Palynological and sedimentary analysis of the Igarapé Ipiranga and Querru 1 outcrops of the Itapecuru Formation (Lower Cretaceous, Paraíba Basin), Brazil

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A B S T R A C T

The siliciclastic sediments of the Itapecuru Formation occur in a large area of the Paraíba Basin and its deposits crop out along the Itapecuru River, in Maranhão State, northern Brazil. The palynological analysis of the Igarapé Ipiranga and Querru 1 outcrops strata yields a rich and diversified data. The presence of index-palynomorphs in assemblages allows the identification of the Complicatisaccus cearensis Zone, of Late Aptian-Early Albian age. Terrestrial palynomorphs are abundant in the assemblages, being represented by bryophytes and pteridophytes, especially perisporate trilete spores (Crybelosporites and Perotrilites), and gymnosperms and angiosperms (Afropollis and Elaterosporites). The composition of palynological assemblages suggests the presence of moist soils for both outcrops. Acritarchs were recovered in the Querru 1 outcrop, which suggest a marine setting supporting a tidal flat environment indicated by facies associations. Furthermore, reworked Paleozoic palynomorphs were observed in the Querru 1 outcrop. The microflora from Igarapé Ipiranga outcrop suggests terrestrial environment corroborating with floodplain environment indicated by facies association.

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1. Introduction

The thick Aptian-Albian deposits of the Itapecuru Formation, which consists of siliciclastic sediments deposited in dominantly continental palaeoenvironments, are exposed throughout a large geographic area in the Paraíba Basin and surrounding basins (Caputo, 1984; Góes and Feijó, 1994; Pedrão et al., 1996; Vaz et al., 2007). This unit is best represented in the subsurface, where it reaches thicknesses of up to 2000 m in the São Luís Basin and 700 m in the Paraíba Basin (Lima and Leite, 1978; Caputo, 1984; Lima et al., 1994; Zalan, 2007). The Itapecuru Formation contains important palynomorphs, which contribute to Early Cretaceous biostratigraphical studies, palaeoenvironment characterization and paleoclimatic interpretation.

A large number of macrofossil and microfossil taxa from the Itapecuru Formation has been documented (Carvalho, 1994; Carvalho et al., 2003; Santos and Carvalho, 2004). Among these microfossils, there are palynomorphs, which are organic remains recovered in palynological preparations, such as spores (bryophytes and pteridophytes), pollen grains (gymnosperms and angiosperms), dinoflagellates, scolecodonts, acritarchs, colonies of chlorophytic algae and prasinophycean phycocyan

The assignment of palynomorphs to terrestrial, freshwater and marine groups, and the variations in abundance of the taxa within these assemblages, alongside sedimentologic data from the Itapecuru Formation, have allowed the development of palaeoenvironmental interpretations (Müller, 1966; Gonçalves and Carvalho, 1996; Rossetti et al., 2001; Pedrao et al., 2002; Vaz et al., 2007; Ferreira, 2015).

The palynomorphs recovered from the Itapecuru Formation allowed the identification of index-fossil bioevents used at biostratigraphic studies (Pedrao, 1995; Pedrao et al., 1996, 2002; Pedrao and Correia-Martins, 1999; Ferreira et al., 2008, 2011; Ferreira, 2015).

The purpose of this study is to characterize biozones based on...
the palynomorphs recovered, to assign relative age dates, and to carry out the paleoecological analysis of the deposits exposed along the banks of the Itapecuru River, in the municipalities of Itapecuru Mirim and Santa Rita, Maranhão State, northern Brazil.

2. Geologic setting

The Parnaíba Basin is located between latitudes 2° and 10° South and longitudes 42° and 48° West (Fig. 1). The basin measures approximately 600,000 km² and extends parts of the states of Piauí, Maranhão, Tocantins, Pará and Ceará (Goes et al., 1989; Goes and Feijó, 1994). The Cretaceous section of this basin is also called the Grajaú Basin by Rossetti et al. (2001).

The Parnaíba Basin contains rocks from the Paleozoic, Mesozoic and Cenozoic ages. The Cretaceous section is represented by the Codó, Grajaú and Itapecuru formations, with the last lithostratigraphic unit being the focus of this study (Fig. 2). This unit conformably overlies the Codó and Grajaú formations and is partially covered by Quaternary sediments (Caputo, 1984). The record of the palynomorph species Sergipea varierrucata in the Codó Formation allowed the identification of a corresponding homonymous zone that dates these deposits to the Late Aptian (Lima, 1982; Pedroa, 1995; Antonioli, 2001; Maizatto et al., 2011).

The Itapecuru Formation was divided into three members...
(lower, middle and upper) based on seismic sections and well profiles. These members are considered to reflect the main stages of rifting during the Gondwana fragmentation. The lower member of the Itapecuru Formation is comprised of sandstones that grade into siltstones. The middle member is composed of sandstones, conglomerates and siltstones. The upper member is predominantly composed of sandstones and siltstones (Aranha et al., 1990; Pedrao et al., 2002).

The Itapecuru Formation was deposited in fluvial, fluvial-estuarine and marine environments (Caputo, 1984; Lima et al., 1994; Gonçalves and Carvalho, 1996; Rossetti et al., 2001; Pedrao et al., 2002; Ferreira et al., 2013; Ferreira, 2015). Tropical to subtropical weathers were suggested for this formation based on the presence of the typical elater-bearing palynomorphs of the Albian-Cenomanian Elaterates Province (Müller, 1966; Pedrao, 1995; Herngreen et al., 1996; Ferreira, 2015). These conditions are...
supported by the palaeogeographic setting of the basin in low latitudes during the Cretaceous (Scotese, 2001).

### 3. Materials and methods

The material for the palynological analysis consisted of 23 samples collected from the Igarapé Ipiranga outcrop (3º15’13.1” S, 44º17’58.6” W) and the Querru 1 outcrop (3º15’27.9” S, 44º19’48.4” W) (Fig. 3). These samples were collected between 8 and 13 December 2013, when the low level of the Itapecuru River allowed access to less weathered exposures of the Itapecuru Formation. The criteria for grain-size classification of the samples from the stratigraphic columns were those of Blair and McPherson (1999).

The roundness and circularity scales of Powers (1953) and Rittenhouse and Gordon (1943) were used to characterize the gravel clasts and sand grains, respectively. The Munsell Rock Color Chart (Geological Society of America (1991)) was used to record the colors of the rocks. The sedimentary facies were classified, in part, using the facies identification codes of Miall (1978, 1996).

The sediments underwent palynological processing for Cretaceous rocks recommended by Uesugui (1979) and Wood et al. (1996).

For the semi-quantitative analysis, 300 palynomorphs were counted according to Chang (1967). The author considers this number to correspond to a population and to involve an error of approximately 4%. The relative abundance of each taxon was

### Table 1: Sedimentary Facies

<table>
<thead>
<tr>
<th>Code</th>
<th>Diagnostic Facies</th>
<th>Description</th>
<th>Process of transportation interpreted</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB1</td>
<td>Intraformational massive breccia with sandstone clasts</td>
<td>Intraformational massive breccia with framework formed by irregular fragments of massive fine sandstone of up to 15 cm. The sandstone clasts may be deformed (elongated) and are 10YR7/4 in colour. The matrix is greenish gray (5GY4/1 or 6/1) sandy silt. Intense bioturbation may be present in both the framework and matrix.</td>
<td>Subaqueous gravitational flow affecting pelitic and sandy unconglomerated to semi-consolidated layers; post-depositional changes (bioturbation)</td>
</tr>
<tr>
<td>IB2</td>
<td>Intraformational breccia with claystone clasts</td>
<td>Massive intraformational breccia with framework formed by claystone clasts and matrix of fine to medium sand; centimetric thicknesses, located at the base of sets of trough cross structures. The colour of the sandy matrix is 10YR8/2.</td>
<td>Accumulation of pelitic clasts at the base of sandy megaform; erosion of pelitic substrate</td>
</tr>
<tr>
<td>D</td>
<td>Diamictite with bioclasts</td>
<td>Diamictite with mud matrix (5GY4/1) and fine sandstone pebbles (10YR7/4) and dispersed bioclasts (fish teeth and scales, coal), massive.</td>
<td>Subaqueous gravity flow.</td>
</tr>
<tr>
<td>Sh</td>
<td>Pebblly sandstone with plane-parallel stratification</td>
<td>Very fine, silty sandstone with fine clay pebbles and fine silicified sandstone pebbles and granules, rounded and highly spherical; plane-parallel laminations and stratification and bioturbation (Skolithos); 5GY6/1.</td>
<td>Superposition of sand sheets in upper flow regime.</td>
</tr>
<tr>
<td>Sm</td>
<td>Massive sandstone</td>
<td>Very fine micaceous sandstone, massive, 5Y7/2.</td>
<td>Driving hydrodynamic flow; post-depositional changes</td>
</tr>
<tr>
<td>St</td>
<td>Sandstone with interbedded mudstone and trough cross-stratification</td>
<td>Fine to medium sandstone, micaceous, with wavy bedding. Trough cross stratification in sets of decimetric thickness with grain size decreasing upward and clay intracalcs at the base of the deposit. Deformation of the cross structures may represent slipping of the frontal face of the dune. 5Y5/2 or 7/2 and 10YR7/4 or 8/2.</td>
<td>Driving unidirectional flow, migration of mid-size dunes with sinuous ridges.</td>
</tr>
<tr>
<td>Sr</td>
<td>Sandstone with cross-lamination</td>
<td>Very fine to medium sandstone, micaceous with cross laminations, sets of 4-5 cm, with mud drapes. 10YR7/4.</td>
<td>Unidirectional driving flow, migration of sandy wavelites and clay settling over the bedforms at times of hydrodynamic current stops.</td>
</tr>
<tr>
<td>Fm1</td>
<td>Massive sandy siltstone</td>
<td>Massive sandy siltstone, 5GY4/1 or 6/1, with strong motling near the ground surface.</td>
<td>Setting of fine sediments and post-depositional changes</td>
</tr>
<tr>
<td>Fm2</td>
<td>Massive to weakly laminated mudstone</td>
<td>Silty claystone, micaceous, massive to weakly laminated.</td>
<td>Setting of fine sediments and post-depositional changes</td>
</tr>
<tr>
<td>HF</td>
<td>Pelite with heterolithic facies</td>
<td>Silty mudstone with linsen lamination and subordinate wavy lamination; 5Y6/1; intensely bioturbated (Planolites)</td>
<td>Setting of fine sediments and migration of scarce isolated sandy wavelites.</td>
</tr>
</tbody>
</table>

Fig. 4. Relationship and summary description of the sedimentary facies identified in the Igarapé Ipiranga and Querru 1 outcrops. Sedimentary facies code partially adopted from Miall (1978, 1996).
assigned to one of three verbal classes: present (1–3 specimens), common (4–30 specimens) and abundant (more than 30 specimens). The percentages are shown in the stratigraphic distribution charts of both outcrops.

4. Results and discussion

4.1. Sedimentary study

Ten sedimentary facies were identified in the Igarapé Ipiranga and Querru 1 outcrops (Figs. 4–6).

The sedimentary facies association 1 observed in the Igarapé Ipiranga profile (Fig. 3) includes very fine to fine sandstones with plane-parallel stratification (Sh facies), massive sandstones (Sm facies) and interbedded mudstone layers (Fm1 facies) of decimetric thickness. Intraformational breccias (IB1 facies) and diamictites (D facies) were also observed. These facies represent a river floodplain depositional environment, most likely one of a meandering river, with a predominantly pelitic sedimentation and strong bioturbation. The fine sandstone facies (Sh and Sm) are attributed to crevasse splays, and the intraformational breccias and diamictites were likely deposited by subaqueous gravitational flows. The sources of the diamictites and intraformational breccias most likely consisted of unconsolidated or semi-consolidated mud and sand layers eroded from the marginal levees of the meander channels in the proximal zones of the breach fans.

The Querru 1 outcrop (Fig. 3) has three distinct sedimentary facies associations. Facies association 2 consists of a 1.50 m-thick heterolithic deposit (HF facies). Facies association 3 consists primarily of sandstones with wavy bedding and trough cross-stratification (St facies), interbedded mudstones and thin layers of intraformational breccias (IB2 facies). Facies association 4 is composed mainly of fine cross-laminated sandstones (Sr facies) and mud drapes. Based on these three facies associations, it is inferred...
that the Querru 1 outcrop represents a tidal flats depositional environment (Martinius et al., 2001; Zacharias and Assine, 2005).

4.2. Palynological study

Twenty-three samples were collected from the Igarapé Ipiranga and Querru 1 outcrops of the Itapecuru Formation and analyzed semi-quantitatively (Figs. 7 and 8). Of the 23 samples collected, 20 contained well-preserved palynological assemblages that included a total of 116 palynomorph taxa (Figs. 9–11; Appendix A). Three samples did not contain palynomorphs, but yield a considerable phytoclasts. The assemblages consist of gymnosperm (68 taxa) and angiosperm pollen (19 taxa) grains, and bryophyte (2 taxa) and pteridophyte spores (12 taxa). Palynomorphs of unknown botanical affinity (6 taxa), Chlorococcalean algae spores (2 taxa) and colonies (1 taxon) were also identified. Furthermore, acritarchs and phyco- mataires of prasinophycean algae are recovered only in the Querru 1 outcrop.

4.2.1. Igarapé Ipiranga outcrop

Only samples IIP6 (142 cm) and IIP7 (164 cm), collected from the silt fraction of the Fm1 facies, showed richer palynological assemblages. The stratigraphic distribution of palynomorphs is exhibited in Fig. 8. The assemblages are dominated by terrestrial palynomorphs which are composed by perisporate trilete spores belonging to the genera *Perotrilites* and *Crybelosporites*. Inaperturate, reticulate tricolpate and polyplicate pollen grains display great morphological variation, but are not abundant.

Marine palynomorphs are represented by acritarchs of subgroups Acanthomorphitae, Polygonomorphitae and Herkomorphitae, according to the systematic classification proposed by Downie et al. (1963). Acritarchs have uncertain biological affinities (Evitt, 1963; Martin, 1993) or have been interpreted as unicellular protozoan (Strother, 1996) or microphytoplankton cysts (Le Hérissé et al.,
2009).

Duvernaysphaera angelae Deunff 1964 and Umbellasphaeridium saharicum Jardine et al., 1974 are among the acritarch taxa identified (Figs. 11.10 and 11.17). Both are widespread in the Devonian strata of Brazilian Paleozoic basins and are interpreted herein as reworked palynomorphs. D. angelae occurs in Middle to Late Devonian deposits in the Algerian Sahara (Jardine et al., 1974), and in late Early to Late Devonian deposits of the Parnaiba Basin and other South American basins (Brito, 1976; Wicander and Wood, 1981; Melo, 2000). U. saharicum has been reported in Late Devonian sequences of the Algerian Sahara (Jardine et al., 1974) and of nearly all Paleozoic basins of Brazil (Quadros, 1980, 1985; Oliveira, 1997; Cruz, 2011). A fragmentary specimen doubtfully of the assigned to the genus Exochordera (Fig. 11.18) could have been reworked from the Devonian. Furthermore, others specimens related to mainly of Acanthomorphitae subgroup (Fig. 11.3) are not restricted to Paleozoic sections (Martínez et al., 2008). Their range of M. mosesii, Maranhites spp., Tasmanites spp., and Cymatiosphaera? sp. (Figs. 11.8, 11.9, 11.15), all of which are considered as phycocomata of prasinophycean algae (Guy-Olson, 1996). Maranhites specimens are Devonian reworked palynomorphs based on a taxonomic and stratigraphic reappraisal by Le Hérisse (2011). The genus Maranhites is common in the Middle and Upper Devonian of South America, particularly in Brazil and Bolivia (Brito, 1978; Le Hérisse, 2009). According to Le Hérisse (2011), the known stratigraphic range of M. mosesii extends from Frasnian through the late Famennian. In turn, occurrences of M. mosesii in Mississippian rocks (Brito, 1971, 1978; Burjack and Oliveira, 1989) are now regarded as reworked (Le Hérisse, 2011). Lastly, algal phycocomata of the genus Tasmanites are common in Brazilian Paleozoic basins (Müller, 1966; Quadros, 2002), and their occurrences in the Itapecuru Formation are interpreted as possibly reworked, even though the genus is also known from post-Paleozoic strata elsewhere in the world (Fensome et al., 1990; Barron et al., 2015). The same applies to Cymatosphaera, a long-ranging (Paleozoic—Neogene) prasinophyte genus common in Brazilian Paleozoic basins, and uncertainly identified in the Queru 1 material.

4.3. Biostratigraphy

The palynostratigraphic framework proposed by Regali et al. (1974) was used for the relative dating of the terrestrial sedimentary sequences of the Lower Cretaceous of Brazil. This framework was modified during the biostratigraphic studies by Beurlen and Regali (1987) in the Pará–Maranhão Basin, where the Complicatisaccus cearensis Zone was defined and included. Later, in the palynological studies in the Ceará Basin, Regali (1989) identified the C. cearensis Zone (Fig. 12), adopted in this work. The biozone was divided into four parts (Basal, Lower, Middle and Upper). The last occurrence of S. variverrucata and the first occurrence of Elateropollenites jardinei and C. polygonalis define the base and top of the Basal part, respectively. The base of the Lower part is defined by the first occurrences of E. jardinei and C. polygonalis, and its top indicated by the last occurrence of Elateropollenites praecursor. The base of the Middle part is characterized by the last occurrence of E. praecursor, and the top by the last occurrence of Elateropollenites dissimilis. Finally, the base of the Upper part is marked by the last occurrence of E. dissimilis, and the top is defined by an unconformity and records the last occurrences of Quadricolpites reticulatus, Psiladicolpites cuptrans, P. laevis, P. papillatus, Penetetrapites mollis, Paludites mamelonatus, Gnetaceae pollenites concisus and Trisectoris

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![Fig. 7. Stratigraphic distribution of the main palynomorphs of the Igarapé Ipiranga outcrop.](image-url)
Fig. 8. Stratigraphic distribution of the main palynomorphs of the Querru 1 outcrop.
reticulatus. Later, Regali and Santos (1999) characterized the *C. cearensis* Zone in the Sergipe-Alagoas Basin and defined five subzones (Fig. 12). These subzones were correlated and calibrated with the *Globigerinelloides barri-Hedbergella (H.) gorbachikae (AP-1), Globigerinelloides ex. Gr. maridales-Hedbergella (H.) similis (AP-2), Globigerinelloides cushmani—Ticinella bejaovaensis (AL-1) and Ticinella bejaovaensis (AL-2) planktonic foraminifera zones proposed by Koutsoukos and Bengston (1993). Thus, the *C. cearensis* Zone was dated as from the Upper Aptian-Lower Albian section. In this work, the palynostratigraphic framework of Regali (1989) is adopted and the chronostratigraphic interpretation is based on Regali and Santos (1999).

4.3.1. Igarapé Ipiranga outcrop

Species with biostratigraphic value in the Igarapé Ipiranga outcrop include *P. mollis, P. laevis* and *Equisetosporites irregularis*. These palynomorphs indicate the Upper part of the *C. cearensis* Zone (Fig. 13). The following species were also observed: *A. jardinus,*

4.3.2. Querru 1 outcrop

The following species with chronostratigraphic value were identified in the Querru 1 outcrop: E. dissimilis and Pentapsis simplex (P. valdiviae sensu Regali, 1989). These palynomorphs characterize the Middle part of the C. cearensis Zone (Fig. 13). This section contains the following species: A. jardinus, Afropollis aff. A. jardinus, C. polygonalis, C. truncatus, Elaterocolpites castelainii form A, Elaterocolpites castelainii form B, E. jardinii, Elaterosporites klaszi, E. protensus, E. verrucatus, Equisetosporites brasiliensis nov. comb., E. irregularis, Gnetaceaepollenites clathratus form α, G. clathratus form

A divergence from the stratigraphic range of E. protensus and E. verrucatus presented by Regali (1989) was noted. According to Regali (1989, p. 240), the occurrence level of these two species is the base of the E. jardinei Zone and was used to differentiate the C. cearensis Zone from the E. jardinei Zone. However, in the palynological assemblage of the Querru 1 outcrop, E. protensus and E. verrucatus are associated with Q. reticulatus, Pentapsis simplex, E. dissimilis, Pennipollis reticulatus, P. comptus, P. laevis and P. papillatus, which have their last occurrences within the C. cearensis Zone. As a result of this record, the stratigraphic ranges of E. protensus and E. verrucatus may be extended.

Fig. 11. Taxon name followed by grain position, outcrop, sample depth and England Finder coordinates. Scale: 20 μm. 1. Penetetrapites mollis Hedlund and Norris 1968. Polar view, medium focus showing the lenticular and polar openings. Igarapé Ipiranga, Depth 142 cm, B48. 2. Quadricolpites reticulatus Wingate 1980 emend. Ward 1986. Polar view, low focus showing the reticulum. Querru 1, Depth 15 cm, E40-2. 3. Acritarch from the subgroup Acanthomorphitae. High focus showing the processes. Querru 1, Depth 169 cm, D15-4. 6. Ovoidites parvus (Cookson and Dettmann 1959) Nakama 1966. Side view, low focus showing the equatorial slit. Querru 1, Depth 110 cm, L47-2. 7. Botryococcus spp. Side view, high focus showing the equatorial arrangement of the cell colony. Querru 1, Depth 48.5 cm, Q61-3. 8. Maranhitites mosessi (Sommer 1956) Brito 1967. High focus showing the five isolated peripheral structures. Querru 1, Depth 75 cm, G46. 9. Tasmanites spp. High focus showing the narrow wall channels. Querru 1, Depth 48.5 cm, F42-3. 10. Duvernaypypha angulata Deunff 1964. High focus showing the equatorial radial folds and equatorial membrane of the vesicle. Querru 1, Depth 96.5 cm, M44-4. 11. Acritarch of the subgroup Herkomorphitae. High focus showing the cristae on the vesicle surface. Querru 1, Depth 63.5 cm, L50-3. 12. Ovoidites sprigii (Cookson and Dettmann 1959) Zippi 1998. Side view, high focus showing side slit. Querru 1, Depth 86.5 cm, G70-3. 13. Acritarch of the subgroup Acanthomorphitae. High focus showing the processes. Querru 1, Depth 75 cm, P49-4. 14. Acritarch of the subgroup Pterospermophyta. High focus showing the processes. Querru 1, Depth 69.5 cm, H53. 15. Cymatisphaera? sp. High focus, showing the processes. Querru 1, Depth 136.5 cm, S41-1. 16. Acritarch of the subgroup Acanthomorphitae. High focus, showing the processes. Querru 1, Depth 96.5 cm, K48-4. 17. Umbellaphaeridium saharicum Jardine et al. 1972. Low focus on processes. Querru 1, Depth 86.5 cm, U66. 18. Exochoderma? sp. High focus on processes. Querru 1, Depth 75 cm, G43-2.
Among the palynomorph-index species identified, some have also been reported in the Cretaceous sections of Africa. In Morocco, specimens of *Q. reticulatus* were found in Albian deposits of the Tarfaya Basin (Bettar and Mécén, 2001), and *T. reticulatus* (=*Cornetipollis herngreenii*) was found in the Middle-Upper Albian sediments of the Agadir-Essaouira Basin (Bettar and Mécén, 2006). The species *Pennipollis reticulatus* was recorded in the Aptian (Doyle, 1992) and Aptian-Albian sections of Egypt and Morocco (Schrank, 1982; Ibrahim, 1996; Ibrahim et al., 2001; Ibrahim, 2002; Bettar and Mécén, 2006). Taxa of *Elaterosporites* were encountered in Cretaceous deposits of Nigeria (Lawal, 1982; Abubakar et al., 2006), Egypt (Schrank and Ibrahim, 1995) and Ghana (Atta-Peters, 2013). In South America, *Elaterosporites* were documented in Albian-Cenomanian rocks in Colombia (Herngreen and Jimenez, 1990). This genus was also identified in the Albian section of ODP Leg 207 in Demerara, Equatorial Atlantic (Krauspenhar et al., 2014).

5. Palaeoenvironmental considerations

Terrestrial palynomorphs represented by ferns, gymnosperms and angiosperms dominate palynological assemblages of the Igarapé Ipiranga and Querru 1 outcrops, comprising more than 90% of the total assemblages. The Querru 1 assemblages showed a greater richness and diversity of trilete spores and pollen grains than the Igarapé Ipiranga ones.

In the Querru 1 palynological assemblages, high percentages of pollen grains (28–85%) and triletes spores (14–70%) are observed. Taxa of *Afropollis* are abundant and indicate humid tropical weather (Doyle et al., 1982). The genus is represented by *A. jardinus* (up to 32%), *Afropollis aff. A. jardinus* (up to 17%) and *Afropollis* spp. (up to 24%). The polylicate pollen grains show great morphological variation, with *Gnetaceae pollenites* (up to 11%) being more abundant. Taxa of *Elaterosporites*, represented mainly by *E. protensus*, reach up to 7%. Perisporate types are found among the trilete spores and assigned to the genus *Perotrilites* (up to 45%) and *C. pannuceus* (up to 11%), all of them attributed to Marsileaceae and Selaginellaceae. Rare marine palynomorphs represented by acritarchs are present (up to 6%). The intervals with high percentages of perisporate trilete spores (*Perotrilites* and *Crybelosporites*) indicate an environment with extremely moist soil and abundant water availability (marshy). Some specimens of acritarch (Acanthomorphitae, Polygonomorphitae and Herkomorphitae subgroups) were interpreted as evidence of marine influence during deposition. This interpretation corroborates the sedimentary analysis that proposed a tidal flat depositional environment for the Querru 1 outcrop (Figs. 3 and 4). The reworked palynomorphs recovered only from the Querru 1 outcrop suggest that the exposure of the Paleozoic section served as the source area of sediments.

*Fig. 12. Correlation of the palynological and planktonic foraminifera zones of the Ceará and Sergipe basins according to Regali and Santos (1999).*

<table>
<thead>
<tr>
<th>CHRONOSTRATIGRAPHY</th>
<th>PALYNOSTRATIGRAPHY</th>
<th>PLANKTONIC FORAMINIFERA</th>
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<tr>
<td>Ceará Basin</td>
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<td><strong>ALBIAN</strong></td>
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<td>E. jardinii (P-320)</td>
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<td><strong>B. breggiensi-G. toxomaensis</strong> (AL-5)</td>
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<td>echinatus (P-355)</td>
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<td></td>
<td>aliformis (P-330)</td>
<td><em>Gr. primula</em> (AL-3)</td>
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<td></td>
<td><strong>COMPLICATISSACUS</strong></td>
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<td></td>
<td>cearensis (P-280)</td>
<td><strong>PEROTRILITES</strong></td>
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<td></td>
<td><strong>Lower</strong></td>
<td>(P-280.5)</td>
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<td><em>T. bejaouensis</em> (AL-2)</td>
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<td>(P-280.4)</td>
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<td></td>
<td></td>
<td><strong>G. cushima-T. bejaouensis</strong> (AL-1)</td>
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<td><strong>CARDIOANGLINIA</strong></td>
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<td></td>
<td></td>
<td>elongata (P-280.3)</td>
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<td><strong>DEJAXPOLLIDES</strong></td>
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<td>microfoveolatus (P-280.2)</td>
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<td><strong>EQUISETOSPORITES</strong></td>
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<td>maculosus (P-280.1)</td>
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<td><strong>ORNAMENTED INCOLPATE</strong></td>
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<td>pollen grains (P-270.2)</td>
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<td><strong>CICATRICOSPORITES</strong></td>
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<td>sp. 1 (P-270.1)</td>
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**Fig. 1.2. Correlation of the palynological and planktonic foraminifera zones of the Ceará and Sergipe basins according to Regali and Santos (1999).**
6. Conclusions

The sediments of the Querru 1 and Igarapé Ipiranga outcrops were deposited during the Early Cretaceous (Early Albian) according to characterization of the middle/upper C. cearensis Zone. The Querru 1 outcrop is older than the Igarapé Ipiranga outcrop due to the occurrence of the index fossils E. dissimilis and Pentapits simplex. The abundance of perisporal trilete spores related to Marsileaceae and Selaginellaceae and Afropollis indicates humid tropical weather for both outcrops. The presence of acritarchs mainly in heterolithic and mud drapes deposits in Querru 1 outcrop indicates marine influence. The palynological data corroborate the interpretation of tidal flat depositional environment for Querru 1 outcrop indicate by succession of the three facies associations (2, 3 and 4). The palynological data support the succession sedimentary facies as floodplain deposits.

Acknowledgments

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Appendix A

List of palynomorphs

**Spores**

Bryophytes

*Stereisporites* cf. *S. psilatus* (Rouse 1949) Manum 1954


Pteridophytes

*Biretisporites potoniei* Delcourt and Sprumont 1955

*Cicatricosisporites sinuosus* Hunt 1985

![Fig. 13. Stratigraphical distribution of selected taxa from the palynological framework proposed by Regali (1989).](image-url)
Crybelosporites pannuceus (Brenner 1963) Srivastava 1975
Crybelosporites striatus (Cookson and Dettmann 1958) Dettmann 1963
Crybelosporites truncatus Lima 1979
Deltoidospora diaphana Wilson and Webster 1946
Deltoidospora hallii Miner 1935
Deltoidospora junctum (Kara-Murza 1956) Singh 1964
Deltoidospora minor (Couper 1953) Pocock 1970
Deltoidospora tenuis Lima 1978
Leptolepidites psarosus Norris 1969
Leptolepidites verrucatus Couper 1953

Unknown botanical affinity
Paludites mamelonatus Lima 1979

Pollen grains
Gymnosperms
Alaticolpites limai Regali et al. 1974
Araucariacites australis Cookson 1947
Araucariacites cf. A. ghoshii Srivastava sensu Volkheimer 1968
Araucariacites guianensis Van der Hammen and Burger 1966
Araucariacites pergranulatus Volkheimer 1968
Araucariacites sp. S. Cl. 265 A Jardiné and Magloire 1965
Araucariacites sp. S. Cl. 265 B Jardiné and Magloire 1965
Balmiopsis limbatus (Balme 1957) Archangelsky 1977
Callialasporites dampieri (Balme 1957) Dev 1961
Callialasporites lucidus (Pocock 1962) Maheshwari 1974
Cingulatipollenites aff. C. aegyptiaca Saad and Ghazaly 1976
Classopollis jardinei Reyre, Kieser and Pujol 1970
Cycadopites follicularis Wilson and Webster 1946
Elaterocolpites castelainii forma A Jardiné 1967
Elaterocolpites castelainii forma B Jardiné 1967
Elateropollenites dissimilis Regali 1989
Elateropollenites aff. E. dissimilis Regali 1989
Elateropollenites jardinei Herngreen 1973
Elateropollenites aff. E. jardinei Herngreen 1973
Elateropollenites klaszi (Jardiné and Magloire 1965) Jardiné 1967
Elateropollenites protensus (Stover 1963) Jardiné 1967
Elateropollenites verrucatus (Jardiné and Magloire 1965) Jardiné 1967
Equisetosporites ambiguus (Hedlund 1966) Singh 1983
Equisetosporites brasiliensis (Herngreen 1973) nov. comb.
Equisetosporites cf. E. brasiliensis (Herngreen 1973) nov. comb.
Equisetosporites concinnus Singh 1964
Equisetosporites dudarensis (Deák 1964) Lima 1980
Equisetosporites irregularis (Herngreen 1973) Lima 1980
Equisetosporites lanceolatus Lima 1980
Equisetosporites leptomatus Lima 1980
Equisetosporites minuticostatus Lima 1980
Equisetosporites strigatus (Brenner 1968) Lima 1980
Eucormiidites cf. E. minor Groot and Penny 1960
Gnetaceae pollenites barghoornii (Pocock 1964) Lima 1980
Gnetaceae pollenites aff. G. barghoornii (Pocock 1964) Lima 1980
Gnetaceae pollenites clathratus form a Stover 1964
Gnetaceae pollenites clathratus form b Stover 1964
Gnetaceae pollenites concisus Regali 1989
Gnetaceae pollenites jansonii (Pocock 1964) Lima 1980
Gnetaceae pollenites mollis (Srivastava 1968) Lima 1980
Gnetaceae pollenites oreadis Srivastava 1968
Gnetaceae pollenites pentaplicatus Regali 1989
Gnetaceepollenites aff. G. pentaplicatus Regali 1989
Gnetaceepollenites cf. G. pentaplicatus Regali 1989
Gnetaceepollenites retangularis Lima 1980
Gnetaceepollenites santosii Lima 1980
Gnetaceepollenites uesuguii Lima 1980
Pentapsis simplex Regali, Pedrão and Barrilari 2000
Singhia acicularis Lima 1980
Singhia montanaensis (Brenner 1968) Lima 1980
Singhia urwashii Srivastava 1968
Spheripollenites psilatus Couper 1957
Spheripollenites scabratus Couper 1958
Steevesipollenites alatiformis Regali, Uesugui and Santos 1974
Steevesipollenites aff. S. alatiformis Regali, Uesugui and Santos 1974
Steevesipollenites binodosus Stover 1964
Steevesipollenites cf. S. binodosus Stover 1964
Steevesipollenites cupuliformis Azéma and Boltenhagen 1974
Steevesipollenites dayani Brenner 1968
Steevesipollenites giganteus Regali et al. 1974
Steevesipollenites gambasti Azéma and Boltenhagen 1974
Steevesipollenites patapscoensis (Brenner 1963) Lima 1980
Steevesipollenites sp. 1 Lima 1980
Steevesipollenites sp. 2 Antonioli 1998
Steevesipollenites sp. 2 Regali 1989

Angiosperms
Afropollis jardinus (Brenner 1968) Doyle, Jardiné and Doerenkamp 1982
Afropollis aff. A. jardinus (Brenner 1968) Doyle, Jardiné and Doerenkamp 1982

Cretaceiporites mulleri Herngreen 1973
Cretaceiporites polygonalis (Jardiné and Magloire 1965) Herngreen 1973
Cretaceiporites scabratus Herngreen 1973
Dichastopollenites reticulatus May 1975
Hexaporotricolpites lamellaferus Jardiné, Doerenkamp and Legoux 1970
Hexaporotricolpites potoniei Boltenhagen 1969
Lillicidites cf. L. variegatus Couper 1953
Penetetrapites mollis Hedlund and Norris 1968
Pennipollis peroreticulatus (Brenner 1963) Friis, Pedersen and Crane 2000
Pennipollis reticulatus (Brenner 1963) Friis, Pedersen and Crane 2000
Quadricolpites reticulatus Wingate 1980 emend. Ward 1986
Stellatopollis dejaxii Ibrahim 2002
Stellatopollis aff. S. limai Ibrahim 2002
Tetracolpites reticulatus Srivastava 1966b
Trisectoris reticulatus (Regali, Uesugui and Santos 1974) Heimhofer and Hochuli 2010

Pollen grains with unknown botanical affinity
Psiladicolpites comptus Regali 1989
Psiladicolpites cf. P. comptus Regali 1989
Psiladicolpites laevis Regali 1989
Psiladicolpites papillatus Regali 1989

Chlorococcalean Algae
Botryococcus spp.
Ovoidites parvus (Cookson and Dettmann 1959) Nakoman 1966
Ovoidites spriggi (Cookson and Dettmann 1959) Zippi 1998
References