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PALYNOLOGICAL ASSEMBLAGE FROM APTIAN/ALBIAN OF THE SERGIPE BASIN: PALEOENVIRONMENTAL RECONSTRUCTION

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ABSTRACT - Palynological analysis was carried out on 272 core samples from two wells (GTP-17-SE and GTP-24-SE) in the Sergipe basin with the aim of reconstruction the paleoenvironment of the upper Aptianmiddle Albian interval. The Paleoecological studies based on the abundance and composition of all palynomorph genera revealed four assemblages. The stratigraphic distribution of these assemblages allowed the definition of seven ecophases. The palynological assemblage reflects the paleoenvironmental history of the succession that is marked by the progressive late Aptian-middle Albian transgression into the area. The data, in particular the ecophases, confirm that the change from a brackish lagoon to open marine environment was controlled by sealevel during deposition of Muribeca Formation, and dominantly by a progressive sea-level rise during the beginning of the Riachuelo Formation deposition.

Key words: palynology, paleoenvironmental reconstruction, Cretaceous.

RESUMO - Com a finalidade de reconstruir os ambientes deposicionais com base em análise palinológica de uma seção aptiana-albiana da plataforma carbonática-siliciclástica da bacia de Sergipe, foram identificadas e analisadas quatro associações palinológicas de 253 amostras de dois poços. A distribuição estratigráfica das quatro associações permitiu identificar sete ecozonas que refletem uma progressiva transgressão marinha aptina-albiana na área estudada. Esses dados confirmam uma mudança paleoambiental de laguna para marinho aberto controlada pela variação do nível do mar durante a deposição da Formação Muribeca e dominantemente por uma subida do nível do mar durante o começo da deposição da Formação Riachuelo.

Palavras-chave: palinologia, reconstrução paleoambiental, Cretáceo.

INTRODUCTION

The Aptian-Albian succession of the Sergipe basin is represented by a mixed carbonate-siliciclastic platform system (Muribeca and Riachuelo formations), corresponding to a transitional phase between the rift phase and the beginning of the open marine phase. These phases reflect the progressive separation of the African and South American continents, which led to sea-level changes basins of the continental margin. However, on a short-term view variations of the sea-level curve are observed and hence variations in local paleoenvironments. The interpretation of these different paleoenvironments based on composition and diversity of palynomorph indicates a transgressive trend upward.

GEOLOGICAL SETTING

The Sergipe basin, which forms the southern part of the Sergipe-Alagoas basin in northeastern Brazil, is a structurally elongated marginal basin between coordinates $9^{\circ} - 11^{\circ}30'$ S and $37^{\circ} - 35^{\circ} 30'$ W. Onshore the basin is 16-50 km wide and 170 km long and covers an area of 6000 km² and the offshore portion comprises an area of about 5000 km² (Figure 1).

The Sergipe basin belongs to the class of sedimentary basins related to passive continental margins. According to Ojeda & Fugita (1976) and Ojeda (1982) the tectonic evolution of the Sergipe basin can be divided into five main phases: intracratonic, pre-rift, rift (earliest Cretaceous to early ?Aptian), transitional (Aptian), and a marine drift phase (late Aptian to Recent).

Study succession

The succession studied in wells GTP-17-SE and GTP-24-SE comprises part of the Muribeca (transitional phase) and Riachuelo (open marine phase) formations (Figure 2).

In well GTP-17-SE (Figure 3) the succession has a thickness of ca. 450 m and is subdivided into: (1) the Muribeca Formation, represented by the evaporitic Ibura Member (63 m) and the carbonate-siliciclastic platform system of Oiteirinhos Member (80 m); and (2) the Riachuelo Formation, represented by the fine to conglomeratic sandstones intercalated with greenish grey shales of Angico Member (312 m).

In well GTP-24-SE, the succession reaches 400 m and is subdivided into (1) the Muribeca Formation, with the Ibura Member (26.9 m) and the Oiteirinhos Member (126.9 m); and (2) the Riachuelo Formation with the intercalations of shales and calcilutites of the Taquari Member (247 m).

PALYNOSTRATIGRAPHY

The biostratigraphical information used in this study was derived from the studied wells and the biostratigraphical framework of Regali & Santos (1999). Four successive biostratigraphic intervals are identified for the upper Aptian– middle Albian of the studied succession.

The Sergipea variverrucata zone and the Equisetosporites maculosus and Dejaxpollenites microfoveolatus sub-zones from the Regali & Santos (1999) were recognized herein (Figure 3). The major difference from the study by Regali & Santos (1999) for the two studied wells, is the recognition of the middle Albian (Classopollis echinatus Zone) characterized by the first occurrence of Elaterosporites klaszi? (Carvalho, 2001). However, it was recorded from samples that were not studied by Regali & Santos (1999).

MATERIAL AND METHODS

The study was carried out using 253 core samples from two wells (101 from GTP-17-SE and 152 from GTP-24-SE) drilled by Petromisa/Petrobras (the Brazilian state-owned oil company) in the Santa Rosa de Lima and Carmópolis areas in Sergipe (see Figure 1).

The method applied of palynological preparation used by Petrobras was compiled by Uesugui (1979) after, e.g., Erdtman (1969), and Faegri & Iversen (1966), where all the mineral constituents are destroyed by hydrochloric and hydrofluoric acids before heavy-liquid separation. The remaining organic matter is sieved through a 10 μ m mesh prior to mounting on slides.

Palynological analysis

The qualitative analysis consisted basically of the identification and recording of the palynomorphs in the samples. The samples were analyzed under a transmitted light microscope. The quantitative analysis was based on the first 200 palynomorphs counted for each slide. This analysis was the basis for the establishment of the palynomorph distribution.

Paleoecological analysis

The paleoecological analysis was carried out using multivariate statistical methods (cluster analysis and Pearson correlation) to identify the ecological similarity between palynomorph assemblages from different depositional settings. In addition, the Palynological Marine Index (PMI) was employed.

Cluster analysis and Pearson coefficient

Cluster analysis was employed based on abundance and composition, in order to establish groupings and to recognize the relationship between the taxa (palynological analysis). To identify the divisions of the studied succession based on palynology approach, Q- and R-mode cluster analyses were performed on counts of palynomorphs. This cluster analysis



Figure 1. Location map of the marginal basins of northeastern Brazil, including the studied wells (adapted from Seeling, 1999).



Figure 2. Lithostratigraphie scheme for the Aptian-Albian of the Sergipe basin (adapted from Mendes, 1994).

forms discrete groupings that are based on the characteristics (abundance) of the objects. The results are clearly displayed in dendrograms which, when combined, allowed assessment reasons for clustering. The Pearson coefficient (+/- 1) obtained from the relative abundance of palynomorphs, is used to yield a correlation matrix and to identify the relationship between the taxa. This coefficient reflects the presence or absence of similarity among the taxa. If coefficient approaching 1 implies a positive correlation and approaching -1, a negative correlation among the palynomorphs. Only the numerically and paleoecologically important taxa were used herein.

Palynological Marine Index (PMI)

This index was created by Helenes *et al.* (1998) to support in the interpretation of depositional environments. PMI is calculated using the formula: PMI=(Rm/Rt + 1)100, where Rm is richness of marine palynomorphs (dinocysts, acritarchs and foraminiferal test linings) and Rt is the richness of terrestrial palynomorphs (pollens and spores) counted per sample. In the present study, the Rm and Rt were expressed as number of genera per sample. The genus level preferred because genera are more easily identified than species and the genera identified herein show the same environmental significance as species. The high values of PMI are interpreted as indicative of normal marine depositional conditions. When the samples have no marine palynomorphs the PMI value is 100.00.



Figure 3. Correlation of the identified palynological zones and sub-zones between the two studied wells.

RESULTS

The succession studied yielded a rich palynomorph assemblage, in particular of terrestrial components. However, the marine palynomorphs, notably in the upper part of the section of well GTP-24-SE, also show relatively high abundances.

The succession is strongly dominated by terrestrial palynomorphs (Figure 4). The pollen group, in particular gymnosperms, is by far the most abundant taxa. This group forms 84.7% of the total palynomorph assemblage in GTP-17-SE and 61.8% in GTP-24-SE. In well GTP-17-SE the second most abundant group is the spores, which reach 8.9% of all palynomorphs. Well GTP-24-SE is characterized by a relatively high abundance of marine palynomorphs with 31.7% of the total palynomorphs. Fresh-water palynomorphs are rare, comprising less than 0.1% in both wells.

Palynological assemblages

R-mode cluster analysis, based on the abundance and composition of all 64 palynomorph genera found in wells GTP-17-SE and GTP-24-SE, revealed four superclusters that represent the palynological assemblages (PA) 1-4 (Figure 4). The major break between clusters 1 and 2 reflects clearly the separation of marine and terrestrial palynomorphs.

Palynological Assemblage 1. Palynological Assemblage 1 assemblage is composed of marine palynomorphs, with the

exception of the fern spore genus Antulsporites. The assemblages contains Pseudoceratium, Prolixosphaeridium Cyclonephelium, Exochosphaeridium, Florentina, Trichodinium, scolecodonts, Spiniferites, palynoforaminifera, Oligosphaeridium, Systematophora and Antulsporites.

Nine out of seventeen genera of the dinocysts recorded in the succession are included in this assemblage, the majority of them belonging to the gonyaulacoid group. Generally, these genera indicate an open marine environment (neritic setting). Spiniferites is the most abundant dinoflagellate and, together with associated dinocysts such as Exochosphaeridium, Trichodinium and, Oligosphaeridium, indicative of open neritic conditions (Downie et al., 1971; Williams, 1977; Masure, 1984; Marshall & Batten, 1988; Lana, 1997). However, the most abundant marine palynomorph is the palynoforaminifera group, which generally, is present in great abundance in nearshore environments (Tyson, 1995). However, according to Lana (1997), which analyzed Cenomanian-Turonian sediments from Potiguar Basin, northeast Brazil, this group shows higher abundance in middle and deep neritic than dinocysts. On other hand, the dinoflagellates were more abundant in shallow marine environments. Like the palynoforaminifera, Cyclonephelium are found in different bathymetry (shallow to middle neritic) (Lana, 1997). However, it seems an agreement among researchers (e.g. (Eshet et al., 1992; Lana, 1997), which high abundances of the genus Cyclonephelium are related to restricted marine environments under stress conditions.



Figure 4. Dendrogram (r-mode) of 64 genera from the two wells studied showing the four palynological assemblages.











Palynological Assemblage 2. PA2 is composed only of terrestrial palynomorphs (e.g. *Gnetaceaepollenites, Bennettitaepollenites, Cycadopites, Equisetosporites, Cyathidites*). This assemblage has the lowest palynomorph abundance of the assemblages, with ephedroid types (*Gnetaceaepollenites* and *Equisetosporites*) being the most abundant. Their pollen grains are related to the modern gymnosperms *Ephedra* and *Welwitschia* (Gnetales), which are found in arid to semi-arid environments (Doyle *et al.*, 1982; Arai & Coelho, in press). As observed by Doyle *et al.* (1982), the correlation of *Gnetaceaepollenites* and *Equisetosporites* with *Classopollis* is negative (-0,19 and – 0,15 respectively), which suggests that these genera are less tolerant of saline conditions than *Classopollis*.

Palynological Assemblage 3. PA3 shows the highest palynomorph abundance among the assemblages, with a dominance of *Classopollis* grains. The assemblage is mainly consisted of terrestrial palynomorphs (*e.g. Brenneripollis*, *Tricolpites*, *Classopollis*, bisaccates, *Striatopollis*, megaspore, *Vitreisporites*, *Echitriletes*). *Classopollis* was produced by the extinct conifer family Cheirolepidiaceae (Doyle *et al.*, 1982) and dominated in regions with arid climates. *Classopollis* is most commonly recorded in nearshore marine-lagoonal environments and often associated with evaporites (Vakhrameev, 1970; Doyle *et al.*, 1982; Hashimoto, 1995; Arai & Coelho, in press). *Classopollis* shows low correlation with the other palynomorphs.

The presence of bisaccate (bisaccate-types and *Vitreisporites*) pollen in PA3 is contradictory because these pollen types are normally associated with temperate highland climates. However, Arai & Coelho (in press) investigated samples from the Aptian–Albian of the Araripe Basin (north of the Sergipe basin) and observed a relatively high correlation between the bisaccate group and *Classopollis*. According to them, the bisaccates were transported by trade winds and that its abundance was influenced by a minor dilution in the arid periods (weaker terrestrial supply), whereas the terrestrial influx responsible for transport of the other palynomorphs was relatively weak.

The fern spores are also present in this assemblage, but in low abundances. The presence of megaspores reflects a nearshore environment. These spores are large, dense and thick-walled and not easily transported, so in general they are deposited near their source (Speelman & Hills, 1980).

Four genera of dinocysts are recorded in PA3: *Palaeoperidinium, Dinopterygium?, Cribroperidinium,* and *Subtilisphaera*. Among them, the genus *Subtilisphaera* is by far the most abundant, being the second most abundant dinocyst genus in the assemblage. Generally, this genus is associated with marine environments with low salinity (Jain and Millepied, 1975). Moreover, the *Subtilisphaera* frequently occurs in restricted marine environments. This genus is also abundant in assemblages of low diversity (Arai *et al.*, 1994; Lana, 1997). It represents 98% of the total of the four genera recorded in PA3, and correlation with other marine palynomorphs is very low.

Arai et al. (1994, 2000) proposed Subtilisphaera euecozones for the Early Cretaceous of the proto-Atlantic Ocean. These euecozones were originally identified in the Aptian-Albian of the Ceará basin (northern Brazil) and later in other continental marginal basins of Brazil. The Subtilisphaera Euecozone represents a predominance of the genus Subtilisphaera cysts making up an almost monospecific assemblage which reflects a worldwide dinoflagellates bloom in mid-Cretaceous epicontinental seas. However, according to Arai et al. (1994, 2000) this euecozone has not been confirmed in the Sergipe basin. Within five euecozones proposed by Arai et al. (1994), the Subtilisphaera spp. diluted by terrestrial palynomorphs Euecozone (type 5) would be the most comparable with the PA3. However, in the GTP-17-SE, the genus Subtilisphaera reaches 70.2% of all palynomorphs at 61.70 m characterizing the Subtilisphaera Euecozone (type 1). Like Subtilisphaera, Palaeoperidinium supports restricted marine conditions. Dinopterygium? and Cribroperidinium shows very low abundances.

Palynological Assemblage 4. PA4 is distinguished by the high diversity of fern spores and the high abundance of the genus *Araucariacites*. It is composed mainly of terrestrial palynomorphs (e.g. *Callialasporites, Afropollis, Steevesipollenites, Leptolepidites, Sergipea, Klukisporites, Botryococcus, Matonisporites, Pilosisporites, Araucariacites, Verrucosisporites, Cicatricosisporites, Cyathidites*).

Araucariacites is the second most abundant genus of the terrestrial palynomorphs. According to Doyle *et al.* (1982) it is related to a tropically-centered group, which is found in lowland deposits of the Early Cretaceous age. These authors mentioned that an increase in aridity resulted in a decline of *Araucariacites* abundance. This was also suggested by Arai & Coelho (in press), who mentioned the fact that *Araucariacites* is characteristic of humid and subtropical to tropical climates. The genus shows a negative correlation with *Classopollis* (-0,30), thus confirming this hypothesis.

PA4 contains the highest number of pteridophyte genera with *Cicatricosisporites* and *Cyathidites* being the most abundant. The fern spores have been largely related to humid conditions, based on modern distributions of the pteridophytes (Doyle *et al.*, 1982; Lima, 1983; Arai & Coelho, in press). Generally, high abundance of these spores is recorded in nearshore environments (Hughes & Moody-Stuart, 1967; Tschudy, 1969; Heusser & Balsam, 1977, Mudie, 1982; Tyson, 1993). The genera *Cicatricosisporites* and *Cyathidites* have a negative correlation with *Classopollis* and ephedroid pollen.

Afropollis is the most abundant angiosperm pollen genus in the succession, although, it is recorded only in small amounts. This genus has been interpreted as typical of arid environments; however; just as the ephedroid group, *Afropollis* was less tolerant to saline soil conditions (Doyle *et al.*, 1982). *Afropollis* also shows a negative correlation with *Classopollis* (-0,24).

Four genera of dinocysts are found in PA4:

Tanyosphaeridium, Circulodinium, Apteodinium, and Odontochitina, with Apteodinium being the most abundant. It has been interpreted as indicative of inner neritic conditions (Wilpshaar & Leereveld, 1994), but others have suggested it could be found in open marine environments (Leckie *et al.*, 1990). Like *Cyclonephelium*, the *Circulodinium* species are found in different bathymetry (shallow to middle neritic) (Lana, 1997), but they occur mainly in restricted marine environments under stress conditions. The other two genera are rare.

In this assemblage is included the only fresh-water palynomorph found in the succession, the genus *Botryococcus*. This genus is characteristic of fresh-water lacustrine, fluvial, lagoonal and deltaic facies (Traverse, 1955; Pocock, 1972; Herngreen *et al.*, 1980; Batten & Lister, 1988; Williams, 1992). According to Tyson (1995), the abundance of *Botryococcus* in marine sediments is usually low.

Ecophases

The application of ecophases was first introduced by Schuurman (1977), who defined as a recognizable step of the successive development of (palynological) assemblages (in Brugman *et al.*, 1994). According to Brugman *et al.* (1994) the ecophases are characterized by the distribution of palynomorph taxa that reflect developments in the local vegetation or phytoplankton communities.

The stratigraphic distribution of the palynological assemblages allowed the definition of seven ecophases (Appendix 1 and Figure 5). These are recognized in both wells, but with some differences that are showed below in Appendix 1.

Palynological Marine Index (PMI)

The PMI curves of both wells show strong fluctuations (see Figure 5). The index ranges from 100.0, where marine palynomorphs are absent to 250.00 (in GTP-24-SE). This fluctuation reflects the major (low PMI values) and minor (high PMI values) influx in the area. However, in both curves there is an increase in abundance of marine palynomorphs upward. The average abundance in well GTP-24-SE is higher (138.90) than in GTP-17-SE (122.90). Most peaks of the PMI from both wells are related to an increase in abundance of palynoforaminifera and/or *Spiniferites*. However, in well GTP-17-SE some of these peaks are related also to the presence of *Subtilisphaera*.

High values of PMI are found in ecophases where PA3 shows moderate abundance (see Figure 5A). This is best observed in well GTP-17-SE (ecophases 1 and 5). In well GTP-24-SE high PMI values are also found in ecophases characterized by PA1 (e.g., ecophases 1, 4, 5 and 7) (see Figure 5B).

Paleoenvironments

The paleoenvironmental reconstruction is based on an integration of data from palynological assemblages and the ecophases (Figure 5). The Aptian-Albian of the Sergipe Basin is characterized by a transgressional trend. The transition from a brackish lagoon to an open marine environment is

recognizable in the data from palynological assemblages and the ecophases, and forms the basis for the subdivision of the succession into these major paleoenvironments. These two paleoenvironments are subdivided into six events that were mainly controlled by sea-level changes. The boundary between the two major paleoenvironments is marked by the first major transgression in the area.

CONCLUSIONS

The data confirm that the change from a brackish lagoon to open marine environment was controlled by sea-level during the deposition of the Muribeca Formation, and dominantly by a progressive sea-level rise during the beginning of the Riachuelo Formation deposition.

The succession studied in wells GTP-17-SE and GTP-24-SE yielded a rich palynomorph assemblage, mainly represented by terrestrial components. The marine palynomorphs show high abundances in the upper part of well GTP-24-SE. Preservation of the palynomorphs is variable, ranging from moderate to well-preserved for the miospores and from poorly to moderately well-preserved for the dinocysts.

The gymnosperms are the most abundant group, as a consequence of the high abundances of the genus *Classopollis* in well GTP-17-SE. In well GTP-24-SE a relatively high abundance of marine palynomorphs is observed. Freshwater palynomorphs are rare.

The cluster analysis based on the abundance and composition of all 68 palynomorph genera revealed four superclusters, which represent different palynological assemblages (PA). The stratigraphic distribution of these assemblages allowed the definition of seven ecophases.

The Palynological Marine Index (PMI) curves confirm the progressively increasing marine influence in the region. However, the strong fluctuations of the curve reflect a continuous terrestrial influx to the area.

The paleoenvironmental history is strongly marked by the progressive late Aptian-middle Albian transgression into the area. The data confirm that the change from a brackish lagoon to open marine environment was controlled by sealevel during the deposition of the Muribeca Formation, and dominantly by a progressive sea-level rise during the beginning of the Riachuelo Formation deposition.

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Ecophases (E)	Main characteristics
E1	Relatively high abundance of marine palynomorphs of PA1. In well GTP-17 a PA1 is composed essentially of
	palynoforaminifera. In well GTP-24-SE palynoforaminifera are also dominant, although dinocysts (Spiniferites)
	are present in moderate abundances.
E2	Absolute dominance of PA3, in particular the genus Classopollis. Marine palynomorphs are rare, and are found
	only in the lower part of the ecophase.
E3	The dominance of PA4, in particular by Araucariacites together with the highest abundance of the palynomorphs
	from PA2. Rare occurrence of marine palynomorphs. In both wells the marine palynomorphs not reach the
	minimum values for statistical evaluation.
	Increase of the abundance of palynomorphs from PA3 due mainly to Classopollis. The great abundance of these
E4	terrestrial palynomorphs from PA3 reflects a high proportion of fine siliciclastic sedimentation, especially shales.
	Within of this ecophase occur the first registers of peaks in abundance of Subtilisphaera. However, in this
	ecophase, the terrestrial palynomorphs, in particular Classopollis, are the most abundant characterizing
	Subtilisphaera spp. diluted by terrestrial palynomorphs Euecozone (type 5) from Arai et al. (1994).
E5	Progressive increase of marine palynomorphs from PA1, mainly due to Spiniferites, Exochosphaeridium, and
	Trichodinium associated with fern spores (Cyathidites and Cicatricosisporites) and Araucariacites from PA4. At
	the base of this ecophase occur peaks in abundance of Subtilisphaera (euecozone type 5) that are progressively
	replaced for dinocysts from PA1. Of all the dinocysts recorded in the succession, these marine components are
	the ones that are most clearly indicative of open marine environments. Therefore, their abundance in this
	ecophase is strong evidence of the beginning of a transgressive phase.
	Percentage of Classopollis (PA3) increases again, but remains lower than in ecophases 2 and 4. This, together
	with a moderate abundance of marine palynomorphs from PA1 (particular in well GTP-24-SE), indicates that the
E6	terrestrial influx was not as strong as in Ecophase 4. In the GTP-17-SE well the strong terrestrial input in this
	phase allowed the occurrence of Subtilisphaera characterizing the Subtilisphaera spp. diluted by terrestrial
	palynomorphs Euecozone (type 5). Moreover, in spite of the evidence of a moderate regression, the environment
	is still characterized as open marine.
E7	Characterized by high abundance and diversity of marine palynomorphs from PA1 indicating an open marine
	environment. This is distinguished mainly in well GTP-24-SE. The abundance of PA1 in well GTP-17-SE is
	relatively low, with PA4 being the most abundant. In fact, in both wells Araucariacites pollen grains from PA4 are
	the most characteristic land-derived elements. The low abundances of PA1 in well GTP-17-SE are taken to
	reflect a proximal facies of the Angico Member. Furthermore, as mentioned previously, at the upper part of this
	ecophase in the GTP-17-SE, occur very high abundance of Subtilisphaera reaching 70.2% (61,7 m) of all
	palynomorphs. This characterizes the Subtilisphaera Euecozone (type 1) in the Sergipe basin.

Appendix 1. The identified ecophases of the wells GTP-17 and GTP-24.