# MORPHOMETRIC STUDY OF FOSSIL AND EXTANT SPORES OF THE FAMILY ANEMIACEAE FROM THE LOWER CRETACEOUS TO THE QUATERNARY

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# ABSTRACT

This study is based on the morphometry of 112 morphospecies of fossil spores of the Family Anemiaceae (Class Polypodiopsida, Order Schizaeales), collected from several strata of Brazilian basins, ranging from the Lower Cretaceous up to the Quaternary, as well as on the morphometry of spores of 129 living species of this family around the world. The objective of the study is to analyze the relationship among their morphometric characters, chronostratigraphy and climate/paleoclimate. The following parameters were established: D1 (larger diameter), D2 (smaller diameter), EM (width of the muri) and DM (distance between the muri). Measurements in micrometers were saved in an Excel spreadsheet in order to make regression analysis charts, which showed the following results: (1) perfect linear correlation between D1 and D2, regardless of geological age and climate, which was expected, as spores of Anemiaceae are equidimensional; (2) no perfect linear correlation between D1 and EM, and an increase in D1, caused by an increase in the denseness of their muri. The lack of linearity is noticeable in Lower Cretaceous species, in which thin muri predominate. In the Lower Cretaceous, the densest murus is no thicker than 4  $\mu$ m, whereas, in the Upper Cretaceous, muri of up to 8 µm were observed. Regardless of the kind of climate, reasonable linearity was observed among extant species, which are devoid of very thin muri; (3) there is no correlation between EM and DM in species from the Cretaceous to the Tertiary, showing a wide range of DM values for each EM value. This result was expected, as the muri denseness and the distance between the muri are, a priori, independent parameters. In the Cretaceous, DM values are generally low, and values lower than 2 µm predominate. In the Tertiary, DM values vary from 0.5 µm to 6 µm. An inverse relationship between EM and DM is shown for living species, especially species of the semi-arid to semi-humid regions. Fossil species did not show this relationship due to the existence of species with thin and dense muri (e.g., Cicatricosisporites microstriatus, C. minutaestriatus and C. avnimelechi) and species with walls of median thickness and great distance between them (e.g., Cicatricosisporites hughesii and C. purbeckensis).

Keywords: Anemiaceae, Cicatricosisporites, Cretaceous, Cenozoic, morphometry.

#### RESUMO

ESTUDO MORFOMÉTRICO DOS ESPOROS FÓSSEIS E ATUAIS DA FAMÍLIA ANEMIACEAE DO CRETÁCEO INFERIOR AO QUATERNÁRIO. O presente estudo foi baseado na morfometria de 112 morfoespécies de esporos fósseis relacionadas à Anemiaceae (Classe Polypodiopsida, Ordem Schizaeales) oriundas de diversos estratos de bacias brasileiras, abrangendo desde o Cretáceo Inferior até o Quaternário, e de esporos de 129 espécies viventes da família no mundo. O objetivo é averiguar a relação existente entre caracteres morfométricos, cronoestratigrafia e clima/paleoclima. Foram levantados os seguintes parâmetros: D1 (diâmetro maior), D2 (diâmetro menor), EM (espessura do muro) e DM (distância entre os muros). As medidas obtidas em micrômetro foram arquivadas na planilha Excel, visando à confecção de gráficos de regressão linear, os quais forneceram os seguintes resultados: (1) D1 e D2 se correlacionam com linearidade perfeita, independente da idade geológica e do clima, o que é esperado, já que os esporos de Anemiaceae se caracterizam pelo âmbito equidimensional; (2) na relação entre D1 e EM, os valores de D1 aumentam, grosso modo, com o aumento da espessura do muro, sem, contudo, apresentar uma linearidade perfeita. A falta da linearidade é notável nas espécies do Cretáceo Inferior, onde predominam muros finos. No Cretáceo Inferior, os muros mais espessos não passam de 4 µm, enquanto no Cretáceo Superior, foram observados muros de até 8 µm. Entre as espécies atuais, desprovidas de muros muito finos, é observada certa linearidade, independentemente do tipo de clima; (3) a relação EM x DM não apresenta nenhuma correlação nas espécies do Cretáceo ao Terciário, registrando uma ampla gama de valores de DM para cada valor de EM. Isto era esperado, já que a espessura do muro e a distância entre os muros são, a priori, parâmetros independentes. No Cretáceo, os valores de DM são geralmente pequenos, predominando valores menores que 2 µm. Já no Terciário, os valores de DM variam de 0,5 µm a 6 µm. As espécies viventes apresentam relação inversa entre EM e DM, principalmente entre as espécies do clima semiárido a semiúmido. Essa relação não existe entre as espécies fósseis, em função da existência de espécies com muros finos e densos (e.g., Cicatricosisporites microstriatus, C. minutaestriatus e C. avnimelechi) e de espécies com muros de espessura mediana com grande distância entre eles (e.g., Cicatricosisporites hughesii e C. purbeckensis).

Palavras-chave: Anemiaceae, Cicatricosisporites, Cretáceo, Cenozoico, morfometria.

## **1 INTRODUCTION**

With over 100 living species, the Family Anemiaceae is a group of embryophytes, tracheophytes that belong to the Order Schizaeales. According to COLLINSON (1996), records of this order date from the Jurassic period, and according to SMITH *et al.* (2006), it has a single genus, *Anemia*.

This family has a group of spores with very singular characteristics, such as the presence of muri alternated with grooves, which some authors call striae (Figure 1). The thickness of these muri, contour, ornaments and morphometric data vary for different species. NÁRVAEZ et al. (2013) made a comparative chart showing the spore morphological features of the cicatricose spores species found in the La Yesera, La Cantera and Lagarcito formations. DETTMANN & CLIFFORD (1991) described Anemiacean spores using measurements to separate the groups. GIACOSA et al. (2012) studied the morphology and wall ultrastructure of Anemiaceae and concluded that there is considerable variation in spore diameter. When analyzing the thickness of the muri and ornamentation, they also identified two different morphological types of Anemiacean spores.



FIGURE 1 – *Cicatricosisporites* sp. and its parallel muri. D1 - greater diameter of the spore; D2 - smaller diameter; DM - distance between the muri; EM - width of the muri; End - endospore; Exi - inner exospore; Exe - outer exospore; Per - perispore. Scale bar =  $10 \mu m$ . Modified from DUARTE *et al.* (2012).

In this present work, morphological variation among species was observed, which can be used to identify some groups along the geological time scale, as there are groups of fossilized spores of this Family. Some of these fossil genera are *Appendicisporites*, *Cicatricosisporites*, *Plicatella* and *Nodosisporites* (Figure 2). These fossil spores also have walls interchanged with grooves, and similarly to present-day spores, their characteristics vary for different species along the geological time scale (DUARTE 2011) (Figure 2).

The objective of this work is to verify the relationship among the morphometric characters, chronostratigraphy and climate/paleoclimate of spores of the family Anemiaceae from the Lower Cretaceous up to the Quaternary.

In order to comprehend and analyze with precision the morphometric characters of presentday and fossil spores of Anemiaceae, it is important to study in depth their morphology. The fossil spores are characterized by a trilete mark, which may or may not be flanked by an extensive marlstone (Figure 2). They have a striated to channeled cicatricose sculpture, composed of a group of parallel or nearly parallel muri (DETTMANN & CLIFFORD 1992). These muri may show a slight tendency to become crested (JANSONIUS & HILLS 1976). Their walls may show perforation, micro warts, granules or peripheral circular folding. The size of these grains varies between 59 and 68 µm in average. There are isospore types (JANSONIUS & HILLS 1976), which may be tetrahedral and present a range of amb types: circular, sub-circular and triangular. Some of them have appendices and plicas (Figure 2).

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FIGURE 2 – (a) *Appendicisporites* sp with appendices at the extremities. (b) *Cicatricosisporites gracilis*. (c) *Nodosisporites macrobaculatus* with bacula type ornaments on the muri. (d) *Plicatella* sp. Scale bar = 20 µm.

The wall of the grains of *Anemia* has four layers. From the innermost to the outermost layer, they are named as follows (Figure 1): Endospore (layer composed of cellulose, which was destroyed during fossilization and palynological preparation), inner exospore (layer composed of sporopollenin), outer exospore (layer composed of sporopollenin), and perispore (layer composed of sporopollenin), which is more electrodense and chemically less stable than the sporopollenin of the exospore) (PLAYFORD & DETTMANN 1996).

The striated aspect of the extant spores of *Anemia* and of their corresponding microfossils is a result of the folding of the superior part of the outer exospore, followed by the folding of the perispore (Figure 1).

#### 2 MATERIALS AND METHODS

#### 2.1 Study area

This study is based on the morphometry of 112 morphospecies of fossil spores of Anemiaceae collected from strata of Brazilian basins, ranging from the Lower Cretaceous up to the Quaternary, and on the morphometry of spores of 129 living species of this family collected around the world, listed by HANKS & MORAN (2008).

The fossil material for the present study has been collected from the following sedimentary basins of Brazil (see also Appendix):

Sanfranciscana Basin (Areado Formation - Lower Cretaceous - lower Aptian - continental/ coastal environment); Parnaíba Basin (Codó Formation - Lower Cretaceous - upper Aptian - coastal/lagoonal environment); Paraná Basin (Bauru Group/ São Carlos Formation - Upper Cretaceous - Santonian - continental environment); Almada Basin (Urucutuca Formation - Upper Cretaceous - Maastrichtian - coastal/marine Pernambuco-Paraíba environment): Basin (Gramame Formation - Upper Cretaceous -Maastrichtian - coastal/marine environment and Maria Farinha Formation - Tertiary - Paleocene - coastal/marine environment); Resende Basin (Resende Formation - Tertiary - Eocene continental environment); Taubaté Basin (Tremembé Formation - Tertiary - Oligocene continental lacustrine environment); São Paulo Basin (Itaquaquecetuba Formation - Tertiary -Oligocene/Miocene - continental environment; and São Paulo Formation - Tertiary - Oligocene continental environment); Bragança-Viseu -Basin (Pirabas Formation / Barreiras Group - Tertiary - Miocene - coastal environment), *Acre Basin* (Solimões Formation - Tertiary - Miocene continental environment); *Caciporé Basin* (Marine Quaternary sediment); *Other Quaternary deposits* (continental environment).

## 2.2 Sample preparation

The majority of the studied samples (see Appendix) have been collected from rocky outcrops by geologists from several institutions, such as PETROBRAS, Federal University of Pará (UFPA), Federal University of Rio de Janeiro (UFRJ), São Paulo State University (UNESP) and University of São Paulo (USP) for the last 15 years. Only samples from the Caciporé Basin (Quaternary) were collected from the ocean floor by box-core. The samples were prepared using paleopalynological techniques, according to the standard procedures (UESUGUI 1979), with hydrochloric acid and hydrofluoric acid at the laboratory of the Applied Biostratigraphy and Paleoecology Management (Gerência de Bioestratigrafia e Paleoecologia Aplicada - BPA) of CENPES (the PETROBRAS Research Centre, Rio de Janeiro - RJ).

2.3 Morphometric parameters of extant and fossil spores

Information about present-day spores, and measurements and descriptions of these spores were obtained on the website Plant Systematic (HANKS & MORAN 2008) and other publications (e.g. DETTMANN & CLIFFORD 1991, GIACOSA *et al.* 2012, NÁRVAEZ *et al.* 2013).

The morphometric parameters of fossil spores were measured using two optical microscopes with 20x, 40x and 100x objective lens and 10x ocular lens: Olympus BX 41 and Zeiss AxioImager A1, respectively, at the Nannofossil and Organic Facies Laboratories, both of the Geology Department of the Institute of Geosciences - UFRJ. The slides were photographed by a coupled camera, using the Soft Imaging System.

The following parameters were measured for each spore: D1 (larger diameter), D2 (smaller diameter), EM (width of the muri) e DM (distance between the muri). Subsequently, the spores and their measurements were grouped by geological time period: Lower Cretaceous, Upper Cretaceous, Tertiary, and Quaternary. The measurements in micrometers were saved in an Excel spreadsheet, and then linear regression charts were prepared based on these measurements.

#### **3 RESULTS**

The obtained results showed that the correlation between D1 and D2 for all groups of Anemiaceae spores was linear, regardless of geological age and climate, which was already expected, as Anemiaceae spores are characterized by equidimensional ambs (Figures 3 - 6).



FIGURE 3 – Chart showing the D1 x D2 relationship for spores of the Lower Cretaceous.



FIGURE 4 – Chart showing the D1 x D2 relationship for spores of the Upper Cretaceous.



FIGURE 5 – Chart showing the D1 x D2 relationship for spores of the Tertiary.



FIGURE 6 – Chart showing the D1 x D2 relationship for extant spores of the Quaternary.

In general, in the relationship between D1 and EM, there is an increase in D1, with an increase in muri width, showing no perfect linearity (Figures 7 and 8). However, in the Lower Cretaceous, period in which spores with thin muri predominate (<4  $\mu$ m), the correlation between muri width and spore diameters is not linear (Figure 9), opposite to what happens to spores of the Upper Cretaceous, Tertiary (Figures 7 and 8) and Quaternary/Recent, that is, spores with thinner muri (of approximately 1  $\mu$ m width) have larger diameters than spores with walls with 3  $\mu$ m of denseness.



FIGURE 7 – Chart showing the D1 x EM relationship in the Upper Cretaceous.



FIGURE 8 – Chart showing the D1 x EM relationship in the Tertiary.



FIGURE 9 – Chart showing the D1 x EM relationship for spores in the Lower Cretaceous.

In the Upper Cretaceous, there were spores with muri of up to  $8 \ \mu m$  of width, and there were also spores similar to the ones of the Lower Cretaceous and Tertiary, which show muri with the same density, in spite of having different diameters.

It could also be observed that when the width of the muri of Upper Cretaceous spores varied, the interval of diameters also varied, which on their turn increased to larger values. (Figure 7).

Reasonable linearity could be observed in present-day spores as well. They do not have very thin walls and, as occurred in the Upper Cretaceous spores (Figure 7), the range of diameters varied according to the variation of denseness of their muri, which increased to larger values.

The relationship between EM x DM shows that, for the same value of EM, different values of DM may occur (Figures 10, 11 and 12). Also regarding the relationship between EM x DM, no correlation between the two variable was observed in the Cretaceous and Tertiary, an already expected result, as EM and DM are, a priori, independent parameters.



FIGURE 10 – Chart showing the EM x DM relationship for spores in the Lower Cretaceous.



FIGURE 11 – Chart showing the EM x DM relationship for spores in the Upper Cretaceous.



FIGURE 12 – Chart showing the EM x DM relationship for spores in the Tertiary.

This study showed that DM was lower than 2  $\mu$ m in the Cretaceous and varied from 0.5  $\mu$ m to 6  $\mu$ m in the Tertiary (Figures 10, 11 and 12).

Through an analysis of the relationships between the morphometric parameters of living species and the climate in which they live, it could be observed that there is an inverse relationship between EM and DM, especially for species of semi-arid to semi-humid regions (Figure 13).



FIGURE 13 – Chart showing the EM x DM relationship for extant spores of semi-humid to humid climate.

Analyses of other morphometric relationships  $(D1 \times D2; D1 \times DM; D1 \times EM; EM \times DM)$  of living species in relation to climate were also carried out.

In the D1 and D2 relationship of species of humid to very humid climates and of semi-arid to semi-humid climates, it was observed that D1 increased almost linearly with D2 (Figures 14 and 15).



FIGURE 14 – Chart showing the D1 x D2 relationship for extant spores of humid to very humid climates.



FIGURE 15 – Chart showing the D1 x D2 relationship for extant spores of semi-arid to semi-humid climates.

Regarding present-day spores of semi-humid to humid climates, it was observed a clustering of D1 values in the range of 50 to 100  $\mu$ m and of DM values in the range of 1 to 5  $\mu$ m (Figure 16). For a same D1 value, several DM values were observed and, similarly, for a same DM value, several D1 values were observed (Figure 16). A clustering of DM values around 5  $\mu$ m and of D1 values in the range of 40 to 110  $\mu$ m was also observed.



FIGURE 16 – Chart showing the D1 x DM relationship for extant spores of semi-humid to humid climates.

By associating the variable D1 to the variable DM of present-day spores of humid to very humid climates, it was observed that there are no linear or proportional patterns. Therefore, for a same D1 value, several DM values may be observed, just as different D1 values may be observed for a same DM value (Figure 17). The same results are obtained for spores of semi-humid to humid climates. However, spores of semi-humid to humid climates show a high concentration of D1 spores of 50 to 100  $\mu$ m and DM spores of 5  $\mu$ m, whereas spores of humid to very humid climates show more dispersed D1 and DM values.

The comparison between the minimum and maximum values of D1 and DM for spores of semi-humid to humid climates and for those of humid to very humid climates shows that there are differences among them. The maximum values of D1 for spores of semi-humid to humid climates (140 µm) are greater than those for spores of humid to very humid climates (118 µm) (Figures 16 and 17). Regarding the minimum values of D1, they are similar, around 40 µm, for all these spores. In relation to DM values, spores of semi-humid to humid climates showed higher values of DM, 10 µm, when compared to those of humid to very humid climates. For spores of semi-humid to humid and of humid to very humid climates, the lowest values of DM fall in the same range, between 0.5 and 1µm (Figures 16 and 17).



FIGURE 17 – Chart showing the D1 x DM relationship for extant spores of humid to very humid climates.

When comparing the relationship between D1 and DM for spores of semi-arid to semi-humid climates, for spores of semi-humid to humid climates and for those of humid to very humid climates, a great difference was observed, although an inverse correlation between D1 and DM was observed for all these spores. For spores of semi-arid to semi-humid climates, D1 and DM values are more spaced out and are not as clustered at certain intervals as they are for spores of other climates (Figure 18).



FIGURE 18 – Chart showing the D1 x DM relationship for extant spores of semi-arid to semi-humid climates.

Regarding the relationship between D1 and EM, D1 varies from 50 to 100  $\mu$ m and EM varies from 2 to 6  $\mu$ m for spores of semi-humid to humid climates, which does not occur for spores of other climates (Figures 19, 20 and 21).



FIGURE 19 – Chart showing the D1 x EM relationship for extant spores of semi-arid to semi-humid climates.



FIGURE 20 – Chart showing the D1 x EM relationship for extant spores of semi-humid to humid climates.



FIGURE 21 – Chart showing the D1 x EM relationship for extant spores of humid to very humid climates.

When EM increased, a subtle increase in D1 was observed for spores of all climates (Figures 19, 20 and 21).

Regarding the relationship between EM and DM, several values of DM were measured for a same EM value for spores of all climates. However, a slight tendency of inverse correlation between EM and DM was observed for spores of all climates (Figures 22, 23 and 24).



FIGURE 22 – Chart showing the EM x DM relationship for extant spores of semi-arid to semi-humid climates.



FIGURE 23 – Chart showing the EM x DM relationship for extant spores of semi-humid to humid climates.



FIGURE 24 – Chart showing the EM x DM relationship for extant spores of humid to very humid climates.

# **4 DISCUSSION**

Despite the fact that some authors believe that palynological measurements may not be reliable, as grains may expand on the slide or be compressed by the slide cover slips and covered by sediment residues on the palynological slides, selected morphological parameters were measured in this study. HUGHES & MOODY-STUART (1966) and FENSOME (1987) also worked with measurements of morphometric parameters of palynomorphs.

HUGHES & MOODY-STUART (1966), for example, made a histogram showing the frequency of maximum diameter in micrometers of *Schizaeopsis americana*. The average diameter of the genus *Schizaeopsis*, which is also a cicatricose spore just like the spores of *Cicatricosisporites*, is similar to that of the Anemiaceae, which ranges from 60 to 80  $\mu$ m. COUPER (1958) even suggested that *Schizaeopsis* would be a synonym for *Cicatricosisporites*.

HUGHES & MOODY-STUART (1966) also analyzed the morphological parameters of *Pelletieria valdensis*, which, according to DAVIES (1985), is associated to the genus *Plicatella*, which is in turn an Anemiaceae as well.

According to HUGHES & MOODY-STUART (1966), the average diameter of *Pelletieria* ranges from 65 to 80  $\mu$ m, which is similar to the average diameter of the fossil and present-day spores of Anemiaceae measured in this study. These authors built a diagram showing the thickness average of the radial equatorial exine for *Pelletieria*. In the present work, the thickness of the radial equatorial exine was not measured because it was impossible to obtain precise values.

For the genus Schizaeopsis, the charts of this study were built similarly to those built by HUGHES & MOODY-STUART (1966), which show the correlation between the distance between the walls and the thickness of the walls, as well as the correlation between the diameter of the spores and the thickness of the walls. The values shown in the charts of this study are similar to those shown in the charts by HUGHES & MOODY-STUART (1966), confirming the suggestion by COUPER (1958) that Schizaeopsis can be a synonym for the genus Cicatricosisporites, which in turn are related to Anemiaceae. However, HUGHES & MOODY-STUART (1969) in their later work noted that Schizaeopsis has thinner stretch marks than the Cicatricosisporites.

According to FENSOME (1987), who deeply studied the characters and morphological parameters of cicatricose grains, there are seven characters that are very important for the identification and classification of species of cicatricose trilete spores. Among these characters, there are the morphometric characters, including some similar to those used in the present work. The seven characters used by FENSOME (1987) are: size (diameter), absolute or relative thickness of the walls and wrinkles, relationship between the thickness of the group of stretch marks and the spore diameter, form of the amb, thickness of the exine and the presence or absence of apical thickness of the exine, height and form of the wall transversal section and standard of ornamentation. However, the author did not establish a relationship between these characters and the paleoclimate or the paleoenvironment.

Taxonomic studies of these types of spores with accurate descriptions and illustrations are very important due to their biostratigraphic significance, and due to the fact that many specimens have been misidentified (NARVÁEZ *et al.* 2013).

A reliable identification can be performed based on a correct description using morphometric parameters, resulting in an accurate biostratigraphy and correlation.

Statistical analysis of the measurements of muri, striae, equatorial diameter and other parameters showed significant variation, and a general idea about the group in terms of morphological and morphometric aspects can be obtained from this analysis. Furthermore, these measurements can be used to obtain a correct description and identification of several types of Anemiacean spores. Sometimes, depending on the methodology used, some grains can expand due to the liquids they absorb during slide mounting. This problem can be avoided by carrying out measurements immediately after the mounting.

# **5** CONCLUSIONS

• There is a perfect linear correlation between D1 and D2.

• In the relationship between D1 and EM, there is an increase in D1, when muri width increases.

• There is no correlation between EM and DM for species from the Cretaceous to the Tertiary. However, for living species, there is a slight inverse correlation between EM and DM.

• There is an inverse correlation between EM and DM for living species, especially for those of semi-arid to semi-humid climates. For fossil species, this correlation was not observed due to the existence of species with fine and dense plicas (e.g., *Cicatricosisporites microstriatus*, *C. minutaestriatus* and *C. avnimelechi*) and species with plicas of medium thickness with great distance between the muri (e.g. *Cicatricosisporites hughesii* and *C. purbeckensis*).

• It is very important to study the morphometric characteristics of Anemiacean

spores, because they are useful to identify different groups of the family Anemiaceae and because they show morphological changes over geological time. Information about paleoclimate and paleoenvironment can be obtained from these changes.

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# APPENDIX

Sanfranciscana Basin

Areado Formation, lower Aptian

Slide 1 - FSJ-1, lower bed, Outcrop sample (9406962).

Slide 2 - FSJ-6, Outcrop sample (9406944).

Slide 3 - FSJ-10, Outcrop sample (9406948).

Slide 4 - FSJ-11, Outcrop sample (9406949).

Slide 5 - FSJ-13, Outcrop sample (9406952).

Parnaíba Basin

Codó Formation, upper Aptian Slide 6 - CD-140, Outcrop sample (9900342). Slide 7 - CD-1-2, Outcrop sample (9900229A). Slide 8 - CD-4, Outcrop sample (9900230A). Slide 9 - CD-6-1-2, Outcrop sample (9900231A). Slide 10 - CD-40, Outcrop sample (9900342A). Slide 11 - CD-130, Outcrop sample (9900234). Slide 12 - CD-130, Outcrop sample (9900234A). Slide 13 - CD-131, Outcrop sample (9900235). Slide 14 - CD-171, Outcrop sample (9902826). Slide 15 - CD-181, Outcrop sample (9902828). Slide 16 - CD-204, Outcrop sample (9902831). Slide 17 - CD-204, Outcrop sample (9902831A). Slide 18 - CD-214, Outcrop sample (9902833). Slide 19 - CD-214, Outcrop sample (9902833A). Slide 20 - CD-218, Outcrop sample (9902834). Slide 21 - CD-218, Outcrop sample (9902834A). Slide 22 - CD-328, Outcrop sample (0101122). Slide 23 - CD-332, Point b, Outcrop sample (0101125). Slide 24 - CD-332 Point d, Outcrop sample (0101121). Slide 25 - CD-336, Outcrop sample (0101126). Slide 26 - CD-340, Point a, Outcrop sample (0101127).

Paraná Basin Bauru Group, Coniacian – Santonian Slide 27 - UNESP-6 sample (0101120).

# Almada Basin

Urucutuca Formation, Maastrichtian
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Slide 29 - Point 2, Outcrop sample, clast from shale(200302044).
Slide 30 - Point 3, Outcrop sample, intercalated shale (200302046).
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Slide 34 - Point 4, Outcrop sample, clast (200302050).
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# Pernambuco-Paraíba Basin

# Gramame Formation, Maastrichtian

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Slide 49 - Nassau Quarry, point 2 (9200686).

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# Maria Farinha Formation, Paleocene

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# Resende Basin

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# Taubaté Basin

Tremembé Formation, Oligocene

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- Slide 69 Aligra Quarry II, point 37, Outcrop sample (8701912).

Slide 70 - T-39 sample, Point A1, Outcrop sample (8701914).

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## São Paulo Basin

# Itaquaquecetuba Formation, Oligocene – Miocene

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São Paulo Formation, Oligocene Slide 98 - Sample Barra Funda D - 75 (8602106).

Bragança-Viseu Basin
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Acre Basin

Solimões Formation, Miocene

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