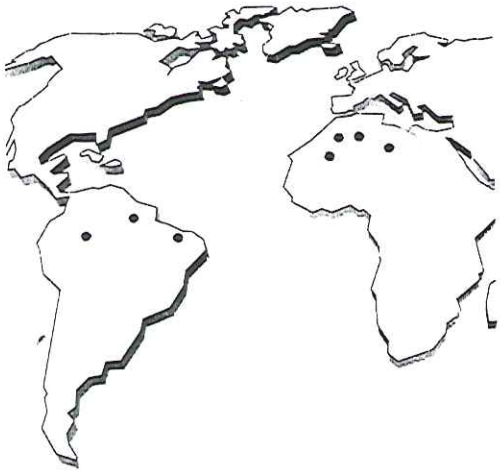
253

LATEST DEVONIAN AND EARLY CARBONIFEROUS PALYNOSTRATIGRAPHY OF NORTHERN BRAZIL AND NORTH AFRICA – A PROPOSED INTEGRATION OF WESTERN EUROPEAN AND GONDWANAN MIOSPORE BIOZONATIONS

PALYNOSTRATIGRAPHIE DU DÉVONIEN LE PLUS RÉCENT ET DU CARBONIFÈRE ANCIEN DU BRÉSIL ET D'AFRIQUE DU NORD – UNE PROPOSITION D'INTÉGRATION DES BIOZONES DE MIOSPORES D'EUROPE OCCIDENTALE ET DU GONDWANA

Stanislas LOBOZIAK, José Henrique G. MELO and Maurice STREEL



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Des successions de miospores du Dévonien le plus récent au Viséen du nord du Brésil et de bassins sélectionnés d'Afrique du Nord sont comparées, et leur remarquable similitude une fois encore confirmée. Elles attirent l'attention sur l'unité de la Microflore à *Aratrisporites saharensis*, une province palynofloristique distincte du Gondwana occidental, dans laquelle plusieurs formes endémiques, d'intérêt biostratigraphique régional, sont présentes en même temps que des espèces de miospores-guides d'affinité euraméricaine.

L'absence apparente de palynoflores du Tournaisien le plus récent et du Viséen ancien sur de vastes étendues de cette province peut être attribuée en partie à la condensation sédimentaire et en partie à des lacunes résultant de l'érosion.

Des réinterprétations de données faunistiques publiées sur les bassins algériens et libyens occidentaux semblent confirmer nos corrélations basées sur les miospores. Cependant des révisions taxonomiques et stratigraphiques de certaines faunes marines sont encore nécessaires dans les bassins carbonifères d'Afrique du Nord. Des contrôles par les faunes au Tournaisien et Viséen manquent dans les bassins du nord du Brésil.

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ABSTRACT

Latest Devonian through Viséan miospore successions from northern Brazilian and selected North African basins are compared, and their remarkable similarities once again confirmed. They point out to the unity of the so-called *Aratrisporites saharaensis* Microflora, a distinctive palynofloral province of western Gondwana where several endemic forms of regional biostratigraphic usefulness occur along with some age-diagnostic miospore species of Euramerican affinity.

Latest Tournaisian and Early Viséan palynofloras apparently remain unproven in extensive portions of that province, which can be attributed partly to sedimentary condensation, partly to erosional truncations.

Reinterpretations of published faunal data from Algerian Sahara and western Libyan basins seem to support our miospore-based correlations. However, taxonomic and stratigraphic updates of some marine faunas are still needed in Carboniferous basins of North Africa. Tournaisian - Viséan faunal controls are missing in northern Brazilian basins.

Keywords: Miospores, Biostratigraphy, Famennian, Lower Carboniferous, Brazil, Solimões Basin, Amazon Basin, Parnaíba Basin, Algeria, Libya, Sahara.

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CONTENTS — *TABLE DES MATIÈRES*

INTRODUCTION 242

1. — CORRELATION OF PETROBRAS' REGIONAL PALYNOZONES — *CORRÉLATION DES PALYNOZONES RÉGIONALES DE PETROBRAS* 242

2. — LOWER CARBONIFEROUS FAUNAL CONTROLS IN SOME ALGERIAN SAHARAN BASINS: BRIEF COMMENTS — *CONTRÔLES FAUNISTIQUES DU CARBONIFÈRE INFÉRIEUR DE QUELQUES BASSINS DU SAHARA ALGÉRIEN : BREFS COMMENTAIRES* 243

3. — REINTERPRETED FAUNAL SUCCESSIONS IN LANZONI & MAGLOIRE'S ZONAL REFERENCE SECTIONS — *RÉINTERPRÉTATION DES SUCCESSIONS DE FAUNES DANS LES SECTIONS DE RÉFÉRENCE DES ZONES DE LANZONI & MAGLOIRE* 244

3.1. Palynozones M2 and M3 (Tournaisian) 247

3.2. Palynozones M4 and M5 (Early to early Late Viséan) 247

3.3. Palynozones M6 and M7 (Late Viséan) 248

4. — LOWER CARBONIFEROUS FAUNAL CONTROLS IN WESTERN LIBYA — *CONTRÔLES DES FAUNES DU CARBONIFÈRE INFÉRIEUR DE LIBYE OCCIDENTALE* 248

4. 1 Tournaisian faunas 249

4. 2. Viséan faunas 249

5. — CORRELATION BETWEEN PALYNOZONAL SCHEMES OF NORTHERN BRAZIL AND NORTH AFRICA — *CORRÉLATIONS ENTRE LES PALYNOZONES DU NORD DU BRÉSIL ET CELLES D'AFRIQUE DU NORD* 250

5 1 Latest Devonian palynozones 250

5.2 Tournaisian palynozones 252

5.3. Viséan palynozones 253

5.4. Latest Viséan - Early Serpukhovian palynozones 254

6. — CONCLUSIONS 255

7. — REFERENCES 255

Annex: Species listed 259

INTRODUCTION

According to the paleophytogeographic terminology currently in use for the Lower Carboniferous (CLAYTON, 1985; RAVN *et al.*, 1994), the Middle East, North Africa and northern Brazil were parts of the same palynofloral province. This is the so-called *Aratrisporites saharaensis* Microflora, which was supposedly restricted to temperate and possibly subpolar Southern belts in Gondwana during the Tournaisian and Viséan. As it contains several endemic miospore species, the *Aratrisporites saharaensis* Microflora is well differentiated from coeval, equatorial to southern subequatorial provinces (*Lophozonotriletes/Monilospora* and *Vallatisporites/Grandispora* Microfloras in Euramerica: *Granulatisporites frustulentus* Microflora in Australia). RAVN *et al.* (1994, p. 5, 6, 9, 10) remark that accurate datings and correlations of the *Aratrisporites saharaensis* Microflora have been hampered by such problems as difficulties in miospore taxonomy, troublesome stratigraphic data from North Africa, and apparently disparate ranges of some of the few miospore species shared with contemporary Euramerican provinces.

Mixed western European and Gondwanan miospore assemblages occur in Carboniferous strata of the Amazon, Solimões and Parnaíba Basins of northern Brazil (LOBOZIAK *et al.*, 1998; MELO *et al.*, 1999). Elements with Euramerican affinity can be directly calibrated in terms of standard miospore successions in Britain and continental Europe (NEVES *et al.*, 1972, 1973; CLAYTON *et al.*, 1977, 1978; HIGGS *et al.*, 1988a-b). In their turn, Early Carboniferous miospores of Gondwanan (*Aratrisporites saharaensis* Microflora) affinity were also used in erecting and tracing PETROBRAS' regional palynozones of northern Brazil (DAEMON & CONTREIRAS, 1971; DAEMON, 1974, 1976; ANDRADE & DAEMON, 1974). These permit correlation with similar biozonal schemes in North Africa, where some marine faunal data are available (LANZONI & MAGLOIRE, 1969; MASSA & VACHARD, 1979; LEMOSQUET *et al.*, 1985; WEYANT, 1985, etc.). Unfortunately, Late Carboniferous miospore successions of northern Brazil (not focused in this paper) remain poorly understood. As they are apparently less easily compared to Euramerican equivalents, correlations must partly rely on faunal datings provided by conodonts or foraminifera (LEMOS, 1992a-b; LEMOS & MEDEIROS, 1989; ALTINER & SAVINI, 1995). These faunas are restricted to carbonate facies, and are mostly consistent with Westphalian or younger ages (LOBOZIAK *et al.*, 1997b; MELO *et al.*, 1998, 1999).

Newly obtained results from the palynostratigraphic study of Tournaisian and Viséan sections from northern Brazilian basins give new insights into the age and succession of similar miospore assemblages in other sites of the *Aratrisporites saharaensis* Microflora. In this contribution, the correlation of PETROBRAS' earlier palynozonation with biozonal schemes of Algeria and western Libya, recently updated by LOBOZIAK *et al.* (1998) for the Viséan section, is now extended to older intervals. Comparisons will focus particularly on those few North African regions where formal palynozonations have been established. These are the Algerian Sahara (Grand Erg Occidental) zonal scheme of LANZONI & MAGLOIRE (1969), based on which the Lower Carboniferous part of PETROBRAS biozonation was largely constructed, and the controversial palynozones from Illizi and Hammadah (Ghadamis) Basins (ATTAR *et al.*, 1980; MASSA *et al.*, 1980; COQUEL *et al.*, 1988; COQUEL & LATRÈCHE, 1989; COQUEL & MASSA, 1993; STREEL & LOBOZIAK, 1994; ABDESSELAM-ROUIGHI & COQUEL, 1997). Obviously, some implications of this review may eventually apply to other occurrences of the same microflora in North Africa and the Middle East, not considered herein, such as those in Iran, Niger, northeast Libya, Morocco and Syria (COQUEL *et al.*, 1977; LOBOZIAK & ALPERN, 1978; CLAYTON & LOBOZIAK, 1985; LOBOZIAK & CLAYTON, 1988; LOBOZIAK *et al.*, 1990; RAVN *et al.*, 1994; COQUEL *et al.*, 1995).

1. — CORRELATION OF PETROBRAS' REGIONAL PALYNOZONES

The correlation of northern Brazilian palynozones ("biostratigraphic intervals") VII to XIII (DAEMON & CONTREIRAS, 1971; DAEMON, 1974, 1976; ANDRADE & DAEMON, 1974) with their latest Devonian - early Late Carboniferous equivalents from western Europe was already discussed to a great extent in previous papers (LOBOZIAK *et al.*, 1997b, 1998; MELO & LOBOZIAK, 1997; MELO *et al.*, 1999). The most conclusive results are from the Amazon Basin, but valuable palynological information was also obtained from adjacent basins (Solimões, Parnaíba). A brief

summary of their main conclusions is provided below. Brazilian biozones younger than interval XII will not be considered in this paper.

Intervals VII (upper part) and VIII are of latest Famennian, or "Strunian", age, for they contain *Retispora lepidophyta*. Usually, it is found in association with other distinctive species which are likewise restricted to the Devonian (*e.g.*, *Rugospora radiata, Leiotriletes struniensis, Grandispora facilis, Spelaeotriletes granulatus* and *Vallatisporites hystricosus*), or still, persist into the Early Carboniferous (*Cordylosporites marciae, C. spathulatus, Indotriradites explanatus, Verrucosisporites nitidus, Vallatisporites vallatus, V. verrucosus, Tumulispora malevkensis*, etc.). In western Europe, such miospore assemblages characterize the *R. lepidophyta - I. explanatus* (LE) - *R. lepidophyta - V. nitidus* (LN) zonal range and correspond to the *praesulcata* conodont Zone (Higgs & Streel, 1984, 1994). As pointed out by Melo *et al.* (1999), even occurrences of the LE Zone are questionable in Brazil, and thus, a more restricted assignment of at least interval VIII to the LN Zone is locally possible. ough demonstrated for some Amazon Basin wells (*e.g.*, 1-RX-1-AM; cf. Loboziak *et al.*, 1997a, Fig. 3), such equivalence may not apply to other areas, like the Parnaíba Basin. There, unpublished miospore data suggest that pre-"Strunian" and even Tournaisian strata may have been lumped together with LN-age beds into interval VIII, *e.g.*, in well 1-TM-1-MA (Andrade & Daemon, 1974, text-fig. p. 132; Daemon, 1976, annex to p. 190).

In well 1-RX-1-AM, according to Loboziak *et al.* (1997a) data, the whole biozone VII corresponds to the upper part of the *D. versabilis - G. cornuta* (VCo) Oppel Zone, of Late Famennian age (Fa2c to earliest Fa2d in Belgium according to Loboziak *et al.*, 1997c). We have noticed the same equivalence in some other Amazon Basin wells, where the "Strunian" section had been entirely assigned by Petrobras biostratigraphers to interval VIII. Except for the top of this latter, which in at least the Amazon Basin closely parallels the Devonian/Carboniferous boundary, it appears that biozonal boundaries of intervals VII through XI can be variably diachronous with relation to Euramerican zonal markers.

Intervals IX to XI are all of Tournaisian age. However, distinction between them remains difficult (Melo *et al.*, 1999, Fig.)ecause recent studies fail to recognize the same stratigraphic succession or ranges of their zonal miospore species as proposed in earlier works (Daemon & Contreiras, 1971, Fig. 4; Daemon, 1974, Tab. I).

In the Amazon Basin, intervals IX and X correspond altogether to the *V. verrucosus - R. incohatus* (VI) to *S. balteatus - R. polyptycha* (BP) zonal range of western Europe, which corresponds to the *sulcata* through lowermost upper *crenulata* conodont Zones of Early to early Middle Tournaisian age (Higgs & Streel, 1984, 1994; Higgs *et al.*, 1992). Several Late Devonian holdovers and the Gondwanan species *Waltzispora lanzonii* characterize the oldest Tournaisian sections of northern Brazilian basins. Those taxa are joined, in late Early to early Middle Tournaisian sections, by such newcomers as *Spelaeotriletes balteatus, Neoraistrickia loganii* and *Raistrickia strumosa*, which first appear in the BP Zone. In the Amazon Basin, the succeeding *S. pretiosus - R. clavata* (PC) Zone seems to fall consistently within the range of intervals X-XI, whereas in the Parnaíba Basin (*e.g.*, wells 1-TM-1-MA and 2-IZ-1-MA) it may include sections previously assigned to interval IX (Andrade & Daemon, 1974, text-fig. p. 132; Daemon, 1976, annex to p. 190). In addition to species shared with older strata, diagnostic PC assemblages in northern Brazil usually include *Spelaeotriletes pretiosus, Colatisporites decorus, Indotriradites mitratus*, and only occasionally *Raistrickia clavata*. In western Europe, the PC Zone is known to extend from the upper *crenulata* Zone in the deep water conodont succession to the lower part of the *communis carina* Zone in the shelf conodont succession of late Middle to early Late Tournaisian age (Higgs *et al.*, 1992; Dreesen *et al.*, 1993). Following the latest palynological review of well 2-LF-1-AM (Amazon Basin) by Loboziak *et al.* (1998), younger Tournaisian or Early Viséan biozones are no longer recognized above the PC Zone in northern Brazil, despite our former belief to the contrary (Loboziak *et al.*, 1991).

Interval XII is now admitted as entirely restricted to the Late Viséan (Melo & Loboziak, 1997; Loboziak *et al.*, 1998; Melo *et al.*, 1999), thus confirming the previous viewpoint of Petrobras workers (Daemon & Contreiras, 1971; Daemon, 1974, 1976). This unit correlates with a yet undefined, but possibly the youngest, portion of the *P. tessellatus - S. campyloptera* through *T. vetustus - R. fracta* (TC - VF) zonal range. In the British Isles, these biozones are known to extend altogether from Late Holkerian through Early Brigantian (Clayton, 1985; Higgs *et al.*, 1988b).

Diagnostic miospore assemblages of Interval XII include *Perotrilites tessellatus, Dictyotriletes* sp. cf. *Reticulatisporites magnidictyus, Foveosporites appositus, Radiizonates* sp. cf. *Hymenozonotriletes dolianitii, Cirratriradites rarus, Diatomozonotriletes fragilis, Spelaeotriletes arenaceus* and *S. triangulus*. Regionally, miospores of the genera *Lycospora, Granulatisporites, Waltzispora* (*sensu stricto*) and *Schopfipollenites* are also first recorded within this interval. In the Parnaíba Basin, additional forms have been identified (Melo *et al.*, 1999), such as *Spelaeotriletes benghaziensis, S. owensii, Vallatisporites agadesi, V. ciliaris*, and scarce *Rotaspora ergonulii*. Also verified in sections assigned to Interval XII is the occasional presence of mixed assemblages with Tournaisian "look", containing taxa like *Vallatisporites vallatus, V. verrucosus, Verrucosisporites nitidus, Spelaeotriletes balteatus* and *S. pretiosus*, amongst others. This may reflect either reworking from Tournaisian sediments or disparate Gondwanan ranges with respect to Euramerican occurrences of the same species, as argued by others (Playford, 1990; Ravn *et al.*, 1994). Interval XII unconformably overlies rocks of Late Devonian to early Late Tournaisian age throughout northern Brazilian basins (Melo & Loboziak, 1997; Loboziak *et al.*, 1998; Melo *et al.*, 1999).

Another regional unconformity separates biozone XII from the succeeding unit, interval XIII. The latter contains pollen grains (both taeniate and non-taeniate) in addition to numerous pseudosaccates and trilete spores. In at least the Amazon Basin, interval XIII is entirely assignable to the Westphalian on the basis of combined miospore and marine faunal evidence (Loboziak *et al.*, 1997b; Melo *et al.*, 1998, 1999). However, in the Solimões Basin, where thick, possibly older siliciclastic sections of interval XIII lack any taeniate pollen, Late Carboniferous sedimentation could have started slightly earlier, possibly still in Late Namurian time (Melo *et al.*, 1999).

2. — LOWER CARBONIFEROUS FAUNAL CONTROLS IN SOME ALGERIAN SAHARAN BASINS: BRIEF COMMENTS

In view of the relative shortage of Euramerican elements in Carboniferous microfloras of western Gondwana, chronocorre-

lation of regional miospore successions with those from outside areas must rely to a great extent on marine faunal datings. Unfortunately, in the Carboniferous of northern Brazil, reliable faunal data are only available from the Bashkirian upwards. On the other hand, several elements of the rich Early Carboniferous microfaunas and invertebrate assemblages from North Africa are shared with coeval Euramerican and eastern European marine basins. Because faunal successions in the former largely mirror those of the latter, it is reasonable to assume that F.A.D.'s (first appearance datum) of most key species are approximately synchronous all over those regions, in particular as concerns the pelagic elements (*e.g.*, conodonts and ammonoids). In addition, certain benthic groups have been also successfully used in long-distance correlations of the North African Carboniferous, like foraminifera, brachiopods, bivalves and corals.

As already stated, of all North African regions, the most important ones for palynostratigraphic correlations with the Lower Carboniferous of Brazil are the Illizi and Hammadah Basins and especially the Grand Erg Occidental. Faunal controls are potentially more conclusive for the latter two. However, their usefulness is greatly hampered by the imprecise way in which data have been presented in the literature (LANZONI & MAGLOIRE, 1969; MASSA & VACHARD, 1979; MASSA *et al.*, 1980). Generalized faunal lists in those papers refer indistinctly to different sections pre-assigned to a same palynozone or lithostratigraphic interval, but no range charts or precise faunal successions have been presented for individual sections probably due to the scarcity of the carbonate beds. Disentangling the original data into a neat sequence of faunal F.A.D.'s or vertical ranges is practically impossible. In the case of Hammadah Basin (western Libya), the situation is further complicated by poor correlations involving composite sections with possibly distinct ages. For the moment, little can be done, except to compare information available for the Grand Erg Occidental and Illizi Basin with better known faunal successions from other Lower Carboniferous sections of the Algerian Sahara.

Varied, reasonably precise faunal data from North African basins have been compiled by the several collaborators in MARTÍNEZ DÍAZ *et al.* (1985, p. 299-447). As shown in Figure 1, the area covered by the palynological study of LANZONI & MAGLOIRE (1969) in the Grand Erg Occidental comprises parts of what is nowadays considered the Béchar - Timimoun - Ahnet basinal complex, plus an adjoining portion of the Reggan Basin in the southwest. Another area of interest is the Mouydir outlier east of Ahnet, due to its intermediate location between the Grand Erg Occidental and the Illizi Basin. Maximum thicknesses of Carboniferous marine successions are attained towards the Tethyan margin of the African Platform (up to 5500 m in the Béchar Basin, near the South Atlas Flexure) and, to a lesser extent, in basins adjacent to the Ougartan Aulacogen, which was inverted into a structural high during post-Paleozoic times. They become considerably thinner southwards in pericratonic and intracratonic areas, where shallower marine sedimentation alternated with erosional cycles and continental progradations (CONRAD, 1985f, p. 333). Due to their remarkable sedimentary development and more accurate faunal controls, the Zousfana - Saoura Valley outcrops of the Béchar Basin constitute a reference section for all other Carboniferous Saharan basins (CONRAD, 1985a, p. 306).

Figure 2 demonstrates our interpretative correlation of selected Lower Carboniferous sections from the Algerian Sahara, based on lithological and faunal criteria, with reference to corresponding bio- and chronostratigraphic units in western Europe. Approximate synchronism is assumed for F.A.D.'s of pelagic zonal species, whose entries in North Africa are supposedly related to maximum flooding events. The illustrated Timimoun Basin outcrop section (after CONRAD, 1985c, p. 319) is believed to correspond reasonably to that of the nearby Timimoun core-drill in the Gourara area. The Bahmer core-drill (litho-log after LANZONI & MAGLOIRE, 1969, p. 444) is from the Touat area, on the northeastern margin of the Reggan Basin. In spite of the Grand Erg Occidental lithostratigraphic terminology used by LANZONI & MAGLOIRE (1969), the Bahmer core-drill seems to correlate best with Carboniferous successions from the adjoining Reggan and Timimoun-Ahnet-Mouydir Basins.

Subsurface sections from the Grand Erg Occidental proper tend to be more incomplete, particularly to the northeast, due to multiple erosional truncations (LANZONI & MAGLOIRE, 1969, Fig. 2, 3). Therefore, only the Bahmer and Timimoun "type sections" are sufficiently continuous to allow tentative faunal comparisons with Lower Carboniferous successions in nearby basins. This will be the subject of a separate discussion.

3. — REINTERPRETED FAUNAL SUCCESSIONS IN LANZONI & MAGLOIRE'S ZONAL REFERENCE SECTIONS

Algerian Saharan Carboniferous faunal/lithological successions and their age implications, compiled by the several collaborators in MARTÍNEZ DÍAZ *et al.* (1985, p. 299-447), provide background information for tentative stratigraphic reinterpretations of LANZONI & MAGLOIRE'S (1969, p. 449-451) faunal lists, used by them to date Palynozones M2 to M7 in at least two reference sections. These are the Timimoun core-drill in the Gourara area of the Timimoun Basin, and the Bahmer core-drill in the Touat area, on the northeastern border of the Reggan Basin (Fig. 1, 2). Some deep wells (UT-1, UT-2, BJ-1, KE-1) have also provided faunal evidence for dating Palynozones M4, M6 and M7. Unfortunately, LANZONI & MAGLOIRE'S (1969) faunal lists have been mostly compiled from more than one section, and the old taxonomic nomenclature used in them also poses serious limitations to subsequent reinterpretations. Therefore, only those faunal elements with more or less obvious identity will be considered.

In respect of the Bahmer core-drill, our correlations follow the scheme shown in Figure 2, which is based on the following assumptions.

(a) As pointed out by CONRAD (1985b, p. 315), the Kahla Sandstone, originally defined by oil companies (B.R.P., 1959), does not correspond exactly to that of LANZONI & MAGLOIRE (1969, Fig. 2), who excluded younger Tournaisian strata from its upper part.

(b) Therefore, we interpret that the lower part of LANZONI & MAGLOIRE'S "*Argiles de Timimoun*" (Palynozone M3) is coeval with shaly sections in the upper Kahla Formation *sensu* CONRAD (1985b), of Middle to early Late Tournaisian age. In this respect, due to the vicinity of the strongly subsident Ougartan Aulacogen (CONRAD, 1985a, p. 305), Tournaisian sections of the Touat area seem to display a shaly lithofacies development intermediate between those from the shallower Timimoun Basin, in the east, and the deeper Tindouf Basin, to the west. In the latter, much as in Touat, the Tournaisian/Viséan boundary is within a dominantly shaly sequence making up a part of

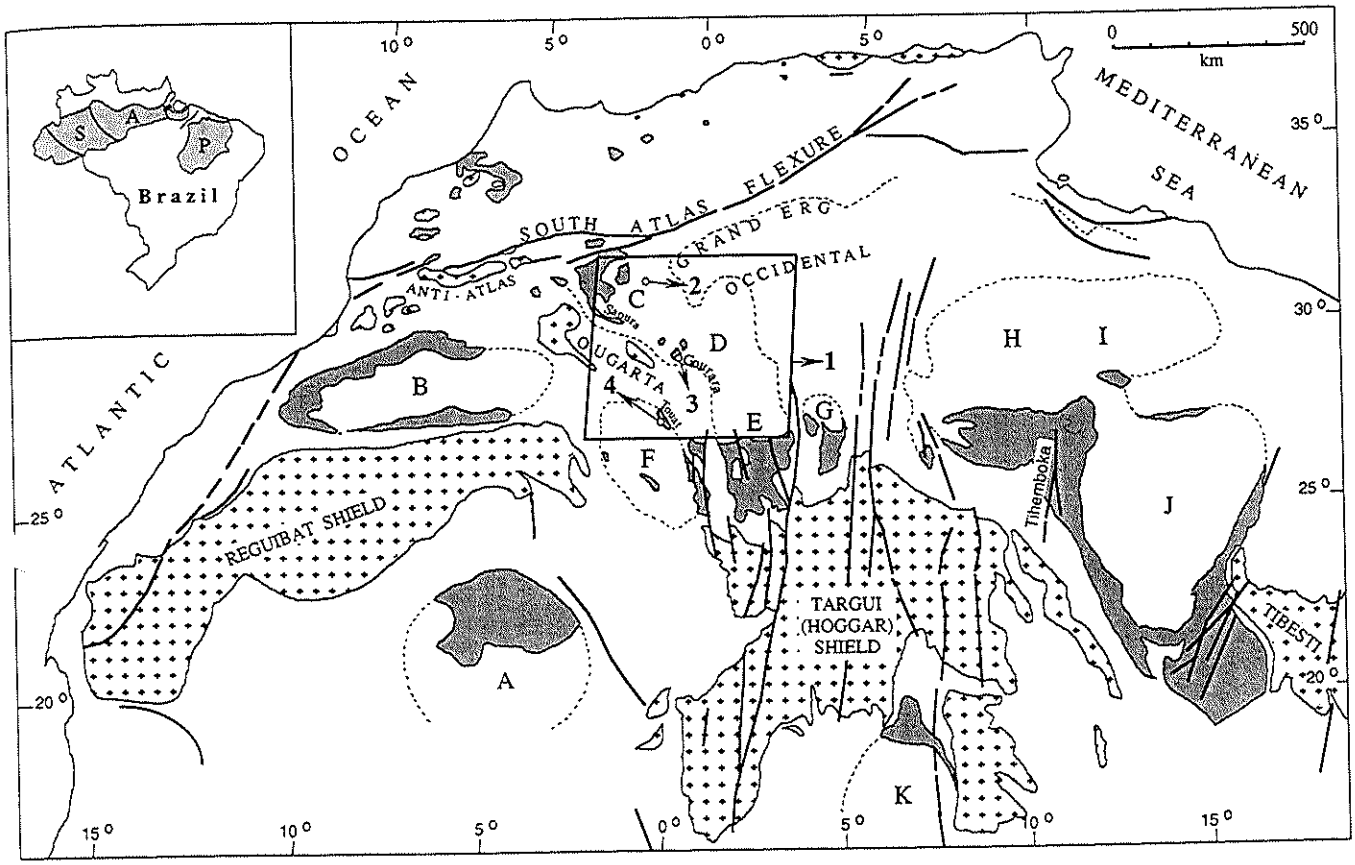


FIGURE 1

Geologic-structural map of northwestern Africa showing the sedimentary basins mentioned in text (modified from CONRAD, 1985a), and simplified location map of northern Brazilian Paleozoic basins (inset). In the former, shaded patterns denote the present-day configuration of Carboniferous basins (dark gray = outcrop areas; light gray = known subsurface distribution). Crosses refer to pre-Carboniferous rocks exposed on Saharan shields or within Hercynian zones to the north of the South Atlas Flexure.

Carte structurale de la partie nord-occidentale de l'Afrique montrant les bassins sédimentaires mentionnés dans le texte (modifiée d'après CONRAD, 1985a) et carte simplifiée de la localisation des bassins Paléozoïques du nord du Brésil (en médaillon). En Afrique, les figurés indiquent la configuration actuelle des bassins carbonifères (gris sombre = aires en affleurement; gris clair = distribution connue en sous-sol). Les croix représentent les roches pre-Carbonifères dans les boucliers sahariens ou à l'intérieur des zones hercyniennes au nord de la flexure sud atlasique.

Northern Brazilian Paleozoic basins (inset):

A = Amazon; P = Parnaíba; S = Solimões.

Carboniferous basins of northwestern Africa:

A = Taoudenni; B = Tindouf; C = Béchar; D = Timimoun; E = Ahnet; F = Reggan;
G = Mouydir; H = Illizi; I = Hammadah (Ghadamis); J = Mourzouk-Djado; K = Iullemedden.

Special notations for the Grand Erg Occidental region

1 = approximate area covered by the geological sketch of LANZONI & MAGLOIRE (1969, Fig. 1);

2 = site of reference well UT-2 (LANZONI & MAGLOIRE, 1969, Fig. 2, 3);

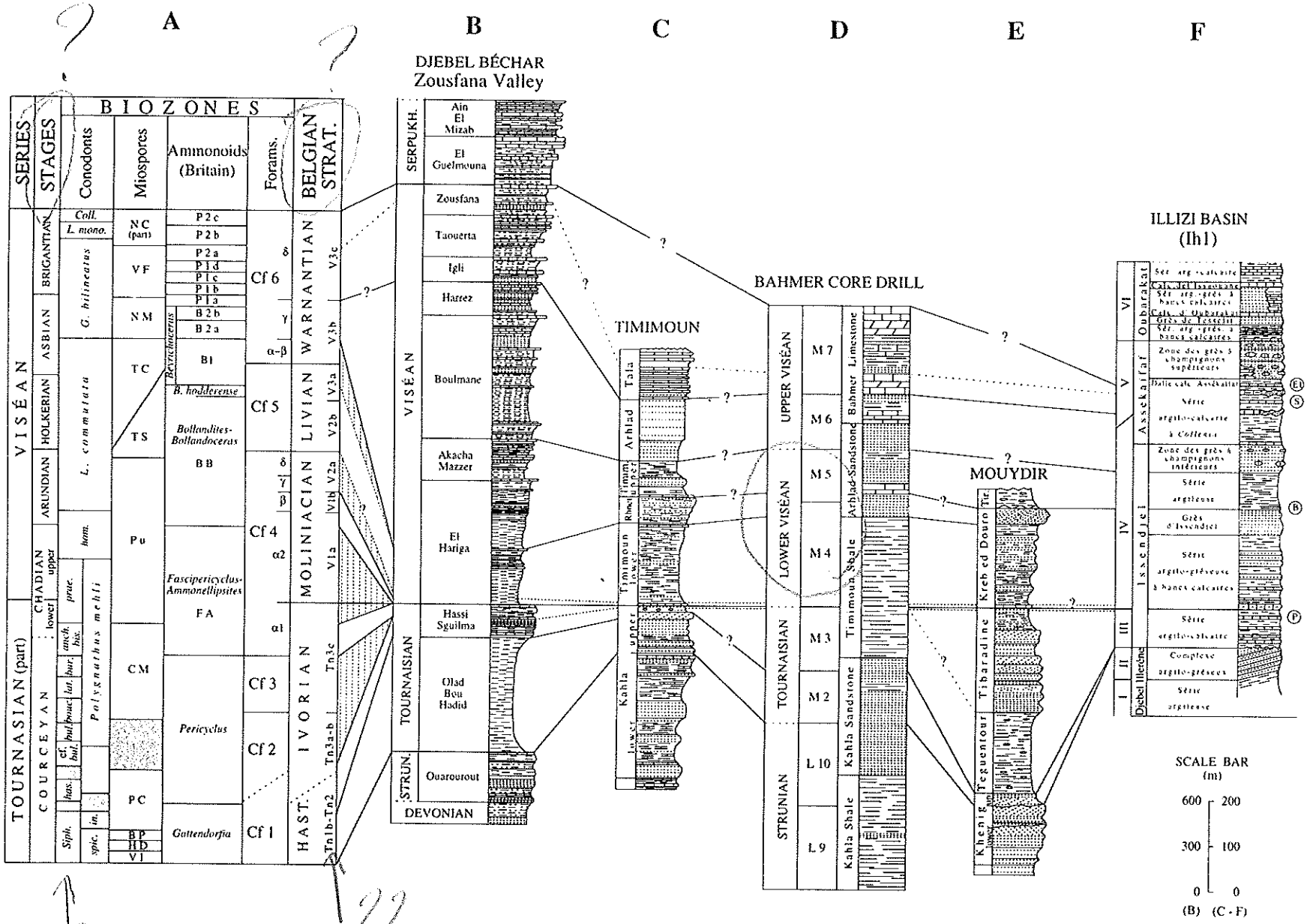
3 = site of the Timimoun core-drill (Gourara area);

4 = site of reference Bahmer core-drill in Touat area (LANZONI & MAGLOIRE, 1969, Fig. 2, 3).

the Betaina Formation (CONRAD, 1985c, Fig. 6; CONRAD, 1985e, p. 326).

(c) Evidently, LANZONI & MAGLOIRE (1969) overlooked the significance of the thin *Merocanites* limestone band, an equivalent of the Iridet Ledge that condenses most of the Late Tournaisian and Early Viséan sedimentation in the Touat section. It probably accounts for the "mixed", incongruous faunal lists given by those authors to justify the age of Palynozones M3 and M4.

In several Algerian Saharan basins, highly condensed marine beds intervene between the Tournaisian and Viséan sequences. Probably due to long-lasting starved basin condi-


A
B
C
D
E
F
SERIES
STAGES
BIOZONES
Conodonts
Miospores
Ammonoids (Britain)
Forams.
BELGIAN STRAT.
VISÉAN
TOURNASIAN (part)
BRIGANTIAN
ASBIAN
HOLKERIAN
ARUNDIAN
CHADIAN upper
lower
COURCEYAN
Coll.
L. mono.
G. bilineatus
L. commutata
hom.
prae.
anch. bis.
bur.
lat.
bouc.
bul.
cf. bul.
has.
Siph.
in.
spic.
Polygnathus mehli
NC (part)
VF
NM
TC
TS
Pu
CM
PC
BP
HD
VI
P2c
P2b
P2a
P1d
P1c
P1b
P1a
B2b
B2a
B1
Beyrichoceras
B. hodderense
Bollandites-Bollandoceras
BB
Fascipericyclus-Ammonellipsites
FA
Pericyclus
Gattendorfia
Cf 6
Cf 5
Cf 4
Cf 3
Cf 2
Cf 1
δ
γ
α-β
α2
α1
WARNANTIAN
LIVIAN
MOLINIACIAN
IVORIAN
HAST.
V3c
V3b
V3a
V2b
V2a
V1b
V1a
Tn3c
Tn3a-b
Tn1b-Tn2
DJEBEL BÉCHAR
Zousfana Valley
SERPUKH.
VISÉAN
TOURNAISIAN
STRUN.
DEVONIAN
Ain El Mizab
El Guelmouna
Zousfana
Taouerta
Igli
Harrez
Boulmane
Akacha Mazzer
El Hariga
Hassi Sguilma
Olad Bou Hadid
Ouarourout
TIMIMOUN
Tala
Arhlad
Timim. upper
Rhoel
Timimoun lower
Kahla upper
lower
BAHMER CORE DRILL
UPPER VISÉAN
LOWER VISÉAN
TOURNAISIAN
STRUNIAN
M 7
M 6
M 5
M 4
M 3
M 2
L 10
L 9
Bahmer Limestone
Arhlad-Sandstone
Timimoun Shale
Kahla Sandstone
Kahla Shale
MOUYDIR
Tir.
Kreb ed Douro
Tibaradine
Teguentour
Khenig
ILLIZI BASIN
(Ih1)
VI
V
IV
III
II
I
Oubarakat
Assekaifaf
Issendjel
Djebel Illerène
Série argilo-calcaire à Collenia
Série argileuse
Grès d'Issendjel
Série argilo-gréseuse à bancs calcaires
Série argilo-calcaire
Complexe argilo-gréseux
Série argileuse
SCALE BAR
(m)
600
300
0
200
100
0
(B)
(C - F)

tions, latest Tournaisian marine faunas lie almost directly on Middle Tournaisian ones, and are joined in close succession by earliest Viséan fossil assemblages. The condensed sediments comprise the Iridet Ledge ("*Dalle des Iridet*") in the Reggan and Ahnet-Mouydir Basins, as well as the equivalent *Dalle à Merocanites* of the Timimoun region (CONRAD, 1985b, p. 316; LEMOSQUET *et al.*, 1985, p. 370). The Iridet, an obvious marker-band of the Saharan Carboniferous, is "a decimetric to metric layer (sometimes two) of oolitic, phosphatic, pellet limestone which is remarkably widespread". There is a faunal renewal at the generic level with the appearance of *Merocanites*, the extinction of *Pericyclus* and *Imitoceras*, and the last representatives of *Ammonellipsites* (...)" (CONRAD, 1985c, p. 321). The Iridet/*Merocanites* limestone band blankets the top of the Tibaradine and upper Kahla Formations in the forementioned basins (Fig. 2). Equivalent strata are best developed in the Béchar Basin, where they consist of thicker limestones and siliciclastics making up the upper member of the Hassi Sguilma Formation (LEMOSQUET *et al.*, 1985, p. 370).

d) It seems that the Viséan part of LANZONI & MAGLOIRE's (1969, Fig. 2) "*Argiles de Timimoun*" in Touat corresponds to only the lower Timimoun Shale of the Gourara section. This implies that the Rhnet Sandstone and the upper Timimoun Shale in the latter area (with limestone and sandstone intercalations) are partly coeval with the Arhlad Sandstone *sensu* LANZONI & MAGLOIRE (1969). The Tala Formation corresponds approximately to the misnamed "*Calcaires de Bahmer*" of the Touat section, as explained by CONRAD (1985b, p. 316).

3.1. PALYNOZONES M2 AND M3 (TOURNAISIAN)

Megafossils (*e.g.*, brachiopods, ammonoids) with disparate stratigraphic ranges are referred indistinctly to these two biozones. If correctly identified, some are clearly related to the Early and Middle Tournaisian faunas, *e.g.*: *Gattendorfia* sp., *Imitoceras rotatorium*, *Pugilis vaughani*, and *Atylephorus tornacensis*. Others, of Late Tournaisian or Early Viséan affinity, are most probably restricted to the *Merocanites* Bed near the M3/M4 boundary, such as *Merocanites* sp., *Muensteroceras rotella*, *Stenoschisma isorhyncha*, and *Syringothyris cuspidata* (unless if representing misidentified specimens of the older Tournaisian *S. ahnetensis*). Due to the highly condensed nature of latest Tournaisian - Early Viséan sedimentation in that region, it is very doubtful if their palynological content has been documented at all by LANZONI & MAGLOIRE (1969, Tab. I, Pl. 4, 5). In any case, the vast majority of miospores illustrated for Palynozones M2 and M3 derives undoubtedly from the underlying section of Early to early Late Tournaisian age (equivalent to upper Tn1b to Tn2 or lowermost Tn3 in Belgium).

3.2. PALYNOZONES M4 AND M5 (EARLY TO EARLY LATE VISÉAN)

Of the foraminifera listed from an erosional remanent of Palynozone M4 (well UT-2; LANZONI & MAGLOIRE, 1969, p. 450), *i.e.*, possibly from its lower part, the most diagnostic elements are *Archaediscus* and *Omphalotis omphalota*. The former is a genus recorded in the British Isles only from foraminiferal Zone Cf5 (Holkerian) upwards (RILEY, 1993, Fig. 9), whilst *O. omphalota* usually indicates ages not older than Middle Viséan (D. VACHARD, pers. comm., *in* LOBOZIAK *et al.*, 1998). In Belgium, *O. omphalota* is generally absent in the older (V2b, Early Livian) part of that biozone (D. Vachard, writ. comm., 1998). In the eastern Alborz Range of Iran, according to LYS *et al.* (1978, p. 70), the F.A.D. of *O. omphalota* is immediately above that of *Archaediscus* spp., near the base of the local Cf5 equivalent. Likewise, LYS (1985, p. 361, Tab. 2, 4) demonstrates that, in many Saharan basins of North Africa (including the Béchar and

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FIGURE 2

Proposed correlation and dating of Lower Carboniferous lithological successions from selected Algerian Sahara localities (B - F) with reference to standard western European bio- and chronostratigraphic units (A), based on reinterpreted faunal data and lithological correlations of Algerian sections by CONRAD (1985c, 1985f). Areas in vertical dashed pattern between columns A and B represent time intervals with poor biostratigraphic resolution, attributed to sedimentary condensation. Note that only sections C to F are drawn to the same vertical scale.

Corrélations et datations proposées pour les successions lithologiques des sites sélectionnés du Sahara algérien (B - F) avec référence aux unités bio- et chronostratigraphiques standards d'Europe occidentale, basées sur une réinterprétation des données faunistiques discutées dans le texte et des corrélations lithologiques par CONRAD (1985c, 1985f) des sections algériennes. Les aires en hachurés verticaux entre les colonnes A et B représentent des intervalles temps avec une résolution biostratigraphique faible, attribuée à une condensation sédimentaire. A noter que seules les sections C à F sont tracées à la même échelle verticale.

A = Lower Carboniferous chronostratigraphic and biostratigraphic units in Britain and Belgium;

B = lithological succession of the Béchar Basin (Zousfana Valley outcrop area), regarded by many authors as a reference section to all other Saharan Carboniferous basins;

C = Timimoun outcrop section (Gourara area, Timimoun Basin), assumed herein as an approximate equivalent of the Timimoun core-drill section studied by LANZONI & MAGLOIRE (1969);

D = Bahmer core-drill section and palynozones in Touat area (Reggan Basin);

E = Oued Temertasset outcrop section (Mouydir Basin);

F = type lithological succession and palynozones of the Illizi Basin.

Bibliographic sources

A = mainly after RILEY (1993), CONIL *et al.* (1976) and PAPROTH *et al.* (1983); RILEY's proposed boundaries for miospore zones TS/TC and foraminiferal zones Cf6g/Cf6d modified after LOBOZIAK *et al.* (1990) and LALOUX *et al.* (1988), respectively;

B = after LEMOSQUET & PAREYN (1985);

C, E = after CONRAD (1985c);

D = after LANZONI & MAGLOIRE (1969); F = after ATTAR *et al.* (1980), with the lower boundary of the Assékaïfaf Formation modified after ABDESSELAM-ROUIGHI & COQUEL (1997).

Illizi Basins), the earliest archaediscids and *O. omphalota* are only recorded in regional equivalents of the Cf5 foraminiferal Zone. These data suggest that both foraminiferal taxa may be good indicators of Holkerian and younger ages in North Africa and the Middle East.

The conchiferous faunas listed by LANZONI & MAGLOIRE (1969, p. 450) include elements of quite different ages. If correctly identified, they probably reflect distinct sampled intervals from the Timimoun and Bahmer core-drills. Part of the fossils derive from the latest Tournaisian - Early Viséan condensed interval, which includes the M3/M4 palynozonal boundary. This is exemplified by FA zone ammonoids from the Tournaisian/Viséan transition (*Muensteroceras browni, M. inflatum, M. occidentale, Dzhaprakoceras hibernicum, Eurites corpulentus*), as well as *Composita ambigua*, an Early Chadian-Late Asbian brachiopod (RAMSBOTTOM & SAUNDERS, 1985, Fig. 4; RILEY, 1993, Fig. 6, 7; N.J. RILEY, writ. comm., 1997). *Bollandoceras hodderense* and *Beyrichoceratoides redesdalensis* are both known from the lowest part of the Tirechoumine Formation in the Ahnet Basin (CONRAD, 1985c, p. 321), which is not older than latest Holkerian according to western European standards (RILEY, 1993, Fig. 1, 2). *Beyrichoceras obtusum* is from a higher interval, correlative with the upper Timimoun Shale member, which succeeds the Rhnet Sandstone in the Timimoun section (CONRAD, 1985c, p. 321). In the British Isles, that species (along with *Bollandites castletonense*) is seemingly restricted to the uppermost Asbian only (B2b Zone), according to RILEY (1990, p. 153, 154, and 1993, Fig. 2). Their entry is preceded (B2a ammonoid Zone, Upper Asbian) by that of *Posidonia becheri*, a distinctive Late Viséan bivalve also mentioned by LANZONI & MAGLOIRE (1969), which persists up to the mid-Brigantian P1d ammonoid Zone (RILEY, 1993, p. 433; N.J. RILEY, writ. comm., 1997).

In conclusion, according to available faunal data, the bulk of Palynozone M4 is not older than Holkerian, whilst Palynozone M5 ranges well into the Late Asbian. The base of Zone M4 may be inside a very thin interval with latest Tournaisian / Early Viséan sediments, which also comprises the top of underlying Palynozone M3.

.3. PALYNOZONES M6 AND M7 (LATE VISÉAN)

Faunal lists for this biozonal interval (LANZONI & MAGLOIRE, 1969, p. 450, 451) have been compiled from at least five distinct subsurface sections, *i.e.*, the Bahmer core-drill and wells UT-1, UT-2, BJ-1 and KE-1. Unfortunately, listed foraminifera are of doubtful biostratigraphic value, because they include practically no index species used nowadays in Late Viséan correlations of North Africa or western Europe. On the other hand, some of the associated megafossils can be more easily evaluated in terms of Algerian and British Viséan faunal successions.

The brachiopod *Fluctuaria undata* is recorded from the Rhnet Sandstone in the Timimoun area, and from the Tirechoumine Shale of the Ahnet-Mouydir regions (an equivalent of the upper Timimoun Shale member). In Britain, it is only known from Late Asbian to the earliest Brigantian (RILEY, 1993, Fig. 7). It is therefore likely that Algerian occurrences of this species prove restricted to sandy/shaly sections underneath the Tala or Djebel Berga carbonates, *i.e.*, not ranging above Palynozone M6.

On the other hand, gigantoproductids and corals mentioned by LANZONI & MAGLOIRE (1969) are probably all from a higher stratigraphic position, *i.e.*, carbonates of the Tala Formation (*sensu stricto*). In terms of western European Viséan faunal successions, the coral *Koninckophyllum interruptum* is apparently the most age-restrictive of all listed species, as in Britain it first appears in assemblage I at a mid-Brigantian position (RILEY, 1993, Fig. 5) and ranges into Namurian strata. In the Béchar Basin, its F.A.D. is within the Boulmane Formation (SEMENOFF-TIAN-CHANSKY, 1985, p. 375). In the Tala section, it concurs with other coral species with older F.A.D.'s in western Europe, viz., *Dibunophyllum bipartitum* (Late Asbian onwards) and *Siphonophyllia benburbensis* (Early Asbian onwards). Gigantoproductids in general can be as old as Early Asbian, but *Latiproductus edelburgensis* is only recorded from Late Asbian or younger intervals in at least the British Isles (RILEY, 1993, Fig. 7). Altogether, these faunal elements are only in permissive agreement with the more constrained datings (Late Brigantian) provided by foraminifera and conodonts from the Viséan part of the Tala and Djebel Berga Formations (CONRAD, 1985d; LYS, 1985; WEYANT, 1985). This is probably the actual age of Palynozone M7, whereas Palynozone M6 can be as old as the Asbian/Brigantian transition.

Subsurface correlations in the westernmost Grand Erg Occidental (LANZONI & MAGLOIRE, 1969, Fig. 3) point out to an unconformity at the base of Palynozone M6, southeast of Béchar Basin's main exposure areas. This is probably an effect of the generalized regression mentioned by CONRAD (1985c, p. 321), "caused by uplift of the basement, [which] can be traced all along the northern border of the Hoggar". It gave rise to extensive fluvial and littoral deposition over much of the Saharan Platform, as documented by prominent, widespread sandy units of Late Viséan age, including the Garet Dehb Formation of the Ahnet-Reggan Basins, the Arhlad Formation (*sensu stricto*) in the Timimoun Basin and adjacent Touat area, and possibly the topmost sandstone unit of the Issendjel Formation ("*Zone des grès à champignons inférieurs*") in the Illizi Basin. In the remote Taoudenni Basin, to the southwest (Fig. 1), a similar truncation of condensed Middle-Late Tournaisian and Early Viséan fossiliferous sediments by Late Viséan strata (containing brachiopods and foraminifera of V3b-V3c affinity) is also demonstrated by LEGRAND-BLAIN (1985a, p. 327, 328) and LYS (1985, p. 361), within the lithostratigraphic range of the Bir en Naharat and Safia Formations.

4. — LOWER CARBONIFEROUS FAUNAL CONTROLS IN WESTERN LIBYA

In comparison to the aforementioned Algerian Saharan basins, Tournaisian and Viséan faunal successions in western Libya are yet too poorly controlled to allow reliable biozonations to be established. The stratigraphic significance of Early Carboniferous marine faunas from scattered sections of the Hammadah and Mourzouk Basins is further obscured by the vague way in which data was presented by the main published account (MASSA & VACHARD, 1979), without any clear indication of stratigraphic ranges or F.A.D. successions. Conodont assemblages reported by WEYANT & MASSA (1985), although conveniently tied to reference sections, are too poor to allow any biostratigraphic refinement of pre-Serpukhovian sections. Ammonoid datings by COQUEL & MASSA (1993, p. 148, 149) are

partly based on doubtful taxonomic identifications and correlations with Algerian localities (STREEL & LOBOZIAK, 1994, p. 269; ABDESSELAM-ROUIGHI & COQUEL, 1997, p. 49). Most of the following discussion will focus on western Libyan faunas only.

4.1. TOURNAISIAN FAUNAS

According to MASSA & VACHARD (1979), the lowest part of the M'rar Formation in the Hammadah Basin is dated as latest Tournaisian, and makes up their "Zone 1 à *Fusella* et *Muensteroceras*". The main argument for the alleged age consists of some ammonoids referred to as *Muensteroceras rotella*, *M.* cf. *crassum* and *Pericyclus* sp. (COQUEL & MASSA, 1993, p. 148), plus *Gnathodus* gr. *texanus*, regarded as "*un indice du Tournaisien supérieur*" (WEYANT & MASSA, 1985, p. 86).

Palynological data do not seem to support any age younger t late Middle or early Late Tournaisan (PC miospore Zone) for the bulk of the Tournaisian section of the lower M'rar Formation, which corresponds to MASSA et *al.*'s (1980) Palynozone XII (see discussion ahead). Faunal data are partly in permissive agreement with this assumption, and partly contradictory. It should be pointed out that WEYANT & MASSA's (1985, p. 86, Fig. 9) identification of *Gnathodus* gr. *texanus* is based on one single specimen from core 8 of well C1-49, whereas closely underlying cores 9 to 11 (formerly misassigned to the Famennian Tahara Formation by MASSA *et al.*, 1980, Fig. 4, 5) contain specimens of *Pseudopolygnathus dentilineatus* and *Polygnathus* gr. *inornatus*. These elements possess quite different stratigraphic ranges. *G. texanus* (which ranges into the Holkerian) is usually unknown below the *Scaliognathus anchoralis* / *Polygnathus bischoffi* conodont Zone of Late Courceyan/Early Chadian age, *i.e.*, latest Tournaisian (SWEET, 1988, Chart 6; RILEY, 1993, Fig. 3). On their turn, *P. dentilineatus* and British representatives of *P. inornatus* are supposedly restricted to the *Siphonodella sulcata* - *S. crenulata* zonal range of Early Courceyan age (SWEET, 1988, Chart 6; RILEY, 1993, Fig. 3). It is therefore clear that local conodont data are still too insufficient and contradictory to provide any precise datings.

As concerns the ammonoid genera *Pericyclus* and *Muensteroceras*, RAMSBOTTOM & SAUNDERS (1985, Fig. 4, Tab. 1) and KULLMANN *et al.* (1991, Fig. 1) show that they can occur in intervals as old as the Middle-Late Tournaisian transition. The biostratigraphic significance of western Libyan specimens assigned to *M. rotella* and *M. crassum* (MASSA & VACHARD, 1979, p. 9) is still questionable, and not much can be said about them until a taxonomic review is carried out, and their source strata are clearly indicated.

Finally, the alleged "Late Tournaisian" brachiopods do not pose any particular age constraints, as many of them are endemic Saharan species (LEGRAND-BLAIN, 1985c, p. 372). The brachiopod genus *Fusella*, one of the eponymous taxa of Zone 1, is too poorly characterized. Indeed, most species formerly assigned to it should rather go under *Unispirifer* (WILLIAMS *et al.*, 1965, p. 705), a genus represented since the Early Tournaisian in Britain and Algeria (LEGRAND-BLAIN, 1985c, p. 372, Tab. 8; RILEY, 1993, Fig. 6).

In conclusion, Tournaisian strata of the basal M'rar Formation are still poorly dated by their faunal content. It is not unlikely that part of the apparent contradictions derives from yet undetected sedimentary condensation of latest Tournaisian and Early Viséan beds near MASSA & VACHARD's (1979) Zone 1 / Zone 2 boundary, such as herein proposed for coeval sections of some Algerian Sahara basins (Fig. 2).

4.2. VISÉAN FAUNAS

Following MASSA & VACHARD's (1979) zonal scheme, the Tournaisian Zone 1 is succeeded by an interzone ("*Zone intermédiaire 2*") within the lower M'rar Formation, grossly equivalent to Palynozone XIII *sensu* MASSA et *al.* (1980), whose age cannot be determined on a faunal basis. It was assigned by MASSA & VACHARD (1979, p. 9, Fig. 3) to the whole V1a - V3a interval based only on the assumption of continuous sedimentation from latest Tournaisian into the early Late Viséan.

In the middle to upper M'rar Formation, the next biostratigraphic unit "*Zone 3 à Beyrichoceras hodderense et Fluctuaria undata*" (providing faunal calibration for Palynozone XIV) was proposed on the basis of scattered occurrences of ammonoids and brachiopods assigned to the eponymous species. The former are from the Illizi and Mourzouk Basins, as well as the Tin Hieddan section at the Algerian/Libyan border, whereas the latter are from sections in the Hammadah Basin and at Serdelès (western margin of the Mourzouk Basin) (MASSA & VACHARD, 1979, p. 9; COQUEL & MASSA, 1993, p. 149). The ranges of those two species are not known to overlap in western Europe: *Bollandoceras hodderense* is restricted to the highest part of the *Bollandites-Bollandoceras* (BB) ammonoid Zone, of Late Holkerian age, whilst *Fluctuaria undata* only occurs in brachiopod assemblages G-H, equivalent to foraminiferal zone Cf6g and ammonoid zones B2a through P1b, of Late Asbian - earliest Brigantian age (RILEY, 1993, Fig. 1, 7). However, many previous Early Carboniferous ammonoid identifications from western Libya and the Algerian Sahara are currently under serious doubt (STREEL & LOBOZIAK, 1994, p. 269; ABDESSELAM-ROUIGHI & COQUEL, 1997, p. 49) and strongly need updated taxonomic revisions. Indeed, age implications from ammonoid lists such as that of COQUEL & MASSA (1993, p. 149) from Illizi Basin are contradictory at face value, as far as western European conspecific ranges are concerned. At least in Britain, *Dzhaprakoceras subglobosum* is from the Tournaisian/Viséan boundary interval, whereas *Bollandoceras hodderense* and *Beyrichoceras obtusum* are respectively Late Holkerian and Late Asbian in age (RILEY, 1990, p. 154; RILEY, 1991, p. 137, 138; RILEY, 1993, Fig. 1, 7).

The highest Viséan biostratigraphic unit, "*Zone 4 à Goniatites striatus et Collenia*", is very poorly characterized in western Libya because the most relevant faunal controls are in the Illizi Basin. According to the single microfaunal account of that biozone in Libya, based on conodonts (WEYANT & MASSA, 1985, Fig. 8), the *Collenia* unit has yielded a low-diversity assemblage with *Ligonodina* sp., *Ozarkodina* spp. and *Rachistognathus* aff. *muricatus*. The latter is rather a Serpukhovian or younger species in Euramerica and the Algerian Béchar Basin (WEYANT, 1985, Tab. 5; SWEET, 1988, Chart 6). In respect of the shelly fauna (MASSA & VACHARD, 1979, p. 10), "*Neospirifer*" *fascicostatus* and *Saharopteria* are known from Asbian equivalents in Algerian Saharan basins (Ahnet, Timimoun), but can also persist upwards into younger strata. In the Illizi Basin, for instance, "*N.*" *fascicostatus* is reported from the Assékaïfaf Ledge within the mid Assékaïfaf Formation, associated with Serpukhovian ammonoids (LEGRAND-BLAIN, 1985b, p. 329).

There seems to be no indisputable faunal evidence for the strict synchronism of the *Collenia* Horizons between the Illizi and Hammadah Basins. In the latter, the *Collenia* unit (of alleged latest Viséan age, equivalent to the upper V3c lithological interval) corresponds to the basal section of Palynozone XV *sensu* MASSA *et al.* (1980), whose main part extends into the Serpukhovian (E1-H) Assedjefar Formation, *i.e.*, "*Zone 5 à Calcifolium punctatum et Cravenoceras*" of MASSA & VACHARD (1979, p. 10-13). In the central Illizi Basin, namely in well Ih1, the lowest *Collenia* Horizon, which corresponds to the basal Palynozone V *sensu* ATTAR *et al.* (1980), is locally 71 metres below an ammonoid occurrence attributed to the species *Goniatites striatus* (now under the genus *Paraglyphioceras*), according to COQUEL & MASSA (1993, p. 149).

In well BN1 of Illizi Basin, furthermore, only the upper *Collenia* Horizon is within Palynozone V, immediately below the Assékaïfaf Limestone Band at the Viséan-Serpukhovian transition (ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 4). The lower *Collenia* Horizon is placed by those authors in the underlying Palynozone IV, which is only distinguished from unit V by lacking *Lycospora* spp.

Thus, in case the latter is accurately identified, the oldest *Collenia* beds cannot be younger than the Asbian / Brigantian transition (RILEY, 1993, Fig. 2; VACHARD & BERKHLI, 1992, Fig. 3). MASSA & VACHARD (1979, p. 10) admit that the *Collenia* Horizons from Djado (southernmost extension of the Mourzouk Basin) are younger than those to the north. It is not unlikely that a similar condition could exist across the Tihemboka Arch between the Hammadah and Illizi Basins. On the other hand, as pointed out by N. RILEY (writ. comm., 1998), "there are a number of striatoid goniataceans which if carelessly identified may be confused with *P. striatus*. These forms, which have striatoid ornament, range from B2b to P2 in Britain. Elsewhere (*e.g.* North Africa, China, USSR and USA), the stratigraphic range of forms that could be confused with *P. striatus* is even broader (B2a-E1)". This case exemplifies the current need for taxonomic revision of many faunal identifications in the older literature concerning the Lower Carboniferous of North Africa.

5. — CORRELATION BETWEEN PALYNOZONAL SCHEMES OF NORTHERN BRAZIL AND NORTH AFRICA

The correlation of latest Devonian to early Late Carboniferous miospore biozones from northern Brazil and North Africa (Grand Erg Occidental, Illizi and Hammadah Basins), as currently envisaged by us, is schematically shown in Figure 3. Zonal correlations are discussed below, mainly with reference to the regional schemes erected in North Africa by LANZONI & MAGLOIRE (1969), ATTAR *et al.* (1980) and MASSA *et al.* (1980), and the Brazilian biozonation updated by MELO *et al.* (1999).

As most palynomorph identifications by LANZONI & MAGLOIRE (1969) are given in open nomenclature, tentative taxonomic reinterpretation of specimens illustrated in their plates provides the only means of correlating Algerian Sahara successions with other zonal schemes from North Africa and Brazil.

5.1. LATEST DEVONIAN PALYNOZONES

There is practically no major controversy involving the correlation of end-Devonian palynozones of northern Brazil (VIII, and locally upper VII) with their North African counterparts, *i.e.*, L7 through L10 Subzones in the Algerian Sahara, Biozones II in the Illizi Basin and XI in the Hammadah Basin. All these units contain *Retispora lepidophyta* and several of its usual latest Famennian associates. However, concerning some of these latter, apparent discrepancies have been detected in regional palynomorph ranges or successions of palynomorph F.A.D.'s, which demand further clarification.

Judging from miospore data presented by LANZONI & MAGLOIRE (1969, Tab. I) for the Algerian Sahara, a *R. lepidophyta - I. explanatus* (LE) - *R. lepidophyta - V. nitidus* (LN) zonal range seems warranted for at least Subzones L9 and L10, if one envisages their *Knoxisporites* sp. n° 3286 (*id.*, Pl. V, fig. 3, 4) and *?Hymenozonotriletes* sp. n° 2918 (*id.*, Pl. V, fig. 11, 12) as actual representatives of *Knoxisporites literatus* and *Indotriradites explanatus*, respectively. On the other hand, the oldest Subzone L7 already contains *Cordylosporites marciae* and possible *Tumulispora rarituberculata* [respectively *Reticulatisporites* sp. n° 3207 and *Knoxisporites* sp. n° 2895 (*id.*, Tab. I, Pl. VI, fig. 7, 8 and Pl. VII, fig. 2, 3)]. In the Amazon Basin, these two species are considered to first occur in sections assigned to the LN Zone. In the same basin the F.A.D. of the acritarch *Umbellasphaeridium saharicum*, within Late Famennian age (Fa2c in Belgium) strata, precedes that of *Retispora lepidophyta*. By contrast, Algerian Saharan occurrences of *U. saharicum* are first recorded [as *Acritarche à "entonnoirs"* n° 441-33 by LANZONI & MAGLOIRE (1969, Tab. I, Pl. VIII, fig. 17, 18)] only at the base of Subzone L8. Therefore, in view of the apparently random pattern displayed by distinctive palynomorph F.A.D.'s in LANZONI & MAGLOIRE's (1969, Tab. I) range chart, it is not unlikely that Subzones L7 and L8 also correlate with the younger part of the LE - LN zonal interval, much as palynozones VII (upper part) and VIII of northern Brazil.

The poor characterization of Palynozone II given by ATTAR *et al.* (1980) in the Illizi Basin is insufficient to permit any reasonable correlation. However, this can be attempted with the limited miospore data provided by COQUEL & LATRÈCHE (1989) and ABDESSELAM-ROUIGHI & COQUEL (1997). The former divided biozone II into three sub-units (IIa to IIc from base to top) based on quantitative data and respectively named the *Spelaeotriletes granulatus*, *Retispora lepidophyta* and Acritarch "abundance" zones. Unfortunately, stratigraphic ranges are omitted for most of the miospore species listed by COQUEL & LATRÈCHE (1989, p. 53, 54).

According to the miospore range chart for well ALS2 and data compiled from other boreholes in the Illizi Basin (COQUEL & LATRÈCHE, 1989, Tab. 3-5, Pl. 1, 2), *Indotriradites explanatus* first appears only within sub-unit IIb, as possibly also *Tumulispora rarituberculata* (= "*Lophozonotriletes rarituberculatus*") in at least well FRG1. The F.A.D. of *Verrucosisporites nitidus* is also recorded in the highest part of Palynozone II (ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 3). This suggests that sub-units IIb and IIc could correspond to part or all of the LE - LN zonal interval, whereas sub-unit IIa may correlate with the oldest "Strunian" *R. lepidophyta - K. literatus* (LL) Interval Zone of western Europe (so far unrecorded in Brazil). On the other hand, in cored sections from wells ALS2 and GTD1, the earliest specimens of *Cordylosporites marciae* (= *Dictyotriletes fimbriatus sensu* COQUEL & LATRÈCHE, 1989 and ABDESSELAM-ROUIGHI & COQUEL, 1997) are recorded along with *Leiotriletes struniensis*, *Cyrtospora cristifera*, *Rugospora radiata* and *Grandispora cornuta* within Palynozone I. This seems to be the regional equivalent of the *D. versabiliis - G. cornuta* (VCo) Oppel Zone, of Late Famennian age (Fa2c to lowermost Fa2d

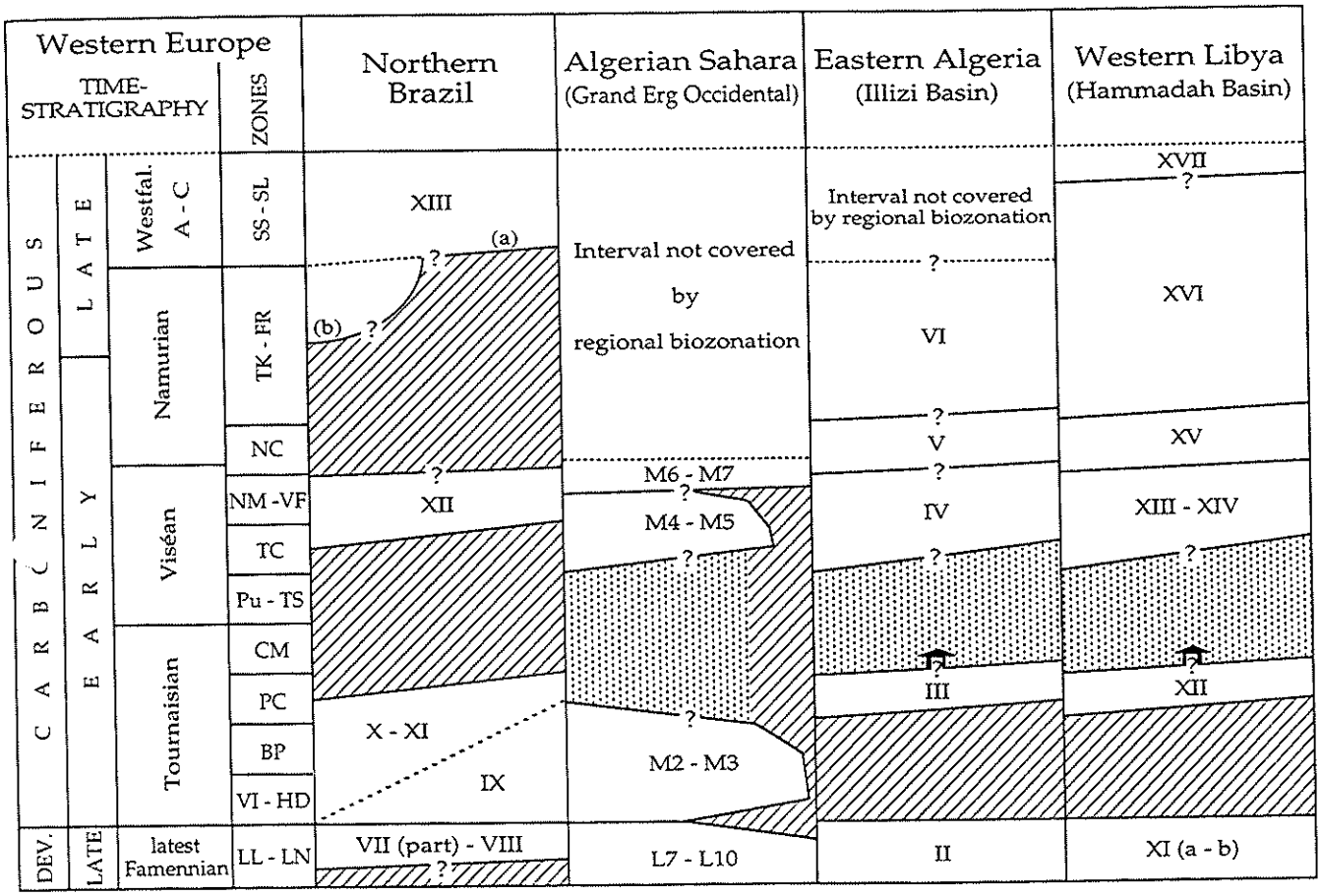

FIGURE 3

Correlation of latest Devonian and Early to early Late Carboniferous palynozones from northern Brazil and selected North African Basins (based on miospore and faunal datings discussed in text), with reference to western European miospore zones and chronostratigraphic units. Intervals in hatched pattern are interpreted as erosional or nondepositional gaps, and vertical dashed lines represent intervals with possible sedimentary condensation.

Corrélations des palynozones du Dévonien le plus récent et du Carbonifère ancien à début du récent du nord du Brésil et des bassins sélectionnés d'Afrique du Nord (basées sur les datations de miospores et de faunes discutées dans le texte), avec référence aux zones de miospores et aux 's chronostratigraphiques d'Europe occidentale. Les intervalles en hachurés obliques sont interprétés comme errodés ou non déposés, tandis que les pointillés verticaux représentent des intervalles avec une possible condensation sédimentaire.

Bibliographic sources

Miospore biochronostratigraphy for western Europe after NEVES *et al.* (1972), CLAYTON *et al.* (1977, 1978) and HIGGS *et al.* (1988a-b). Regional palynozones for northern Brazil (biostratigraphic intervals VII to XIII) modified from DAEMON & CONTREIRAS (1971), DAEMON (1974, 1976) and ANDRADE & DAEMON (1974). As concerns interval XIII, (b) and (a) point out to possible diachronism of its base, as noticed between the Solimões Basin (b) and the Amazon/Parnaíba Basins (a), respectively (after MELO *et al.*, 1999). Grand Erg Occidental units (Subzones L7 to L10 and M2 to M7) modified from LANZONI & MAGLOIRE (1969). Palynozones of Illizi Basin (II to VI) and Hammadah Basin (XIa-b to XVII) modified from ATTAR *et al.* (1980) and MASSA *et al.* (1980), respectively, including also subsequent changes by others (COQUEL *et al.*, 1988; COQUEL & MASSA, 1993; ABDESSELAM-ROUIGHI & COQUEL, 1997).

in Belgium) (LOBOZIAK *et al.*, 1997c). So, Algerian data, including also those from the Grand Erg Occidental (LANZONI & MAGLOIRE, 1969, Tab. I), suggest that the F.A.D. of *C. marciae* may be somewhat older in North Africa than in the Amazon Basin. A possible reason could be that, in at least the Illizi Basin, Late Famennian sedimentation was apparently more continuous than in northern Brazilian basins.

In western Libya (Hammadah Basin), Palynozone XI was designed to equal the regional range of *Retispora lepidophyta* (MASSA & MOREAU-BENOIT, 1976, Fig. 5). It was further characterized by the alleged presence of species like *Knoxisporites hederatus, K. literatus, Verrucosisporites nitidus* and *V. congestus*, whose poor documentation renders their identification, very doubtful to say the least. The unit was divided by MASSA *et al.* (1980) into Subzones XIa and XIb. The former is the acme zone of *Retispora lepidophyta*, and contains such species as *Verrucosisporites gibberosus*, *Tumulispora rarituberculata* and *Cordylosporites marciae* (respectively: *Pustulatisporites gibberosus*, *Lophozonotriletes rarituberculatus* and *Dictyotriletes fimbriatus*, according to those authors' nomenclatural usage).

Subzone XIb comprises the decline of *R. lepidophyta*, and is further characterized, amongst other species, by the first appearance of *Aratrisporites saharaensis* (= *Grandispora balteata sensu* MASSA *et al.*, 1980, Pl. VI, fig. 7).

It is therefore clear that Palynozone XI in Hammadah Basin corresponds to at least a portion of the LE - LN zonal range. On the other hand, due to the absence of detailed miospore control, its base is still too poorly characterized to allow any precise correlation with other zonal schemes. Furthermore, certain range extensions shown in the chart of MASSA *et al.* (1980, Fig. 4) are unacceptable to us. This is the case of *Spelaeotriletes arenaceus*, a distinctively Viséan and younger species, whose alleged presence since the base of Palynozone XI must reflect either taxonomic misidentifications or poor sampling control.

5.2. TOURNAISIAN PALYNOZONES

Imprecisions concerning the age, correlation and faunal controls of Tournaisian and Viséan biozones from North Africa, discussed herein and in previous papers (RAVN *et al.*, 1994; STREEL & LOBOZIAK, 1994; LOBOZIAK *et al.*, 1998), still persist up to the present day. Incongruous miospore ranges and faunal datings, sometimes biased by doubtful lithological correlations, have hampered recent attempts at integrating the different palynozonal schemes now existing for the Lower Carboniferous of that region. Unfortunately, the situation will remain largely unchanged until important stratigraphic and taxonomic revisions are undertaken. However, critical reinterpretations of available data may not only disclose the nature of some pending problems, but also suggest possible ways to solve them.

According to the miospore biozonation of the Grand Erg Occidental (LANZONI & MAGLOIRE, 1969), the Tournaisian in that area is to be restricted to Subzones M2 and M3. The former is characterized by the disappearance, at its base, of diagnostic Devonian species such as *Retispora lepidophyta* and *Vallatisporites hystricosus*, noted as *Hymenozonotriletes lepidophytus* Kedo nº 2939 and *?Vallatisporites* sp. nº 2910, respectively. In addition, Subzone M2 is further characterized by the continued occurrence of latest Devonian holdovers, including *Cordylosporites marciae* and large spiny forms of the *Grandispora uncata/G. senticosa* plexus (= *Reticulatisporites* sp. nº 3207 and "*Spore trilète à grandes épines*" nº 3268), as well as several densospores and murornate/reticulate forms. However, the persistence of *Ancyrospora* spp. and Devonian acritarchs (*id*, Tab. I) is herein interpreted as the result of reworking.

Practically all miospore taxa supposedly first appearing in Subzone M2 are shown to range into the overlying Subzone M3. Of these, apparently only a few are of potential stratigraphic significance for regional correlations, like *Raistrickia strumosa* and possible representatives of *Raistrickia macrura* and *Vallatisporites splendens* (respectively: cf. *Reticulatisporites peltatus* nºs 2932 and 2932B, *Raistrickia* cf. *baculosa* nº 2951 plus *Raistrickia* nº 2928, and *Vallatisporites* cf. *splendens* nº 2930). In Subzone M3, they are joined by miospores assignable to such species as *Neoraistrickia loganii*, *Waltzispora lanzonii*, *Schopfites augustus* and *Densosporites infacetus* (respectively: *Triquitrites* sp. nº 2836, *Waltzispora* sp. nº 2890, *Raistrickia* sp. nº 2928 and *Densosporites* sp. nº 3284). All these taxa are usually found in the IX – XI zonal range [= *V. verrucosus* - *R. incohatus* (VI) - *S. pretiosus* - *R. clavata* (PC)] of northern Brazilian basins (MELO *et al.*, 1999; S. LOBOZIAK, unpubl. data). ATTAR *et al.* (1980, Tab. III, p. 603) refer to the conspicuous absences of *Spelaeotriletes pretiosus* and *Vallatisporites vallatus* in M2-M3 miospore assemblages, in contrast to their occurrence in Tournaisian equivalents of the Illizi and Hammadah Basins. Another missing species is *Aratrisporites saharaensis*, which is first recorded by LANZONI & MAGLOIRE (1969, Tab. I) only in the Viséan section of the Algerian Sahara (under the designation "Spore monolète zonale" nº 2874). In the Illizi and Hammadah Basins, the same species is noted (as *Grandispora balteata*) since the Tournaisian and latest Famennian, respectively (ATTAR *et al.*, 1980, Tab. I; MASSA *et al.*, 1980, Fig. 4). The latter conforms to the F.A.D. of *A. saharaensis* in Brazil.

As already pointed out herein, faunal lists given by LANZONI & MAGLOIRE (1969, p. 449) to justify the Tournaisian age of Subzones M2 and M3 in the Timimoun and Bahmer core-drills (Timimoun and Reggan Basins) are ambiguous. Implied ranges are partly discrepant in terms of currently accepted Early Carboniferous marine megafossil biozonations (BRUNTON, 1984; RAMSBOTTOM & SAUNDERS, 1985; RILEY, 1993), and suggest that a considerable time span is involved. The ammonoid *Gattendorfia*, for instance, is restricted to the homonymous genus-zone in Early Hastarian (Early Tournaisian) strata, whereas the concurrence of *Imitoceras* and *Muensteroceras* is only verified in the succeeding *Pericyclus* genus-zone, of Late Hastarian - Early Ivorian (late Early to early Late Tournaisian) age. The brachiopods *Pugilis vaughani* and *Unispirifer* are widely distributed in the British Courceyan. These faunal elements all correspond to the VI - PC zonal range indicated by the miospores.

On the other hand, brachiopods like *Spirifer konincki*, *Syringothyris cuspidata* and *Stenoschisma isorhyncha* are seemingly restricted to Chadian - Early Arundian (Early Viséan) sections in the British Isles, corresponding to parts of the *Schopfites claviger* - *Auroraspora macra* (CM) and *Lycospora pusilla* (Pu) miospore Zones (RILEY, 1993, Fig. 1, 7). If coeval strata actually occur in the Grand Erg Occidental, then they have no distinct palynological signature. Indeed, miospore assemblages from Subzones M2 and M3 apparently do not support any age assignments younger than Middle or early Late Tournaisian. One possible explanation is that latest Tournaisian - earliest Viséan strata have passed unnoticed (unsampled?) in previous palynological investigations of that area, either in the form of very condensed sections or as erosional remnants of limited extent (Fig. 3).

It is concluded that, in the Grand Erg Occidental, a regional gap or sedimentary condensation occurs on the top of Tournaisian strata, *i.e.*, around the M3/M4 zonal boundary, separating them from late Middle or early Late Viséan strata (LOBOZIAK *et al.*, 1998). This is confirmed by faunal evidence from adjacent basins (*"Dalle des Iridet"* and correlative rock units of the Algerian Sahara), and also by the distinctive palynological break noted at the M3/M4 transition (LANZONI & MAGLOIRE, 1969, Tab. I). The latter is partly due to the regional disappearance of several miospore species. These include *Waltzispora lanzonii* and *Densosporites infacetus* (Tournaisian index species in northern Brazilian basins), *Vallatisporites* cf. *banffensis*, plus forms herein assigned to *Raistrickia strumosa*, *Neoraistrickia loganii*, *Schopfites augustus*, *Knoxisporites literatus* and *Indotriradites explanatus*. Stratigraphic correlations by LANZONI & MAGLOIRE (1969, Fig. 3) across the Grand Erg Occidental indicate that Subzone M4 truncates older units (M3 down to L7), varying in age from Middle or Late Tournaisian

through "Strunian", much in the same way as Palynozone XII in northern Brazilian basins (LOBOZIAK *et al.*, 1998). On the other hand, no major gap can be inferred from Algerian Sahara miospore successions at the Devonian/Carboniferous (L10/M2) boundary, at least in sections where the palynozonal sequence is fully preserved, such as in the Bahmer and Timimoun coredrills.

Tournaisian strata in the Illizi and Hammadah Basins contain essentially analogous microfloras, and are seemingly restricted to Palynozones III and XII, respectively (ATTAR *et al.*, 1980; MASSA *et al.*, 1980; ABDESSELAM-ROUIGHI & COQUEL, 1997). The faunal calibration on which both palynozonations rely (MASSA & VACHARD, 1979) places the Tournaisian interval of those basins within Zone 1, named the *Fusella - Muensteroceras* Zone (ATTAR *et al.*, 1980, Fig. 3; MASSA *et al.*, 1980, Fig. 3, 4). Due to the scarcity or poor characterization of its diagnostic elements, this faunizone is too poorly defined to allow any precise dating. As currently understood, Zone 1 is only consistent with a comprehensive Middle-Late Tournaisian age.

cording to our current interpretations (Fig. 3), miospore assemblages of Palynozones III and XII lie most probably within the late Middle to early Late Tournaisian age and hence, can be correlated with the PC Zone of western Europe. In the Illizi Basin, this is confirmed by the appearance of the two eponymous species, *Spelaeotriletes pretiosus* and *Raistrickia clavata*, in cores recovered from the base of the Issendjel Formation (= lowest Palynozone III), only a few meters above the top of the Famennian Illerène Formation (Attar et al., 1980, Tab. I; ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 3, 4). In addition, *Umbonatisporites baculatus in* ABDESSELAM-ROUIGHI & COQUEL (1997, Fig. 4, Pl. 2, fig. 9) probably corresponds to *Neoraistrickia loganii*, another species common in *S. balteatus - R. polyptycha* (BP) - PC age strata of the Amazon Basin (MELO *et al.*, 1999). In the Hammadah Basin, the PC Zone is indicated by the presence of *S. pretiosus* and *Colatisporites decorus - C. denticulatus* in the basal M'rar Formation, *i.e.*, at the base of Palynozone XII (MASSA *et al.*, 1980, Fig. 4, 5). Amongst the other constituents of the Tournaisian microflora in those basins, there is also *Vallatisporites vallatus, Aratrisporites saharaensis, Cordylosporites marciae* (= *Dictyotriletes fimbriatus* in the usage of those authors), *Radiizonates genuinus, Ve cosisporites nitidus*, etc. In the absence of any younger zo... species, these miospores are all in permissive agreement with a PC Zone assignment. Most of them also occur in PC equivalents of northern Brazilian basins

Miospore data implies that a considerable gap intervenes between latest Devonian and late Middle to Late Tournaisian strata in parts or all of the Illizi and Hammadah Basins. Therefore, their poor correlation with Subzones M2 and M3 of the Grand Erg Occidental (ATTAR *et al.*, 1980, p. 603) highlights the fact that the Tournaisian is partly older in the latter area (Fig. 3). The Devonian acritarchs recorded in Palynozone III (ATTAR *et al.*, 1980, Tab. I) probably derive from reworking of Famennian strata. Reworked Middle to Late Devonian miospores and chitinozoans are also detected in this biozone (ABDESSELAM-ROUIGHI & COQUEL, 1997, p. 52). On the other hand, alleged occurrences of well-known Viséan miospores within Tournaisian biozones (*e.g.*, *Diatomozonotriletes fragilis, Spelaeotriletes arenaceus, Vallatisporites agadesi, V. ciliaris*) are now unacceptable to us, and must reflect defficient sampling controls. In the Illizi Basin, most of those can be regarded as caved-in specimens in cuttings (e.g., in well BN1; see ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 4). However, lithological miscorrelations may have been another cause of confusion in the Hammadah Basin, where proposed Early Carboniferous miospore successions do not rely on discrete reference sections. Instead, their documentation is based on a series of composite sections, involving parts from different boreholes (MASSA *et al.*, 1980, Fig. 4, 5). Because vertical ranges of miospores and faunal elements have not been demonstrated for separate wells, we suspect that, in cases like this, rock intervals of similar lithology but different ages may have been lumped together into one same biozone.

5.3. VISÉAN PALYNOZONES

Most problems and controversies involving the age and correlation of the Viséan strata in North Africa have been discussed in sufficient detail elsewhere (STREEL & LOBOZIAK, 1994; LOBOZIAK *et al.*, 1998), and so, no unnecessary repetition is given here. In particular, the dispute about the "belated" first appearance of *Lycospora* spp. in regions of the *Aratrisporites saharaensis* Microflora (COQUEL & MASSA, 1993; RAVN *et al.*, 1994) has lost much of its former significance in view of the latest developments. First, our recent palynological results from northern Brazilian basins confirm that *Lycospora* spp. may be too erratic and facies-sensitive to be reliably used in long-distance correlations, and even in tracing synchronous Viséan sections within a same sedimentary basin. Secondly, following the viewpoint adopted in our latest Brazilian reviews (MELO & LOBOZIAK, 1997; LOBOZIAK *et al.*, 1998; MELO *et al.*, 1999), we now suspect that Early Viséan strata may be missing or highly condensed over much of western Gondwana. This is possibly in response to common tectono-eustatic settings.

Reinterpretation of published accounts on Viséan miospore and faunal successions from North Africa (LOBOZIAK *et al.*, 1998, and herein) now suggest that Subzones M4 - M7 in the Algerian Sahara, Palynozones IV and lower V in the Illizi Basin, and Palynozones XIII to lower XV in the Hammadah Basin are mostly of Middle to latest Viséan age (Fig. 3). Altogether, these units seem to correspond to the *P. tessellatus - S. campylopterа* (TC) - lower *Bellispores nitidus - Reticulatisporites carnosus* (NC) miospore zonal range of western Europe, currently dated as Late Holkerian through latest Brigantian.

Integrated foraminiferal/miospore data from the Mdakra Massif in Morocco (LOBOZIAK *et al.*, 1990), as pointed out by LOBOZIAK *et al.* (1998), indicate that the base of TC Zone can be older than usually shown in western European charts. In Morocco, it coincides with the boundary of foraminiferal zones Cf4δ and Cf5, which in Belgium lies near the Molinacian/Livian stage boundary (V2a/V2b transition). In Britain, the same horizon corresponds approximately to the Arundian/Holkerian stage boundary, which is currently placed within the *K. triradiatus - K. stephanephorus* (TS) miospore Zone.

The remainder of Palynozones V and XV are possibly coeval with the upper NC Zone, of earliest Namurian (E1) age, as suggested by faunal data, despite the apparent scarcity of saccate pollen grains, whose earliest known record is in the topmost part of Palynozone XV (COQUEL *et al.*, 1988, p. 7). Except for their youngest and oldest age extensions, which remain unproven in Brazil, those North African units are essentially equivalent to Interval XII of northern Brazilian basins, that contains very similar miospore assemblages.

Judging from available miospore range charts for the Illizi and Hammadah Basins (ATTAR *et al.*, 1980, Tab. I; MASSA *et al.*, 1980, Fig. 3; ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 4), the

IV/V and XIII/XIV/XV zonal boundaries seem rather diffuse. Some of the miospore events used to characterize them may only reflect paleoecological controls, like the disappearance of *Spelaeotriletes pretiosus*, alleged rises and falls in the proportion of *Aratrisporites saharaensis* (a reasonably abundant component of northern Brazilian microfloras from latest Devonian to latest Viséan), and the "belated" entry of *Lycospora* spp. Others may be of biostratigraphic significance, such as the "development" (possibly the actual F.A.D.) of *Spelaeotriletes arenaceus / S. triangulus* within Palynozones IV and XIII, and the entry of *Rotaspora* spp. in the lower part of Palynozone XIV. This is because they represent potential tie-points for identifying the *R. nigra – T. marginatus* (NM) and succeeding miospore zones of western Europe, with Late Asbian and younger ages (CLAYTON *et al.*, 1977, 1978). Faunal datings on which both Illizi and Hammadah zonal schemes rely (*e.g.*, MASSA & VACHARD, 1979) fail to provide any appropriate justification for the "Early Viséan" interval in those basins (STREEL & LOBOZIAK, 1994; LOBOZIAK *et al.*, 1998). In fact Palynones IV (lower part) and XIII are said to correspond to a section "*non caractérisée paléontologiquement*" (ATTAR *et al.*, 1980, Fig. 3; MASSA *et al.*, 1980, Fig. 3, 4).

On their turn, Subzones M4 and M5 from the Grand Erg Occidental (LANZONI & MAGLOIRE, 1969, p. 450) are calibrated, in the Timimoun and Bahmer core-drills, by faunal elements with disparate ranges, some of which contradict the proposed Early Viséan age. Indeed, the bivalve *Posidonia* cf. *becheri* (shared with Subzone M5) points out to a Late Viséan (Late Asbian - Middle Brigantian) age, equivalent to that of the B2 - P1d ammonoid zones (N.J. RILEY, personal communication, June 1997). The shelly fauna listed for the upper part of Subzone M5 is more clearly of Late Viséan age. Ammonoids like *Bollandoceras hodderense*, *Beyrichoceratoides redesdalensis* and *Beyrichoceras obtusum* are consistent with a latest Holkerian - Asbian age span (RILEY, 1993, Fig. 1, 2, 7), which is precisely that of the combined TC - NM miospore zones in Britain.

Based on correlations with adjacent Saharan basins (Fig. 2), we interpret faunal datings for Subzone M4 as corresponding to an indeterminate portion of the Holkerian - Early Asbian range while Subzone M5 is certainly as young as Late Asbian. However, we admit that the basal part of this whole unit may ocally include thin, strongly condensed beds of latest Tournaisian - earliest Viséan age in areas like Colomb-Béchar, Gourara and Touat, where the M3/M4 transition was preserved from younger Viséan erosional events. A similar Holkerian - Asbian age range is also implied for Palynozones XIII-XIV and the bulk of Palynozone IV in the Hammadah and Illizi Basins, if one accepts their correlation with Subzones M4 and M5 of the Grand Erg Occidental, as proposed by ATTAR *et al.* (1980, Tab. III) and COQUEL *et al.* (1988, Tab. 1).

From the palynological viewpoint, and in the light of new miospore data obtained from northern Brazilian basins, the following two arguments are also in favor of a Middle to Late Viséan age for biozones M4/M5, IV and XIII-XIV in North Africa:

— sections from forementioned palynozones (and also from biostratigraphic interval XII in Brazil) yield the distinctive miospore *Diatomozonotriletes fragilis* (ATTAR *et al.*, 1980, Pl. 3 Fig. 7; MASSA *et al.*, 1980, Fig. 4, Pl. V, fig 22; ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 4, Pl. II, fig. 4; *Diatomozonotriletes* sp. n° 2997 in LANZONI & MAGLOIRE, 1969, Tab. I, Pl. III, fig. 20, Pl. IV, fig. 1). The earliest occurrence of prominently saetose-coronate miospores (*i.e.*, the true *Diatomozonotriletes* spp.) is a widely recognized biostratigraphic event in the Lower Carboniferous of Euramerica, which is first recorded only from lower Asbian (upper TC Zone) regional equivalents (CLAYTON, 1996, p. 592). Assuming that this bio-event also affected western Gondwana at about the same time as Euramerica, then North African and Brazilian sections containing similar miospore groups are possibly not older than Late Holkerian or Asbian. In Algeria, *Diatomozonotriletes* spp. proliferate in intervals as low as Subzone M4 in the Grand Erg Occidental, and also occur since the basal part of Palynozone IV in the Illizi Basin (LANZONI & MAGLOIRE, 1969, Tab. I, p. 449; ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 4).

— North African and northern Brazilian basins share some characteristic Gondwanan (*Aratrisporites saharaensis* Microflora) miospore species, including *Radiizonates* sp. cf. *Hymenozonotriletes dolianitii*, *Dictyotriletes* sp. cf. *Reticulatisporites magnidictyus*, *Spelaeotriletes benghaziensis*, *S. owensii* and *Vallatisporites agadesi*. At least in Brazil, they often occur associated with usual TC-VF elements of western Europe, such as *Lycospora* spp., *Granulatisporites* spp., *Perotrilites tessellatus*, *Waltzispora polita* , *W. planiangulata*, *Cirratriradites rarus*, *Rotaspora ergonulii*, etc. This confirms the Holkerian - Asbian age assigned to those Gondwanan taxa in North Africa, based on independent palynological and faunal datings.

5.4. LATEST VISÉAN - EARLY SERPUKHOVIAN PALYNOZONES

The latest Viséan age of M6/M7, lower V and lower XV miospore zones of Algeria and western Libya is indisputable. As indicated by previous discussions, this seems to be in good agreement with available faunal data from those regions and surrounding North African basins. On the other hand, as already pointed out herein, the palynological criteria used to separate them from underlying biozones seem unconvincing and not age-diagnostic.

Subzones M6 and M7 in the Grand Erg Occidental contain numerous densospores and verrucose forms, but are best characterized by the proliferation of Gondwanan species which continue from older biozones. The regional disappearances of *Aratrisporites saharaensis* and *Diatomozonotriletes* spp. (LANZONI & MAGLOIRE, 1969, Tab. I) can be best referred to paleoecological constraints, because these elements persist (even though in decreased numbers) within contemporary units of the Illizi and Hammadah Basins, respectively Palynozones V and XV (MASSA *et al.*, 1980, Fig. 4, 5; ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 4). The lack of reported *Lycospora* spp. from Subzones M6 and M7, discussed by COQUEL *et al.* (1988, p. 12, 14), can be ascribed to similar facies controls, or still, to the fact that patchy occurrences of those tiny miospores may simply have been overlooked by LANZONI & MAGLOIRE (1969). There is currently no palynological or faunal evidence of Serpukhovian age for even the youngest unit (Subzone M7), whose main part is seemingly assignable to the upper V3c based on faunal correlations (Fig. 3).

In the Illizi and Hammadah Basins, the Viséan part of Palynozones V and XV is also poorly differentiated from underlying units. The most remarkable palynological feature is the early appearance, higher up within those units, of insufficient representatives of the praecolpate genus *Schopfipollenites* (COQUEL *et al.*, 1988, Fig. 2; ABDESSELAM-ROUIGHI & COQUEL, 1997, Fig. 4), much in the same way as in biostratigraphic interval XII of the Amazon Basin (LOBOZIAK *et al.*, 1998). Particularly

in Palynozone XV, the entry or proliferation of certain miospores with clear Late Viséan affinity allow improved correlations with coeval miospore successions of western Europe and northern Brazil, including *Granulatisporites* spp., *Waltzispora* spp., *Tricidarisporites* spp., *Foveosporites appositus*, etc. (MASSA *et al.*, 1980, Fig. 4). On the other hand, entries of *Schulzospora campyloptera* reported from near the Viséan/Serpukhovian boundary within Palynozones V and XV are less age-significant. Elsewhere, the earliest *Schulzospora* spp. are reported from the Middle to Late Viséan TC Zone (CLAYTON *et al.*, 1977), as demonstrated in the Moroccan Variscides by LOBOZIAK *et al.* (1990). Most of the other miospore species present in those two biozones (including many Gondwanan taxa shared with northern Brazilian basins) persist upwards into younger sections. For this reason, the Viséan/Serpukhovian boundary does not have any distinct palynological signature in the Illizi Basin, and even in the Hammadah Basin, where the earliest *Florinites* spp. (near the top of Palynozone XV) are found only some tens of meters above the entry of Serpukhovian marine faunas (COQUEL *et al.*, 1988, p. 7). Likewise in northern Brazilian basins, the ...an-Serpukhovian transition (if present at all) cannot be distinguished on the basis of palynological evidence.

6. — CONCLUSIONS

This study confirms the unity of the *Aratrisporites saharaensis* Microflora, which allows long-range correlations of Early Carboniferous miospore assemblages from northern Brazil and Saharan Platform basins. It also suggests that latest Tournaisian and Early Viséan microfloras remain largely unproven in those areas. This may be partly due to erosional truncations, and partly ascribed to sedimentary condensation. The latter possibility (often, but not necessarily, associated with black shales or thin, pelagic phosphate-carbonate beds) has been seldom considered in previous stratigraphic studies of Gondwanan regions. This is possibly because it can be readily detected only on sound paleontological grounds. Condensation events partly coeval with those proposed herein f... Saharan basins have been identified in the Lower Carboniferous of western Europe, so suggesting that they may have shared common tectono-eustatic causes. They are exemplified by the Rußschiefer Formation of Thuringia, Germany, where only *ca.* 20 m of black shales contain the basal lower *crenulata* through *anchoralis-latus* conodont zonal succession of early Middle to latest Tournaisian age (KULLMANN *et al.*, 1991, p. 128). The Erdbach Limestone in Germany also includes nonsequences and highly condensed sequences within the range of the FA and BB ammonoid zones (RILEY, 1991, p. 137), which in Britain comprises nearly the entire Chadian - Holkerian succession of Early and Middle Viséan age (Fig. 2).

COQUEL & MASSA (1993, p. 150) state that only marine faunas - in particular goniatites, conodonts and foraminifera - can provide the "*Vérité Stratigraphique Essentielle*" for accurately dating and correlating the Carboniferous palynozones of the Saharan Platform. However, the present paper demonstrates that several unsolved contradictions still persist in the biostratigraphy of North African Carboniferous faunas. These, as currently documented, suggest disparate ages for a same interval, even when one single fossil group (*e.g.*, ammonoids) is considered. Moreover, different reinterpretations of published faunal data from Saharan basins are possible, some of which seem to confirm our independent miospore datings based on the western European palynozonation.

The problem of disparate faunal - miospore ranges in the North African Carboniferous literature, as compared to standard zonal schemes of Euramerican regions, is rather complex and may have multiple causes. At least five can be suggested: (a) some critical taxa of the North African faunas and microfloras may have been misidentified in the literature; (b) their local ranges are still poorly controlled and dated or (c) they actually differ to some extent from those in Euramerica, possibly in response to ecological or paleogeographic factors; (d) critical horizons yielding some key fossil groups (*e.g.*, ammonoids, conodonts) may have not been considered for others (*e.g.*, miospores) due to unsuitable lithology, coarse or selective sampling, and other biases; and finally, (e) some proposed biozones or rock units may enclose gaps, condensed sections, or miscorrelated intervals with discrepant ages. Obviously, none of these hypotheses can be favored *a priori*, until detailed taxonomic and stratigraphic revisions are carried out in Carboniferous basins of North Africa.

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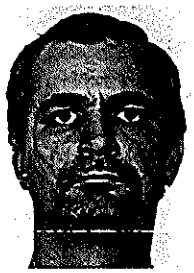
Stanislas LOBOZIAK, Doctor of Science at the University of Lille, is a researcher at the French National Centre of Scientific Research. His work deals mainly with the palynology of Paleozoic dispersed miospores and its applications, especially in the field of biostratigraphy. He has contributed to the development of reference scales for the Devonian and Carboniferous of Western Europe and to their implementation in comparative studies, particularly with Central Europe, North Africa, Western Asia and North and South America. He is a consultant palynologist to Elf E.P. and Petrobras, and has participated for a few years, in an updating of the chronobiostratigraphy of the Devonian and Lower Carboniferous of North Brazil Paleozoic basins.

Stanislas LOBOZIAK, Docteur ès Sciences de l'Université de Lille, est chercheur au C.N.R.S. Ses travaux concernent surtout la palynologie des miospores dispersées du Paléozoïque supérieur et ses applications, dans le domaine de la biostratigraphique plus particulièrement. Il a contribué à l'élaboration d'échelles de référence pour le Dévonien et le Carbonifère d'Europe Occidentale et à leur mise en application dans des études de comparaison, notamment avec l'Europe centrale, l'Afrique du Nord, l'Asie occidentale et l'Amérique du Nord et du Sud. Il est consultant auprès de Elf E.P. et de Pétrobras, et participe, depuis quelques années, à une actualisation de la chronobiostratigraphie du Dévonien et du Carbonifère inférieur des bassins paléozoïques du nord du Brésil.



José Henrique G. MELO holds a B.Sc. in geology from the Rio de Janeiro Federal University (1978), and an M.Sc. from the same university (1985). Since 1984 he has worked at Petrobras Research Centre (CENPES) as a stratigrapher, paleontologist and palynologist. His main research interests are in Silurian-Devonian palynology, stratigraphy and paleogeography of Brazilian Paleozoic basins. Jointly with Dr. Stanislas LOBOZIAK, he is currently leading a research project at CENPES. This involves a re-evaluation and an update of the Devonian-Mississippian miospore biostratigraphy in the Amazon and Solimões basins of northern Brazil.

José Henrique G. MELO a reçu son diplôme de géologie (1978) et sa Maîtrise es-sciences (1985) à l'Université de Rio de Janeiro. Depuis 1984 il est stratigraphe, paléontologue et palynologiste au Centre de Recherches Petrobras (CENPES). Ses thèmes de recherches concernent principalement la palynologie, la stratigraphie et la paléogéographie du Silurien-Dévonien des bassins paléozoïques du Brésil. Actuellement à la tête d'un projet de recherches du CENPES, il travaille avec le Dr. Stanislas LOBOZIAK à la révision de la palynostratigraphie du Dévonien-Mississipien des bassins d'Amazonie et de Solimões au nord du Brésil.

Maurice STREEL graduated (1957) as a Botanist from Liège University, Belgium. His Ph.D (1961) was a contribution to the phytogeography of Central African Savannahs. Later he joined the Department of Palaeontology in the same University and tought Palaeobotany and Stratigraphy to students of Botany, Geology and Applied Geology. His main research interest was in the miospore stratigraphy of the Devonian of the Ardenne-Rhine regions. He retired from the University in 1995 but still works in Palynology particulary on the Quaternary and the quantitative approach of Late Devonian assemblages in relation to sedimentology and climatology.

Maurice STREEL a reçu son diplôme de botaniste en 1957 à l'Université de Liège, Belgique. Son Doctorat (1961) concernait la phytogéographie des savannes d'Afrique Centrale. Ultérieurement il a rejoint le Département de Paléontologie de la même Université et a enseigné la paléobotanique, la palynologie et la stratigraphie aux étudiants en botanique, géologie et géologie appliquée. Ses principales recherches concernent la stratigraphie par miospores du Dévonien des régions ardenno-rhénanes. Il a pris sa retraite en 1995, mais continue à s'intéresser à la palynologie, en particulier dans les domaines du Quaternaire et de l'approche quantitative des associations de miospores en relation avec la sédimentologie et la climatologie.

ANNEX

Species listed

a) Miospores

Aratrisporites saharaensis LOBOZIAK, CLAYTON & OWENS, 1986
Cirratriradites elegans (WALTZ) POTONIÉ & KREMP, 1956
Cirratriradites rarus (IBRAHIM) SCHOPF, WILSON & BENTALL, 1944
Colatisporites decorus (BHARADWAJ & VENKATACHALA) WILLIAMS *in* NEVES *et al.*, 1973
Colatisporites denticulatus NEVILLE *in* NEVES *et al.*, 1973
Cordylosporites marciae PLAYFORD & SATTERTHWAIT, 1985
Cordylosporites spathulatus (WINSLOW) PLAYFORD & SATTERTHWAIT, 1985
Cyrtospora cristifera (LUBER) VAN DER ZWAN, 1979
Densosporites claytonii RAVN, MCPHILEMY, RUTHERFORD, TALLI & BAHRA, 1994
Densosporites infacetus DAEMON, 1974
Densosporites pseudoannulatus BUTTERWORTH & WILLIAMS, 1958
Densosporites variomarginatus PLAYFORD, 1978
'atomozonotriletes fragilis CLAYTON *in* NEVES *et al.*, 1973
Dictyotriletes fimbriatus (WINSLOW) KAISER, 1970
Foveosporites appositus PLAYFORD, 1971
Grandispora cornuta HIGGS, 1975
Grandispora facilis (KEDO) AVKHIMOVITCH, 1988
Grandispora senticosa (ISCHENKO) BYVSHEVA, 1985
Grandispora uncata (HACQUEBARD) PLAYFORD, 1971
Hymenozonotriletes dolianitii DAEMON, 1974
Indotriradites explanatus (LUBER) PLAYFORD, 1991
Indotriradites mitratus (HIGGS) HIGGS, 1996
Knoxisporites hederatus (ISHCHENKO) PLAYFORD, 1963
Knoxisporites literatus (WALTZ) PLAYFORD, 1963
Leiotriletes struniensis MOREAU-BENOIT, 1979
Neoraistrickia loganii (WINSLOW) COLEMAN & CLAYTON, 1988
Perotrilites tessellatus (STAPLIN) NEVILLE *in* NEVES *et al.*, 1973
Radiizonates genuinus (JUSHKO) LOBOZIAK & ALPERN, 1978
Raistrickia clavata HACQUEBARD emend. PLAYFORD, 1964
Raistrickia macrura (LUBER) DOLBY & NEVES, 1970
Raistrickia strumosa PLAYFORD, 1976
Reticulatisporites magnidictyus PLAYFORD & HELBY, 1968
Retispora lepidophyta (KEDO) PLAYFORD, 1976
Rotaspora ergonulii (AGRALI) SULLIVAN & MARSHALL, 1966
Rugospora radiata (JUSHKO) BYVSHEVA, 1985
Schopfites augustus PLAYFORD, 1964
Schulzospora campyloptera (WALTZ) HOFFMEISTER, STAPLIN & MALLOY, 1955
Spelaeotriletes arenaceus NEVES & OWENS, 1966
Spelaeotriletes balteatus (PLAYFORD) HIGGS, 1996
Spelaeotriletes benghaziensis LOBOZIAK & CLAYTON, 1988
Spelaeotriletes granulatus (KEDO) MOREAU-BENOIT, 1980
Spelaeotriletes owensii LOBOZIAK & ALPERN, 1978
Spelaeotriletes pretiosus (PLAYFORD) NEVES & BELT, 1970
Spelaeotriletes triangulus NEVES & OWENS, 1966
Tumulispora malevkensis (KEDO) TURNAU, 1978
Tumulispora rarituberculata (LUBER) PLAYFORD, 1991
Umbonatisporites baculatus Coquel & Moreau-Benoit, 1986
Vallatisporites agadesi LOBOZIAK & ALPERN, 1978
Vallatisporites banffensis STAPLIN & JANSONIUS, 1964
Vallatisporites ciliaris (LUBER) SULLIVAN, 1964
Vallatisporites hystricosus (WINSLOW) BYVSHEVA, 1965
Vallatisporites splendens STAPLIN & JANSONIUS, 1964
Vallatisporites vallatus HACQUEBARD, 1957
Vallatisporites verrucosus HACQUEBARD, 1957
Verrucosisporites congestus PLAYFORD, 1964
Verrucosisporites gibberosus (HACQUEBARD) HIGGS, CLAYTON & KEEGAN, 1988
Verrucosisporites nitidus PLAYFORD, 1964
Waltzispora lanzonii DAEMON, 1974
Waltzispora planiangulata SULLIVAN, 1964
Waltzispora polita (HOFFMEISTER, STAPLIN & MALLOY) SMITH & BUTTERWORTH, 1867

b) Acritarchs

Umbellasphaeridium saharicum JARDINÉ, COMBAZ, MAGLOIRE, PENIGUEL & VACHEY, 1972

c) Foraminifera

Omphalotis omphalota (RAUSER & REITLINGER, 1936)

d) Conodonts

Gnathodus texanus ROUNDY, 1926
Polygnathus inornatus E.R. BRANSON, 1934
Pseudopolygnathus dentilineatus E.R. BRANSON, 1934
Rachistognathus muricatus (DUNN, 1965)

e) Bivalves

Posidonia becheri (BRONN, 1828)

f) Ammonoids

Beyrichoceras obtusum (PHILLIPS, 1836)
Beyrichoceratoides redesdalensis HIND, 1918
Bollandites castletonense (BISAT, 1924)
Bollandoceras hodderense (BISAT ,1924)
Dzhaprakoceras hibernicum (DELÉPINE, 1940)
Dzhaprakoceras subglobosum (LIBROVITCH, 1927)
Eurites corpulentus (CRICK, 1899)
Imitoceras rotatorium (KONINCK, 1844)
Muensteroceras browni (M'COY, 1844)
Muensteroceras crassum FOORD, 1903
Muensteroceras inflatum DELÉPINE, 1940
Muensteroceras occidentale FOORD, 1903
Muensteroceras rotella (KONINCK, 1880)
Paraglyphioceras striatus (J. SOWERBY, 1814)

g) Brachiopods

Atylephorus tornacensis (KONINCK, 1883)
Composita ambigua (SOWERBY, 1823)
Fluctuaria undata (DEFRANCE, 1826)
Latiproductus edelburgensis (PHILLIPS, 1836)
Neospirifer fascicostatus (MENCHIKOFF, 1930)
Pugilis vaughani (MUIR-WOOD, 1928)
Spirifer konincki Douglas, 1909
Stenoschisma isorhyncha (M'Coy, 1844)
Syringothyris ahnetensis LEGRAND-BLAIN, 1974
Syringothyris cuspidata (MARTIN, 1796)

h) Corals

Dibunophyllum bipartitum (M'COY, 1849)
Koninckophyllum interruptum THOMSON & NICHOLSON, 1876
Siphonphyllia benburbensis (LEWIS, 1927)