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Original article

Angiosperm pollen grains in sedimentary profiles from two Brazilian Atlantic rainforests, northernmost coastal plain from Rio Grande do Sul, southern Brazil. Part II

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ABSTRACT

The state of Rio Grande do Sul (RS) is located in the extreme south of Brazil, within a transition region between the tropical and subtropical zones of South America that has been frequently affected by fluctuations in climate and vegetation over the last millennia. Palynomorphs preserved in sediments have provided excellent study material for paleoenvironmental reconstitutions of this region, as they reveal the source organisms and their respective environments over geological time. The present study was conducted to provide additional palynological reference material preserved in Quaternary sediments from the RS coastal plain for paleoenvironmental reconstruction studies. Here, we present taxonomic descriptions of pollen from 29 angiosperm taxa extracted along two Quaternary sedimentary profiles: the Pirataba forest profile (29° 15' S 49° 51'W) and the Faxinal forest profile (29° 21' S 49° 45' W), Torres municipality, in the extreme north of the coastal plain of RS. Ecological data and pollen photomicrographs accompany the taxonomic descriptions. This reference material, together with the other palynomorphs found in the two sedimentary profiles, was the basis for our study of paleoenvironments from the last millennia in southern Brazil, according to the dynamics of climate and vegetation.

Keywords: angiosperms, palynology, Quaternary, sedimentary profiles, southern Brazil, taxonomic descriptions

Introduction

The state of Rio Grande do Sul (RS), in the extreme south of Brazil, is situated approximately halfway between the Equator and the Antarctic Polar Circle, within a transitional area between the tropical and subtropical zones of South America (Marchiori 2004). The state harbors an extensive coastal plain of more than 600 km in length that, on a global scale, is affected by changes in climate and sea-level fluctuations (Seeliger *et al.* 1998). In this coastal plain, lakes, lagoons, marshes, and forests allow for the preservation of palynomorphs in sediments, offering abundant material for paleoenvironmental reconstructions

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of the last millennia related to climate change and sea-level oscillations (Lorscheitter & Romero 1985; Cordeiro & Lorscheitter 1994; Neves & Lorscheitter 1995a; Lorscheitter & Dillenburg 1998; Neves 1998; Lorscheitter 2003; Macedo *et al*. 2007; Masetto & Lorscheitter 2019; Roth *et al*. 2021). Results of these reconstructions can provide information for environmental preservation and monitoring.

Palynological catalogs of reference materials preserved in sediments are a good support for paleoenvironmental analyses. For the extensive coastal plain of RS, there are few palynological catalogs including pollen from angiosperms (Lorscheitter 1989; Cordeiro 1991; Neves & Lorscheitter 1995b; Neves *et al*. 2003; Neves & Cancelli 2006; Macedo *et al*. 2009; Masetto & Lorscheitter 2016; Roth & Lorscheitter 2017).

The present study completes the series of catalogs of palynomorphs preserved in Quaternary sediments from two sedimentary profiles of tropical Pirataba and Faxinal forests in the northernmost region of the RS coastal plain (Roth & Lorscheitter 2013; 2016; 2017). These catalogs have been used for the paleoenvironmental reconstitution of the last 24,000 years in the region (Roth *et al*. 2021).

The angiosperm pollen catalog presented here represents Part II of the angiosperm material previously described by Roth & Lorscheitter (2017) and includes morphological descriptions, measurements, and photomicrographs. Ecological data for the respective sporophytes accompany the descriptions. The objective is to provide more reference material for paleoenvironmental reconstitutions related to the late Quaternary of the coastal plain.

Material and methods

Study sites

The two sedimentary profiles were collected from the interior of two Atlantic rainforests *sensu stricto* (*s. str*.) located at approximately the same latitude in Torres municipality, on the extreme northernmost coastal plain of RS, southern Brazil: one profile (254 cm in length) was obtained from the Pirataba forest (29° 15' S 49° 51' W), 17 km from the coastline and the second profile (612 cm in length) was obtained from the Faxinal forest (29° 21' S 49° 45' W) 2 km from the coastline (Fig. 1). The profiles were obtained using a Hiller sampler (Faegri & Iversen 1989), and the subsamples were collected along the profiles at regular intervals about 5 cm. The radiocarbon age near the profile bases allowed us to determine the time interval (Roth *et al*. 2021).

Chemical treatment and analysis

The standard chemical treatment of the subsamples (one sample = 8 cm^3) involved treatment with hydrochloric acid, hydrofluoric acid, potassium hydroxide, and acetolysis, followed by filtration through 250-μm mesh (Faegri & Iversen 1989). The subsamples were mounted on slides in glycerol jelly (Salgado-Labouriau 1973; Faegri & Iversen 1989) and examined under light microscopy (DIAPLAN, Leitz, Wetzlar, Germany). Taxonomic identification was based on the pollen reference collection of the Palynology Laboratory, Department of Botany, Universidade Federal of Rio Grande do Sul, Brazil, and reference pollen catalogs (Erdtman 1952; Heusser 1971; Markgraf & D'Antoni 1978; Hooghiemstra 1984; Roubik & Moreno P. 1991; Lorente *et al*. 2017). Taxonomic ordination of orders was based on APG IV (Byng *et al*. 2016). Taxonomic names followed the Missouri Botanical Garden (MOBOT) nomenclature (2020). We identified the material to the lowest taxonomic level permitted by the pollen morphology and level of preservation. The word "type" was used when precise identification was not possible (Berglund 1986). Distinct materials within the same taxon were separated by numbers. A minimum of 300 angiosperm pollen grains was counted for each subsample (Birks & Gordon 1985), with this number determined using saturation curves (Roth *et al*. 2021).

For the taxonomic pollen descriptions, the morphological nomenclature was based on Punt *et al*. (2007). We tried to find 25 grains to each taxon to calculate the measurements. This number could not be reached at the rare taxa, indicated in the descriptions. In some cases, it was not possible to measure the polar axis because of their permanent position in polar view. At the end of each palynological description, we provide brief ecological information for the plant in southern Brazil, for use in future paleoenvironmental studies. Photomicrographs were captured using a digital camera (DFC295; Leica Microsystems, Wetzlar, Germany) connected to a light microscope.

Results

In this Part II of angiosperm pollen descriptions of Pirataba and Faxinal sediment profiles, we describe the final 29 taxa below.

Angiosperms

Santalales

Loranthaceae

1. ***Phrygilanthus*** Eichler
(Fig. 2A)

Radially symmetric, isopolar. Triangular in polar view, with concave mesocolpia and truncate angles. Tricolpate and sincolpate. Mesocolpia with a hyaline baculate layer, formed by small projections densely disposed. Thick exine (*ca*. 2 μm), evident columellae. Equatorial diameter: *ca*. 27

Figure 1. Study sites. **A**. Map of South America with the location of Rio Grande do Sul (RS) in southern Brazil; **B**. Detailed relief map with the locations of the present-day Pirataba (1, left) and Faxinal (2, right) forests in Torres municipality, on the extreme northern RS coastal plain; **C**. Satellite image from Google Earth, 2021, indicating the locations of the two sedimentary profiles: Pirataba profile (1, left above: 29° 15' S 49° 51' W) and Faxinal profile (2, right below: 29° 21' S 49° 45' W).

μm. Ecological data: common hemiparasitic herbs, on forest trees (Schultz 1990; Joly 2002).

Caryophyllales

Amaranthaceae

2. ***Alternanthera*** Forssk.
(Fig. 2B, C)
Spheroidal, radially symmetric, apolar. Pantoporate, metareticulate. Large lumina and straight muri, forming a polygonal grain. Microechinate muri. Thick exine (*ca.* 2 μm), evident columellae. Diameter: *ca.* 24 μm. Ecological data: commonly occurring herbs, in grassland and ruderal habitats, also found on coastal dunes of southern Brazil (Joly 2002).

3. ***Amaranthus*** L. type
(Fig. 2D, E)
Spheroidal, radially symmetric, apolar. Pantoporate. Numerous pores (*ca.* 70) regularly distributed. Psilate. Thick exine (*ca.* 2 μm), evident columellae. Diameter: *ca.* 35 μm. Ecological data: *Amaranthus* are herbs, common in grassland and ruderal habitats (Joly 2002; Souza & Lorenzi 2012).

4. ***Gomphrena*** L. 1
(Fig. 2F, H)
Spheroidal, radially symmetric, apolar. Pantoporate, metareticulate. Large lumina and straight muri. Psilate muri. Thick exine (*ca.* 2 μm), evident columellae. Diameter: *ca.* 16 μm. Ecological data: *Gomphrena* are common herbs, generally found in dry grasslands (Marchant *et al*. 2002).

5. ***Gomphrena*** L. 2
(Fig. 2I, J)
Spheroidal, radially symmetric, apolar. Pantoporate, metareticulate. Large lumina and undulating muri. Psilate muri. Thick exine (*ca.* 4 μm), evident columellae. Diameter: *ca.* 29 μm. Ecological data: the same as for *Gomphrena* L. 1.

Caryophyllaceae

6. **Caryophyllaceae**
(Fig. 2K-M)
Spheroidal, radially symmetric, apolar. Pantoporate. Sparse and regularly distributed pores. Granulate. Thick exine (*ca.* 2 μm), evident columellae. Rare grains. Diameter: *ca.* 25 μm. Ecological data: general herbs that can be found in diverse environments (Cronquist 1981; Souza & Lorenzi 2012).

Polygonaceae

7. ***Polygonum*** L.
(Fig. 2N-P)
Spheroidal, radially symmetric, apolar. Pantoporate, eureticulate. Large lumina and straight muri. Sparse and regularly distributed pores, present only in a few lumina. Psilate muri. Thick exine (*ca.* 4 μm), evident columellae. Diameter: *ca.* 48 μm. Ecological data: herbs, in open environments (Joly 2002).

Ericales

Ericaceae

8. ***Gaylussacia*** Kunth
(Fig. 2Q, R)
Tetrahedral tetrad. Pollen grain oblate, radially symmetric, heteropolar. Equatorial view with convex distal pole and fusiform proximal pole. Tricolporate, ectoapertures with marginal thickening. Scabrate. Exine with obscure stratification. Rare grains. Tetrad diameter: *ca.* 54 μm. Pollen grain: polar axis, *ca.* 21 μm; equatorial diameter, *ca.* 39 μm. Ecological data: shrubs, in swamps (Joly 2002; Souza & Lorenzi 2012).

Primulaceae

9. ***Myrsine*** L.
(Fig. 2S-V)
Spheroidal, radially symmetric, isopolar. Tetracolporoidate. Psilate. Exine with evident columellae. Polar axis and equatorial diameter: *ca.* 30 μm. Ecological data: pioneer tree species widely dispersed by fauna with developmental capacity in any type of soil (Backes & Irgang 2002). Common in forests in southeast Brazil (Souza & Lorenzi 2012).

Sapotaceae

10. ***Chrysophyllum marginatum*** (Hook. & Arn.) Radlk.
(Fig. 2W, X)
Prolate, radially symmetric, isopolar. Elliptic in equatorial view, with broad convex poles. Tricolporate, circular endoapertures. Psilate. Thicker exine at the poles (*ca.* 4 μm), where there are longer columellae. Polar axis: *ca.* 29 μm; equatorial diameter: *ca.* 17 μm. Ecological data: small trees, pioneer in several forest systems (Backes & Irgang 2002).

Symplocaceae

11. ***Symplocos*** Jacq.
(Fig. 2Y)
Radially symmetric, isopolar. Subtriangular in polar view. Triporate, rugulate. Exine with obscure stratification. Equatorial diameter: *ca.* 33 μm. Ecological data: trees or shrubs, in varied habitats (Barroso 1978; Cronquist 1981).

Gentianales

Apocynaceae

12. **Apocynaceae**
(Fig. 3A, B)
Subspheroidal, radially symmetric, isopolar. Slightly elliptic in equatorial view. Triporate, pores with a wide

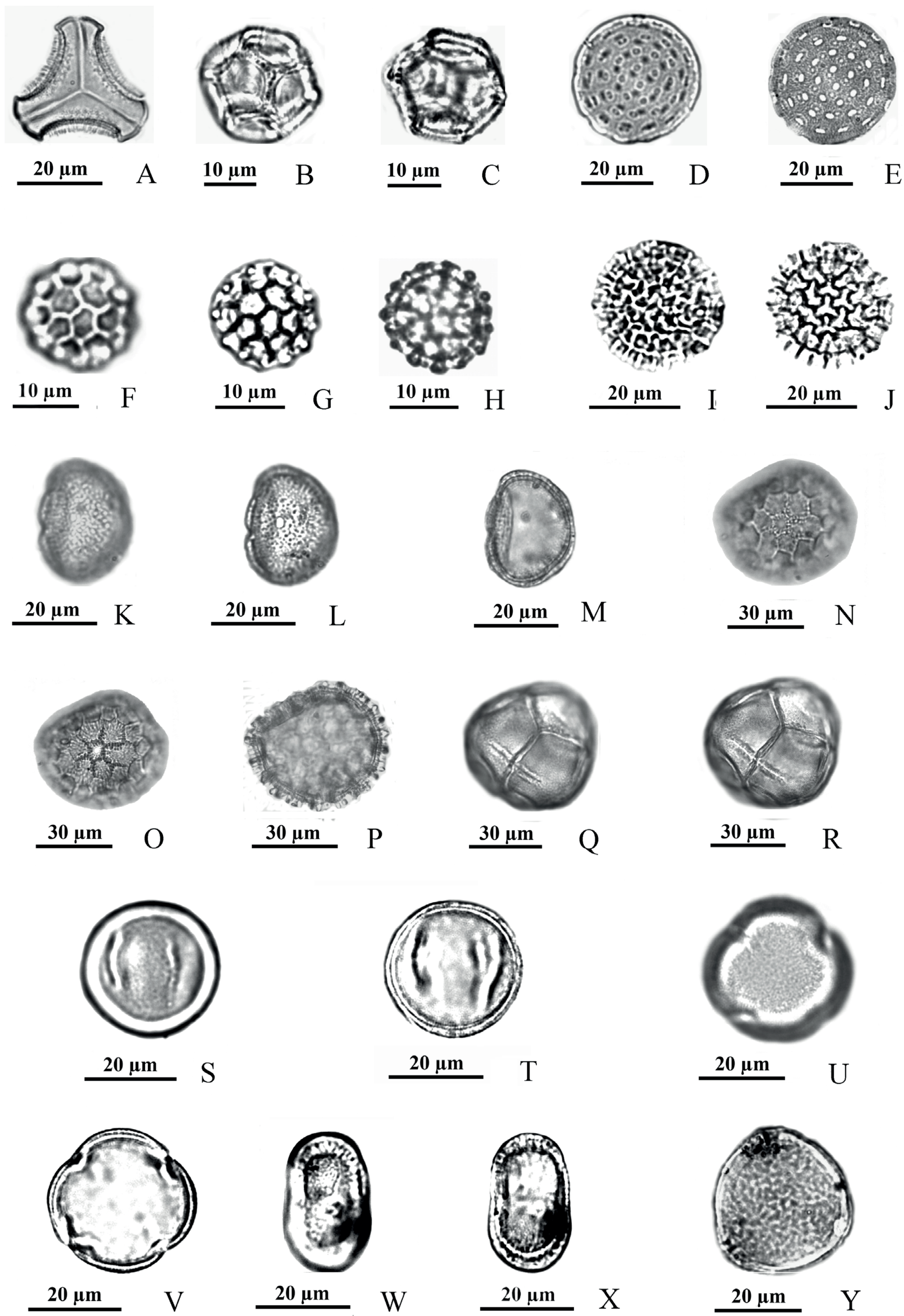

Figure 2. Angiosperms. **A.** *Phrygilanthus* Eichler (PV); **B**-**C.** *Alternanthera* Forssk: 1º-2º pl; **D**–**E.** *Amaranthus* L. type: 1º-2º pl; **F**-**H.** *Gomphrena* L. 1: 1º-3º pl; **I**-**J.** *Gomphrena* L. 2: 1º-2º pl; **K**-**M.** Caryophyllaceae (folded up): 1º-3º pl; **N**-**P.** *Polygonum* L. (folded up): 1º-3º pl; **Q**-**R.** *Gaylussacia* Kunth: 1º-2º pl; **S**-**V.** *Myrsine* L. **S**-**T** (EV): 1º-2º pl, **U**-**V** (PV): 1º-2º pl; **W**-**X.** *Chrysophyllum marginatum* (Hook. & Arn.) Radlk. (EV): 1º-2º pl; **Y.** *Symplocos* Jacq. (PV). (PV) polar view, (EV) equatorial view, pl planes.

irregular annulus. Psilate. Exine with obscure stratification. Rare grains. Polar axis: *ca.* 52 µm; equatorial diameter: *ca.* 49 µm. Ecological data: herbs, sub-shrubs, trees, or often, climbing plants, in both grasslands and forests (Joly 2002; Souza & Lorenzi 2012).

Rubiaceae

13. ***Borreria*** G. Mey. type
(Fig. 3C, D)
Radially symmetric, isopolar. Circular in polar view. Zonocolpate, *ca.* nine colpi. Eureticulate, thin reticulum. Thick exine (*ca.* 4 µm), evident columellae. Equatorial diameter: *ca.* 56 µm. Ecological data: *Borreria* are herbs with a wide habitat range, in open environments (Marchant *et al.* 2002).

14. ***Galium*** L.
(Fig. 3E)
Radially symmetric, isopolar. Circular in polar view. Zonocolpate, *ca.* six colpi in exine depressions. Scabrate. Exine with evident columellae. Equatorial diameter: *ca.* 18 µm. Ecological data: semi-climbing plants from humid locations (Barroso 1986; Joly 2002).

15. **Rubiaceae** type 1
(Fig. 3F, G)
Subspheroidal, radially symmetric, isopolar. Elliptic-fusiform in equatorial view, slightly tapered poles. Tricolporate, circular costate endoapertures. Microreticulate. Exine with evident columellae. Polar axis: *ca.* 58 µm; equatorial diameter: *ca.* 46 µm. Ecological data: Rubiaceae are herbs, shrubs, trees, or climbing plants found in diverse environments (Cronquist 1981; Joly 2002; Souza & Lorenzi 2012).

16. **Rubiaceae** type 2
(Fig. 3H, I)
Radially symmetric, isopolar. Circular in polar view. Zonocolporate, *ca.* eight colpori. Eureticulate, thin reticulum. Thick exine (*ca.* 4 µm), evident columellae. Equatorial diameter: *ca.* 25 µm. Ecological data: the same as for the Rubiaceae type 1.

17. **Rubiaceae** type 3
(Fig. 3J)
Spheroidal, radially symmetric, isopolar. Zonocolporate, *ca.* eight colpori. Endocingulate. Eureticulate, thin reticulum. Thick exine (*ca.* 3 µm), evident columellae. Polar axis: *ca.* 30 µm; equatorial diameter: *ca.* 30 µm. Ecological data: the same as for the Rubiaceae type 1.

Lamiales

Bignoniaceae

18. **Bignoniaceae** type
(Fig. 3K)
Radially symmetric, isopolar. Circular in polar view. Tricolpate, very long colpi, forming a small apocolpium region. Microreticulate. Exine with evident columellae. Equatorial diameter: *ca.* 44 µm. Ecological data: Bignoniaceae are trees, shrubs or climbing plants found in diverse environments (Schultz 1990; Marchant *et al.* 2002).

Lamiaceae

19. **Lamiaceae** type
(Fig. 3L-N)
Subspheroidal to prolate, radially symmetric, isopolar. Elliptic-fusiform in equatorial view, slightly tapered poles. Zonocolpate, *ca.* eight long colpi. Eureticulate, thin reticulum. Exine with evident columellae. Polar axis: *ca.* 39 µm; equatorial diameter: *ca.* 20 µm. Ecological data: Lamiaceae are herbs, shrubs, or rarely, trees, from diverse environments (Barroso 1986; Schultz 1990; Joly 2002; Souza & Lorenzi 2012).

Plantaginaceae

20. ***Plantago*** L.
(Fig. 3O, P)
Spheroidal, radially symmetric, apolar. Pantoporate, pores sparse and regularly distributed. Verrucate. Exine with obscure stratification. Diameter: *ca.* 28 µm. Ecological data: herbs occurring in grassland, soil on sandbanks, dry to swampy fields, wetlands, or peat bogs (Rahn 1966).

Scrophulariaceae

21. **Scrophulariaceae** type
(Fig. 3Q)
Subspheroidal, small and hyaline, radially symmetric, isopolar. Elliptic in equatorial view. Tricolporate, long ectoapertures. Psilate. Exine with obscure stratification. Polar axis: *ca.* 12 µm; equatorial diameter: *ca.* 9 µm. Ecological data: Scrophulariaceae are herbs, sub-shrubs or shrubs, or less often, small trees, from diverse environments (Ichaso & Barroso 1970; Barroso 1986; Schultz 1990; Souza & Lorenzi 2012).

Verbenaceae

22. ***Verbena*** L.
(Fig. 3R, S)
Radially symmetric, isopolar. Triangular in polar view. Tricolporate, long ectoapertures, with a marginal thickening. Psilate. Exine with obscure stratification. Equatorial diameter: *ca.* 42 µm. Ecological data: grassland herbs, widely distributed (Crespam 2010).

Aquifoliales

Aquifoliaceae

23. ***Ilex pseudobuxus*** Reissek
(Fig. 3T-Y)

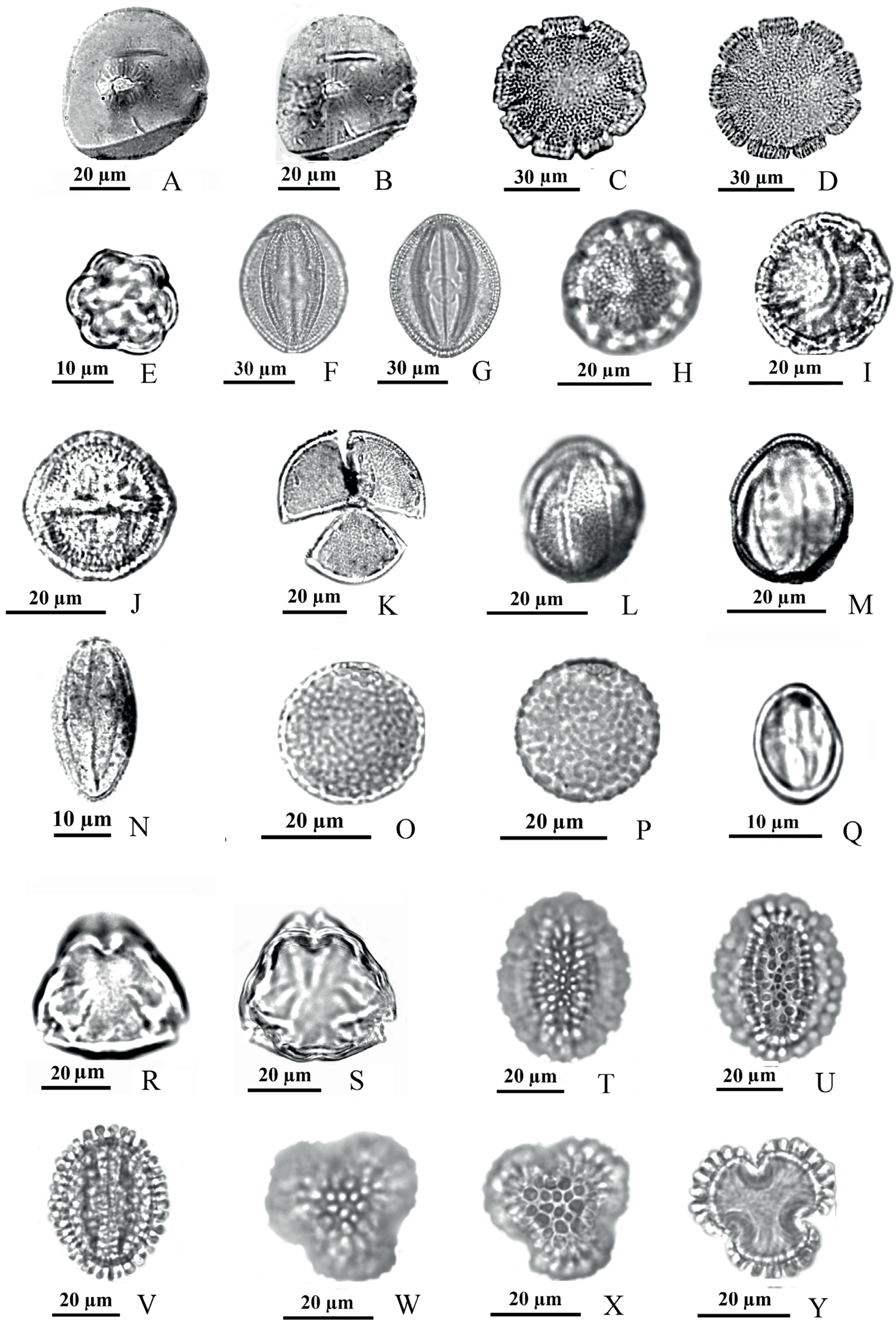

Figure 3. Angiosperms. **A-B**. Apocynaceae (EV): 1º-2º pl; **C-D.** *Borreria* G. Mey. type (PV): 1º-2º pl; **E.** *Galium* L. (PV); **F-G**. Rubiaceae type 1 (EV): 1º-2º pl; **H-I**. Rubiaceae type 2 (PV): 1º-2º pl; **J.** Rubiaceae type 3 (EV); **K.** Bignoniaceae type (PV); **L-N.** Lamiaceae type. **L-M (**EV): 1º-2º pl, **N** (EV); **O-P.** *Plantago* L.: 1º-2º pl; **Q.** Scrophulariaceae type (EV); **R-S.** *Verbena* L. (PV): 1º-2º pl; **T-Y.** *Ilex pseudobuxus* Reissek. **T-V** (EV): 1º-3º pl, **W-Y** (PV): 1º-3º pl. (PV) polar view, (EV) equatorial view, pl planes.

Prolate, radially symmetric, isopolar. Elliptic in equatorial view, subtriangular with rounded angles in polar view. Tricolporate. Clavate. Exine with obscure stratification. Polar axis: *ca.* 40 µm; equatorial diameter: *ca.* 28 µm. Ecological data: small trees, common on coastal plains in Atlantic rainforests (Edwin & Reitz 1967).

Asterales

Asteraceae

24. ***Baccharis*** L. type
(Fig. 4A-D)
Subspheroidal, radially symmetric, isopolar. Circular to elliptic in equatorial view. Tricolporate. Echinate, conspicuous spines. Caveate. Exine with evident columellae. Polar axis: *ca.* 30 µm; equatorial diameter: *ca.* 26 µm. Ecological data: *Baccharis* are herbs or shrubs, common in Brazilian grasslands (Joly 2002; Souza & Lorenzi 2012).

25. ***Gnaphalium*** L.
(Fig. 4E, F)
Subspheroidal, radially symmetric, isopolar. Elliptic in equatorial view. Tricolporate. Echinate, short spines. Exine with evident columellae. Polar axis: *ca.* 25 µm; equatorial diameter: *ca.* 22 µm. Ecological data: common herbs in open environments on coastal plains (Joly 2002).

26. ***Mutisia*** L. f.
(Fig. 4G)
Prolate, radially symmetric, isopolar. Elliptic-fusiform in equatorial view, slightly tapered poles. Tricolporate. Psilate appearance. Exine with evident columellae. Rare grains. Polar axis: *ca.* 68 µm; equatorial diameter: *ca.* 48

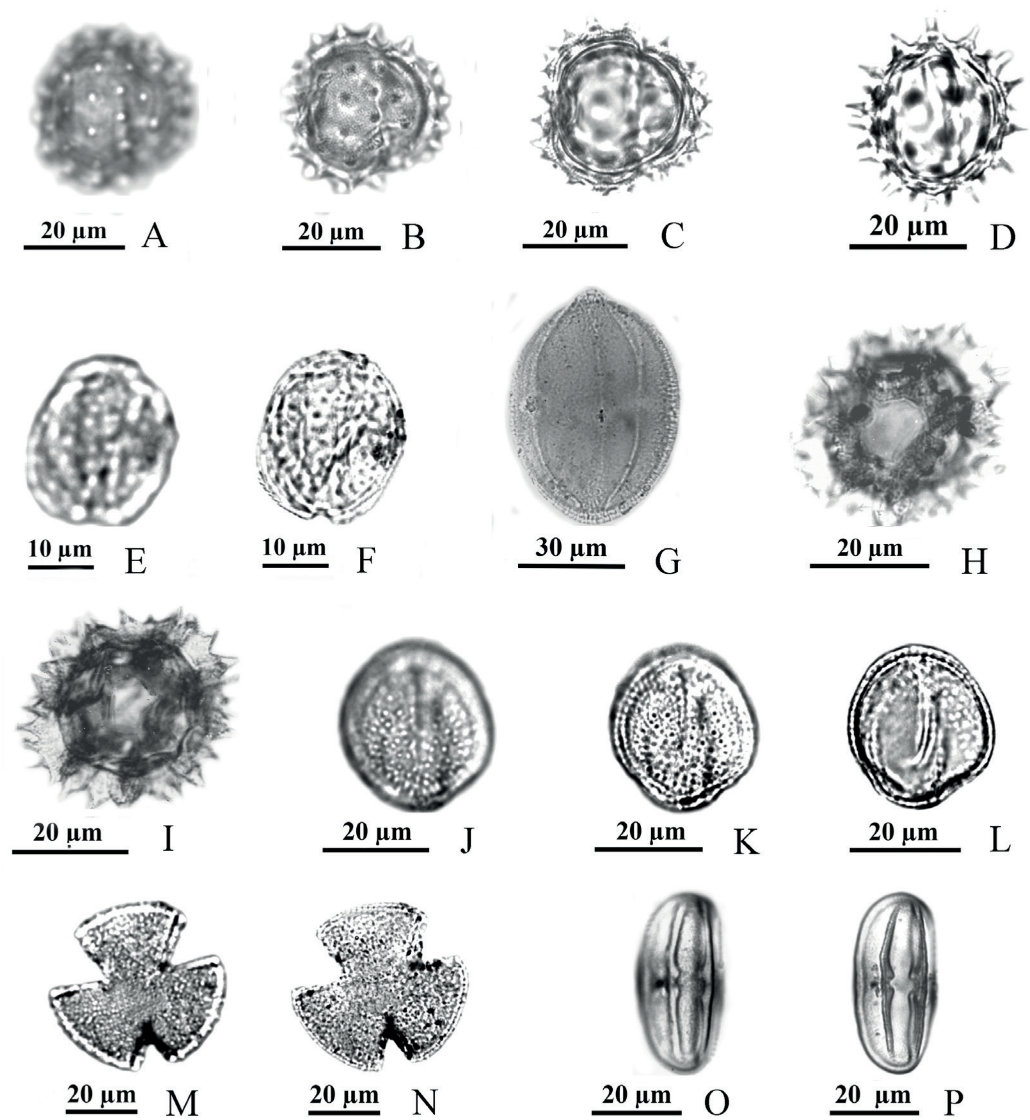

Figure 4. Angiosperms. **A**-**D**. *Baccharis* L. type. **A**-**C** (EV, oblique): 1°-3° pl, **D** (EV); **E**-**F**. *Gnaphalium* L. (EV): 1°-2° pl; **G**. *Mutisia* L. f. (EV); **H**-**I**. *Vernonia* Schreb. (PV): 1°-2° pl; **J**-**N**. *Valeriana* L. **J**-**L** (EV): 1°-3° pl, **M**-**N** (PV): 1°-2° pl; **O**-**P**. *Eryngium* L. (EV): 1°-2° pl. (PV) polar view, (EV) equatorial view, pl planes.

μm. Ecological data: herbs, shrubs, climbing plants, or trees, mostly in open environments (Mondim 1996).

27. ***Vernonia*** Schreb.
(Fig. 4H, I)
Spheroidal, radially symmetric, isopolar. Approximately circular in equatorial and polar view. Tricolporate. Eureticulate, echinolophate, conspicuous spines. Thick exine (*ca*. 6 μm), evident stratification. Polar and equatorial diameter: *ca*. 35 μm. Ecological data: herbs, common in grasslands (Souza & Lorenzi 2012).

Dipsacales

Caprifoliaceae

28.***Valeriana*** L.
(Fig. 4J-N)
Subspheroidal, radially symmetric, isopolar. Elliptic in equatorial view, circular in polar view. Tricolporoidate, long ectoapertures. Microechinate. Exine with evident columellae. Polar axis: *ca*. 29 μm; equatorial diameter: *ca*. 36 μm. Ecological data: herbs or sub-shrubs, rarely climbing plants. They occur in grasslands, inland and along the margins of forests and wetlands, with a wide distribution (Sobral 1999).

Apiales

Apiaceae

29. ***Eryngium*** L.
(Fig. 4O, P)
Perprolate, radially symmetric, isopolar. Elliptic in equatorial view. Tricolporate, long ectoapertures, with rectangular endoapertures. Psilate. Exine with evident columellae. Polar axis: *ca*. 40 μm; equatorial diameter: *ca*. 19 μm. Ecological data: generally grassland herbs (Schultz 1990) that can occur in soaked sites, swamps, ponds, and peat bogs (Irgang 1974). Common in grasslands and mainly found in wetlands (Joly 2002; Souza & Lorenzi 2012).

Discussion

The 29 taxa included in our study represent the second and final part of the taxonomy of angiosperm pollen grains of Roth & Lorscheitter (2017). The angiosperm pollen analyzed here, taken from the same sedimentary profiles of the northernmost region of the RS coastal plain used by Roth & Lorscheitter (2013; 2016; 2017), contributed to paleoenvironmental reconstructions of the last 24,000 years for this region (Roth *et al.* 2021). Over this time interval, sets of distinct palynomorphs indicated phases of dry and humid grassland and herbaceous marsh, the Holocene marine transgression, and the development of the Atlantic rainforest *s. str.* (Roth *et al*. 2021). These novel results exemplify the need for *a priori* discrimination of palynomorphs obtained from sediment in paleoenvironmental analyses.

Reference catalogs on many taxa of palynomorphs preserved in Quaternary sediments, related to other portions of the expansive RS coastal plain, have already been produced (Lorscheitter 1988, 1989; Cordeiro 1991; Neves & Lorscheitter 1992, 1995b; Neves & Bauermann 2003; Neves *et al*. 2003; Neves & Bauermann 2004; Neves & Cancelli 2006; Macedo *et al*. 2009; Roth & Lorscheitter 2013; Masetto & Lorscheitter 2014, 2016; Roth & Lorscheitter 2016, 2017). Future cataloging efforts should continue to the coastal plain, with descriptions and illustrations of palynomorphs and ecological data of the source organism, i.e., the basic reference material for paleoenvironmental analyses.

The results have deepened our understanding of climate and vegetation dynamics over the last millennia in southern Brazil and have thus provided crucial information for understanding natural trends in monitoring and conservation efforts.

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