

# Cretaceous conchostracans from Potiguar Basin (northeast Brazil): relationships with West African conchostracan faunas and palaeoecological inferences<sup>1</sup>



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Revised manuscript accepted 10 April 2002

Many fossil groups have been used in biostratigraphic and palaeoenvironmental analyses in order to understand the geological evolution of the Potiguar Basin, northeast Brazil. The present record of conchostracans (Conchostraca, Branchiopoda) adds to the diversity of fossil groups known to have lived in the area. Two distinct conchostracan faunas have been recovered from different stratigraphic levels in the basin. The first was encountered in cores of onshore lacustrine shales of the Pendência Formation (Lower Cretaceous). The second was found in exposures of marls within the Jandaira Formation (Upper Cretaceous). Both are monospecific faunas belonging to the families Cyzicidae (*Cyzicus mawsoni*) and Limnadiidae (*Estheriina astartoides*). Both species are well preserved and normally show the two articulated valves. Conchostracans belonging to these families are common in Gondwanan basins. The Lower Cretaceous associations are very similar to coeval assemblages of West African basins (e.g., Cameroon, Congo and Gabon). Conchostracans are common in ephemeral freshwater ponds of hot, alkaline waters; they can even occur in brackish waters of coastal lagoons and tidally-influenced zones. This is presumed to be the life environment of the Late Cretaceous conchostracans in the Potiguar Basin.

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KEY WORDS: conchostracans; Cretaceous; palynofacies; palaeoecology; Potiguar Basin; West African basins.

## 1. Introduction

Conchostracans (Crustacea, Branchiopoda) were one of the most important components of faunas of the northeastern basins of Brazil during the Early Cretaceous (Carvalho, 1993). Despite their richness, little has been published on their occurrence, geographical distribution and palaeoecology, probably owing partly to the scarcity of unweathered and easily accessible exposures in the interior basins of northeast Brazil. On the other hand, the abundance of other fossils, such as ostracods, plants, palynomorphs, fish and insects, and the wide biostratigraphic range of the conchostracan species, has probably excluded the latter from non-applied or oil-industry biostratigraphic studies. Carvalho (1993) noted a strong similarity between the Brazilian and West African faunas. Twelve endemic species, belonging to four families,

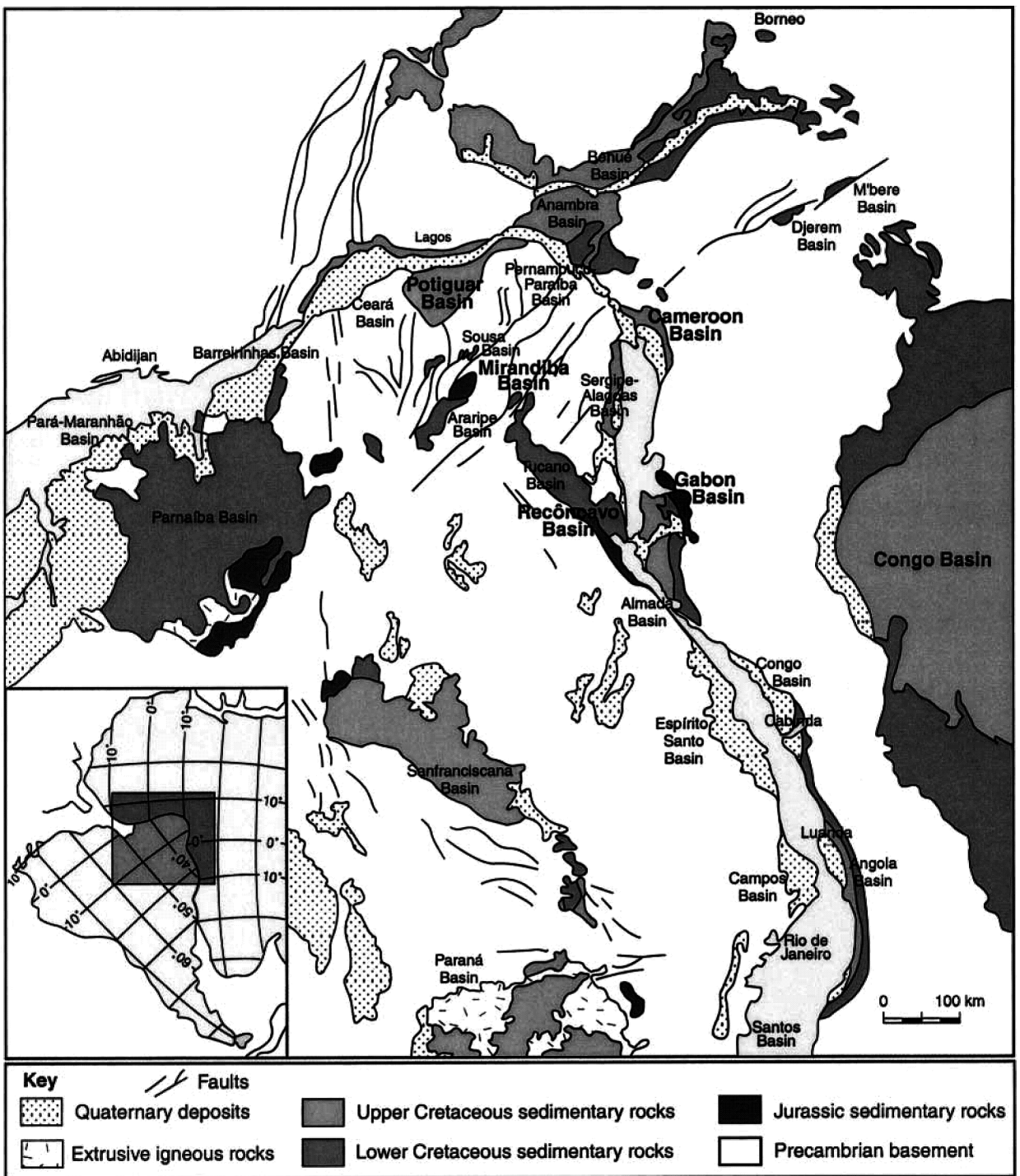
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essentially make up the Brazilian Lower Cretaceous lacustrine and fluvial assemblages. Among these it is possible to recognize both Neocomian and Aptian–Albian species. According to the currently available literature, their occurrence was restricted to northeast Brazilian and West African sedimentary basins (Figure 1).

The Upper Cretaceous sedimentary cover of northeast Brazil (Potiguar, Sergipe-Alagoas and Pernambuco-Paraíba basins) is mainly dominated by marine facies; hence the lack of a conchostracan record in both Brazil and West Africa. The sole report of Late Cretaceous conchostracans is from the Potiguar Basin. Rebouças (1962) encountered them in his study on the gypsite mines of Dix-Sept Rosado County.

The Potiguar Basin is the easternmost of Brazilian equatorial basins (Figure 2), and its origin and development are closely related to the geological evolution

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**Figure 1.** Geological map of a sector of Gondwana at about 140 Ma: distribution of the northeast Brazilian and West African basins (modified from De Wit *et al.*, 1988). The basins on which emphasis is placed herein are indicated in bold face.

of the Brazilian continental margin. As in the other marginal basins, three main tectono-sedimentary phase sequences are recorded within it: a rift-continental phase followed by a transitional phase and then a predominantly marine-drift phase; for a syn-

thesis of the evolution of the basin, see Araripe & Feijo (1994; Figure 3 herein).

Two monospecific conchostracan assemblages were identified in the Potiguar Basin: one from the Lower Cretaceous, composed of *Cyzicus mawsoni*, and the

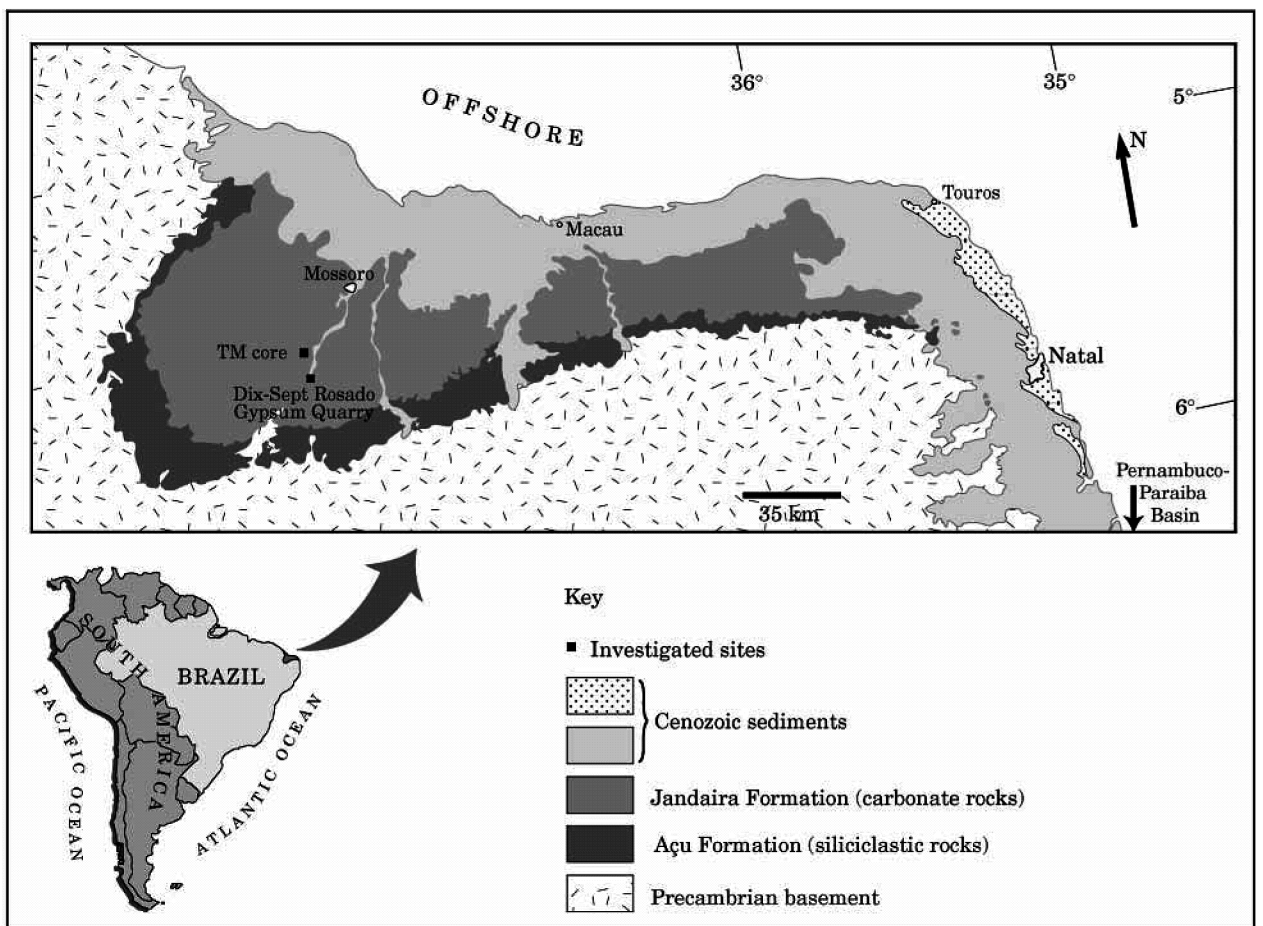


Figure 2. Location map of the Potiguar Basin showing the two onshore sites investigated.

other from the Upper Cretaceous that comprises *Estheriina astartoides*. The specimens recovered are described herein and compared with previously known species from northeast Brazil and West Africa. Their palaeoecology is also discussed.

## 2. Systematic section

The classification proposals of Tasch (1969, 1987) are used herein, although the *Cyzicus* subgenera *Lioestheria* and *Euestheria* are considered to be invalid. The criteria for distinguishing these two subgenera based on different ornamentation of the valves were regarded as inadequate by Musacchio (1970), who showed that two different types of valve ornamentation can occur in the same species.

Suborder: Spinicaudata Linder, 1945

Superfamily: Cyzicoidea Stebbing, 1910



Family: Cyzicidae Stebbing, 1910

Genus *Cyzicus* Audouin, 1837; emend. Depéret & Mazeran, 1912

*Type species.* *Cyzicus tetracerus* (Krynicky, 1830)

*Cyzicus mawsoni* Jones, 1897a

Figure 4A–C

*Description.* Carapace obliquely subovate. Umbo at the anterior third of the valve, above a short, straight, dorsal margin. Height of anterior sector greater than that of the posterior region. Anterior margin rounded, posterior more steeply rounded. About 80 concentric growth lines, pronounced just below the umbo, narrower towards the ventral region of the valve. Interstitial spaces broad on the upper (dorsal) area of the valves, more closely set below. Ornamentation between the growth lines consists of small vertical bars (hachure-type), slightly sinuous, and occasionally branching and anastomosing.

Superfamily: Limnadioidea Baird, 1894

Family: Limnadiidae Baird, 1894

Subfamily Estheriinae Kobayashi, 1954

Genus *Estheriina* Jones, 1897

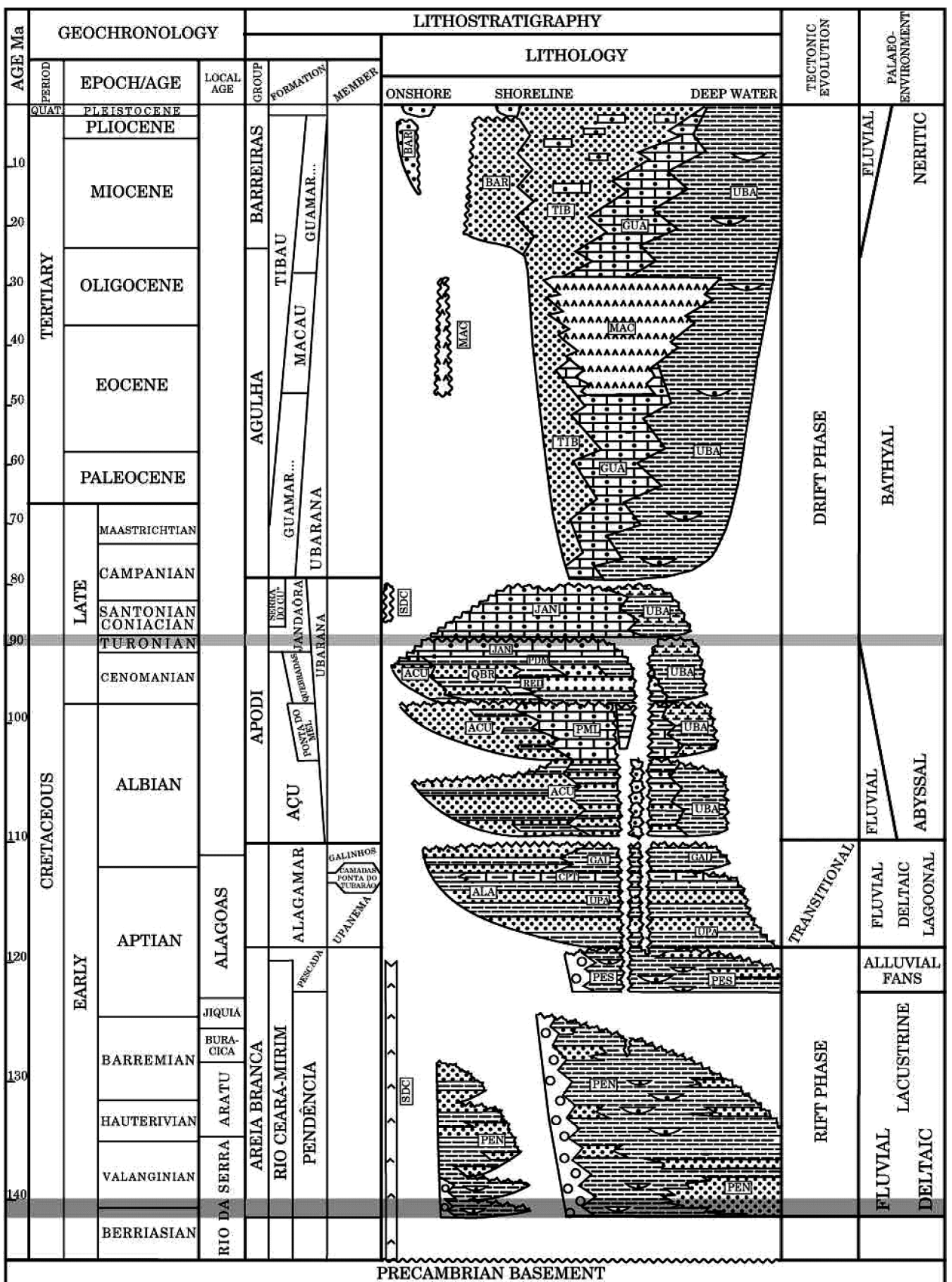
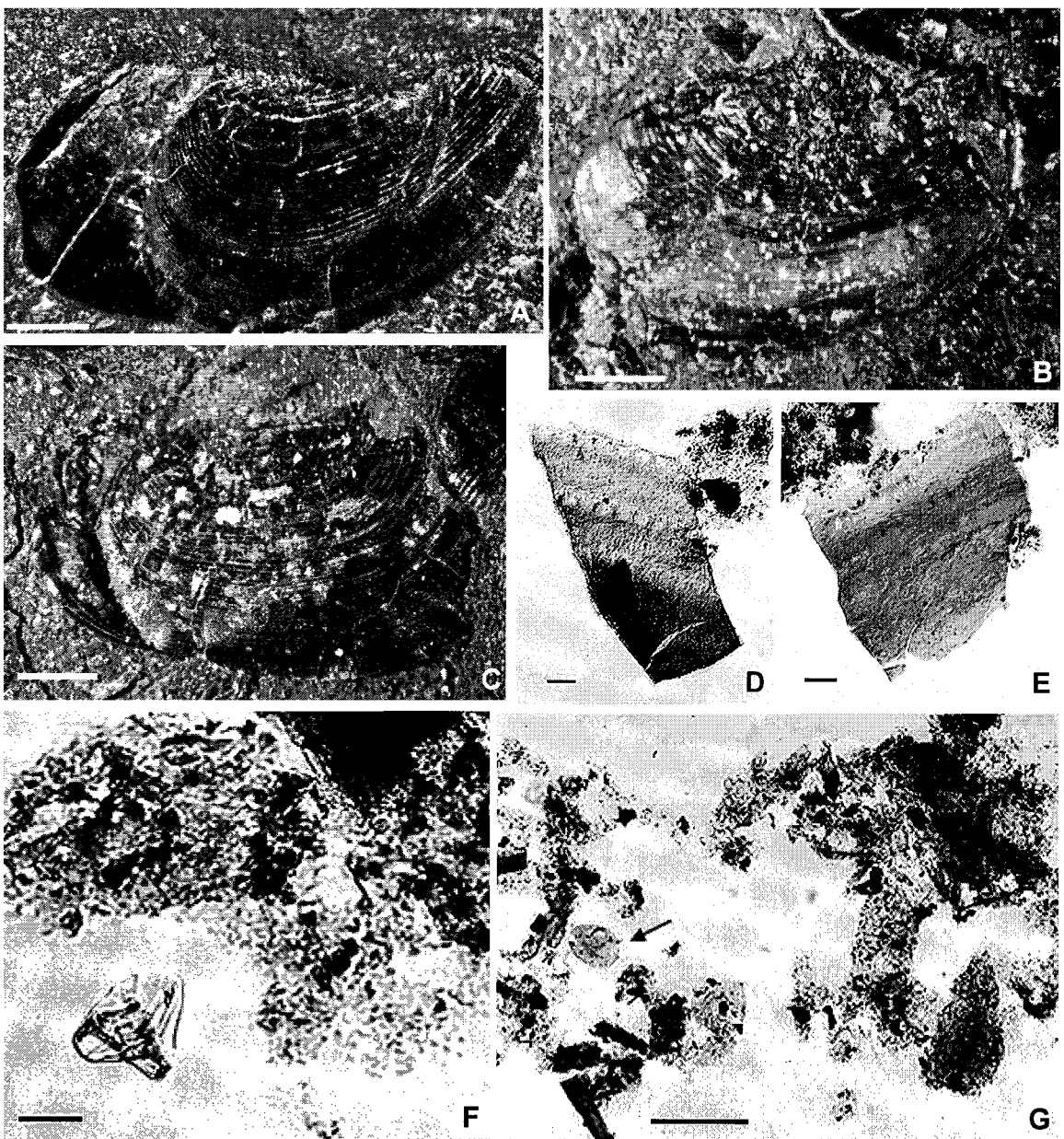


Figure 3. Stratigraphic column for the Potiguar Basin, modified from Araripe & Feijó (1994). The abbreviations shown in the lithological column (e.g., PES, JAN, UBA) represent the lithostratigraphic units (formations and members).  
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**Figure 4.** *Cyzicus mawsoni* conchostracan fauna and associated palynofacies. A–C, articulated entire specimens of *Cyzicus mawsoni*, sample Co 061 (UFRJ); scale bar represents 1 mm. D–G, constituents of palynological slide 9801059 (PETROBRAS/CENPES/SEBIPE); all photographs taken using differential interference contrast (DIC). D, E, ‘chitin-like’ fragments of conchostracan carapaces showing growth lines and typical polygonal shapes. F, *Dictyophyllidites harrisii* and amorphous organic matter (AOM). G, palynofacies dominated by AOM, with rare pollen grains (arrow indicates the pollen grain *Inaperturopollenites turbatus*). Scale bars represent 20  $\mu\text{m}$  for D–F; 150  $\mu\text{m}$  for G.

*Type species.* *Estheriina brasiliensis* Jones, 1897

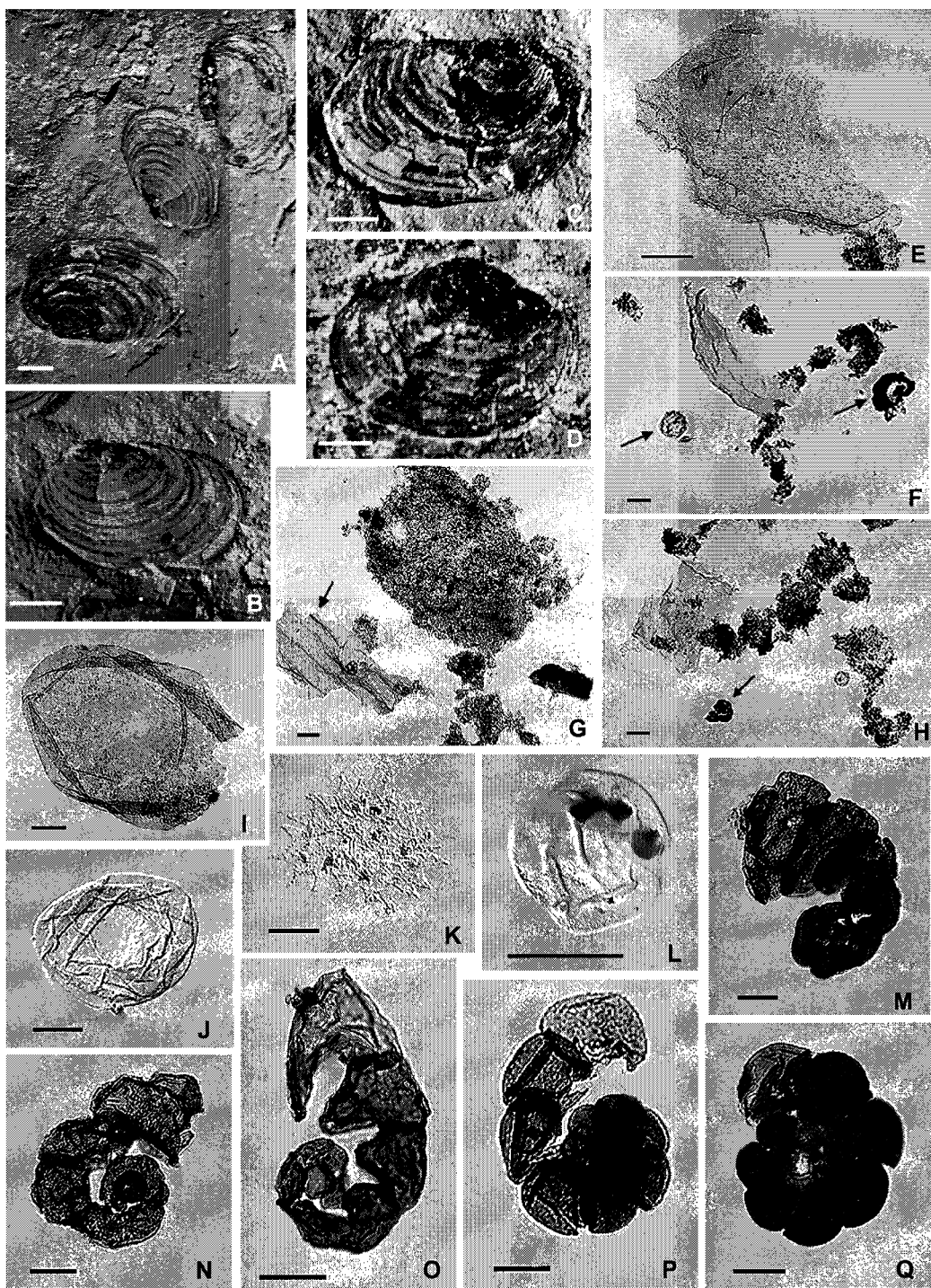
*Estheriina astartoides* Jones, 1897b

Figure 5A–D

*Description.* Carapace somewhat gibbose, subcircular to subovate. Pronounced concentric ridgelets near the umbo, on the swollen and thick part of each valve. Faint concentric lines on the broad, flat areas of the free margins. Feeble traces of some transverse lineation in the larger concentric interstices. Differences in the shape of the valves are either related to sexual dimorphism (subcircular, female?; subovate, male?) or to ontogenetic stages. Umbonal sector with widely spaced growth bands is distinct from the rest of the valve (flattened or not), with more widely spaced growth bands.

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**Figure 5.** *Estherina astartoides* conchostracan fauna and associated palynofacies. A, general view of the *Estherina astartoides* fauna, with well-preserved carapaces. B–D, specimens of *E. astartoides* showing dimorphic valves: B, C, suboval; D, subcircular. Scale bars for A–D represent 1 mm. E–Q, constituents of palynological slide 9801060 (PETROBRAS/CENPES/SEBIPE); all photographs taken using differential interference contrast (DIC) unless otherwise stated. E, chitinous conchostracan fragment with one discernible growth line. F–H, general views of palynofacies (without DIC), dominated by AOM, with common ‘chitin-like’ fragments. F, arrows indicate a dark palynoforaminifer and a possible conchostracan egg shell. G, arrow indicates a possible fragment of conchostracan carapace. H, arrow points to a palynoforaminifer. Scale bars for F–H represent 50  $\mu$ m. I, J, conchostracan egg shells? K, *Pediastrum* sp. L, *Cretacaeiporites mulleri*. M–Q, various undetermined palynoforaminifera. Scale bars for I–Q represent 20  $\mu$ m.

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**Table 1.** Correlation between Upper Jurassic–Lower Cretaceous international and Brazilian stages, as proposed by Arai *et al.* (1989; slightly modified).

Brazilian Local Stages	International Stages	Age (My)
Alagoas	Lower Aptian–Lower Albian	112

Jiquiá	Upper Barremian (upper part)–Lower Aptian	118
Buracica	Upper Barremian (lower part)	120
Aratu	Hauterivian?–Lower Barremian	122
Rio da Serra	Berriasian?–Hauterivian?	130?
Dom João	Callovian?–Lower Berriasian?	143?
		165?

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spaced growth bands. Dorsal margin short both behind and in front of umbo; umbo close to the anterior margin.

### 3. Geological and chronostratigraphical setting of the Potiguar conchostracan faunas

The *Cyzicus mawsoni* fauna was recovered from a dark grey shale in the lower section of the Pendência Formation (Araripe & Feijó, 1994), a rock unit of non-marine origin related to the rift stage of the Potiguar Basin (Figure 3). Both palynological and ostracod evidence indicate a ‘Rio da Serra age’ (Brazilian local stage; see Arai *et al.*, 1989 and Table 1) for the onshore Três-Marias (TM) core samples (Figure 2).

A palynological preparation of the conchostracan-rich level revealed a palynofacies dominated by amorphous organic matter, a few poorly preserved pollen grains, including *Classopollis* sp. and the inaperturate *Araucariacites* sp. and *Inaperturopollenites turbatus* Regali *et al.*, 1974, and rare trilete spores (*Dictyophylidites harrisii* Couper, 1958). Both palynofacies and sedimentological data point to a low terrigenous input to a shallow lacustrine basin at the time. Several thick



'chitin-like' fragments, polygonal in shape and with common growth lines, were encountered. These are probably remains of conchostracan carapaces (Figure 4D–E).

The *Estheriina astartoides* fauna comes from the lower section of the Jandaíra Formation. This rock unit, which ranges from the Lower Turonian to the Middle Campanian, consists mainly of carbonate marine facies (Araripe & Feijó, 1994; see Figure 3). A regional study interpreted two main depositional models for the formation, one with terrigenous input and the other without it (Monteiro & Faria, 1990).

The formation also includes evaporites, with primary and secondary gypsum layers. The section that is exposed in the Gypsum Quarry of Governador Dix-Sept Rosado (Figure 2) comprises the association of facies shown in Figure 6. The lower third of the outcrop is composed of grey shales and decimetre-thick marls, intercalations of fibrous and columnar gypsite with laminated claystones, passing at the top into massive claystones with centimetre-thick horizontal and curved bands of fibrous gypsite (layers 2–8 in Figure 6). In the middle third columnar and fibrous gypsite prevails, but subordinate reddish nodular gypsite and marls are also present (layer 9 in Figure 6). The upper third begins with a massive red claystone with minor, millimetre-thick hyaline gypsite layers at the top (layers 11–11a in Figure 6). Above, a succession of metre-thick, massive grey claystones with interbedded brown marls passes upwards to interbedded light brown, massive marls, calcilutites and calcarenites. The uppermost bioclastic muddy calcarenite (layer 14 in Figure 6) contains remains of bivalves, bryozoans, echinoid spines and plates, benthic foraminifera (*Pyrgo* and *Triloculina*) and

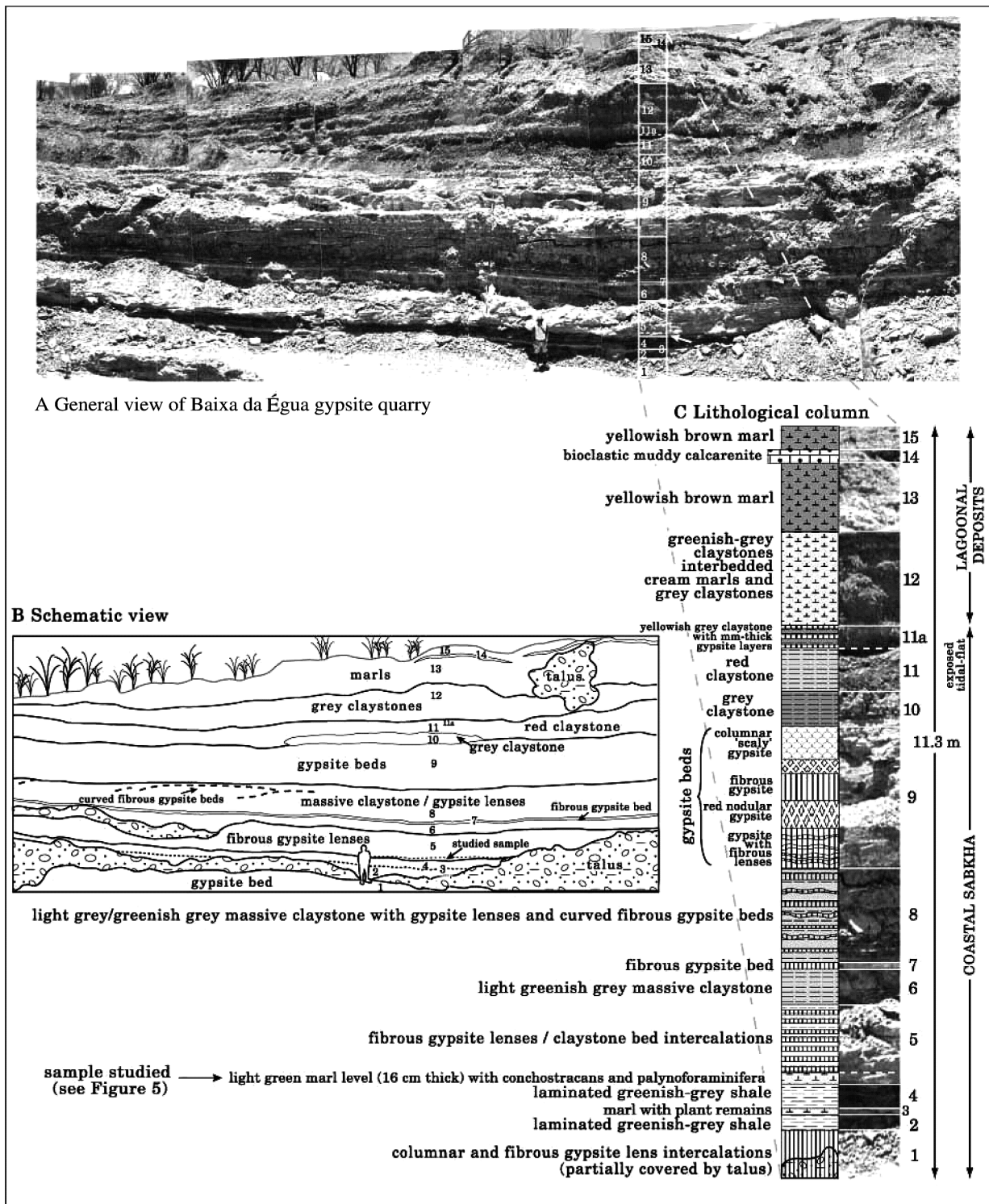
fragments of crustaceans.

The facies exposed have been interpreted as lagoonal evaporitic deposits, built up in isolated basins nourished by the sea (Rebouças, 1962), or indicating a restricted, evaporitic, supratidal depositional environment with known marine connection (Farias *et al.*, 1990; Monteiro & Faria, 1990). Bagnoli & Farias (1994, p. 27) interpreted the exposed section as “an initially supratidal, restricted depositional environment, depositing evaporites in depressions of a coastal sabkha. The sea transgressed over this lowland and finally a lagoon, with increasingly more open sea water conditions, was established.” The bioclastic muddy calcarenite would indicate some incursions of less restricted marine waters in the lagoon.

The *Estheriina astartoides* fauna was recovered from a light green marl lying immediately beneath the lower gypsum-rich layer (bottom of layer 5 in Figure 6).

Precise dating of this part of the Jandaíra succession has proved difficult because of a lack of age-diagnostic micro- and macrofossils. Rebouças (1962) suggested an early Turonian age because the overlying limestones were supposed to be of this age. More recently, Pereira (1994) proposed a chronostratigraphic framework for the filling of several Brazilian marginal basins, including the Potiguar Basin, based on the time-correlation of tectonic and eustatic events recorded from the Brazilian continental margin. He considered the gypsum-rich deposits of Dixt-Sept





**Figure 6.** Baixa da Égua gypsite quarry in Dix-Sept Rosado County (A) with schematic descriptions of sedimentary facies (B, C). The white arrow points to the marl level with *Estheriina astartoides* fauna. This photograph (courtesy of P. R. C. de Farias) and the sample were taken at the beginning of the 1990s when most of the gypsite facies and associated beds in the quarry were exposed, including the lowermost gypsite layers.

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Rosado to be related to a marine regressive phase of late Turonian age.

The palynological content of the marl is dominated by amorphous organic matter, and palynoforaminifera (organic remains of foraminifera; foraminiferal linings) predominate among the palynomorphs. These are represented by both planispiral and trochospiral morphotypes, and are probably related to small agglutinated benthic foraminifera (Figure 5M–Q). Several specimens of the colonial algae *Pediastrum* sp.

(Figure 5K) also occur along with numerous indeterminate inaperturate corpuscles with spherical to ovoid shapes (conchostracan egg shells?), as seen in Figure 5I, J. Brownish particles of irregular shape also occur, and the rare growth lines observed suggest their conchostracan origin (Figure 5E–H). The sporomorphs, which constitute the allochthonous, land-derived fraction, are represented by rare pollen grains of *Cretacaeiporites mulleri* Herngreen 1974 (with an Albian–Campanian age-range), dwarf tricolporate forms and a few indeterminate perisporate spores.

#### **4. Taphonomic remarks**

The valves of *Cyzicus mawsoni* are brownish in colour. This either reflects the appearance of the original carapace or is a result of thermal alteration following burial (cf. Tasch, 1977).

The *Estheriina astartoides* fauna is composed of male and female specimens in which the bivalved carapaces are flattened in marl; open articulated valves are commonly preserved.

Both conchostracan faunas are very well preserved, being composed of entire and undamaged carapaces. There is no evidence of transportation and reworking.

#### **5. Similarities between Brazilian and African conchostracan species**

Jones (1897c) first described *Cyzicus mawsoni* from Lower Cretaceous rocks (Ilhas Group, Rio da Serra and Aratu local stages) in the Recôncavo Basin (Figure 1). A variety of this species (*C. mawsoni* var. *mirandibensis*) was described by Cardoso (1966) from the Upper Jurassic Aliança Formation in the

Mirandiba Basin (Figure 1).

A correlation between the Brazilian and international Upper Jurassic–Lower Cretaceous stages, presented by Arai *et al.* (1989), is shown in Table 1. In Africa, Defretin & Boureau (1952) and Defretin (1953) identified *Cyzicus mawsoni* in the Cameroon Basin (Pont du Mayo Loutit locality). These are the same age as the Brazilian specimens from the Recôncavo Basin (Figure 1). Some specimens from the Lower Cretaceous of the Congo Basin, including *Cyzicus mangaliensis* (Jones, 1862), *C. malangensis* (Marlière, 1950), *C. lerichei* (Marlière, 1950) and *C. sambaensis* (Defretin-Lefranc, 1963), closely resemble each other as well as *Estheriina astartoides* (Marlière, 1950; Defretin-Lefranc, 1967; Tasch, 1987). Young specimens of *Cyzicus malangensis* can be confused with *C. lerichei*. These similarities suggest that the species are probably the ontogenetic stages of a single taxon. *Cyzicus gabonensis* (Marlière, 1950), which was described from the Gabon Basin (Série d'Agoula, Lower Cretaceous), is also similar to *Estheriina astartoides*. All of these *Cyzicus* species can probably be referred to *Estheriina astartoides*.

The similarities of the conchostracan faunas of Brazil and Africa are, not surprisingly, related to the palaeogeography of the southern continents during the Early Cretaceous. As noted by Tasch (1979), *Cyzicus* and *Estheriina* are among the conchostracans that were cosmopolitan on the southern continents (South America and Australia), and cyziciids spread as far north as the Algerian Sahara. The low diversity of the faunas may have been because other forms were out-competed by the dominant cyziciid species. Tasch (1979) postulated the Congo, Angola and northeast Brazil as a centre of conchostracan distribution during

the Early Cretaceous. The extreme resistance of conchostracan eggs to desiccation, the fact that they are easily wind-transported, and their capacity for hatching during flooding events (Tasch, 1987), together with a rapid life cycle, probably explains the dispersal of the species among the several basins.

## 6. Palaeoecological discussion

The Early Cretaceous conchostracan occurrences in northeast Brazil and West Africa are all in non-marine sedimentary facies, but this is not the case for the Late Cretaceous fauna. Almost all previous palaeontological reports that concern the Jandaíra Formation refer only to marine macro- and microfossils (Maury, 1924, 1934; Beurlen, 1961a, b, 1964; Viviers *et al.*, 1992, among others), the exception being Rebouças's work (1962) on the sedimentology and palaeontology of the gypsum mines of Dix-Sept Rosado County. Rebouças recognized that the delicate, chitinous, two-valved shells with numerous growth lines, which were abundant in the argillaceous layers of the mines, belonged to the genus *Estheria* (now no longer a valid conchostracan genus), and that these testify to the existence of temporary freshwater ponds within a general lagoonal-evaporitic environment. The coexistence of unequivocal marine microfossils (palynoforaminifera) and conchostracans, which are usually presumed to

live in freshwater environments, therefore represents an apparent paradox.

Living conchostracans are commonly found in small, temporary, freshwater inland pools, but they can also occur in more saline environments such as

large playa lakes and coastal salt flats (Hutchinson *et al.*, 1932; Tasch, 1961). The pH of these waters generally varies from neutral to alkaline in temperatures ranging from 13–41°C. Dissolved oxygen levels should be more than 0.4 ppm at 23°C (Gislén, 1936; Bishop, 1967; Rzoska, 1961; Moore & Burn, 1968).

Although most fossil conchostracans are presumed to have lived in freshwater endorheic environments in conditions similar to those of the most common extant forms (Webb, 1979; Frank, 1988), based upon analyses of their distribution in Palaeozoic and Mesozoic rocks of Europe and Asia, Kobayashi (1954) considered that they could have inhabited shallow seas. Tasch (1961) attributed the association of conchostracans with marine faunas to the existence of temporary pools close to ancient fluctuating shorelines or lagoons, so that episodic invasion of the sea over such areas could have mixed the faunas. Other possibilities include the dispersal of conchostracan eggs to near-shore marine or estuarine areas, and torrential flooding that covered pools temporarily, forming a widespread sheet of water that drained towards the sea, mingling the faunas. Webb (1979) postulated that some fossil species inhabited at least brackish and possibly marine environments, because living forms can withstand brackish water and many conchostracan assemblages have been found associated with saltwater faunas. Gierlowsky-Kordesch & Rust (1994) recorded conchostracans from the finely laminated shale facies of the Jurassic East Berlin Formation of the Newark Supergroup. These occur within a black shale unit and were interpreted as lacustrine facies that accumulated in a saline lake-playa system that was sometimes affected by palaeosol development. According to Gierlowsky-Kordesch & Rust, the con-

costracans recovered could have been subsaline to stenohaline varieties.

The palaeoenvironmental context of the gypsite quarry of Dix-Sept Rosado, along with taphonomic aspects of the conchostracan fauna, suggest that some Late Cretaceous conchostracans were euryhaline forms, certainly capable of tolerating at least brackish water. Corroborative evidence that *E. astartoides* was tolerant of raised salinities comes from the analysis of the associated palynofacies. The organic residue consists largely of amorphous, 'blocky' organic matter, virtually lacking any continental palynomorphs and organic matter, and is further characterized by the occurrence of palynoforaminifera. These could have been opportunistic agglutinating foraminifera that tolerated low salinity conditions, as has been reported from some levels of the Wealden Group (Lower Cretaceous) in the Isle of Wight, southern England (Radley, 1994, 1995).

The associated specimens of *Pediastrum* can also be ascribed to the inferred brackish environmental conditions, since modern species of these algae are most typical at salinities below 1.7–3.5‰ (Tyson, 1995). Several records of these fossil algae from marine strata have led some authors to question the palaeoecological significance of *Pediastrum* as an exclusive indicator of freshwater environments (Evitt, 1963; Singh *et al.*, 1973; Singh & Khanna, 1978). The usual interpretation of these fossil occurrences in marine or coastal deposits is that they have been transported from freshwater environments (Uwins & Batten, 1988; Powell *et al.*, 1990; Batten, 1996a). Their abundance in many Cenozoic and some Mesozoic lacustrine oil shales might, however, be attributable more to the ecological requirements of *Pediastrum*. They are often

associated with eutrophic water conditions (Tyson, 1995; Batten, 1996b).

## 7. Concluding remarks

Our study confirms the cosmopolitanism of the fossil genera *Cyzicus* and *Estheriina* in the southern continents during the Early Cretaceous. The dispersal of conchostracans among the Gondwanan basins was probably a result of the extreme resistance of their eggs to desiccation and their rapid life cycles. The two conchostracan faunas investigated imply different depositional conditions. Whereas the genus *Cyzicus* inhabited exclusively freshwater environments, *Estheriina astartoides* may have been able to withstand more saline conditions, such as in the evaporitic, supratidal environment indicated by the gypsum-rich deposits of the Jandaíra Formation of the Potiguar Basin, which were related to a marine depositional system.

## Acknowledgments

We thank PETROBRAS (CENPES), Fundação Universitária José Bonifácio/Rio de Janeiro Federal University and Fundação de Amparo à Pesquisa do Rio de Janeiro (FAPERJ) for funding support. José Henrique Gonçalves de Mello (PETROBRAS/CENPES) is thanked for making linguistic and other amendments. Rosemarie Rohn Davies (Universidade Estadual Paulista, São Paulo) reviewed the manuscript and offered many excellent suggestions for its improvement. We especially thank Paulo R. C. de



Farias for kindly making available material from the Baixa da Égua gypsite quarry and for useful discussions. We also thank Dr John Hudson for helpful remarks and David Batten for his constructive review.

## References

- Arai, M., Hashimoto, A. T. & Uesugui, N. 1989. Significado cronoestratigráfico da associação microflorística do Cretáceo Inferior do Brasil. *Boletim de Geociências da PETROBRAS* 3, 87–103.
- Araripe, P. T. & Feijó, F. J. 1994. Bacia Potiguar. *Boletim de Geociências da PETROBRAS* 8, 127–141.
- Bagnoli, E. & Farias, P. R. C. 1994. *Field trip guide to Potiguar Basin, 14th International Sedimentological Congress, Recife, 1994*, 44 pp.
- Batten, D. J. 1996a. Palynofacies and paleoenvironmental interpretation. Chapter 26A. In *Palynology: principles and applications* 3 (eds Jansonius, J. & McGregor, D. C.), pp. 1011–1064 (American Association of Stratigraphic Palynologists' Foundation, Dallas).
- Batten, D. J. 1996b. Colonial Chlorococcales. Chapter 7C. In *Palynology: principles and applications* 1 (eds Jansonius, J. & McGregor, D. C.), pp. 191–203 (American Association of Stratigraphic Palynologists' Foundation, Dallas).
- Beurlen, K. 1961a. Observações geopaleontológicas no Cretáceo do Rio Grande do Norte e Ceará, com descrições de amonóides. *Coleção Mossoroense, Série B* 58, 1–12.
- Beurlen, K. 1961b. O Turoniano marinho do nordeste do Brasil. *Boletim da Sociedade Brasileira de Geologia* 10, 39–52.
- Beurlen, K. 1964. A fauna do Calcário Jandaíra da região de Mossoró (Rio Grande do Norte). *Coleção Mossoroense* 13, 215 pp.
- Bishop, J. A. 1967. Seasonal occurrence of a branchiopod crustacean *Limnadia stanleyana* King (Conchostraca) in eastern Australia. *Journal of Animal Ecology* 36, 77–95.
- Cardoso, R. N. 1966. Conchostráceos do Grupo Bahia. *Boletim do Instituto de Geologia* 1, 43–76.
- Carvalho, I. S. 1993. *Os conchostráceos fósseis das bacias interiores do Nordeste do Brasil*. Unpublished PhD thesis, Federal University of Rio de Janeiro, Volume 1: 319 pp.; Volume 2: 223 pp.
- De Wit, M. J., Margaret, J. & Hugh, B. 1988. Geological map of sectors of Gondwana reconstructed to their disposition – 150 Ma. (American Association of Petroleum Geologists, Tulsa).
- Defretin, S. & Boureau, E. 1952. Le Wealdien du Nord-Cameroun.

- Comptes Rendues de l'Académie des Sciences, Paris* **34**, 1459–1460.
- Defretin, S. 1953. Quelques conchostracés du Nord-Cameroun. *Bulletin du Service du Territoire de Cameroun* **1**, 111–120.
- Defretin-Lefranc, S. 1967. Étude sur les phyllopoques du Bassin du Congo. *Annales du Musée Royal de l'Afrique Centrale, Série In 8°, Sciences Géologiques* **56**, 122 pp.
- Evitt, W. R. 1963. Occurrence of freshwater alga *Pediastrum* in Cretaceous marine sediments. *American Journal of Science* **261**, 890–893.
- Farias, P. R. C., Castro, J. C., Tibana, P. & Barrocas, S. L. S. 1990. Cretáceo da Bacia Potiguar. PETROBRAS, unpublished internal report, 25 pp.
- Frank, P. W. 1988. Conchostraca. *Palaeogeography, Palaeoclimatology, Palaeoecology* **62**, 399–403.
- Gierlowsky-Kordesch, E. & Rust, B. R. 1994. The Jurassic East Berlin Formation, Hartford Basin, Newark Supergroup (Connecticut and Massachusetts): a saline lake-playa-alluvial plain system. In *Sedimentology and geochemistry of modern and ancient saline lakes* (eds Renault, R. W. & Last, W. M.), *SEPM (Society for Sedimentary Geology) Special Publication* **50**, 249–265.
- Gislén, T. 1936. Contributions to the ecology of *Limnadia*. *Acta Universitatis Lundensis, Lund Universitet N.F. Avd. 2* **32**, 1–20.
- Hutchinson, G. E., Pichford, G. E. & Schuurman, J. F. M. 1932. A contribution to the hydrobiology of pans and other inland waters of South Africa. *Archives of Hydrobiology* **24**, 1–154.
- Jones, T. R. 1897a. On some fossil Entomotraca from South America. Part II. *Geological Magazine, New Series, Decade IV* **4**, 289–293.
- Jones, T. R. 1897b. On some fossil Entomotraca from Brazil. *Geological Magazine, New Series, Decade IV* **4**, 195–202.
- Jones, T. R. 1897c. On some fossil Entomotraca from South America. Part I. *Geological Magazine, New Series, Decade IV* **3–4**, 259–265.
- Kobayashi, T. 1954. Fossil estherians and allied fossils. *Journal of the Faculty of Sciences, Tokyo University* **9**, 1–192.
- Marlière, R. 1950. Ostracodes et Phyllopoques du Système du Karroo au Congo Belge et les régions avoisinantes. *Annales du Musée du Congo Belge, Série In 8°, Sciences Géologiques* **6**, 43 pp.
- Maury, C. J. 1924. Fósseis cretáceos do Rio Grande do Norte. In *Fósseis Terciários do Brasil. Serviço de Geologia e Mineralogia do Brasil, Monografia* **4**, 495–551; 555–585.
- Maury, C. J. 1934. Fossil Invertebrata from northeastern Brazil. *Bulletin of the American Museum of Natural History* **67**, 123–179.
- Monteiro, M. C. & Faria, R. T. 1990. Formação Jandaíra. PETROBRAS, unpublished internal report, 7 pp.

- Moore, W. G. & Burn, A. 1968. Lethal oxygen thresholds for certain temporary pond invertebrates and their applicability to field situations. *Ecology* **49**, 349–351.
- Musacchio, E. 1970. Ostracodos de las superfamilias Cytheracea y Darwinulacea de la Formación La Amarga (Cretácico Inferior) en la Provincia de Neuquen, Republica Argentina. *Ameghiniana* **7**, 301–316.
- Pereira, M. J. 1994. *Seqüências deposicionais de Segunda e Terceira Ordem (50 a 2.0 Ma) e tectono-estratigrafia no Cretáceo de cinco bacias marginais brasileiras: comparação com outras áreas do globo e implicações geodinâmicas*. Unpublished PhD thesis, Federal University of Rio Grande do Sul, Volume 1: 280 pp.; Volume 2: 210 pp.
- Powell, A. J., Dodge, J. D. & Lewis, J. 1990. Late Neogene to Pleistocene palynological facies of the Peruvian continental margin upwelling, Leg 112. *Proceedings of the Ocean Drilling Program, Scientific Results* **112**, 297–321.
- Radley, J. D. 1994. A foraminiferal datum in the Vectis Formation (Wealden Group, Lower Cretaceous) of the Isle of Wight. *Proceedings of the Geologists' Association* **99**, 133–140.
- Radley, J. D. 1995. Foraminifera from the Vectis Formation (Wealden Group, Lower Cretaceous) of the Wessex Sub-basin, southern England: a preliminary account. *Cretaceous Research* **16**, 717–726.
- Rebouças, A. C. 1962. Estudo sedimentológico e paleontológico do perfil das minas de gipsita-Mossoró (RN). *Coleção Mossoroense, Série B*, **61**, 245–258.
- Rzoska, J. 1961. Observations on tropical rainpools and general remarks on temporary waters. *Hydrobiology* **17**, 265–286.
- Singh, H. P., Khanna, A. K. & Sah, S. C. D. 1973. Problems and prospects of Tertiary palynology in northern India. *Bulletin of the Indian Geologists' Association* **6**, 71–77.
- Singh, H. P. & Khanna, A. K. 1978. Some fossil species of *Pediastrum* and their palaeoecological significance in the Subathu Formation of Himachal Pradesh. *The Palaeobotanist* **25**, 466–473.
- Tasch, P. 1961. Paleolimnology. Part 2. Harvey and Sedgwick counties, Kansas. Stratigraphy and biota. *Journal of Paleontology* **35**, 836–865.

- Tasch, P. 1969. Branchiopoda. In *Treatise on invertebrate paleontology, Part R—Arthropoda 4, Crustacea (except Ostracoda)* (ed. Moore, R. C.), pp. 128–191 (Geological Society of America, Boulder, and University of Kansas Press, Lawrence).
- Tasch, P. 1977. Experimental valve geothermometry applied to fossil conchostracan valves, Blizzard Heights, Antarctica. In *Antarctic Geoscience. Symposium on Antarctic Geology and Geophysics, 1977* (ed. Craddock, C.), Part 5, Palaeontology, pp. 661–668 (University of Wisconsin Press, Madison).
- Tasch, P. 1979. Crustacean branchiopod distribution and speciation in Mesozoic lakes of the southern continents. *Antarctic Research Series* **30**, 65–74.

- Tasch, P. 1987. Fossil Conchostraca of the Southern Hemisphere and continental drift. Paleontology, biostratigraphy and dispersal. *Geological Society of America, Memoir* **165**, 290 pp.
- Tyson, R. V. 1995. *Sedimentary organic matter. Organic facies and palynofacies*, 615 pp. (Chapman and Hall, London).
- Uwins, P. R. J. & Batten, D. J. 1988. Early to mid-Cretaceous palynology of northeast Libya. In *Subsurface palynostratigraphy of northeast Libya* (eds El-Arnauti, A., Owens, B. & Thusu, B.), pp. 215–257. (Garyounis University Publications, Benghazi).
- Viviers, M. C., Richter, A. J., Silva-Telles, A., Moura, J., Nascimento, N. L., Dino, R. & Shimabukuru, S. 1992. Bacia Potiguar. In *Bioestratigrafia das bacias Mesozóicas-Cenozóicas Brasileiras* (eds Beurlen, G., Richter, A. J., Cunha, A. S., Silva-Telles, A., Martinis, E., Pedrão, E., Moura, J. A. *et al.*). PETROBRAS, unpublished internal report 2, pp. 337–408.
- Webb, J. A. 1979. A reappraisal of the palaeoecology of conchostracans (Crustacea: Branchiopoda). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* **158**, 259–275.