

MIDDLE DEVONIAN CHITINOZOAN BIOSTRATIGRAPHY AND SEDIMENTOLOGY IN THE EASTERN OUTCROP BELT OF THE PARNAÍBA BASIN, NORTHEASTERN BRAZIL

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ABSTRACT – This paper presents the first account of palynomorphs (chitinozoans) from the eastern outcrop belt of the Parnaíba Basin. The chitinozoans are obtained from shallow well core samples, penetrating the Pimenteira Formation, and indicate a late Eifelian – early Givetian age span for this stratigraphic unit, suggesting the absence of a 3rd order unconformity. On the other hand, six minor forced regression unconformities (4th/5th order) occur in the Pimenteira Formation (sequences C-H by Young & Borghi, 2006). A major transgression, initiated in the late Eifelian, reached its maximum in the earliest Givetian, as evidenced by a Maximum Flooding Surface in Sequence D. The investigated sequences are also of interest for the hydrocarbon exploration of the basin, since the sediments include both source-rocks and reservoirs.

Key words: Chitinozoa, Parnaíba Basin, Pimenteira Formation, Maximum Flooding Event, Hydrocarbon exploration, Devonian.

RESUMO – Este artigo apresenta o primeiro registro de palinomorfos (quitinozoários) da faixa oriental de afloramentos da Bacia do Parnaíba. Os quitinozoários foram obtidos de testemunhos de sondagens rasas, que penetram a Formação Pimenteira e indicam uma idade neo-eifeliana – eogivetiana indicando a inexistência de uma descontinuidade de 3^a ordem neste intervalo. Por outro lado, seis descontinuidades menores, relacionadas à regressões forçadas (4^a/5^a ordem), ocorrem na Formação Pimenteira (seqüências C – H de Young & Borghi, 2006). Uma grande transgressão, iniciada no Neo-Eifeliano, atingiu o seu apogeu no Givetiano inicial, conforme evidenciado por uma Superfície de Inundação Máxima na seqüência D. As seqüências investigadas representam também interesse para a exploração de hidrocarbonetos da bacia, uma vez que tais sedimentos incluem tanto rochas geradoras quanto rochas reservatório.

Palavras-chave: Quitinozoários, Bacia do Parnaíba, Formação Pimenteira, Superfície de Inundação Máxima, Exploração de Hidrocarbonetos, Devoniano.

INTRODUCTION

Devonian rocks crop out along the eastern margin of the Parnaíba Basin, in a belt roughly extending N-S (Figure 1A). All Devonian formations present in the Parnaíba Basin have been defined from localities within this outcrop belt (see Grahn, 1992).

The Pimenteira Formation was proposed by Small (1914) for a 20 m thick shale sequence near Pimenteiras town in the State of Piauí (Figure 1B). Plummer (1948) divided the Pimenteira into an upper sandy member and a lower shale

member. Kegel (1953) referred the shale member to his Picos Member (now Pimenteira Formation s.s.), and a lower part not considered by Plummer, to the Itaim Mbr. (now Itaim Formation s.s.). The overlying Cabeças Formation was defined by Plummer (1948), who divided it into three members, in ascending order: Passagem, Oeiras and Ipiranga. The Passagem member was later transferred to the Pimenteira Formation by Beurlen (1965) and Campanha & Mabesoone (1974), and this concept will be followed here. Except for the diachronous contact between Pimenteira/Cabeças and Cabeças/Longá, all Devonian formations may be considered

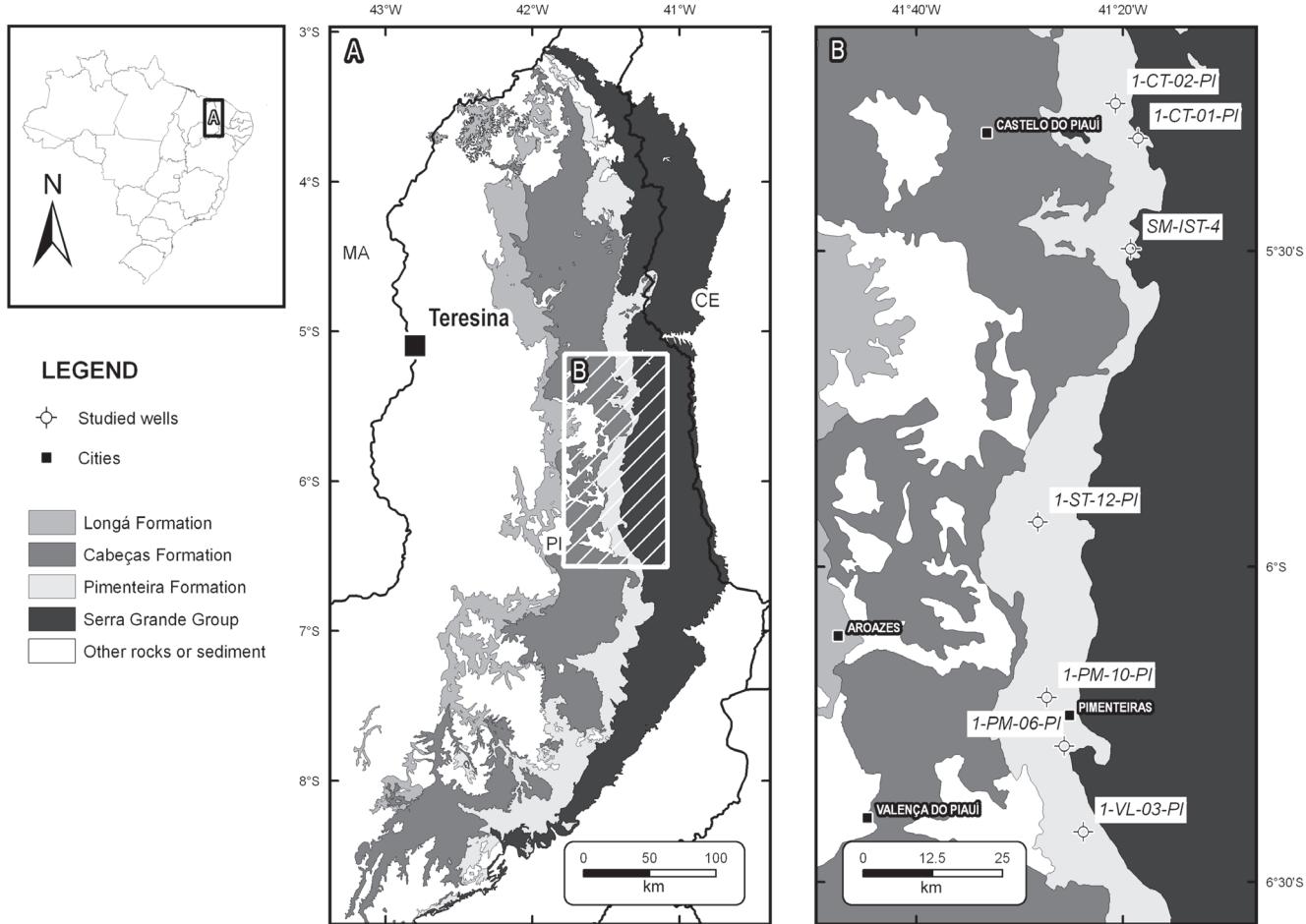


Figure 1. Location maps for the eastern margin of the Parnaíba Basin investigated in this study. **A**, regional overview of the studied area; **B**, detailed map showing the sampled wells and nearby towns. Geology after Buzzi *et al.* (2003).

synchronous through the basin. The Pimenteira Formation ranges from latest Eifelian to early Famennian in the central and western part of the basin (Loboziak *et al.* 2000), but seems to be more restricted on the eastern margin, where the Cabeças Formation is fully developed. The ages based on the megafossils (e.g., Fonseca & Machado, 2002, Silva & Machado, 2002) need to be confirmed and refined with palynomorphs, hitherto undescribed from the type area. Palynomorphs are the standard biostratigraphic tool in Western Gondwana, and have been extensively used to date pre-Carboniferous rocks in the Parnaíba Basin and other intracratonic basins of Brazil (Melo & Loboziak, 2003, Grahn, 2005, Grahn *et al.*, 2006).

From a genetic stratigraphic point of view (Galloway's Stratigraphy), Della Fávera (1990) and Albuquerque (2000), recognized five sequences for the Pimenteira Formation and the lowermost Cabeças Formation, thus admitting a conformable (normal regressive) boundary for the Pimenteira/Cabeças formations along the entire basin. No unconformities were proposed. Young (2006) and Young & Borghi (2006) proposed a high resolution sequence stratigraphic analysis (Exxon's or Vail's Stratigraphy) for

this particular interval on the eastern border of the basin (from where the studied samples were collected), and conceived six depositional sequences of 4th/5th order (minor forced regression unconformities). These subdivide the Pimenteira Formation into six units (Figure 2), which leave no room for a third order unconformity, since each unit spans less than 1 MA. The upper contact with the Cabeças Formation was proposed as a major unconformity (3rd order?). In this respect, biostratigraphical information is the key to enhancing the chronostratigraphic resolution, helping in litho- and sequence stratigraphic approaches. The present study is a contribution to a more accurate stratigraphic picture of the Devonian of the Parnaíba Basin, which will allow a better understanding of its potential source-rock and reservoir distribution and quality, helping in hydrocarbon exploration efforts.

GEOLOGICAL SETTING

The present day Parnaíba Basin extends over ca. 600,000 km² in northeastern Brazil. It is an intracratonic basin with a more restricted access to the open ocean than adjacent

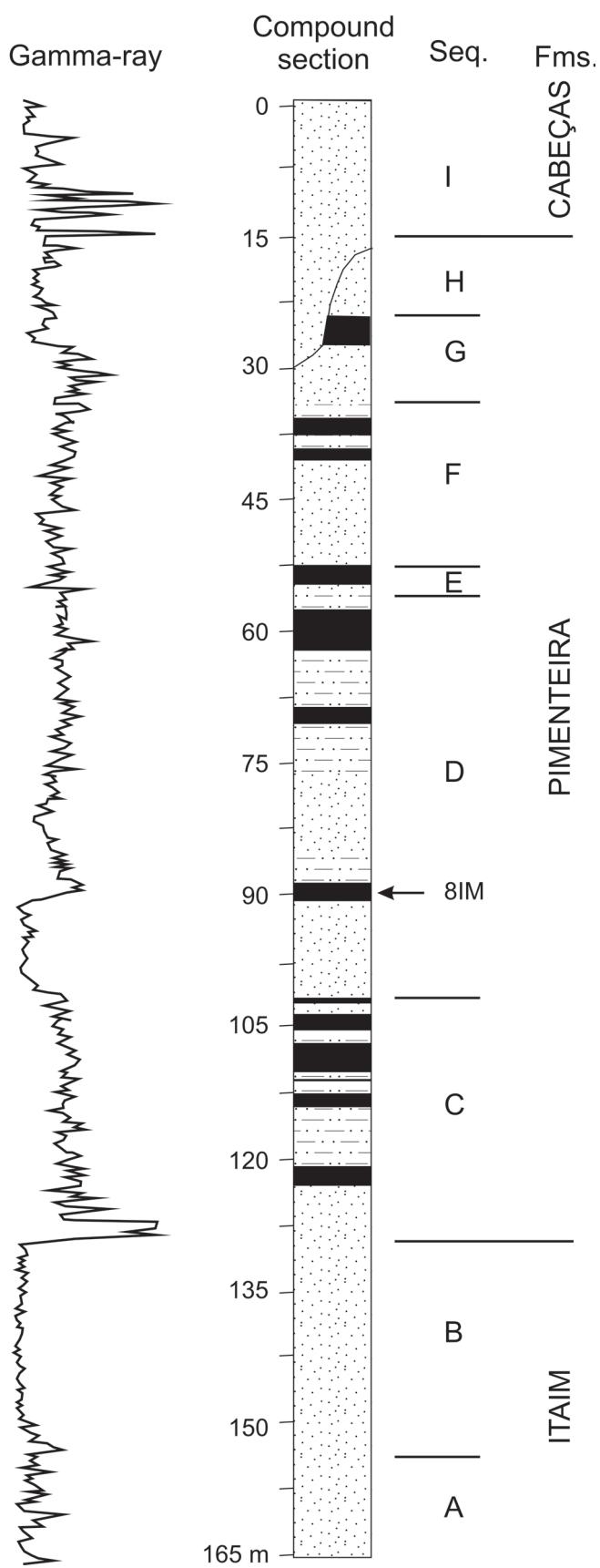


Figure 2. Schematic stratigraphy for the Pimenteira Fm. in the studied area (modified from Young & Borghi, 2006). 8IM = Maximum Flooding Surface by Young & Borghi (2006).

contemporary intracratonic basins, and with sediments deposited in a more shallow sea (Grahn *et al.*, 2006). The Pimenteira beds were mainly influenced by storm-generated waves and currents (Della Fávera, 1990). They also record the first widespread Devonian transgression over the Parnaíba Basin (Melo, 1988). A sea-link also existed from the late Emsian and onwards during the Devonian between the Parnaíba Basin and the Paraná Basin in the southwest (Melo 1988). In the investigated area Young (2006) and Young & Borghi (2006) divided the Middle Devonian interval into 9 depositional sequences (Figures 2-4). Sequences A-B correspond to the upper part of the Itaim Formation; sequences C-H to the Pimenteira Formation and sequence I to the lower part of the Cabeças Formation. This framework will be used in this study for a tentative correlation between biostratigraphic and sequence stratigraphic events.

CHITINOZOAN BIOSTRATIGRAPHY

The sections investigated (Figures 3-4), all display a characteristic late Eifelian to early Givetian chitinozoan shallow water fauna dominated by *Ancyrochitina* species (Figures 6-7). The variation of the *Ancyrochitina* species is also typical for the early Givetian in western Gondwana (see Grahn, 2005, Grahn & Melo, 2005). The chitinozoan biostratigraphy for the Pimenteira Formation (sequences C-H of Young, 2006) will be discussed below (Figures 2-5). It is worth noting that the Itaim Formation was not sampled, and all samples from the Cabeças Formation were barren of Chitinozoa.

Sequence C

Sequence C (the lowermost part of the Pimenteira Formation) was sampled in the wells 1-VL-03-PI, 1-PM-06-PI, SM-IST-4, 1-CT-01-PI, and 1-PM-10-PI (Figures 3-4). The uppermost Itaim Formation (Sequence B) is recorded in the basal part of the well SM-IST-4 (Figure 4). The co-occurrence of *Eisenackitina aranea* and *Alpenachitina eisenacki* indicate a late Eifelian age span. As pointed out by Paris *et al.* (1985), spiny specimens of *E. aranea* (= *E. castor* Jansonius, 1964 in Legault, 1973 and Paris *et al.*, 1985) are significant for the early Givetian, and glabrous specimens, as in sequence C (Figure 8N), for the late Eifelian. Furthermore, in Western Gondwana *Alpenachitina eisenacki* is common in the late Eifelian, but rare in the early Givetian (Grahn, 2005). Other chitinozoan species in the sequence C (Figures 2-4) indicate an undifferentiated Middle Devonian age (Figure 5).

Sequence D

The increase in chitinozoan diversity in sequence D (Figures 2-4) is characteristic for the early Givetian of Western Gondwana (Grahn, 2005). Sequence D was sampled in wells 1-VL-03-PI, 1-PM-06-PI, 1-CT-01-PI, 1-PM-10-PI, and 1-CT-02-PI (Figures 3-4). *Alpenachitina eisenacki* is still present and suggests that the Eifelian – Givetian transition is at the C-D boundary. The presence

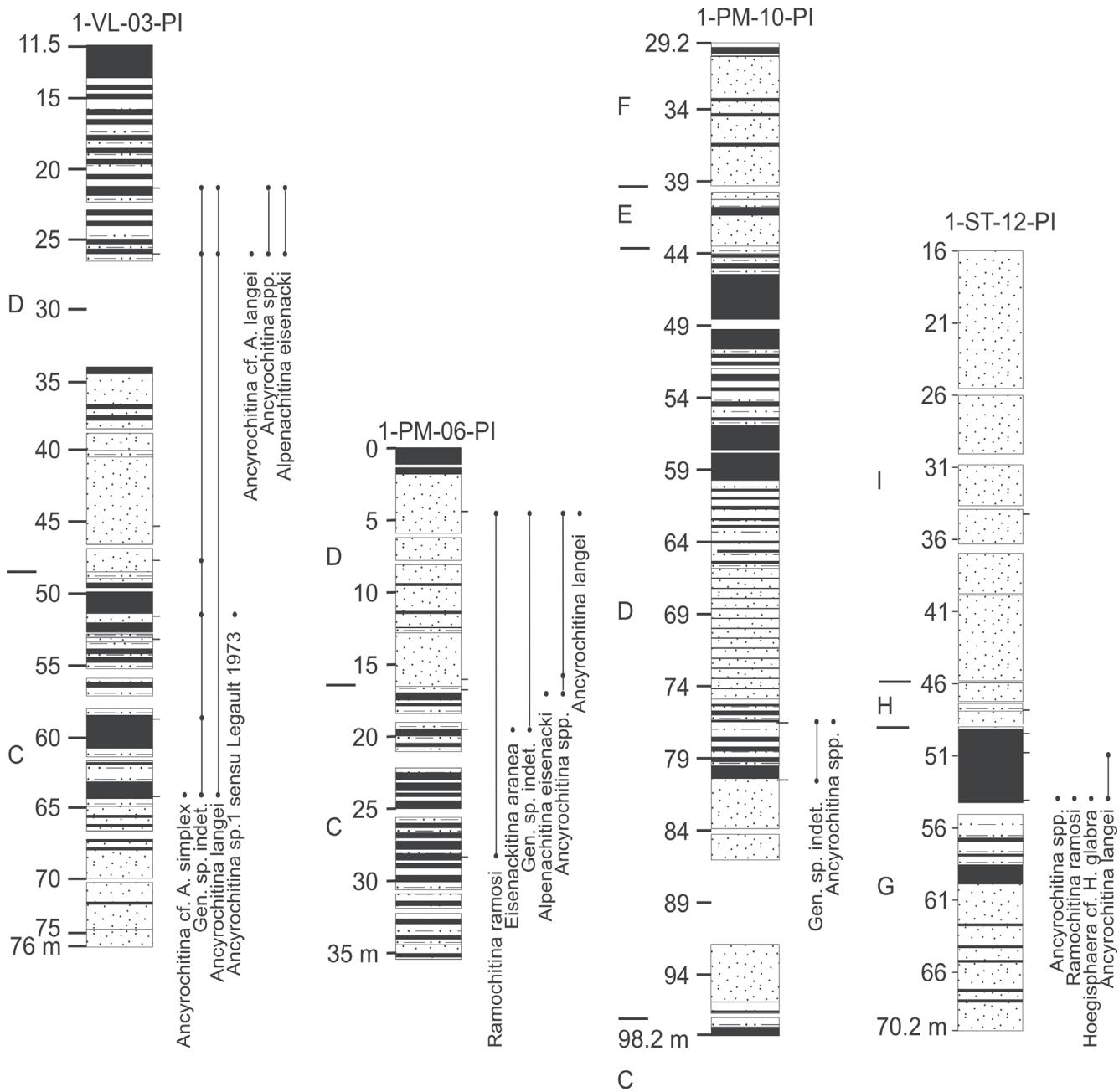


Figure 3. Lithologic columns and chitinozoan range chart for the 1-VL-03-PI, 1-PM-06-PI, 1-PM-10-PI and 1-ST-12-PI wells. South to north from left to right in the figure. For legend, see figure 4.

of *Ancyrochitina simplex* and the variations of *Ancyrochitina langei* further strengthen an early Givetian age span (Figure 5).

Sequence E

The impoverished chitinozoan assemblage in sequence E (Figures 2-4) is probably due to unfavourable environmental conditions for chitinozoans in this interval. Sequence E was encountered in well 1-PM-10-PI and sampled in well 1-CT-02-PI (Figures 3-4). The species present, only indicate a Middle Devonian age span in general (Figure 5).

Sequence F

Sequence F is similar to sequence E, with a low diversity chitinozoan fauna of a general late Eifelian – early Givetian affinity. Sequence F (Figures 2-4) is present in the wells 1-PM-10-PI and 1-CT-02-PI (Figures 3-4), and was sampled in the latter well.

Sequence G

The chitinozoan assemblage in the sequence G is characteristic for the pre late Givetian, and the presence of *Ancyrochitina arirambaense* indicates an early, but not late early (TA miospore Zone) Givetian age span (Figure 8).

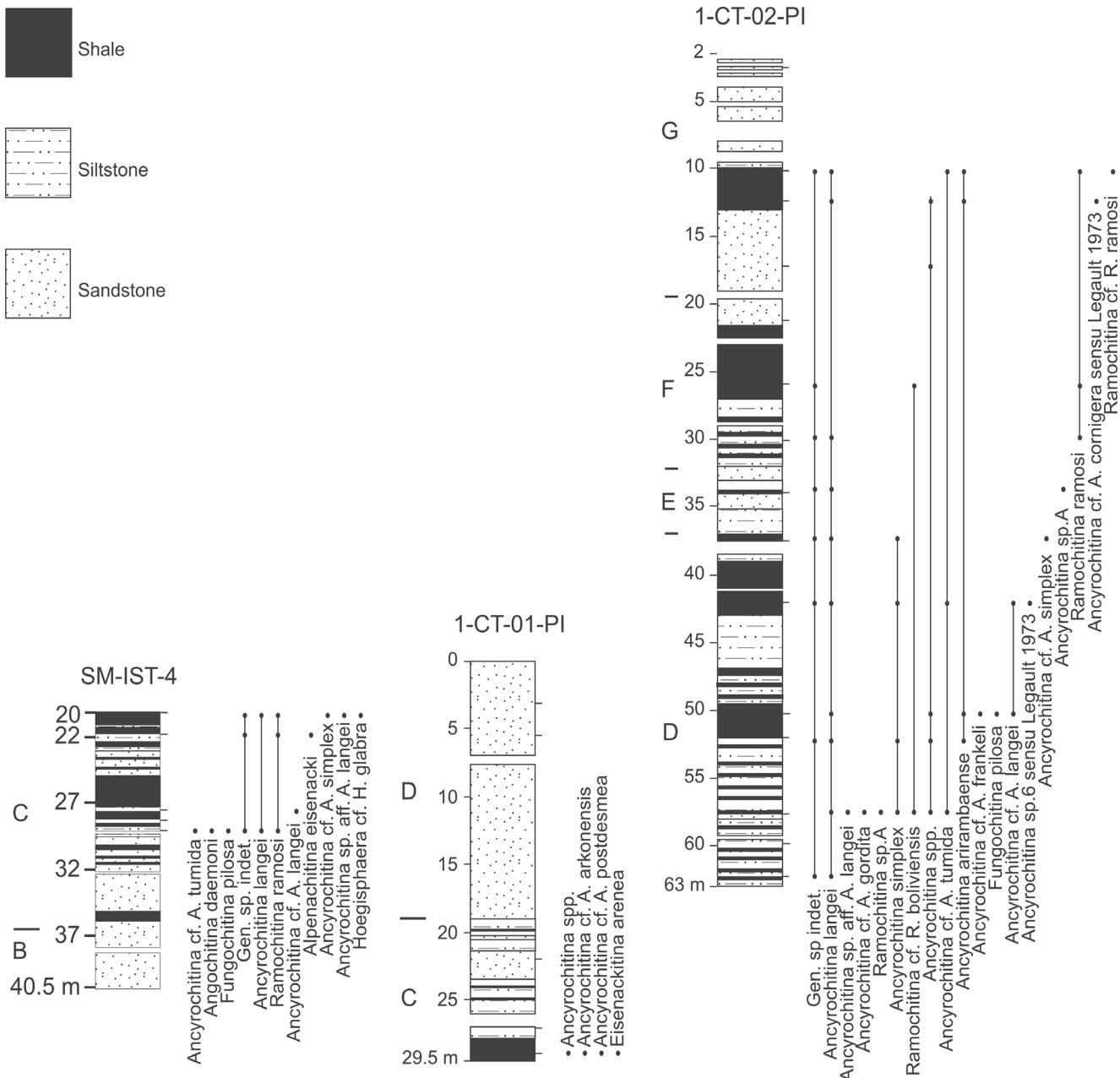


Figure 4. Lithologic columns and chitinozoan range chart for the SM-IST-4, 1-CT-01-PI and 1-CT-02-PI wells. South to North from left to right in the figure.

Sequence G (Figures 2-4) was sampled in wells 1-ST-12-PI and 1-CT-02-PI (Figures 3-4).

Sequence H

The uppermost part of the Pimenteira Formation along the eastern rim of the Parnaíba Basin is barren of Chitinozoa, and it is therefore not possible to establish if late early Givetian, or younger Givetian sediments, are present on the eastern margin of the basin or not. Sequence H (Figures 2-3) and the lower Cabeças Formation are recorded and sampled in well 1-ST-12-PI (Figure 3), where the sediments in the latter formation consist of fluvialite sandstones.

CONCLUDING REMARKS

A characteristic late Eifelian to early Givetian chitinozoan shallow water fauna, dominated by *Ancyrochitina* species, is present in the Pimenteira Formation on the eastern margin of the Parnaíba Basin. In this area the Pimenteira Formation could be assigned to late Eifelian – early Givetian, representing its lower part in the deeper parts (center) of the basin. It is worth noting that the biostratigraphic data supports the stratigraphic correlations established by Young (2006), although no unconformity could be recognized. The difficulty in achieving a time-designation for the unconformities of Young (2006) and Young & Borghi

Chitinozoan species in the Pimenteira Formation	Sequences					
	C	D	E	F	G	H
1. <i>Alpenachitina eisenacki</i> Dunn & Miller 1964	●	●				
2. <i>Ancyrochitina arirambaense</i> Grahn & Melo 2005		●				●
3. <i>Ancyrochitina langei</i> Sommer & Boekel 1964	●	●	●	●	●	●
4. <i>Ancyrochitina</i> cf. <i>A. postdesmea</i> Grahn 2002	●					
5. <i>Ancyrochitina simplex</i> Grahn 2002			●			
6. <i>Ancyrochitina</i> cf. <i>A. arkonensis</i> Legault 1973	●					
7. <i>Ancyrochitina</i> cf. <i>A. cornigera</i> (Collinson & Scott 1958) sensu Legault 1973						●
8. <i>Ancyrochitina</i> cf. <i>A. frankeli</i> Wright 1976		●				
9. <i>Ancyrochitina</i> cf. <i>A. gordita</i> (Cramer 1964) sensu Legault 1973		●				
10. <i>Ancyrochitina</i> cf. <i>A. langei</i> Sommer & Boekel 1964		●				
11. <i>Ancyrochitina</i> sp. aff. <i>A. langei</i> Sommer & Boekel 1964		●				
12. <i>Ancyrochitina</i> cf. <i>A. simplex</i> Grahn 2002	●	●				
13. <i>Ancyrochitina</i> cf. <i>A. tumida</i> (Taugourdeau & Jekhowsky 1960) sensu Legault 1973		●				●
14. <i>Ancyrochitina</i> sp.1 sensu Legault 1973	●					
15. <i>Ancyrochitina</i> sp.6 sensu Legault 1973		●				
16. <i>Ancyrochitina</i> sp.A			●			
17. <i>Ancyrochitina</i> spp.	●	●				●
18. <i>Angochitina daemoni</i> Grahn 2000	●					
19. <i>Eisenackitina aranea</i> Urban 1972	●					
20. <i>Fungochitina pilosa</i> (Collinson & Scott 1958)		●				
21. <i>Hoegisphaera</i> cf. <i>H. glabra</i> Staplin 1961						●
22. <i>Ramochitina ramosi</i> Sommer & Boekel 1964	●	●		●	●	●
23. <i>Ramochitina</i> cf. <i>R. ramosi</i> Sommer & Boekel 1964						●
24. <i>Ramochitina</i> cf. <i>R. boliviensis</i> Grahn 2002	●			●		
25. <i>Ramochitina</i> sp.A		●				
26. Gen. sp. indet.	●	●	●	●	●	
Age				late Eifelian	early Givetian	

Figure 5. Chart showing chitinozoan species recognized in this paper and their occurrences.

(2006), was in fact expected due to its lower rank (4th/5th order) in the sequence stratigraphical analyses. Another interesting aspect concerns the importance of a particular marine flooding surface (MFS) named by these authors as 8IM. The 8IM surface, as defined by Young (2006; Figure 2), is one of the most conspicuous stratigraphic correlation surfaces in the studied area, being found in all the wells that drilled through its interval in Sequence D. Young (2006) described this interval as comprised of thinly laminated black shales, with a total absence of bioturbation, and with higher-than-average gamma ray values. It was interpreted as a maximum flooding event with associated sea bottom anoxia. Further studies of the same interval by Souza (2007)

indicated predominance of preserved and fluorescent amorphous organic matter, further corroborating the interpretation as a flooding event. The positioning of the Eifelian – Givetian boundary around the C - D sequence boundary suggests that this very clear flooding event probably represent Rodrigues (1995) Early Givetian Maximum Flooding event of “Folhelhos radioativos A”. This Early Givetian maximum flooding event has been recognized in other wells deeper in the basin, such as 1-TB-2-MA (Testa Branca n° 2, 7° 25' 25,7'' S, 46° 5' 59,7'' W, Grahn & Melo, 2005) and 1-CP-1-MA (Capinzal n° 1, 4° 45' 50'' S, 44° 17' 49'' W, Góes & Feijó, 1994) where it also is represented by a radioactive shale (Rodrigues, 1995). The recognition of

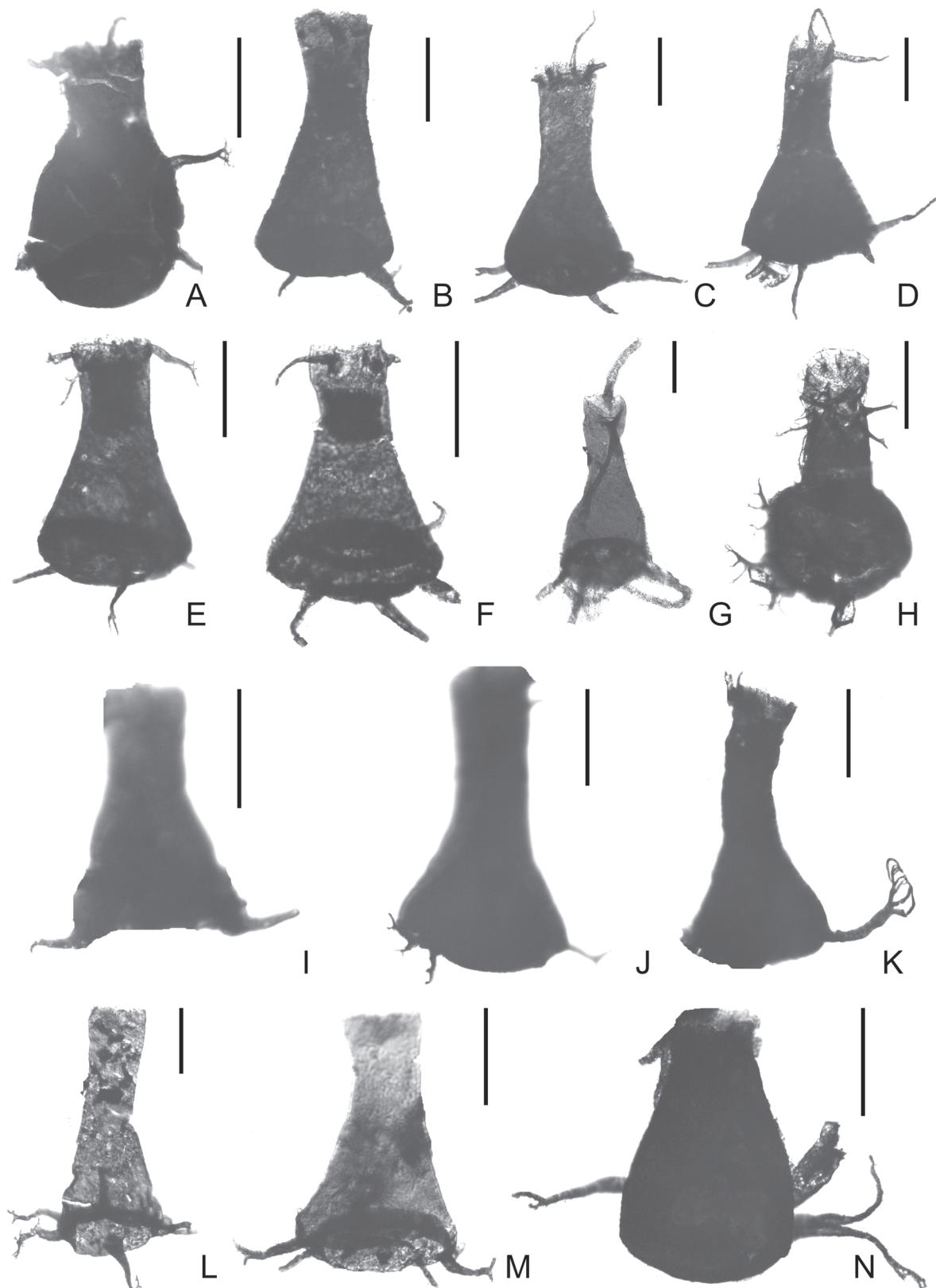


Figure 6. Selected chitinozoans from Pimenteira Fm. on the eastern margin of the Parnaíba Basin. Identification is follow by the well and depth of occurrence. **A**, *Alpenachitina eisenacki*, 1-VL-03-PI, 26.00 m; **B**, *Ancyrochitina arirambaense*, 1-CT-02-PI, 52.07 m; **C**, *Ancyrochitina langei*, 1-CT-02-PI, 50.27 m; **D**, *Ancyrochitina langei*, 1-CT-02-PI, 50.27 m; **E**, *Ancyrochitina langei*, 1-CT-02-PI, 52.07 m; **F**, *Ancyrochitina langei*, 1-CT-02-PI, 42.07 m; **G**, *Ancyrochitina langei*, 1-VL-03-PI, 21.21 m; **H**, *Ancyrochitina* cf. *A. postdesmea*, 1-CT-01-PI, 28.90 m; **I**, *Ancyrochitina simplex* Grahn 2002. Well 1-CT-02-PI, 37.47 m; **J**, *Ancyrochitina* cf. *A. arkonensis*, 1-CT-01-PI, 28.90 m; **K**, *Ancyrochitina* cf. *A. cornigera*, 1-CT-02-PI, 12.55 m; **L**, *Ancyrochitina* cf. *A. frankeli*, 1-CT-02-PI, 50.27 m; **M**, *Ancyrochitina* cf. *A. gordita*, 1-CT-02-PI, 57.67 m; **N**, *Ancyrochitina* cf. *A. langei*, 1-CT-02-PI, 42.07 m. Scale bars = 50 µm.

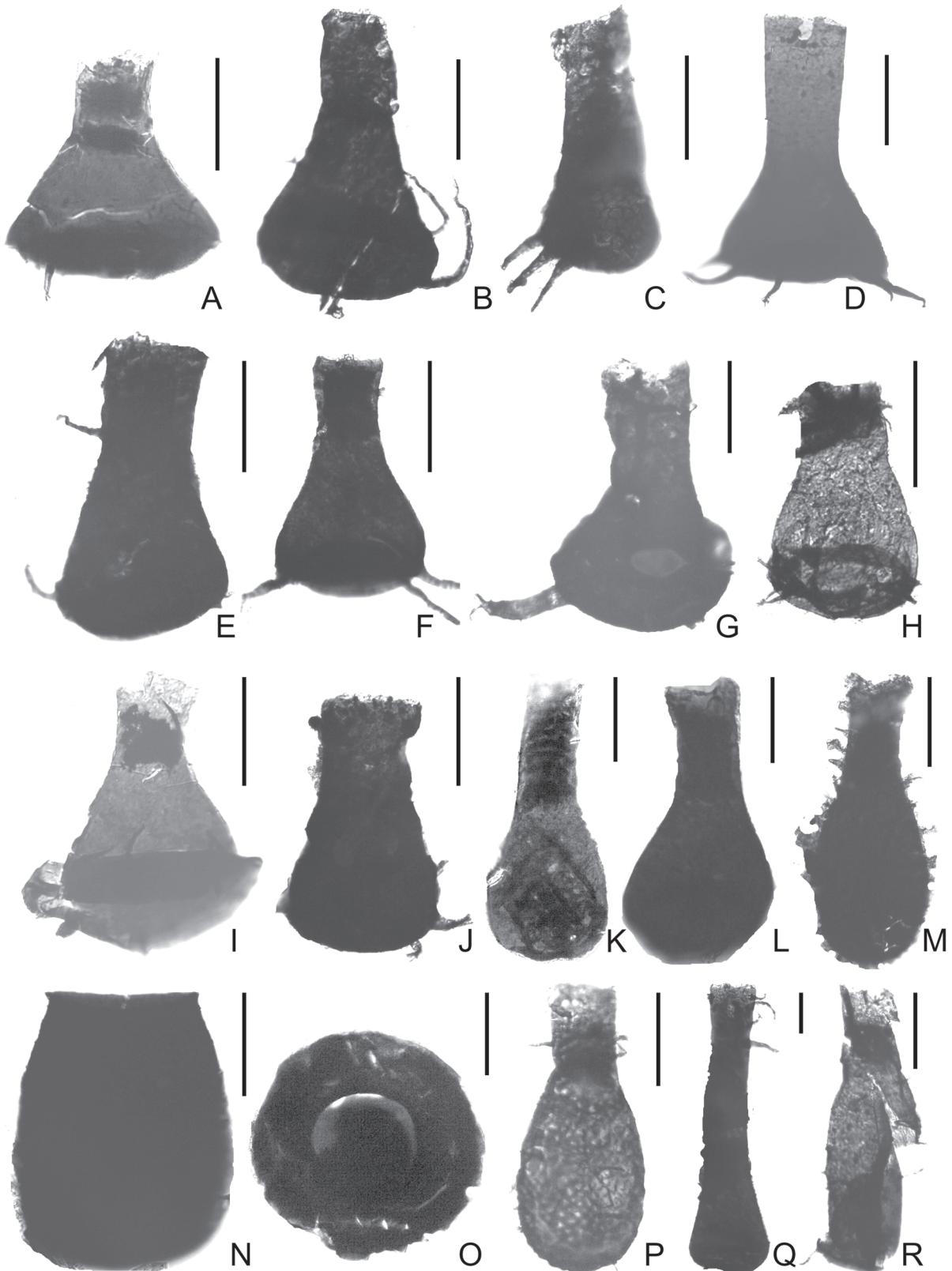


Figure 7. Selected chitinozoans from Pimenteira Fm. on the eastern margin of the Parnaíba Basin. **A**, *Ancyrochitina* cf. *A. langei*, SM-IST-4, 27.49 m; **B**, *Ancyrochitina* sp. aff. *A. langei*, 1-CT-02-PI, 57.67 m; **C**, *Ancyrochitina* cf. *A. simplex*, 1-CT-02-PI, 37.47 m; **D**, *Ancyrochitina* cf. *A. simplex*, 1-VL-03-PI, 64.15 m; **E**, *Ancyrochitina* cf. *A. tumida*, 1-CT-02-PI, 57.67 m; **F**, *Ancyrochitina* cf. *A. tumida*, 1-CT-02-PI, 42.07 m; **G**, *Ancyrochitina* cf. *A. tumida*, 1-CT-02-PI, 10.25 m; **H**, *Ancyrochitina* sp. 6, 1-CT-02-PI, 42.07 m; **I**, *Ancyrochitina* sp. 1, 1-VL-03-PI, 51.40 m; **J**, *Ancyrochitina* sp. A, 1-CT-02-PI, 33.85 m; **K**, *Angochitina daemoni*, SM-IST-4, 28.89 m; **L**, *Angochitina daemoni*, SM-IST-4, 28.89 m; **M**, *Ramochitina ramosa*, 1-PM-06-PI, 4.30 m; **N**, *Eisenackitina aranea*, 1-PM-06-PI, 19.20 m; **O**, *Hoegisphaera* cf. *H. glabra*, 1-ST-12-PI, 54.30 m; **P**, *Ramochitina ramosi*, SM-IST-4, 21.89 m; **Q**, *Ramochitina* cf. *R. boliviensis*, 1-CT-02-PI, 57.67 m; **R**, *Ramochitina* cf. *R. boliviensis*, 1-CT-02-PI, 25.86 m. Scale bar = 50 µm.

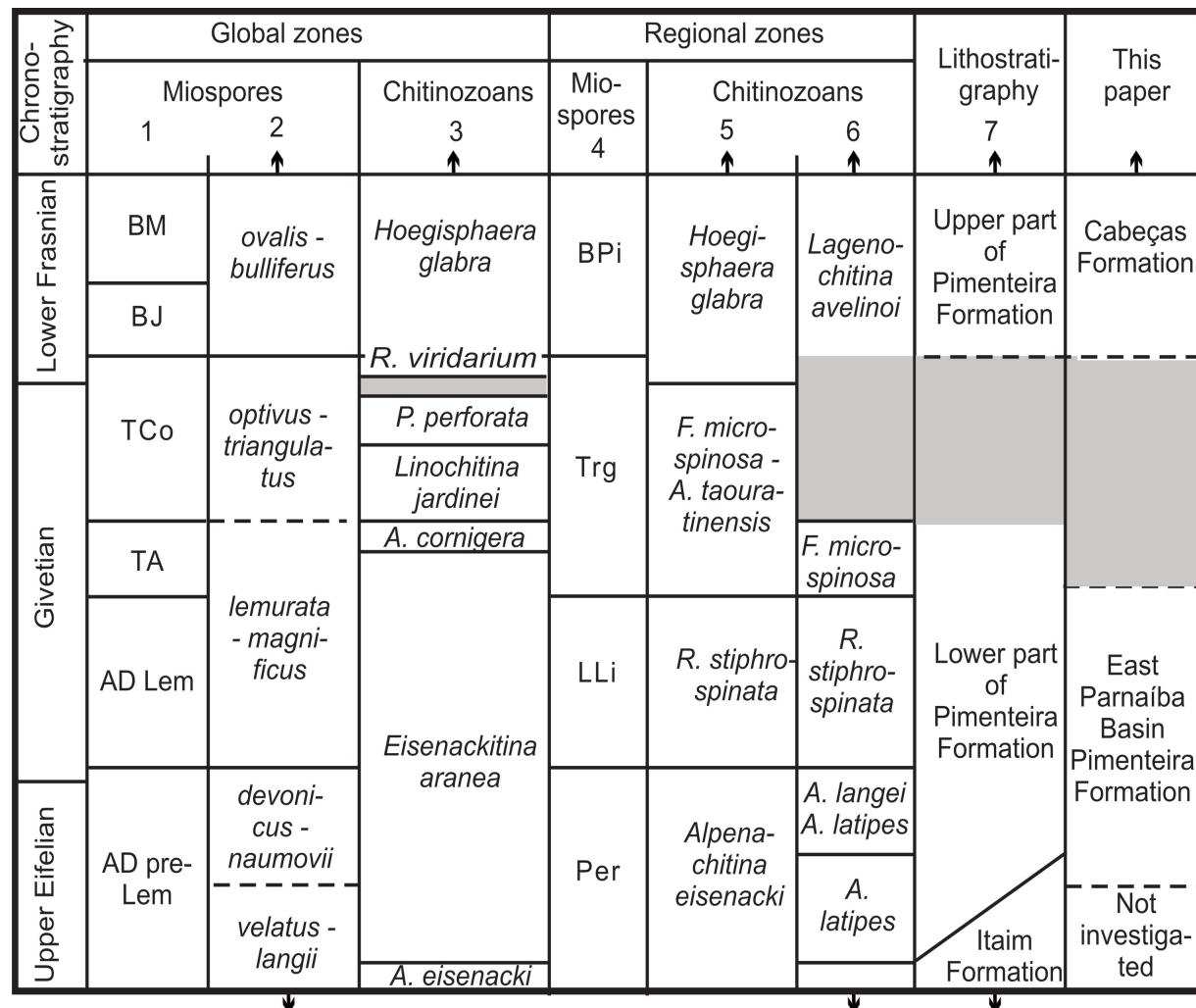


Figure 8. Correlation scheme for the Middle Devonian on the eastern margin of the Parnaíba Basin. **Conventions:** 1, Ardenne-Rhenish (Western European) miospore zonation after Strelc et al. (1987) and Steemans (1989); 2, Old Red Sandstone Continent miospore zonation after Richardson & McGregor (1986); 3, Global chitinozoan zonation after Paris et al. (2000); 4, Western Gondwanan (North Brazil) miospore zonation after Melo & Loboziak (2003); 5, Western Gondwanan chitinozoan zonation after Grahn (2005); 6, Parnaíba Basin chitinozoan zonation after Grahn & Melo (2005). 7, Late Eifelian–early Frasnian lithostratigraphy of the Parnaíba Basin after Grahn et al. (2006).

this event is of great importance for long distance well-to-well correlations and for detailed outcrop mapping.

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