



The Permian palynological *Lueckisporites*-*Weylandites* Biozone in the San Rafael Block and its correlation in Western Gondwana



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ABSTRACT

A palynological study of the Yacimiento Los Reyunos Formation (San Rafael Block) Argentina was carried out in order to correlate the palynological data with other Permian assemblages and biozones from South America. The unit is included in the Cochicó Group deposited under the volcanic influence of the Choiyoi event. The palynological assemblages recovered from subsurface samples show a dominance of taeniate bisaccates like *Corisaccites*, *Lueckisporites*, *Lunatisporites*, *Protohaploxypinus*, *Vittatina* and *Weylandites*. A *Lueckisporites* complex, which would have biostratigraphical value, is established to include species of *Lueckisporites*, *Corisaccites* and *Staurosaccites* showing a wide morphological variation. The composition of the assemblages allows their inclusion in the *Lueckisporites*/*Weylandites* Biozone of Argentina, which is closely related to other biozones from southern South America. Analysis of the distribution of the species using cluster analysis confirms its similarity with the biozones from Bolivia and Brazil. Radiometric datings suggest an age not older than Kungurian for the occurrence of these assemblages in the Southern Hemisphere.

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1. Introduction

The knowledge of the Permian palynology of the Argentinian basins is based on assemblages recovered from the Paganzo, Chacoparaná, San Rafael, Claromecó and Macachín Basins. The palynofloras from central-western Argentina have been referred to the earliest Permian *Pakhapites fusus*/*Vittatina subsaccata* Biozone and the overlying *Lueckisporites*/*Weylandites* Biozone (Césari and Gutiérrez, 2001). The later biostratigraphic unit is only recognized in few localities and the reference section of the LW Biozone is the Yacimiento Los Reyunos Formation in the E-49 well (San Rafael Block). Therefore, a revision and comparison of the palynofloras from this unit is presented. Césari et al. (1996) studied the first palynological record, which was compared with the Striatites Biozone of the Chacoparaná Basin. Radiometric ages and associated tetrapod and invertebrate trace fossils have been reported in the last years for the Yacimiento Los Reyunos Formation. New additional palynological samples are analyzed and comparisons are presented with assemblages recently described in this Gondwanan region.

2. Geology

The Yacimiento Los Reyunos Formation was deposited in the San Rafael Block located in the western margin of Gondwana (south of Mendoza Province, Fig. 1). The volcano-sedimentary succession of the Choiyoi Group was divided into two sections (Fig. 2): the lower Choiyoi (Cochicó Group) and the upper Choiyoi (Agua de los Burros, Quebrada del Pimiento and Cerro Carrizalito Formations).

The Yacimiento Los Reyunos Formation (about 800 m thick) is included into the Cochicó Group which overlies unconformably the El Imperial Formation (Pennsylvanian-earliest Cisuralian). The unit has been divided into four members: Pseftic, Toba Vieja Gorda (exclusively ignimbrites, laterally interfingering the other members), Areniscas Atigradas and Andesitic which are composed of brechas and clastic sedimentation (Llambías et al., 1993).

The outcrops of the Cochicó Group are scarce and disperse in the south area of the Mendoza Province and west of the La Pampa Province. In particular, the outcrops of the Yacimiento Los Reyunos Formation are dominated by volcanic rocks (Toba Vieja Gorda and Andesitic Members) whereas the Areniscas Atigradas and Pseftic Members are clastic deposits. Well exposed eolian sandstones occur in the area, where thick eolian dune deposits are covered by

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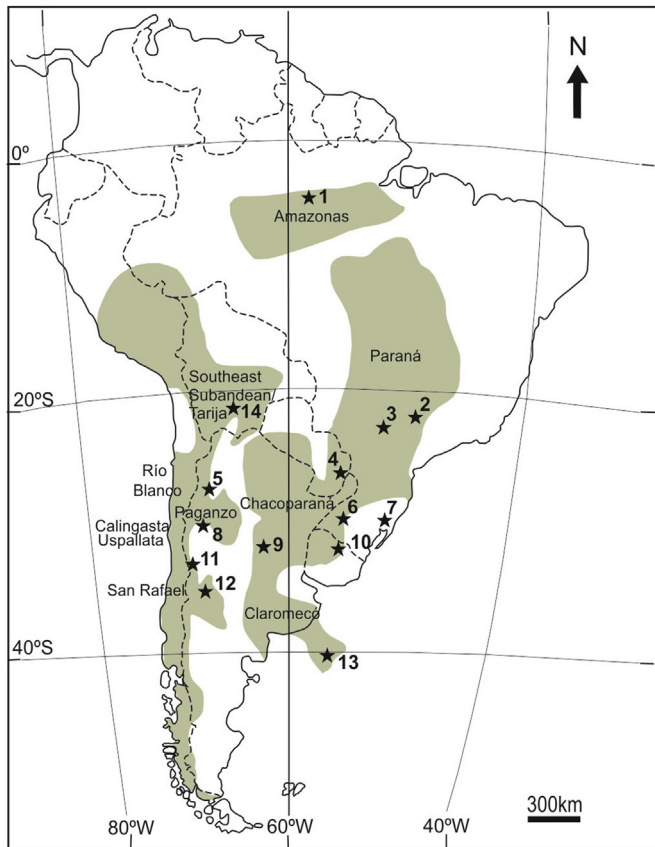


Fig. 1. Map showing the Permian basins and the location of the main stratigraphic units discussed in this paper. 1: Tapajos Group (Playford and Dino, 2000a, b); 2: Teresina and Rio do Rasto Formations (Neregato et al., 2008); 3: Irati Formation (Santos et al., 2006); 4: San Miguel Formation (Perez Loinaze et al., 2010a); 5: De La Cuesta and La Veteada Formations (Aeñolaza and Vergel, 1987; Gutiérrez et al., 2011, Gutiérrez et al., 2014); 6: 5-CA-41-RS well (Souza and Marques-Toigo, 2005); 7: 2-TG-69-RS well (Souza and Marques-Toigo, 2005); 8: La Deheza and Andapaico Formations (Balarino et al., 2012, 2015); 9: Ordoñez and Victoriano Rodríguez Formations (Russo et al., 1980); 10: 254 well, Melo Formation (Beri et al., 2011); 11: Santa Máxima Formation (Ottone, 1989); 12: Yacimiento Los Reyunos Formation (Césari et al., 1996); 13: La Estrella. x-1 and Cruz de Sur. x-1 boreholes (Balarino, 2014); 14: Copacabana Formation (di Pasquo et al., 2015).

ignimbrites belonging to the Toba Vieja Gorda Member (Spalletti and Mazzoni, 1972). The Psefitic Member (c.a. 150 m thick) is characterized by the dominance of conglomerates with intercalated sandstones and a thin carbonaceous level recognized up to now only in the exploration well E-49 of CNEA (Comisión Nacional de Energía Atómica).

Two palynological samples from the E-49 well, located in the Yacimiento Dr. Bauliés area (34°44'06.91"S 68°38'37.10"W), were recovered by Césari et al. (1996). This well comprises deposits of the uppermost part of the El Imperial Formation (58 m) and rocks of the Yacimiento los Reyunos Formation, represented by the Psefitic and Toba Vieja Gorda Members. The Psefitic Member was divided by Maloberti (1983) into two cycles; the first (25 m thick) is separated by an intercalation of the Toba Vieja Gorda Member (123 m thick) from the upper cycle. Above this intercalation to the top of the well the upper cycle of the Psefitic Member is recorded. The palynological assemblages come from the second cycle where 12 m of dark carbonaceous claystone-siltstone (122 m–134 m b.b.p.) occurs. Four new productive samples were obtained from that interval.

	Puesto Viejo Group	235.8 ± 2.0 Ma
Choiyoi Upper Section	Cerro Carrizalito Fm.	251.9 ± 2.7 Ma
	Quebrada del Pimiento Fm.	264.8 ± 2.3 Ma
	Agua de los Burros Fm.	264.7 ± 2.9 Ma
Choiyoi Lower Section	Cochicó Group	Arroyo Punta del Agua Fm.
		Yacimiento Los Reyunos Fm.
		Areniscas Atigradas Mb.
		Andesitic Mb.
		Toba Vieja Gorda Mb.
		Psefitic Mb.
		upper
		lower
		281.4 ± 2.5 Ma
	El Imperial Fm.	

Fig. 2. Stratigraphic chart of the Upper Paleozoic sequence in San Rafael Basin and available radiometric SHRIMP U-Pb datings from Rocha-Campos et al. (2011) and Ottone et al. (2014).

3. Fossil content of the Yacimiento Los Reyunos Formation

The fossil record of the unit consists on tetrapod and invertebrate fossil traces usually present in the eolian deposits of the Areniscas Atigradas Member (Ceí and Gargiulo, 1977; Aramayo and Farinati, 1983; Aramayo, 1993; Melchor, 1997, 1998; Caselli and Arcucci, 1999; Krapovickas et al., 2015); and palynological assemblages (Césari et al., 1996) from the Psefitic Member. The first mentions of vertebrate fossil traces were made by Ceí and Gargiulo (1977) who compared them with “Laberintodontes” footprints from the Triassic of United States and Africa. Later, Aramayo and Farinati (1983) and Aramayo (1993) described similar fossil trackways from a new locality (“Estancia La Julia”) at north of San Rafael city. Melchor (1997) performed the first detailed description of the ichnites. The assemblage is characterized by a low diversity and a predominance of the genus *Chelichnus*, of small size (lower than 4 cm). Melchor (2001) interpreted the parental fauna as dominated by small mammalian reptiles. Krapovickas et al. (2015) reinterpreted the ichnoassemblages and presented the first record of invertebrate and vertebrate fossil traces in association. Moreover, they described for the first time vertebrate fossil traces in the Psefitic Member.

Césari et al. (1996) described two palynological assemblages from the Psefitic Member, recovered from cutting samples of the E-49 well in the intervals: 122 m–124 m b.b.p. and 124 m–126 m b.b.p. The palynofloras are dominated by taeniate pollen with subordinate proportion of monosaccate pollen (about 15%). The presence of *Marsupipollenites striatus*, *Lunatisporites varie-sectus*, *Staurosaccites cordubensis*, *Lueckisporites virkkiae*, *Striomonosaccites cicatricosus*, *Colpisaccites granulosus* and *Convolutispora ordonezii* allowed Césari et al. (1996) to propose a correlation with the Striatites Biozone defined by Russo et al. (1980) in the Chacoparaná Basin. Therefore, the palynofloras were considered late Cisuralian in age. The Yacimiento Los Reyunos Formation has also been assigned previously by its stratigraphic position to the Permian by different authors (e.g., Polanski, 1966).

3.1. Palynological assemblages

New sampling of the fossiliferous interval of the E-49 well provided four additional palynological assemblages to those originally studied by Césari et al. (1996). The slides are held at the

Palynological Collection of the Museo Argentino de Ciencias Naturales B. Rivadavia, Argentina. Sample/slide numbers and England Finder coordinates for all illustrated specimens are provided in the Appendix. All samples are similar in composition and characterized by the abundance of *Lueckisporites*, *Protohaploxylinus*, *Potoniisporites*, *Plicatipollenites* *Weylandites* and *Vittatina*, species with rare spores. The palynomorphs identified from the Yacimiento los Reyunos Formation are listed below. The species recognized in the new samples are marked with an asterisk in the list.

3.1.1. Spores

Calamospora sp.

Cristatisporites sp.

Leiotriletes sp.

Vallatisporites arcuatus (Marques-Toigo) Archangelsky and Gamarro, 1979*.

Laevigatosporites vulgaris (Ibrahim) Ibrahim emend. Alpern and Doubinger, 1973*.

3.1.2. Non-taeniate monosaccate pollen grains

Circumplicatipollis plicatus Ottone and Azcuy, 1988.

Chordasporites sp*.

Crucisaccites variosulcatus Djupina, 1970* (Fig. 3.19).

Remarks. *Crucisaccites variosulcatus* is smaller than *C. monoletus*, the type species of the genus (120–160 µm), and is characterized by the presence of slightly expanded exoexine of the saccus that have attachment bilateral, cruciate with respect to each other on the two sides (Djupina, 1970). The specimens here referred to this species differ only in the thickening of the exine, which is of leathery appearance. They are relatively abundant in the studied assemblages and there is a wide morphological variation similar to the illustrated by Visscher (1973). *Crucisaccites* sp. illustrated by Balarino et al. (2015, Plate 2, Fig. 25) from the Assemblage 3 of the La Deheza Fm. is closely similar to *C. variosulcatus*, as well as, Perez Loinaze et al. (2010a) illustrated a comparable specimen (Fig. II, F) from the San Miguel Formation, described as *Staurosaccites cordubensis* Archangelsky and Gamarro.

Stratigraphic range. Djupina (1970) reported the species to be widely distributed in the Artinskian and Kungurian of the Ural Mountains. *C. variosulcatus* also occurs in the Guadalupian of Russia, but is unknown from the Russian Lopingian. A Thuringian (=Roadian-Wordian) age was proposed by Visscher (1973) and Visscher et al. (1974) for the assemblages from the area of Domè de Barrot that contain: *Lueckisporites virrkiae*; *Paravesicaspora splendens*; *Crucisaccites variosulcatus* among other species. Later, Pittau et al. (2006) found a similar association in the Conglomerato della Val Daone (South-central Alps) and proposed a *Crucisaccites variosulcatus-Lueckisporites virrkiae* Zone to characterize the Roadian-Wordian in Western Europe. This biozone seems to span, in Europe, from Roadian-Wordian to slightly younger Permian times (Cassinis et al., 2012). Bercovici et al. (2009) described an abundant palynoflora from Permian deposits in Minorca (Balearic Islands), including also *C. variosulcatus* and *L. virrkiae* among other species. The authors remark the dominance of bisaccate pollen grains as a general characteristic of “Thuringian” palynofloras and particularly the abundance of the last mentioned species. Similar associations were described from the Roadian-Wordian of Spain but the Minorca palynofloras differ in the high diversity of *Lueckisporites* and abundance of small bisaccate pollen grains (Bercovici et al., 2009).

Warrington (2008) also mentioned the presence of *C. variosulcatus* in mid-late Permian assemblages from Britain. Zhu et al. (2005) recognized the first occurrence of *C. variosulcatus* in the Kungurian of the Tarim and Junggar Basins of China.

Plicatipollenites malabarensis (Potonié & Sah) Foster, 1975.

3.1.3. Non-taeniate bisaccate pollen

Alisporites splendens (Leschik) Foster, 1979 (Fig. 3.1).

Alisporites australis de Jersey, 1962 (Fig. 3.2).

Colpisaccites granulosus Archangelsky and Gamarro, 1979 (Fig. 3.3).

Falcisporites stabilis Balme, 1970* (Fig. 3.4–5).

Remarks. The specimens from the Yacimiento Los Reyunos Formation are in the lowest range of size proposed for the species.

Klausipollenites cf. *vestitus* Jansonius, 1962* (Fig. 3.6).

Limitisporites hexagonalis Bose and Maheshwari, 1968.

Limitisporites rectus Leschik, 1956* (Fig. 3.7).

Platysaccus cf. *P. leschiki* Hart, 1964* (Fig. 3.8).

Pteruchipollenites sp. (Fig. 3.9).

Scheuringipollenites medius (Burjack) Días-Fabricio, 1981 (Fig. 3.10).

Scheuringipollenites ovatus (Balme & Hennelly) Foster, 1975* (Fig. 3.14).

Vesicaspora wilsoni (Schemel) Venkatachala and Kar, 1968* (Fig. 3.11–12).

3.1.4. Taeniate pollen

Infernopollenites sp.* (Fig. 3.13).

Remarks. Few diploxylooid specimens up to 136 µm in size, with three taeniae and rigid sacci are assigned provisionally to *Infernopollenites* Scheuring, a Triassic genus characterized by its thickened exine, large sacci and corpus with only three taeniae. It may be that these few specimens result aberrant variations of *Lunatisporites pellucidus*.

Hamiapollenites fusiformis Marques-Toigo emend. Archangelsky and Gamarro, 1979 (Fig. 3.17).

Remarks. This species was emended by Archangelsky and Gamarro (1979) to include specimens with up to 15 taeniae and only one thickened distal band perpendicular to the taeniae orientation. Those authors revised the type specimens and agreed with Marques-Toigo that the two distal narrow bands described originally by her (Marques-Toigo, 1974), are in fact a unique band with thickened borders. Recently, Stephenson (2015a) also described the species from the Cisuralian of Oman, with unusual lateral connections of the sacci and poorly defined haptotypic mark. *Hamiapollenites bullaeformis* (Samoilovich) Jansonius is a closely similar species and possibly *H. fusiformis* results a junior synonym.

This species has been also identified at the top of the underlying El Imperial Fm. by Garcia (1996).

Lunatisporites pellucidus (Goubin) Helby (in de Jersey, 1972)* (Fig. 3.21–22).

Remarks. The specimens referred to this species are closely similar to the originally illustrated by Goubin (1965). When Balme (1970) combined to *Taeniasporites* the species described by Goubin (1965) characterized the specimens by the presence of four taeniae; however, the original specimens have at least five as it was mentioned by Balme (1970). Goubin (1965) distinguished the species from *Protohaploxylinus goraiensis* by its wider cappula, but the transversely oval corpus and more number of narrow taeniae in *P. goraiensis* are also significant. The Triassic *Infernopollenites* is characterized by the presence of three taeniae and thickened sexine.

Stratigraphic range. Although, *L. pellucidus* is considered a usual species of early Triassic assemblages, Goubin (1965) recognized its occurrence in the late Permian Lower Sakamena Group as well as Metcalfe et al. (2009) in China and the late Permian Eastern Australian APP602 Subzone (Price, 1997) is defined by its first appearance.



Fig. 3. 1. *Alisporites splendens*, 2. *Alisporites australis*, 3. *Colpisaccites granulosis*, 4–5. *Falcisporites stabilis*, 6. *Klausipollenites* cf. *vestitus*, 7. *Limitisporites rectus*, 8. *Platysaccus* cf. *P. leschiki*, 9. *Pteruchipollenites* sp., 10. *Scheuringipollenites medius*, 11–12. *Vesicaspora wilsoni*, 13. *Infernopollenites* sp., 14. *Scheuringipollenites ovatus*, 15, 20. *Corisaccites alutas*, 16. *Staurosaccites* cf. *S. quadrifidus*, 17. *Hamiapollenites fusiformis*, 18. *Lunatisporites variesectus*, 19. *Crucisaccites variosulcatus*, 21–22. *Lunatisporites pellucidus*, 23. *Protohaploxypinus amplus*, 24. *Lueckisporites angoulaensis*, 25. *Marsupipollenites striatus*, 26. *Protohaploxypinus hartii*, 27. *Protohaploxypinus limpidus*, 28. *Protohaploxypinus microcorpus*, 29. *Protohaploxypinus rugatus*, 30. *Protohaploxypinus samoilovichii*.

Lunatisporites variesectus Archangelsky and Gamarro, 1979 (Fig. 3.18).

Marsupipollenites striatus (Balme & Hennelly) Foster, 1975 (Fig. 3.25).

Pakhapites fusus (Bose and Kar) Menéndez, 1971 (Fig. 5.1).

Protohaploxypinus amplus (Balme & Hennelly) Hart, 1964 (Fig. 3.23).

Protohaploxypinus hartii Foster, 1979* (Fig. 3.26).

Protohaploxypinus limpidus (Balme & Hennelly) Balme and Playford, 1967* (Fig. 3.17).

Protohaploxypinus microcorpus (Schaarschmidt) Clarke, 1965* (Fig. 3.28).

Protohaploxypinus rugatus Segroves, 1969* (Fig. 3.29).

Remarks. Balarino (2012) included in *P. goraiensis* (Potonié and Lele) Hart, specimens described as *P. rugatus* by Segroves (1969) and *P. perexigus* (Bharadwaj and Salujha) Foster. However, the assemblages studied here lack the typical large specimens of *P. goraiensis*; therefore the few specimens characterized by a poorly defined corpus, narrow cappa and subcircular outline are considered belonging to *P. rugatus*.

Protohaploxypinus samoilovichii (Jansonius) Hart, 1964* (Fig. 3.30).

Striatoabieites multistriatus (Balme & Hennelly) Hart, 1964 (Fig. 5.2).

Striatoabieites anaverrucosus Archangelsky and Gamarro, 1979* (Fig. 5.4).

Remarks. Balarino (2012) combined *Striatoabieites anaverrucosus* Archangelsky and Gamarro to *Tiwarisporis* by the presence of irregular grana or verrucae on the distal surface. However, following Foster (1979) and Backhouse (1991) *Tiwarisporis* is here considered without sacci, which seems a more robust diagnostic difference.

Striomonosaccites cf. *S. cicatricosus* Archangelsky and Gamarro, 1979* (Fig. 5.3).

Vittatina subsaccata (Samoilovich) Jansonius, 1962 (Fig. 5.6).

Vittatina fasciolata (Balme & Hennelly) Bharadwaj, 1962 (Fig. 5.5).

Weylandites lucifer (Bharadwaj & Salujha) Foster, 1975 (Fig. 5.9–10).

Weylandites magmus (Bose & Kar) Backhouse, 1991 (Fig. 5.7–8).

3.1.5. *Lueckisporites* complex (Fig. 4)

Although, the specimens from the Yacimiento Los Reyunos Formation are not so well preserved, they show a variation of forms that allow to characterize a complex of coexisting pollen grains that share the presence of two taeniae (*Lueckisporites* and *Corisaccites*) or the corpus divided by a cleft (*Staurosaccites*). Some of them are comparable to the forms described by Visscher (1972, 1973). Visscher (1971, 1972) proposed to include in the non-hierarchical category named palynodeme, pollen grains conventionally classified as species of *Lueckisporites* from late Permian and early Triassic assemblages of Western Europe. The concept of *Lueckisporites* palynodeme based on the *deme* terminology proposed by Gilmour and Gregor (1939), characterizes “any group of contemporaneously dispersed spores or pollen grains which may be suspected to represent a palynological reflection of a known or hypothetical plant species” (Visscher, 1971). van der Zwan (1979) considered that the term palynodeme introduced by Visscher (1971, 1972) has an evolutionary significance, showing a gradual and natural variation of a hypothetical plant. van der Zwan (1979) chose to use the morphon concept as “a group of palynological species united by continuous variation of morphological characteristics”, when it is not possible to know if they represent one or more natural species. Finally, the term complex has been applied by different authors to encompass taxa with shared characters but without remarkable gradation among them.

Within the series of *Lueckisporites* “palynodeme”, Visscher (1972, 1973) recognized changes over time, including: a progressive solidification of the sexine of the cappa, a reduction of the sacci and development of nonsaccate pollen grains. According to Visscher (1971) the *Lueckisporites* pollen grains from the “Thuringian” of Europe show a continuum of morphological variations; the extreme forms are conventionally classified as *Guttulapollenites* and *Stellapollenites*. Unfortunately, the “deme” terminology was not

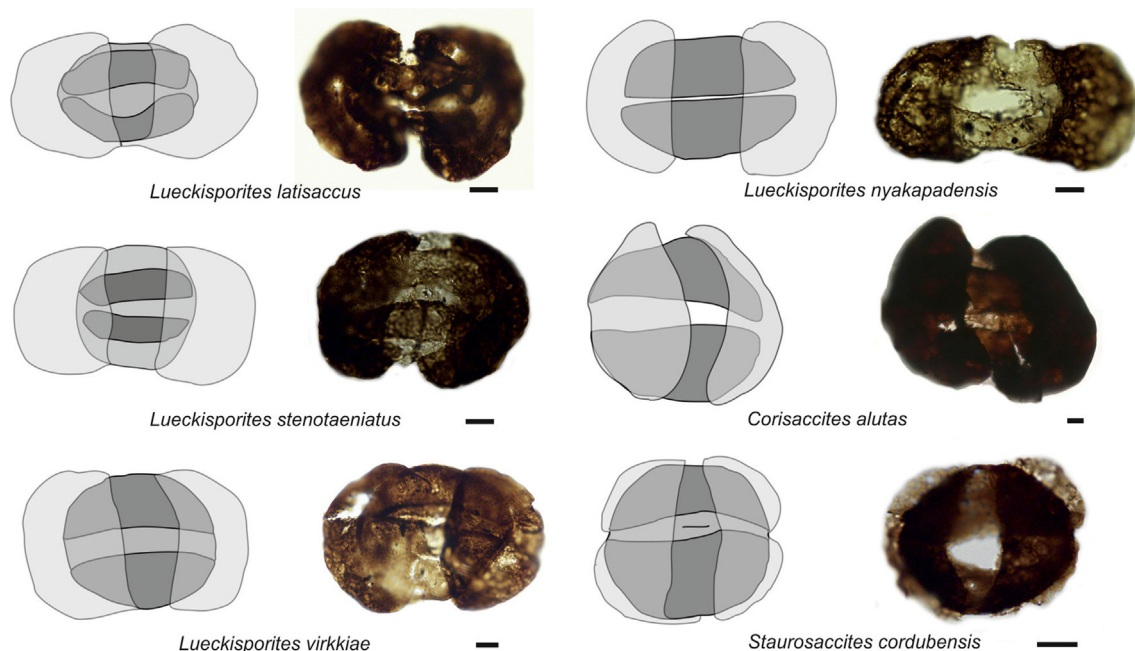


Fig. 4. Some species included in the *Lueckisporites* complex, lineal figures are based on the type specimens and images correspond to specimens from the Yacimiento Los Reyunos Fm. Scale = 10 μ m.

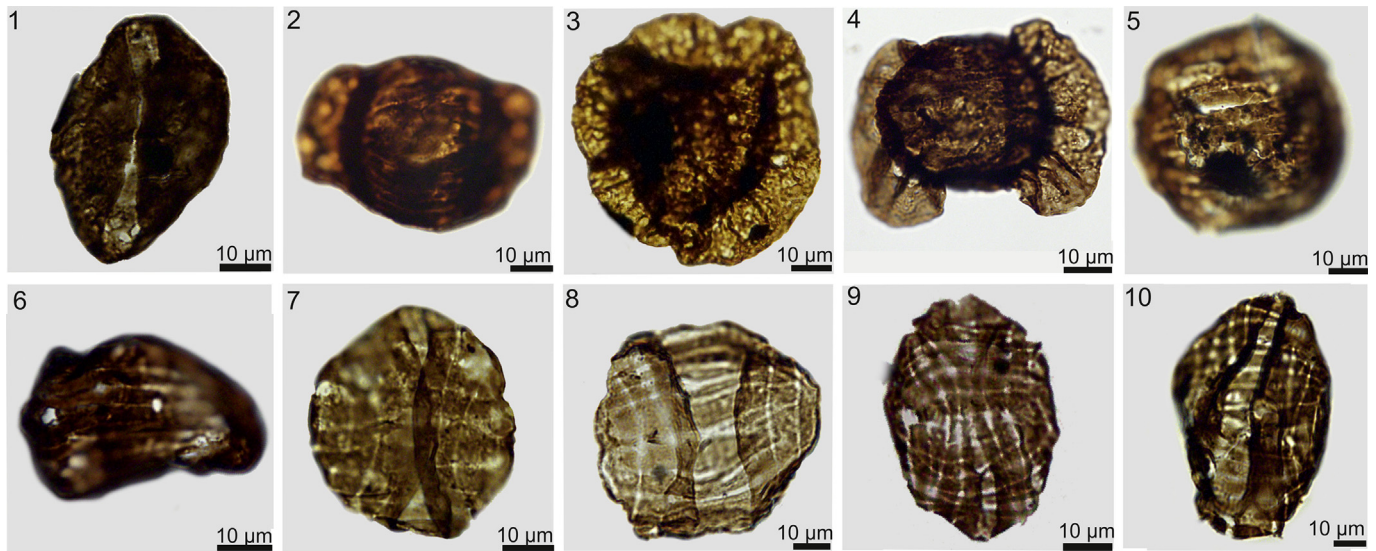


Fig. 5. 1. *Pakhapites fusus*, 2. *Striatoabieites multistriatus*, 3. *Striatoabieites anaverrucosus*, 4. *Striomonosaccites* cf. *S. cicatricosus*, 5. *Vittatina fasciolata*, 6. *Vittatina subsaccata*, 7–8. *Weylandites magnus*, 9–10. *Weylandites lucifer*.

successful and fell into disuse.

Lueckisporites virkkiae (Pottonié & Klaus) Klaus, 1963 (Fig. 4).

Remarks. The concept of the species proposed by Klaus (1963) is accepted to include bisaccate pollen grains with a wide separation of sacchi which are slightly higher than corpus, and two taeniae reaching the margin of the corpus.

Stratigraphic range. This distinctive pollen has the first occurrence in the lower part of the Kazanian (Roadian) in its type area in the Russian Platform (Warrington, 1996; Utting et al., 1997), and reaches the latest Permian sequence there and elsewhere (Utting and Piasecki, 1995; Koloda and Kanev, 1996; Gomankov et al., 1998; Lozovsky et al., 2016) when becomes more abundant. Therefore, it characterizes the current stages Roadian, Wordian and Capitanian, which comprise the Guadalupian Series, and the Wuchiapingian and Changhsingian stages, which comprise the overlying Lopingian Series. Stephenson (2015b) called the attention about the older ages assigned to the first occurrences of *L. virkkiae* in South America. Mori et al. (2012) reported an earlier date of 281 ± 3.4 Ma (debated by Griffis et al., 2015; Cagliari et al., 2016) for the occurrence of *Lueckisporites virkkiae* in the area of the Candiota coal mine (Paraná Basin). di Pasquo et al. (2015) proposed an Asselian-Sakmarian age for the incoming of *L. virkkiae* in the Copacabana Formation (Tarija Basin, Bolivia), based on a study of ash layers by Henderson et al. (2009). Stephenson (2015b) considered that the discrepancy between South American and Euramerican first occurrences of *L. virkkiae* may be the result of misinterpretation of the concept of this species or the consequence of inaccuracies in radiometric dating. A revision of those specimens allow us to confirm their subcircular outline, narrow cappa and sacchi higher than the corpus in the specimen illustrated by Mori and Souza (2010) and Mori et al. (2012), suggest that possibly belong to another species of the genus. The two poorly preserved specimens illustrated by di Pasquo et al. (2015) with sacchi higher than the corpus and similar to the inflated sacchi of some forms attributed to *Corisaccites alutas*, or with haploxyelonoid outline, look different to the original concept of *L. virkkiae*. Anderson (1977) also recognized *Lueckisporites* spp. in the South African upper zone 3 d of the Vryheid Formation attributed to the Artinskian.

Corisaccites alutas Venkatachala and Kar, 1966* (Fig. 3.15, 20,

Fig. 4).

Remarks. This species is characterized by its sacchi usually greater than the corpus, loosely attached, and the variable width of the cappula. Broutin et al. (1990) proposed that there are intermediate forms between *L. virkkiae* and *C. alutas* (see Broutin et al., 1990; plate IV, Figs. 2 and 4). Therefore, Anderson (1977) includes in *Lueckisporites* all those variants. Clement-Westerhof (1974) when described *Corisaccites*-like pollen grains recovered *in situ* remarked the same opinion: "In some instances, specimens from this cone have reduced sacchi and compare with the norm B of Visscher (1971) *Lueckisporites* palynodemes".

Lueckisporites agoulaensis Jardiné, 1974* (Fig. 3.24).

Lueckisporites latisaccus Archangelsky and Gamarro, 1979 (Fig. 4).

Remarks. This species differs from *L. stenotaeniatus* by its small size and more rigid sacchi.

Lueckisporites nyakapandensis Hart, 1960* (Fig. 4).

Remarks. Premaor et al. (2006) considered *L. latisaccus* a junior synonym of this species. However, *L. latisaccus* differs in having elongate and relatively narrow taeniae which not reach the equatorial margin of the central body (Hart, 1960, 1965; Broutin et al., 1990). The specimen referred to *L. nyakapandensis* by Gutiérrez et al. (2011) possesses taeniae not reaching the equator.

Lueckisporites stenotaeniatus Menéndez, 1976 (Fig. 4).

Staurosaccites cordubensis Archangelsky and Gamarro, 1979 (Fig. 4).

Remarks. Archangelsky and Gamarro (1979) described this species as taeniate, however the presence of two distinctive or thickened taeniae are not distinguished in the holotype and the ectexine of the corpus was described without differences with the sacchi. In addition, it should be noted that the genus *Staurosaccites* was described by Dolby (in Dolby and Balme, 1976) as a bisaccate pollen with the cappa dissected transversely by a narrow cleft into two equal halves (not described as taeniae). Some South American specimens resemble in the cruciate appearance to *Crucisaccites variusulcatus*, but this species is monosaccate.

Staurosaccites cf. *S. quadrifidus* Dolby and Balme, 1976* (Fig. 3.16).

Remarks. *Staurosaccites quadrifidus* described by Dolby and

Balme (1976) to characterize an Australian Triassic biozone, differs in having a more distinctive corpus and the cappa and saccus exoexine finely columellate. Beri et al. (2011) illustrated specimens from Permian assemblages of Uruguay, similar to the studied here. Differences may be result of the deficient preservation of the South American specimens.

3.1.6. Algae

Brazilea scissa (Balme & Hennelly) Foster, 1975.

3.2. Comparisons with Permian biozones from Argentina

Césari and Gutiérrez (2001) defined four biozones for the upper Paleozoic of Central-Western basins of Argentina (Paganzo, Río Blanco, Calingasta-Uspallata, and San Rafael Basins). The stratigraphic order of the biozones is: *Cordylosporites–Verrucosiporites* (CV) Biozone, *Raistrickia densa–Convolutispora murionata* (DM) Biozone (divided into the A, B and C Subzones), *Pakhapites fusus–Vitattina subsaccata* (FS) Biozone and *Lueckisporites–Weylandites* Biozone.

Césari and Gutiérrez (2001) defined the assemblage *Lueckisporites–Weylandites* (LW), considered Cisuralian–Guadalupian in age and characterized by the first occurrence of *Lueckisporites*, the dominance of taeniate and plicate pollen like *Lunatisporites* spp., *Weylandites* spp., *Vittatina* spp., and *Marsupipollenites* spp. Those authors proposed the stratigraphic interval between 122 m and 132 m of the Yacimiento Los Reyunos in the E–49 well as one of the reference sections of the LW Biozone. This interval corresponds to a small and poorly oxygenated water body, which was developed in a volcanic setting (Césari et al., 1996).

The palynological samples from the Yacimiento los Reyunos Formation are composed by some species (e.g., *Limitisporites*, *Plicatipollenites*, *Potonieisporites*, and *Cristatisporites*) recorded in both, FS and LW biozones. However, the presence and/or abundance of the following species allowed to recognize the LW biozone: *Corisaccites alutas*, *Staurosaccites cordubensis*, *Lueckisporites latisaccus*, *L. stenotaeniatus*, *L. virkkiae*, *Lunatisporites variesectus*, *Marsupipollenites striatus*, *Striatoabieites anaverrucosus*, *Striatoabieites multistriatus*, *Scheuringipollenites medius*, *Vittatina fasciolata*, *Weylandites magmus* and *W. lucifer*.

3.3. Comparison with Permian Argentinian assemblages

The characterization of the LW Biozone is assumed by the presence of several species here included in the *Lueckisporites* complex. *Lueckisporites* seems to be a significative index taxon for correlation within the Gondwana basins (Césari and Gutiérrez, 2001; Mori et al., 2012). Therefore, a comparison with palynological assemblages containing these species will be analyzed. Recently, palynofloras from the La Deheza Formation (Balarino et al., 2015), La Veteada Formation (Gutiérrez et al., 2014), De la Cuesta Formation (Gutiérrez et al., 2011), Río Francia Formation (Gutiérrez et al., 2010) and the Andapaico Formation (Balarino et al., 2012) belonging to the Paganzo Basin have been referred to the Striatites or the LW Biozones (see locations on Fig. 1).

3.3.1. De la Cuesta and La Veteada Formations

Aceñolaza and Vergel (1987) described palynological assemblages recovered from outcrops of the upper section of De la Cuesta Formation at the Los Jumes area (Sierra de Narváez), Río Chaschuil, Catamarca Province. These authors mentioned and illustrated the presence of *Lunatisporites variesectus*, *Lueckisporites virkkiae*, *L. stenotaeniatus*, *Striatoabieites anaverrucosus*, *Striatoabieites* sp., *Staurosaccites cordubensis*, *Protohaploxylinus* sp. A, P. sp. B., *Vittatina subsaccata*, *Vittatina* sp. (considered here *Vittatina vittifera*),

Marsupipollenites striatus, *Cycadopites* sp., *Limitisporites* sp., *Alisporites* sp., *Sulcatiporites* sp., *Illinites* sp., *Potonieisporites* sp., *Caheniasaccites ovatus*, *Plicatipollenites malabarensis*, *Calamospora microrugosa*, *C. pedata*, *Convolutispora ordonezii* and *C. sp.* (considered here *Convolutispora archangelskyi*). These authors proposed a correlation with the Striatites Biozone from the Chacoparaná Basin. It is likely that the recently described palynological sample from outcrops at the Sierra de Narváez by Gutiérrez et al. (2011) may be equivalent to those reported by Aceñolaza and Vergel (1987). The location of the outcrops given by Gutiérrez et al. (2011) in the Los Jumes area is a bit ambiguous, because the geographical coordinates not coincide with the position marked on the geological map. However, the thickness, lithological description and stratigraphic position of the deposits are similar to those given by Aceñolaza and Vergel (1987) as well as the composition of the palynofloras. However, Gutiérrez et al. (2011) referred the stratigraphic section to the La Veteada Formation, a unit outcropping 100 km to the south and yielding also palynological assemblages.

Aceñolaza and Vergel (1987) and Gutiérrez et al. (2011) pointed out the predominance of taeniate and bisaccate (non-taeniate) pollen in the assemblages. The later authors add to the species reported by Aceñolaza and Vergel (1987) the recognition of: *Alisporites rioclarensis*, *Lueckisporites angoulaensis*, *L. balmei*, *L. nyakapandensis*, *L. singhii*, *Tornopollenites toreutos* and *Striatopodocarpites cancellatus* among other species. Gutiérrez et al. (2011) assigned their assemblage to the upper part of the *Lueckisporites–Weylandites* Biozone and described the environmental setting as carbonate-rich shallow lacustrine deposits.

The palynological assemblages from the Yacimiento los Reyunos Formation show similarities to the associations from the Sierra de Narváez by the presence of taeniate and bisaccate pollen as: *Alisporites* spp., *Lueckisporites virkkiae*, *Lunatisporites variesectus*, *Marsupipollenites striatus*, *Striatoabieites anaverrucosus* and *Staurosaccites cordubensis*. However, the absence of Triassic taxa recorded by Gutiérrez et al. (2011) as: *Vitreisporites*, *Protodiploxylinus*, *Minutosaccus* and *Klausipollenites* results a difference between the palynofloras.

Later, Gutiérrez et al. (2014) described new palynofloras from the upper part of the La Veteada Formation in its type locality (Sierra de Famatina, La Rioja Province). The assemblages are characterized by a high diversity of spores, pollen, algae and fungi. Triassic genera of bisaccate pollen grains (i.e. *Minutosaccus*, *Falcisporites*, *Protodiploxylinus*, and *Klausipollenites*) were recognized for La Veteada Formation, supporting an age not older than Guadalupian. Taeniate pollen is represented by numerous species, highlighting *Striatopodocarpites*, *Protohaploxylinus*, *Lueckisporites* and *Lunatisporites* genera. Gutiérrez et al. (2014) proposed a Lopingian age for the assemblages which were considered younger than the LW Biozone and assigned to a new and unnamed palynological association. The environmental conditions were interpreted as hypersaline lacustrine bodies with periodically stages of expansion and contraction.

In order to avoid confusion in the following comparisons the two palynofloras described from the Catamarca Province will be considered as only one and referred as “Sierra de Narváez”, whereas the recovered from the outcrops in La Rioja Province will be named as La Veteada Formation.

3.3.2. La Deheza Formation

Balarino et al. (2015) described three associations in the La Deheza Formation (San Juan Province). The lowermost is correlated with the DM biozone. The middle association is characterized by similar species of the lower association but with an abundant proportion of non-taeniate and taeniate pollen grains like *Protohaploxylinus*, *Vittatina* and *Minutosaccus*, which report there their

first appearance. This association was correlated with the DM and FS biozones. The uppermost association, recovered from lagoon deposits, possesses a high diversity of bisaccate non-taeniate, taeniate and plicate pollen grains; whereas the diversity of spores decreases. The assemblage was characterized by the presence of *Caheniasaccites densus*, *Hamiapollenites ruditaeniatus*, *Illinites unicus*, *Latusipollenites quadrisaccatus*, *Lueckisporites* sp. cf. *L. virkkiae*, *L. cf. L. balmei*, *Pakhapites fusus*, *Protohaploxypinus goraiensis*, *P. amplus*, *Scheuringipollenites medius*, *Striatopodocarpites* sp., *Vittatina costabilis*, and *Weylandites* spp. [Balarino et al. \(2015\)](#) correlated this association with the LW Biozone, by the presence of *Hamiapollenites ruditaeniatus*, *Lueckisporites* spp., *Protohaploxypinus microcorpus* and *Weylandites lucifer*.

The Yacimiento los Reyunos samples show similarities with the uppermost assemblage of the La Deheza Formation sharing the following species: *Lueckisporites* spp., *Pakhapites fusus*, *Protohaploxypinus amplus*, *Scheuringipollenites medius*, *Weylandites lucifer*, and *Weylandites magmus*.

3.3.3. Andapaico Formation

[Balarino et al. \(2012\)](#) analyzed three palynological samples from the upper part of the Andapaico Formation, San Juan Province. The fossiliferous succession was interpreted as lagoon deposits. The assemblages were referred to the basal part of the LW Biozone based on the presence of: *Lueckisporites singhii*, *L. stenotaeniatus*, *L. cf. L. angoulaensis*, *Weylandites lucifer*, *Corisaccites alutas*, *Lunatisporites variesectus*, *Striomonosaccites cicatricosus*, *Vittatina corrugata*, *Alisporites parvus*, *Striatopodocarpites gondwanensis* and *Vitreisporites* cf. *V. signatus*. Taeniate pollen predominates in the associations, mainly represented by *Vittatina*, *Protohaploxypinus* and *Hamiapollenites* genera.

[Balarino et al. \(2012\)](#) considered the species: *Accinctisporites ligatus*, *Alisporites opii*, *Alisporites similis*, *Brazilea* sp. A, *Corisaccites vanus*, *Crustaesporites globosus*, *Cycadopytes crassimarginis*, *C. follicularis*, *Hamiapollenites erebi*, *H. ruditaeniatus*, *Limitisporites amazoniensis*, *L. cf. L. delassaucei*, *Lueckisporites singraulensis*, *Lunatisporites ovatus*, *L. cf. L. pellucidus*, *Protohaploxypinus microcorpus* and *Striomonosaccites ovatus* exclusive components of those assemblages.

The palynological associations of the Yacimiento Los Reyunos Formation share the following species with the Andapaico Formation: *A. australis*, *Colpisaccites granulosus*, *Limitisporites* spp., *Scheuringipollenites medius*, *Hamiapollenites fusiformis*, *Lueckisporites* spp., *Lunatisporites variesectus*, *Marsupipollenites striatus*, *Pakhapites fusus*, *Protohaploxypinus amplus*, *Striomonosaccites ovatus*, *Vittatina fasciolata*, *Vittatina subsaccata*, *Weylandites lucifer* and *Weylandites magmus*. A distinctive feature of the Andapaico's assemblages is the presence of *Converrucosisporites confluens*, a diagnostic species of the early Cisuralian.

3.3.4. Río Francia Formation

[Gutiérrez et al. \(2010\)](#) described one sample from fluvial deposits of the upper part of the Río Francia Formation (= Patquía Formation *sensu* [Bossi and Andreis, 1985](#)), which was referred to the LW Biozone, despite of its similitude to the FS Biozone too. The assemblage includes the following species. *Barakarites rotatus*, *Scheuringipollenites barakarensis*, *Striatopodocarpites cancellatus*, *Vittatina minima*, *Kraeuselisporites punctatus*, *Tuberisaccites varius*, *Striatopodocarpites phaleratus*, *Polarisaccites bilateralis* together with *Lueckisporites*, *Weylandites*, *Minutosaccus* and *Klausipollenites* specimens. Among the key-biostratigraphic genera was only illustrated *Lueckisporites* sp., therefore the biostratigraphic position of the assemblage results somewhat doubtful.

The common species between the association here study with the described by [Gutiérrez et al. \(2010\)](#) are: *Plicatipollenites*

malabarensis, *Alisporites* spp., *Colpisaccites granulosus*, *Limitisporites rectus*, *Scheuringipollenites medius*, *Hamiapollenites fusiformis*, *Lueckisporites* spp., *Protohaploxypinus amplus* and *Vittatina subsaccata*.

3.3.5. Santa Máxima Formation

Palynofloras from the upper section of the Santa Máxima Formation were described by [Ottone \(1989\)](#) and included in the LW Biozone by [Césari and Gutiérrez \(2001\)](#). The following species characterize those palynofloras: *Brevitriteles cornutus*, *Horriditriteles gondwanensis*, *Osmundacidites senectus*, *Vallatisporites arcuatus*, *Illinites unicus* (described as *Staurosaccites cordubensis* by [Ottone, 1989](#)), *Lueckisporites stenotaeniatus*, *L. brasiliensis*, *Protohaploxypinus claroensis*, *Pakhapites fusus*, *Striatopodocarpites solitus*, *Platysaccus trumpii*, and *Hamiapollenites insolitus*. Some Pennsylvanian spores are mentioned by [Ottone \(1989\)](#) together with the above group, suggesting probable reworking or contamination. The presence of *O. senectus*, a typical Mesozoic species, may be considered doubtful and perhaps the specimens belong to *Cyclogranisporites*, a taxon also recognized in the assemblage by [Ottone \(1989\)](#).

The assemblage of Yacimiento los Reyunos contains the following species in common with the palynoflora recorded by [Ottone \(1989\)](#): *Plicatipollenites malabarensis*, *Alisporites* spp., *Lueckisporites* spp., *Pakhapites fusus*, *Protohaploxypinus* spp., and *Vittatina* spp. The presence of *Lueckisporites* allowed [Césari and Gutiérrez \(2001\)](#) to refer the Sta. Máxima Fm. to the LW Biozone.

3.3.6. La Puerta Formation

Permian palynomorphs from upper limestones of the La Puerta Formation (Cordillera Frontal) were described by [Ottone and Rossello \(1996\)](#). The sample allows the recognition of *Lueckisporites* sp., *Platysaccus trumpii*, *Vittatina* sp., *Lunatisporites* sp., and *Pakhapites* sp. as diagnostic species which suggest a Permian age. The few species recorded by [Ottone and Rossello \(1996\)](#) preclude a detailed comparison with the association under study. However, the presence of diagnostic taxa as *Lueckisporites* among others, allows us to confirm the presence of the LW Biozone in the La Puerta Formation.

3.3.7. Cordón de Jagüel Formation

[Perez Loinaze et al. \(2010b\)](#) reported the finding of Permian palynofloras in outcrops of the Uspallata area (Mendoza Province), which were later assigned to the Cordón de Jagüel Formation ([Limarino et al., 2013](#)). The palynoflora was recovered from deposits also bearing invertebrates referred to the *Costatumulus* Zone. Although poorly diversified, the assemblage contains *Lueckisporites virkkiae*, *Hamiapollenites indaraensis* and *Verrucosisporites insuetus*. According to [Perez Loinaze et al. \(2010b\)](#) the presence of *Lueckisporites virkkiae* allows correlation with the LW Biozone.

The species in common with the palynoflora of the Yacimiento los Reyunos Fm. are: *Alisporites australis*, *Scheuringipollenites* sp., *Lueckisporites virkkiae*, *Protohaploxypinus* spp., *Vittatina* spp.

4. Comparisons with South American biostratigraphic units

The Yacimiento Los Reyunos Formation assemblages are also compared with the palynostratigraphic schemes proposed for the upper Paleozoic of Western Gondwana. The main biostratigraphic proposals analyzed are those from the Chacoparaná Basin ([Russo et al., 1980](#); [Vergel, 1993](#)), Amazonas Basin ([Playford and Dino, 2000a, b](#)), Paraná Basin in Brazil ([Souza and Marques-Toigo, 2003, 2005](#); [Mori and Souza, 2010](#)), Claromecó Basin ([Balarino, 2014](#)), Bolivia ([di Pasquo et al., 2015](#)) and Paraná Basin in Uruguay ([Beri et al., 2011](#)), see locations on [Fig. 1](#).

4.1. Chacoparaná Basin

Russo et al. (1980) analyzed palynological samples from the Ordoñez and Victoriano Rodríguez formations in the Ordoñez well (Córdoba Province). These authors recognized three palynological biozones; the uppermost named Striatites and considered late Cisuralian-early Guadalupian in age. Systematic description of those assemblages was published by Archangelsky and Gamberro (1979) and later increased with the contributions of Vergel (1986, 1987) and Césari et al. (1995). Russo et al. (1980) and Vergel (1993) described a predominance of taeniate and plicate pollen in the Striatites Biozone of the Chacoparaná Basin. It is characterized by a high percentage of taeniate pollen (over 80%), including: *Marsupipollenites striatus*, *Lunatisporites variesectus*, *Striatoabieites* sp., *Staurosaccites cordubensis*, *Lueckisporites* cf. *L. virkkiae*, *Corisaccites* cf. *C. alutas*, *Lunatisporites* spp. and *Colpisaccites granulatus*, together *Scheuringipollenites ovatus*, *Striatodocarpites* sp., *Illinites* sp., *Protohaploxylinus micros*, *Vittatina saccata* and *Striomonosaccites crucistriatus*. Later, Césari et al. (1996) proposed a correlation of the assemblages from the Yacimiento los Reyunos Formation with the Striatites Biozone. Although Archangelsky and Vergel (1996, Table 1) reported the occurrence of *C. confluens* in assemblages of the Striatites Biozone, it has not been supported by detailed data in studies of the Chacoparaná Basin and securely is an involuntary error. This possible mistake was later considered as true by Playford and Dino (2002, Text-Fig. 8) and Stephenson (2009) when discussed the stratigraphic range of the species.

The assemblage here described shows similarities with Striatites Biozone by the abundance of taeniate pollen and low diversity of spores together with the common presence of: *Marsupipollenites striatus*, *Lunatisporites variesectus*, *Staurosaccites cordubensis*, *Lueckisporites virkkiae*, *Colpisaccites granulatus*, *Vittatina subsaccata* and *Striomonosaccitesciscatricosus*.

Playford and Dino (2002) revised three core samples from the Ordoñez well in the southern Chacoparaná Basin which were referred to the Striatites Biozone. However, *Lueckisporites* and *Weylandites* are absent in the palynofloras studied by Playford and Dino (2002).

4.2. Claromecó Basin

The Claromecó Basin is located in the southwest of the Buenos Aires Province. upper Paleozoic deposits are recognized in the Sierras de Pillahuincó and Tunas, and in the subsurface of the Argentinean plataform. The Pillahuincó Group includes the Sauce Grande, Piedra Azul, Bonete and Tunas formations in ascending stratigraphic order. The lower part of the Tunas Formation was deposited, during a transgressive event, in shallow marine, tidally influenced environments, whereas the upper section includes tuffs with interbedded sandstones, derived from the volcanic evidencing volcanic influence. These tuff levels have been dated by SHRIMP U/Pb in 282.4 ± 2.8 Ma by (Tohver et al., 2008) and 280.8 ± 1.9 Ma (López-Gamundí et al., 2013). Alessandretti et al. (2013) reported LA-ICP-MS mean age of 284 ± 15 Ma and Ramos et al. (2014) considered an interval between 280 and 288 Ma as representative of the crystallization age.

Balarino (2014) proposed two palynological biozones for the assemblages recovered from subsurface deposits of the Grupo Pillahuincó in the Argentinean Continental Plataform: *Converrucosporites confluens*-*Vittatina vittifera* (CV) Zone and *Tornopollenites toreutos*-*Reduviasporonites chalastus* (TC) Zone.

The lower *Converrucosporites confluens*-*Vittatina vittifera* (CV) Zone occurs in the Piedra Azul and Bonete formations of the UTAL. CMM1 La Estrella. x-1 and UTAL. CMM1 Cruz de Sur. x-1 boreholes. The *Tornopollenites toreutos*-*Reduviasporonites chalastus* (TC)

assemblage zone is identified in levels of the Tunas Formation in the UTAL. CMM1 La Estrella. x-1 borehole. The age proposed by Balarino (2014) for the Tunas Formation is Guadalupian–Lopingian that differs from the absolute dating that suggests a late Cisuralian age. The stratigraphic ranges of *Circulisporites parvus*, *Crustaesporites globosus*, *Laevigatosporites plicatus*, *Lundbladispota willmottii*, *Phidiasporites fosteri*, *Reduviasporonites chalastus*, *Striatopodocarpites gondwanensis* and *Tornopollenites toreutos* were considered to assign the age. However, some of these species occur in older assemblages.

The taxa *Scheuringipollenites ovatus*, *Hamiapollenites fusiformis*, *Protohaploxylinus bharadwajii*, *Vittatina corrugata*, *V. vittifera* have the first appearance at the boundary between the lower subzone and upper subzone of the CV Biozone proposed by Balarino (2014). The base of the TC biozone was defined by the first occurrence of *Tornopollenites toreutos*, *Weylandites magmus*, *Leiotriletes ulutus*, *Pseudoreticulatispora pseudoreticulata*, *Gondwanapollis frenguelli*, *Vallatisporites arcuatus*, *Laevigatosporites flexus*, *Leiosphaeridea crescentica* and *Portalites gondwanensis*. Balarino (2014) considered seventeen species exclusive of the TC assemblage, however some of them have extended stratigraphic range into older assemblages from Argentina like *Weylandites magmus*, *Gondwanapollis frenguelli*, *Potonieisporites brasiliensis*, *Leiotriletes corius*, *Vallatisporites arcuatus* and *Portalites gondwanensis*.

Considering the assumption of the present analysis, the first records (based on well cores) of *Lueckisporites* in the assemblages studied by Balarino (2014) occur at 3428 mbsl according to core samples, represented by two specimens (Balarino, 2009). In the same stratigraphic level of the Tunas Formation are recorded the first appearances of *Thymospora cricumensis*, *Vittatina costabilis*, *Hamiapollenites andiraensis*, *Striatoabieites anaverrucosus*, *Lunatisporites variesectus*, among other diagnostic species. Therefore, the boundary between the lower and upper CV biozone is considered at the 3428 mbsl for the goals of this study. Despite of some specimens of *Lueckisporites* illustrated by Balarino (2012) are doubtful, like *L. singrauliensis* which seems to have more than two taeniae, or the circumstance that the illustrated specimens selected by Balarino (2014, Fig. 6) come from reworked material in the Cretaceous (e.g. *Lueckisporites singhii* and *Lueckisporites virkkiae*), it is assumed their presence starting from that depth and with very scarce abundance in all the well.

These assemblages share the following taxa with the Yacimiento los Reyunos Formation: *Colpisaccites granulatus*, *Hamiapollenites fusiformis*, *Lueckisporites virkkiae*, *Lunatisporites variesectus*, *Marsupipollenites striatus*, *Pakhapites fusus*, *Protohaploxylinus amplus*, *P. limpidus*, *Scheuringipollenites medius*, *Staurosaccites cordubensis*, *Vittatina fasciolata*, *Vittatina subsaccata*, and *Weylandites lucifer*. Therefore, the Yacimiento Los Reyunos Formation palynoflora possesses similarities with the CV upper subzone and TC Biozone.

4.3. Paraná Basin (Brazil)

Two palynological biozones: *Vittatina costabilis* (Vc, Cisuralian) and *Lueckisporites virkkiae* zones (Lv, upper Cisuralian-Guadalupian) characterize the Permian of the Paraná Basin in Brazil. The Vc Biozone is recognized in palynofloras recovered from the Rio Bonito Formation and the Lv Biozone in those from the uppermost levels of Rio Bonito Formation or from the basal levels of Palermo Formation, including the Iratí Formation, reaching up the lowermost portion of the Rio do Rasto Formation. The limit between the LvZ and the VcZ is marked by the first appearance of certain species of bissacate and taeniate pollen grains and the age assigned to these biozones is Asselian to Artinskian and Artinskian to Wuchiapingian, respectively. Studies on absolute age datings and palynology are available from the Rio Bonito (Matos et al., 2001;

Guerra-Sommer et al., 2005, 2008a, b; Rocha-Campos et al., 2006, 2007; Mori et al., 2012; Cagliari et al., 2016) and Iratí Formations (Rocha-Campos et al., 2006, 2007; Santos et al., 2006). The information about the Rio Bonito is focused on the Candiota coal mine which comprises several tonstein levels. Several authors have been related these tonsteins to Choiyoi explosive eruptions of San Rafael Block (see Rocha-Campos et al., 2011). Recently, Cagliari et al. (2016) reported a new U–Pb age of 298.8 ± 1.9 Ma obtained from the lower interval of the Rio Bonito Formation which is equivalent to that obtained by Rocha-Campos et al. (2006) in a tonstein exposed in the Candiota coal seam (U–Pb ages of 303.6 ± 0.66 Ma, Gzelian). These results supported the assumption of that the Rio Bonito Formation comprises a long interval from the Asselian to Artinskian, taking into account that Guerra-Sommer et al. (2008a, b) obtained ages of 285.4 ± 8.6 Ma and 288.76 ± 1.4 Ma for the Faxinal coals, which contain palynofloras referred to the *Hamiapollenites karroensis* Subzone (upper part of the VcZ).

Santos et al. (2006) recognized in the same aged layer of the Iratí Formation (SHRIMP, 278.4 ± 2.2 Ma) a palynological assemblage including: *Lueckisporites virkkiae*, *L. densicarpus*, *L. stenotaeniatus*, *Vittatina vittifera*, *V. saccata*, *Weylandites lucifer*, *Alisporites splendens*, *Marsupipollenites striatus*, *Striatoabieites* spp. and *Striatopodocarpites* spp. The spores are very scarce, highlighting the presence of *Laevigatosporites vulgaris*.

The Lv Biozone was characterized by Souza and Marques-Toigo (2005) based on contributions of Dellazzana (1976), Menéndez (1976) and Picarelli et al. (1987). Recently, new contributions of Neregato et al. (2008), Mori and Souza (2010) for Brazilian units and Perez Loinaze et al. (2010a) from assemblages of the San Miguel Formation (Paraguay) increased the knowledge of those palynofloras. Earliest occurrences of *Lueckisporites*-like pollen in the Paraná Basin are related to the uppermost part of the Rio Bonito Formation (Mori et al., 2012), characterizing the basal limit of the eponymous biozone, and the last appearances of this species were recorded in the lowermost Rio do Rasto Formation (Neregato et al., 2008). Must be noted that palynofloras recognized by Mori and Souza (2010) at the C4 coal seam of Rio Bonito Formation, which contain rare (up to 2%) specimens of *Lueckisporites*, included also key species of the VC Biozone as *C. confluens*, which is characteristic of the Pennsylvanian–Cisuralian boundary (Stephenson, 2009). Although the LvZ was defined by first occurrences, these assemblages from the C4 can be considered transitional to the Lv Biozone, originally defined from palynofloras of the Iratí Formation.

The Yacimiento los Reyunos Formation assemblage possesses similarities with Lv Zone, by the following taxa: *Lueckisporites virkkiae*, *Lunatisporites variesectus*, *Weylandites lucifer*, *Limitisporites rectus*, *Striatoabieites multistriatus*, *Striomonosaccites ovatus*, *Pakhapites fusus*, *Hamiapollenites fusiformis* and several species of *Vittatina* and *Protohaploxylinus* genera.

4.4. Paraná Basin (Uruguay)

The Permian of the southernmost part of the Paraná Basin in Uruguay is represented by two palynological biozones: 1) *Cristatisporites inconstans*–*Vittatina saccata* (IS) defined by the predominance of trilete spores and bisaccate pollen (early Cisuralian), and 2) *Striatoabieites anaverrucosus*–*Staurosaccites cordubensis* (AC) with abundant taeniate and plicate pollen (late Cisuralian–early Guadalupian) (Beri et al., 2011). The AC Biozone is identified in the Melo Formation (Fig. 1).

The limit between these zones is recognized by the first appearances of *Lueckisporites brasiliensis*, *L. crassus*, *L. nyakapendensis*, *L. singrauliensis*, and *Lueckisporites stenotaeniatus*, *Striatoabieites anaverrucosus*, *Staurosaccites cordubensis*, *Staurosaccites quadrididus*, *Lunatisporites paliensis*, *Protohaploxylinus samoilovichii*,

Striatopodocarpites gondwanensis, *Corisaccites alutas*, *Alisporites parvus* and *Platysaccus leschikii*.

The assemblages from the Yacimiento los Reyunos Formation present several taxa that allow a correlation with the AC assemblage of Paraná Basin: *Colpisaccites granulatus*, *Lueckisporites virkkiae*, *Lunatisporites variesectus*, *Staurosaccites cordubensis*, *Striatoabieites anaverrucosus* and *Vittatina* spp., with the dominance of taeniate and bisaccate pollen grain.

4.5. Amazonas Basin

Playford and Dino (2000a, b) proposed a palynological zonation for the Tapajós Group, Amazonas Basin (Brazil) where the younger units are the *Vittatina costabilis* Zone and *Tornopollenites toreutos* Zone. These zonal subdivisions are distinguished by the predominance of taeniate pollen including *Lueckisporites* specimens in the upper part of the Vc Biozone and the Tt zone. The base of the Tt biozone is marked by the occurrence of *Tornopollenites toreutos*, *Thymospora obscura*, *Verrucosisporites insuetus* and *Laevigatosporites minor*. For the purposes of this contribution we will take the appearance of *Lueckisporites* as a biostratigraphic event for comparison with other assemblages.

The assemblages from the Yacimiento Los Reyunos Formation present several taxa that allow a correlation with the Vc/Tt assemblage of Amazonas basin: *Hamiapollenites fusiformis*, *Pakhapites fusus*, *Lueckisporites virkkiae*, *Vittatina* spp., and a dominance of taeniate and bisaccate pollen grains.

4.6. Cochabamba Sub-Basin (Bolivia)

Sempere et al. (1992) described a palynological assemblage from the Vitiacua Formation in southern Bolivia containing *Lueckisporites virkkiae*, *Lunatisporites noviaulensis*, *Vitreisporites pallidus*, *Corisaccites alutas*, *Weylandites* sp. cf. *W. magmus*, *Alisporites parvus*, *Lunatisporites taeniaeformis*, *Protohaploxylinus enigmaticus* and *Protohaploxylinus varius*. Later, Sempere et al. (2002) reported two samples from the Vitiacua Formation in the Eastern Cordillera, characterized by the presence of *Lueckisporites virkkiae*, *Tornopollenites toreutos*, *Corisaccites alutas*, *Weylandites lucifer* (= *Paravittatina cincinnata*). The marine deposits of the Vitiacua Formation have been considered coeval to the Brazilian Iratí Formation and Whitehill Formation of South Africa (Sempere et al., 1992). Di Pasquo and Grader (2012b) revised new samples from the lower part of the Vitiacua Formation at Apillapampa and proposed a possible correlation with the Lv assemblage based on their common miospore species (e.g. *Lueckisporites virkkiae*, *Polypodiisporites mutabilis* and *Reticuloidosporites warchianus*). All these assemblages from the Vitiacua Formation are similar to the analyzed here from the Yacimiento Los Reyunos Formation.

Recently, di Pasquo et al. (2015) presented revised palynological and radiometric data from the Copacabana Formation in central Bolivia, originally described by di Pasquo and Grader (2012a). These authors defined a *Lueckisporites virkkiae* assemblage recovered from marine and coal-bearing transitional deposits of the upper part of the Copacabana Formation. According to di Pasquo et al. (2015) the stratigraphic distribution of the species supports the subdivision of the Lv assemblage in the Lv *sensu stricto* and the Lv-Hk-Pm assemblages. These authors proposed a correlation based on the first occurrence of *Lueckisporites virkkiae* and considered the Bolivian biozone equivalent to the LW and Striatites biozones from Argentina, the Lv Biozone from Brazil and AC Biozone from Uruguay. This comparison also highlights the exclusive presence of *Vittatina costabilis*, *Hamiapollenites karroensis*, *Lueckisporites brasiliensis*, *Convolutispora uruguaiensis* and *C. ordonezii*, but some of these species are also recognized in older assemblages of the

region.

U–Pb radiometric ages (ID-TIMS) of zircon-bearing interbedded tuffs suggest that the lower member of the Copacabana Formation is Asselian and Sakmarian (Henderson et al., 2009). The uppermost dated ash at 242 m is late Sakmarian (291.6 ± 0.9 Ma; James Crowley, in di Pasquo et al., 2015) and occurs near the base of the Coal Member. Therefore, di Pasquo et al. (2015) proposed that the appearance of *Lueckisporites virkkiae* at Apillapampa is the oldest record of the species in the region.

The association of Yacimiento los Reyunos presents the following species in common with Lv Biozone in Bolivia: *Calamospora* spp., *Plicatipollenites malabarensis*, *Scheuringipollenites medius*, *Hamiapollenites fusiformis*, *Lueckisporites latisaccus*, *L. virkkiae*, *Lunatisporites variesectus*, *Marsupipollenites striatus*, *Pakhapites fusus*, *Protohaploxylinus amplus*, *Staurosaccites cordubensis*, *Striatoabieites multistriatus*, *Striatoabieites anaverrucosus*, *Vittatina subsaccata*, *Weylandites lucifer* and *W. magmus*. The presence and diversity of the genera *Lueckisporites*, *Weylandites* and *Marsupipollenites* in both associations allow us to correlate them.

5. Statistical analysis

With the objective to identify similarities between different palynological assemblages were selected a total of 133 (see Appendix, Table 2) species including those characteristics of each biozone or associations described for the basins of Argentina, Bolivia, Brazil, Paraguay and Uruguay. The data set consists of species which range from local endemics to those found in as many as 11 of the 15 assemblages analyzed.

In the case of Argentina, the palynoflora described for the La Puerta Formation (Ottone and Rossello, 1996) have not been included because of the small number of diagnostic species identified. However, it is accepted that they belong to the Biozone LW. The data about palynofloras from the La Veteada Formation, in its type locality in the province of La Rioja, should be taken with caution because of total specimens have been only described the monosaccate, bisaccate taeniate and colpate pollen grains. Moreover, Gutiérrez et al. (2014) considered that these palynofloras are younger than the LW biozone.

The diagnostic species with the largest distribution between units and basins compared are: *Alisporites australis*, *Brevitriletes cornutus*, *Convolutispora archangelskyi*, *Corisaccites alutas*, *Hamiapollenites fusiformis*, *Horriditriletes ramosus*, *Lueckisporites angoulaensis*, *L. nyakapandensis*, *L. singhii*, *L. stenotaeniatius*, *L. virkkiae*, *Lunatisporites variesectus*, *Mabuisaccites crucistriatus*, *Marsupipollenites striatus*, *Pakhapites fusus*, *P. ovatus*, *Protohaploxylinus bharadwajii*, *P. goraiensis*, *P. limpidus*, *P. microcorpus*, *P. samoilovichii*, *Scheuringipollenites medius*, *S. ovatus*, *Staurosaccites cordubensis*, *Striomonosaccites cicatricosus*, *Striatopodocarpites cancellatus*, *S. fusus*, *S. gondwanensis*, *S. pharellatus*, *S. solitus*, *Striatoabieites anaverrucosus*, *Vittatina corrugata*, *V. costabilis*, *V. fasciolata*, *V. subsaccata*, *V. vittifera*, *Weylandites lucifer* and *W. magmus*. These species occur in five or more of the fifteen associations compared (Appendix, Table 1).

A second group of species is recorded in only four or three associations and is composed of: *Anapiculatisporites tereteangulatus*, *Convolutispora candiotensis*, *Falcisporites nuthallensis*, *Hamiapollenites andiraensis*, *H. karroensis*, *Latusipollenites quadrisaccus*, *Lueckisporites balmei*, *Polarisaccites bilateralis*, *Retusotriletes diversiformis*, *Scheuringipollenites circularis*, *S. maximus*, *Striomonosaccites ovatus* and *Vittatina saccata* among others (Appendix, Table 1).

Some species display a constrained distribution that suggests possible biostratigraphic significance. This is the case of *Tornopollenites toreutos* which characterizes the eponymous biozone in the Amazonas Basin and is also recognized in the eastern Paraná

Basin in Paraguay, and the De la Cuesta Formation (Paganzo Basin). However, must be considered that the worldwide stratigraphic range of this species spans all the Permian.

Bisaccate pollen referred to *Minutosaccus*, a taxon characteristic of the Triassic, has been described or mentioned in palynofloras from La Deheza, De la Cuesta and southern Paraná Basin (Uruguay). The poor preservation of the few specimens recovered from the La Deheza (3) and De la Cuesta (2) give some doubts about their assignment.

Some species possess only one record like *Verrucosisporites andersonii* (not described and possibly coespecific with *V. menendezii* according to illustrations), and *Vittatina minima* (one specimen) described in Permian assemblages from Catamarca Province (Gutiérrez et al., 2011) were not included in the comparisons. As well as, *Alisporites opii* with an exclusive record in the Andapaico Formation was not described by Balarino et al. (2012) and not considered in the original contribution of the same authors (Correa et al., 2012).

Assemblages from the Claromecó Basin contain one of the highest numbers of exclusive records, including: *Baculatisporites bharadwajii*, *Converrucosisporites pustulatus*, *Didecitriletes uncinatus*, *D. ericianus*, *Horriditriletes filiformis*, *Accentisporites excentricus*, *Triadispora epigona*, *Tiwarisporis simplex*, *Platysaccus crassimarginatus*, *Protohaploxylinus diagonalis*, and *Laevigatosporites plicatus*. Some of these biostratigraphic diagnostic species were not described by Balarino (2012, 2014) but a revision of the few specimens (7) assigned by Balarino (2009) to *D. ericianus* provide doubts, because their sculpture is mainly of baculae with subordinate spines, up to 2 μm high. Balme and Hennelly (1956), Foster (1979) and Backhouse (1991) described *D. ericianus* with ornamentation exclusively composed by acuminate processes of bulbous bases and usually 5 μm long or more, which reduce on the proximal surface to some conical and granular. In the same way, *D. uncinatus* represented by only one specimen with spines up to 1 μm high, differ of the Australian specimens usually with longer sculpture but it is maintained in the present comparisons. Although *Triadispora epigona* is considered a Triassic species, Foster (1979) referred with doubts to this taxon specimens from the Permian that are similar to those from the Claromecó Basin.

La Veteada Formation also contains some exclusive species like *Goubinispora morondavensis*, monosaccate taeniate pollen characterized by the saccus usually tri- or five-divided (Tiwari and Rana, 1980). The specimens figured by Gutiérrez et al. (2014) are devoid of the characteristic lobation of the outer margin of the saccus and seem to be a variation of those *Striomonosaccites* specimens illustrated by the authors. Therefore, the species is not considered in the present analysis until its presence can be confirmed. The presence of *Striasulcites* in the La Veteada Fm. is not considered because this genus is junior synonym of *Pakhapites* (Playford and Dino, 2000b). In the same way *Lahirites* is considered synonym of *Striatopodocarpites* which has priority (Stephenson, 2015a). Specimens referred to *Striatopodocarpites* cf. *S. rotundus* by Gutiérrez et al. (2014) are smaller than the original, which on the other side was compared with *Protohaploxylinus goraiensis* by Maheshwari (1967). The specimens illustrated as *Striatopodocarpites* cf. *S. renisaccatus* are smaller than the original of the species that moreover differ in its strong diploxylonoid outline. *Weylandites circularis* was considered synonym of *W. lucifer* by Foster (1979), this concept is followed here and the specimens from La Veteada are included in *W. lucifer*. Gutiérrez et al. (2014) illustrated *Hamiapollenites* cf. *H. insolitus* which differs from the original specimens and *Lunatisporites arluki* Utting is very similar to *L. noviaulensis* according to Utting (1994) and it is considered here synonym. The most distinctive feature of *Lahirites segmentatus* Dino and Playford is the division of the taenia by perpendicular striae is

also recognized in the specimens assigned to *Striatoabieites rugosus* (Jansonius) Zavattieri and L. cf. *L. raniganjensis* Bharadwaj by Gutiérrez et al. (2014). Probably the specimens referred to the three species by Gutiérrez et al. (2014), could be variations of the same taxon, but neither description nor discussion of them is available.

Species of the AC Biozone from Uruguay were selected from Appendix C of Beri et al. (2011). The total number of pollen and spores species present in each stratigraphic or biostratigraphic unit is shown in Table 1. Some assemblages have small size with less than 15 taxa, therefore with a higher chance of error in the results. Moreover, it is known that assemblages sharing rare species appear as more similar (lower probability of finding rare species together), than communities sharing the same number of common species.

Cluster analysis was performed using the PAST software Package 3.1 (Hammer et al., 2001) and the Raup-Crick coefficient, which is calculated using a “Monte-Carlo” randomization procedure to determine how often a comparable level of similarity occurs in 200 randomly, replicated samples of the same size. This method provides information on the degree to which pairwise communities are more different (or more similar) than expected by chance.

We preferred the Raup-Crick index (Raup and Crick, 1979) over the Jaccard's distance because the last measure is confounded by the level of diversity of the samples, producing distorted values of dissimilarity when some samples are poorer in species than other (Vellend et al., 2007). Raup-Crick index is the probability that compared sampling units have non-identical species composition. Data in the matrix are scored as 0 (absence, scored as no similarity) and 1 (presence, scored as equality).

Because the goal of the analysis is biostratigraphic, the following taxa were not included in the data set: 1) those species also recorded in the Pennsylvanian or without biostratigraphic significance and 2) those species constrained to particular environmental conditions like algae. In addition, a comprehensive review of the literature was realized to consider the synonyms and doubtful assignments.

Firstly, the relationship of the regional biozones was analyzed. The similarity between the biozones proposed for the region is shown in Fig. 6. A dissimilarity exists between the AC Biozone from Paraná Basin (Uruguay) and the cluster linking the units. The Striatites Biozone (Chacoparaná Basin) and the tight pair Lv Biozone from Brazil and the Vc/Tt Biozone constitute a distinctive cluster with the Lv Bolivia. The CV upper/TC Biozones from Claromecó Basin join those groups but present a higher dissimilarity with their components. Results show a tight similarity between the CVupper Subzone and the TC Subzone from the Claromecó Basin.

When the Yacimiento los Reyunos assemblages are introduced in the data set, a close similarity with the Striatites biozone is shown (as was originally proposed by Césari et al., 1996) and with the cluster formed by the rest of the assemblages except the AC Biozone (Fig. 7).

Palynofloras from Yacimiento Los Reyunos Formation were also

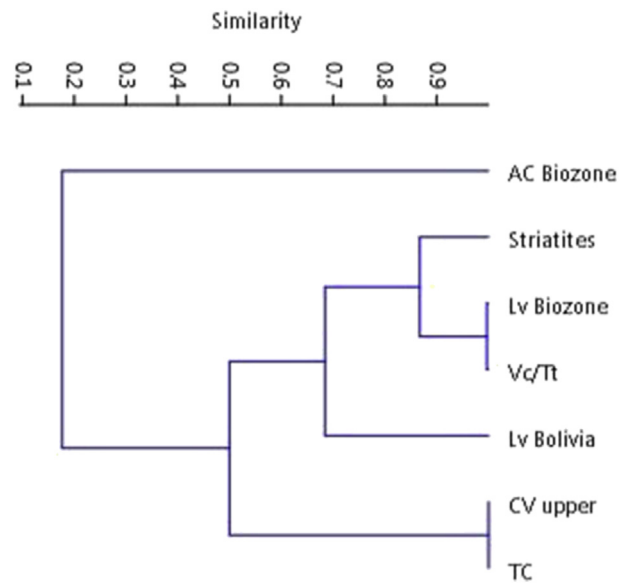


Fig. 6. Cluster analysis of the South American biozones. *Striatoabieites anaverrucosus-Staurosaccites cordubensis* Biozone from Uruguay (AC); *Striatites* Biozone from Chacoparaná Basin; *Lueckisporites virkkiae* Biozone from Paraná Basin (Lv); *Vittatina costabilis/Tornipollenites toreutos* Biozones from Amazonas Basin (Vc/Tt); *Lueckisporites virkkiae* Zone from Cochabamba Sub-Basin (Lv Bolivia); *Converrucosporites confluens-Vittatina vittifera* (CV) upper Subzone (CV upper) and *Tornipollenites toreutos-Reduviasporonites chalastus* (TC) Biozone from Claromecó Basin.

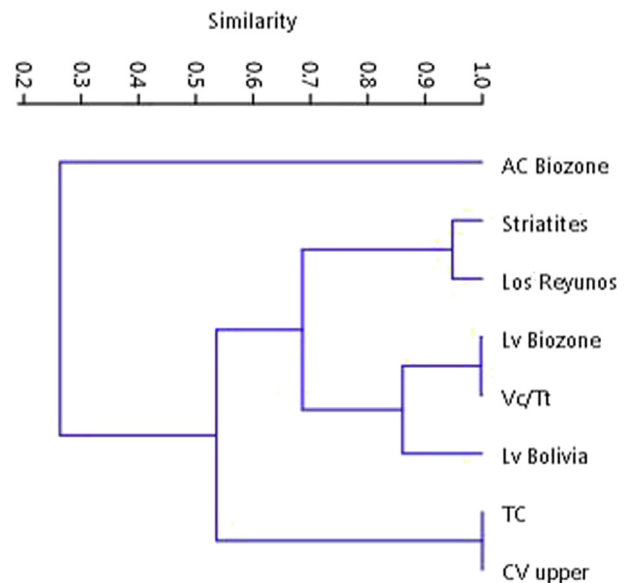


Fig. 7. Cluster analysis of the Los Reyunos palynofloras and the biozones.

Table 1
Amount of species of each stratigraphic or biostratigraphic unit included in the analysis.

Stratigraphic unit	Stratigraphic unit	Stratigraphic unit	Stratigraphic unit
Yacimiento Los Reyunos	30	Sta. Máxima Fm.	8
Río Francia Fm.	17	CV/TC Biozones	48/44
La Deheza Fm.	37	Striatites Biozones	34
Andapaico Fm.	56	AC Biozone	70
Sa. Narváez	46	Lv Biozone	65
La Veteada Fm.	51	Vc/Tt Biozones	14
C. del Jaguel Fm.	15	Lv Biozone (Bolivia)	38

compared with assemblages from different stratigraphic units of central-western Argentina (Fig. 8). The results show two dissimilar groups. A cluster is formed by Los Reyunos and La Veteada Formations. This joins in a distinctive cluster with the one of Santa Máxima Fm., and with the pair Río Francia Fm./Sa. Narváez. The other cluster is formed by the pair La Deheza/Cordón del Jagüel joined to the Andapaico Formation. It should be noted that this last cluster includes assemblages from the Andapaico Formation containing *Converrucosporites confluens* that were referred to the basal part of the LW Biozone (Balarino et al., 2012). Assemblages from La Deheza Formation are represented by few poorly preserved

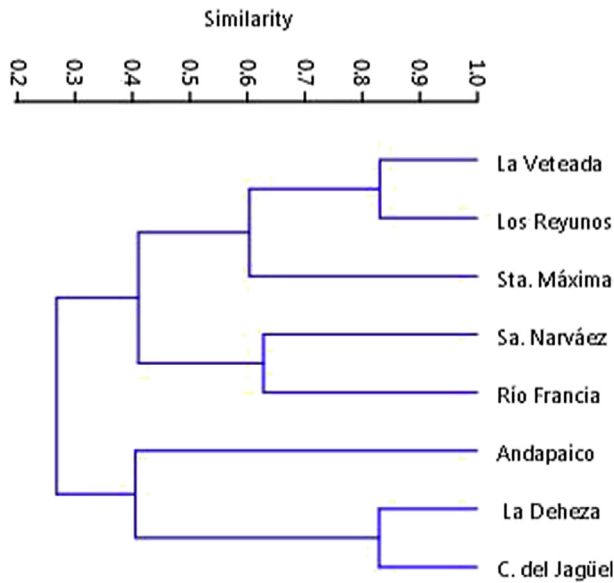


Fig. 8. Cluster analysis of the assemblages from the analyzed stratigraphic units.

samples containing only two species of *Lueckisporites*, which were also compared with the *Pakhapites fusus/Vittatina subsaccata* Biozone (Balarino et al., 2015). Finally, the assemblages from the Cordón del Jagüel Fm. are represented by a few species. The analysis shows also that palynofloras from Sa. de Narváez not seem closely similar to those from the La Veteada Fm. in its type locality of La Rioja province.

With the goal of corroborate if all these assemblages from central western Argentina are closely comparable with the biozones of the region as it was supposed (Balarino et al., 2012; Césari et al., 1996; Gutiérrez et al., 2011, 2014; Ottone, 1989; Perez Loinaze et al., 2010a) additional analysis was performed. These results show palynofloras from La Veteada Formation have low similarity with the biozones (Fig. 9). Gutiérrez et al. (2014) have proposed an informal independent biostratigraphic unit for the La Veteada but similar (based on the high number of shared species) to the LV Biozone, Vc/Lv from Brazil and IS/AC biozones from Uruguay.

Palynofloras from the Santa Máxima Formation, Cordón del Jagüel and Sierra de Narváez have similarity with Striatites and the pair Lv Brazil and the Vc/Tt of the Amazonas Basin. All form a cluster with the Lv from Bolivia (see Appendix). Assemblages from Río Francia Fm. form a cluster with the AC Biozone, and Andapaico and La Deheza show low similarity with the biozones (see Appendix).

6. Stratigraphic correlation

According to Limarino et al. (2014) the latest Carboniferous and early Permian of the Paganzo Basin was characterized by widespread red-bed successions (usually known as Patquía Formation) comprising fluvial sandstones and conglomerates in the Lower Member, and ephemeral river, playa lake and eolian deposits in the Upper Member. Gulbranson et al. (2010) reported an Asselian age (ID-TIMS 296.09 ± 0.08 Ma) for an ash level intercalated within eolian sandstones of the Lower Member. The thick eolian deposits found in the Upper Member of the Patquía Fm. were included in the Postglacial Stage proposed by Limarino et al. (2014) for South American basins, which comprises upper part of the Río Bonito Formation, Serrinha and Iratí Formations in Brazil and middle-upper part of the Melo Formation in Uruguay.

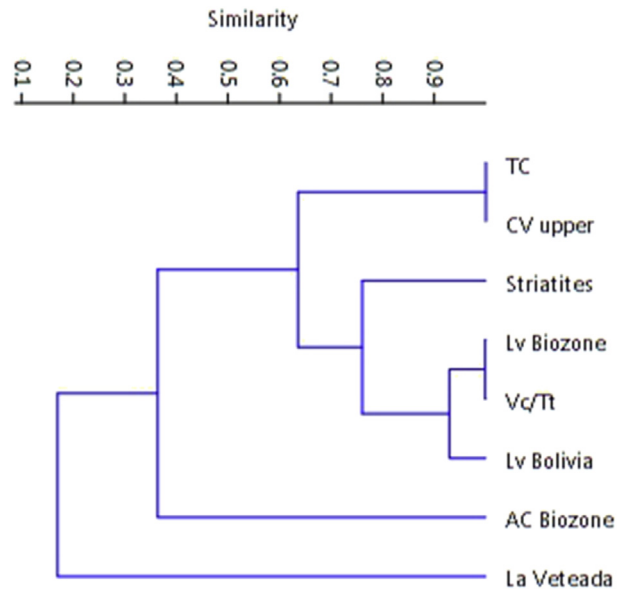


Fig. 9. Cluster analysis of the assemblages from La Veteada Formation and the biozones.

Palynological assemblages analyzed here from the Río Francia, Andapaico, De la Cuesta, La Deheza and Los Reyunos Formations were recovered from stratigraphic sections overlying or closely related to eolian deposits correlated with the Patquía Formation. Therefore, stratigraphy also supports a post-Asselian/Wordian age for the palynofloras.

The Talampaya Formation unconformably overlies these rocks. Zircons from a tuff in the upper part of the Talampaya Formation provided an ID-TIMS U/Pb age of $252.38 \pm 0.09/-0.22$ Ma, which indicates that this unit was deposited during the latest middle and late Permian and very probably reached the Permian-Triassic boundary (Gulbranson et al., 2015). The Talampaya Formation may be included in the arid or semiarid stage (Guadalupian–Lopingian in age) proposed by Limarino et al. (2014) throughout the major part of southern South America.

7. Absolute ages

Many radiometric datings were made on tuffs from the San Rafael Block (Polanski, 1966; Toubes and Spikermann, 1976; Linares et al., 1979; Melchor, 2000; Rocha-Campos et al., 2011). Linares et al. (1979) analyzed several volcanic rocks from the Choiyoi event, obtaining a range between 276 Ma (middle Permian) to 234 Ma (Upper Triassic), with errors from ± 3 to ± 13 Ma, using K/Ar method. Melchor (2000) reported an age of 266 ± 1 Ma (middle Guadalupian) for the beginning of the sedimentation based on $^{40}\text{Ar}/^{39}\text{Ar}$ dating for the Toba Vieja Gorda Member at the base of the Yacimiento Los Reyunos Formation. Later, the same Toba Vieja Gorda Member of the Yacimiento los Reyunos Formation was dated by Rocha-Campos et al. (2011) in 281.4 ± 2.5 Ma (upper Cisuralian) using SHRIMP U–Pb zircon analyzes. New ages of approximately 264 Ma for the overlying Agua de los Burros and Quebrada del Pimiento Formations (Rocha-Campos et al., 2011) allow to discard the $^{40}\text{Ar}/^{39}\text{Ar}$ dating for the Yacimiento Los Reyunos Formation reported by Melchor (2000).

The rocks dated by Rocha-Campos et al. (2011) come from the Pseftic Member, basal section of the Yacimiento Los Reyunos Formation, whereas the palynological samples were recovered from the upper section of the Pseftic Member in subsurface deposits.

The thickness of the stratigraphic interval between the palynofloras and the dated rocks is somewhat imprecise (ca. 140 m); however the dating of 264 Ma reported by Rocha-Campos et al. (2011) for the Agua de los Burros Formation allow proposing a Kungurian-Wordian age for the palynological assemblages.

The U/Pb dating from the Yacimiento Los Reyunos Fm. results similar to the obtained for the Irati Formation (Brazil) of 278.4 ± 2.2 Ma, which contain equivalent palynofloras of the Lv Biozone.

The presence of *Lueckisporites virkkiae*, which is considered to appear first in the Russian Platform in the Wordian (Utting et al., 1997), also contributes to constrain the age of the biostratigraphic unit. However, the oldest record of *Lueckisporites*-like pollen in South America was reported by Mori et al. (2012) from outcrops of the uppermost part of the Río Bonito Formation dated in 281.4 ± 3.4 Ma. This last age was recently discussed by (Griffis et al., 2015; Cagliari et al., 2016) and the Brazilian Candiota coals seem to be constrained to the early Cisuralian. Therefore, the incoming of *Lueckisporites*-like pollen in western Gondwana may be early Cisuralian.

Recently, Asselian records of *Lueckisporites* were also described by di Pasquo et al. (2015) from the Copacabana Formation (Bolivia). Five U–Pb radiometric ages (ID-TIMS of zircon-bearing interbedded tuffs) reported by Henderson et al. (2009) suggest that the lower member of the Copacabana Formation is Asselian and Sakmarian. Henderson et al. (2009) determined at the Apillapampa section a mid-Asselian age at 120 m above the base, early Sakmarian ages at 154 m and 185 m, and a mid-Late Sakmarian age at 242 m. The presence of conodonts throughout the section allow to Henderson et al. (2009) to propose that the *Sweetognathus* lineage evolved first in Bolivia. *Lueckisporites virkkiae* occurs at 69 m above the base of the Copacabana Formation according to di Pasquo et al. (2015). However, Chernykh (in Henderson et al., 2009) questioned the Asselian age of the conodont complex considering that some forms are reworked and proposed an Artinskian or late Sakmarian age for the assemblage. Moreover, she suggested that isotopic data could be wrong. Chernykh and Chuvashov (2014) reaffirm that point of view about the age of the conodont association. Currently neither

the description of conodonts nor Copacabana's ages have been duly published. Therefore, until the value of the datings and conodonts of the Copacabana Formation is confirmed, the Asselian record *Lueckisporites* is considered debatable. It is remarkable that if the biostratigraphic correlation of the Copacabana Fm. is based on the first occurrence of *Lueckisporites*, a post-Artinskian age results consistent (see di Pasquo et al., 2015, Fig. 10).

Datings from the Paraná Basin in Uruguay are scarce and comprise two samples collected from ash fall deposits of the Mangrullo Member (Melo Formation) which contains assemblages of the AC Biozone. U–Pb SHRIMP ages of 269.8 ± 4.7 Ma and 275.9 ± 4.8 Ma were reported by Rocha-Campos et al. (2006) for that unit. Santos et al. (2006) obtained an age of 278.4 ± 2.2 Ma for the Irati Formation in Brazil and Rocha-Campos et al. (2006) and age of 275.1 ± 5.4 Ma for the Rio do Rastro Formation in the Paraná Basin of Brazil.

Fig. 10 illustrates the correlations between stratigraphic and biostratigraphic units from Argentina, Brazil and Uruguay taking into account the available U/Pb datings.

8. Conclusions

The new sampling of the productive interval of the Yacimiento Los Reyunos Formation allows an update of the palynological content and correlations with coeval assemblages. Palynological assemblages are characterized by the predominance of taeniate pollen and scarce spores. Diverse specimens assigned to *Lueckisporites* and closely related fossil genera promoted their inclusion in the *Lueckisporites* complex. *Crucisaccites variosulcatus*, which in association with *Lueckisporites* is considered characteristic of the Roadian-Wordian in Western Europe, is identified for the first time in westernmost Gondwana. The presence or absence of diagnostic species from different Argentinian stratigraphic units and southern South American biozones were used as data for cluster analyses. We have carried out unweighted pair-group clustering using arithmetic averaging (UPGMA) and Raup-Crick coefficient. Palynofloras from Yacimiento Los Reyunos Formation are closely related

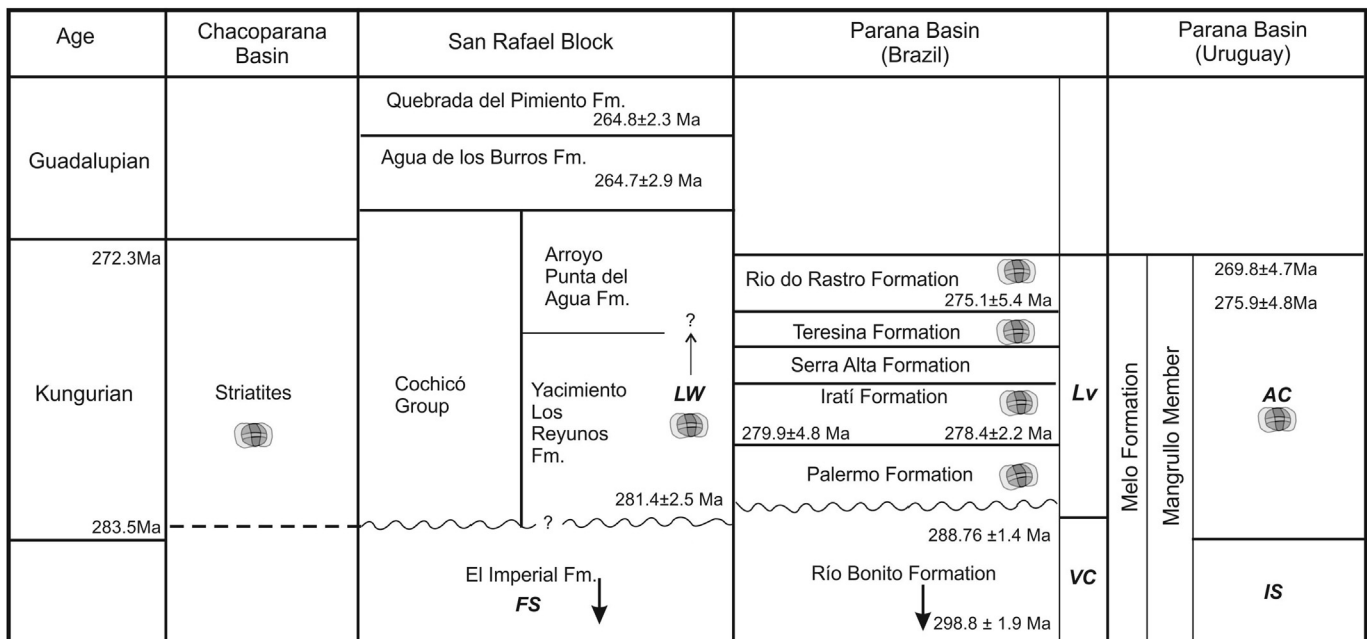


Fig. 10. Chart correlating the stratigraphic and biostratigraphic units from Argentina, Brazil and Uruguay and some available absolute ages. Pollen symbol represents the *Lueckisporites* complex.

to the Striatites (Chacoparaná Basin), *Lueckisporites virkkiae* Biozone (Paraná Basin), *Vittatina costabilis/Tornopollenites toreutos* (Amazonas Basin) and *Lueckisporites virkkiae* (Bolivia) biozones. The most shared species among the assemblages from southern South America containing *Lueckisporites* are: *Alisporites australis*, *Brevitriletes cornutus*, *Convolutispora archangelskyi*, *Corisaccites alutas*, *Hamiapollenites fusiformis*, *Horriditriletes ramosus*, *Lueckisporites agoulaensis*, *L. nyakapandensis*, *L. singhii*, *L. stenotaeniatus*, *L. virkkiae*, *Lunatisporites variesectus*, *Mabuisaccites crucistriatus*, *Marsupipollenites striatus*, *Pakhapites fusus*, *P. ovatus*, *Protohaploxylinus bharadwajii*, *P. goraiensis*, *P. limpidus*, *P. microcorpus*, *P. samoilovichii*, *Scheuringipollenites medius*, *S. ovatus*, *Staurosaccites cordubensis*, *S. cicatricosus*, *Striatopodocarpites cancellatus*, *S. fusus*, *S. gondwanensis*, *S. pharellatus*, *S. solitus*, *Striatoabieites anaverrucosus*, *Vittatina corrugata*, *V. costabilis*, *V. fasciolata*, *V. subsaccata*, *V. vittifera*, *Weylandites lucifer* and *W. magmus*.

According to the current International Chronostratigraphic Chart 2016, radiometric datings from Argentina and Brazil suggest an early Kungurian maximum age for the first South American palynofloras characterized by the *Lueckisporites* complex and related species. If the oldest records of *Lueckisporites*-bearing assemblages are confirmed with accurate data, they would constitute transitional associations, characterized by a larger participation of earliest Cisuralian species.

New studies of stratigraphically well constrained palynological assemblages will allow the refining of the biostratigraphic scheme.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jsames.2017.02.009>.

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