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Megaspores from coals of the Triunfo Member, Rio Bonito Formation (Lower Permian), northeastern Paraná State, Brazil

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ABSTRACT

This paper presents the results of a detailed study of megaspores occurring in coal seams of the Triunfo Member, Rio Bonito Formation at Figueira, Paraná State, Brazil. This coal-bearing sequence accumulated in a marine delta system during the Early Permian.

Four species are described and illustrated: *Lagenoisporites triunfensis, L. scutiformis, Sublagenicula* cf. *brasiliensis*, and *Setosisporites* cf. *furcatus*. Of these, the two species of *Lagenoisporites* are predominant. Relationships to other megaspore species are discussed; and the temporal and spatial distributions of the four species in the Paraná Basin are documented.

Key words: megaspores, Permian, Rio Bonito Formation, Paraná Basin.

INTRODUCTION

Recent studies of the Rio Bonito paleoflora in the Figueira region revealed abundant megaspores associated with plant megafossils (Ricardi-Branco 1997).

Lagenoisporites triunfensis Arai and Rösler is by far the most abundant megaspore species and has not previously been reported outside its type locality (São João do Triunfo, Paraná State). Another abundant species, *L. scutiformis* Trindade, is recorded for the second time outside its type locality (Monte Mor, São Paulo State). In the present study, 123 specimens of *L. triunfensis* and 34 of *L. scutiformis* were found. Previous studies documented four specimens of *L. triunfensis* (Arai and Rösler 1984); and 20 and 23 specimens of *L. scutiformis* (Trindade 1970, Arai and Rösler 1984, respectively).

The two other, less abundant species identified are *Sublagenicula* cf. *brasiliensis* (7 specimens) and *Setosisporites* cf. *furcatus* (3 specimens). Previous records of these two species show a wide temporal and geographic distribution. For example, they have been recorded from the Monte Mor exposure of the Itararé Subgroup in southeastern Brazil (Trindade 1970) as part of a Late Carboniferous flora. They are also components of Early Permian floras of the Rio Bonito Formation in southern Brazil (Dijkstra 1956, Trindade 1962); e.g., at Barro Branco (Santa Catarina State) and Leão and Candiota coal mines (Rio Grande do Sul State).

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FIGUEIRA REGION: LOCALITY AND GEOLOGY

The Figueira region is located in southern Brazil, in the northeastern part of Paraná State (Fig. 1). The upper Paleozoic lithostratigraphic succession includes the Upper Carboniferous to Lower Permian Itararé Subgroup sediments overlain by the Lower Permian Rio Bonito Formation (Triunfo and Paraguaçu Members) (Fig. 2) and the Palermo, Irati, Serra Alta, and Teresina Formations (Soares and Cava 1982, Aborrage and Yamamoto 1982, Morrone and Daemon 1985). The megaspores described herein are from the lower part of Triunfo Member, specifically from siltstones immediately overlying the coal bed.

The depositional environment of the coal at Figueira (Soares and Cava 1982, Morrone and Daemon 1985, Della Fávera et al. 1993, Della Fávera and Chaves 1998) is thought to have been related to a delta-plain system wherein extensive swampy areas were covered by vegetation and possibly surrounded by sandy banks. Subsequent change in the drainage regime caused the collapse of the basin and effectively terminated peat deposition.

SOURCE OF THE PALYNIFEROUS SAMPLES

The megaspore-bearing samples were collected in the coalfields of Companhia Carbonífera do Cambuí (Fig. 1, Table I): Amando Simões mine (AS, well 01 and 06), Slope Plan mine 115 (SP-115), and from the general waste deposit (GWD) of the Amando Simões mine. The megaspores are from the grey siltstones located at the top of the coal seams. Also occurring with the megaspores are carbonized compressions of coniferous leaves, cones, seeds, branches, and microphylls, together with lycophyte shoots and glossopterid leaves.

MATERIALS AND METHODS

The samples were treated initially with 50% Schulze reagent for 5 to 6 days. The megaspores were retrieved from the residues using a fine paintbrush and then rinsed with distilled water. They were then immersed in a 20% solution of hydrofluoric acid for 24 hours in order to remove adherent mineral matter. After further thorough washing to neutrality, the specimens were left to dry at room temperature (20-30°C).

The 16 samples (6 from SP-115 mine, 5 from AS, and 5 from GWD) yielded a total of 352 megaspores. These were mounted on slides for observation by stereoscopic binocular microscopy.

Selected specimens were studied and photographed with a scanning electron microscope (SEM) in Centro de Pesquisas e Desenvolvimento Leopoldo A. Miguez de Mello (CENPES-PETROBRÁS), Rio de Janeiro, RJ.

The palyniferous samples are housed in the scientific collections of the Instituto de Geociências da Universidade de São Paulo (IG/USP), São Paulo, Brazil. The catalogue numbers are as follows: GP/3T 2137, 2138, 2143, 2146, 2147, 2155, 2156, 2158, 2160b, 2162, 2165, 2167, 2182, 2185, 2189, and 2204c.

SYSTEMATIC PALYNOLOGY

Anteturma **Megasporites** Pant, 1962

Turma **Triletes** Reinsch emend. Potonié and Kremp, 1954

Suprasubturma **Lagenotriletes** Potonié and Kremp, 1957

Subturma **Gulati** Bharadwaj, 1957

Genus ***Lagenoisporites*** Potonié and Kremp, 1955

Lagenoisporites triunfensis
Arai and Rösler, 1984

Figure 3 (pictures 1-5) and Figure 5 (pictures 1, 2). Samples: GP/3T 37, 2143, 2146, 2147, 2155, 2156, 2158, 2160b, 2162, 2165, 2167, 2182, 2185, 2189, and 2204c.

Description: Megaspores with gula. Rounded in polar compression; oval in lateral compression and slightly prolate. Gula pyramidal with acute apex. Straight or slightly undulatant, thick trilete rays. Arcuate ridges well-defined, confluent with the trilete rays, and marked by prominent lateral auriculae. Contact faces psilate, distal surface baculate.

Dimensions: a) Equatorial view: 1267 (2060) 2689 μm × 1044 (1663) 2133 μm. Gula 556 (814) 1333

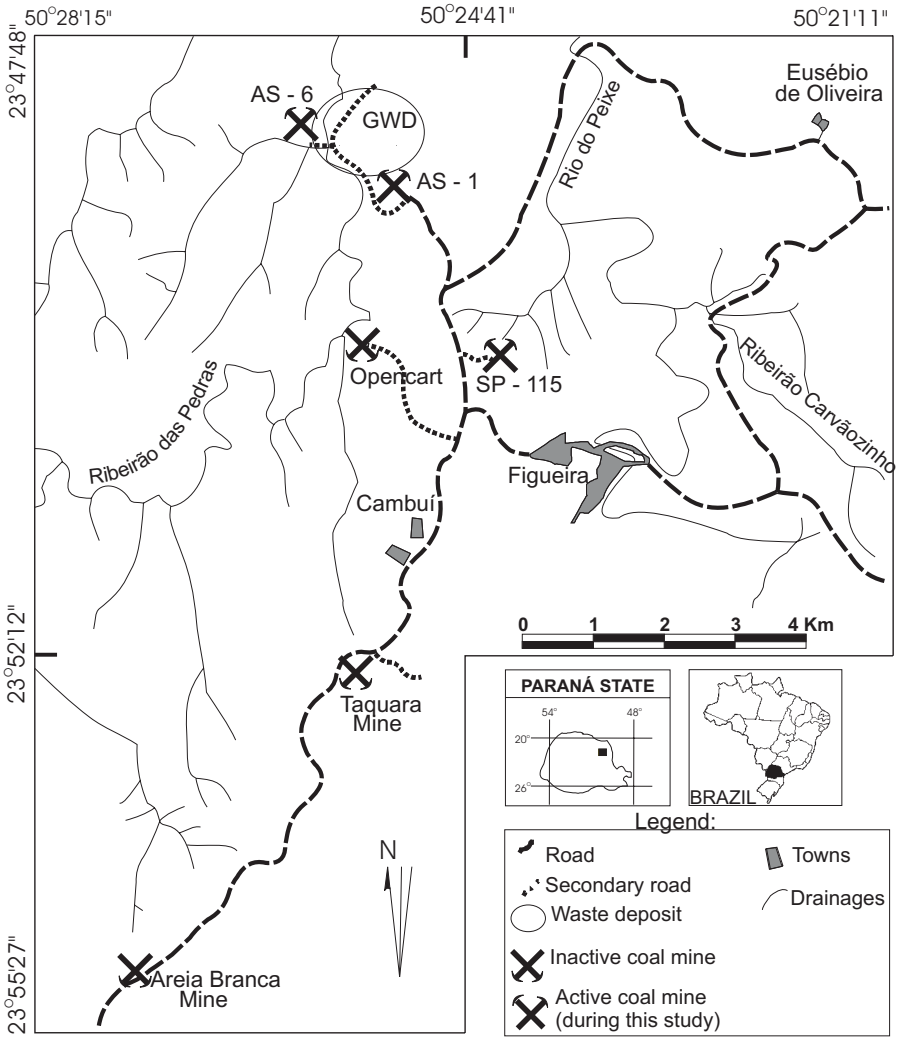

Fig. 1 – Map of the Figueira region, Paraná State, showing locations of the Amando Simões mine (AS-1 and AS-6) ,the Slope Plan mine 115 (SP-115) and the General waste deposit (GWD). Source: Carta do Brasil 1970 – IBGE – Folha Figueira, PR.

μm × 800 (1114) 1606 μm. Trilete rays 578 (836) 1111 μm. Arcuate ridges 844 (1038) 1222 μm. Auriculae 156 (236) 400 μm × 133 (220) 312 μm.

b) Polar view: Equatorial diameter 1133 (1646) 1955 μm. Gula 444 (592) 756 μm × 711 (895) 1000 μm. Trilete rays 556 (698) 778 μm. Auriculae 178 (222) 267 μm × 133 (224) 356 μm.

Discussion: One hundred and twenty-three whole megaspores were observed, 96 of them compressed laterally (Fig. 3, pictures 1, 2, 4; Fig. 5, picture 1). The other 27 specimens are proximo-distal compressions (Fig. 3, picture 3).

Among the specimens examined, 33 had evidently germinated, as indicated by their open gula. These were not measured, as measurements are con-

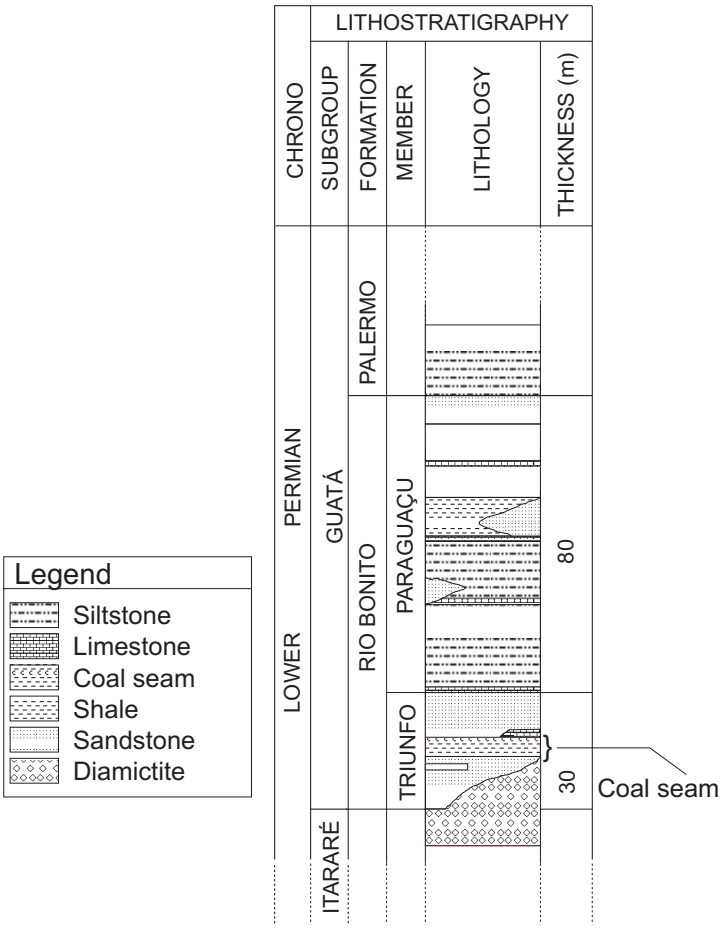

Fig. 2 – Lithostratigraphy of the Rio Bonito Formation in the Figueira region. Modified from: Morrone and Daemon 1985.

ventionally based on specimens with closed gula. The latter account for approximately 67% of the specimens studied.

The dimensions of laterally compressed specimens are typically 2000-2400 μm long (49 specimens) and 1400-1800 μm wide (54 specimens). The majority of specimens preserved as proximo-distal compressions range between 1400 and 1800 μm in equatorial diameter (17 specimens).

The smaller specimens were found among the megaspores of the samples GP/3T 2162 and 2165 (e.g., 956 μm long in the latter sample). These are considered aborted forms, following the criterion applied by Dijkstra (1956) to small specimens of *Triletes brasiliensis*.

All these megaspores are very similar to *L. triunfensis*, previously reported as occuring only at the type locality [i.e., the outcrop of S.J. do Triunfo (Rio Bonito Formation): Arai and Rösler 1984]. The main difference is that the average size of the Figueira specimens is larger (1267-2689 μm $\times$ 1044-2133 μm) than typical *L. triunfensis* (1280-1800 μm $\times$ 1250-1800 μm). This difference can be explained by the number of specimens measured during this study: i.e., 123 compared with only four studied by Arai and Rösler (1984). Most probably, the differences reflect intraspecific size-variations. Other characters, such as shape, gula, arcuate ridges,

TABLE I

Occurrence of megaspore species identified, with number of specimens per sample.

Species/ Samples GP/3T	Locality	*Lagenoisporites triunfensis* Trindade	*Lagenoisporites scutiformis* Arai and Rösler	*Sublagenicula* cf. *S. brasiliensis* (Dijkstra)	*Setosisporites* cf. *S. furcatus* (Dijkstra)
2137	AS-1	1			
2138	AS-1			1	
2143	SP-115	1			
2146	SP-115	7	3		
2147	SP-115	18	9	4	1
2155	AS-6	1			
2156	AS-6	5	1		
2158	SP-115		1		
2160b	GWD	30	4		
2162	GWD	6	3		
2165	GWD	24	6	2	
2167	GWD	2	2		
2182	GWD	2	1		2
2185	GWD	1			
2189	GWD	13	2		
2204c	GWD	12	2		
Total		123	34	7	3

Key to locates: slope plain mine 115 (SP-115); Amando Simões well 1 (AS-1) and well 06 (AS-6); general waste deposit (GWD).

ornamentation, etc., justify inclusion of the present specimens in *Lagenoisporites triunfensis*. Thus the Figueira region is the second site from which this species has now been reported.

L. triunfensis shows many similarities to *L. scutiformis* Trindade. However, salient differences lie in the ornamentation of the distal hemisphere. In *L. triunfensis* it is apiculate-capillate (Arai and Rösler 1984), but is smooth in *L. scutiformis* (Trindade 1970). Although size is considered a valid differential parameter, its validity decreases as the range of variation increases, as in *L. triunfensis*. In this case, size cannot be used as the sole criterion for distinguishing *L. triunfensis* from *L. scutiformis*. In other words, distal ornamentation remains the prime means of differentiating these two species.

Dybová-Jachowicz et al. (1979) proposed a novel classification of gulate megaspores, based on the type of gula, According to their scheme, many species formerly included in the genus *Lagenoisporites* were reallocated to a new genus *Sublagenicula*, which includes many of the subgulate megaspores. According to these authors, *L. triunfensis* features an anguligula, typical of the genus *Auritolagenicula*, which ranges from Upper Devonian through Namurian A. In contrast to *Lagenoisporites*, *Auritolagenicula* typically exhibits a thick exine which is more or less densely ornamented. The Figueira specimens do not comply with this system, and accordingly we prefer to retain the specimens described above in *Lagenoisporites*.

L. triunfensis shows no resemblance to other

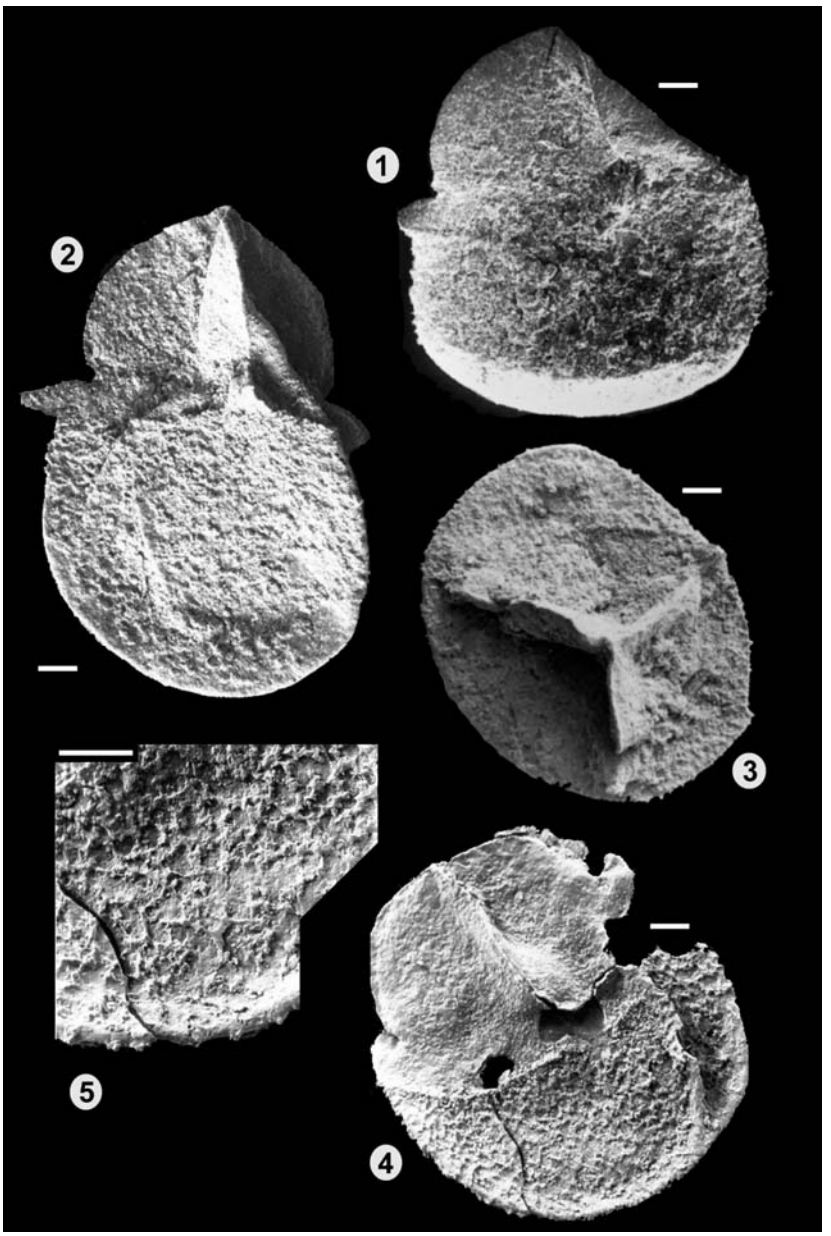

Fig. 3 – Megaspores *Lagenoisporites triunfensis*: 1. Lateral compression (GP/3T 2160b); 2. Distal-lateral compression (GP/3T 2160b); 3. Polar compression, proximal view (GP/3T 2165); 4. Lateral compression (GP/3T 2160b); 5. Magnification of fig. 4 showing ornamentation. Scale bar = 200μm.

species of megaspores that have been described from either Argentina or Brazil. However, it shows similarities, in shape and type of gula, to certain specimens that were described from the Namurian of the Illizi Basin (Candilier et al. 1982) and were included in *Auritolagenicula*. When comparing *A. spinulata* Candilier, Coquel and Loboziak and *A. bacculata* Candilier, Coquel and Loboziak with the specimens

studied herein, we can observe several differences relating to size and sculpture of the contact faces and of the distal hemisphere. Concerning size, the specimens of *A. spinulata* (1360-1800 μm × 1240-1680 μm) and *A. bacculata* (800-1100 μm × 700-800 μm) are smaller than those of *L. triunfensis*. The ornamentation of *A. spinulata* consists of long spinules that cover both the contact faces and the distal hemisphere, while the baculate ornamentation of *A. bacculata* is limited to the distal hemisphere. *L. triunfensis* can also be set apart from *A. bacculata* by comparing their ornamentation, insofar as the latter species bears spinules that are borne irregularly on the distal hemisphere.

Beyond Gondwana, *Auritolagenicula auricula*, described by Winslow (1962) as *Triletes auritulus* from the Lower Mississipian of Ohio, U.S.A., shows some similarity to *L. triunfensis* in size and in the type of gula, but the ornamentation and shape of the auriculae are different.

Lagenoisporites scutiformis
Trindade, 1970

Figure 4 (pictures 1-6) and Figure 5 (picture 3)
Samples: GP/3T 2143, 2147, 2156, 2158, 2160b, 2162, 2165, 2167, 2182, 2189, and 2204c.

Description: Megaspores with gula, rounded to oval in polar compression and prolate in lateral compression. Gula pyramidal with acute apex. Trilete rays thick and straight. Arcuate ridges well-defined, confluence between the trilete rays and the arcuate ridges marked by large lateral auriculae. Contact faces psilate, distal surface granulate to scabrate.

Dimensions: a) Equatorial view: 1622 (2070) 2511 μm × 1177 (1584) 1956 μm. Gula 667 (863) 1111 μm × 889 (1063) 1178 μm. Trilete rays 600 (765) 933 μm. Arcuate ridges 800 (1000) 1222 μm. Auriculae 222 (273) 378 μm × 133 (203) 267 μm.

b) Polar view: Equatorial diameter 1133 (1767) 2022 μm. Gula 668 (689) 711 μm × 778 (929) 1000 μm. Trilete rays 600 (772) 889 μm. Auriculae 222 (253) 311 μm × 200 (222) 268 μm.

Discussion: The 34 megaspores studied represent 18% of the total and constitute the second most numerous species. Twenty specimens appeared in lateral compression (Fig. 4, pictures 3, 5 and 6) and 7 in polar compression (Fig. 4, pictures 1 and 2).

The most common dimensions, for specimens in lateral compression, range from 1800 to 2200 μm in length (16 specimens) and 1400 to 1800 μm in width (14 specimens). The most common equatorial diameter ranges from 1800 to 2100 μm (4 specimens).

Based on such characters as shape, dimensions, and exine ornamentation, these specimens are attributable to *Lagenoisporites scutiformis* Trindade. This species has previously been recorded from Monte Mor (Itararé Subgroup), State of São Paulo, by Trindade (1970); and from S.J. do Triunfo (Rio Bonito Formation) Paraná State, by Arai and Rösler (1984).

As mentioned above, *L. triunfensis* and *L. scutiformis* differ in distal ornamentation (baculate and psilate-scabrate, respectively).

As with *L. triunfensis*, *L. scutiformis* might also be included in the genus *Auritolagenicula*, according to the taxonomy proposed by Dybová-Jachowicz et al. (1979), because it shows an anguligula. However, its psilate to scabrate distal ornamentation precludes such reassignment.

Besides, if the synonymy between *Lagenoisporites* and *Auritolagenicula* was confirmed, the priority must be given to the former genus, because *Lagenoisporites* was erected in 1955 and *Auritolagenicula* in 1979.

Trindade (1970) and Arai and Rösler (1984) alluded to resemblance between *Auritolagenicula angulata* (=*Lagenicula*) and *L. triunfensis*. Distinction between these two species is discussed above. The difference between *L. scutiformis* and *A. angulata* lies in the nature of the thick exinal ornamentation (psilate in the case of *L. triunfensis*).

A. angulata has been reported from the Lower Carboniferous of Egypt, North America, and Poland. It is possible that a relationship exists between it and *L. scutiformis*, but this can be estab-

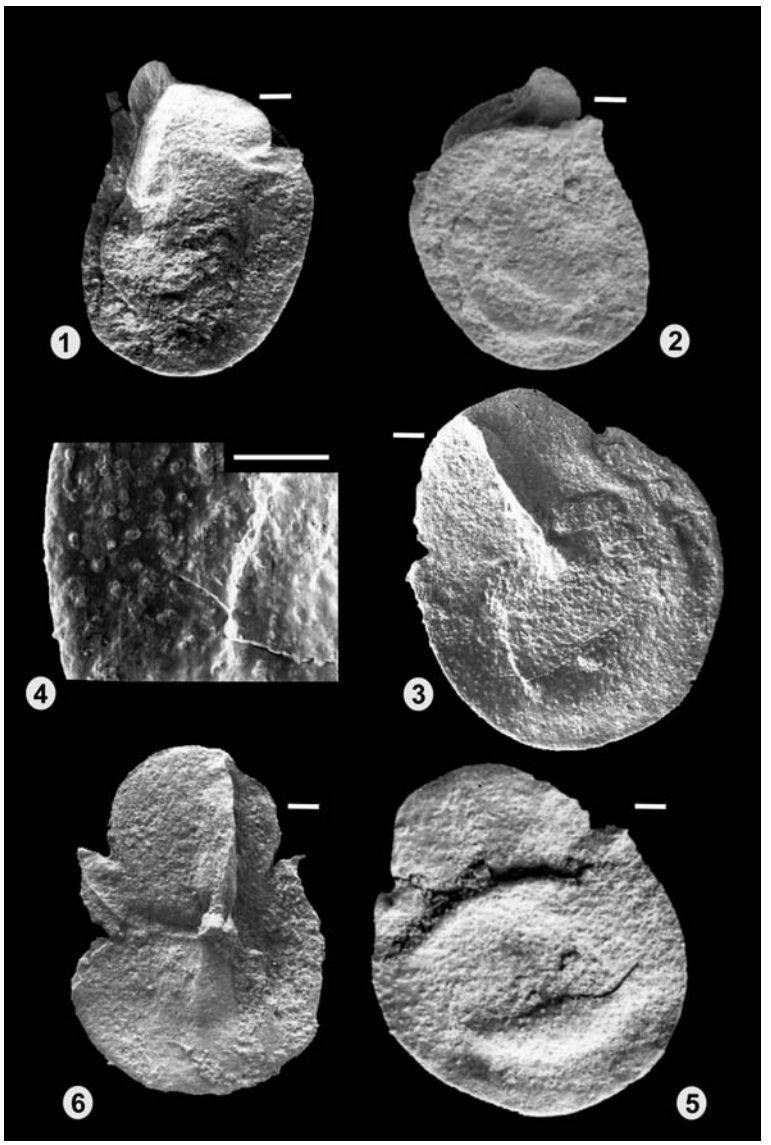

Fig. 4 – Megaspores *Lagenoisporites scutiformis*: 1. Oblique proximal view (GP/3T 2165); 2. Oblique distal view; 3. Lateral compression (GP/3T 2165); 4. Magnification of fig. 3 showing ornamentation; 5. Oblique distal view of fig. 3; 6. Typical specimen, oblique proximal view (GP/3T 2147). Scale bar = 200μm.

lished only on the basis of specimens obtained from intermediate time intervals and localities.

Genus ***Sublagenicula*** (Potonié and Kremp) Dybová-Jachowicz, Jachowicz, Karczewska, Lachkar, Loboziak, Piérart, Turnau and Zoldani 1979

Sublagenicula* cf. *S. brasiliensis
(Dijkstra) Dybová-Jachowicz, Karczewska, Lachkar, Loboziak, Piérat, Turnau and Zoldani 1979

Figure 5 (pictures 4-6).
Samples: GP/3T 2138, 2146, and 2165.

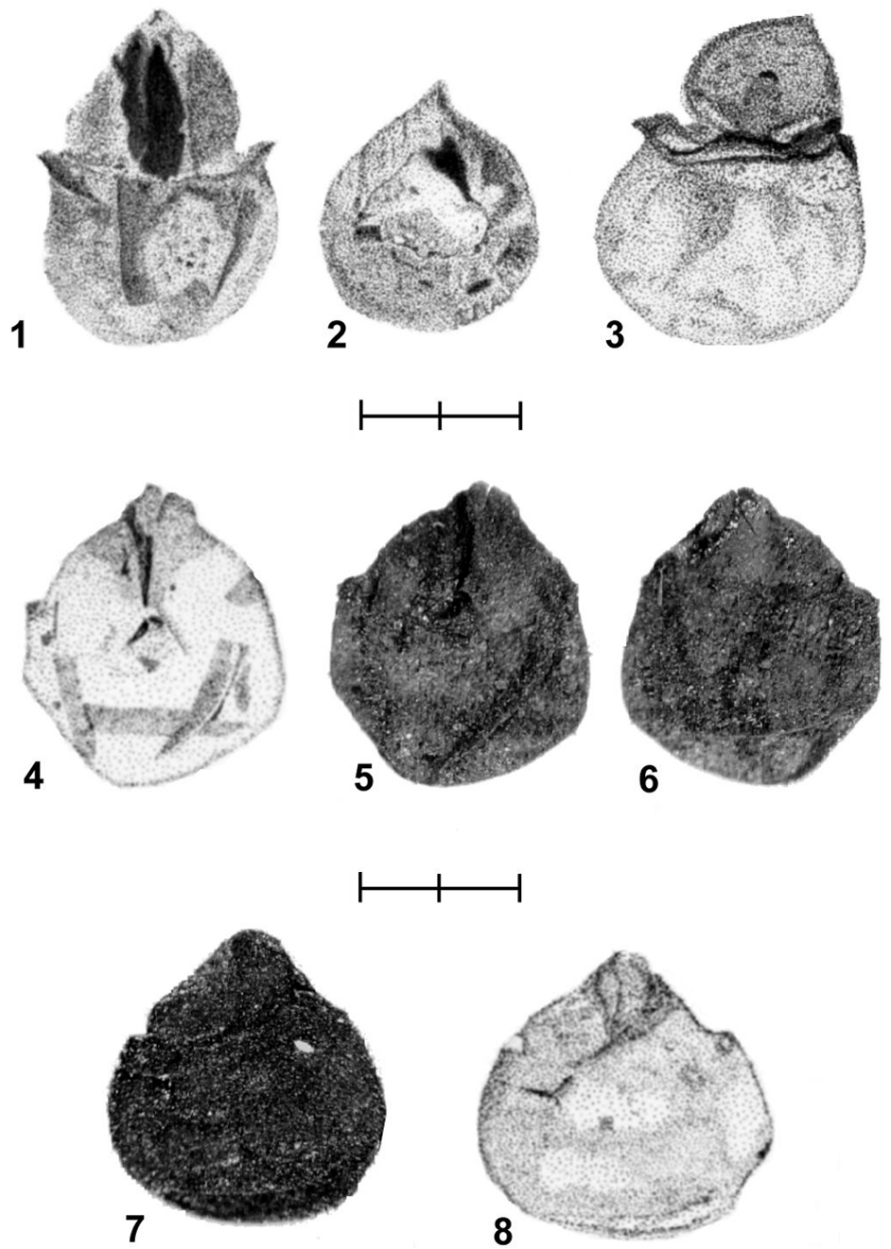

Fig. 5 – Megaspores *L. triunfensis* (pictures 1 and 2), *L. scutiformis* (picture 3), *Sublagenicula* cf. *brasiliensis* (pictures 4-6), *Setosisporites* cf. *furcatus* (pictures 7 and 8): 1. *Lagenoisporites triunfensis*, lateral compression. (GP/3T 2189); 2. *Lagenoisporites triunfensis*, polar compression, proximal view (GP/3T 2204); 3. *Lagenoisporites scutiformis*, distal view in lateral compression (GP/3T 2182); 4. *Sublagenicula* cf. *S. brasiliensis*, lateral compression (GP/3T 2147); 5. *Sublagenicula* cf. *S. brasiliensis*, oblique proximal view; 6. *Sublagenicula* cf. *S. brasiliensis*, oblique distal view; 7. *Setosisporites* cf. *S. furcatus*, lateral compression (GP/3T 2147); 8. *Setosisporites* cf. *S. furcatus*, lateral compression. Scale bar: 1mm.

Description: Megaspores subgulate, prolate in lateral compression. Trilete rays straight. Arcuate ridges poorly defined, their confluence with trilete rays well-defined by small triangular auriculae. Contact faces psilate; distal surface scabrate to psilate.

Dimensions: Equatorial view: 1556 (1850) 2156 μm $\times$ 1400 (1658) 1911 μm. Subgula 556 (716) 800 μm. 844 (866) 111 μm.

Discussion: Seven megaspores were studied, all in lateral compression; length 1500-1900 μm (4 specimens). They resemble *Sublagenicula brasiliensis* (Dijkstra) Dybová-Jachowicz et al. in shape, gula, exine ornamentation, trilete rays, and arcuate ridges. But there are size differences (Table II): the studied specimens are larger than those reported previously from Brazil (Dijkstra 1956, Piérart and Dijkstra 1961, Trindade 1959, 1962, 1970, Cauduro and Zingano 1965, Marques-Toigo et al. 1975), Argentina (Spinner 1969, Archangelsky et al. 1989, Cúneo et al. 1991, García 1995), and South Africa (Pant and Srivastava 1962). Leinz (1940) illustrated megaspores from coal samples of the Rio Carvãozinho (Figueira region) that are very similar to our specimens. It seems unusual that this is the only previous record of these megaspores from the Figueira region.

It is important to note that differences in size may relate to climatic, ecological, or intraspecific variations. Taking into account the fact that *S. brasiliensis* has a broad distribution range, in both space and time (being known from the Lower Carboniferous of Chad, Egypt, and Nigeria and Carboniferous-Permian of Argentina, Australia, and South Africa), we prefer to identify the Figueira megaspores as *Sublagenicula* cf. *brasiliensis*.

Genus ***Setosisporites*** (Potonié and Kremp) Dybová-Jachowicz, Jachowicz, Karczewska, Lachkar, Loboziak, Piérart, Turnau and Zoldani 1979

Setosisporites* cf. *S. furcatus
(Dijkstra) Dybová-Jachowicz, Jachowicz, Karczewska, Lachkar, Loboziak, Piérat, Turnau and Zoldani 1979

TABLE II

Comparison between dimensions of *Sublagenicula brasiliensis* from the literature and from Figueira.

	Length (μm)	Width (μm)
Figueira	1556-2156	1400-1911
Brazil (elsewhere)	575-1530	760-1400
Argentina	600-1378	400-978
South África	585-1780	458-1425

Figure 5 (pictures 7and 8).
Sample: GP/3T 2147.

Description: Megaspores subgulate, prolate in lateral compression. Trilete rays straight and smooth. Arcuate ridges smooth. Contact faces psilate; distal surface baculate.

Dimensions: Equatorial view: 1689-1933 μm $\times$ 1667-1867 μm. Trilete rays 511-1000 μm. Bacula 22 μm long.

Discussion: Of the three specimens identified, two are very poorly preserved. The best preserved specimen, from sample GP/3T 2147, is 1689 μm and 1667 μm in length and width respectively.

The specimens show some resemblance to *Setosisporites* sp., as recorded previously from Monte Mor (Trindade 1970). However, the latter reportedly measures 1800 $\times$ 1600 μm and its exine is comprehensively capillate rather than distally baculate. Similarities with *Setosisporites furcatus* are in shape, type of gula, and exinal sculpture of both hemispheres. Nevertheless, it should be noted that furcate bacula, reportedly typical of this species, are not conspicuous in our specimens. Furthermore, as with *S. brasiliensis*, the Figueira specimens are larger than those reported previously from elsewhere in Brazil (Dijkstra 1956, Piérart and Dijkstra 1961, Pant and Srivastava 1962, Cauduro and Zingano 1965, Marques-Toigo et al. 1975) and from India (Bharadwaj and Tiwari 1970, as *Gulatrileites furcatus*). They proved to be approximately 300 μm longer.

These Figueira megaspores are clearly attributable to *Setosisporites*, and are obviously closest to *S. furcatus*. However, in view of differences in size and exine ornamentation, it is prudent to designate them as *Setosisporites* cf. *S. furcatus*.

DISCUSSION AND CONCLUSIONS

This paper is a contribution to the knowledge of Early Permian megaspores of Brazil. Details are provided concerning their morphology and distribution, especially for the species *Lagenoisporites triunfensis* and *L. scutiformis*.

The megaspore flora discussed here originated from a coastal swamp vegetation characterized by lycophytes. Of the latter, *Brasilodendrom* cf. *pedroanum* is quite possibly related to at least one of the species of *Lagenoisporites*. However, the precise botanical affinities can only be established via *in situ* observation of the megaspores; so far, no suitable (fertile) megafossils have been found.

The Figueira megaspore flora is of low diversity, and is dominated by *L. triunfensis*. This concurs with the low diversity of the preserved lycophyte megaflora, and is a likely consequence of a somewhat stressed, tide-influenced coastal paleoenvironment.

The notable endemism of the taphoflora, alluded to in previous megaspore research, are reinforced by the present study. Neither *L. triunfensis* nor *L. scutiformis* is known outside of Brazil, nor even beyond the states of São Paulo and Paraná. Nevertheless, we do not exclude the possibility of finding these species in more meridional localities, because the swampy regions of the Early Permian (typified by the Triunfo Member) characterized the entire paleo-shoreline, extending into the state of Rio Grande do Sul.

Considering the interval between the early and middle Artinskian, related to S.J. do Triunfo (Arai and Rösler 1984), and that between the end of the Sakmarian and the beginning of the Artinskian in Figueira (Ricardi-Branco 1997), it seems reasonable to assume that both *L. triunfensis* and *L. scutiformis* are typical of the middle Early Permian.

Finally, it is interesting to note Piérart's (1962, 1975, 1981, 1984) suggestion that *Sublagenicula brasiliensis* could belong to the group called "transgressive megaspores" (along with *Setosisporites furcatus*, among others) that migrated during the Carboniferous from regions close to the glaciation limits to regions subsequently colonized by the *Glossopteris* Flora.

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RESUMO

No presente trabalho são apresentados os resultados obtidos a partir do estudo sistemático detalhado dos megásporos provenientes das camadas de carvão do Membro Triunfo, Formação Rio Bonito, Estado do Paraná, Brasil. A seqüência portadora de carvão, foi o resultado do acúmulo de matéria orgânica num de sistema deltaico marinho durante o Eopermiano.

Quatro espécies são aqui descritas e ilustradas: *Lagenoisporites triunfensis*, *L. scutiformis*, *Sublagenicula* cf. *brasiliensis*, e *Setosisporites* cf. *furcatus*. Destas, as duas espécies de *Lagenoisporites* são dominantes. São igualmente discutidas as relações existentes com outras espécies de megásporos, assim como documentada a distribuição temporal e espacial das quatro espécies na Bacia do Paraná.

Palavras-chave: megásporos, Permiano, Formação Rio Bonito, Bacia do Paraná.

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