uppermost Strunian of South China (see discussion below on "South China"). More detailed observations

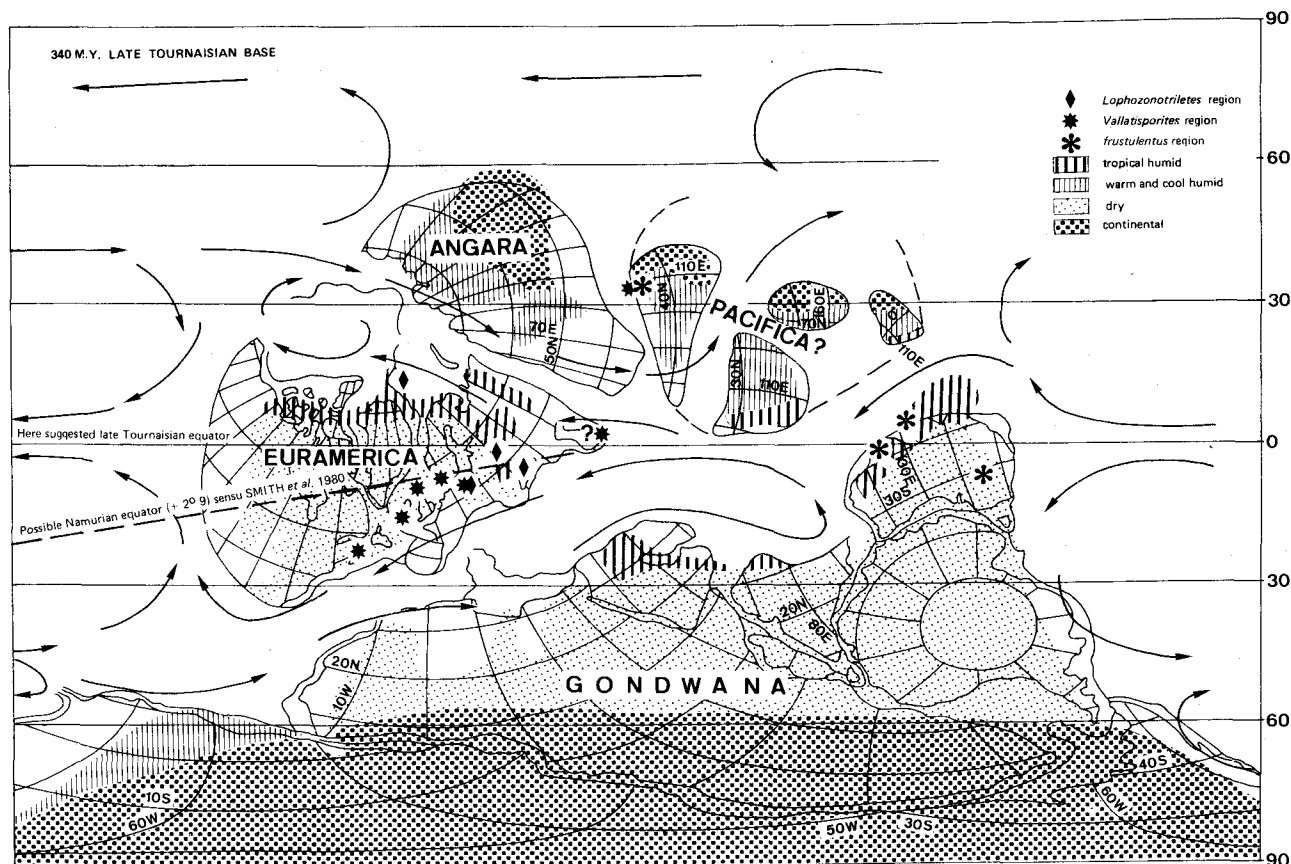


Figure 7. - Middle Tournaisian-early Visean miospore assemblages studied by Van der Zwan 1980 & 1981. and climatic reconstruction after the same author, slightly modified.

on the Russian Platform as well as in the Canadian North-West Territories (see Braman *in* Norris, 1985) might well increase the present small amount of data supporting this uppermost Strunian latitudinal zonation.

The middle Tournaisian-early Visean climatic model of Van der Zwan (1980) is reproduced on fig. 7 with a few changes related to the modified configuration of the continents that we have adopted. Jaccard and Simpson correlation values have been established by Van der Zwan (1981) for the assemblages located on fig. 7. They allow the recognition in Euramerica of two regions corresponding to different climatic belts reconstructed using the distribution of climatically sensitive rocks.

In order to assess the marked differences between North and South Euramerica, Van der Zwan, Boulter & Hubbard (1985) have applied a multivariate statistical analysis to percentage frequency data for palynological assemblages of twenty Lower Carboniferous (Tournaisian-Namurian) different localities.

The resulted principal components were also related to climatically sensitive rocks and the relationship interpreted in term of humidity curves and climatic zones. However the data are still too scarce to allow any correlation lines between the humidity curves

of North and South Euramerica during the middle Tournaisian-early Visean timespan.

The miospore zonal scheme of present Western Europe, then in South Euramerica (Clayton, Coquel *et al.*, 1977), and the miospore zonal scheme of present Eastern Europe, then in North Euramerica are poorly comparable in this time interval (Owens, Loboziak & Teteriuk, 1978).

The comparison of the four palynophytogeographic maps shows that the equator shift between the Frasnian and the late Tournaisian approximated 8° at the most. Van der Zwan, Boulter & Hubbard (1985) have concluded that the humid climatic zone characteristic of the equatorial region has shifted southwards during the lower Carboniferous as a consequence of a northward drift of the continent.

The middle-late Famennian and Strunian miospore distribution maps (figs. 5 and 6) show specific characteristics : paucity and floral regionalism of the middle-late Famennian records contrasted with abundance and floral homogeneity of the Strunian ones.

The few middle-late Famennian palynological informations might not simply reflect a lack of sampling but rather poor environmental conditions for plant cover and/or fossilization. On the contrary, the abundance of Strunian miospores might be related to a global change of these environmental conditions.

4. - RELATIONS BETWEEN MIOSPORE ZONAL SCHEME AND EVENT STRATIGRAPHY

It is beyond the scope of this paper to analyse the detailed relations between the North-Western Europe miospore zonal scheme and all parts of the world where miospores have been isolated. Instead, we have selected five regions, four of them rather "close to" (see map, fig. 6) the N-W European region. Two are on the Euramerica continent (N-W Canada-W-USA and S-E Canada-E-USA), two on the Gondwana (Northern Africa and South America). They range from the equatorial belt (N-W Canada) to very high latitudes (South America). Most offer interesting, well documented sedimentological data. The fifth (South China) is tentatively analysed because new data are now available on this region but the actual knowledge of miospores and sedimentology cannot be compared with that of the other regions.

4.1. - NORTH-WESTERN CANADA TO WESTERN UNITED STATES

In the Yukon territories and the District of Mackenzie, most of the Upper Devonian Imperial and Tuttle formations largely consists of supposed flysch-like sediments and turbidites derived from an uplifted area to the North (Norris, 1985). An unconformity probably occurs between both formations, the most recent Imperial Fm sediments (containing spores) being early Famennian (Upper *crepida* conodont-zone, Braman in Norris, 1985), the oldest Tuttle Fm sediments having yielded Strunian miospores (Braman in Norris, 1985; Hills, Hyslop *et al.*, 1985). The lower part of the Tuttle Fm contains reworked miospores of mid-Frasnian age (McGregor in Norris, 1985). However the contact between both formations might be somewhat diachronous as, in the South, conodonts from the upper part of the Imperial Fm, although fragmentary, suggest "rhomboidea" to "styriaca" zones of middle Famennian age (Uyeno in Norris, 1985). The Tuttle Fm characterized by the presence of conglomerates and coals and by the complete absence of carbonates, carries three successive miospore zones. The lower two including *Retispora lepidophyta* might correspond to the early and/or late Strunian, the third one to the early-middle Tournaisian (after Braman, 1981 unpublished thesis). The presence of *Lophozonotriletes triangulatus* (here used for both *Tumulispora malevkensis* and *T. rarituberculata*, see Byvsheva, Higgs & Streel, 1984) in the first *R. lepidophyta* assemblage would elsewhere suggest that the earliest Strunian is not present. However, we do not know if this argument is substantiated so near the Strunian equator. Nor do we know if the *Lophozonotriletes* are as abundant as they are on the Russian Platform where they constitute a well characterized facies.

In Montana, the middle shale unit of the Sappington Mbr of the Three Forks Fm. contains a spore

assemblage with *R. lepidophyta* and *V. pusillites* but also *V. vallatus* and *V. verrucosus* and murornate spores like *D. trivialis*, characteristic of the late Strunian (Sandberg, Streel & Scott, 1971). This late Strunian age is confirmed by the presence of *S. praesulcata* near the top of the preceding unit.

The occurrence of *Geminispora cf. svalbardiae* and an *Archaeoperisaccus*, similar to *A. regalis*, abundant in the Imperial Fm of the District of MacKenzie, N.W.T. Canada (Braman & Hill, 1985), suggests the incorporation of reworked Frasnian spores in the Strunian assemblage. Conodont data show that the basal black shale unit of the Sappington Mbr belongs to the Lower *expansa* zone. (In term of the new conodont zonation of Ziegler & Sandberg, 1984). The Sappington Mbr is bounded by unconformities. It is underlain by the Trident Mbr of the same formation, dated of the *trachytera* zone and overlain by the Cottonwood Canyon Mbr of the Lodge pole Fm, dated of the Lower Carboniferous *sandbergi* and *crenulata* zones.

A similar spore assemblage occurs in the Coleville Sandstone Mbr of the Bakken Fm in southeastern Alberta (Walton & Mason in McQueen & Sandberg, 1970) as well as in the Bakken Fm of southern Saskatchewan (Coquel, Loboziak & Lethiers, 1976). No late Famennian nor early Strunian spore assemblage have been described from these areas where each late Strunian spore assemblage is underlain by black shales, often rich in Tasmanaceae. The Exshaw Formation of the Rocky Mountains part of Alberta is believed to be a correlative of the Sappington Mbr in Montana and of the lower black shales and Coleville Sandstone Mbr of the Bakken Fm in southeastern Alberta and Saskatchewan.

In terms of the new conodont zonation (Ziegler & Sandberg, 1984) all these lithostratigraphic units are considered to start in the late Famennian Lower *expansa* zone after McQueen & Sandberg (1970), much higher, in the Strunian, after Lethiers (1981) who claims to have calibrated his ostracode zonation with the standard stages. The underlying gap covers the *postera* zone after McQueen & Sandberg (1970). It would be diachronous ranging from the *marginifera* zone at the earliest to the *praesulcata* zone at the latest, after Lethiers, 1981.

4.2. - EASTERN UNITED STATES AND SOUTH-EASTERN CANADA

The most detailed miospore zonation is known in the North-East part of this area (New York and Pennsylvania States). But miospores occur in separated localities, often in discontinuous continental beds. They are listed below from the late Famennian to the early-middle Tournaisian : late Famennian miospore zone with *Retusotriletes phillipsii*, in the Western New York uppermost Canadaway and Chadakoin formations (Clendening, Eames & Wood, 1980); latest

Famennian miospore zone with *Vallatisporites pusillites* below the first entry of *Retispora lepidophyta* in the Pennsylvania Lower Sandstone Mbr of the Pocono Fm (Streel & Traverse, 1978); early Strunian miospore zone, in Pennsylvania near the contact of a "Catskill" formation and the "Lower Sandstone unit" of the Pocono Fm (Warg & Traverse, 1973) and also near the base of the Middle Sandstone and Shale Mbr of the Pocono Fm (Streel & Traverse, 1978), in New York State and North-Western Pennsylvania in the Oswayo and Knapp formations (Richardson in Tschudy & Scott, 1969 and author's unpublished data); late Strunian miospore zone in Pennsylvania 65 m above the base of the Middle Sandstone & Shale Mbr of the Pocono Fm and some 10 m below a early or middle Tournaisian miospore zone (Streel & Traverse, 1978).

The late Famennian miospore zone corresponding to the maximum westward and southward progradation of the Catskill deltaic complex has been traced in the continental Hampshire Fm of West Virginia and in the marine Three Lick Shale of Ohio and Kentucky and the Ellsworth Shale of Michigan (Clendening, Eames & Wood, 1980). They ascertain the correlation suggested by Matthews (1983) between Ohio and Michigan.

The late Strunian miospore zone corresponding to a progression of the continental Pocono Fm. has also been recognized in the Bedford and Berea formations in Ontario (McGregor, 1971; Wood, 1984), Michigan (Wood, 1984), Ohio (Winslow, 1962; Eames, 1978; Wood, 1984; Molyneux, Manger & Owens, 1984) and in the Chattanooga Shale of Tennessee (Reaugh in Wood, 1984). Reworked Silurian (Wood, 1984) and possibly Devonian (Molyneux, Manger & Owens, 1984) acritarchs and Frasnian spores (Wood, 1984) occur in the Bedford Shale of Ohio and Michigan.

The overwhelming early Tournaisian, transgressive Sunbury Shale have poor miospore assemblages (Winslow, 1962). Similarly, the Cleveland Shale Mbr. of the Ohio Fm in Ohio contains poor miospore assemblages (Winslow, 1962) partly belonging to the early Strunian (with *R. lepidophyta*), partly characterized by *Endosporites chagriniensis* also met in the latest Famennian Lower Sandstone Mbr of the Pocono Fm in Pennsylvania (Streel & Traverse, 1978, p. 29). The Ohio Fm in Ohio is rich in *Tasmanites*. Most of the New Albany and Chattanooga Shales occurring in the South-East are spore-barren. These observations match rather well (*) the schematic model of deposition of black shales in Kentucky recently proposed by Etensohn & Elam (1985). They suggest that "the Cleveland Shale Mbr of the Ohio Shale and its equivalents in the New Albany and Chattanooga Shales, as well as black-shale equivalents of the Bedford represent deposition in deep water, more distal, basinal environments where a pycnocline, and anaerobic conditions below it, were easily established and maintained"... "the overlying Sunbury Shale represents a period of regional transgression and subsidence during which deeper cratonic seas inun-

dated large parts of the Bedford-Berea delta complex"... "the black shales of the underlying Cleveland Shale and overlying Sunbury Shale represent near "starved basin" conditions when the associated delta systems were relatively small and distant, and clastic influx was greatly reduced" (Etensohn & Elam, 1985).

4.3. - NORTHERN AFRICA

In the Mac Mahon basin, Lanzoni & Magloire, (1976) have demonstrated a Strunian regressive shift of the detrital deposit from the North-East to the South-West. A discontinuity is obvious between these deposits with *R. lepidophyta* (L₇ to L₁₀) assemblages and overlying deposits with *Convolutispora* (M₂ to M₇) assemblages. This discontinuity, increasing towards the North-East, suggests a Tournaisian transgression in that direction. No information exists on possible pre-*lepidophyta* assemblages, but the two first mentioned miospore zones (L₇ and L₈) contain many, supposedly reworked, species (i.e. *Hymenozonotriletes* 2388, *H.* 2967, spore trilete 513, spore trilete 2979, etc.). Most of these species occur indeed in the Middle Devonian of Libya (Massa & Moreau-Benoît, 1976; Paris, Richardson *et al.*, 1985). The last two zones contain *Knoxisporites literatus* (*K.* sp. 2737) and possibly *Vallatisporites vallatus* (? *V.* sp. 2910) and also many murornate spores of the group *Dictyotriletes/Corbulispora*, characteristics of the upper part of the Strunian. The lowest *Convolutispora* assemblage (M₂) has no characteristic miospores which allow accurate dating of the beginning of the transgression but the next zone (M₃) - with abundant *Schopfites* (*Raistrickia* 2928), *Waltzisporea*, *Anulatisporites*, *Densosporites*, *Ceratosporites* (*Triquitrites* 2836) but without *S. pretiosus* - might well belong to the late Tournaisian.

In the Illizi and Rhadames basins, on either side of the Algerian/Libyan boundary, the Famennian is present with assemblages containing the late Famennian *Rugospora flexuosa* (*Trachytriletes radiatus* in Attar, Fournier *et al.*, 1980, Djébel Illeréne Fm and in Boumendjel *et al.* (in preparation), upper part of the Gazelle Fm, both in the Illizi Basin) and assemblages correlated with an interval of rocks dated by conodonts of the "crepida" and "costatus" zones, in the Rhadames Basin. These last assemblages (Palynozones 9 and 10) contain many reworked Frasnian miospores (*Verrucosisporites bullatus*, *Ancyrospora langii*, *Geminosporea lemurata*, *Rhabdosporites parvulus*, etc. in Massa & Moreau-Benoît (1976), Aouinet Ouenine IV Fm, in the Rhadames Basin).

* But the well-established biostratigraphic evidence of a late Strunian age for the Bedford and Berea formations make irrelevant the tentative explanation by the same authors for the absence of Mississippian conodonts.

In both regions, there are few palynological evidences for the Famennian to be continuously recorded. In the Illizi Basin, 190 m of nearly barren sediments separate the Lower Givetian part of the Gazelle Fm from its late Famennian part (Boumendjel *et al.*, in preparation). In the Rhadames Basin, the thickness of the Aouinet Ouenine IV Fm is variable and the "Upper Famennian" is sometimes condensed (Massa & Moreau-Benoît, 1976, p. 307). The palynozones 9 and 10 have no Famennian zonal characteristic species and may correspond to any lower or middle Famennian spore zones.

In the Illizi basin, late Famennian (Palynozone I) and Strunian (Palynozone II) assemblages seem to occur in a conformable succession. The lack of late Strunian miospores and the occurrence of *Spelaeotriletes pretiosus* in the next zone (Palynozone III) suggest a gap which, following the authors, increases eastwards but decreases northwards. This gap encompasses the late Strunian, the early and the middle Tournaisian.

In the Rhadames basin, the Famennian/Strunian contact, corresponds to the base of the Tahara Fm. The "*lepidophyta*" assemblage is better known here than in the Illizi Basin but we have not recognized in the plates published by these last authors and by Moreau-Benoît (1979, 1980), the *Verrucosiporites nitidus* and *Knoxisporites literatus* mentioned by them. Therefore, we believe that the palynozone 11 entirely belongs to the early Strunian as does the corresponding palynozone II in the Illizi basin. The same is true for the new data provided by Massa & Moreau-Benoît, 1985 from three boreholes in the Southern part of the Rhadames Basin.

The subdivision of this palynozone 11 in XI a and XI b by Massa, Coquel *et al.*, (1980), mainly on quantitative data, does not offer a different opinion. In the Rhadames basin, as in the Illizi basin, a significant gap occurs between the palynozones XI and XII, the latter one containing *S. pretiosus* and dated late Tournaisian by the authors.

In the North-East of Libya (Cirenaica) (Paris, Richardson *et al.*, 1985), the Famennian spore assemblages are also poorly known. 100 m separate earliest Famennian acritarchs and spores (with *Cyrtospora cristifer*) and late Famennian acritarchs and spores (with *Rugospora flexuosa*). On the contrary, a rather detailed zonation has been established in cores for the late Famennian to the early Strunian with a well preserved latest Famennian assemblage characterised by the occurrence of *Vallatisporites pusillites* below the first entry of *Retispora lepidophyta*.

Acritarchs are absent in the highest Devonian miospore assemblages reflecting a regressive trend which has been observed in different localities.

No characteristic late Strunian species have been recorded. In the studied boreholes, a few tenths of metres with reworked or/and contaminated assemblages in

cuttings separate the early Strunian miospores and assemblages considered to be early Visean by Clayton & Loboziak (1985).

In conclusion, Famennian miospore assemblages are poorly known in North Africa, except in the late Famennian. A large regression culminates at the end of the early Strunian in Libya and surrounding areas, somewhat later, in the late Strunian, in North-West Algeria. A sedimentological break covers most of the early and middle Tournaisian.

4.4. - SOUTH AMERICA

The South American palynological data discussed here were summarized by Daemon & Contrairas (1971). They concern the Amazonas basin and Parnaíba basin in Brazil. Their bio- (palyno) stratigraphic scheme was subsequently equated by Daemon (1974) with the Mac Mahon basin palynological scheme of Lanzoni & Magloire (1969) in North Africa.

Daemon has emphasized that deposition, erosion and regression were synchronous in both parts of the Gondwana Continent (see also Bär & Riegel, 1974). If we apply the ages here assigned to the miospore zones in North Africa to the South American basins, we arrive at some interesting conclusions (fig. 8) : Zones VI, VII and VIII of Daemon & Contrairas (1971) do not cover all of the interval from Frasnian to Strunian times as suggested by a recent paper of Caputo (1985, fig. 2). Zone VIII (at least the subzones m and s of Daemon, 1974, tab. I) does correspond to the upper part, and zone VII (and subzone i of VIII) to the lower part of the Strunian only. It is also surprising to find many "Middle Devonian types" of spores (i.e. F-2070, F-2065, F-2043, F-2080) in zone VII of South America as in the first two "*lepidophyta* zones" of the MacMahon basin in Northern Africa where they were considered to be reworked.

The precise age of zone VI (at least subzones i (?) and m "characterized by *Contagisporites regalii*") is not known and their stratigraphically non-diagnostic miospores might be alternatively dated as Middle Devonian-Frasnian or late Famennian with reworked "Middle Devonian-Frasnian types".

In any case, a large depositional gap must be present during most of the Famennian in these South American basins. And similarly, a sedimentological gap is present in the early Tournaisian as also observed in the MacMahon basin in Northern Africa (see fig. 8).

These new observations enable a different interpretation of the South American late Devonian-early Carboniferous glaciation suggested by Caputo (1985). This author stated (p. 295) that "during the Famennian Stage, the . . . , Curiri and Lower Orixí miná (Amazonas basin) and Cabeças (Parnaíba basin) Formations were laid down under glacial and peri-glacial conditions" and that "the Visean . . . , Faro (Amazonas Basin) and Poti

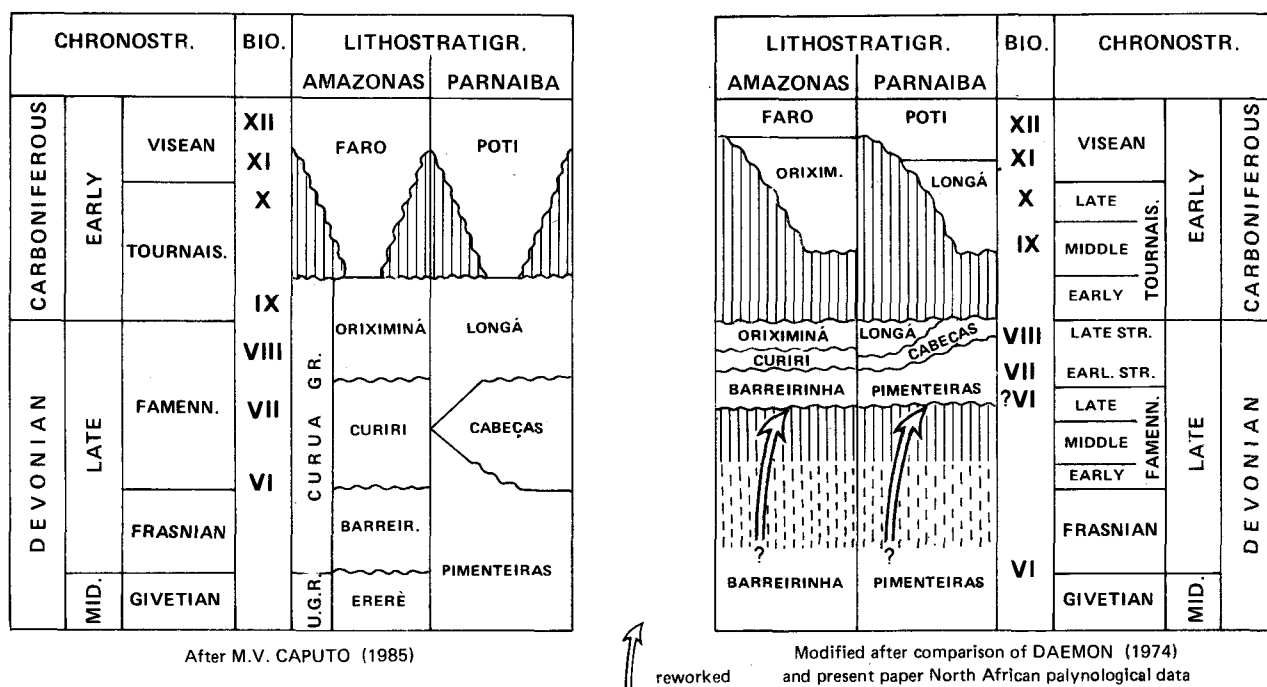


Figure 8. - Chrono-bio(miospores)- and lithostratigraphy of the late Devonian and early Carboniferous of Amazonas and Parnaíba basins in South America : alternative interpretations.

(Parnaíba basin) Formations also show features of glacial and glacio-fluvial activity". In view of the large sedimentological gap preceding both these Strunian and Viséan deposits, we wonder whether the maxima of these suggested South American glaciations were not Famennian and again Tournaisian, each one followed by "interglacial phases" (with periglacial conditions in South America) allowing sedimentation and vegetation cover during Strunian and during Viséan times.

4.5. - SOUTH CHINA

No Famennian assemblages have been described so far in South China apart from the Frasnian and the Strunian material mentioned by Gao (1981). Gao has kindly shown us (1985) however an unpublished late Famennian assemblage with *Rugospora flexuosa* preceding a Strunian assemblage with *Retispora lepidophyta*, from the Hunan Province.

Strunian assemblages also occur in Southeastern China (Yudu, South Kiangsi) (Gao, pers. com. 1985), Central Hunan and Lower Yangtze (Gao, 1981). In the Jiangsu Province (Lower Yangtze), the Legutai Mbr of the Wutong Fm contains a well-preserved Strunian miospore assemblage (Li, Cai & Ouyang, 1984) with rare (Ouyang, pers. com. 1983) *R. lepidophyta* var. *minor*. In the Central Hunan, the Oujiaochong Fm (fig. 9) contains a similar assemblage with small size *R. lepidophyta* (Hou Jipeng, 1982). No characteristic spore of the late Strunian has been recognized. Therefore these assemblages are tentatively considered here as early Strunian.

The Shaodong Fm in Central Hunan has less abundant *R. lepidophyta* in its lower part and no *R. lepidophyta* in its upper part. The age of the Shaodong Fm is controversial. The lower part with the coral *Ceriphyllum elegantum* has a conodont assemblage dated "Lower *costatus*" by Wang & Ziegler (1982), along with typical Etroeungtian brachiopods (*Mesoplica* and *Sphenospira*) and corals (*Caninia dorlodoti* and *Caninia patula*), a typical conodont fauna of the Lower K zone in England. However, *Caninia* cf. *dorlodoti* and *Ceriphyllum* have been found with *Siphonodella crenulata* as high as the middle Tournaisian by Ning, Bai & Jin (1984) in a deep facies of the Guangxi Province. On the other hand, the typical conodont fauna (*Clydagnathus cavusformis*) of the Lower K zone in England is no longer believed to be restricted to the Devonian (Sandberg, pers. com. 1983). Moreover, the basal K zone (in the Shirehampton beds) in the Avon Gorge in England has a post-*lepidophyta* VI miospore zone (Higgs & Clayton, 1984) and might be of early Tournaisian age. Gao (*in P'an*, 1978) who had determined a *R. lepidophyta* zone in the lower part of the Shaodong Fm and a "*Dictyotriletes trivialis* - *Lophozonotriletes rarituberculatus* zone" in the upper part of this formation had thus correctly assigned only the lower part to the Devonian. But there is no reason to accept the "Tn1a age" given by Hou Jingpen (1982) to her "*Lophozonotriletes rarituberculatus* - *Vallatisporites batiambes* zone". The same is true for the "*Knoxisporites literatus* - *Reticulatisporites cancellatus* Ass. of Li, Cai & Ouyang (1984) in the upper part (fig. 9) of the Legutai Mbr of the Wutong Fm in the Jiangsu

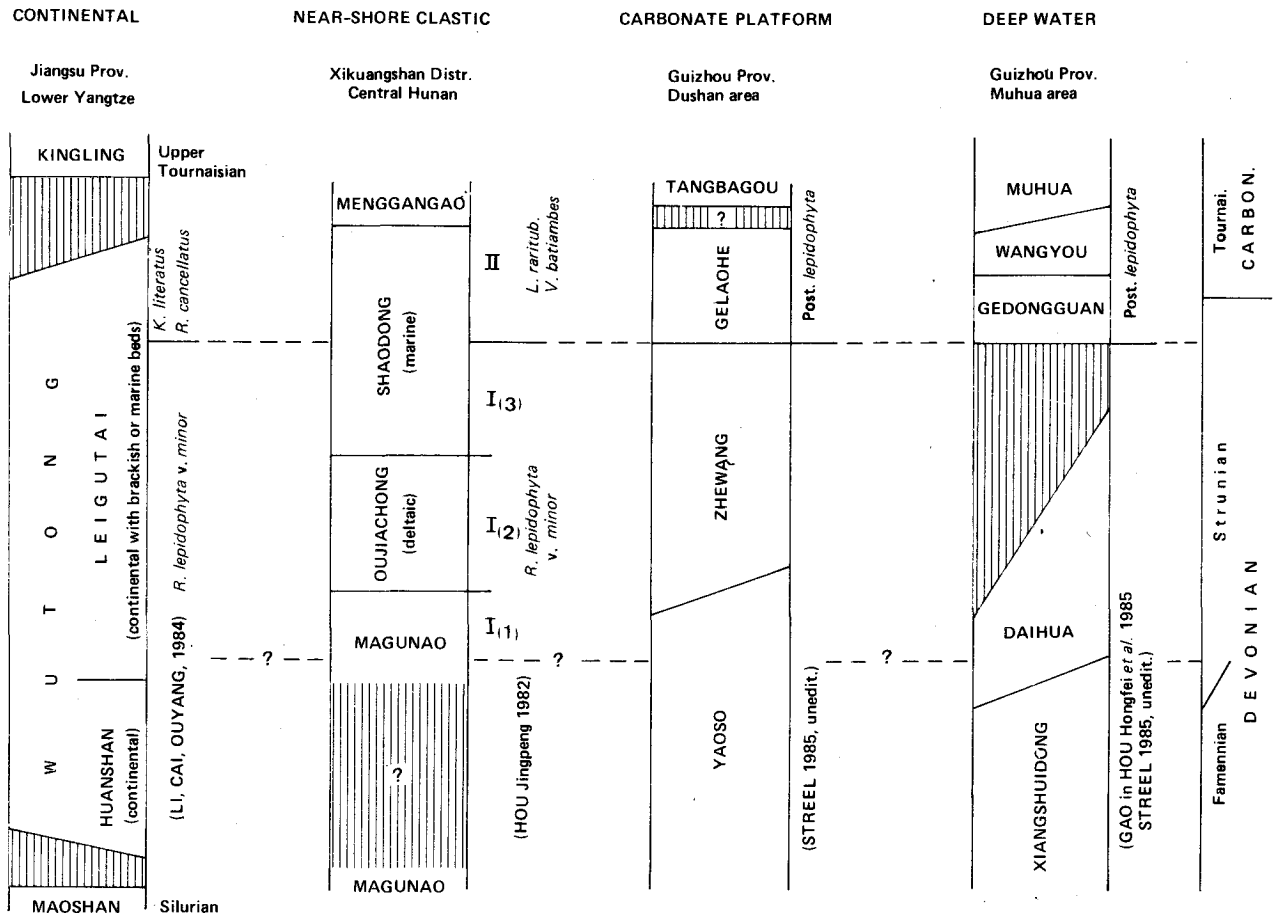


Figure 9. - Comparison of four sections spanning the Devonian-Carboniferous boundary in South China.

Province (Lower Yangtze) which might also be of Carboniferous age.

The lowermost sample of the Gelaohé Fm in the carbonate platform facies of the Dushan area (Guizhou Province) carries post-*lepidophyta* assemblages (author's unpublished data) and is therefore of probable Carboniferous age (fig. 9).

In the deep water facies of the Muhua area (Guizhou Province), the Gedongguan bed contains a rich, but poorly preserved, miospore assemblage described by Gao in Hou Hongfei, Ji *et al.* (1985). This assemblage is very rich in *Lophozonotriletes* spp. No *R. lepidophyta* has been recorded and we have not recognized *Vallatisporites pusillites* in their photographs 11 to 16 on plate 9, nor in the material kindly shown to us (1985) by Gao. Therefore we believe that this assemblage corresponds to that part of the "Malevskensis Ass. (ml 2) of the Russian authors that does not contain *R. lepidophyta* (see Byvsheva, Higgs & Streel, 1984). Its uppermost Strunian age is however here controlled by the occurrence in the immediately overlying limestone of conodonts delineating the Devonian/Carboniferous boundary (Hou Hongfei, Ji *et al.*, 1985).

DISCUSSIONS AND CONCLUSIONS

Event stratigraphy and miospore zonation in Europe, Africa and America are compared on figure 10.

1) The North-Western Europe miospore zonation works rather well in the South-Eastern Canada and Eastern United States regions. This might be expected from regions which were all in a same Southern tropical belt (fig. 6). Correlations with North-Western Canada and Western United States, then close to the equatorial belt, are less obvious. First occurrence of diagnostic species in Europe are not recorded here but Strunian assemblages have other common characteristics. Correlations are comparatively easier with Gondwana and particularly with Northern Africa, then in the subtropical belt. But a lack of late Strunian-Middle Tournaisian assemblages prevents detailed observations at that stratigraphic level.

As a first conclusion, miospore correlations across paleolatitudes seem easiest during the late Famenian-early Strunian timespan even if sampling might be somewhat biased in favour of this period. On

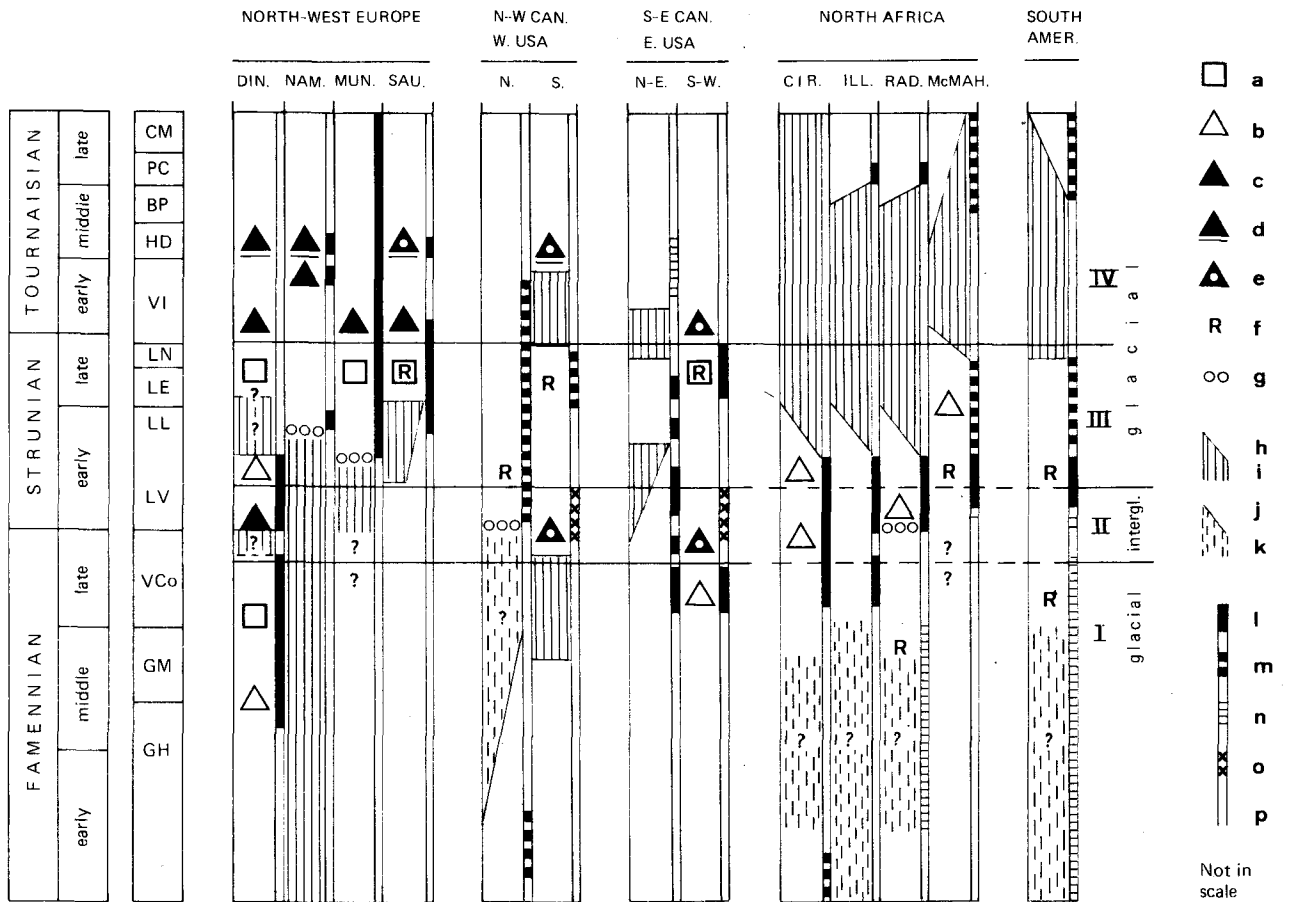


Figure 10. - Comparison of event-stratigraphy and miospore zonation in Europe, Africa and America.

a : Optimum of a regression; b : Regressive trend; c : Transgressive trend; d : Abrupt transgressive trend; e : idem c. or d. with anoxic black shale; f : Reworked miospores or/and acritarchs; g : Coarse sediments; h,i : Sediment gap (h : possible range of lower or upper limit); j,k : Possible sediment gap (j : range of lower or upper limit); l-p : l. N-W Europe characteristic species; m. other species than N-W Europe characteristics; n. idem but stratigraphic position not known in the suggested range; o. *Tasmanaceae*; p. no miospore data available or considered here.

the contrary, early-middle Famennian and late Strunian-Tournaisian palynostratigraphy does not offer many arguments for the existence of floral homogeneity across these paleolatitudes. Raymond (1985) demonstrates a high level of phytogeographic differentiation in the Tournaisian-early Viséan that decreases in the late Viséan-early Namurian. Altogether these conclusions would fit with a cyclic scheme of periods of more pronounced latitudinal climatic gradient between equatorial and higher latitudes (early-middle Famennian and late Strunian-early Viséan) alternating with periods of less pronounced gradient (late Famennian-early Strunian and late Viséan-early Namurian).

Raymond (1985) suggests that climatic amelioration, in late Viséan-early Namurian was caused by the collision of Laurussia and Gondwana. Some global cause like glaciation pulses might however provide an alternative explanation. The South American glacial features argued by Caputo (1985) can be interpreted indeed (see discussion higher on) as matching early-middle Famennian and late Strunian-early Viséan glacial phases.

2) Palynostratigraphy allows accurate dating of regression-transgression events. But the composition of the assemblages can also have been influenced by these events. For instance, regressive sediments often display reworked miospores or/and Acritarchs; transgressive dark shales often do not contain miospores but sometimes only *Tasmanaceae*.

The available data show that regression-transgression events are strikingly synchronous on the Euramerica (Old Red) continent. Two cycles are obvious : regression I of middle to late Famennian age, transgression II of late Famennian-early Strunian age, regression III of early Strunian to late Strunian age, transgression IV of late Strunian-Tournaisian age (fig. 10).

The two Euramerican cycles are also noticeable in China : change from continental to marine conditions in the (? early) Strunian of continental and near-shore clastic facies (Cycle I-II), clastic Gedongguan to carbonate Wangyou formations in the uppermost Strunian of deep water facies (Cycle III-IV).

These cycles are not observed on the Gondwana continent where regressive or even emergence conditions

are prevailing. This might correspond to regional conditions.

3) It is known that continental glaciation could have large effects on sea level. As there is a direct time relationship between most of the sequence of regressions-transgressions (I-II-III) and the sequence of glacial-interglacial phases here suggested from the Famennian to the late Strunian, we can accept that glaciation was a major cause of sea level fluctuation in the Famennian-Strunian timespan.

On the contrary, the Tournaisian transgression (IV) obviously does not correspond to an interglacial phase and we can suppose that tectonic processes like growth of oceanic ridge systems (Armstrong, 1969) might have been of major importance.

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