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An overview on the Palynostratigraphy of the Upper Paleozoic strata of the Brazilian Paraná Basin*

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Abstract: Based on analysis of previous zonations and new studies, an overview of the palynological succession of the Upper Paleozoic strata of the Paraná Basin is given, and new data are introduced. The *Cannanoropollis korbaensis* Zone is renamed *Vittatina costabilis* Zone, and one of its subzones (*Caheniasaccites ovatus*) is regarded as belonging to the *Protohaploxypinus goraiensis* Subzone. Four interval zones characterize this stratigraphic section; in ascending order, these are the *Ahrensisporites cristatus*, *Crucisaccites monoletus*, *Vittatina costabilis* and *Lueckisporites virkkiae* Zones. The ranges of some species have been modified and new trends of investigation are suggested, including a definitive palynological study on the lithostratigraphical limits in order to understand environmental influences.

Key words: palynology, Paraná Basin, palynostratigraphy, Upper Paleozoic, Brazil.

Resumen: Se presenta una revisión y puesta al día de la palinoestratigrafía del Paleozoico Superior de la Cuenca Paraná (Brasil), sobre la base de un nuevo análisis de las propuestas anteriores sobre el tema y la incorporación de nuevos datos. La Biozona *Cannanoropollis korbaensis* es renominada como Biozona *Vittatina costabilis* y una de sus subzonas, la Sub-biozona *Caheniasaccites ovatus*, es considerada como perteneciente a la Sub-biozona *Protohaploxypinus goraiensis*. Cuatro biozonas de intervalo caracterizan la sección, las Biozonas *Ahrensisporites cristatus*, *Crucisaccites monoletus*, *Vittatina costabilis* y *Lueckisporites virkkiae*, en orden estratigráfico. Modificaciones en los rangos de los principales taxones de esporas y granos de polen son presentados, así como nuevos desafíos en la resolución de algunos de los problemas estratigráficos y paleoambientales de la cuenca.

Palabras clave: palinología, Cuenca Paraná, palinoestratigrafía, Paleozoico Superior, Brasil.

The biostratigraphy of the Upper Palaeozoic strata of the Brazilian Paraná Basin has been studied by several authors, who proposed different zonations based on plants, invertebrates and palynomorphs. Palynology seems to be the most efficient tool in providing biostratigraphic data for the Paraná Basin, because of the abundance, diversity and widespread distribution of spore-pollen assemblages. Radiometric data are scarce and there are no clear reference-levels with chronologically significant elements, like marine invertebrates, which could permit wide correlation and more accurate age calibration among the available biostratigraphic schemes.

Pioneering studies on Paraná Basin palynology were started in the 1960's, related to oil and coal investigations. Then, regional and local schemes were proposed on distinct criteria and scales. Most of the papers concerned the southern part of the basin, especially the Rio Bonito Formation coal beds in Rio Grande do Sul and Santa Catarina States. Palynological data from the northeastern Paraná Basin has been meaningfully improved only during the past two decades.

This contribution aims to present an overview on this theme, including recent advances and new proposals, main problems, and new trends of investigation.

GEOLOGY AND PALEONTOLOGY SYNOPSIS

The Paraná Basin comprises a thick, widespread sedimentary-magmatic sequence, located in central-eastern South America, coverring about 1,700,000 km^2 in area in Brazil, Uruguay, Argentina and Paraguay and reaching thicknesses of *ca.* 5,000 m (Fig. 1). According to Milani (1997), six supersequences represent the sedimentary record of this basin: Rio Ivaí (related to the Rio Ivaí Group

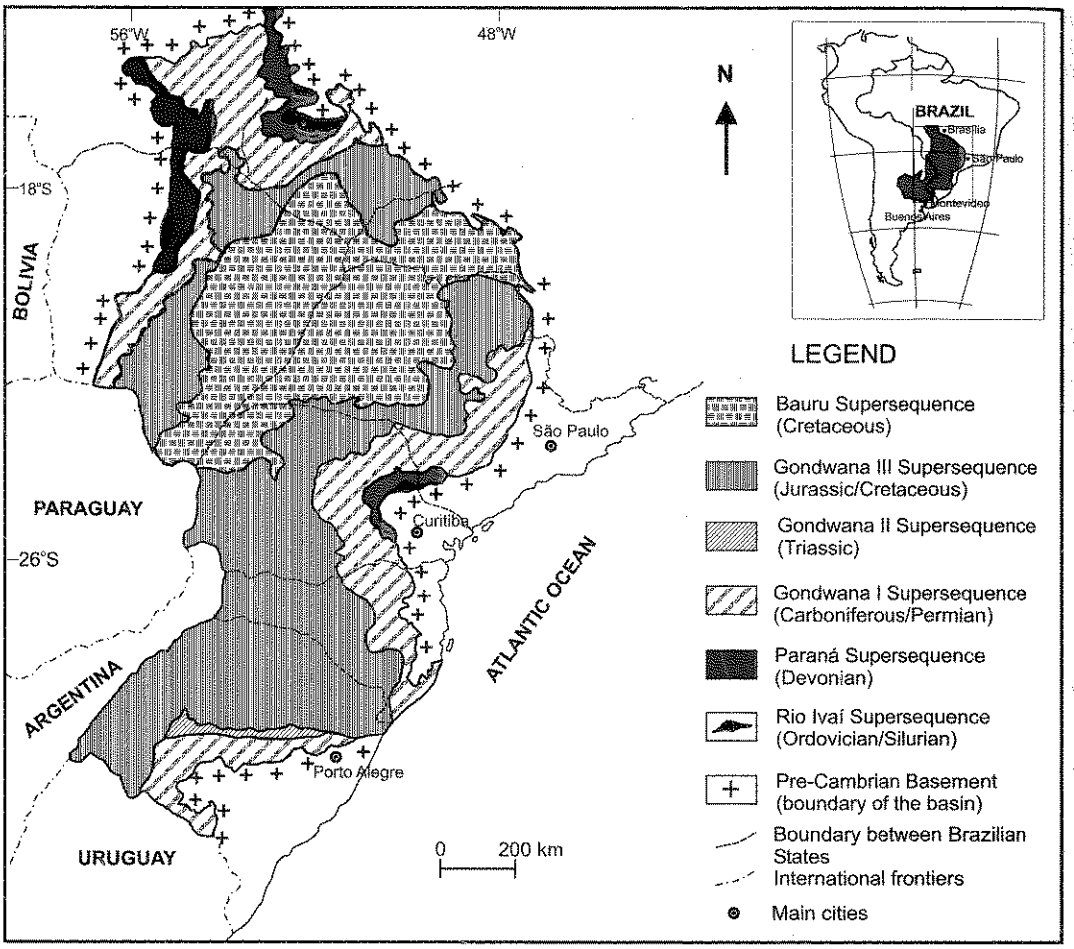

Fig. 1. Location and distribution of Paraná Basin Supersequences (after Milani, 1997).

of Ordovician-Silurian age), Paraná (Paraná Group, Devonian), Gondwana I (Tubarão and Passa Dois Groups, Carboniferous-Permian), Gondwana II (Triassic formations), Gondwana III (São Bento Group, Jurassic-Cretaceous) and Bauru Super-sequence (Bauru Group, Cretaceous) (see Fig. 1).

The Gondwana I Supersequence corresponds to a major transgressive-regressive cycle. The Tubarão The Gondwana I Supersequence corresponds to a major transgressive-regressive cycle. The Tubarão Group is partially representative of the late Palaeozoic Gondwana glacial event. Its lower beds constitute the Itararé Subgroup, followed upwardly by the Rio Bonito and Palermo Formations (Guatá Subgroup), comprising a transgressive cycle. These last units are correlated with the Tatuí Formation in the notheastern basin, and with the Aquidauana Formation, exposed in the northern portion.

The Passa Dois Group comprises the Irati, Serra Alta, Teresina and Rio do Rasto Formations, in ascending order. These last three units are represented in the north portion by the Corumbataí Formation. A summary on this lithostratigraphic subdivision and its geological significance is given by Milani *et al.* (1994).

The upper Paleozoic sequence contains diverse and abundant fossils, representing marine, transitional marine to continental and continental environments. Its paleontological content includes invertebrates, vertebrates, plant remains and palynomorphs. Permo-Carboniferous invertebrates are related to the *Eurydesma* Fauna and the plant remains are linked to the Pre-*Glossopteris* and the *Glossopteris* Flora, very commonly found in the Lower Gondwana strata.

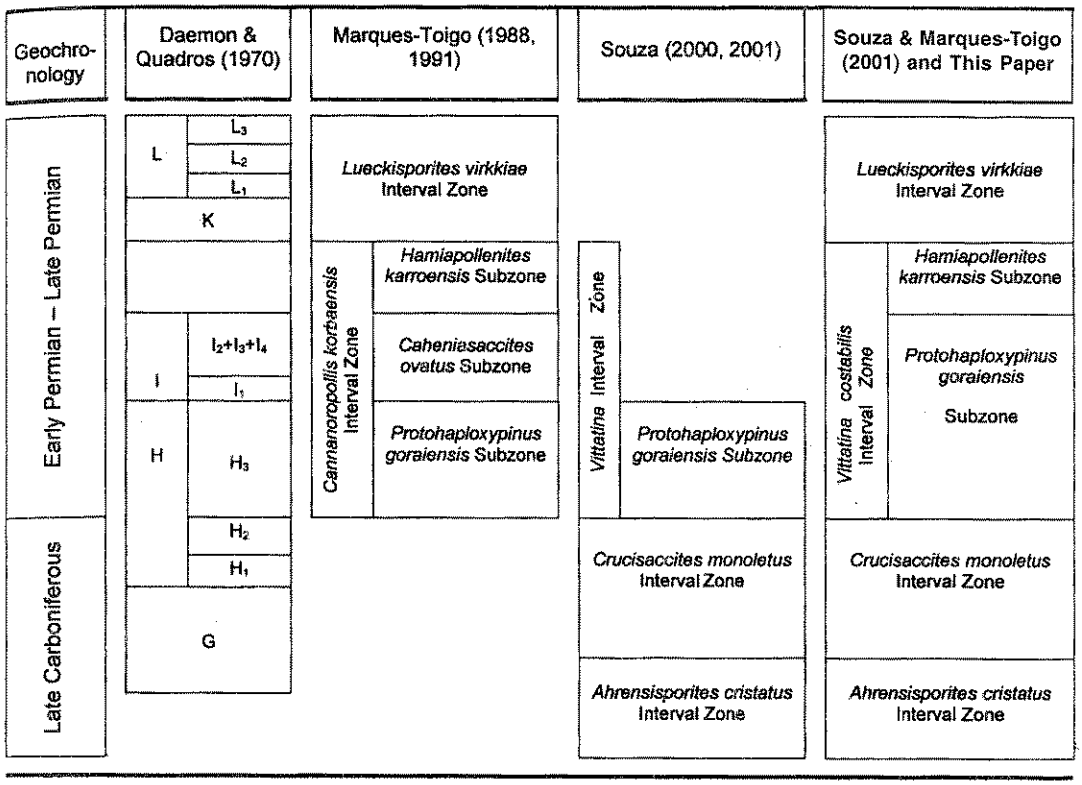

Fig. 2. Correlation of main Upper Palaeozoic Brazilian Paraná Basin palynozones (after Souza & Marques-Toigo, 2001).

Palynological zonations have been proposed by Daemon (1966), Daemon & Quadros (1970), Bharadwaj *et al.* (1976), Saad (1977), Arai (1980), Sundaram (1980, 1986), Marques-Toigo (1988, 1991) and Souza (2000). Souza & Marques-Toigo (2001) summarized the palynological succession, based on these previous papers, mainly on Daemon & Quadros (1970), Marques-Toigo (1988, 1991) and Souza (2000), which were based on substantial geographic and stratigraphic sampling. Furthermore, analysis of new samples were made and new data were introduced, and new species were selected as guides, in order to refine the palynological units.

PALYNOSTRATIGRAPHY

Further studies on this theme have been developed after Souza & Marques-Toigo (2001) and were synthesized herein. Changes in the palynozone names and occurrence and ranges of selected species are proposed preliminarily.

Four interval zones characterize the palynological succession of the Upper Paleozoic strata of the Paraná Basin. These take into account spore-pollen distribution and horizons of appearance and disappearance of selected species.

A tentative correlation between these units and the previous proposal for the Paraná Basin is shown in the Figure 2. The ranges of the selected species of spores and pollen grains used as guides in these palynozones are shown in the Chart 1. The most important spore and pollen taxa are illustrated in the Figure 3.

Detailed biostratigraphic data, such as assemblage characteristics and stratotype section, will be given in subsequent papers.

Ahrensisporites cristatus Interval Zone

This zone is characterized by eleven stratigraphically restricted spores species: *Anapiculatisporites argentinensis, Raistrickia pinguis, Foveosporites hortonensis, Granulatisporites varigranifer, Ahrensisporites cristatus, Cristatisporites menendezii, C. inordinatus, C. spinosus, C. indignabundus, Cirratriradites veeversii*, and *Psomospora detecta*. It has been recognised in the lowermost Itararé Subgroup, in

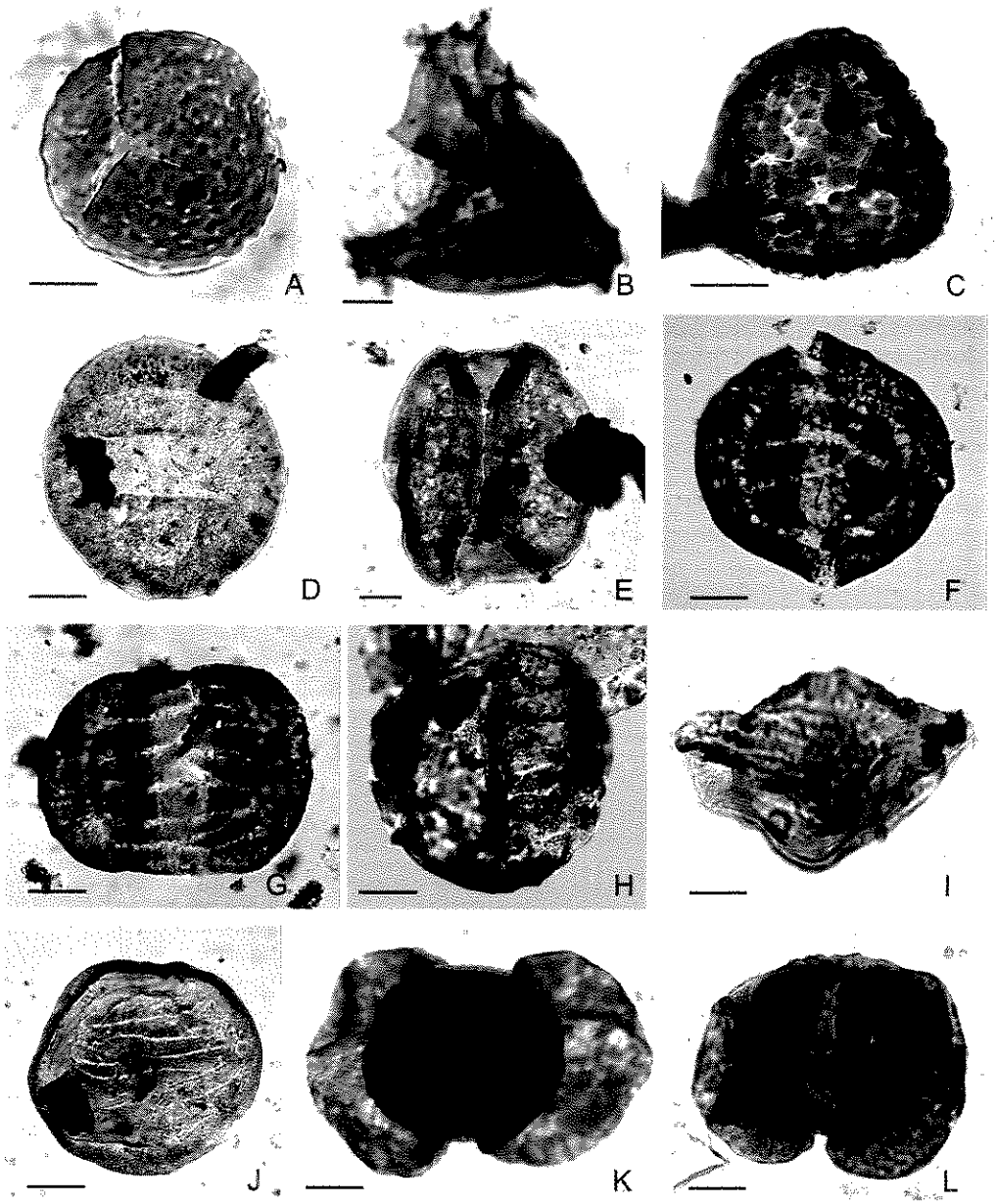

Fig. 3. Selected species of the Upper Paleozoic Paraná Basin palynozones. A, *Foveosporites hortonensis* (Provenance: Buri Coal; Slide: IG-P: 12B; England Finder coordinate: E-47). B, *Ahrensisporites cristatus* (A-IG-85 well, Araçoiaba da Serra; GP4E: 1406; Q29-4). C, *Cristatisporites menendezii* (A-IG-85 well, Araçoiaba da Serra; GP4E: 1397; C17-4). D, *Crucisaccites monoletus* (Jundiaí; IG-P: 108C; Q45). E, *Scheuringipollenites maximus* (IG-01 well, Itaporanga; IG-P: 49F; K51-1). F, *Illinites unicus* (J-IG-93 well, Jumirim; IG-P: 153A; E45-3). G, *Protohaploxypinus goraiensis* (2-CB-1-SP well, Cuiabá Paulista; IG-P: 197A; H38). H, *Vittatina costabilis* (Tietê; IG-P: 377B; L38-4). I, *Hamiapollenites karroensis* (MP-P: 1534, Q35-4). J, *Vittatina vittifera* (2-TB-1-SP well; IG-P:214A; R46-2). K, *Lueckisporites densicorpus* (Jataí; MP-P: N4, S33-4). L, *Lueckisporites virkkiae* (Jataí; MP-P: N4, O41). Bar scale corresponds to 20 µm. Slides under codes "IG-P" are housed at the Instituto Geológico/SMA, São Paulo, "GP4E" at the Universidade de São Paulo, São Paulo, and "MP-P", at the Universidade Federal do Rio Grande do Sul, Porto Alegre.

the northeastern portion of the basin (São Paulo and Paraná States). Several palynofloras attributed to this palynozone occur in subsurface and outcrop samples in São Paulo State, like the ones at Araçoiaba da Serra (Lima *et al.*, 1983; Souza, 1996; Souza *et al.*, 2003), Buri (Souza *et al.*, 1993; Souza, 2003) and Monte Mor (Souza *et al.*, 1997) and others in Paraná State (Daemon & França, 1993; Souza, 2000).

Crucisaccites monoletus Interval Zone

This zone is characterized by the disappearance of restricted species of the former unit and by the appearance of *Scheuringipollenites maximus* and *Crucisaccites monoletus*. The latter species is stratigraphically restricted to this unit. The upper limit of the palynozone is marked by disappearance of several species of spores and pollen grains, such as *Cyclogranisporites firmus*, *Dibolisporites disfacies*, and *Potonieisporites triangulatus*, and by the appearance of characteristic species of the subsequent unit. This interval zone occurs in the northeastern portion of the basin and has been recognized from the lower to middle portion of the Itararé Subgroup. Palynofloras of the Itaporanga subsurface (Di Pasquo *et al.*, 2003a, 2003b), as well as from outcrops, such as Jundiaí (Souza *et al.*, 2000), Salto (Longhim, 2003) and in Paraná State (Souza, 2000), are included in this palynozone.

In these two palynozones, the most important genera of spores and monosaccate pollen grains include *Punctatisporites, Leiotriletes, Lundbladispora, Vallatisporites, Cristatisporites, Cannanoropollis, Plicatipollenites, Potonieisporites*, and *Caheniasaccites*. A tentative correlation can be established with the G, H_1 and H_2 intervals of Daemon & Quadros (1970), taking in account only pollen grains. Species stratigraphically restricted to the *Ahrensisporites cristatus* Interval Zone were found from subsurface samples included within the G Interval (Daemon & Quadros, 1970), e.g. from the 2-PP-1-SP borehole. Correlations are indicated with Argentinean palynozones, i.e. *Ancistrospora* and *Potonieisporites* palynozones of Azcuy & Jelin (1980), or *Raistrickia densa-Convolutispora muriornata* Assemblage Biozone (César & Gutiérrez, 2001) of central western Argentina. Similarities are also evident with material from Tarija Basin belonging to the *Kraeuselisporites volkheimerii-Circumplicatipollis plicatus* Superzone (Di Pasquo, 2003). According to Souza (2000) and Di Pasquo (2003), about 50% of the taxa are shared by the Carboniferous strata of these basins.

Vittatina costabilis Interval Zone

This palynozone was previously proposed as the *Cannanoropollis korbaensis* Interval Zone (Marques-Toigo, 1988, 1991). However, this pollen grain was recognized from the Lower Itararé Subgroup (see Chart 1). Instead, the genus *Vittatina* occurs from a well marked biohorizon, related to the H_3 subinterval (Daemon & Quadros, 1970).

Its lower limit is marked by the first appearance of the genus *Vittatina* (*V. saccata, V. subsaccata, V. costabilis, V. vittifera*), species of *Protohaploxypinus* (*P. goraiensis, P. micros*) and *Illinites unicus*. Pollen grains, in general more abundant than the spores, include species of *Caheniasaccites*, *Scheuringipollenites*, and *Vesicaspora*.

This palynozone is well represented in the Paraná Basin, and is now subdivided in two units, the *Protohaploxypinus goraiensis* and *Hamiapollenites karroensis* Subzones. The first is defined by the range of *P. goraiensis* and *Illinites unicus* and comprises coal bearing strata from the uppermost Itararé Subgroup to the middle Rio Bonito Formation (Guatá Subgroup). These coal beds were previously referred to as the *Caheniasaccites ovatus* subzone (Marques-Toigo, 1991), which is here regarded as an ecofacies. Such spores as *Punctatisporites*, *Horriditriletes*, *Lundbladispora*, *Cristatisporites*, and *Vallatisporites* are dominant in these coal beds. The *Hamiapollenites karroensis* Subzone is defined by the range of this species and by the first appearance of *Striatopodocarpites fusus* and *Staurosaccites cordubensis*. It has been recognized in the uppermost Rio Bonito Formation.

Correlations can be made with the H_3-I intervals of Daemon & Quadros (1970). Closely correlative assemblages, commonly found from Argentina, are the *Cristatisporites* Zone (sensu Vergel, 1993) and the *Fusacolpites fusus-Vittatina subsaccta* Interval Biozone (César & Gutiérrez, 2001). Similar assemblages occur elsewhere in Gondwana, in Australia, India, Antarctica, Oman and Saudi Arabia (e.g., Jones & Truswell, 1992; Stephenson & Filatoff, 2000).

Lueckisporites virkkiae Interval Zone

This zone is characterized mainly by the appearance of the genus *Lueckisporites* (*L. virkkiae, L. densicorpus)* and species of *Staurosaccites* and *Weylandites lucifer*. These pollen grains, as well as species of *Protohaploxypinus, Striatopodocarpites, Striatoabieites, Lunatisporites* and *Marsupipollenites,* are dominant in this zone, reaching up to 80% of the association. Some species of spores

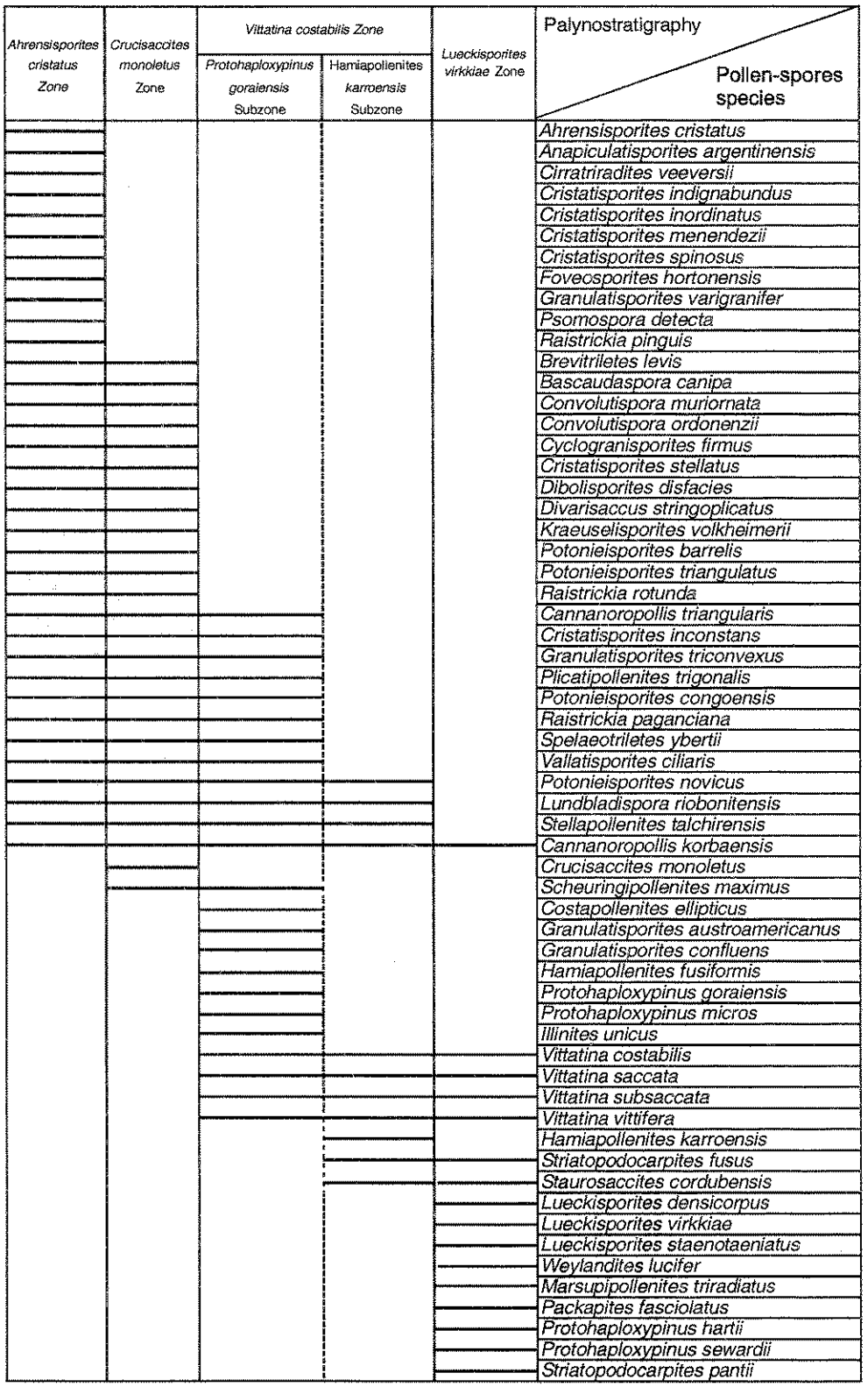

Chart 1. Stratigraphic distribution of selected palynomorphs along the Upper Paleozoic Paraná Basin palynozones (after Souza & Marques-Toigo, 2001).

and monosaccate pollen grains of the former units are also present and new species of the genera *Convolutispora* and *Thymospora* occur. This zone has been recognized from the uppermost Rio Bonito Formation, Palermo Formation (Upper Guatá Subgoup) to the Irati Formation (Lower Passa Dois Group), and is correlated with the K and L intervals of Daemon & Quadros (1970). Palynomorphs recovered from Serra Alta, Teresina and Rio do Rasto Formation are very scarce. Based on Daemon & Quadros (1970) and new unpublished data, they seem to correspond to the *Lueckisporites virkkiae* Interval Zone. Like the *Vittatina costabilis* Zone, this unit is widely known from the middle to late Permian Gondwana strata.

These last two palynozones are correlated with the H_3-L intervals of Daemon & Quadros (1970), and occur throughout the Paraná Basin. Assemblages have been recovered from subsurface material (e.g., Daemon & Quadros, 1970; Picarelli *et al.*, 1987), and from outcrops, the states of Rio Grande do Sul (e.g., Dellazzana, 1976; Ybert, 1975; Dias, 1993), Santa Catarina (Pons, 1977, 1978), Paraná (Marques-Toigo *et al.*, 1981) and São Paulo State (Menéndez, 1976; Souza *et al.*, 1999).

CONCLUDING REMARKS

New palynofloras have been recorded from the Paraná Basin in recent decades, especially from its northeastern portion, based on subsurface and surface samples. These studies have enabled refinement of the palynological succession. Certain changes in the range of diagnostic species of some previous zonation schemes are proposed and selected species are used as additional zonal criteria.

According to Daemon & Quadros (1970), *Plicatipollenites gondwanensis* (P906) appears from the I_1 subinterval and *P. trigonalis* (P490) and *Cannanoropollis triangularis* (P501) would be restricted to the G Interval. These last two species were recorded in the Upper Itararé Subgroup in Rio Grande do Sul State (Dias, 1993) from strata assignable to the H_3-I interval. Moreover, *P. gondwanensis* occurs from the base of the Itararé Subgroup in the northeastern basin, at Araçoiaba da Serra (Souza, 1996; Souza *et al.*, 2003) and from its middle-upper portion at Itaporanga (Di Pasquo *et al.*, 2003b). Additional information on the spore-pollen distribution in these intervals was given by Daemon & Quadros (1970) and Daemon (1981).

Late Carboniferous palynofloras have been recognized in the Lower and Middle Itararé Subgroup in São Paulo and Paraná States, northeastern basin. The Carboniferous ages assigned to these palynozones are based on the presence of diagnostic species, and on correlation between the main Gondwanan palynozones, especially from the Argentinian basins (e.g., Paganzo, San Rafael, Tarija and Chacoparaná basins), where the Carboniferous sequence are more complete. Radiometric data are scarce in the Paraná Basin, and absent in the Carboniferous sequence, limiting against accurate age calibration among the available palynostratigraphic schemes.

The subzones comprised in the *Vittatina costabilis* Zone have been reanalysed in order to find biohorizons of significant floral changes. The *Caheniasaccites ovatus* Subzone (*sensu* Marques-Toigo, 1991) seems to be related to a restricted facies, i.e., the southern Brazilian coal beds in Santa Catarina and Rio Grande do Sul States. The taeniate pollen *Protohaploxypinus goraiensis* and *Illinites unicus* range from the base of the *Protohaploxypinus goraiensis* Subzone to the base of the *Hamiapollenites karroensis* Subzone, and are used herein as guides to this subzone.

Lithostratigraphic boundaries are not coincident with the main biohorizons. The *Vittatina costabilis* Interval Zone includes the Upper Itararé Subgroup and part of the Rio Bonito Formation. No significant biostratigraphic difference has been recorded in these sections, despite lithological changes in the basin. The boundary between the *Vittatina costabilis* and *Lueckisporites virkkiae* Interval Zones is recorded in the Upper Rio Bonito Formation and the Lower Palermo Formation, and is related to the J/K intervals (Daemon & Quadros, 1970).

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Appendix. List of taxa.

Spores

Ahrensisporites cristatus Playford & Powis
Anapiculatisporites argentinensis Azcuy
Bascaudaspora canipa Owens
Brevitriletes levis (Balme & Hennelly) Bharadwaj & Srivastava
Cirratriradites veeversii Playford
Convolutispora Hoffmeister, Staplin & Malloy
C. muriornata Menéndez
C. ordonenzii Archangelsky & Gamerro
Cristatisporites (Potonié & Kremp) Butterworth *et al.*
C. inconstans Archangelsky & Gamerro
C. indignabundus (Potonié & Kremp) Staplin & Jansonius
C. inordinatus (Menéndez & Azcuy) Playford
C. menendezii (Menéndez & Azcuy) Playford *emend.* Césari
C. spinosus (Menéndez & Azcuy) Playford *emend.* Césari
C. stellatus (Azcuy) Gutiérrez & Limarino
Cyclogranisporites firmus Jones & Truswell
Dibolisporites disfacies Jones & Truswell
Foveosporites hortonensis (Playford) Azcuy
Granulatisporites austroamericanus Archangelsky & Gamerro
G. confluens Archangelsky & Gamerro
G. triconvexus Staplin
G. varigranifer Menéndez & Azcuy
Horriditriletes Bharadwaj & Salujha
Kraeuselisporites volkheimerii Azcuy
Leiotriletes (Naumova) Potonié & Kremp
Lundbladispora (Balme) Playford
Lundbladispora riobonitensis Marques-Toigo & Picarelli
Psomospora detecta Playford & Helby
Punctatisporites (Ibrahim) Potonié & Kremp
Raistrickia paganciana Azcuy
R. pinguis Playford
R. rotunda Azcuy
Spelaeotriletes ybertii (Marques-Toigo) Playford & Powis emend. Playford, Dino & Marques-Toigo
Thymospora (Wilson & Venkatachala) Alpern & Doubinger
Vallatisporites Hacquebard
Vallatisporites ciliaris (Luber) Sullivan

Pollen grains

Caheniasaccites Bose & Kar *emend.* Azcuy & Di Pasquo
Cannanoropollis Potonié & Sah
Cannanoropollis korbaensis (Bharadwah & Tiwari) Foster
C. triangularis (Mehtae) Bose & Maheshwari
Costapollenites ellipticus Tschudy & Kosanke
Crucisaccites monoletus Maithy
Divarisaccus stringoplicatus Ottone
Hamiapollenites fusiformis (Marques-Toigo) Archangelsky & Gamerro
H. karroensis Hart
Illinites unicus Kosanke *emend.* Jansonius & Hills
Lueckisporites (Potonié & Klaus) Klaus
Lueckisporites densicorpus Archangelsky & Gamerro
L. stenotaeniatus Menéndez
L. virkkiae (Potonié & Klaus) Klaus
Lunatisporites (Leschik) Scheuring
Marsupipollenites triradiatus Balme & Hennelly
Marsupipollenites (Balme & Hennelly) Balme
Marsupipollenites triradiatus Balme & Hennelly
Pakhapites fasciolatus (Balme & Hennelly) Hart
Plicatipollenites Lele
Plicatipollenites gondwanensis (Balme & Hennelly) Lele
P. trigonalis Lele

Potonieisporites Bhardwaj *emend.* Bharadwaj
Potonieisporites barrelis Tiwari
P. congoensis Bose & Maheshwari
P. novicus Bhardwaj *emend.* Poort & Veld
P. triangulatus Tiwari
Protohaploxypinus Samoilovich *emend.* Morbey
P. goraiensis (Potonié & Lele) Hart
P. hartii Foster
P. micros (Hart) Hart
P. sewardii (Virkki) Hart
Scheuringipollenites Tiwari
Scheuringipollenites maximus (Hart) Tiwari
Staurosaccites Dolby
Staurosaccites cordubensis Archangelsky & Gamerro
Stellapollenites talchirensis Lele
Striatoabieites (Zoricheva & Sedova *ex* Sedova) Hart
Striatopodocarpites (Sedova) Hart
Striatopodocarpites fusus (Balme & Hennelly) Potonié
S. pantii (Jansonius) Balme
Vesicaspora Schemel
Vittatina (Luber) Wilson
Vittatina costabilis Wilson
V. saccata (Hart) Jansonius
V. subsaccata Samoilovich
V. vittifera (Luber & Waltz) Samoilovich
Weylandites lucifer (Bharadwaj & Srivastava) Foster