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The Carboniferous-Permian boundary in the central western Argentinean basins: paleontological evidences

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ABSTRACT. The central western Argentinean basins of Río Blanco, Calingasta-Uspallata and western Paganzo, enclose the most complete marine successions used for examining the Carboniferous-Permian boundary in Gondwana. A detailed review of the key stratigraphical sections has allowed the identification of the latest Carboniferous assemblages; NBG, Interval megafloristic Zone and DM (*Raistrickia densa-Convolutispora muriornata*) Palynological Zone in the lower part, and the earliest Permian T-S (*Tivertonia jachalensis-Streptorhynchus inaequiornatus*) invertebrate Zone and FS (*Pakhapites fusus-Vittatina subsaccata*) Palynological Zone in the upper part. This diagnostic mega/microflora and marine invertebrate paleontological evidence provides a biostratigraphical framework for the definition of the Carboniferous-Permian boundary inside the basins of central western Argentina.

Keywords: Late Carboniferous, Early Permian, Biostratigraphy, Gondwana, Argentina.

RESUMEN. El límite Carbonífero-Pérmico en las cuencas del centro oeste de Argentina: evidencias paleontológicas. Las cuencas del centro oeste de Argentina, Río Blanco, Calingasta-Uspallata y el sector oeste de la cuenca Paganzo, contienen las secuencias marinas más completas para el estudio del límite Carbonífero-Pérmico en Gondwana. Un estudio detallado de secciones estratigráficas claves ha permitido la identificación de las asociaciones megaflorísticas NBG y de Intervalo, y de la palinozona DM (*Raistrickia densa-Convolutispora muriornata*), del Carbonífero Tardío, en la parte inferior de dichas secciones; en tanto, en la parte media superior de las secciones estudiadas, se han identificado la biozona de invertebrados T-S (*Tivertonia jachalensis-Streptorhynchus inaequiornatus*) y la palinozona FS (*Pakhapites fusus-Vittatina subsaccata*), ambas asignadas al Pérmico Temprano. El registro de estas asociaciones diagnósticas de mega/microflora e invertebrados marinos provee un esquema bioestratigráfico integrado que permite ubicar el límite Carbonífero-Pérmico en las cuencas del centro oeste de Argentina.

Palabras clave: Carbonífero Tardío, Pérmico Temprano, Bioestratigrafía, Gondwana, Argentina.

1. Introduction

The Carboniferous-Permian (Gzhelian-Asselian) boundary has been biostratigraphically defined in stratotype sections in the latest Carboniferous and earliest Permian marine sequences from the Uralian Region (Russia and Kazakhstan), by key conodonts and fusulinid foraminiferid species. The beginning of the Asselian stage is indicated by the first appearances of the conodont *Streptognathodus isolatus*, the fusulinid *Sphaeroschwagerina aktjubensis* (=*vulgaris*) and the distinctive ammonoid species of the genera *Boesites, Daixites, Glaphyrites, Artinskia, Svetlanoceras, Prostacheoceras* and *Prothalassoceras* (Bogoslovkaya *et al*., 1995; Davydov *et al*., 1997; Mei *et al*., 1999; Lucas *et al*., 2001). However in Gondwana and the peripheral gondwanan regions, these faunal groups, considered the principal tools for correlation, are absent or more often, extremely rare. The marine faunas and terrestrial microflora data from the early Permian (Asselian-Early Artinskian) interval of these regions (Australia, Afghanistan-Pakistan, Himalaya, China, Southeast Asia, India, Africa, Arabia, Antarctica and South America), has been compiled by Archbold (2001). This author has also suggested the importance of using palynological data to link the marine successions in the definition of the Carboniferous-Permian boundary. Recently early Permian faunal and palynological records from eastern Australia and the Argentine Precordillera have been discussed by Archbold *et al*. (2004). The authors concluded that integrating the studies of marine faunas with the palynological record is required to both date the record and to strengthen Gondwanan wide correlations.

The central western Argentinean basins (Fig. 1A) examined here, appear to enclose one of the more complete successions for the study of the Carboniferous-Permian boundary in this part of Gondwana. Because more precise biostratigraphical elements, such as conodonts and fusulinids that would define the boundary in the type section of the Uralian region are absent, this paper attempts to match the marine faunal data (primarily brachiopods, the most biostratigraphically important group available and the conspicuous bivalve fauna), with the extensive megafloristic and palynological records in different key sections inside the Argentine Precordillera. A biostratigraphic local scheme of the Carboniferous-Permian boundary, based in the integrated study of these fossil groups, and the possible correlation with other Gondwan localies, is provided herein.

2. The Carboniferous-Permian boundary in the marine successions of the Argentine Precordillera

The latest Carboniferous-earliest Permian interval in the Argentine Precordillera is associated with a Paleo-Pacific transgressive event that represents the transition from a glacial to postglacial condition, with the posterior climatic amelioration in this area (López Gamundí, 1989; Limarino *et al.,* 2002).

Previous studies of the authors (Cisterna and Sabattini, 1998; Cisterna and Simanauskas, 2000; Cisterna and Sterren, 2007; Cisterna *et al.,* 2002, 2005, 2006b, 2006c; Coturel and Gutiérrez, 2005; Gutiérrez *et al.,* 2005; Sterren, 2000, 2004), indicate that the most complete and fossiliferous gondwanan successions identified for this interval of time have been documented in the central western Argentinian basins, *i.e.* the Río Blanco basin (Río del Peñón and Quebrada Larga Formations) and in the west part of the Paganzo basin (Tupe Formation) (Fig. 1B). Paleontological evidence, located throughout each stratigraphical section of these units, have allowed for integrated studies of the marine faunal data with the associated palynological and megafloristic records.

A diversified marine faunal assemblage composed of brachiopods, bivalves, gastropods and ostracods, with brachiopods clearly exhibiting Permian gondwanan affinities (Cisterna and Simanauskas, 2000; Cisterna *et al.,* 2002, 2006a; Cisterna, 2010), is typically related to the marine horizons of a transgressive event. This fauna belongs to the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Zone (Sabattini *et al.,* 1991), considered to be early Permian by Cisterna *et al.* (2002) and Archbold *et al*. (2004). Detailed studies conducted in the stratigraphical sections of the Tupe Formation inside the western Paganzo Basin (*i.e*., La Herradura Creek, La Delfina Creek and Mina La Ciénaga) (Fig. 1B), have allowed to understand the compositional variations of the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* fauna and its relationship with the new palynological and paleofloristic records from the associated horizons (Cisterna *et al.*, 2002, 2005, 2006b; Gutiérrez *et al.*, 2005). The latest Carboniferous (NBG and Interval megafloristic zones; *Raistrickia densa-Convolutispora muriornata* Palynological

Zone) and earliest Permian assemblages (*Pakhapites fusus-Vittatina subsaccata* Palynological Zone and *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Zone), recognized in these studies in the Tupe Formation, restricts the timing of the paleo-Pacific transgression into the western Paganzo basin to the latest Carboniferous-earliest Permian interval (Cisterna *et al*., 2005).

Recent field work in the Agua del Jagüel Formation (Calingasta-Uspallata basin), in the southernmost part of the Argentine Precordillera, allows suggesting a probable new key section to define the Carboniferous-Permian boundary. This stratigraphical unit is characterized by a sedimentary succession grading upwards from a deglaciation facies to a fluvial and shallow marine facies (Henry *et al*., 2008). The lower part of this unit (deglaciation phase) includes the diagnostic late Carboniferous *Rhipidomella-Micraphelia* faunal assemblage, located immediately above the diamicitic horizons, in the lower part of the section (Martínez *et al*., 2001). Additionally, a K-Ar date in biotite of 307±5.2 Ma (Lech, 2002) from dacitic pillow lavas, located about 150 m above of the *Rhipidomella-Micraphelia* faunal assemblage, indicates a Late Carboniferous age. The upper part of the Agua del Jagüel Formation, distinguished by shoreface sandstones and offshore shales, contains the lower Permian *Costatumulus amosi* fauna (Cisterna, 2010).

3. Key sections for the definition of the Carboniferous-Permian boundary in Argentina

Here we review the stratigraphic and paleontological evidence of key stratigraphical sections for the Carboniferous-Permian boundary in the central western Argentinean basins. The completed study places emphasis on the Río del Peñón and Quebrada Larga formations of the Río Blanco basin and on the Tupe Formation in western Paganzo Basin (Fig. 1B).

3.1. Río Blanco Basin

3.1.1. Río del Peñón Formation

The main outcrops of the Río del Peñón Formation (Borrello, 1955; González and Bossi, 1986) are exposed at the Rincón Blanco syncline, located 35 km west of the village of Jagué in the La Rioja province (Fig. 1B). This unit, about 1,200 m thick in the examined reference section (Fig. 2), encloses several fossiliferous horizons containing rich and

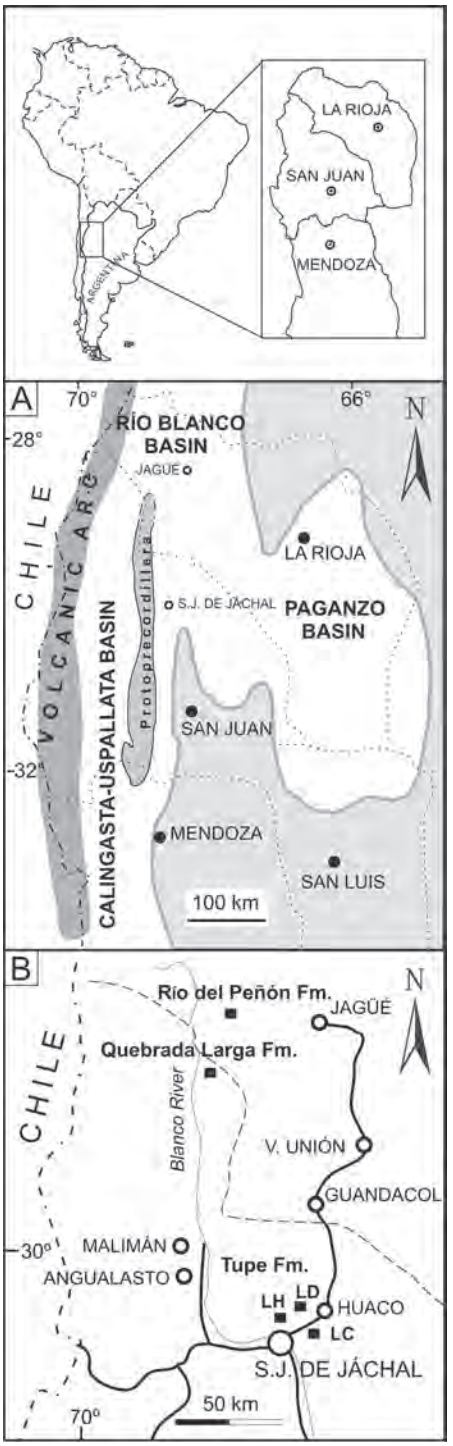


FIG. 1. **A.** location maps with the paleogeography of the Río Blanco and Paganzo basins in western Argentina; **B.** generalized map showing the geographical location of the studied key sections; **LH**. La Herradura creek; **LD.** La Delfina creek; **LC.** Mina La Ciénaga.

diversified invertebrate marine fauna and megafloristic assemblages. The marine faunal assemblages in this section are more abundant and diversified than those from the other sections studied herein. Three informal members are recognized in the Río del Peñón Formation. The lower member of the section is characterized by an abundance of conglomerates probably deposited in a proximal glacimarine environment (Gulbranson *et al*., 2008), and by sedimentary associations representing fluvial distributary channels and interdistributary bay deposits identified by coal beds. The middle-upper member of the section is characterized by vertically-stacked, coarsening-upward successions that suggest mouth bars overlaying prodeltaic mudstones. Locally bioclastic sandstone-mudstone horizons with marine invertebrate fauna have been recognized in the middle member. An interval approximately 25 m thick, characterized by carbonate and siliciclastic facies with an excellent record of marine invertebrates has been identified in the middle member (Fig. 2). This interval is interpreted to be a marginal marine environment, such as a tidal and subtidal flat with mixed sedimentation and deltaic front with a reworking wave in the upper part of the interval (Cisterna, 1997; Sterren, 2000). In the upper part of the section, complexes of fluvial distributary channels associated with overbank deposits have been identified (Cisterna, 1997; Sterren, 2000).

The Río del Peñon Formation and the underlying Punta del Agua Formation have been objects of several radiometric studies. Radiometric ages reported from andesites of the Punta del Agua Formation (295 Ma, Fauqué *et al*., 1999), as well as from a riodacitic sill intercalated in the lowermost part of the Río del Peñón Formation (287.8±0.7 Ma Ar/Ar method, *i.e.,* a Sakmarian age, Coughlin, 2000), suggests a Stephanian age for the base of the Río del Peñón Formation, whose lower member would have been deposited before the Sakmarian.

Three different faunal marine assemblages, closely related to the associated paleofloristic record, have been identified in the stratotype section of the Río del Peñón Formation (Cisterna and Simanauskas, 2000).

(i) The first assemblage, in the lower member, occurs in a mudstone stratigraphical interval located about 24 m immediately above beds containing the latest Carboniferous NBG megaflora (*Nothorhacopteris argentinica* (Figs. 3.9), *Botrychiopsis weissiana* and *Fedekurtzia argentina* (Figs. 3.1-2), as well as *Eusphenopteris* sp. (Figs. 3, 5)). The microflora can be included in the DM Biozona (*Raistrickia densa-Convolutispora muriornata*, Césari and Gutiérrez, 2000) and contains *Anapiculatasporites conncinus* (=*A. argentinensis*), *Apiculatisporis variornatus*, *Brevitriletes levis, Leiotriletes directus*, *Verrucosisporites andersonii*, *Converrucosisporites* sp. A, *Cristatisporites rollerii*, *C. scabiosus, C. stellatus, Vallatisporites arcuatus, V. russoi, V. ciliaris* (Fig. 4.18), *Spelaeotriletes ybertii* (Fig. 4.13), *Spheripollenites* sp. A; *Cannaropollis* spp., *Potoniesiporites* spp, *Plicatipollenites* spp., *Crucisaccites* sp., *Latusipollenites quadrisaccatus* (Fig. 3.6), *Pteruchipollenites* sp., and *Limitisporites* sp., have been also identified and associated with the NBG assemblage.

Although fragmentary, the fauna that integrates the first assemblage (Assemblage I of Cisterna and Simanauskas, 2000), is well diversified and composed of brachiopods (*Streptorhynchus* sp., *Etherilosia* sp., *Costatumulus* sp. A, *Kochiproductus*? sp., Linoproductidae indet., *Pericospira* sp., *Spiriferellina* sp., Spiriferida indet., and *Orbiculoidea* sp.), gastropods (*Barrealispira* sp. aff. *B. tupensis*) and bivalves indet. which would suggest lowest Permian affinities (Cisterna and Sabattini, 1998; Cisterna and Simanauskas, 2000; Cisterna *et al*., 2006c). However, new palynological data associated with this faunal assemblage suggest that the DM Zone occurs in this interval. Particularly, the presence of the scolecodonts *Marlenites* sp. (Fig. 4.12), and *Kielanoprion* sp. (Fig. 4.11), allows these marine horizons to be included in the sub-Zone C of the DM Zone (Césari and Gutiérrez, 2000), that characterizes the latest Pennsylvanian successions from central western Argentina.

(ii) The second faunal assemblage identified in the Río del Peñón Formation occurs in the middle part of the section, 600 m above the base, in a stratigraphical interval 38 m thick (Fig. 2) which is composed of the type of brachiopods that characterize the early Permian *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Zone. The species *Tivertonia jachalensis* (Figs. 5.10-11), *Streptorhynchus inaequiornatus*, *Kochiproductus riojanus* (Fig. 5.12, 15), *Costatumulus* sp. B, *Pericospira riojanensis* (Figs. 5.7-8), *Spiriferellina* sp., and *Orbiculoidea* sp., accompanied by the gastropods *Barrealispira* sp. aff. *B. tupensis*, have been described from this assemblage (Cisterna and Sabattini, 1998; Cisterna and Simanauskas, 2000). However the recent field work has allowed for the identification of new taxa

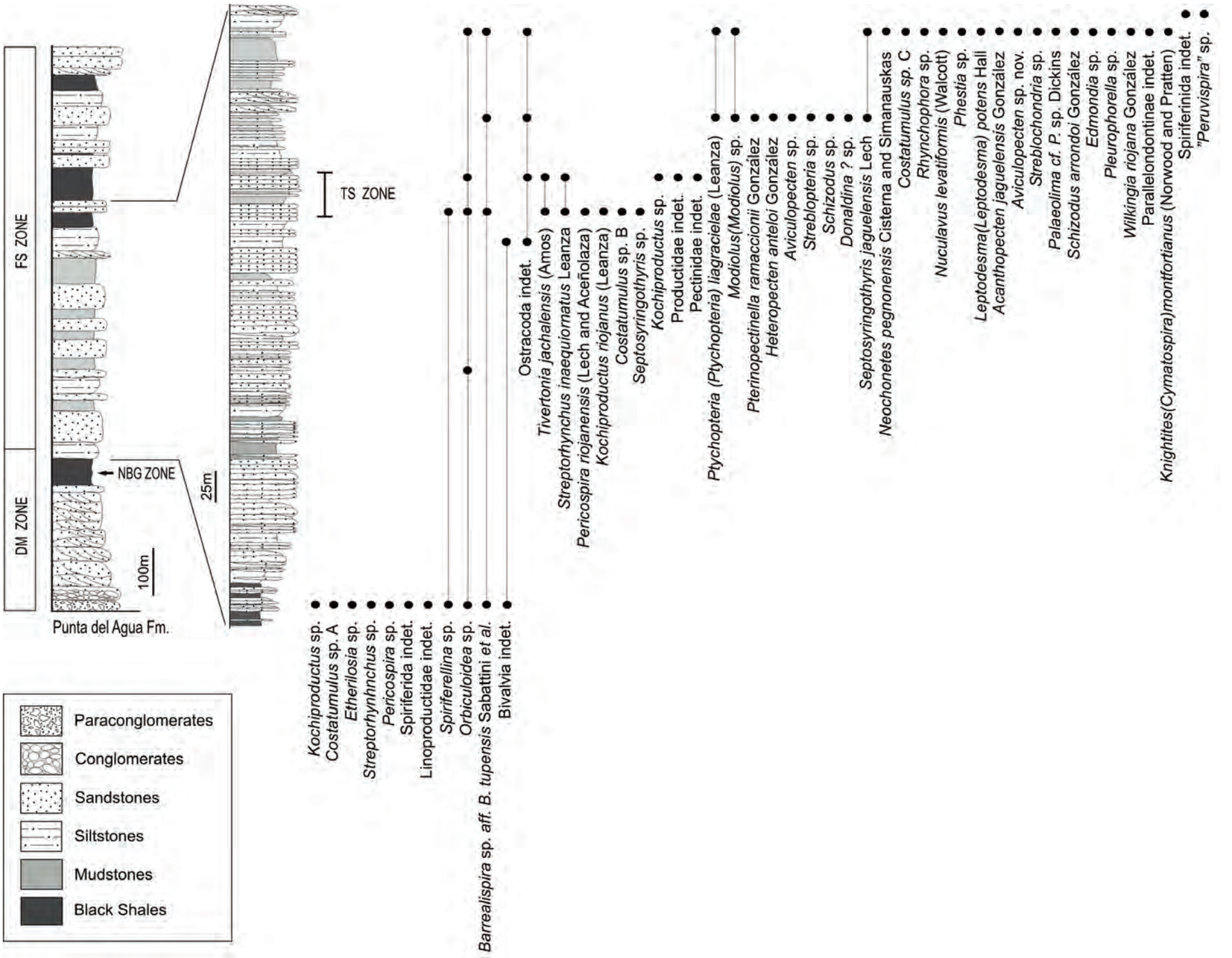


FIG. 2. Stratigraphical section of the Río del Peñón Formation (modified from Cisterna and Simanauskas, 2000) and vertical distribution of the invertebrates, mega and microflora assemblages. **DM ZONE:** *Raistrickia densa-Convolutispora muriornata* Palynological Zone; **FS ZONE:** *Pakhapites fusus-Vittatina subsaccata* Palynological Zone; **NBG ZONE:** *Nothorhacopteris argentinica, Botrychiopsis weissiana, Ginkgophyllum diazii* Megafloristic Zone; **TS ZONE:** *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Invertebrate Zone.

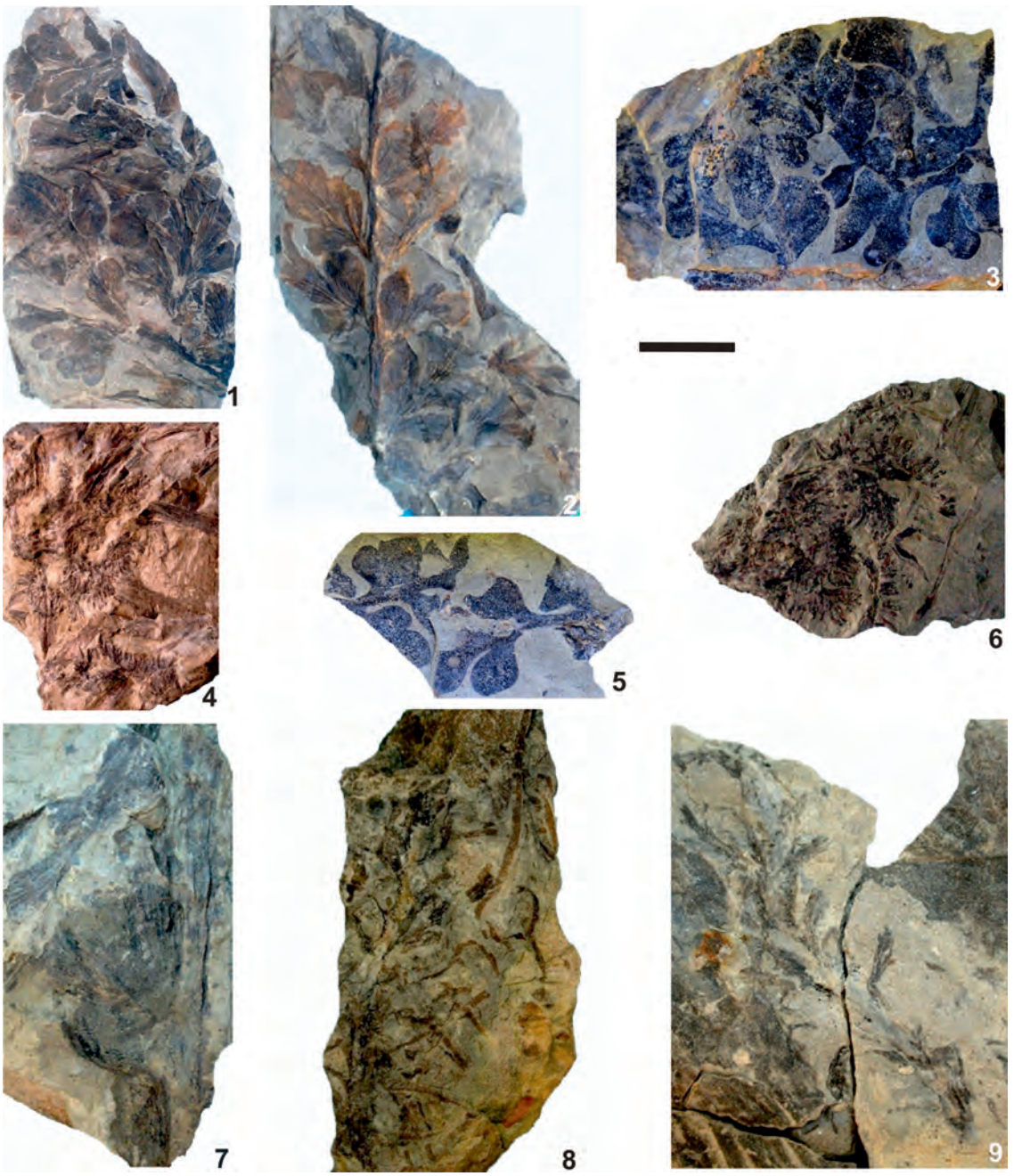
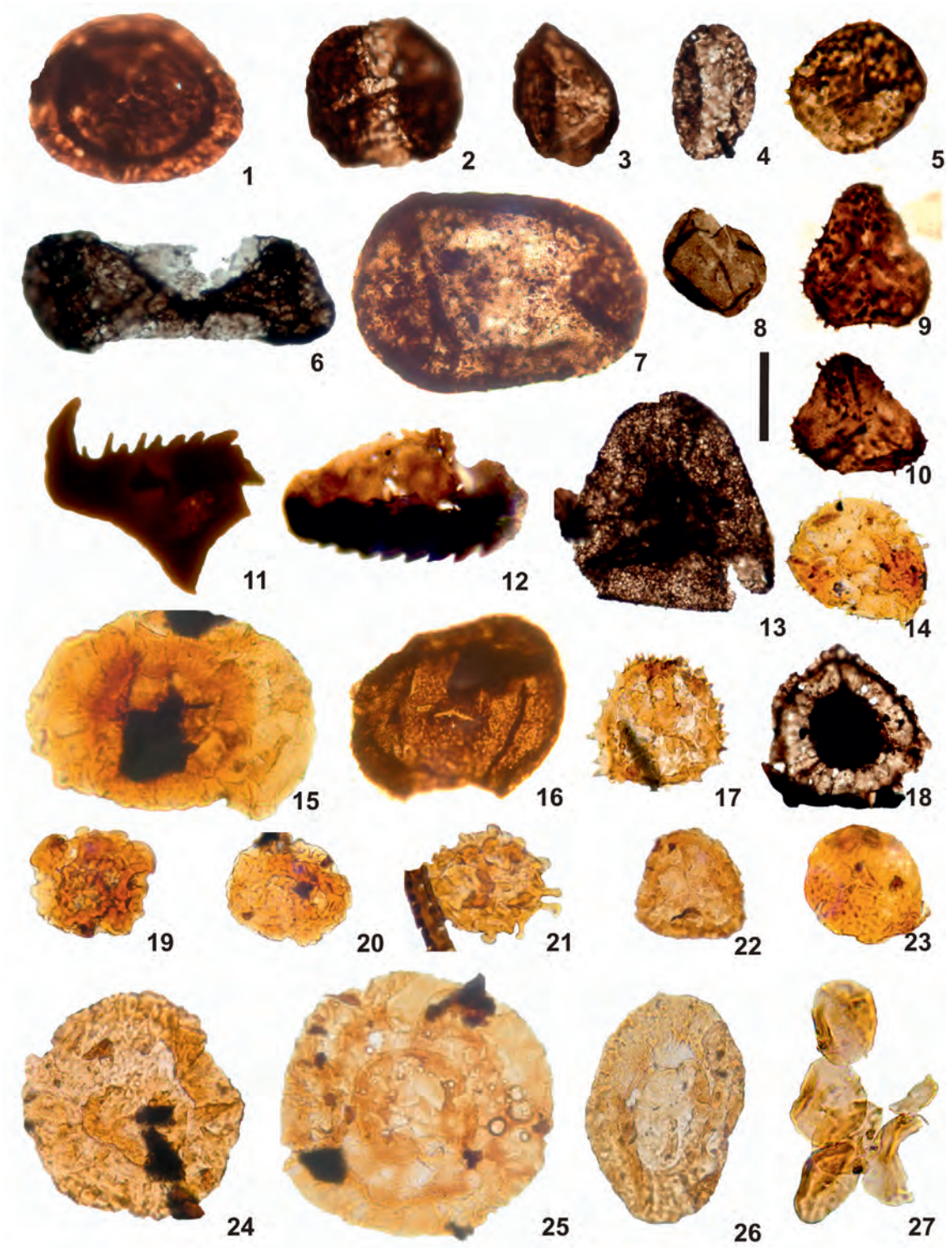


FIG. 3. Latest Carboniferous megafloristic assemblages from the western Argentinean basins. **1-2.** *Fedekurtzia argentina* (Kurtz) Archangelsky, Río del Peñón Formation; **1.** BA Pb 19; x1, **2.** BA Pb 12, x1; **3, 5.** *Eusphenopteris* sp., Río del Peñón Formation, **3,** BA Pb 12c, x3; **5,** BA Pb 12b, x3; **4, 6.** *Rinconadia archangelskyi* Vega, Tupe Formation, **4.** BA Pb 13587, x1; **6.** BA Pb 13586b, x1; **8-9**. *Kraeuselcladus* sp. cf. *K. argentinus* Archangelsky, Tupe Formation; **8.** BA Pb 13590, x2; **9.** BA Pb 13589b, x2; **7.** *Nothorhacopteris argentinica* (Geinitz) Archangelsky, Tupe Formation, BA Pb 13559, x3. Scale bar, 20 mm, except, 3, 5, 7 (=60 mm), 8-9 (=40 mm). Repository: BA Pb, *Colección Nacional de Paleobotánica del Museo Argentino de Ciencias Naturales 'Bernardino Rivadavia'*.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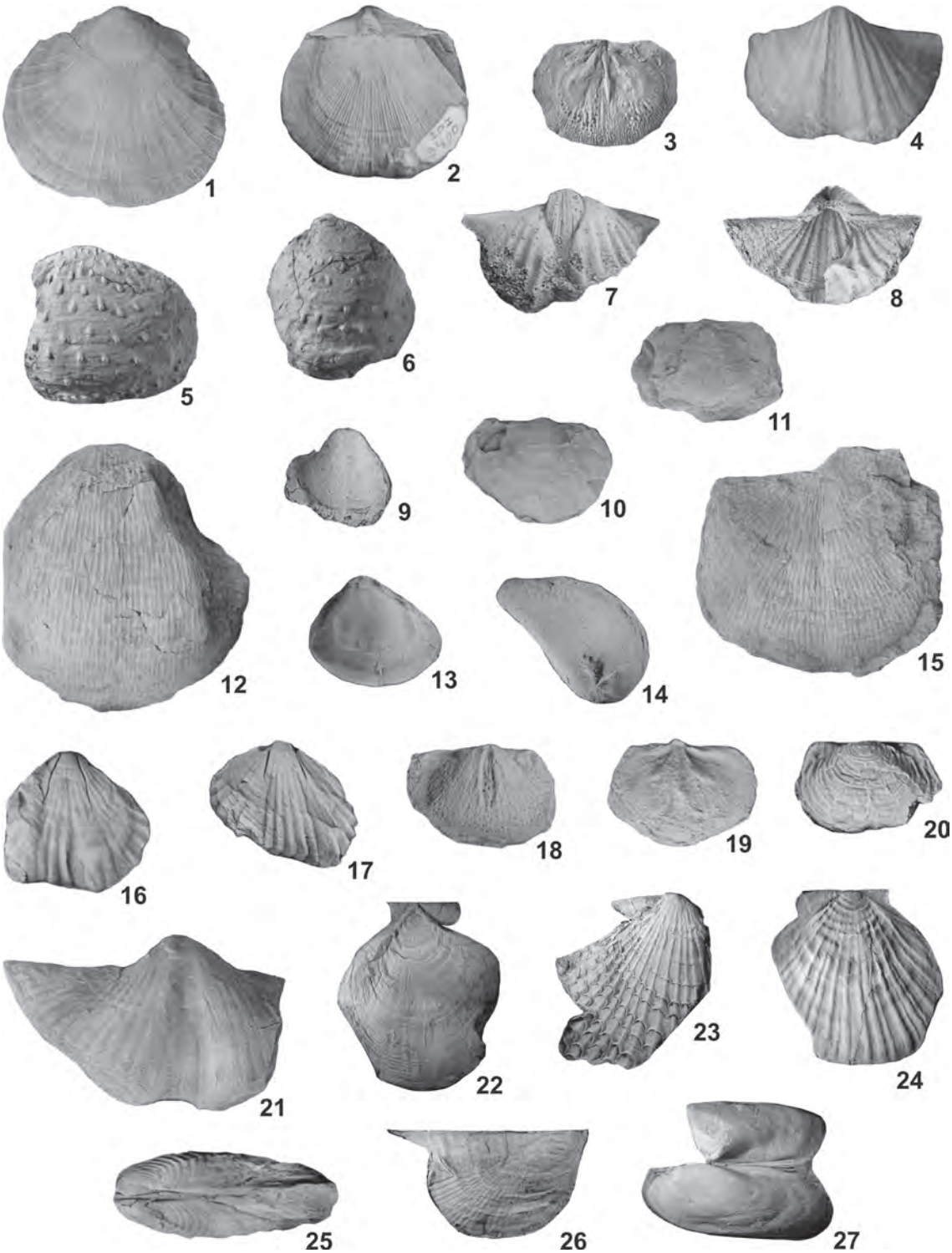
(the brachiopods *Septosyringothyris* sp., productidae indet, ostracods and very scarce bivalves and gastropods), as well as, the recognition of a pattern of vertical faunal distributed along the interval that contains the T-S fauna. The lower part of the brachiopod fauna that appears concentrated in a sandstone horizon, is clearly dominated by *Pericospira riojanensis* (Figs. 5.7-8), and accompanied by *Kochiproductus riojanus* (Fig. 5.12, 15), *Costatumulus* sp. B, *Septosyringothyris* sp., *Spiriferellina* sp. and *Orbiculoidea* sp. However, *Tivertonia jachalensis* and *Streptorhynchus inaequiornatus,* which define the T-S Zone, are scarce in this location. In the upper part of the fossiliferous interval, the faunal assemblage is associated with mudstone horizons and it is composed of brachiopods and ostracods. The dominant brachiopod species is *T. jachalensis* accompanied by *S. inaequiornatus*, *Kochiproductus*? sp., Productidae indet. (a possible new species for this zone) and very scarce linguliforms.

A fossiliferous interval, dominated primarily by bivalves, is located between the second and third brachiopod faunal assemblages. Taphonomic and paleoecologic features of this mudstone interval have been studied by Cisterna and Simanauskas (2000) and Sterren (2000, 2002). Bivalves *Modiolus* (*Modiolus*) sp., *Ptychopteria* (*Ptychopteria*) *liagracielae* (Fig. 5.26), *Heteropecten anteloi*, *Pterinopectinella ramaccionii*, *Aviculopecten* sp., *Streblopteria* sp., *Schizodus* sp. are identified, along with the gastropods *Barrealispira* sp. aff. *B. tupensis*, *Donaldina*? sp. and ostracods indet.

(iii) The third faunal assemblage identified in the Río del Peñón Formation, previously described from the middle part of the section (Fig. 2), is composed of the brachiopods *Neochonetes pegnonensis* (Figs. 5.18-19), *Costatumulus* sp. C (Fig. 5.20), *Rhynchopora* sp. (Figs. 5.16-17), *Septosyringothyris jaguelensis* (Fig. 5.21) and *Orbiculoidea* sp., and is accompanied by bivalves (*Nuculavus levatiformis*, *Phestia* sp., *Modiolus* (*Modiolus*) sp., *Leptodesma* (*Leptodesma*) cf. *L. potens*, *Ptychopteria* (*Ptychopteria*) *liagracielae*, *Palaeolima* cf. *P.* sp., *Aviculopecten* sp. nov. (Figs. 5.22, 24), *Aviculopecten* sp., *Acanthopecten jaguelensis*, *Streblochondria* sp., *Schizodus arrondoi*, *Edmondia* sp., *Pleurophorella* sp., *Wilkingia riojana,* and Parallelodontidae indet.), gastropods (*Barrealispira* sp. aff. *B. tupensis*, *Knightites* (*Cymatospira*) *montfortianus*), crinoids and ostracods. The brachiopods identified in this assemblage show faunal affinities with species from the early Permian of Western Australia; this similarity has been noted by Cisterna and Simanuskas (2000) and Archbold *et al*. (2004). However, the associated bivalve assemblage is mostly composed of cosmopolite and some tethyan genera (Sterren, 2004).

FIG. 4. Latest Carboniferous-earliest Permian palynological assemblages from the western Argentinean basins. **1.** *Barakarites rotatus* (Balme and Hennelly) Bharadwaj and Tiwari, BA Pal 6281(2) V42/1, x500; **2.** *Pakhapites fusus* (Bose and Kar) Menéndez, BA Pal 6281(1) T52/2, x500; **3.** *Marsupipollenites striatus* (Balme and Hennelly) Foster, BA Pal 6281(1) C33/1, x500; **4.** *M. triradiatus* Balme and Hennelly, BA Pal 6268(4) V35/1, x500; **5.** *Brevitriletes levis* (Balme and Hennelly) Bharadwaj and Srivastava, PB Pal 399(1) J35/2, x1000; **6-7.** *Latusipollenites qudrisaccatus* Marques-Toigo; **6.** BA Pal 6268(4) S65/3, x400; **7.** BA Pal 6270(1) G61/4, x400; **8.** *Brazilea scissa* (Balme and Hennelly) Foster, BA Pal 6279(2) V37/1, x500; **9.** *Anapiculatisporites tereteangulatus* (Balme and Hennelly) Playford and Dino, PB Pal 6281(7) Y23/4, x500; **10.** *Horriditriletes ramosus* (Balme and Hennelly) Bharadwaj and Salujha, PB Pal 6281(2) T38/3, x500; **11.** *Kielanoprion* sp., BA Pal 6275(3) K39/1, x750; **12.** *Marlenites* sp., BA Pal 6275(3) O37/3, x500; **13.** *Spelaeotriletes ybertii* (Marques-Toigo) Playford and Powis, BA Pal 6275(2) A39/2, x500; **14.** *Apiculatisporis variornatus* Di Pasquo, Azcuy and Souza, BA Pal 5842(3) M28/0, x750; **15.** *Costatascyclus crenulaatus* Urban, BA Pal 5843(4) B32/0, x500; **16.** *Colpisaccites granulatus* Archangelsky and Gamerro, BA Pal 6270(1) Z62/4, x500; **17.** *Cristatisporites stellatus* (Azcuy) Gutiérrez and Limarino, BA Pal 5843(4) E59/3, x750; **18.** *Vallatisporites ciliaris* Sullivan, BA Pal 6275(2) B31/0, x500; **19.** *Raistrickia densa* Menéndez, BA Pal 5843(3) H33/2, x500; **20.** *Convolutispora muriornata* Menéndez, BA Pal 5843(4) H52/0, x500; **21.** *Raistrickia rotunda* Azcuy, BA Pal 5840(7) Z58/3, x1000; **22.** *Cristatisporites menedezii* (Menéndez and Azcuy) Playford, BA Pal 5843(3) R52/2, x1000; **23.** *Brevitriletes parmatus* (Balme and Hennelly) Backhouse, BA Pal 5839(2) F51/0, x750; **24.** *Tuberisaccites tuberculatus* (Maheshwari) Lele and Makada, BA Pal 5846(1) X49/3, x500; **25.** *Circumplicatipollis plicatus* Ottone and Azcuy, BA Pal 5843(1) G42/1, x500; **26.** *Barakarites rotatus* (Balme and Hennelly) Bharadwaj and Tiwari, BA Pal 5843(3) P43/0, x500; **27.** *Spheripollenites* sp. A; BA Pal 5838(1) U42/3, x1000. Scale bar, 40 µm, except, 6-7 (=44 µm), 11, 14, 17, 23 (=30 µm), 5, 21-22, 27 (=20 µm). **1-13, 16, 18,** from the Río del Peñón Formation; **14-15, 17, 19-27.** from the Tupe Formation. Repository, BA Pal: Buenos Aires, *Colección Nacional de Paleopalinología del Museo Argentino de Ciencias Naturales 'Bernardino Rivadavia'*.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From the upper part of the Río del Peñón section the new palynogical records (Gutiérrez and Limarino, 2006), suggest the occurrence of elements that characterize the *Pakhapites fusus-Vittatina subsaccata* (FS) Zone (early Cisuralian), *i.e., Pakhapites fusus* (Fig. 4.2), such as *Marsupipollenites striatus* (Fig. 4.3), *M. triradiatus* (Fig. 4.4), *Cycadopites* sp., *Protohaploxypinus goraiensis, Polarisaccites* sp., *Anapiculaisporites tereteangulatus* (Fig. 4.9), *Kraeuselisporites spinosus, Alisporites rioclarensis, Scherungipollenites ovatus, Pteruchipollenites gracilis, Valialasaccites* sp., *Colpisaccites granulosus* (Fig. 4.16), *Barakarites rotatus* (Fig. 4.1), *Caheniasaccites* cf. *flavatus, Latusipollenites quadrisacctaus* (Figs. 4.6-7), *Crucisaccites monoletus, Brazilea scissa* (Fig. 4.8), *Calamospora breviradiata, Horriditriletes ramosus* (Fig. 4.10) and *Spheripollenites* sp. A.

3.1.2. Quebrada Larga Formation

Outcrops of the Quebrada Larga Formation (Scalabrini Ortiz, 1972) can be recognized on the west flank of the Punilla Hill in the Carrizalito area, San Juan province. In the reference section located to the left margin of the Blanco River (Fig. 6), about 60 km northern of Malimán, the succession is characterized by a predominance of sandstones, occasionally interbedded fine conglomerates and mudstones that contain remains of NBG flora (Scalabrini Ortiz and Arrondo, 1973). Besides the reference section, remains of plants (*Botrychiopsis weissiana, Malanzania nana, Nothorhacopteris* sp., *Paracalamites* sp., and *Cordaites* sp.), that characterize the NBG Zone have been recognized in the basal part of the Quebrada Larga Formation (Cingolani *et al.,* 1992; Caminos *et al.,* 1993) exposed to the northwest of the Punilla Hill, close to the Llanos de Chaparro locality in La Rioja Province. The NBG Zone has also been identified in the uppermost part of the Cortaderas Formation (Scalabrini Ortiz, 1973), in horizons that would otherwise be included in the Quebrada Larga Formation (Cardó *et al*., 2001; Carrizo, 1990). The records of the NBG Zone in the Quebrada Larga Formation have been documented in the lower part of the section.

In the upper part of the reference section of the Quebrada Larga Formation (Fig. 6), two marine fossil assemblages are described in a 120 m thick stratigraphical interval (Cisterna and Sterren, 2007): the lower assemblage is dominated by brachiopods (*Septosyringothyris* sp. aff. *S. jaguelensis* accompanied of *Tivertonia jachalensis*, *Orbiculoidea* sp. and very scarce and fragmentary *Streptorhynchus inaequiornatus*), accompanied of gastropods (probably *Peruvispira* sp.) and bivalves indet.; while the upper assemblage is composed of the brachiopods *Coronalosia* sp., *Svalbardia* sp., *Septosyringothyris*

FIG. 5. Earliest Permian brachiopods and bivalves from the western Argentinean basins. **1-2**. *Streptorhynchus inaequiornatus* Leanza. **1**. articulate specimen, ventral view, IPI 3398, x1; **2**. articulate specimen, dorsal view, IPI 3400, x2. **3, 10-11**. *Tivertonia jachalensis* (Amos). **3**. dorsal interior, DCG-MLP 354f, x2; **10**. ventral valve, IPI 2941, x2; **11**. dorsal valve, IPI 2942, x2; **4**. *Pericospira pericoensis* (Leanza), ventral valve, IPI 2869, x2; **5**. *Coronalosia argentinensis* Archbold and Simanauskas, ventral valve, DCG-MLP 356b, x2; **6**. *Tupelosia paganzoensis* Archbold and Simanauskas, ventral valve, DCG-MLP 356e, x1.8; **7-8**. *Pericospira riojanensis* (Lech); **7**. internal mould of ventral valve, IPI 4515, x1.2; **8**. external mould of articulate specimen, dorsal view, IPI 4516, x1,2; **9**. *Crurithyris?* sp., ventral valve, IPI 2895, x3; **12, 15**. *Kochiproductus riojanus* (Lenaza); **12**. ventral valve, IPI 3169b, x1; **15**. dorsal valve, IPI 3169a, x1; **13**. *Nuculavus levatiformis* (Walcott), outer view of right valve, CEGH-UNC 17657, x3.3; **14**. *Septimyalina* sp., internal mould of left valve, CEGH-UNC 19729, x5; **16-17**. *Rhynchopora* sp.; **16**. internal mould of ventral valve, IP 3361, x1.5; **17**. internal mould of ventral valve, IPI 3364, x1.5; **18-19**. *Neochonetes pegnonensis* Cisterna and Simanauskas; **18**. internal mould of ventral valve, IPI 2960, x2.5; **19**. dorsal valve, IPI 2969, x2.5; **20**. *Costatumulus* sp. C, dorsal valve, IPI 3389, x2; **21**. *Septosyringothyris jaguelensis* Lech; ventral valve, IPI3066, x1; **22**. *Aviculopecten* sp. nov., outer view of right valve, CEGH-UNC 17707, x1; **23**. *Acanthopecten jaguelensis* González, latex replica external mould of left valve, CEGH-UNC 17712, x1,3; **24**. *Aviculopecten* sp. nov., outer view of left valve CEGH-UNC 17703, x1; **25**. *Wilkingia riojana* González, dorsal view of internal mould, CEGH-UNC 17739, x1.5; **26**. *Ptychopteria (Ptychopteria) liagracielae* (Leanza), outer view of right valve, x1; **27**. Parallelodotinae indet., internal mould of articulated valves, CEGH-UNC 17669, x1.3.

1-6, 9, 14. specimens from the Tupe Formation; **7-8, 10-12, 13, 15-27.** specimens from the Río del Peñón Formation. Repository: IPI, *Instituto de Paleontología, Fundación Miguel Lillo*; DCG-MLP, *Departamento Científico de Geología*, *Museo de La Plata*; CEGH-UNC, *Centro de Investigaciones Paleobiológicas (CIPAL), Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba*.

sp. aff. *S. jaguelensis* and scarce gastropods. From outcrops located on the left margin of the Blanco River, immediately to the north of the Quebrada Larga reference section, another marine faunal assemblage has been recognized (Cisterna and Sterren, 2007). This assemblage appears in calcareous horizons interbedded in mudstones and is dominated by the bivalves *Schizodus* sp., *Pleurophorella* sp., *Edmondia* sp., *Modiolus*? sp., *Aviculopecten* sp. and *Streblochondria* sp., accompanied by gastropods (*Peruvispira*? sp.) and the brachiopods *Septosyringothyris* sp. and Productida indet. Unfortunately the diagnostic elements of the T-S fauna have not been found in this isolated assemblage, and therefore it cannot be correlated with the fauna from the Quebrada Larga reference section.

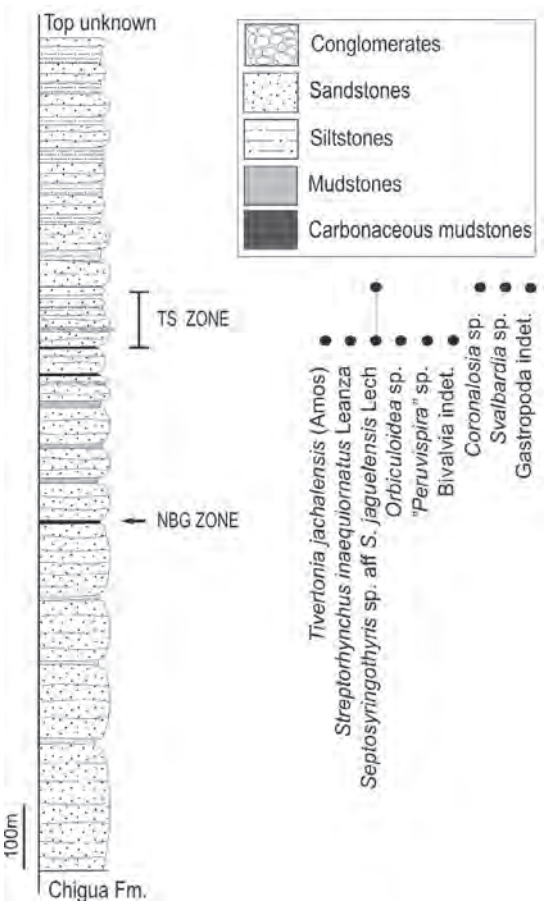

FIG. 6. Stratigraphical section of the Quebrada Larga Formation in the type locality (modified from Cisterna and Sterren, 2007) and vertical distribution of the fossiliferous horizons.

The marine fauna from the Quebrada Larga Formation can be included in the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Biozone (Sabattini *et al*., 1991). However some compositional variations have been observed, including the occurrence of *Coronalosia* sp. and *Svalbardia* sp., which probably represents two new species, both with Permian gondwanan affinities. The reference section of the Quebrada Larga Formation is a potential key section to study of the Carboniferous-Permian boundary (Cisterna and Sterren, 2007), as early Permian *Tivertonia jachalensis-Streptorhynchus inaequiornatus* fauna occurs above beds carrying elements of the Late Carboniferous megafloristic assemblage NBG, such as *Nothorhacopteris argentinica*.

3.2. Western Paganzo basin

From a paleogeographic viewpoint, outcrops of the Tupe Formation in the western region of the Paganzo basin (La Herradura creek, La Delfina creek, Mina La Ciénaga and Paslean localities, on the west flank of Perico Hill, San Juan province) (Fig. 1B), belong to the 'Guandacol embayment' (López Gamundí *et al.,* 1994). The Tupe Formation consists primarily of sandstone, conglomerate, mudstone and coal, and uncomfortably overlies the Guandacol Formation. Although the Tupe Formation typically suggests deposition in continental environments, in some localities this continental succession is punctuated by a marine interval interpreted as the Panthalassan marine ingression, indicating an extensive geographical breach of the Proto-Precordillera at that time (López Gamundí *et al*., 1994).

3.2.1. Tupe Formation at La Herradura creek

Outcrops of the Tupe Formation at La Herradura creek are located about 20 km northeast of San José de Jáchal locality in the San Juan province (Fig. 1B). This stratigraphic section is considered to be the stratotype of the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Biozone (Sabattini *et al*., 1991). The marine fossiliferous horizons that contain this fauna are located in the upper part of the Tupe Formation, in a stratigraphical interval approximately 20 m thick, composed of mudstones interbedded with carbonate beds (Fig. 7).

The fossil assemblage that characterizes the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Biozone in the Tupe Formation at La Herradura

creek is dominated by brachiopods (*Streptorhynchus inaequiornatus* (Figs. 5.1-2), *Tivertonia jachalensis* (Fig. 5.3), *Kochiproductus* sp., *Costatumulus* sp., *Coronalosia argentinensis* (Fig. 5.5), *Tupelosia paganzoensis* (Fig. 5.6), *Pericospira pericoensis* (Fig. 5.4), *Septosyringothyris* sp. aff. *S. jaguelensis*, *Crurithyris*? sp. (Fig. 5.9), *Lingula* sp. and *Orbiculoidea* sp.), accompanied by bivalves (*Nuculavus levatiformis*, *Phestia* sp. aff. *P. bellistriata*, *Modiolus* (*Modiolus*) sp., *Septimyalina* sp. (Fig. 5.14), *Palaeolima retifera*, *Aviculopecten* sp., *Streblochondria* sp., *Schizodus* sp., *Pleurophorella*?), gastropods (*Barrealispira* sp. aff *B. tupensis)* and ostracods. Taxonomy, biostratigraphy and paleobiogeographic implications of the brachiopods from this assemblage have been studied by Cisterna *et al.* (2002); and bivalves reviewed by Sterren (2004), who suggested an assemblage mostly dominated by cosmopolitan genera, although some of them show tethyan affinities.

The new palynological data from the upper part of the fossiliferous interval include diagnostic species of the Early Permian palynofloras, such as *Converrucosisporites confluens, Pseudoreticulatispora pseudoreticulata*, *Horriditriletes ramosus*, *Anapiculatisporites tereteangulatus*, *Laevigatosporites colliensis*, *Marsupipollenites triradiatus*, *Protohaploxypinus sewardii,* and *Pakhapites fusus* (Vergel, 2008).

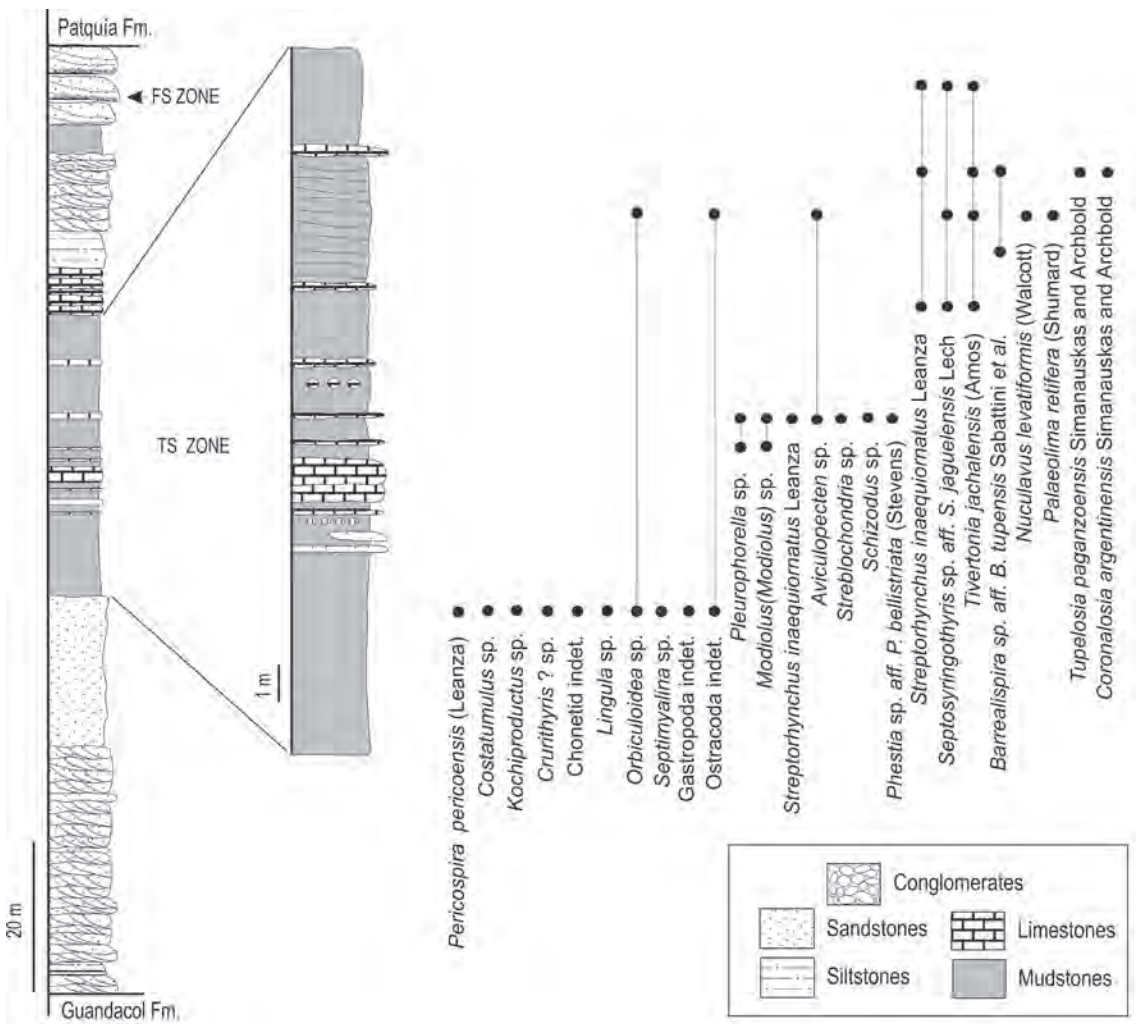

FIG. 7. Stratigraphical section of the Tupe Formation at La Herradura creek showing the vertical distribution of the invertebrate and mega/microflora assemblages (modified from Cisterna *et al.,* 2005).

3.2.2. Tupe Formation at La Delfina creek

The stratigraphical section of the Tupe Formation, located south of the Mina La Delfina locality, about 29 km northeast of San José de Jáchal (Figs. 1B, 8), encloses an important paleontological record, composed of megafloristic, palynological and marine invertebrate assemblages. The lower part of Tupe Formation at La Delfina Creek, characterized by sandstone and mudstone with coal facies, has been interpreted as a deltaic, swamp system containing a high proportion of organic matter (Ottone and Azcuy, 1986). Two megafloristic assemblages have recently been identified in this part of the section (Coturel and Gutiérrez, 2005). The lower assemblage is composed of *Fedekurtzia argentina Nothorhacopteris argentinica* (Fig. 3.7), *Rinconadia archangelskyi* (Figs. 3.6-7), Coniferae indet. and *Eusphenopteris* sp., and can be included in the NBG Zone. The upper assemblage, 55 m above, contains scarce remains of *Kraeuselcladus* sp. cf. *K. argentinus* (Figs. 3.8-9), suggesting the presence of the Interval megafloristic Zone. Furthermore, of the nine palynological associations that can be assigned to the *Raistrickia densa-Convolutispora muriornata* Zone, Gutiérrez *et al.* (2005) has identified *Anapiculatasporites conncinus, Apiculatasporites parviapiculatus, Apiculatisporites variornatus* (Fig. 4.14), *Brevitriletes levis, B. parmatus* (Fig. 4.23), *Convolutispora muriornata* (Fig. 4.20), *Dibolisporites disfacies, Foveosporites hortonensis, Raistrickia densa* (Fig. 4.19), *R. rotunda* (Fig. 4.21), *Reticulatisporites passaspectus, Verrucosisporites andersonii, Cristatisporites rollerii*, *C. menendezii* (Fig. 4.22), *C. scabiosus, C. stellatus* (Fig. 4.17), *Vallatisporites* spp., *Botryococcus braunii*, *Brazilea* spp., *Leiosphaeridia* sp., *Cannanoropollis* spp., *Crucisaccites latisulcatus, Potonieisporites* spp., *Caheniasaccites* spp., *Circumplicatipollis plicatus* (Fig. 4.25), *Costatascyclus crenatus* (Fig. 4.15), *Plicatipollenites* spp., *Gondwanapollis frenguelli, Tuberisaccites tuberculatus* (Fig. 4.24), *Barakarites rotatus* (Fig. 4.26), *Colpisaccites* sp., *Protohaploxypinus* sp. and *Spheripollenites* sp. A (Fig. 4.27).

In the middle part of the section, in a stratigraphical interval of alternating sandstones and claystones with mudstones lenses, a marine fossil assemblage composed of brachiopods (*Costatumulus* sp. and *Orbiculoidea* sp. dominant, accompanied by *Pericospira pericoensis*, *Kochiproductus* sp., *Streptorhynchus inaequiornatus*, *Septosyringothyris* sp. and scarce *Tivertonia jachalensis*), bivalves (*Heteropecten*? sp., *Myofossa* sp., *Sanguinolites*? sp. and Anomalodesmata indet.), gastropods and scarce crinoids, have been recognized (Cisterna *et al*., 2006b). This association, dominated by *Costatumulus* and *Orbiculoidea*, is compositionally comparable to the fauna described in the lowest marine horizon of the Tupe Formation at La Herradura creek (Cisterna and Simanuskas, 2002) and it could represent the oldest part of the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Zone in the Paganzo basin (Cisterna *et al*., 2006b). The marine interval that contains this invertebrate fauna represents the maximum flooding surface; the trace-fossils situated in the strata located over them evidence low diversity and high abundance, suggesting a stressed environment (Desjardins *et al.,* 2009, 2010).

3.2.3. Tupe Formation at Mina La Ciénaga

A detailed sedimentologic and high-resolution sequence stratigraphic analysis of the lower member of the Tupe Formation at Mina La Ciénaga locality (Figs. 1B, 8), carried out by Desjardins *et al*. (2009), has provided insight into the geographically larger latest Carboniferous-early Permian transgression within the Paganzo Basin. The lower member of Tupe Formation shows the transition from a coastal-plain to a marine embayment. The detection of a transgressive surface within the coastal-plain deposits has significantly expanded the volume of deposits than can be included as part of the latest Carboniferous-early Permian transgression (Desjardins *et al*., 2009).

Although the transgression is well represented at the Mina La Ciénaga locality, only one fossiliferous horizon, about 110 m from the base, has been recognized. The faunal assemblage integrates a coquina horizon composed of large gastropods; these appear to be closely related to those identified in the middle part of the fossiliferous interval in La Herradura creek. However other diagnostic elements of the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Zone have not yet been found at Mina La Ciénaga.

4. Discussion

The Late Paleozoic marine sedimentary sequences in Argentina are characterized by the absence of the most important key faunal groups, such as conodonts and fusulinid foraminiferids, which when present, provide a precise correlation with the defined Carboniferous-Permian boundary in

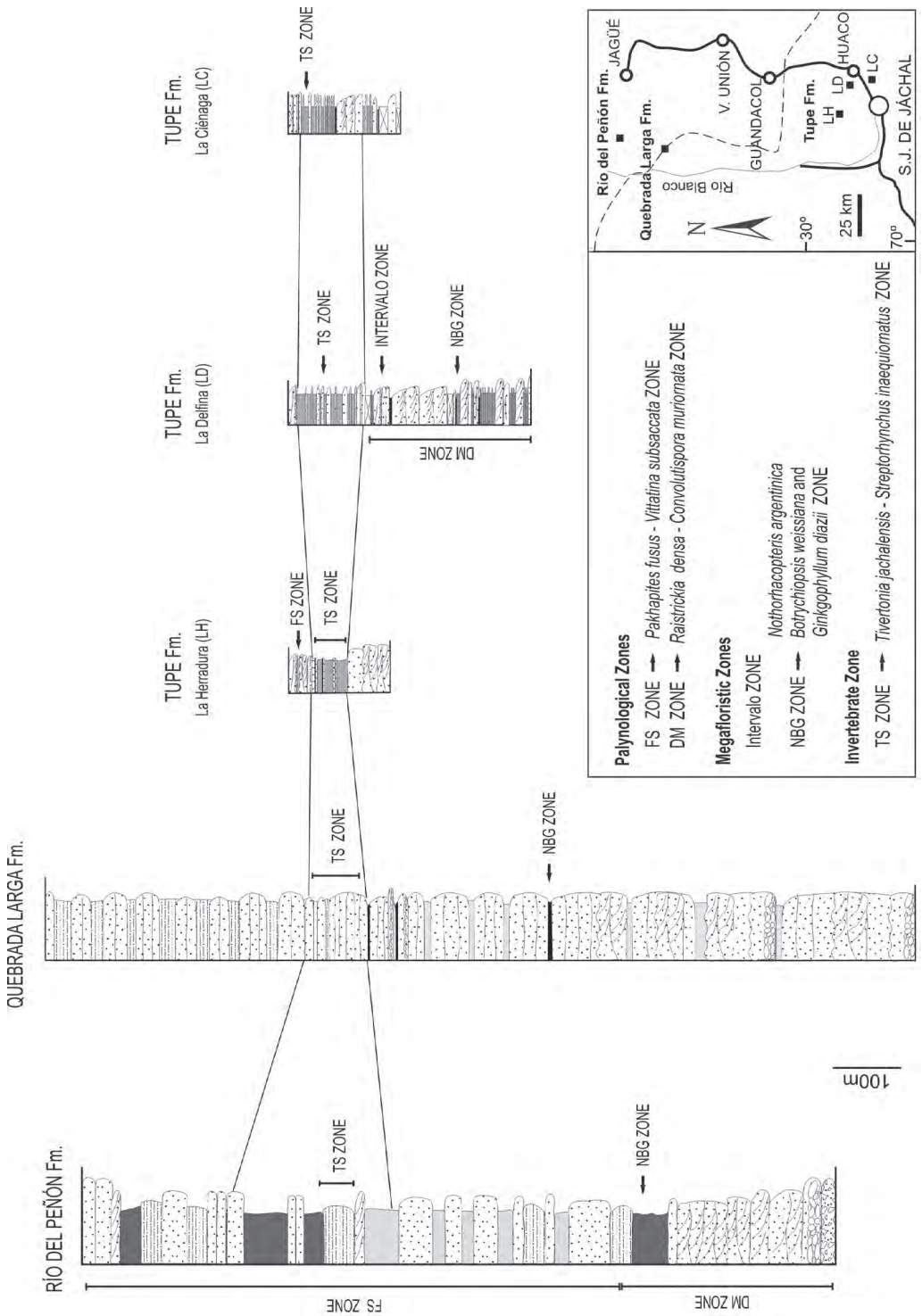

FIG. 8. Stratigraphic correlation as the hypothetical matching of the sections studied, showing the latest Carboniferous-early Permian transgression with the record of the *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Invertebrate Zone and its relationship with the mega and microflora assemblages. Captions as previous figures.

the northern hemisphere. However a detailed study of several stratigraphical sections from the western Argentinean basins suggests that the Río del Peñón and Tupe formations (mainly La Herradura Creek and La Delfina Creek localities), deposited into the western Paganzo basin, have the best paleontologic elements to define the Carboniferous-Permian boundary. Particularly, the Tupe Formation is an excellent example, as the beds just a few meters thick include diagnostic paleontological evidence of mega and microflora, as well as of marine invertebrates. These data has led the authors to propose a biostratigraphical framework that relates the Latest Carboniferous assemblages NBG, Interval megafloristic Zone and DM (*Raistrickia densa-Convolutispora muriornata*) Palynological Zone, in the lower part of this succession, with the earliest Permian T-S (*Tivertonia jachalensis-Streptorhynchus inaequiornatus*) invertebrate Zone and FS (*Pakhapites fusus-Vittatina subsaccata*) Palynological Zone, from the middle to upper part of the section. This biostratigraphical scheme is proposed as an aim to restrict the Carboniferous-Permian boundary in the Argentine Precordillera; it could also be applied to intra and inter basinal correlations. The occurrence of diagnostic elements in the widely distributed T-S Zone could have important implications for the definition of the Carboniferous-Permian boundary in the west-central basins of Argentina. This is expressed in the stratigraphic correlation of the studied sections, which shows the latest Carboniferous-early Permian transgression and the relationship between the fossil assemblages (Fig. 8).

The marine interval of the Tupe Formation, characterized by changes in thickness between adjacent localities, records the maximum transgression of the Paganzo Basin (Dejardins *et al*., 2009). In several sections of the Tupe Formation in the western Paganzo basin (Fig. 8), the marine horizons containing diagnostic elements of the T-S Zone are bounded by the upper and lower part of the micro and megafloristic key assemblages. The best and most developed section of the T-S Zone within the basin is documented in the Tupe Formation at La Herradura Creek, the westernmost fossiliferous locality. A distinctive vertical distribution of the T-S fauna has been recognized along a 15 m thick fossiliferous interval, allowing the identification of the possibly oldest T-S faunal assemblages (Cisterna *et al.,* 2002). The assemblage of brachiopod genera such as *Pericospira-Kochiproductus-Costatumulus*, that appear to be dominant in the oldest part of this zone, represent the main component of the T-S fauna in La Delfina Creek section, where the fauna is vertically concentrated. The bivalves that appear associated in the T-S Zone in the La Herradura Creek section have also been identified in the upper part of Río del Peñón Formation, which overlies the T-S zone. The more characteristic Permian bivalves from this assemblage are *Nuculavus levatiformis* and *Septimyalina* sp. whose tethyan affinities have been discussed previously by Sterren (2004).

In the Tupe Formation at the Mina La Ciénaga locality, the latest Carboniferous-early Permian transgression is well represented in stratigraphical terms, but the fauna is not abundant and the the diagnostic elements of the T-S Zone have not been identified. The marine horizons of this section, apart from those of La Delfina Creek, represent the easternmost location that the Panthalassan marine ingression reaches in the western Paganzo Basin; the fauna here is comparatively impoverished in relation to those registered in other localities inside of the western part of the Paganzo basin (Cisterna *et al.,* 2006b).

A similar biostratigraphical pattern that includes the invertebrate, palynological and megafloristic zones has also been recognized in the thicker succession of the Río del Peñón Formation in its reference section (Rincón Blanco locality, Río Blanco basin). The T-S Zone appears in a 38 m thick succession, in the upper part of the marine member, showing a particular vertical distribution. Although the key species *Tivertonia jachalensis* and *Streptorhynchus inaequiornatus* are present, they are not in abundance in the lower part of the fossiliferous interval; the brachiopod faunal assemblage is dominated by *Pericospira riojanensis*. In the upper part of the interval, brachiopods and ostracods constitute the dominant taxa. *Tivertonia jachalensis* is abundant and the species identified in the lower part disappear. As it was noted in the Tupe Formation, in the youngest part of the T-S Zone, the diagnostic species *Tivertonia jachalensis* is *Streptorhynchus inaequiornatus* appear to be more abundant. Some brachiopod genera that characterize the T-S fauna (*i.e., Streptorhynchus*, *Pericospira, Costatumulus*), have also been identified in the lowest part of the Río del Peñón section, immediately above the latest Carboniferous megafloristic assemblages. However, the fossil material that integrates this assemblage

(Assemblage I, Cisterna and Simanuskas, 2000), is fragmentary and has not been determined at specific level. Also, the brachiopod species *Septosyngothyris jaguelensis*, similar to those described from the Tupe Formation, has been recognized in the uppermost brachiopod assemblage of the Río del Peñón section, informally identified as *Neochonetes-Rhynchopora* (Assemblages III, Cisterna and Simanauskas, 2000). This assemblage could represent the latest Early Permian marine horizons inside the Río Blanco and Paganzo basins, but its biostratigraphical relationship with the Early Permian *Costatumulus amosi* fauna, from the Calingasta-Uspallata basin, has not yet been examined in detail.

The mollusks are markedly less abundant compared to the brachiopods in the T-S assemblage of the Río del Peñón section. Gastropods are present with *Barrealispira* sp. aff. *B. tupensis*, characteristic of the Tupe Formation, but bivalves are almost absent. The typical bivalves with Permian affinities appear in two levels above the T-S fauna. The lower one, is characterized by *Heteropecten anteloi*, *Pterinopectinella ramaccionii* and *Ptychopteria* (*Ptychopteria*) *liagracielae.* In the upper level the fossil assemblage is composed of a more diversified bivalve fauna (*Nuculavus levatiformis*, *Leptodesma* (*Leptodesma*) cf. *potens*, *Ptychopteria* (*Ptychopteria*) *liagracielae*, *Acanthopecten jaguelensis*, *Schizodus arrondoi*, *Wilkingia riojana* and Parallelodontidae indet., Sterren, 2000, 2002), accompanied by the gastropods *Knightites* (*Cymatospira*) *montfortianus* and *'Peruvispira'* sp. (Cisterna and Sabattini, 1998), that also exhibit Permian affinities.

Palynological records have been well documented along the fossiliferous marine interval of the Río del Peñón Formation (Gutiérrez and Limarino, 2006). The T-S Zone is associated with elements of the Early Permian FS (*Pakhapites fusus-Vittatina subsaccata*) Palynological Zone and below this faunal assemblage, with the Latest Carboniferous DM (*Raistrickia densa-Convolutispora muriornata*) Zone, which has also been identified by Gutiérrez and Limarino (2006). The new palynological evidence from the upper part of the Río del Peñón section, presented in this article, suggests the presence of the *Pakhapites fusus-Vittatina subsaccata* (FS) Zone (late Cisuralian-early Guadalupian). The palynological record associated with the T-S Zone in the Río del Peñón Formation would define the age of the Panthalassan marine transgression into the Río Blanco Basin, as well as provide another tool for correlation.

The oldest part of the T-S Zone appears to be not present in the Quebrada Larga Formation, but the faunal assemblage shows a compositional variation along the fossiliferous interval. *Septosyringothyris* sp. aff. *S. jaguelensis*, the dominant brachiopod species, accompanied by *Tivertonia jachalensis*, *Orbiculoidea* sp. and very scarce *Streptorhynchus inaequiornatus*, characterizes the lower part of the interval, and *Coronalosia* sp. and *Svalbardia* sp. (two new species with Permian gondwanan affinities that are being studied by one of the authors), the upper. Although there is no palynological evidence from the Quebrada Larga Formation, the occurrence of *Tivertonia jachalensis-Streptorhynchus inaequiornatus* fauna above a bed carrying elements of the Late Carboniferous megafloristic assemblage NBG, allows to consider this unit as a potential key section for studying the Carboniferous-Permian boundary.

The geographical extension of the T-S Zone is clearly restricted to the Río Blanco and western Paganzo basins; however some of their brachiopods (*Tivertonia jachalensis, Pericospira rioajensis, Pericospira pericoensis*), bivalves (*Modiolus* (*Modiolus*), *Schizodus*, *Edmodia*, *Wilkingia*, Myalinidae and Parallelodontidae), and gastropods (*Knightites* (*Cymatospira*) *montfortianus* and *'Peruvispira'* sp.), are common and show affinities with those recognized in the lower member of the Del Salto Formation in the Calingasta-Uspallata Basin. Furthermore, the identification of the *Tivertonia jachalensis* in the Del Salto Formation (Taboada, 2006), appears to extend the geographical distribution of *Tivertonia jachalensis-Streptorhynchus inaequiornatus* fauna into the Calingasta-Uspallata Basin. The stratigraphical relationship between the T-S Zone and the *Costatumulus amosi* Zone (Taboada, 1998), from the early Permian successions of the Agua del Jagüel and Santa Elena formations (Mendoza province, Calingasta-Uspallata Basin) is not clear. Taboada (2006) has proposed a youngest age (latest Asselian- Sakmarian?) for the *Costatumulus amosi* Zone, but several common diagnostic species have been suggested for both zones. Further studies will allow the correct biostratigraphical relationship between *Tivertonia jachalensis-Streptorhynchus inaequiornatus* Zone and the *Costatumulus amosi* Zone. A better biostratigraphical and paleobiogeographic

knowledge of the Precordilleran Permian marine faunas will provide a better understanding of their relationship with those fauna from the Patagonian basins (Tepuel Genoa and San Rafael basins), as well as with faunas from Perú, Bolivia and Chile, which have recently been studied (Cisterna and Niemeyer, 2010; Cisterna *et al.,*2009).

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APPENDIX

Alphabetical list of the identified species and illustration references

Megaflora

Fedekurtzia argentina (Kurtz) Archangelsky 1981 (figures 3.1-2)
Kraeuselcladus sp. cf. *K. argentinus* Archangelsky 1979 (figures 3.8-9)
Nothorhacopteris argentinica (Geinitz) Archangelsky 1983 (figure 3.7)
Rinconadia archangelskyi Vega 1995 (figures 3)
Botrychiopsis weissiana Kurtz emend. Archangelsky and Arrondo 1971
Eusphenopteris sp. (figures 3.3, 5)
Malanzania nana Archangelsky, Azcuy and Wagner 1981

Spores and pollen grains

Alisporites rioclarensis Menéndez 1976
Anapiculatasporites conncinus Playford 1962 (=*A. argentinensis* Azcuy 1975)
Anapiculatisporites tereteangulatus (Balme and Hennelly) Playford and Dino 2002 (figure 4.9)
Apiculatasporites parviapiculatus Azcuy 1975
Apiculatisporis variornatus Di Pasquo, Azcuy and Souza 2003 (figure 4.14)
Barakarites rotatus (Balme and Hennelly) Bharadwaj and Tiwari 1964
Botryococcus braunii Kutzing 1849
Brevitriletes levis (Balme and Hennelly) Bharadwaj and Srivastava 1969 (figure 4.5)
Brevitriletes parmatus (Balme y Hennelly) Backhouse 1991 (figure 4.23)
Caheniasaccites sp. cf. C. elongatus Bose and Kar 1966
Calamospora breviradiata Kosanke 1950
Circumplicatipollis plicatus Ottone and Azcuy 1988
Converrucosisporites confluens (Archangelsky and Gamerro) Playford and Dino 2002
Converrucosisporites sp. A
Convolutispora muriornata Menéndez 1965 (figure 4.20)
Costatascyclus crenulatus Urban 1971
Cristatisporites menedezii (Menéndez and Azcuy) Playford (figure 4.22)
Cristatisporites rollerii Ottone 1989
Cristatisporites scabiosus Menéndez 1965
Cristatisporites stellatus (Azcuy) Gutiérrez and Limarino 2001 (figure 4.17)
Crucisaccites latisulcatus Lele and Maithy 1964
Crucisaccites monoletus Maithy 1965
Dibolisporites disfacies Jones and Truswell 1992
Foveosporites hortonensis (Playford) Azcuy 1975
Gondwanapollis frenguelli (Césari) Gutiérrez 1993
Horriditriletes ramosus (Balme and Hennelly) Bharadwaj and Salujha 1964 (figure 4.10)
Kraeuselisporites spinosus Jansonius 1962
Laevigatosporites colliensis (Balme and Hennelly) Venkatachala and Kar 1968
Latusipollenites qudrisaccatus Marques-Toigo 1974 (figures 4.6-7)
Leiotriletes directus Balme and Hennelly 1956
Marsupipollenites striatus (Balme and Hennelly) Foster 1975
Marsupipollenites triradiatus Balme and Hennelly 1956
Pakhapites fusus (Bose and Kar) Menéndez 1971

Protohaploxypinus goraiensis (Potonié and Lele) Hart 1964
Protohaploxypinus sewardii (Virkki) Hart 1964
Pseudoreticulatispora pseudoreticulata (Balme and Hennelly) Bharadwaj and Srivastava 1969
Pteruchipollenites gracilis (Segroves) Foster 1975
Raistrickia densa Menéndez 1965 (figure 4.19)
Raistrickia rotunda Azcuy 1975 (figure 4.21)
Reticulatisporites passaspectus Ottone 1991
Scherungipollenites ovatus (Balme and Hennelly) Foster 1979
Spelaeotriletes ybertii (Marques-Toigo) Playford and Powis 1979 (figure 4.13)
Tubersicaccites tuberculatus (Maheswari) Lele and Makada 1972 (figure 4.24)
Vallatisporites ciliaris Sullivan 1964 (figure 4.18)
Verrucosisporites andersonii (Anderson) Backhouse 1991

Acritarchs
Brazilea scissa (Balme and Hennelly) Foster 1975 (figure 4.8)

Brachiopods
Coolkilella keideli Taboada 1998
Coronalosia argentinensis Archbold and Simanauskas 2001 (figure 5.5)
Costatumulus sp. C (figure 5.20)
Crurithyris sp. (figure 5.9)
Kochiproductus riojanus (Leanza 1948) (figures 5.12, 15)
Neochonetes pegnonensis Cisterna and Simanauskas 2000 (figures 5.18-19)
Pericospira pericoensis (Leanza 1945) (figure 5.4)
Pericospira riojanensis (Lech and Aceñolaza 1987) (figures 5.7-8)
Rhynchophora sp. (figures 5.16-17)
Septosyringothyris jaguelensis Lech 1986 (figure 5.21)
Streptorhynchus inaequiornatus Leanza 1948 (figures 5.1-2)
Tivertonia jachalensis (Amos 1961) (figures 5.3, 10-11)
Tupelosia paganzoensis Archbold and Simanauskas 2001 (figure 5.6)

Bivalves
Acanthopecten jaguelensis González 1997 (figure 5.23)
Aviculopecten sp. nov. (figures 5.22, 24)
Heteropecten anteloi González 1997
Leptodesma (Leptodesma) potens Hall 1883
Nuculavus levatiformis (Walcott 1884) (figure 5.13)
Palaeolima cf. *P*. sp. Dickins 1963
Parallelodontidae (figure 5.27)
Phestia bellistriata (Stevens 1858)
Pterinopectinella ramaccionii González 1997
Ptychopteria (*Ptychopteria*) *liagracielae* (Leanza 1948) (figure 5.26)
Schizodus arrondoi González 1992
Septimyalina sp. (figure 5.14)
Wilkingia riojana González 1992 (figure 5.25)

Gastropods
Barrealispira tupensis Sabattini, Ottone and Azcuy 1991
Knightites (*Cymatospira*) *montfortianus* (Norwood and Pratten) Sturgeon 1964