MIDDLE DEVONIAN TO LOWER CARBONIFEROUS MIOCSPORE STRATIGRAPHY IN THE CENTRAL Parnaiba Basin (BRAZIL)

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(4 figures and 2 plates)

ABSTRACT.- The miospore assemblages of samples from three boreholes drilled by Petrobras in the central part of the Parnaiba Basin are studied. They range in age from Middle Devonian marine beds to Late Devonian and Early Carboniferous, mainly continental beds.

The Devonian/Carboniferous boundary is emphasized and the age of Devonian glacial beds known in this region is discussed.

All data are compared to former local biostratigraphy and referred to the Western European palynostratigraphy.

RESUME.- Les assemblages de miospores provenant d'échantillons de trois sondages forés par Petrobras dans la partie centrale du Bassin du Parnaiba sont étudiés. Il s'agit d'assemblages marins d'âge Dévonien moyen à des sédiments continentaux d'âge Dévonien supérieur et Carbonifère inférieur.

La limite Dévonien/Carbonifère est mise en évidence et l'âge des couches dévonieniennes à caractère glaciaire, connus dans cette région, est discuté.

Toutes les données sont comparées à la biostratigraphie connue antérieurement dans cette région et correspondent à la palynostratigraphie ouest-européenne.

INTRODUCTION

The results presented below derive from a miospore analysis of cores from boreholes 1-TB-1-MA (Testa Branca wildcard), 2-PM-1-MA (Pindare Mirim stratigraphic test) and 1-PA-1-MA (Palestina wildcard) drilled in 1986, 1987 and 1981 respectively by Petrobras in the central part of the Parnaiba Basin, formerly known as Maranhão Basin, in northeastern Brazil (Fig. 1).

They constitute a second contribution to a wider investigation of Devonian and Carboniferous miospore zonation in the Amazonas and Parnaiba Basins proposed by Petrobras. The first one concerned uppermost Devonian and Lower Carboniferous of the Amazonas Basin (LoboziaK, Streel, Caputo and Meio, 1991).

The present contribution aims to identify, in terms of the Western European miospore stratigraphy, a sequence of rocks ranging from middle Devonian to early Carboniferous and belonging to the successive formations Itain, Pimenteira, Cabeças, Longá and Poti. Some of these formations contain strong evidence of deposition under glacial conditions (Caputo, 1985; Caputo & Crowell, 1985) and are therefore in the center of controversies about the existence of a late Devonian glaciation.

Boreholes lithostratigraphy

In the borehole 2-PM-1-MA, productive samples are from 1729.9-1726.8 m (core 48) in the

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Biostratigraphic results

Well 2-PM-1-MA

Marine organic-walled microfossils are abundant in the lower half of this sequence: acritarchs are frequent in cores 49 to 48, less numerous in 47, 44/46 and 42/43 and absent higher; chitinozoans are frequent in core 47. Thus the Itaim and Pimenteira formations have marine character which contrasts with the more continental nature of the next Cabeças to Potí formations in the studied area. In the Pimenteira Fm, amorphous organic matter dominated kerogen is abundant.

Misspores are well preserved, often of yellow colour. They are more abundant and diversified in continental than in marine beds. Fig 2 represents a part of the continental taxa. These are almost all known in Western Europe and allow some accurate correlations with the Ardennes-Rhenish regions for the Devonian (after Stred et al., 1987) and Ireland for the Lower Carboniferous (after Huggins et al., 1988). Some other taxa not listed are nevertheless figured on plates.

In the lowermost core 49, Acanthosporites acanthomamillatus is the most interesting species because its first occurrence corresponds to the base of the AD (A. acanthomamillatus-D. devincicus) Oppel Zone in the Ardennes-Rhenish basins. The absence of the characteristic misspores Hystrosporites reflexus and Geminispora lemura, whose first occurrences mark the middle and upper part of this Oppel Zone AD, suggest that these samples belong to the lower part (Interval Zone Mac) of this Oppel Zone. However, no hystrosporites have been encountered in this borehole, neither in the continental nor in the marine facies, so that we suspect some ecological/sedimentological control of this absence must have operated. Therefore we prefer to name pre-Lem Interval Zone the lower and middle parts of this AD Oppel Zone. This pre-Lem Interval Zone corresponds, in the type Eifel area, to the correlative-based correlative to Lower ensimass Zones, all of Eifelian to lowestmost Givetian age. We have no criteria to distinguish between the almost equivalent valutus-longi and devincicus-naumanni assemblage zones of Richardson & McGregor (1986).

Containing a more diversified microflora, core 47 has also Geminispora lemura but lacks the characteristic species of the higher TA (S. triangulatus-A. ancyrea var. ancyrea) Oppel Zone. Therefore it belongs to upper part of the AD Oppel Zone (= Lem Interval Zone). A recent work in the Eifelian/Givetian transitional layers in the Eifel area (Loboziani, Streel and Weddige, 1981) clearly demonstrates that the first occurrence of G. lemura is within the ensimsens-obligamarginatus correlative section and very close to the first occurrences of Polygnathus ensimass ensimass and P. hemianaxis, which are the first candidate levels of the Eifelian/Givetian boundary proposed by the Subcommission on Devonian Stratigraphy. Therefore core 47 will be probably
within the lower Givetian. It also belongs to the temurata-magnifica Assemblage Zone of Richardson and McGregor (1996).

In the next higher cores (44/46 and 42/43), the joint occurrence of Scoloplosites triangu- latus, verrucosesperites bulliferus and Rugospira bricci, which enter the stratigraphic column in succession in Western Europe, suggests an Upper Devonian miospore assemblage. R. bricci is the youngest of the three species, first occurring at the base of a not yet formally defined zone, called phase IV in the Boulognis area of the Ardennes-Rhenish region. The absence of the Famenian, miospores Diduclites versatilis and Knospisporites dedalus allows to assign cores 44/46 and 42/43 to the phase IV, which corresponds to the condont-based Ancyrognathus triangularis to Palmatepis triangularis zones of late Fassman to earliest Famenian ages.

In cores 38/40, the joint occurrence of Retispora lepidophyta, Hymenozonotrites explana- natus, Tumulispora malvensis, Valtiosperites verrucous, Valtiosperites vallatus, Verrucosisperites nubis and Cyrtospora cristata allows to recognize the upper part of the LN (R. lepidophyta- V. nubis interval Zone, which occurs below but very near the Devonian/Carboniferous boundary. The absence of the Retispora lepidophyta Assemblage Zone defined in Ireland by Van Veen (1981).

The presence of Spaelatozites pretiosus in cores 32/33, and of Raistrickia clavata and Protospirara rugulosa in core 29 allows to place the upper part of the studied stratigraphic section in the PC (S. pretiosus - R. clavata) Zone of middle to late Tournaisian age.

Well 1-TB-1-MA

Only three samples have provided characteristic miospores in addition to many specimens with simple morphology. Some of these miospores are given on Fig. 3.

Cores 15 and 14 contain a comparable assemblage but differ in having Retispora lepidophyta only of the upper (core 15) and Valtiosperites vallatus and Spaelatozites sp. only above (core 14).

Despite the scarcity of the miospore record, we have to conclude to a succession of the two interval Zones LN (R. lepidophyta - V. nubis) and VI (V. verrucosus - R. inconstantus). The limit between these occurrences is known immediately below the Devonian/Carboniferous boundary in the reference sections of Germany (Higgs and Street, 1984).

On core 15 is in the uppermost Devonian and core 14, also from the Longi FM, belongs to the uppermost Devonian or the lowermost Carboniferous.

The absence of Valliosperites nubis and of Valtiosperites verrucous or V. vallatus suggests that this sample belongs to the Interval Zone LE (R. lepidophyta - H. explanatus) known in the uppermost Devonian in Germany below the Interval Zone LN.

The Devonian/Carboniferous transition in the boreholes

The latest Devonian miospore assemblages found in the three boreholes are characterized by the presence of Retispora lepidophyta and for this reason belong to what is usually called 'Strumian', the uppermost part of the Fassmanian in the France Basin.

The degree of abundance of this species and the presence or absence of associated species like Hymenozonotrites explanatus, Verrucosisperisites pipee, V. nubis generally allow more precision. All uppermost Devonian miospore assemblages in the three boreholes have at least one of these associated species and are considered here to correspond to the upper part of the Retispora lepidophyta range which, in Germany, belongs to the condont Lower to Upper Praeasuctata Zone.

In the preceding species Retispora verrucous and of other associated species like Valtiosperites verrucous and Valtiosperites vallatus allow to subdivide this upper part of the Retispora lepidophyta range into two interval zones widely recognized throughout the world and named LE (R. lepidophyta - H. explanatus) and LN (R. lepidophyta - V. nubis). However, cores 38/40 to 34 of 2-PM-1-MA obviously belong to the last interval Zone because all characteristics are present. Hence, the present age of the related samples of boreholes 1-TB-1-MA and 1-PA-1-MA (where miospores are scarce and badly preserved) is less sure because it is based only on the presence (1-TB-1-MA) or absence (1-PA-1-MA) of only some associated miospores.

The succeeding VI (V. verrucous - R. inconstantus) Zone, which in Germany spans the Devonian/Carboniferous boundary, is certainly present in the borehole 1-TC-1-MA, within the Longi Formation.

Comparison with former biostratigraphers in the 2-PM-1-MA borehole

Comparison with Daenon's (1974, fig.2) biostratigraphy gives the following results: the phase IV corresponds to Zone VI and the lowest part of Zone VII (Daenon). Interval Zone LN is included in zones VIII to X + XI (Daenon) and Zone PC 15 + XI (D. F. Daenon).

Zone VII of Daenon (1974, table 1) contains R. lepidophyta but we do not know how the base of this Zone VII is defined. It might be that the first entry of this species occurs somewhere within Zone III rather than exactly at its base. Indeed, only the next Zone VIII has abundant R. lepidophyta. This taxon is used besides to name the Zone VIII. Interval Zone LE found in core 3 of the borehole 1-PA-1-MA should be included in the upper part of Zone VIII (Daenon).

The limit between Late Devonian and Early Carboniferous, traced by Daenon (table 1 and fig 2) near the VI/IX zones boundary, is now higher than the upper part of the Retispora lepidophyta range in the Longi FM or in the lower part of the Poti FM. No limits between the stasian/Fassmanian/Strumian, Tournaisian/Visean have been proposed by Daenon (1974).

Comparison with other stratigraphic schemes in the Parnaiba Basin

Caputo (1986, fig.2) has published a correlation chart between the stages (chronostratigraphy), the biostratigraphic intervals of Andrade and Daenon (1974) and the lithostratigraphic in the Parnaiba Basin.

These relations between the chronostratigraphy and the biostratigraphy have been challenged by Stree (1986, fig.8) on the published evidence both in South America and North Africa. Daenon (1974, fig.4) had indeed compared with some details the North Brazilian and the North African palynofacies. Stree (1986) supposed two stratigraphical gaps within the sequence of the Parnaiba Basin, the first one covering at least most of the Fassmanen, the second one centered in the Tournaisian.

The present work allows some new insights into this problem as we now know, on one hand, the relations between the chronostratigraphic scale of Western Europe and the standard palynostratigraphy of the Parnaiba Basin through the present paper, and on another hand, the relations between such standard palynostratigraphy and the biostratigraphic intervals of Daenon through the common analyses of the borehole 2-PM-1-MA.

These comparisons are made on Fig.4. Here, column 1 is the stratigraphic chart proposed by Caputo (1986). Column 2 is the Parnaiba Basin stratigraphic chart proposed by Stree (1986) after Daenon (1974). Column 3 shows the correlation between Daenon (1974) and this paper, considering boreholes 2-PM-1-MA, 1-TB-1-MA and 1-PA-1-MA. They suggest that the chrono/bio/litho- stratigraphic correlations proposed by Caputo (1986) in the Devonian are largely confirmed. For instance, a latest Fassmanian stage for Zone VI of Daenon is correct. We have no evidence that this
Explanations of plates

All palynological material is housed in the collections of the Laboratory of Palaeobotany and Palaeopalynology, University of Liège. Illustrated specimens magnification x500. The numbers assigned to palynological slides correspond to those of the borehole cores. The spore locations in the slides are based on England Finder graticules.

PLANCHE I

1. - Grandispora douglastic warfare McGregor 1973
   Slide 49(2): M41.
2. - Grandispora mammillata Owens 1971
3. - Acinosporites acanthomammillatus Richardson 1965
   Slide 49(1): Z44.
4. - Craspediopora paranensis Loboziak, Streef and Burjack 1988
   Slide 48(3): U34.
5. - Chelinospora figurata Allen 1965
   Slide 43/43: R21.
6. - Chelinospora tianica (Naumova) Loboziak and Streef 1969
   Slide 47(4): V49.
7. - Rhabdosporites parvulus Richardson 1965
   Slide 42/43(1): E27.
8. - Acinosporites eumammillatus Loboziak, Streef and Burjack 1988
9. - Cymbosporites exulatus Allen 1965
   Slide 42/43(1): P22.
10. - Cymbosporites catillus Allen 1965
    Slide 47(2): H93.
11, 12. - Verrucosporites bulliferus Richardson and McGregor 1986
13. - Geminispora lemurata (Balme) emend. Playford 1983
    Slide 42/43(1): P37.
14, 15. - Geminispora punctata Owens 1971
       15. - Slide 42/43: S38.
16. - Samarispores triangularius Allen 1965
    Slide 44/46: O39.
17. - Verrucosporites scurrus McGregor and Camfield 1982
18. - Chelinospora paravermiculata Loboziak, Streef and Burjack 1988
19. - Rugospora brisi Loboziak and Streef 1989
20. - Archaeozonotrites variabilis (Naumova) Allen 1965
    Slide 42/43(1): T27.
21. - Auroraspora macra Sullivan 1968
22. - Synarispores tripapillatus Richardson and Lister 1969
    Slide 49(2): C94.
PLANCHE II

1. *Radizonates genuinus* (Jussik) Lobozia and Alpern 1975

2. *Aurataspora solisorta* Hoffmeister, Staplin and Malloy 1956
   Slide 38/40(1): G36.

3. *Verrucosporites nitidus* (Naumova) Playford 1964
   Slide 34(1): W42.

4. *Verrucosporites geobettii* Playford 1962

5. *Convolutispora insolosa* Playford 1978
   Slide 38/40(1): H36.

6. *Velamisporites magnus* (Hughes and Playford) Playford 1971

7. *Vallatisporites verrucosus* Hacquebard 1957
   Slide 38/40(1): H36.

8. *Vallatisporites valatus* Hacquebard 1957
   Slide 38/40(1): G27.


11. *Gorgonispora convoluta* (Butterworth and Spinner) Playford 1976

12. *Grandispora spiculifera* Playford 1976
    Slide 38/40(1): Z34.


15. *Acatrissporites saharaensis* Lobozia, Clayton and Owens 1986

16. *Cyopora cristifera* (Luber) Van der Zwann 1979
    Slide 38/40(1): X33.


18. *Cristatisporites sp.*

19. *Hymenoconotriletes explanatus* (Luber) Kedo 1963


zone could also correspond to the «Strunian» as suggested by Streel (1986). However, if R. lepidophyta first occurs near the base of the Zone VII, marking the base of the «Strunian», then a large gap would be confirmed.

The Carboniferous part of the correlations proposed by Caputo (1985) and Streel (1986) is not confirmed because Zone XI, the youngest of Daenon’s zones, has not a Viséan age but a middle to late Tournaisian age. A gap in the early Tournaisian may be present at the base of the Poti Fm in this borehole.

**Age of the glacial evidences**

The uppermost part of the Cabecas Fm and the Poti Fm are considered by Caputo (1985) and Caputo & Crowell (1986) to have been deposited under glacial and periglacial conditions as deduced from the rock texture, striated pebbles, striated pavements, varve-like sediments, exotic blocks and wide distribution of diamictites in three large basins (SãoMães, Amazonas and Parnaiba Basins) in Northern Brazil. Tiliates, first identified by Kegel (1953), occur in the uppermost Cabecas Fm.

The Cabecas Fm and Poti Fm are respectively dated as middle Famennian and Viséan by Caputo & Crowell (1986, fig.5). However, evidence provided in the present work suggests that their ages are latest Famennian and middle-late Tournaisian respectively. There is also still a possibility that most of the Famennian is missing within the upper Pimenteira and lower Cabecas Formations in this area or, at least, strongly condensed and devoid of plant microfossils.

The latest Famennian age of the Cabecas Fm in the central Parnaiba Basin is now controlled by the presence of LE (R. lepidophyta-H. exsulans, well 1-PA-1-MA) and LN (R. lepidophyta-V. nitidus) interval zones, which characterize the Devonian Hangenberg shales sensu lato in Western Germany. These shales are known to correspond to the upper III regression of Johnson et al. (1986) or the event 12 of Sandberg et al. (1986). The LE interval zone may be correlated, for the first time, with a glacial event in South America.

**CONCLUSION**

This study of miolespore of Devonian and Carboniferous Parnaiba Basin allows the following conclusions:

- the Western European miolespore stratigraphy can be applied to the Parnaiba Basin as well as to the Amazonas Basin,
- the Itaim Formation belongs to the Eifelian;
- where fully developed, the Pimenteira Formation ranges in age from the latest Eifelian or earliest Givetian to the latest Frasnian or earliest Famennian at least;
- occurrences of Retispora lepidophyta in samples belonging to the upper part of Zone VII of Daenon (1974) might suggest that a sedimentary gap is present between the Pimenteira and Cabecas Formations in the studied area, corresponding to the lower and middle parts of the Famennian;
- in the studied boreholes, the Cabecas Formations is of late Famennian age, the Longa Formation (LN and VI interval zones) spans the Devonian/Carboniferous boundary (well 1-TB-1-MA), and the Poti Formation ranges into the middle-late Tournaisian. An early Tournaisian gap possibly occurs in the Poti Formation, but is not yet confirmed;
- the glaciogenic sediments of the upper Cabecas Formation in the Parnaiba Basin belong to the late Famennian LE Interval Zone. They correspond to at least a part of a worldwide regression (Hangenberg Event) well-known almost at the top of the Devonian system.

**Species listed**

Aeocospores ecanthomammillatus Richardson 1985
Aratrispores saharahensis Loboziaik, Clayton and Owens 1986
Archaosporites variabilis (Naumova) Allen 1965
Auroraspora macro Sullivan 1968
Auroraspora solisorta Hoffmeister, Steplin and Malloy 1965
Chelinoaspera taimanica (Naumova) Loboziaik and Streel 1989
Colatisporites decorus (Bharadwaj and Venkatachala) Williams in Neves et al. 1973
Craspedispores parasparaisis Loboziaik, Streel and Burjack 1988
Cymbosporites calithus Allen 1965
Cymbosporites cyathus Allen 1965
Cymbosporites magnificus (McGregor) McGregor and Camfield 1982
Cymbosporites crasifera (Luber) Van der Zwan 1979
Densospores variomarginalus Playford 1962
Dulexites variabilis (Kano) Van Veen 1961
Emphasinosporites annulatus McGregor 1961
Geminospores lemurata (Balme) emend. Playford 1983
Geminospores punctata Owens 1971
Grandispores douglasianense McGregor 1973
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EXPLORATION MINERALE PAR GEOCHIMIE DES SOLS DANS LA REGION D'ARTEAGA (MICHOCAN, MEXIQUE)

par

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(10 figures et 3 tableaux)

RESUME.- Un programme d'exploration minérale par géochimie des sols fut réalisé à cabo en México durant un an. Les travaux de campo, réalisés en une région montagnueuse difficile de accès, durèrent six mois. Les travaux de laboratoire (analyse chimiques), les processos de data process (processos de resultats quimicos et de imágenes de satélites) avec I'interpréation géochimie fust effectués, en maior parte, en Bélgica. Les résultats principales sont les suivants:

- La puesta en aplición con éxito del programa d'exploration minéral por el medio de la géochimie de sols, en une région donde la évolution PEDOLÓGIC es poco desarrollada.
- La puesta en evidencia de algunas anomalías poliméticas y de una anomalía estructurada de oro.
- La asociación espacial del oro y del arsénico.
- El discimiento de rocas auríferas.
- La propoção de un modelo metalógénico suicto llegando a un guía de prospección por lo menos local sin ei régional.

Por último, la abundancia relativa de afloramientos en la región de Arteaga permitió de elaborar un plano geológico bastante detallado para conocer las caractérsticas químicas de las seis prolocuciones litológicas principales de esta región.

Los resultados parcielles del programa realizado son bastante esperanzadores para justificar la continuação de los estudos y de los trabajos de exploration minéral en esta región.

ABSTRACT.- A geochemical exploration programme was carried out in Mexico during one complete year. Field studies, executed in a montane area not easily accessible, lasted six months. Laboratory work (chemical analysis), data processing (chemical data processing & satellite image processing) and their geochemical interpretation were mostly realized in Belgium. The main results obtained are following:

- The successful execution of the pedochemical method in a region where soil evolution is not very developed.
- The localization of various polymetallic anomalies and one gold anomaly.
- The discovery of gold-bearing rocks.
- The proposal of a metallogenic model leading to a prospection guide of at least local and perhaps regional scale.

Finally, the relative abundance of outcrops in the Arteaga region allowed to elaborate a geological map with sufficient detail in order to know the chemical characteristics of the six major lithological populations from that area.

The partial results of this exploration programme are encouraging enough to justify the continuation of the work and studies in progress in that region.

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