Age and Correlation of the Barreirinha Formation (Curuá Group, Amazon Basin): New Evidence from the Miospore Biostratigraphy

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ABSTRACT

The recognition of Western European-defined miospore zones in the subsurface of the Amazon Basin allows some new insights into the age of the Barreirinha Shale and the magnitude of the anoxic event recorded in its lower, highly radioactive black shale section. A significant biostratigraphic gap across the Barreirinha/Ererê formational boundary as well as a "miospore-barren interzone" throughout the radioactive shale interval of the Barreirinha Formation have been identified. They correspond respectively to the mid Givetian – earliest Frasnian and latest Frasnian – mid Famennian. The upper, less radioactive part of the Barreirinha Formation consistently displays a late Famennian age. Tentative correlations of the identified discontinuities with events of the standard Devonian sea-level curve are proposed herein.

Key words: Miospores, anoxia, Late Devonian, Amazon Basin, Gondwana.

INTRODUCTION

This contribution summarizes the preliminary results of ongoing studies carried out jointly at the PETROBRAS Research Center (Rio de Janeiro) and the CNRS, URA 1365 (Lille, France). They involve the detailed investigation of the miospore biostratigraphy in cored sections of the Ererê, Barreirinha and Curiri Formations (Middle to Late Devonian) in selected boreholes drilled by PETROBRAS all over the Amazon Basin.

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According to the available literature on the Devonian of this region, the Barreirinha Formation (lower part of the Curuá Group) has been generally assigned an age within the Frasnian – earliest Famennian range (e.g., Lange, 1967; Daemon & Contreiras, 1971; Daemon, 1974, 1976; Caputo, 1984; Quadros, 1985; Grahn, 1992). In terms of the PETROBRAS operational biozonation, the whole unit has been ascribed a single broad palynozone, i.e., the biostratigraphic interval VI of Daemon & Contreiras (1971) and followers. This situation was modified to some extent by Loboziak *et al.* (1993), who first indicated the occurrence of late Famennian strata in the upper part of the formation.

New miospore evidence provided by this study allows some new insights into the age prob-

lem of the Barreirinha Formation and the magnitude of the anoxic event recorded in its basal, highly radioactive black shale section. This was enabled by the continued recognition of Western European-defined miospore zones in the Amazon Basin. Such a procedure, pioneered in the basin by Loboziak *et al.* (1993), permits direct correlation of the local sections with the type marine Devonian of the Ardenne-Rhenish region in Western Europe, where miospore zonal successions are accurately calibrated by means of the standard conodont biozonation (Streel *et al.*, 1987).

THE BARREIRINHA/ERERÊ BOUNDARY

The detailed palynological investigation of cored sections which cut across the Ererê/Barreirinha formational boundary (e.g.: cores 32-35 of well 1-TR-1-AM, cores 16-19 of well 1-AM-1-AM and core 4 of well 1-AM-15-AM) clearly demonstrates that a considerable biostratigraphic gap intervenes between both units. Wherever dated by miospores, the upper Ererê Formation displays an age not younger than early Givetian (Lem Interval Zone within the AD Oppel Zone, equivalent to the *ensensis-obliquimarginatus* conodont Zone[1]). On the other hand, the lowest Barreirinha strata right at the base of the radioactive shale section are no older than later early to late Fresnian (ranging from the BJ Oppel Zone to Palynophase "IV" in the forementioned wells), and therefore equivalent to the *transitans* or *punctata* through *linguiformis* conodont Zones. A highly condensed section seems to occur in the basal Barreirinha Formation, for the first appearance of distinctive late Frasnian (Palynophase "IV") miospore species such as *Rugospora bricei* is detected just a few meters above the top of the Ererê Formation (e.g., 5m in well 1-AM-15-AM, and possibly less than 3m in well 1-TR-1-AM).

[1]According to the currently accepted Devonian standard conodont zonation (Clausen *et al.*, 1993), the former *ensensis-obliquimarginatus* Zone and the overlying *ensensis-bipennatus* Zone now constitute the single *hemiansatus* Zone, whose base defines the lower boundary of the Givetian Stage.

In terms of the Western European Devonian biostratigraphy, the "missing" interval between the Ererê and Barreirinha Formations in the studied boreholes comprises at least two miospore zones (TA and TCo Oppel zones), which correspond to about five or six conodont zones, i.e., *ensensis-bipennatus* (= upper *hemiansatus*) through *falsiovalis* or *transitans* Zones. This discontinuity coincides with a sharp lithological contact, at which bioturbated and/or wavy siltstones and fine-grained sandstones of the upper Ererê Formation are directly overlain by a section almost entirely composed of laminated black shales belonging to the basal Barreirinha Formation. This change is further stressed by a break in the character of palynofacies, whereby land-plant debris such as miospores, cuticle scraps and woody matter (usually very common in the Ererê Formation) are replaced by amorphous organic matter in the lower part of the Barreirinha Formation. Marine microfossils like tasmanaceans, acritarchs and chitinozoans (mostly consistent with a generalized Late Devonian age) also become far more abundant than miospores in the latter unit.

Noteworthily, a very similar situation was also recorded by Rodrigues *et al.* (1995) in a correlative section of the Parnaíba Basin (Pimenteira Formation, core 7 of well 1-IZ-2-MA), in which early to mid Givetian bioturbated siltstones (TA Oppel Zone) are succeeded by laminated black shales of later early Frasnian age (BJ Oppel Zone). In the Amazon Basin, however, TA-age beds have not yet been recorded in the Ererê Formation, so implying that the Givetian/Frasnian gap is apparently wider there than in the Parnaíba Basin.

BIOSTRATIGRAPHIC RELATIONSHIPS OF THE LOWER AND UPPER PARTS OF THE BARREIRINHA FORMATION

Making up most or all of the lower half of the Barreirinha Formation, the radioactive shale section proper (up to 108m thick in well 2-LF-1-AM) is almost invariably barren of miospores and other land-plant debris, except for its basal part, of later early to late Frasnian age. The miospores reappear in moderate numbers only above the top of the ra-

)active interval, where the siltier, upper part of : Barreirinha Formation consistently displays a e (not latest) Famennian age, as seen in wells 2-N-1-AM (core 27), 2-NA-1-PA (cores 27-28), 1-X-1-AM (core 123), 1-TR-1-AM (cores 28-29), UA-1-AM (cores 29-30) and 1-CM-2-PA (cut-ıgs from interval 531-565m). This upper section dated by low-diversity miospore assemblages ontaining *Rugospora radiata* and *Verruciretusis-ora magnifica*, indicative of the VCo Oppel Zone, vhich persists up to the lowest part of the overly-ng Curiri Formation (*Protosalvinia* Zone). Also ıoticed in the upper Barreirinha section is the first occurrence of the acritarch species *Umbellas-phaeridium saharicum*, which characterizes P. OBRAS's biostratigraphic intervals VII and VIII, of Famennian age (Daemon, 1974). However, the VCo Oppel Zone is equivalent to the *trachytera* or *postera* and lower *expansa* conodont Zones, and hence, immediately precedes the first appearance of *Retispora lepidophyta*, a distinctive latest Famennian ("Strunian") miospore species, whose presence defines biostratigraphic intervals VII and VIII in Brazil.

So, in terms of the Western European Devonian biozonation, the interval lacking any biostratigraphic resolution within the lower, radioactive part of the Barreirinha Formation corresponds to at least three miospore zones (Palynophase "V" and the GH to GF Oppel Zones), which encompass four to six conodont zones (*triangularis* through *marginifera* or *postera* Zones), altogether ranging age from early to mid Famennian. Besides, it cannot be ruled out that even a greater part of the uppermost Frasnian (equivalent to the higher parts of Palynophase "IV") is eventually also included within this "miospore-barren interzone". Therefore, the anoxic event recorded by the radioactive shale interval was probably a long-lasting one, intensified over much of the Amazon Basin from latest Frasnian to at least mid or early late Famennian[2].

[2]In the neighboring Solimões Basin (Jandiatuba Sub-basin), the upward extension of a coeval radioactive black shale section into the Famennian was also demonstrated by Hünicken *et al.* (1988) based on conodont evidence.

TENTATIVE RECOGNITION OF MIDDLE TO LATE DEVONIAN EUSTATIC EVENTS

As previously stated, the Western European miospore zones of Middle to Late Devonian age are calibrated in their type areas by the standard conodont biozonation (cf. Streel *et al.*, 1987). Therefore, they allow a tentative correlation of the Devonian eustatic events detected in the Amazon Basin with coeval, conodont-calibrated transgressive-regressive (T-R) cycles shown in the Devonian sea-level curve (Johnson *et al.*, 1985, 1986). Such correlation is here depicted in Fig. 1, which also shows preliminary palynostratigraphic results obtained by the present study for other Devonian formations of the Amazon Basin.

As seen in Fig. 1, the stratigraphic gap between the Ererê and Barreirinha Formations possibly testifies to a non-depositional phase. This can be ascribed partly to the sharp regression within the upper part of T-R cycle If – which elsewhere in the world "was great enough to offlap some cratonic terranes, resulting in subaerial exposure and erosion" (Johnson *et al.*, 1985, p. 578) –, and partly to subsequent condensation zones brought about by the long-sustained transgressions of T-R cycles IIa and IIb (onset of the late Givetian to early Frasnian deepening events).

The early phases of the maximum flood of the Devonian, i.e., T-R cycles IIc and IId, are recorded as condensed sections within the lower part of the Barreirinha Formation, Palynophase "IV" (late Frasnian) being reached only a few meters above the top of the Middle Devonian Ererê Formation. This lowest condensed interval is topped by a distinctive, laterally persistent sandier section of reduced thickness, which occurs within Palynophase "IV" at a position consistently close to the base of the radioactive section throughout much of the Amazon Basin. This deeper-water sandy interval is recognized in well logs by its lower gamma-ray readings. It may eventually correlate with some of the recurrent eustatic fluctuations which characterize T-R cycle IIc. Higher up in the section, a "miospore-barren interzone" of variable thickness, bracketed between Palynophase "IV" and the VCo Oppel Zone, corresponds to the bulk of the radio-

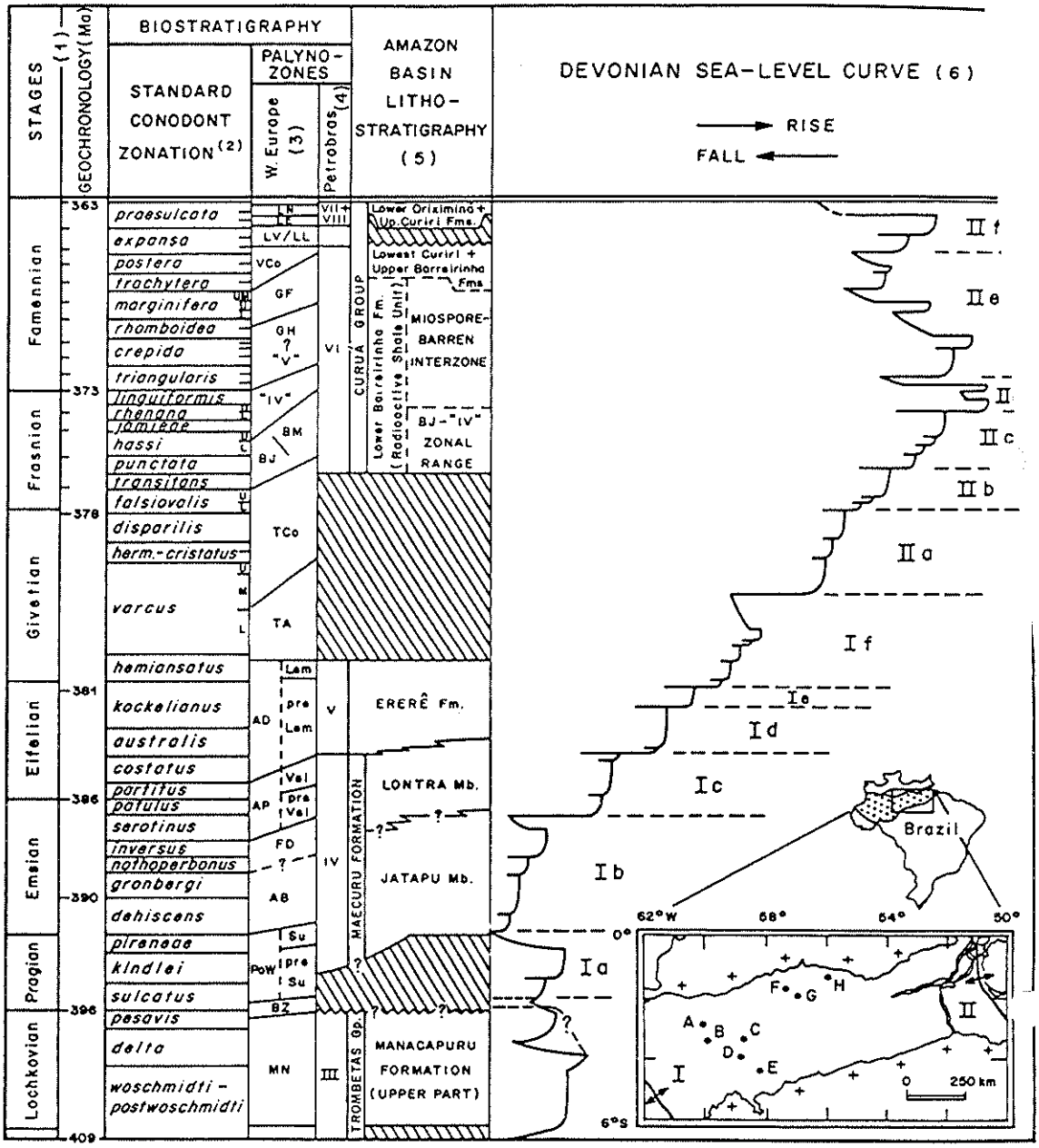

Fig. 1 — Location of Amazon Basin and boreholes mentioned in the text (inset map), and correlation of Devonian bio- and lithostratigraphic units of the Amazon Basin with the qualitative eustatic curve for the Devonian. Imprecise relationships between conodont/miospore zones are depicted as oblique zonal boundaries. Biostratigraphic data for the Early Devonian units are still provisional. Sources of data: (1) after Harland *et al.* (1989), with Frasnian/Famennian geochronology modified by Ziegler & Sandberg (1990), including one-Ma divisions; (2) after Clausen *et al.* (1993); (3) after Streel *et al.* (1987) modified by Streel & Loboziak (in press); (4) modified from Daemon & Contreiras (1971) and Daemon (1974, 1976); (5) modified from Caputo (1984); (6) after Johnson *et al.* (1985) and Dennison (1985). The absolute time scale for the D/C boundary was more recently proven by Claoué-Long *et al.* (1993) to be 353 ± 4 Ma. Late Devonian datings at least should probably be modified accordingly. Codes for inset map: I – Purus Arch; II – Gurupá High; wells: A – 2-MN-1-AM, B – 1-AM-1-AM and 1-AM-15-AM, C – 1-TR-1-AM, D – 1-UA-1-AM, E – 1-RX-1-AM, F – 2-NA-1-PA, G – 2-LF-1-AM, H – 1-CM-2-PA.

active shale interval. This basinal facies is assumed to correspond to a sustained sea-level highstand, initiated still in the late Frasnian by the greatest of the Devonian transgressions (T-R cycle IId), and further intensified during the earliest, strongly transgressive phases of the Famennian T-R cycle IIe. The onset of this major eustatic event was probably coeval with the Kellwasser Event, a well known, worldwide biotic crisis which is recorded about the Frasnian-Famennian boundary (Walliser, 1986; Kauffman & Walliser, 1990), and characterized by extensive deposition of black shales over epeiric seas of nearly all continents.

Above the radioactive shale interval, the progressive basinward offlap of shallower marine rata onto more distal marine ones is recorded from the upper Barreirinha section up to the lower part of the Curiri Formation. This can be correlated with the persistent regressive tendencies that typified the last phases of T-R cycle IIe (VCo depositional time).

Finally, the main part of the Curiri Formation consists of glacio-marine sediments of latest Famennian age. They contain abundant, well preserved miospore assemblages assigned to the LN Interval Zone (Loboziak *et al.*, 1992), which is equivalent to the middle to upper *praesulcata* conodont Zones. The glacio-eustatic event recorded in the Curiri and lower Oriximiná Formations fits well the worldwide middle *praesulcata* regression at the end of T-R cycle IIf, related to a biotic crisis known as the Hangenberg Event (Walliser, 1986). Such regression accounts for the massive reworking of Middle and earlier Late Devonian microfossils within the Curiri Formation as the result of extensive erosion along the exposed margins of the Amazon Basin.

CONCLUSIONS

New biostratigraphic information provided by miospores from selected wells of the Amazon Basin has allowed more precise dating and correlation of the Late Devonian Barreirinha Formation than ever obtained in previous studies. This was made possible by the use of Western European-defined, conodont-calibrated Devonian miospore zones, which allow easier inter-correlation of global events between the O.R.S. Continent and Gondwana.

The Barreirinha/Ererê formational boundary was found to correspond to an authentic *paraconformity* in the sense of Bates & Jackson (1987). The break coincides with a sharp lithological contact, at which early Givetian siltstones and sandstones are directly succeeded by a condensed section consisting of later early to late Frasnian black shales. The implied gap comprises at least two missing miospore zones in terms of the Western European zonal scheme. Based on the geochronological table of Fig. 1, the non-depositional phase recorded between the two formations probably lasted not less than 2-3 Ma at a rough estimate.

A very important, long-lasting anoxic event is recorded by radioactive black shales in the lower half of the Barreirinha Formation. Most of this section cannot be dated accurately due to the general absence of miospores and other age-diagnostic microfossils. On the other hand, some approximate age constraints are possible, because this "blind interzone" is bracketed at the base and on the top by Barreirinha strata containing miospore assemblages of late Frasnian and late Famennian age, respectively. At least three Western European miospore zones remain unrecorded between such limits. A minimum duration of ca. 5 Ma can be estimated for the whole anoxic event on the basis of the geochronological data provided in Fig. 1.

Finally, another major gap (up to 2 Ma in duration) intervenes between late Famennian strata of the upper Barreirinha and lowest Curiri Formations and the latest Famennian rocks of the upper Curiri Formation. It probably corresponds to the important glacio-eustatic regression of the end-Devonian.

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