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Upper Cretaceous Palynology of the Campos-01 Well, Northern Campos Basin: Paleoenvironmental Inferences

Palinologia do Cretáceo Superior do Poço Campo Campos-01, Norte da Bacia de Campos: Inferências Paleoambientais

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Abstract

A detailed palynological analysis was conducted on 29 samples obtained from the Cretaceous interval of the well Campos-01, drilled in the Northern portion of the offshore Campos Basin. The main objectives of this study were to precise the age the rocks and to perform an analysis and interpretation of the depositional environment of the interval. The material consists of mainly shales, marls, calcareous mudstones and sandstones deposited in a deep marine environment. The palynological analysis consisted on identification and counting of all palynomorphs. The paleoenvironmental and paleoecological investigations were supported by cluster analysis, ecological indices (e.g. diversity, dominance) and ratios (e.g. continental:marine) were used. A total of 97 taxa was identified, which included 46 genera of dinoflagellates cysts, 25 genera of spores, 21 genera of pollen grains, 2 genera of freshwater algae and microforaminiferal linings. The recorded assemblage (e.g. *Trichodinium castanea*, *Dinogymnium acuminatum*, *Zlivisporis blanensis*) was assigned to a late Campanian—late Maastrichtian age for the studied section. The interval is clearly dominated by the dinoflagellate cysts that reach 90.7% of total of palynomorphs. On the basis of cluster analysis (r-mode) three dinoflagellate associations were recognized: *Systematophora, Areoligera* and *Spiniferites*. The stratigraphic distribution of dinoflagellates associations indicates three intervals (I1-I3). The intervals I1 and I2, dominated by *Systematophora* and *Spiniferites* respectively, are interpreted as open marine environment. In the interval I3, the dominance of *Areoligera* Association indicates a nearshore environment, also supported by the large amount of continental elements, including the genus *Callialasporites,* which is attributed to high altitude flora, suggesting the presence of highland feeding areas.
Keywords: Palynology; Paleoenvironment; Cretaceous; Campos Basin

Resumo

Uma detalhada análise palinológica foi realizada em 29 amostras do Cretáceo obtidas do poço Campos-01 perfurado na porção norte da Bacia de Campos. Os principais objetivos do estudo foram precisar a idade das rochas e performar uma análise e interpretação dos ambientes doposicionais do intervalo. O material consiste principalmente de folhelhos, margas, calcilutitos e arenitos depositados em ambiente marinho profundo. A análise palinológica consistiu na identificação e contagem de todos os palinomorfos. Para investigações paleoambientais e paleoecológicas foram usadas análise de agrupamento, índices ecológicos (e.g. diversidade, dominância) e razões (e.g. continental:marinho). Um total de 97 táxons foi identificado, sendo 46 gêneros de cistos de dinoflagelados, 25 gêneros de esporos, 21 gêneros de grãos de pólen, 2 gêneros de algas de água doce e palinoforaminíferos. A assembleia registrada (e.g. *Trichodinium castanea*, *Dinogymnium acuminatum*, *Zlivisporis blanensis*) foi atribuída a idade Campaniano final-Maastrichtiano final para a seção estudada. O intervalo é fortemente dominado por cisto de dinoflagelados que alcançam 90,7% do total dos palinomorfos. Baseado na análise de agrupamento (modo-r), três associações de dinoflagelados foram reconhecidas: *Systematophora, Areoligera* e *Spiniferites*. A distribuição estratigráfica das associações de dinoflagelados indica três intervalos (I1-I3). Os intervalos I1 e I2, dominados por *Systematophora* e *Spiniferites* respectivamente, são interpretados como ambiente marinho aberto. No Intervalo 3, a dominância da Associação *Areoligera* indica um ambiente costeiro, corroborado pela grande quantidade de elementos continentais, incluindo o gênero *Callialasporites*, que é atribuído à flora de altitude, sugerindo a presença de áreas de terras altas.
Palavras-chave: Palinologia; Paleoambiente; Cretáceo; Bacia de Campos

1 Introduction

The growing knowledge on dinoflagellates reported by Arai (2007) has shown the quite importance of these palynomorphs for paleoenvironmental and biostratigraphic studies in the Brazilian marginal basins. However, only few studies (e.g., Arai, 2007; Arai & Viviers, 2013; Carvalho *et al*., 2016) have correlated dinocyst distribution and ecological characteristics to the environmental changes. Palynological studies of Cretaceous sediments in Campos Basin have shown variations in palynomorphs, especially dinoflagellates, and have been correlated with environmental parameters such as distance from shoreline, diversity, productivity, terrigenous inputs.

The present study aims to infer paleoenvironment changes for the Cretaceous interval of the Ubatuba Formation of Campos Basin. The findings and interpretation, especially concerning the dinoflagellate cyst associations, will broaden our understanding of the environments changes for this interval in that basin and further highlight the influence of sea level changes and terrestrial inputs on the associations recorded in the interval.

2 Geological Settings

The Campos Basin is located in the Southeastern part of the Brazilian margin and encompasses mainly the offshore areas of Rio de Janeiro and Espírito Santo states, with an area of approximately 100.000 square kilometers. The basin is limited to the north by the Vitória High and south by the Cabo Frio High (Winter *et al*., 2007) (Figure 1).

Winter *et al*. (2007) divided the sedimentary sequence of the Campos Basin into three tectonic--sedimentary supersequences: Rift, Post-Rift and Drift, related to distinct phases during the opening of the South Atlantic Ocean. This study focuses only on part of the Drift Supersequence, more specifically part of the lithostratigraphic interval known as Ubatuba Formation. This interval is composed by shales, marls and calcilutites, and were deposited by hyperpycnal flows, in deep marine environment (lower bathyal) (Winter *et al*., 2007; Castro & Picolini, 2015).

3 Material and Methods

This study covers an interval of 563m (2740–3303 m) of the well Campos-01 which is located in

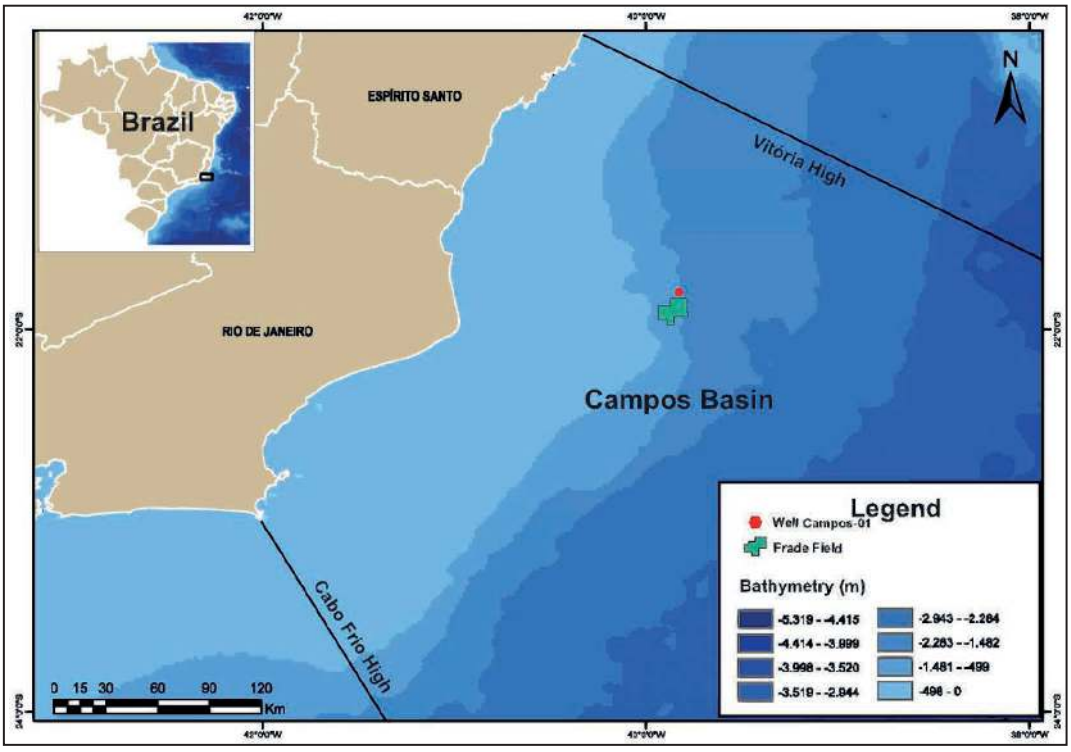

Figure 1 Location of the well Campos-01 and limits of the Campos Basin

deep water of the Northern Campos Basin (Figure 1). Twenty-nine cutting samples were analyzed, each sample covering a space de 3 meters and having been taken at intervals of about 20 meters. The samples were collected within shales, marls and siltstones; sandy layers were not sampled due to their poor fossil content (Figure 2). All samples were processed and analyzed at the Laboratory of Applied Micropaleontology (LabMicro) of the Department of Geology (DGEO)/Institute of Geosciences (IGEO) of the Rio de Janeiro Federal University (UFRJ), using the processing method compiled by Oliveira (2003) and Oliveira *et al.*, (2004; 2006). For better recovery of dinoflagellate cysts (dinocysts) panning technique of Matsouka & Fukuyo (2000) was applied. Minerals were removed by hydrochloric and hydrofluoric acids. The samples were sieved through a 10 µm mesh and mounted on slides. The palynomorph specimens were analyzed, under a Zeiss AXIOIMAGER A2M optical microscope, equipped with white light transmitted and blue light (fluorescence).

Dinocysts identification was conducted with the support of specialized bibliography (e.g. Williams & Bujak, 1985; Lana & Botelho Neto, 1989; Powell, 1992; Fensome *et al*., 1993; Arai, 1994, 2007; Lana *et al*., 2002; Williams *et al*., 2004 and Fensome *et al*., 2009). For the terrestrial palynomorph identification, the following publications were utilized: Germeraad *et al*. (1968), Regali *et al*. (1974b), Lowal & Moullade (1986), and Salard-Cheboldaeff (1990).

The cluster analysis (Ward method with Person-r similarity to recognize relationships between taxa) based on dinocyst count, was used for the paleoenvironmental and paleoecological interpretation. Furthermore, paleoecological trends, diversity and equability indices were reconstructed with the support of the PAST software (Hammer *et al*., 2001). The diversity indices of Shannon-Weaver take into account the abundance of each species and dominance indices share individual number of index divides the number of individuals of the main rate by all species.

The ratio of continental to marine palynomorphs (C/M) was calculated by Versteegh (1994) methodology, where C/M is described as C/M = nC/(nC+xM), where *n* is the number of specimens counted, C = spore + pollen grains + freshwater algae and M = dinocyst. The C/M ratio was used to reconstruct changes in terrestrial input to the Campos Basin.

For the interpretation of the primary productivity, peridinioid to gonyaulacoid ratio (P/G), introduced by Harland (1973), was used. The peridinioid-dominated assemblage indicates nutrient-rich and low-salinity conditions, while where gonyaulacoid-dominated assemblages, indicates open-marine environments. This ratio was described by Versteegh (1994) and calculated by the following formula P/G = nP/(nP+nG), where *n* is the number of specimens counted, *P* is peridinioid dinocyst number, *G* gonyaulacoid dinocyst number.

4 Results

4.1 Biochronostratigraphy

The palynomorphs recorded herein are typical of those reported from upper Campanian to Maastrichtian strata of the Brazilian marginal basins and can be assigned to the biozones *Retiperiporites piacabucuencis* (Biozone PC-62) to *Proteacidites longispinosus* (Biozone PC-66) of Regali *et al.*(1974a).

The last occurrence of some key species of palynomorphs was recorded in the well, viz. *Dinogymnium acuminatum*, *Alisogymnium euclaense*, *Chatangiella* spp., *Gabonisporis vigourouxii*, *Triporoletes blanensis* and *Trichodinium castanea*, *Isabelidinium* spp. (Figure 2).

In the interval between 2740 and3200 m, the key species: *Cerodinium* spp., *Isabelidinium* spp., *Alisogymnium euclaense*, *Dinogymnium acuminatum* and the miospores *Crassitricolporites brasiliensis*, *Zlivisporis blanensis* and *Gabonisporis vigourouxii* were recognized. These species indicate a late Maastrichtian age (Arai, 2007). According to Regali *et al*. (1974a), the species *Crassitricolporites brasiliensis* spans the late Campanian—Maastrichtian.

The presence of *Trichodinium castanea* from 3200 to 3225 m and *Palaeohystrichophora infusorioides* from 3225 to 3285 m is, to some extent, problematic. The relative position of the last occurrence

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(LO) of these taxa as pointed out in the present work is in accordance with Foucher & Monteil (1998), since these authors registered that, in the boreal province, *T. castanea* disappeared in the earliest early Maastrichtian, while *P. infusorioides* became extinct in the latest late Campanian. However, several authors (*e.g.,* Arai, 1994; Arai & Botelho-Neto, 1996; Lana & Roesler, 2002; Lana *et al*., 2013) have indicated that, in the Brazilian continental margin, the extinction of *T. castanea* (middle Campanian) occurred before that of *P. infusorioides* (early Maastrichtian). Then, it is suggested that the occurrence of *T. castanea* in the interval 3200–3225m corresponds to reworking, while the first occurrence (FO) of *P. infusorioides* at 3225 m is *in situ* and indicates that the sediments at that depth is of early Maastrichtian age or older.

4.2 Palynological Analysis

The samples from the studied interval of the well Campos-01 contain an abundant and diverse palynoflora, with all samples showing moderate to high abundance of well-preserved palynomorphs, especially dinocysts (Table 1). The studied samples are currently stored at the LabMicro/DGEO/IGEO/UFRJ.

The palynological analysis conducted on well Campos-01 showed a total of 97 taxa, including

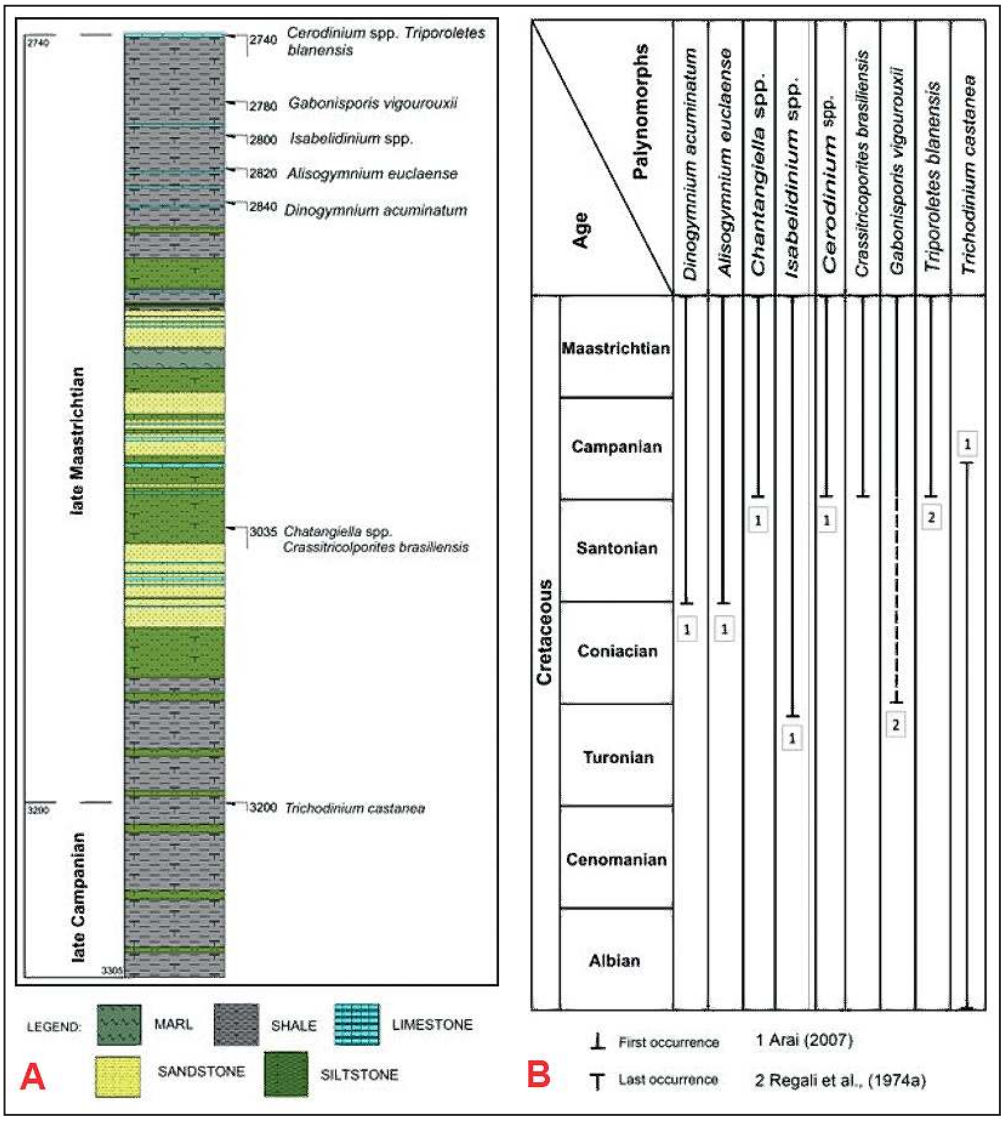

Figure 2
A. Schematic lithological profile with last appearance of biostratigraphically significant palynomorphs found in this study;

B. Summary of the amplitude of biostratigraphically significant palynomorph found in this study

dinocysts (46 genera), spores (25 genera), pollen grains (21 genera) and 2 genera of freshwater algae (*Pediastrum* and *Scenedesmus*). Microforaminiferal linings are also recorded in all samples.

The palynological associations for the studied section are composed of a high percentage of dinocysts (up to 90.7%). Common taxa include the gonyaulacacean dinocysts (G-cysts) (up to70%) assigned to late Cretaceous age, while peridiaceans and ceratiaceans are present in small amounts.

Several genera of continental palynomorphs were also present in the studied section (>63%), including fern spores (e.g. *Cicatricosisporites* spp.) and pollen grains (e.g. *Callialasporites* and *Classopollis*). Low abundance of freshwater algae (4.5%) was also identified at depth of 2880 m.

4.3 Dinocyst Associations

Three dinocysts associations were obtained from the cluster analysis (r-mode) and named after their most dominant genera, viz., *Systematophora*, *Areoligera* and *Spiniferites* (Figure3).

4.3.1 *Systematophora* Association

Systematophora Association is the least abundant of the three dinocyst associations, representing only 1.5% of the total occurrence, the exception is at depth of 3285 m, where concentrations reach around 50%. The association includes the genera *Andalusiella*, *Cyclonephelium*, *Dinogymnium*, *Isabelidinium*, *Odontochitina*, *Palaeohystrichophora*, *Pterodinium*, *Systematophora* and *Trichodinium,* being the most genera with short processes, a feature assumed to be an indication of nearshore conditions. The *Systematophora* Association is the more abundant in the lower part of the section and is absent in 6 of the 29 samples studied, mainly in the upper part of the section (Figure 4).

The genus *Systematophora* has been associated with open marine environments (e.g. Brinkhuis,

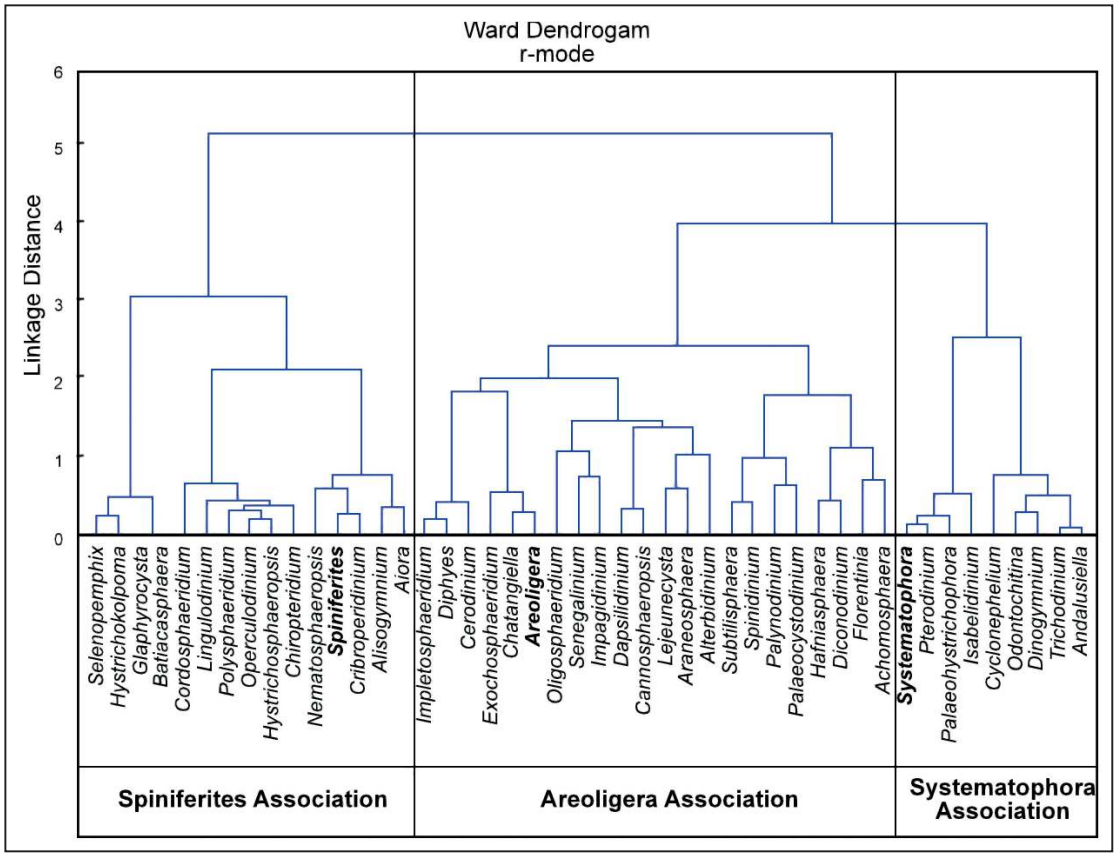

Figure 3 Ward dendrogram (r- mode) showing the three dinocyst associations: *Systematophora*, *Areoligera* and *Spiniferites*

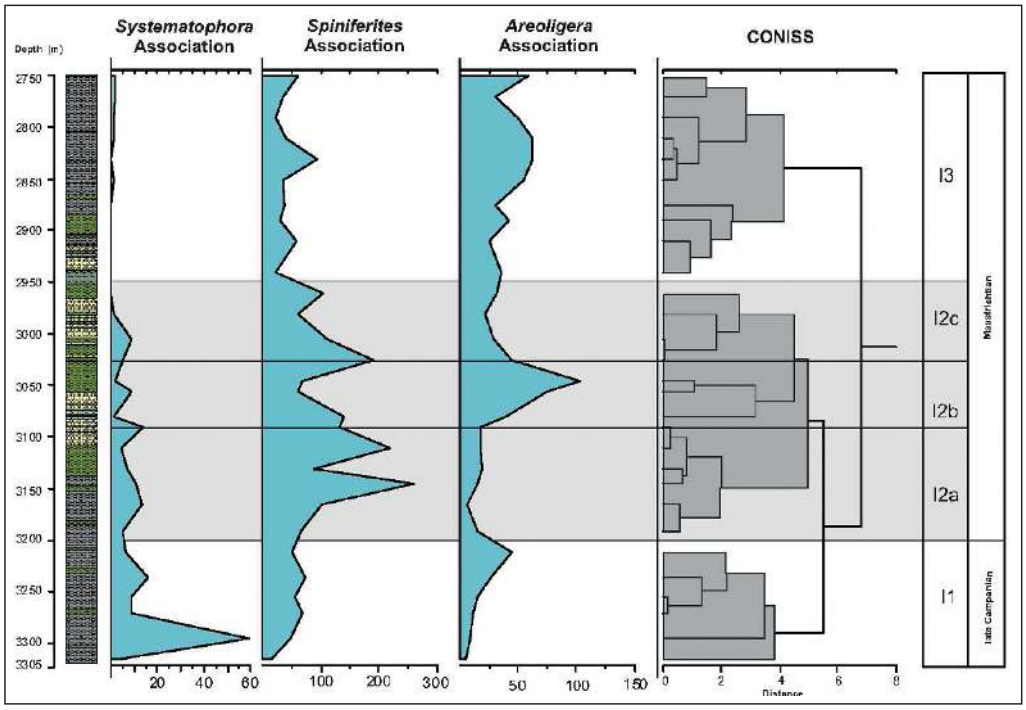

Figure 4 Stratigraphical distribution of the dinocyst associations and stratigraphically constrained cluster analysis (CONISS)

1994), but some studies place its occurrence in nearshore environments (e.g. Zevenboom *et al*., 1994), which is compatible with the environment of the second most abundant genus, *Palaeohystrichophora* (Hradecká *et al*., 2005). The third most important genus is the *Dinogymnium*, which is also related to shallow marine environment (Hradecká *et al*., 2005; Boboye, 2013).

4.3.2 *Spiniferites* Association

The *Spiniferites* Association is the most abundant association reaching 91% of total association at 3100 m. The association is composed by the genera *Aiora*, *Alisogymnium*, *Batiacasphaera, Chiropteridium*, *Cordosphaeridium*, *Cribroperidinium*, *Glaphyrocysta*, *Hystrichokolpoma*, *Hystrichosphaeropsis*, *Lingulodinium*, *Nematosphaeropsis*, *Operculodinium*, *Polysphaeridium*, *Selenopemphix* and *Spiniferites*. High abundances of this association occur in the middle part of the section (Figure 4).

The *Spiniferites* are associated with open marine environment (Brinkhuis, 1994; Sluijs *et al*., 2008; Carvalho *et al*., 2016). However, some species are also found in sediments associated to the nearshore conditions (Hultberg & Malmgren, 1986; Carvalho *et al*., 2016). The second and third most abundant genera in this association are *Hystrichokolpoma* and *Operculodinium*, respectively. Like *Spiniferites*, both also recorded in several marine environments, but preferentially in open marine conditions (Brinkhuis, 1994).

4.3.3 *Areoligera* Association

The *Areoligera* Association reaches 59.2% (3035 m) of the total associations. They are characterized by being the highest diversified association, especially in the upper part of the section (Figure 4). The association is composed by the genera *Achomosphaera*, *Alterbidinium*, *Araneosphaera*, *Areoligera*, *Cannosphaeropsis*, *Cerodinium*, *Chantangiella*, *Dapsilidinium*, *Diconodinium*, *Diphyes*, *Exochosphaeridium*, *Florentinia*, *Hafniasphaera*, *Impagidinium*, *Impletosphaeridium*, *Lejeunecysta*, *Oligosphaeridium*, *Palaeocystodinium*, *Palynodinium*, *Senegalinium*, *Spinidinium* and *Subtilisphaera*.

Areoligera is the most abundant genus and it has been associated with inner neritic environment (e.g. Brinkhuis, 1994; Sluijs *et al*., 2008; Skupien &

Mohamed, 2008; Sluijs & Brinkhuis, 2009). According to Sluijs *et al*. (2008), the *Areoligera* complex species is usually associated with environment of high energy.

4.4 Continental Influence

The presence of dinocysts in all studied samples indicates a marine depositional environment. However, terrestrial input occurred throughout the studied well section, especially in the upper part of the section (Figure 5). This terrestrial input is represented by spores, pollen grains and *Scenedesmus* and *Pediastrum* algae. The pollen grains are the most abundant of the total sporomorphs. They reach 81.4% (at 3035 m) of the total associations, with the gymnosperm pollen grains *Callialasporites* and *Classopollis* the most abundant. Among the spores, the *Cicatricosisporites* are the most abundant.

5 Paleoenvironmental Interpretation

The paleoenvironmental interpretation was based on dinocyst and continental palynomorphs, through the use of ecological indices. Intervals were interpreted from hierarchical clustering and stratigraphically constrained (CONISS) analyses. The distribution of the dinocyst genera revealed three intervals (I1-I3): Interval 1 (3305-3200 m); Interval 2 (3200-2950 m); and Interval 3 (2950-2740 m) (Figure 6).

5.1 Interval 1 (late Campanian)

The Interval 1 (3305-3200 m) coincides with late Campanian age in the section. The Interval is characterized by high abundance of the *Systematophora* Association (Figure 6), which has been used as indicator for open marine settings (see item 4.3.1), and lowest values of continental elements (low C/M ratio values).

The Shannon-Weaver diversity is low in this interval. This is probably due to high abundance of *Systematophora placacantha* (Figure 6). However, both *Systematophora* Association as well as the diversity index decreases upward, accompanied with increasing of continental elements. A peak of peridinioid cysts is recorded at the 3285 m, this event coincides with a peak of *Palaeohystrichophora* that suggest a more shallower condition.

5.2 Interval 2 (Maastrichtian)

The Interval 2 (Maastrichtian) is characterized by the predominance of the *Spiniferites* Association. However, based on the abundance curve, three smal-

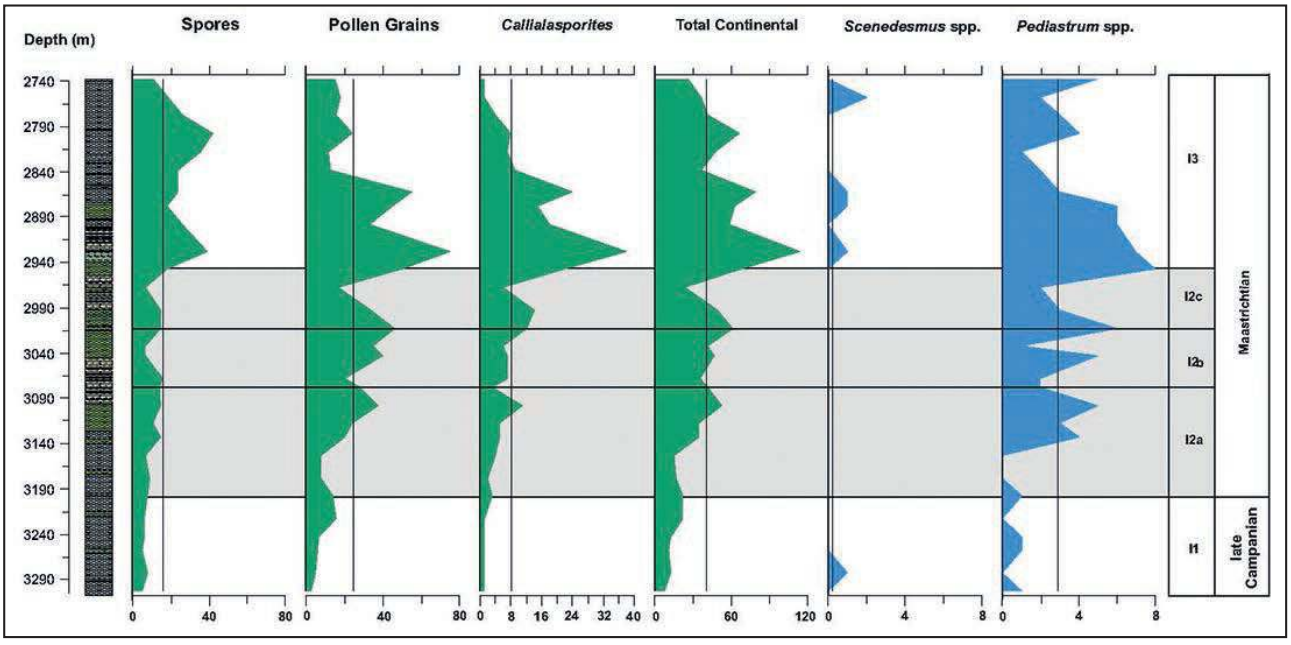

Figure 5 Stratigraphic distribution of significant groups of continental palynomorphs

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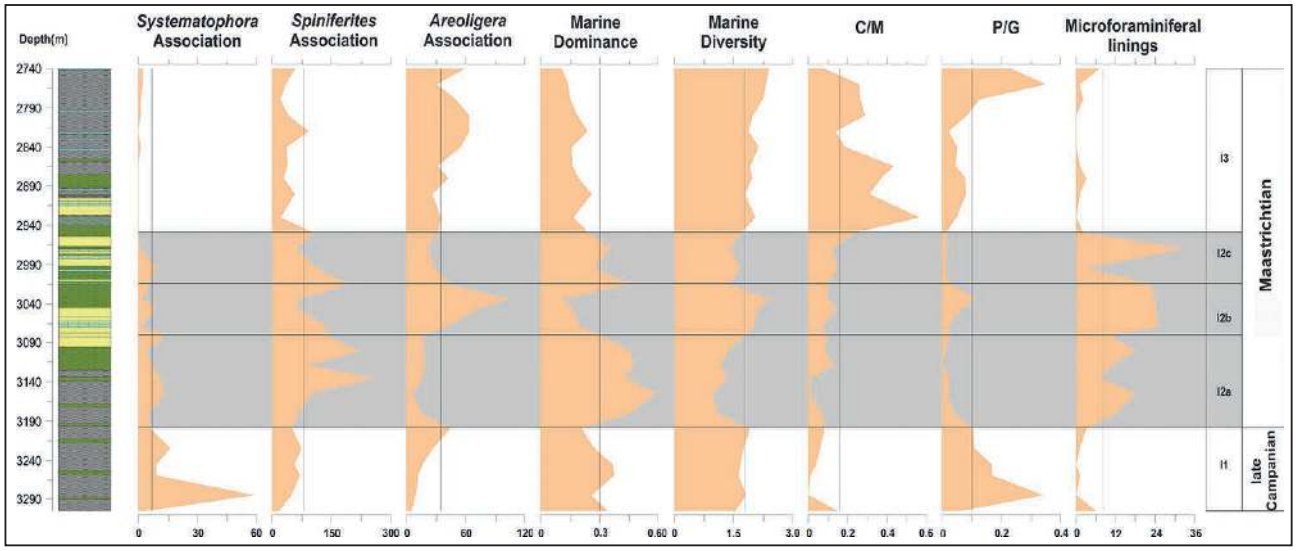

Figure 6 Stratigraphic distribution of dinocyst associations and ecological parameters

ler intervals can be distinguished in the dendrogram (2a - 2c) (Figure 6). These subdivisions can also be observed by the diversity and dominance curves.

In the Interval 2a (3200-3080 m), the sudden increase in *Spiniferites* Association corresponds to an increase in dominance indices. The increase of the dominance of *Spiniferites* is directly related to the detriment of the other associations. The increase in *Spiniferites* in this interval reflected in the low values of C/M and P/G ratios, and suggests a more open marine condition.

The Interval 2b (3080 - 2995 m) exhibits an abrupt decrease of the *Spiniferites* Association towards the top of the interval. A single sample (3035 m) shows exceptionally high *Areoligera* Association abundance, suggesting a short excursion from a general trend. This excursion is accompanied by a sudden decrease of dominance index and increase of diversity. The high abundance of *Areoligera* suggests a shelf environment. The low values of C/M ratio persist, which reinforce a low contribution of terrigenous sediments. The P/G ratio shows values below average, suggesting also open marine conditions (Harland, 1973). However, this interval recorded a slight increase of peridinioid cysts (P/G ratio).

Open marine conditions return to the Interval 2c (2995 - 2950 m) with high abundance of *Spiniferites* Association identified (although decreasing trend upwards). However, unlike the Interval 2b, the *Areoligera* Association also decreases and C/M and P/G ratios show similar pattern observed on Interval 2b. The Interval 2 shows a distinctive increase in microforaminiferal linings, which are recorded throughout the section (Figure 6). According to Stancliffe (1996), the high abundance of microforaminiferal linings is an indicator of shallow marine environments. According to some authors (e.g., Cross *et al*., 1966; Melia, 1984; Tyson, 1993) high abundances can be associated with more nutrient availability and upwelling area.

5.3 Interval 3 (late Maastrichtian)

The Interval 3 (2950-2740 m) is characterized by high abundance of *Areoligera* Association and continental palynomorphs (Figure 6). This interval exhibits signs of shallowing toward to the top as revealed by the increase of the genus *Areoligera* (Brinkhuis, 1994; Sluijs *et al*., 2008; Sluijs & Brinkhuis, 2009). According to Sluijs and Brinkhuis (2009), the increases in diversity together with *Areoligera* suggest a relative sea-level rise in nearshore environment (inner neritic). We also observe a strong terrigenous sedimentation as indicated by high values of C/M ratio. In fact, peaks of continental elements in this interval are related to increase in

sand deposition, which was more significant in the low part of the interval.

6 High Abundance of *Callialasporites* Versus Denudation

The *Callialasporites* pollen grains are abundant throughout the well and their abundance increases abruptly from 3100 to 2865 meters. The *Callialasporites* are accompanied by the presence of the following spores: *Zlivisporis*, *Murospora* and *Cyathidites.* The *Callialasporites* have been assigned to the Podocarpaceae family and it is commonly found in the South Atlantic Margin and dated as Cretaceous. Nowadays, the family is commonly associated to high relief flora and moderate to high humidity (Archangelsky & Gamerro, 1967; Anderson *et al*., 2007; Dutra *et al*., 2007; Maizatto *et al*., 2009; Carvalho *et al.*, 2017).

According to Maizatto *et al*. (2009) during the Campanian - Maastrichtian interval of Espírito Santo Basin, the family Podocarpaceae, represented by the pollen genus *Callialasporites*, was present in uplands near our studied area. The uplift of the highlands was originated after major tectonic event in the region, which was followed by erosion and continental sediment dumping into the basin (Zalan & Oliveira, 2005; Maizatto *et al*., 2009).

According to Maizatto *et al*. (2009), at the Cretaceous/Paleogene boundary (K/Pg) the relief was interpreted to be as high as 2.000 m, when compared to the sea level today. Additionally, to the presence of typical mountain flora pollen (*Callialasporites*) in the sediments studied by Maizatto *et al*. (2009), the evidence of highlands is confirmed by apatite fission study conducted by Chemale Jr. & Hadler Neto (2005) (Figure 7).

Maizatto *et al*. (2009) recorded high abundance of *Callialasporites* in four of the six wells they have studied. In the more distant wells (ES-5 and ES-6), the presence of this pollen was not recorded. Despite its dispersion especially by the wind, according to the authors, the *Callialasporites* are not recorded further south of latitude 21ºS, which could indicate lack of highland sources in that region. However, the well Campos-01, which is further south of the wells ES-5 and ES-6, exhibits a high abundance of *Callialasporites*, indicating possible presence of highlands toward the region of current Paraiba do Sul River (Figure 7).

7 Conclusions

The palynological analysis based on dinocyst distributions from the well Campos-01 evidenced paleoenvironmental changes during the late Campanian - late Maastrichtian interval for the Campos Basin. The key conclusions for this study are described below:

The dinoflagellate associations recorded in the well Campos-01 contain 46 genera of dinocysts; 25 genera of miospores, 2 genera of freshwater.

The taxa *Cerodinium* spp., *Zlivisporis blanensis*, *Gabonisporis vigourouxii*, *Isabelidinium* spp., *Alisogymnium euclaense*, *Dinogymnium acuminatum*, *Chatangiella* spp., *Crassitricolporites brasiliensis* and *Trichodinium castanea* indicate the late Campanian - late Maastrichtian age for the studied section.

Cluster analysis indicated the existence of three associations with distinct paleoenvironmental preferences: (1) *Systematophora*, (2) *Spiniferites* and (3) *Areoligera* associations.

The stratigraphical distribution of the associations allows subdivision of the section into three main intervals: Interval 1 and 2 are interpreted as open marine environment, indicated by the dominance of *Systematophora* and *Spiniferites*, respectively; and Interval 3 is interpreted as nearshore environment which is dominated by *Areoligera* Association.

The highest marine influence is observed in the Interval 2 with dominance of *Spiniferites*. On the other hand, the Interval 3 has significant continental influence and it is dominated by *Areoligera* and continental elements.

The high abundance of altitudinal flora *Callialasporites* suggested the presence of highlands during the late Maastrichtian close to the Campos Basin.

8 Acknowledgments

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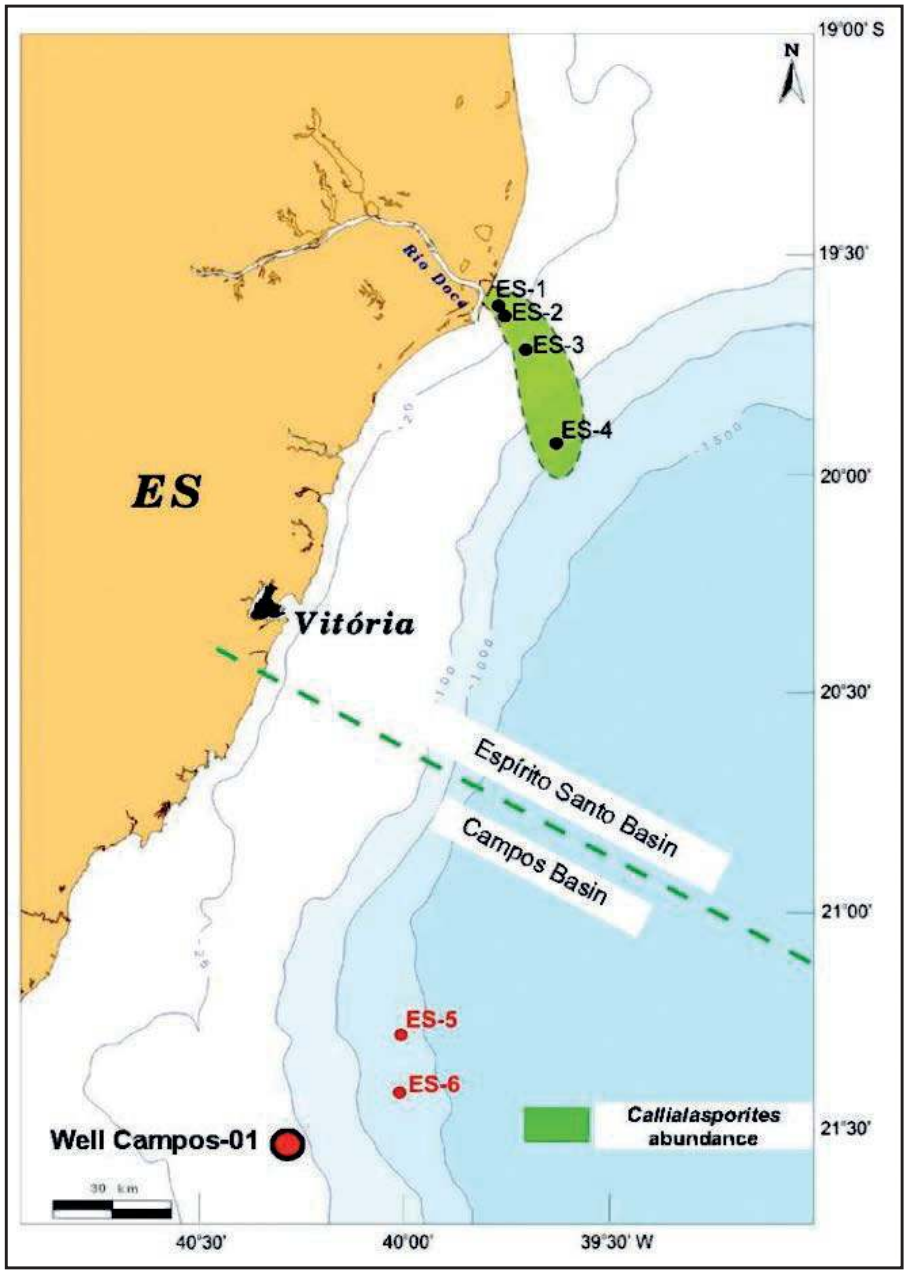

Figure 7 Map showing the area of occurrence of *Callialasporites* sp. as pointed out by Maizatto et al. , 2009 (green area), besides the location of the well Campos-01, where *Calliasporites* was also found in this study (adapted Maizatto et al., 2009)

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9 References

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