



## Reassessment of Viséan miospore biostratigraphy in the Amazon Basin, northern Brazil

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### Abstract

A late Viséan age within the late Holkerian–early Brigantian time span (TC–VF zonal range) is proposed for the highest, shalier, transgressive part of the Faro Formation in well 2-LF-1-AM and equivalent sections of other Amazon Basin boreholes, which in some cases have been misattributed to the underlying Oriximiná Formation. Late Tournaisian–middle Viséan microfloras (CM–TS zonal succession) are now regarded as absent in at least the Amazonian regions of northern Brazil. This supports the hypothesis of a regional unconformity separating the late Viséan sequence from the latest Famennian/early late Tournaisian sequence in those areas. Palaeoenvironmental factors of uncertain nature seem to have controlled the presence or absence of miospore index-species (either of Euramerican or Gondwanan affinities) in the Amazon Basin. Such erratic nonoccurrences have led to miscorrelations of local miospore successions. Early to middle Viséan sections are either missing or highly condensed in northern Brazil, and a similar situation may occur in North Africa and adjacent regions. © 1998 Elsevier Science B.V. All rights reserved.

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### 1. Introduction

Unpublished results from recently concluded and ongoing palynological investigations in the subsurface of the Amazon, Solimões and Parnaíba basins (northern Brazil) confirm the occurrence of Viséan miospore assemblages in those areas, as already pointed out in the earlier literature (Daemon and Contreiras, 1971; Daemon, 1974, 1976; Andrade and Daemon, 1974). In the Amazon Basin (Fig. 1), such

assemblages characterize mainly the upper, shalier part of the Faro Formation, and less frequently, correlative sections in a few wells which have been improperly assigned by Petrobras geologists to the underlying Oriximiná Formation. In the Solimões Basin (Jandiatuba Sub-basin), Viséan sandy strata are lumped incongruously with Devonian shales into a single rock unit, the Jandiatuba Formation. In the Parnaíba Basin, miospores of Viséan age are restricted to the Poti Formation. In all three basins, the Viséan corresponds almost invariably to the so-called biostratigraphic interval XII of Petrobras' earlier zonal scheme (Daemon and Contreiras, 1971; Daemon, 1974).

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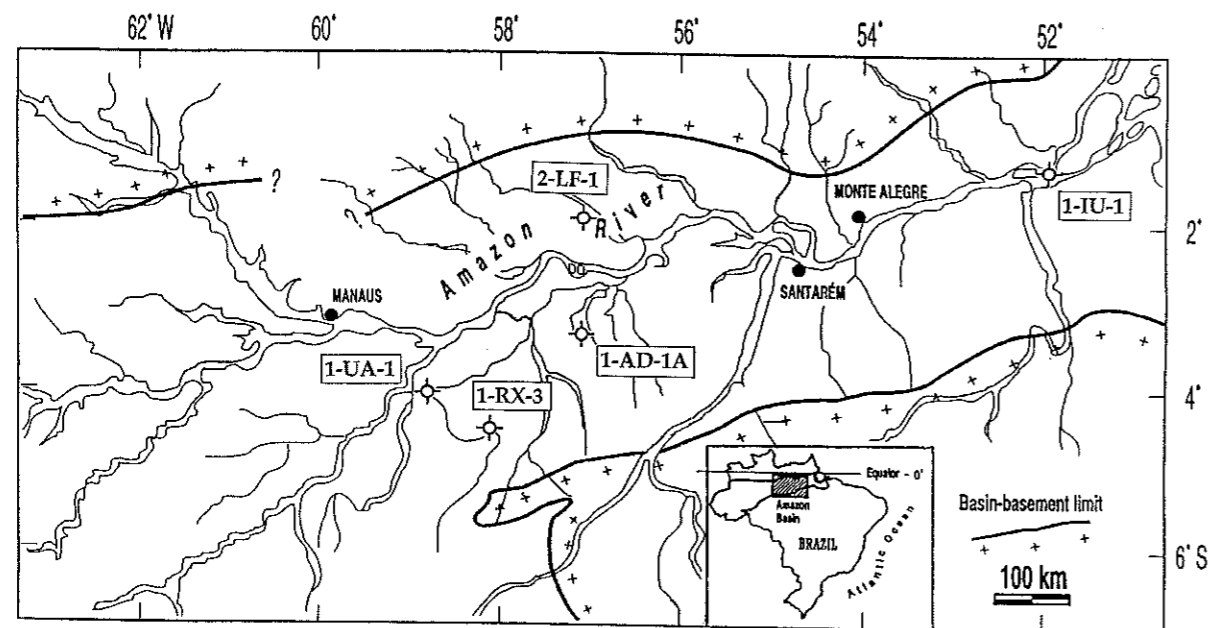


Fig. 1. Location map of selected wells in the Amazon Basin (modified from Loboziak et al., 1997). Borehole names are abbreviated by omitting the ending -AM. Borehole sites compiled from Andrade and Cunha (1971), Daemon and Contreiras (1971) and Carozzi et al. (1972).

Continued palynological research in northern Brazilian basins (especially the Amazon Basin) has added considerable accuracy to the dating and correlation of regional Viséan miospore assemblages. Furthermore, it has also provided new insights into facies control and compositional variations of the palynofloras, which may bear on the understanding of coeval assemblages in other Gondwanan areas.

During earlier phases of this review, Viséan datings in Brazil relied mainly on local identifications of erratic *Lycospora* spp., sometimes joined by some Tournaisian holdovers which are usually unknown in the later Viséan (Loboziak et al., 1991, 1993). These assemblages suggest ages not older than early to middle Viséan (zones Pu–TS in the sense of Clayton, 1985 and Higgs et al., 1988b). As the result of additional work, however, certain sections in northern Brazilian basins (with or without *Lycospora* spp.) are now admitted to bear miospores of indisputable late Viséan age, including zonal or characteristic species shared with Western Europe (e.g., *Diatomozonotriletes fragilis*, *Perotriletes tessellatus*, *Rotaspora ergonulii*, *Waltzisporea* spp., etc.) and Gondwana (e.g., *Reticulatisporites magnidictyus* and *Hymenozonotriletes dolianitii* sensu Daemon,

1974). In such cases, age assignments as young as late Holkerian or early Asbian to Brigantian are acceptable, which suggest a probable correlation of the Brazilian sections with at least part of the TC through VF miospore zonal succession of Western Europe (Clayton et al., 1977, 1978; Clayton, 1985). Lithological and electric marker correlations in at least the Amazon Basin indicate that the studied Viséan sections are mutually correlative and, therefore, coeval.

In nearly all wells analyzed in the course of the present study, late Viséan sediments were found to rest unconformably on strata ranging in age from late Famennian to middle or early late Tournaisian (i.e., equivalent to the VCo through BP-PC miospore zones sensu Streel et al., 1987 and Higgs et al., 1988a). For some time, the only apparent exception to this rule was well 2-LF-1-AM in the Amazon Basin, where late Viséan miospore assemblages had been mistaken for latest Tournaisian and early Viséan ones (Loboziak et al., 1991). This problem has been finally clarified by subsequent palynological reinvestigations, whose main results are presented herein.

The purpose of this paper is, therefore, to update the Viséan miospore biozonation of the Ama-

zon Basin, and to consider possible implications for the Viséan stratigraphy of other Gondwanan areas. In this context, a palynological reevaluation of well 2-LF-1-AM is of key importance for the following reasons:

- the latest published study (Loboziak et al., 1991) did not take Gondwanan index species into consideration. Moreover, some previous local identifications of Western European taxa can be now reinterpreted in the light of subsequent studies based on additional material from Brazilian basins;
- 2-LF-1-AM was the only known section in the basin where a supposed late Tournaisian/early Viséan transition had been recorded and correlated with the CM–Pu miospore zones of Western Europe sensu Clayton et al., 1977, 1978 and Higgs et al., 1988a,b). This ‘bridging’ interval is evidently lacking anywhere else in the Amazon and Solimões basins;
- 2-LF-1-AM is the type section of the Faro Formation (Lange, 1967; Caputo et al., 1972), where the unit displays exceptional sedimentary development. It is also the type section of Daemon’s (1974, 1976) biostratigraphic interval XI, i.e., the only known section in Brazil where this problematic unit of alleged early Viséan age has ever been clearly delimited beneath interval XII;
- because 2-LF-1-AM has been investigated in terms of Petrobras and Western European miospore biozonations, it permits direct comparison of both zonal schemes. In addition, Petrobras operational palynozones take Gondwanan Viséan index species into consideration. These taxa coexist with Western European-defined miospore index species of Viséan age in well 2-LF-1-AM, so allowing tentative reinterpretation of miospore zones erected elsewhere in Gondwana and adjacent regions on the basis of similar assemblages (e.g., Algeria, Libya and the Middle East).

## 2. Reevaluation of the Tournaisian–Viséan miospore biostratigraphy in well 2-LF-1-AM

In a previous paper, Loboziak et al. (1991, pp. 6–8, fig. 2) presented some biostratigraphic results based on the distribution of the most significant

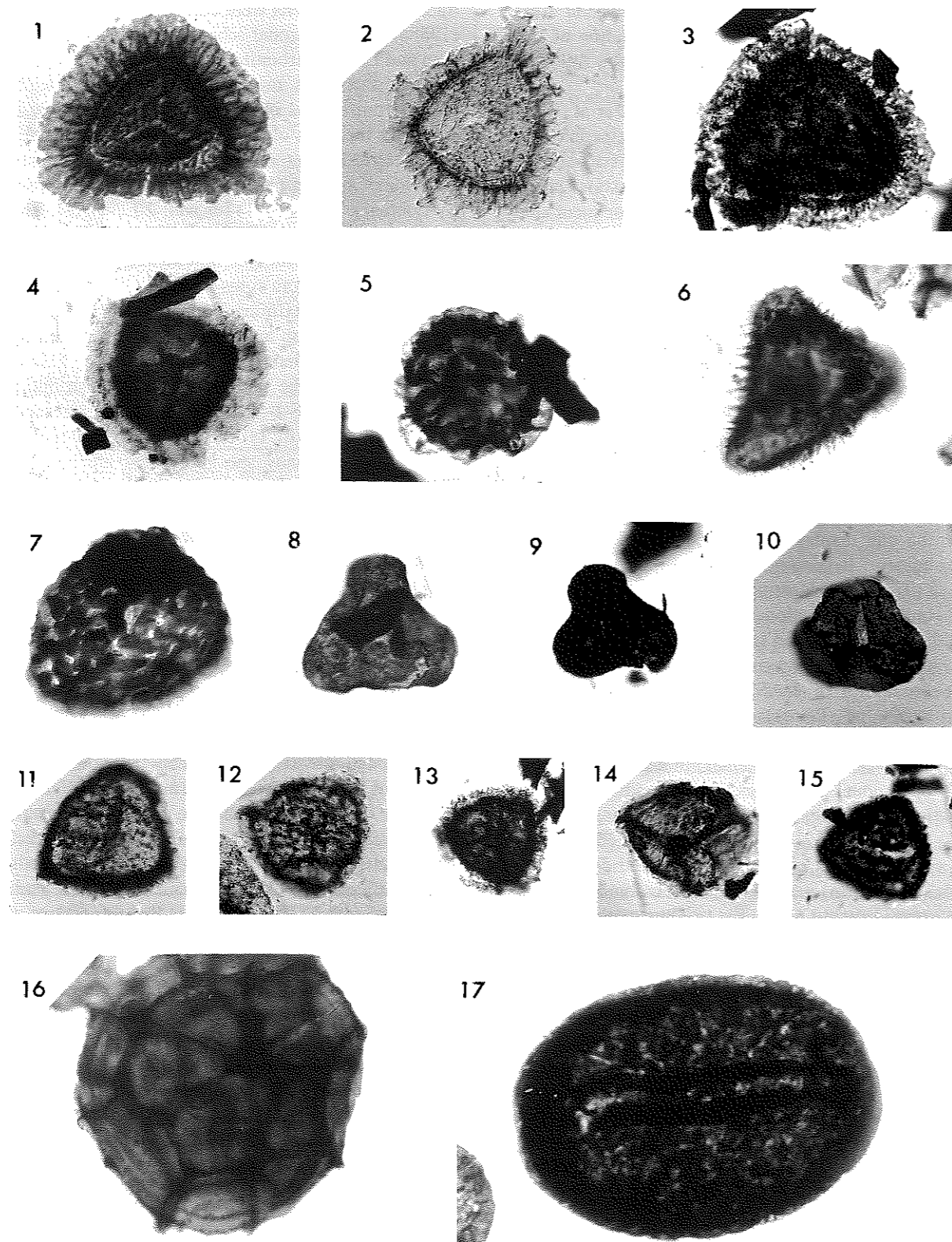
miospore species of well 2-LF-1-AM. The local miospore successions were compared to Higgs et al. (1988a) miospore zonal scheme for the latest Devonian and Lower Carboniferous of Western Europe.

Since then, new miospore results have been obtained from several other boreholes in the Amazon Basin, in the light of integrated palynostratigraphic and electric marker regional correlations. The new data do not support part of the biozonation proposed by Loboziak et al. (1991) for well 2-LF-1-AM. This justifies a re-examination of slides studied some years ago by those authors, now supplemented by additional samples from cores 51 to 53 (2252.0–2327.0 m) within the Oriximiná Formation, and cores 15 at 2151.5–2156.6 m and 13 at 2148.53 m, from the Faro Formation (Plate I).

Fig. 2 shows the updated miospore distribution chart in well 2-LF-1-AM. It confirms the presence and ranges of most of the previously recognized taxa. However, many specimens first attributed to *Rugospora polyptycha* in cores 29 through 21 are now assigned to *Perotriletes tessellatus*, as illustrated by Neville in Neves et al. (1973, p. 39, plate 2, figs. 9, 10 and 17). Furthermore, from the same stratigraphic interval and in overlying samples (cores 18, 16 and 15), some elements formerly included within a comprehensive ‘Densosporites Group’ were found to correspond to *Hymenozonotriletes dolianitii*, an index species of Daemon’s (1974) Viséan *Reticulatisporites* cf. *magnidictyus* miospore Zone (i.e., biostratigraphic interval XII of Petrobras regional palynozonation). These specimens are identical to *Radiizonates* sp. n° 2922, a form recorded by Lanzoni and Magloire (1969, table 1, plate II, figs. 14 and 15) from the upper part (subzone M5) of their “biozone à spore monolète zonale n° 2874” and the “biozone à *Densosporites* et *Verrucosisporites*” (subzones M6 and M7), erected for Viséan sections of the Grand Erg Occidental (Algerian Sahara).

*Perotriletes tessellatus* is shown to occur from the *Perotriletes tessellatus*–*Schulzospora campyloptera* (TC) to the *Raistrickia nigra*–*Triquitrites marginatus* (NM) Biozones in miospore range charts for Western Europe (Neves et al., 1972, fig. 2; Neves et al., 1973, table 1; Riley, 1993, fig. 8). According to Clayton (1985, fig. 1), Higgs et al. (1988b, fig. 1) and Riley (1993, fig. 8), these biozones correspond to the upper part of the Holkerian (or the Lower Asbian according

## PLATE I



to Riley, 1993, p. 438) and the whole Asbian, i.e., the British regional stages for the lower and middle parts of the upper Viséan. Therefore, such a late Viséan age, rather than late Tournaisian, can be in part assigned to the interval of well 2-LF-1-AM (cores 29 to 21). Note that in an integrated miospore–foraminifer study of the Oued Zemrine section (Mékra Massif, Morocco), Loboziak et al. (1990) demonstrated that the base of the TC Biozone can be somewhat older. It coincides with the boundary of foraminiferal zones Cf4c and Cf5, which in Belgium is close to the Molinacian/Livian regional stage boundary (i.e., the mid part of the middle Viséan).

Due to the presence of *Lycospora* spp., a Viséan age is more obvious for the overlying interval comprising cores 16 to 13. In addition to this genus, other main taxa first appearing in the Viséan are also present. For instance, cores 16 and 15 contain 'Hymenozonotriletes' *dolianitii* (shown in the Fig. 2 as *Radiizonates* sp. cf. *H. dolianitii*) and a large reticulate form (= *Dictyotriletes* sp. cf. *R. magnidictyus* in

Fig. 2) identical to the eponym species of the aforementioned *Reticulatisporites* cf. *magnidictyus* Biozone. This form is also recorded, as *Dictyotriletes* sp. n° 2908 in Lanzoni and Magloire (1969, plate II, figs. 2 and 3), from the M4 (upper part) to the M7 subzones of the Grand Erg Occidental. Other taxa present in well 2-LF-1-AM include *Cirratriradites rarus* and *Waltzispota* spp. (both in the two highest cores 14 and 13) and *Granulatisporites granulatus* (only in core 13).

Typical representatives of the genus *Waltzispota* (see *W. planiangularata* in Riley, 1993, fig. 8) are known to appear at the base of the TC Biozone together with *Perotriletes tessellatus*. They still persist well above the extinction level of the latter. So, because other index species of the late Viséan or younger intervals are locally absent, the section including core 18 and cores 16–13 (all lacking *P. tessellatus*) can be tentatively attributed to the *Tripartites vetustus*–*Rotaspora fracta* (VF) Biozone. This unit immediately succeeds the NM miospore Zone in

## PLATE I

The slides from well 2-LF-1-AM (except for 940501) are housed in the palynological collection of the Laboratory of Palaeobotany and Palaeopalynology, University of Liège, Belgium. Slide 940501 and materials from other wells are housed in the palynological slide collection of the Biostratigraphy and Paleocology Sector of Petrobras Research Centre (Cenpes/Divex/Sebipe), Rio de Janeiro, Brazil. Miospore locations on the slides are based on England Finder graticules. Magnification of illustrated specimens:  $\times 500$ .

- 1, 2. *Radiizonates* sp. cf. *Hymenozonotriletes dolianitii* Daemon, 1974.
  1. Slide 23(1): L30/3, well 2-LF-1-AM, core 23 at 2178.10/2180.10 m.
  2. Slide 960560: U38, well 1-RX-3-AM, core 24 at 2207.25 m.
- 3, 4. *Cirratriradites rarus* (Ibrahim) Schopf, Wilson and Bentall, 1944.
  3. Slide 940848: B57/4, well 1-IU-1-PA, core 1 at 1274.20 m.
  4. Slide 8706167 (5567): W56, well 1-AD-1A-AM, core 24 at 3159.17/3162.20 m.
5. *Perotriletes tessellatus* (Staplin) Neville in Neves et al., 1973 = *Rugospora polyptycha* Neves and Ioannides, 1974 in Loboziak et al., 1991, plate 1, fig. 4. Slide 21(1): L27/3, well 2-LF-1-AM, core 21 at 2173.80/2176.10 m.
6. *Diatomozonotriletes fragilis* Clayton in Neves et al., 1973. Slide 960560: U46/1, well 1-RX-3-AM, core 24 at 2207.25 m.
7. *Foveosporites appositus* Playford, 1971. Slide 15(1): F39/1, well 2-LF-1-AM, core 15 at 2151.50/2156.60 m.
- 8, 9. *Waltzispota polita* (Hoffmeister, Staplin and Malloy) Smith and Butterworth, 1967.
  8. Slide 940749: U61/4, well 1-UA-1-AM, core 23 at 3016.75 m.
  9. Slide 940847: P46/2, well 1-IU-1-AM, core 1 at 1273.76 m.
10. *Granulatisporites granulatus* Ibrahim, 1933. Slide 940501: X42/3, well 2-LF-1-AM, core 13 at 2148.53 m.
- 11, 12. *Lycospora pusilla* (Ibrahim) Somers, 1972.
  11. Slide 940744: A46/3, well 1-UA-1-AM, core 22 at 2962.45 m.
  12. Slide 940745: V33/3, well 1-UA-1-AM, core 22 at 292.75 m.
13. *Lycospora pellucida* (Wicher) Schopf, Wilson and Bentall, 1944. Slide 940848: N59/2, well 1-IU-1-PA, core 1 at 1274.20 m.
14. *Lycospora rotunda* (Bharadwaj) Somers, 1972. Slide 8706167: E55/3, well 1-AD-1A-AM, core 24 at 3159.17/3162.20 m.
15. *Lycospora noctuina* Butterworth and Williams, 1958. Slide 940862: H40/2, well 1-IU-1-PA, core 1 at 1279.70 m.
16. *Dictyotriletes* sp. cf. *Reticulatisporites magnidictyus* Playford and Helby, 1968. Slide 960560: K36, well 1-RX-3-AM, core 24 at 2207.25 m.
17. *Schopfipollenites* sp. = *S. ellipsoides* in Loboziak et al., 1991, plate 1, 17. Slide 21(1): E31, well 2-LF-1-AM, core 21 at 2173.80/2176.10 m.



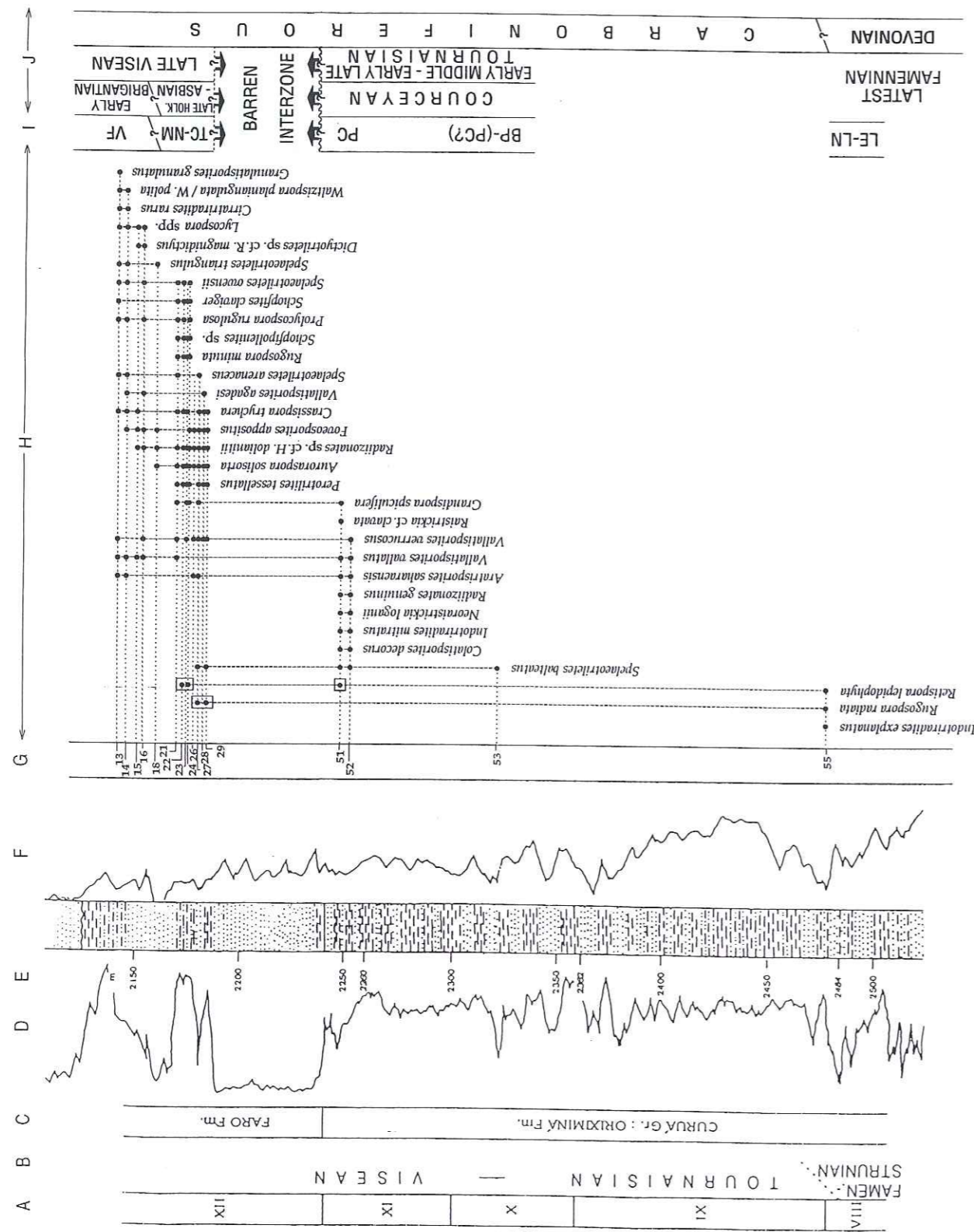


Fig. 2. Miospore distribution chart for well 2-LF-1-AM (modified from Loboziak et al., 1991). A. Petrobras regional biozonation. B. Palynological datings of Daemon (1974, 1976). C. Lithostratigraphy. D. Gamma-ray log. E. Depth (m) and lithological log. F. Resistivity log. G. Productive cores. H. Local ranges of selected miospore species. Dots enclosed in rectangles denote reworking of Devonian forms into the Carboniferous. I–J. Western European miospore biozones and datings, as discussed in text.

Western Europe, and corresponds to the lower part of the Brigantian Stage in Britain (i.e., the uppermost Viséan).

In conclusion, the whole interval between core 29 and core 13 is now considered to be of late Viséan age. Some praecolpates, previously assigned by Loboziak et al. (1991) to the species *Schopfipollenites ellipsoides* in spite of their smaller size range (about 110–125 µm rather than 200–500 µm), have been recorded from core 24 to core 21. Because *Schopfipollenites* spp. are virtually unknown below the upper Viséan in the British Isles (Riley, 1993, fig. 8; see also Coquel and Massa, 1993, p. 150), the Brazilian specimens had been regarded in the previous paper as late Tournaisian praecursors of the typical late Viséan forms. Their presence in well 2-LF-1-AM is now demonstrated to be in permissive agreement with their known range elsewhere in Euramerica.

Tournaisian miospore assemblages in this well are therefore only identified in cores 51 to 53 (2252.0–2327.0 m). In core 53, *Speleotriletes balteatus* is the only zonal species thus far recognized. In Western Europe, its first occurrence defines the base of the *S. balteatus*–*R. polyptycha* (BP) Biozone (Higgs et al., 1988a, p. 12, 13, fig. 3). This unit ranges from the higher part of the lower *crenulata* to the basal upper *crenulata* conodont Zones of early (but not earliest) middle Tournaisian age (Higgs et al., 1992, p. 157, fig. 3). However, a younger Tournaisian attribution cannot be completely excluded for this core, as unpublished biostratigraphical results from other wells in the Amazon Basin point out to the presence of the succeeding *S. pretiosus*–*R. clavata* (PC) Biozone in sections of similar electric-log signature. For this reason, a comprehensive BP–(PC?) zonal range is suggested for core 53 in Fig. 2. In well 2-LF-1-AM, the PC Zone is only confirmed in cores 52 and 51, due to the presence of *Colatisporites decorus*, *Indotriletes mitratus* and *Raistrickia cf. clavata* in the newly studied samples. In Western Europe, this biozone extends from the upper *crenulata* Zone in the deep water conodont succession to the lower part of the *communis carina* Zone in the platform conodont succession of late middle to early late Tournaisian age (Higgs et al., 1992, fig. 3, p. 157; Dreesen et al., 1993, fig. 10).

### 3. Comparison of palynozonal schemes in 2-LF-1-AM

As previously stated, well 2-LF-1-AM is unique to the understanding of the Lower Carboniferous palynostratigraphy in the Amazon Basin, because it has been investigated according to two independent biozonal schemes, viz.: that of Petrobras (Daemon, 1974, 1976) and the Western European miospore biozonation (Loboziak et al., 1991 and the present study). Correlations between both schemes and their implied datings are shown in Fig. 2, and discussed next in further detail.

Biostratigraphic interval XII, within the Faro Formation, corresponds to an upper shaly/sandy section containing a distinctive late Viséan palynoflora (cores 13 to 29, within the TC-VF biozonal range), and to a lower sandy section of uncertain age, but supposed to have been quickly deposited, and which is barren of miospores (cores 30 to 50).

In the upper part of the underlying Oriximiná Formation, biostratigraphic interval XI, formerly assigned to the early Viséan by Daemon (1974, 1976), has its upper boundary near the middle/upper Tournaisian transition (cores 51 and 52, PC Biozone). Its lower boundary is above core 53, i.e., within the BP–(PC?) biozonal range, and therefore cannot be older than middle Tournaisian.

Biostratigraphic interval X, in the middle part of the Oriximiná Formation, includes core 53 and corresponds to BP or younger biozone of Western Europe (middle Tournaisian).

From the above discussion, it follows that the base of the Viséan section in well 2-LF-1-AM cannot be placed below that of the Faro Formation (which locally coincides with the base of biostratigraphic interval XII). Cores 51 and 52, on the top of interval XI, contain a miospore assemblage not younger than late middle or early late Tournaisian (PC Biozone). The early Viséan age of interval XI and its alleged correlation with Lanzoni and Magloire's (1969) subzone M4, as proposed by Daemon (1974, 1976), lack sufficient palynological support. In fact, in the way as originally defined, interval XI has no biostratigraphic identity. It cannot be traced away from its reference section in well 2-LF-1-AM to any other boreholes in northern Brazilian basins, without invariably merging with older or younger units



(Daemon and Contreiras, 1971, figs. 2 and 3; Daemon, 1974, text-fig. 2; Daemon, 1976, fig. attached to p. 190; Andrade and Daemon, 1974, text-fig. p. 132). By contrast, interval XII is laterally persistent all over those regions, often truncating underlying biostratigraphic units. These facts are all in agreement with the proposition of a regional unconformity delineating the base of the late Viséan sequence in northern Brazilian basins.

#### 4. Comparisons with Tournaisian–Viséan miospore successions in North Africa and the Middle East

##### 4.1. Algerian Sahara Grand Erg Occidental

To our knowledge, the earliest, best documented account on the Upper Devonian–Lower Carboniferous miospore biostratigraphy of North Africa is the paper by Lanzoni and Magloire (1969), which concerns the Grand Erg Occidental (Algerian Sahara).

Daemon (1974), while reviewing the palynozones defined by Daemon and Contreiras (1971), has already emphasized the remarkable similarity between the miospore successions from Palaeozoic basins of northern Brazil and those from the Grand Erg Occidental.

Results of the present study largely confirm Daemon's viewpoint. As mentioned above, biostratigraphic interval XII of Petrobras regional biozonation can be correlated with the interval ranging from Subzone M4 (upper part) to Subzone M7 in the Grand Erg Occidental, based on the common occurrence of forms here named *Radiizonates* sp. cf. *H. dolianitii* and *Dictyotriletes* sp. cf. *R. magnidictyus*.

Subzone M4 was recorded by Lanzoni and Magloire (1969, p. 450) in a section of borehole UT 2 (SN Repal), which contains foraminifers assigned by those authors to the lower Viséan. However, of the listed taxa, *Archaeodiscus* sp. (non *Archaeodiscus*) and *Omphalotis omphalota* (Rauser and Reitlinger) Shykova, 1969 (= *Endothyra omphalota* in Lanzoni and Magloire, 1969) rather suggest an age not older than middle Viséan (D. Vachard, personal communication, June 1997).

Lanzoni and Magloire (1969, p. 450) also mention a macrofauna from Subzones M4 and M5 in the

Timimoun and Bahmer core-drills, in the southern part of the basin. Again, their list includes elements of contradictory age. The ammonoids, if correctly identified, suggest a late Tournaisian age, whereas the bivalve *Posidonia* cf. *becheri* (Bronn) is typically a late Viséan taxon (N. Riley, personal communication, June 1997). It is unclear from their account whether those incongruous fossil assemblages have been gathered from a same section or from distinct stratigraphic intervals.

Lemosquet et al. (1985, p. 367) report, from the same area, an ammonoid fauna which supposedly characterizes the earliest Viséan and is followed throughout the basin by a late Viséan fauna. In contradiction to the statement by Coquel and Massa (1993, p. 146), the regional stratigraphic succession is not accurate, as far as the Viséan is concerned. After Weyant (1985, p. 364), the *Paragnathodus homopunctatus* Zone (earliest Viséan) and the *Gnathodus bilineatus* Zone (which characterizes the whole Viséan except its earliest part) are not so clearly separated in the southern part of the basin as they are in the north. Coquel and Massa (1993, p. 147) point out that the Tournaisian/Viséan boundary is rather sharp in the southern area. This may be due to a stratigraphic gap separating the *Scaliognathus anchoralis* and *Doliognathus latus* zones of late Tournaisian age from conodont assemblages of undifferentiated (possibly late) Viséan age.

##### 4.2. Eastern Algeria Illizi Basin and western Libya Hammadah (Ghadamis) Basin

Almost all palynological data available for North Africa and the Middle East since the pioneer work of Lanzoni and Magloire (1969) postdate and/or rely on the paper of Massa et al. (1980), which concerns the Carboniferous of western Libya. Therefore, it is appropriate to start this discussion with brief remarks on the faunal and palynological evidence given in that publication and in a related paper (Massa and Vachard, 1979).

A detailed review of this subject was already provided by Streel and Loboziak (1994), and it is unnecessary to repeat here all the arguments presented in their paper. They conclude that no occurrences of early and middle Viséan strata can be confirmed in either the M'rar Formation of the western

Libyan Hammadah Basin or the Issendjel Formation of the eastern Algerian Illizi Basin (Attar et al., 1980).

Subsequent objection to such conclusions by Abdesselam-Rouighi and Coquel (1997) does not provide any credible alternative. On the contrary, in addition to their poor lithological correlations, these authors concede that available goniatite identifications from the Algerian Sahara (i.e., *Bollandoceras hoderense* (Bisat), *Dzhaprakoceras subglobosum* (Librovitch), etc.) cannot be confirmed from either the illustrations by Pareyn (1961) or the faunal list given by Dubois et al. (1959). Consequently, no recognition of the middle Viséan/late Viséan boundary is possible on the basis of available faunal evidence, contrary to the statement of Abdesselam-Rouighi and Coquel (1997, p. 51).

Streel and Loboziak (1994, p. 269) conclude that Palynozones XIV and XIII in western Libya as well as Palynozones IV in eastern Algeria are poorly dated. They suggest that either sedimentary condensation or a gap possibly occurs beneath the so-called *Collenia* beds, a late Viséan formation reliably dated by foraminifers in the Illizi Basin. Therefore, the proposed earliest Viséan age was one possible alternative for the above-mentioned palynozones. But, of course, another acceptable possibility is that they are late Viséan, and in this case, the sedimentary condensation or gap could occur somewhere between Palynozones XIII and XII in western Libya and between Palynozones IV and III in eastern Algeria. The latter alternative is more consistent with the Brazilian data, and is further substantiated by a break in the palynological content of those biozones<sup>1</sup> (Attar et al., 1980, table IV; Abdesselam-Rouighi and Coquel, 1997, fig. 4).

Judging from palynological data provided by Massa et al. (1980), Palynozones XIII is obviously of late Viséan age, as demonstrated by the presence (ibid., plate V, fig. 22) of *Diatomozonotriletes*

<sup>1</sup> There is an apparent contradiction between this viewpoint and that of Coquel and Latrèche (1989, p. 60), who advocate that the Tournaisian/Viséan boundary is transitional in the Illizi Basin, based on a 'gradual' quantitative change in populational successions of *Aratrisporites saharaensis*. However, those authors also admitted (ibid. p. 63) that sedimentary condensation could have occurred at that same level.

*fragilis*<sup>2</sup> This species is also known from the base of Palynozones IV in Borehole BN1, in the south-eastern part of the Illizi Basin (Abdesselam-Rouighi and Coquel, 1997, fig. 4). Furthermore, the late Viséan age of that section is confirmed by the first occurrence, a few metres higher, of *Reticulatisporites cancellatus* (ibid., plate III, fig. 4), also referred to as *Reticulatisporites* cf. *magnidictyus* in Daemon (1974, plate VIII, figs. 5 and 6) and *Dictyotriletes* sp. n° 2908 in Lanzoni and Magloire (1969, plate II, figs. 2 and 3) (see also Ravn et al., 1994, p. 14)<sup>3</sup>. The joint occurrence of *Spelaeotriletes pretiosus* and miospores of late Viséan age, either in the Illizi and Hammadah Basins or in northern Brazilian basins, may be the result of reworking.

*Lycospora* spp. have been found in neither Palynozones XIII of the Hammadah Basin nor Palynozones V of the Illizi Basin. However, new observations made in Brazil on erratic occurrences of *Lycospora* spp. within miospore assemblages of late Viséan age lead us now to admit that most of the M'rar and Issendjel Formations might be of late Viséan age. The lower part of these formations is clearly of early late Tournaisian age, based on miospore (PC Zone) and faunal evidence (Massa and Vachard, 1979). It does not mean that we accept the conclusion of Coquel and Massa (1993, p. 149) that "l'arrivée tardive, au Viséan terminal, de *Lycospora pusilla*, dans l'ensemble Illizi-Rhadamès, est un fait rigoureusement établi". Their statement lacks biostratigraphic support, because older Viséan strata have never been reliably dated in those regions. Nevertheless, such misconception about the Viséan palynology of eastern Algerian and western Libyan basins has had a direct bearing on the viewpoints of authors concerned with other basins in North Africa and the Middle East. For this reason, we maintain that, "in

<sup>2</sup> The alleged presence of *Diatomozonotriletes fragilis* (characteristically a late Viséan species) in the middle part of the upper Tournaisian (Massa et al., 1980, p. 433, fig. 4, 5) is, from our viewpoint, unacceptable. This problem may rather reflect incongruous composite sections, including mixed strata with disparate ages, or still, the reworking of Tournaisian miospores into late Viséan assemblages.

<sup>3</sup> The same species has also been recorded in both the Illizi Basin, from the base of Palynozones IV (Attar et al., 1980, table I, plate 2, fig. 1), and the Hammadah Basin (Massa et al., 1980, plate V, fig. 1)



the absence of confirmed lower and middle Viséan miospore assemblages, without *Lycospora*, a belated first occurrence of this genus in North Africa is not supported by available data" (Streel and Loboziak, 1994, p. 269).

Probably based on inaccurate palynological datings (BEICIP/NOC, 1972, western Libya Exploration Study: unpubl. rept.), Withbread and Kelling (1982, p. 1091 and 1093) assumed that deltaic sediments making up the M'rar Formation (865 m thick) could have been stacked continuously over a time span of 15 Ma. They ascribed (p. 1106) the virtual absence of plant remains in the M'rar Formation to the very low subsidence rate which supposedly persisted during its deposition. However, an average subsidence rate of less than 1 mm in 15 years is very unlikely for deltaic systems. Indeed, now admitting that the bulk of the M'rar Formation was probably deposited during the late Viséan, we believe that sedimentary accumulation was discontinuous and much faster than previously considered.

#### 4.3. Cyrenaica, northeast Libya

When Clayton and Loboziak (1985) and Loboziak and Clayton (1988) studied the Early Carboniferous palynology of several boreholes in northeast Libya, there were no local faunal datings which they could count upon. Therefore, their age inferences relied on a comparison with assemblages XIII and XIV of western Libya (Massa et al., 1980). They attributed the miospore assemblage from interval 7941–8185 ft of well A1-37 to the Viséan, based on the abundance of *Aratrisporites saharaensis* in the lowermost part of the studied section. The presence or absence of miospore species like *Spelaeotriletes pretiosus* and *Vallatisporites vallatus* provided the only arguments to differentiate early Viséan from late Viséan strata. On the other hand, those authors overlooked the significance of *Diatomozonotriletes fragilis*, present in several samples of A1-37. We now propose a late Viséan age for all of these, considering that the occurrence of *Spelaeotriletes pretiosus* and *Vallatisporites vallatus* in cores below 8131 ft. is possibly due to reworking. However, this contradicts Vachard et al. (1993) who, using foraminifers and conodonts, assigned a late Tournaisian or earliest Viséan age to sample CCY-1 within this section.

#### 4.4. Tim Mersoï and Agades Basins of northern Niger

In the Tim Mersoï Basin, the Talak Formation, of indisputable late Viséan age, was shown by Coquel et al. (1995) to encroach on the Farazekat Formation (dated as Tournaisian–early Viséan on the basis of megaflores) and further away on the granitic basement. The lowermost samples from the Talak Formation contain rare specimens of *Spelaeotriletes pretiosus*. Their presence in the upper Viséan was not explained by those authors. Such miospores may have been reworked from the Farazekat Formation. In addition, there occur some recycled Devonian palynomorphs (*Grandispora inculta*, chitinozoans), which probably derived from fluvial and glacio-marine sediments documented by Valsardieu and Dars (1971) and Lang et al. (1991).

A late Viséan assemblage containing *Lycospora pusilla* has been recorded from coals in the Agades Basin (Loboziak and Alpern, 1978).

#### 4.5. Middle East

Early Carboniferous miospores were reported by Clayton (1995) from a few boreholes in Saudi Arabia. Although the studied samples were rather scanty, no early or middle Viséan miospores have been found in those boreholes, which contain only middle Tournaisian and late Viséan–Namurian assemblages. Reworked miospores of latest Devonian age were also recorded amidst the late Viséan–Namurian palynoflora.

Miospore assemblages comparable to those from the Upper Devonian and Lower Carboniferous of the Saharan Platform were recorded by Ravn et al. (1994) in northeastern Syria. Faunal controls are missing, but their "upper assemblage" is very similar in its overall composition to the late Viséan miospore assemblages of the Algerian Sahara (Grand Erg Occidental), as evidenced by the common occurrence of *Dictyotriletes* sp n° 2908 and *Radiizonates* sp. n° 2922.

The "middle assemblage" is apparently of Early Carboniferous age, due to the absence of *Retispora lepidophyta*. The presence of species like *Cyrtospora cristifera*, *Cordylosporites spathulatus*, *Dictyotriletes glumaceus*, and their joint occurrence with

*Aratrisporites saharaensis* and *Radiizonates genuinus*, are features shared with several Tournaisian sections of Western Gondwana. Therefore, they are by no means incompatible with such age assignment, contrary to the belief of Ravn et al. (1994, p. 11). The lower part of this "middle assemblage" is obviously of Tournaisian age. On the other hand, its upper part, which contains *Spelaeotriletes giganteus*, is seemingly of undifferentiated Viséan age and still requires more precise dating.

#### 5. Conclusions

Based on new miospore determinations from well 2-LF-1-AM, including both Gondwanan and Euramerican taxa, Petrobras operational palynozones can be now more precisely correlated with the miospore biozonation of Western Europe.

The present review confirms the late Viséan age assigned by Petrobras palynologists to biostratigraphic interval XII in northern Brazilian basins (TC-VF zonal range). In principle, this assignment is consistent with the late Holkerian–early Brigantian span in Western Europe. However, the age of miospore assemblages from interval XII is more likely restricted to the younger part of that interval, due to the joint occurrence of such species as *Diatomozonotriletes fragilis*, *Rotaspora ergonulii* and *Perotriletes tessellatus*, followed by disappearance of the latter one, within productive sections usually no more than a few tens of metres thick.

Our miospore results from the Amazon Basin also point out to serious inconsistencies in the definition of the underlying interval XI, which is apparently devoid of any Viséan miospores. In the way as originally devised, the 'type' interval XI, now dated as middle to early late Tournaisian (BP-PC zonal range), is hardly distinguishable from the underlying interval X in its palynological content. The unit lacks stratigraphic identity, because it cannot be traced away from 2-LF-1-AM to any other boreholes as a discrete biozone.

Similar problems may affect equivalent 'transitional' intervals in North Africa, e.g., M3–M4 subzones of Lanzoni and Magloire (1969), or zones XII to lower XIII sensu Massa et al. (1980). In both instances, miospore biostratigraphy seems to have been

constrained by pre-existing, lithologically-based regional correlations involving distinct units with different ages (Streel and Loboziak, 1994).

There is a serious need for revised miospore zonal schemes in the so-called 'lower Viséan' of North Africa and adjacent regions, with potential implications for the alleged diachronism between first appearances of *Lycospora* spp. in Euramerica and Gondwana. Early to middle Viséan strata may be missing over much of North Africa and the Middle East, as they are apparently in northern Brazilian basins. Nevertheless, palaeoecologic control seems to have had a major bearing on local distributions of *Lycospora* spp. and other miospore taxa of either Gondwanan or Euramerican affinities, regardless of their stratigraphic position within Viséan sections.

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#### Appendix A. Species listed

- Aratrisporites saharaensis* Loboziak, Clayton and Owens, 1986
- Auroraspora solisorta* Hoffmeister, Staplin and Malloy, 1955
- Cirratriradites rarus* (Ibrahim) Schopf, Wilson and Bentall, 1944
- Colatisporites decorus* (Bharadwaj and Venkatachala) Williams in Neves et al., 1973
- Cordylosporites spathulatus* (Winslow) Playford and Satterthwait, 1985
- Crassispora trychera* Neves and Ioannides, 1974
- Cyrtospora cristifera* (Luber) Van der Zwan, 1979
- Diatomozonotriletes fragilis* Clayton in Neves et al., 1973
- Dictyotriletes glumaceus* Byvsheva, 1976
- Foveosporites appositus* Playford, 1971
- Grandispora inculta* Allen, 1965
- Grandispora spiculifera* Playford, 1976
- Granulatisporites granulatus* Ibrahim, 1933



*Hymenozonotrites dolianitii* Daemon, 1974  
*Indotriradites explanatus* (Luber) Playford, 1991  
*Indotriradites mitratus* (Higgs) Higgs, 1996  
*Lycospora noctuina* Butterworth and Williams, 1958  
*Lycospora pellucida* (Wicher) Schopf, Wilson and Bentall, 1944  
*Lycospora pusilla* (Ibrahim) Somers, 1972  
*Lycospora rotunda* (Bharadwaj) Somers, 1972  
*Neoraistrickia loganii* (Winslow) Coleman and Clayton, 1988  
*Perotrilites tessellatus* (Staplin) Neville in Neves et al., 1973  
*Prolycospora rugulosa* (Butterworth and Spinner) Turnau, 1978  
*Radiizonates genuinus* (Jushko) Loboziak and Alpern, 1978  
*Raistrickia clavata* Hacquebard emend. Playford, 1964  
*Reticulatisporites cancellatus* (Waltz) Playford, 1962  
*Reticulatisporites magnidictyus* Playford and Helby, 1968  
*Retispora lepidophyta* (Kedo) Playford, 1976  
*Rotaspora ergonulii* (Agrali) Sullivan and Marshall, 1966  
*Rugospora minuta* Neves and Ioannides, 1974  
*Rugospora polyptycha* Neves and Ioannides, 1974  
*Rugospora radiata* (Jushko) Byvsheva, 1985  
*Schopfipollenites ellipsoides* (Ibrahim) Potonié and Kremp, 1954  
*Schopfites claviger* (Sullivan) Higgs, Clayton and Keegan, 1988  
*Speleotrilites arenaceus* Neves and Owens, 1966  
*Speleotrilites balteatus* (Playford) Higgs, 1996  
*Speleotrilites giganteus* Loboziak and Clayton, 1988  
*Speleotrilites owensii* Loboziak and Alpern, 1978  
*Speleotrilites pretiosus* (Playford) Neves and Belt, 1970  
*Speleotrilites triangulus* Neves and Owens, 1966  
*Vallatisporites agadesi* Loboziak and Alpern, 1978  
*Vallatisporites vallatus* Hacquebard, 1957  
*Vallatisporites verrucosus* Hacquebard, 1957  
*Waltzispota polita* (Hoffmeister, Staplin and Malloy) Smith and Butterworth, 1967  
*Waltzispota planiangulata* Sullivan, 1964

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