Statistical analysis of palynological assemblages from the Aptian-Albian of the Araripe Basin, northeast Brazil: a case study of paleoenvironmental significance of Early Cretaceous terrestrial palynomorphs

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Abstract. Statistical treatment of palynological data from Rio da Batateira and Santana formations (Aptian-Albian) of the Araripe Basin provides mathematical support to paleoclimatic interpretations. In addition to *Classopollis* and ephedroid pollen, widely accepted as aridity indicators, other typical xerophytic elements include *Afropollis* spp., *Spheripollenites subgranulatus* Couper, *Monosulcites* s.l., *Brenneripollis peroreticulatus* (Brenner), and bisaccate pollen. The correlation between ephedroid pollen and perisporium-bearing spores is surprising, since pteridophytic spores normally tend to be incompatible with xerophytic elements. This fact may be explained by the habitat of this pteridophytic flora which occupied humid river-side lands under general dry climatic conditions. Another unexpected correlation is that of bisaccate pollen with *Classopollis* and ephedroid pollen. In the Aptian-Albian of the Araripe Basin, as elsewhere in the West African-South American Microfloristic Province, bisaccates are never dominant, but occasional peaks in their relative abundance coincide with relative peaks of other arid climate palynomorphs. This fact is explained by their wind-born transportation. They may concentrate in basins situated in dry scenarios with low local palynomorph production. Interesting interpretations may be established from the correlation observed in angiospermoid pollen. While primitive monoaperturate pollen grains (*Afropollis* and *Brenneripollis*) are closely related to arid climates, tricolpate pollen grains show some divergence in their correlations. The correlation of tricolpates with both ephedroid and trilete spores is significant, but its correlation with *Classopollis* is weak. This may indicate the occupation of a wide range of habitats by the primitive angiosperm flora.

Key words. Brazil. Araripe Basin. Cretaceous. Palynology. Statistical analysis.

Introduction

Palynology has been considered as one of the most efficient micropaleontological tools in paleoclimatic interpretations. The accuracy of paleoecological reconstructions based on palynology depends on the knowledge of the paleoecological behavior of palynomorph-bearing plants. The relation between plant families and fossil palynomorphs is more apparent in post-Cretaceous palynomorphs, since most of the living plant families emerged during the Cenozoic (Muller, 1970, 1981). For the Mesozoic, most of the palynological climatic interpretation is based on other criteria which include non-biotic parameters such as mineralogy, sedimentology, geochemistry, etc. Some palynologists (*e.g.*, Reyre, 1979; Hochuli and Kelts, 1980; Lima, 1983; Dino, 1992) tried to establish, even though precariously, some basic rules to obtain paleoclimatic information from the Cretaceous palynological associations. In this work, we intend to show several correlations of palynomorphs traditionally regarded as paleoclimatic indicators with other groups whose paleoclimatic behavior is less known.

Methodology

The Rio da Batateira and Santana formations of the Araripe Basin, Northeast Brazil, were chosen for this study because they represent a very restricted stratigraphic interval of the Aptian-Albian transition and one of the most polleniferous strata in Brazil. Moreover, several palynological samples have been collected from both stratigraphic units. The absolute palynomorph count varies from 20 to 400 specimens for each sample, but most of them present more than 100 specimens. Statistical treatment of palynological data obtained from samples having more than 60 specimens provided mathematical support to traditional paleoclimatic interpretations based on palynomorphs. The following formula was then applied to the use of the Pearson coefficient of correlation (r):

$$r = \frac{\Sigma xy - \Sigma x\, \Sigma y / n}{(\Sigma x^2 - (\Sigma x)^2 / n)^{1/2}\, (\Sigma y^2 - (\Sigma y)^2 / n)^{1/2}}$$

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Table 1. Taxon-taxon correlation matrix. Significant values in bold.

	Classopollis spp. (1)	Ephedroid pollen grains (2)	Araucariacites spp. (3)	Araucariacites australis Cookson (4)	Exesipollenites tumulus Balme (5)	Spheripollenites subgranulatus Couper (6)	Callialasporites spp. (7)	Monosulcites s.l. (8)	Cycadopites spp. (9)	Eucommiidites spp. (10)	Afropollis spp. (11)	Brenneripollis peroreticulatus (Brenner) (12)	Stellatopollis spp. (13)	Sergipea variverrucata Regali, Uesugui and Santos (14)	Retitricolpites s.l. (15)	bisaccate pollen grains (16)	Vitreisporites spp. (17)	smooth trilete spores (18)	verrucate trilete spores (19)	Perotriletes s.l. (20)	Matonisporites silvai Lima (21)	Cicatricosisporites spp. (22)	Uvaesporites spp. (23)	Botryococcus spp. (24)
1	-	**.501**	-.039	.198	.249	**.542**	.287	**.392**	.204	**.403**	**.536**	**.522**	-.254	.246	.207	**.428**	**.438**	-.135	.067	-.153	.132	-.060	.098	**.655**
2	**.501**	-	.124	-.039	.283	**.373**	-.074	**.470**	.230	.208	**.862**	**.598**	.107	**.489**	.320	**.593**	**.401**	.342	.073	**.433**	-.011	.053	.317	**.731**
3	-.039	.124	-	-.211	**.358**	-.117	**.389**	.077	.002	.048	-.081	-.052	-.066	.181	**.376**	-.009	.010	-.032	**.764**	-.054	-.115	**.656**	**.529**	-.057
4	.198	-.039	-.211	-	.103	.330	-.088	-.073	-.169	**.387**	-.041	-.056	-.109	-.066	-.115	-.078	-.080	-.074	-.046	-.086	**.583**	-.124	-.016	-.164
5	.249	.283	**.358**	.103	-	.133	.153	.330	.132	.219	**.369**	.138	.135	.012	.175	.127	**.503**	.002	.285	-.025	**.390**	**.376**	**.442**	.188
6	**.542**	**.373**	-.117	.330	.133	-	.018	.195	.105	**.647**	**.373**	.168	-.126	.335	.106	**.428**	.074	-.066	.073	-.094	.221	-.016	.166	**.384**
7	.287	-.074	**.389**	-.088	.153	.018	-	-.069	-.081	.221	-.053	-.091	-.177	-.002	-.039	.038	-.027	-.078	**.515**	-.118	.201	**.465**	.164	-.119
8	**.392**	**.470**	.077	-.073	.330	.195	-.069	-	.157	.233	**.556**	**.705**	-.016	.296	-.023	.093	**.568**	-.024	.019	-.019	.012	.105	.246	**.520**
9	.204	.230	.002	-.169	.132	.105	-.081	.157	-	-.105	.169	.215	.227	.102	.158	.242	.110	-.066	-.055	-.096	-.098	.274	.209	**.352**
10	**.403**	.208	.048	**.387**	.219	**.647**	.221	.233	-.105	-	.274	.041	-.121	.026	.031	.191	-.015	-.051	.195	-.085	.201	.113	.019	.090
11	**.536**	**.862**	-.081	-.041	**.369**	**.373**	-.053	**.556**	.169	.274	-	**.657**	.057	**.409**	.165	**.554**	**.544**	.191	-.087	.238	.108	-.025	.220	**.763**
12	**.522**	**.598**	-.052	-.056	.138	.168	-.091	**.705**	.215	.041	**.657**	-	-.037	.261	-.039	.097	**.700**	.006	-.072	-.033	-.030	-.095	.111	**.658**
13	-.254	.107	-.066	-.109	.135	-.126	-.177	-.016	.227	-.121	.057	-.037	-	-.088	-.076	.016	-.052	**.357**	-.140	**.414**	-.058	**.390**	.098	-.112
14	.246	**.489**	.181	-.066	.012	.335	-.002	.296	.102	.026	**.409**	.261	-.088	-	.222	**.610**	.154	-.033	.084	-.049	-.072	.092	**.550**	**.484**
15	.207	.320	**.376**	-.115	.175	.106	-.039	-.023	.158	.031	.165	-.039	-.076	.222	-	**.414**	-.055	-.025	.333	-.057	-.062	.164	.229	.332
16	**.428**	**.593**	-.009	-.078	.127	**.428**	.038	.093	.242	.191	**.554**	.097	.016	**.610**	**.414**	-	.040	-.033	.013	-.049	-.065	.038	**.368**	**.663**
17	**.438**	**.401**	.010	-.080	**.503**	.074	-.027	**.568**	.110	-.015	**.544**	**.700**	-.052	.154	-.055	.040	-	.031	-.047	-.004	-.043	-.110	.158	**.457**
18	-.135	.342	-.032	-.074	.002	-.066	-.078	-.024	-.066	-.051	.191	.006	**.357**	-.033	-.025	-.033	.031	-	-.022	**.777**	.008	-.017	.005	-.054
19	.067	.073	**.764**	-.046	.285	.073	**.515**	.019	-.055	.195	-.087	-.072	-.140	.084	.333	.013	-.047	-.022	-	-.090	.133	**.531**	**.453**	-.137
20	-.153	**.433**	-.054	-.086	-.025	-.094	-.118	-.019	-.096	-.085	.238	-.033	**.414**	-.049	-.057	-.049	-.004	**.777**	-.090	-	-.052	-.038	-.014	-.075
21	.132	-.011	-.115	**.583**	**.390**	.221	.201	.012	-.098	.201	.108	-.030	-.058	-.072	-.062	-.065	-.043	.008	.133	-.052	-	.053	.139	-.060
22	-.060	.053	**.656**	-.124	**.376**	-.016	**.465**	.105	.274	.113	-.025	-.095	**.390**	.092	.164	.038	-.110	-.017	**.531**	-.038	.053	-	**.433**	-.128
23	.098	.317	**.529**	-.016	**.442**	.166	.164	.246	.209	.019	.220	.111	.098	**.550**	.229	**.368**	.158	.005	**.453**	-.014	.139	**.433**	-	.235
24	**.655**	**.731**	-.057	-.164	.188	**.384**	-.119	**.520**	**.352**	.090	**.763**	**.658**	-.112	**.484**	.332	**.663**	**.457**	-.054	-.137	-.075	-.060	-.128	.235	-

Where: x, relative frequency of taxon x; y, relative frequency of taxon y; n = total number of samples.

The adopted critical value for the coefficient was 0.35, compatible with the size of population (54 samples) and significance level of 1% ($\alpha = 0.01$). All situations with significant coefficient values have been evaluated, with special attention to the ephedroid pollen grains and trilete spores which, according to traditional assumptions, have the most consistent paleoecological meaning. Mathematical calculations were automatized by means of a routine coupled to the program of Numerical Paleoecological Analysis elaborated by the second author. Thanks to this program, dendrograms could be presented concomitantly, facilitating the visual grouping analysis.

Results

This study, involving 69 taxons, generated 2346 taxon-taxon correlations. This number can be foreseen by the following formula:

$$N = \frac{n(n-1)}{2}$$

Where: N, number of performed correlations; n, total number of identified taxa.

Most of these correlations supplied coefficient values below the critical one, as shown in the taxon-taxon correlation matrix (table 1). Of all correlations that involved main palynomorph taxa, about 60 significant cases were selected (see values in bold on table 1) and considered in the present work.

Interpretations

In addition to *Classopollis* and ephedroid pollen (*Equisetosporites*, *Gnetaceaepollenites* and *Steevesipollenites*), widely accepted as aridity indicators (Pocock and Jansonius, 1961; Vakhrameev, 1970; De Jersey, 1973; Srivastava, 1976; Lima, 1976, 1978, 1983; Courtinat, 1980), other typical xerophytic elements include *Afropollis* spp., *Spheripollenites subgranulatus* Couper, *Monosulcites* s.l., *Brenneripollis peroreticulatus* (Brenner) and bisaccate pollen including *Vitreisporites* spp. All of them present significant correlation with *Classopollis* and ephedroid pollen (figure 1, table 1). Some palynomorphs such as *Retitricolpites* s.l. (*Albertipollenites*, *Rousea* and *Tricolpites*), *Sergipea variverrucata* Regali, Uesugui and Santos, and perisporium-bearing spores present significant correlation with ephedroid pollen only, and the values of their correlation with *Classopollis* are

low (r= 0.290, 0.246 and -0.153, respectively). *Eucommiidites* presents good correlation with *Classopollis* (r= 0.403), but its correlation with ephedroid pollen grains is poor (r= 0.208). This suggests that other parameters besides aridity are involved, making the ecological relation between these plant groups more complex. The significant correlation (r= 0.433) observed between ephedroid pollen and perisporium-bearing spores is surprising, since

pteridophytic spores normally tend to be incompatible with xerophilous elements. This fact may be explained by the probable habitat of this pteridophytic flora, which seems to have developed on humid river-side lands under dry climatic conditions. Another unexpectedly significative correlation is that of bisaccate pollen grains with *Classopollis* and ephedroid pollen grains. In the Albian-Aptian of the Araripe Basin, as almost anywhere else in the West African -
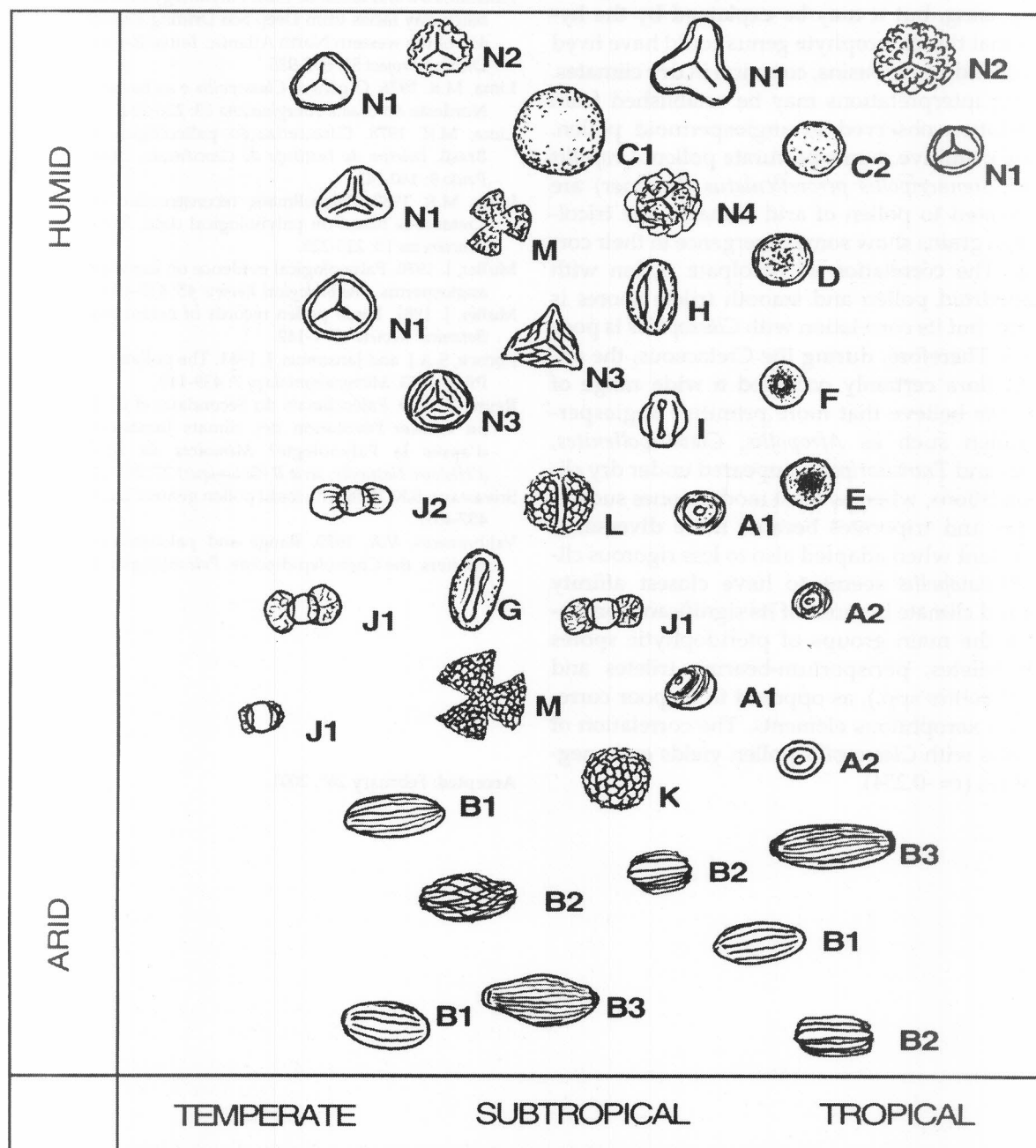

Figure 1. Schematic representation of the behavior of main paleoclimate index palynomorphs. **A**, *Classopollis s.l.* (**A1**, *Classopollis classoides* Pflug; **A2**, *Circulina* spp.). **B**, Ephedroid pollen (**B1**, *Equisetosporites*; **B2**, *Gnetaceaepollenites*; **B3**, *Steevesipollenites*). **C**, *Araucariacites* (**C1**, *Araucariacites australis* Cookson; **C2**, *Araucariacites* spp.). **D**, *Inaperturopollenites*. **E**, *Spheripollenites subgranulatus* Couper. **F**, *Exesipollenites tumulus* Balme. **G**, *Monosulcites s.l.* **H**, *Cycadopites*. **I**, *Eucommiidites*. **J**, Bisaccate pollen (**J1**, *Disaccites s.l.*; **J2**, *Vitreisporites*). **K**, *Afropollis*. **L**, *Brenneripollis peroreticulatus* (Brenner). **M**, *Retitricolpites s.l.* **N**, Trilete spores (**N1**, smooth trilete spores; **N2**, ornamented trilete spores; **N3**, *Cicatricosisporites s.l.*; **N4**, *Perotrileti*).

South American Microfloristic Province during the middle Cretaceous, bisaccate pollen grains are never dominant elements, but occasional increases in their relative abundance usually coincide with relative increases in the proportion of other arid climate palynomorphs. This fact is explained by the wind-born transportation of these pollen grains. They may concentrate in basins situated in dry scenarios with low local palynomorph production. The good correlation between aridity indicators and *Botryococcus* algae is also surprising, but it may be explained by the hypothesis that this chlorophyte genus could have lived in lakes of endorheic basins, common in dry climates. Interesting interpretations may be established from the correlation observed in angiospermoid pollen. While the primitive monoaperturate pollen *Afropollis* spp. and *Brenneripollis peroreticulatus* (Brenner) are closely related to pollen of arid climates, the tricolpate pollen grains show some divergence in their correlations. The correlation of tricolpate pollen with both ephedroid pollen and smooth trilete spores is significant, but its correlation with *Classopollis* is poor (r= 0.290). Therefore, during the Cretaceous, the angiosperm flora certainly occupied a wide range of habitats. We believe that more primitive angiospermoid pollen such as *Afropollis*, *Clavatipollenites*, *Liliacidites* and *Transitoripollis* appeared under dry climatic conditions, whereas most modern ones such as tricolpates and triporates became more diversified and abundant when adapted also to less rigorous climates. *Stellatopollis* seems to have closest affinity with humid climate because of its significant correlation with the main groups of pteridophytic spores (smooth triletes, perisporium-bearing triletes and *Cicatricosisporites* spp.), as opposed to its poor correlation with xerophilous elements. The correlation of *Stellatopollis* with *Classopollis* pollen yields even negative values (r= -0.254).

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