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Revision of the first Carboniferous palaeofloristic locality discovered in Argentina

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ABSTRACT. The first Carboniferous palaeofloristic locality recognized in Argentina is situated to the south of the Sierra Chica de Zonda in San Juan Province, Argentina. The fossiliferous site known as Retamito or Río del Agua provided plant remains which were studied by the Polish scientist Ladislaus Szajnocha in 1891. Szajnocha proposed an early Carboniferous age for the assemblage and described some species of lycophytes and sphenophytes, and foliage of cordaitalean and probable pteridosperms. Subsequent studies of this outcrop and its palaeontological content have been few, and a new interdisciplinary approach is needed. The succession is interpreted as fluvial-deltaic in origin, with intercalation of shallow marine deposits, which provided diagnostic plant components of the *Nothorhacopteris* / *Botrychiopsis* / *Ginkgophyllum* Biozone of the late Carboniferous in Argentina. Palynological assemblages recovered from the same strata contain bisaccate taeniate pollen and spores (e.g. *Striatosporites heyleri*) that support an age probably not older than early Moscovian.

KEYWORDS: palynology, palaeoflora, Carboniferous, Moscovian, Argentina

INTRODUCTION

The Carboniferous outcrops located near the town of Pedernal in San Juan Province, Argentina, have been mentioned in the literature since the end of the 19th century. The site, known as Retamito but also identified as Río del Agua or Las Crucecitas (see González Amicón 1973), provided the first Carboniferous plant remains in Argentina. Berg (1891a, b), Kurtz (1891, 1894), Szajnocha (1891) and Bodenbender (1893), were the first to recognize the importance of the stratigraphic section. Later, Frenguelli (1944, 1946), Polanski (1970) and González Amicón (1973) improved the palaeontological and geological knowledge of the fossiliferous site.

Previously, Geinitz (1876) had mentioned the presence of fossil plants in outcrops referred today to the Carboniferous Agua Colorada Formation in La Rioja Province, but proposed a Triassic age for the unit. When Kurtz (1921) revised the palaeoflora, the stratigraphic section was considered to be Carboniferous in age.

The Polish scientist Ladislaus Szajnocha was the first to illustrate a plant fossil collection (given by Berg) from the Retamito or Río del Agua locality (Szajnocha 1891). Szajnocha reported that at the end of 1889 he received from Dr. Carlos Berg (Professor of Zoology and Botany at the University of Buenos Aires) a collection of fossil plant remains collected at Retamito in San Juan Province, Argentina. According to information provided by Fernando Meister (priest and director of the seminary in San Juan) to Szajnocha, the fossiliferous outcrops are located "three *leguas* west of the Retamito [railway] station between the towns of Divisadero and Los Berros in a ravine deeply excavated by rain." At that time one *legua* equaled approximately 5 km;

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that makes a distance of ca 18 km between the presently abandoned Retamito railway station and the outcrops (Figs 1, 2C).

Despite the importance of this fossiliferous site, there have been few geological and palaeontological studies of it; an update of its palaeofloristic content is needed to constrain the age of the deposits and to improve their correlation. The present contribution also is intended to stress the importance of the taxonomic identifications made by Szajnocha (1891), which allowed a Carboniferous flora to be recognized in Argentina for the first time.

HISTORICAL BACKGROUND

In 1870, Law 448 enacted by the Argentine government boosted the search for coal by granting leases to the discoverers of high-quality deposits. Around 1887, José Maasen discovered a coal deposit near the Retamito locality and informed Fernando Meister (priest and director of the seminary in San Juan), who collected plant remains that were sent to Carlos Berg at the Museum of Buenos Aires (Berg 1891b: 70, 71).

Berg sent plant remains found in the Retamito locality to Professor Szajnocha in Kraków and published the first news about Carboniferous coal deposits in the country (Berg 1891a, b). In the following months, Szajnocha (1891) confirmed the age of the deposits by describing the fossil flora preserved in the coal. Kurtz (1891) also supported the age of the deposits, based on plant samples sent him by Brackebush, a geologist who visited the mine, accompanied by Maasen (Berg 1891: 71). Zuber (1892) distinguished the coal deposits of Retamito from the Triassic coal deposits that had been discovered

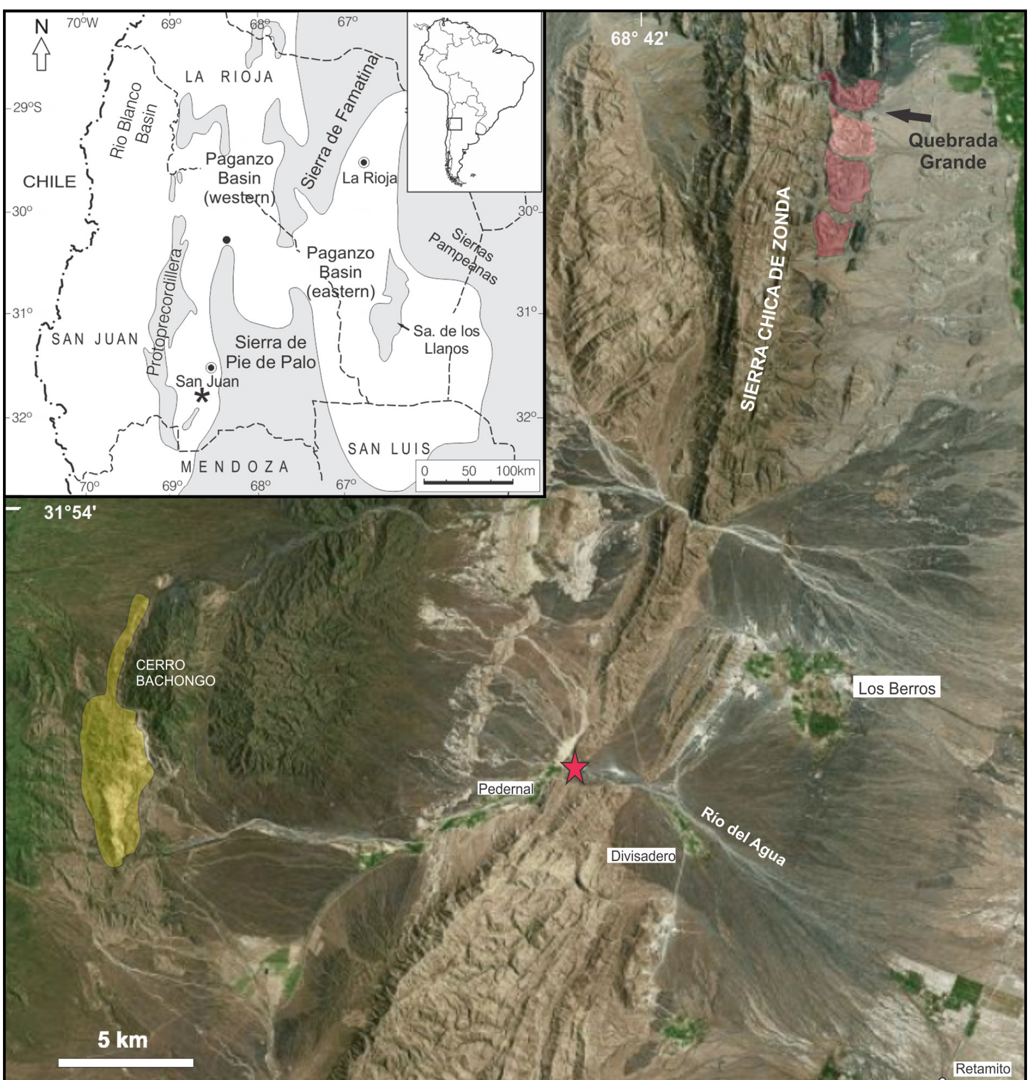

Fig. 1. Location of the Río del Agua site (star) within the Paganzo Basin (inset) and in the southern part of San Juan city, showing the outcrops of the Jejenes Formation (pink) and Andapaico Formation (yellow)

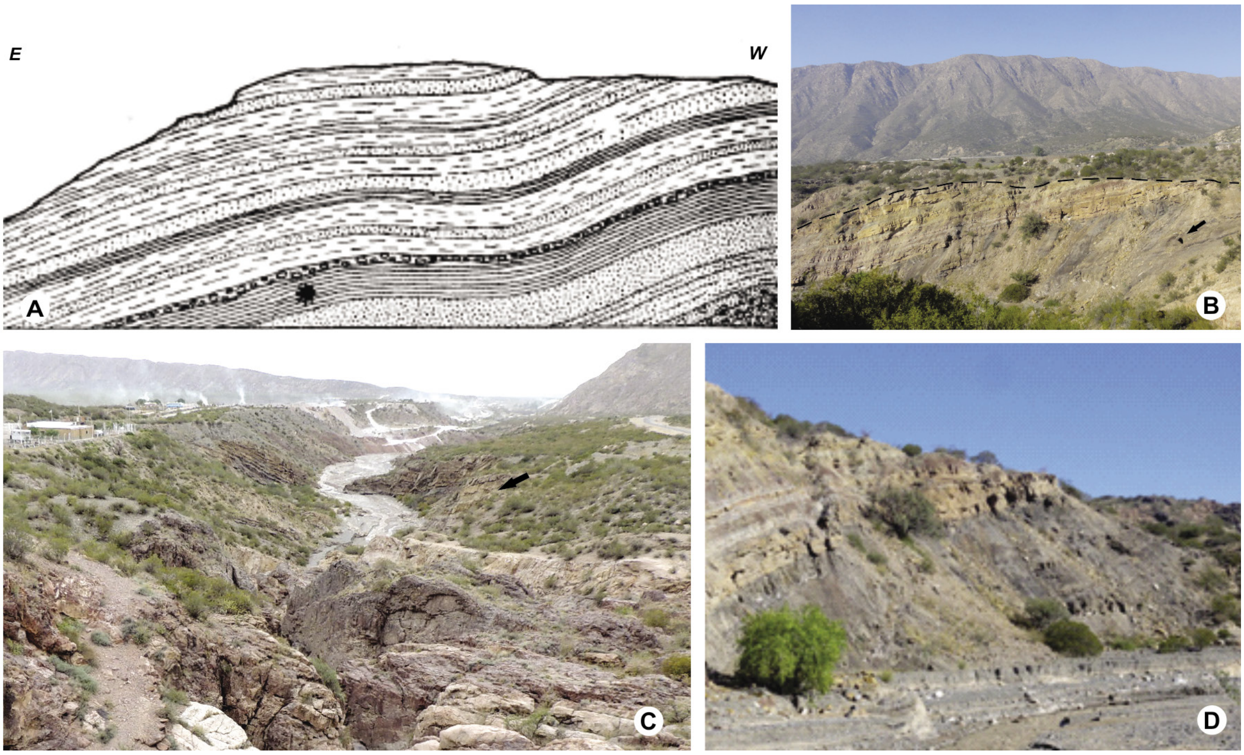

Fig. 2. **A** – Reproduction of fig. 4 from Frenguelli (1944); star indicates the fossiliferous strata; **B** – View of the outcrops of A, arrow points to a mine gallery; **C** – View west to east of the outcrops along the Río del Agua creek. Arrow points approximately to the position of the mine gallery shown in B; **D** – View of the fossiliferous strata in the creek

in Argentina. Bodenbender (1893) visited the fossiliferous site, accompanied by Maasen, and provided the first description of its location and geological setting, as well as an excellent historical account of the discovery. He also provided a detailed description of the Retamito or Río del Agua succession, dividing it into sixteen horizons, from the limestone basement to the reddish shales and sandstones of the upper sector, including the plant fossil-bearing black shales, all together 127 meters thick.

Later, Bodenbender (1896) made the first correlation of Retamito with other Argentinian localities containing coal, such as Huaco (Tupe Formation), Cerro Bola (Tupe Fm), Cerro El Fuerte (Tupe Fm), Panacán (Panacán Fm) and Trapiche (Volcán Fm). Valentin (1897) used geological and palaeontological data to confirm the existence of the Carboniferous System in Argentina, noting the fossil plants studied by Szajnocha and Kurtz from Retamito.

Half a century later, the fossiliferous outcrops were examined by Frenguelli (1944), who located the site near the Río del Agua waterfall, 16–17 km west of the Retamito railway station, and published a stratigraphic section of the outcrops, indicating the position of the fossiliferous levels (ca 10 m above the basal conglomerate; Fig 2A). He described and illustrated new specimens, and proposed a younger age for the assemblage that referred to the upper Westphalian. Bracaccini (1946) improved the stratigraphy of the Río del Agua deposits mentioned by Bodenbender (1902), with detailed tectonic and sedimentary descriptions, giving a total thickness of 650–700 m for the deposits; according to Bracaccini, an angular discordance separates the Carboniferous outcrops from eopalaeozoic limestones.

The low quality of the coal deposits in Río del Agua discouraged geological studies in the area, but the northern Carboniferous outcrops of the Sierra Chica de Zonda were analyzed by Amos (1954) and referred to the Jejenes Formation. He pointed out the absence of evidence for including the deposits of Retamito in that lithostratigraphic unit. Following that scheme, Polanski (1970) proposed the new name "Retamito Formation" for the Carboniferous succession at Río del Agua, and González Amicón (1973) described the succession in detail in a palynological analysis.

In brief communications, Ruzycki de Berenstein (1987) and Ruzycki de Berenstein and Bercowski (1988) interpreted the whole unit as having been deposited in a fluvial palaeoenvironment. Recently, Vázquez et al. (2016) reinterpreted the succession as alternating

Table 1. Taxa identified by previous authors, compared with those reported in this publication

Szajnocha 1891	Kurtz 1894–1921	Frenguelli 1944	Archangelsky et al. 1981	Archangelsky et al. 1995	This paper
Archaeocalamites radiatus	*Archaeocalamites radiatus* var. *scrobiculatus*	*Calamites peruvianus*		Sphenopsida *incertae sedis*	*Gondwanites subtilis*
Lepidodendron gr. *L. nothum*	*Lepidodendron australe*			*Bumbudendron* (?) sp. *B*	*Brasilodendron* cf. *B. pedroanum*
Lepidodendron pedroanum	*Lepidodendron pedroanum*	*Lepidodendron peruvianum*	*Bumbudendron paganzianum*	*Bumbudendron* (?) sp. *B*	
					Malanzania nana
Rhacopteris cf. *machaneki*					*Nothorhacopteris argentinica*
Cordaites cf. *borassifolius*	*Cordaites* sp.				*Cordaites riojanus*
Rhabdocarpus sp.					
	Botrychiopsis weissiana	*Botrychiopsis weissiana*		*Botrychiopsis weissiana*	*Botrychiopsis weissiana*
		Gondwanidium plantianum		*Botrychiopsis weissiana*	
					Diplothmema bodenbenderi

fluvial-deltaic palaeoenvironments with shallow marine intercalations. An angular unconformity separates the deposits from the underlying early Palaeozoic limestones. The fossiliferous black shales and coals at 80 m from the base (Fig. 2 B, D) would be coeval to the coal deposits found in the Tupe Formation (Paganzo Basin). The upward change of color in the Río del Agua succession from greenish to reddish would be equivalent to the transition from the Tupe Formation to the overlying Patquía Formation.

PALAEOFLORISTIC CONTENT

We analyzed the palaeofloristic content of the unit by revising several original specimens studied by Kurtz (deposited at the Paleobotanical Collection of Córdoba University under CORD PB) and Frenguelli (deposited at the La Plata Museum under LPPB) and also new mega- and microfloristic samples. We also compared the specimens described by Szajnocha (1891); Table 1 compiles data on equivalence to previous identifications.

In the original collection of eighteen specimens, Szajnocha (1891) identified the following species: *Archaeocalamites radiatus* Brongniart, *Lepidodendron* of the Group *L. nothum* Unger, *Lepidodendron pedroanum* Carruthers, *Rhacopteris* cf. *machaneki* Stur, *Cordaites* cf. *borassifolius* Brgt. and ?*Rhabdocarpus* sp. He mentioned that the plant remains are preserved in “rock, black, hard, anthracite slate, highly reflective”, comparable with some Austrian or German Culm slate varieties. About the age of the assemblage, Szajnocha established that four of the determinable plants (ignoring the somewhat questionable *Rhabdocarpus*) are well known in Europe, where three of them (*Archaeocalamites radiatus*, *Lepidodendron nothum*, *Rhacopteris machaneki*) occur only in the lower part of the Culm, while only one (*Cordaites borassifolius*) indicates the upper part.

Kurtz (1894) studied a new assemblage provided by Brackebusch and characterized the new genus *Botrychiopsis*, a taxon that years later was shown to be a diagnostic species of the Pennsylvanian floras in the region (Archangelsky & Azcuy 1985). Kurtz (1894) had compared the frond with the Mississippian species *Cardiopteris* from Europe. Kurtz (1921) recognized the presence of *Archaeocalamites radiatus* var. *scrobiculatus* (Schloth.)

Seward., *Botrychiopsis weissiana* Kurtz, *Lepidodendron australe* McCoy and *Cordaites* sp. in the Retamito palaeoflora.

The flora was characterized as a “Flora of *Lepidodendron*” and considered early Carboniferous, equivalent to the basal stage of the “Kuttung series” of New South Wales and chronologically equivalent to the middle part of the Dinantian of Europe and the Mississippian of North America. However, Frenguelli (1944) made a new collection in the carbonaceous strata of the lower section which were interpreted as probably glacilacustrine in origin; he described the dominance of *Calamites peruvianus* Gothan stems and rare specimens of *Botrychiopsis weissiana* Kurtz, *Gondwanidium plantianum* (Carr.) Gerth (=*Neuropteridium validum* Carruthers) and *Lepidodendron peruvianum* Goth., and assigned a late Carboniferous (Stephanian) age to the flora. Later, Archangelsky and Arrondo (1971) revised the specimens of *G. plantianum* studied by Frenguelli and concluded that they belong to *B. weissiana* Kurtz.

UPDATED SYSTEMATICS

Class SPHENOPSIDA

Order EQUISETALES

Family NOTOCALAMITACEAE Rigby 1972

Genus ***Gondwanites***
Césari & Perez Loinaze 2006

Gondwanites subtilis
Césari & Perez Loinaze 2006
Pl. 1, figs 1–4

Comments. Specimens illustrated by Szajnocha (1891) were described as “larger to 35 mm wide, as well as younger barely 2 mm wide and somewhat blurred branches”; long, narrow, thin leaves occur scattered in the samples, and ribbed contorted stems were interpreted as roots (Szajnocha 1891: pl. I, fig. 3). He assigned the specimens from Argentina to *Archaeocalamites radiatus* Brongniart, a species characterized by having whorls of narrow and bifurcated leaves.

Later, Kurtz (1921) mentioned the presence of *Archaeocalamites radiatus* (Brong.) var. *scrobiculatus* (Schloth.) Seward at the Río del Agua locality. Archangelsky et al. (1995) revised specimens CORD PB no. 393–395 of Kurtz’s collection, describing leaf whorls bearing narrow leaves bifurcated several times, attached to stems similar to *Paracalamites*; they proposed that the specimens represent a new taxon. Here we reproduce (Pl. 1, fig. 3) figure 5 of plate XXXVI of Kurtz (1921), corresponding to specimen CORD PB no. 394 (Pl. 1, fig. 4) which probably was broken.

We collected small axis fragments 2 cm long and 0.2 cm wide (PBSJ 1475, Pl. 1, fig. 1) bearing narrow, linear, bifurcated leaves, which are equivalent to those illustrated by Szajnocha (1891). A larger stem, 9.5 cm long and 2 cm wide, is represented in sample CORD PB 874 (Pl. 1, fig. 2), also bearing the holotype of *B. weissiana* (Kurtz 1894). It preserved a node with continuous ribbing, without leaves. Some specimens collected (LPPB 10752) and described by Frenguelli (1944) and referred to *Calamites peruvianus,* up to 2.5 cm wide and 17 cm long, complete the assemblage of equisetalean stems.

Gondwanites subtilis Césari & Perez Loinaze described from Pennsylvanian deposits in the nearby Sierra de Barreal (Césari & Perez Loinaze 2006) appears to be the taxon of the specimens from Retamito. It has slender ultimate axes bearing whorls of very thin, simple or divided leaves in the same whorl. Bractless fertile whorls are located just below the vegetative whorls.

Class LYCOPSIDA

Order PROTOLEPIDODENDRALES

Remarks. The description and interpretation of the lycophytes preserved as impression specimens are based on the morphological distinctions proposed by Thomas and Meyen (1984).

Genus ***Brasilodendron***
Chaloner, Leistikow & Hill 1979

Brasilodendron cf. ***B. pedroanum***
(Carruthers) Chaloner, Leistikow & Hill 1979
Pl. 1, figs 5, 8–10

Comments. Szajnocha (1891) described as *Lepidodendron pedroanum* Carruthers, stems with “spiraling, rounded-rhombic leaf cushions between 5 and 6 mm in size, showing, in

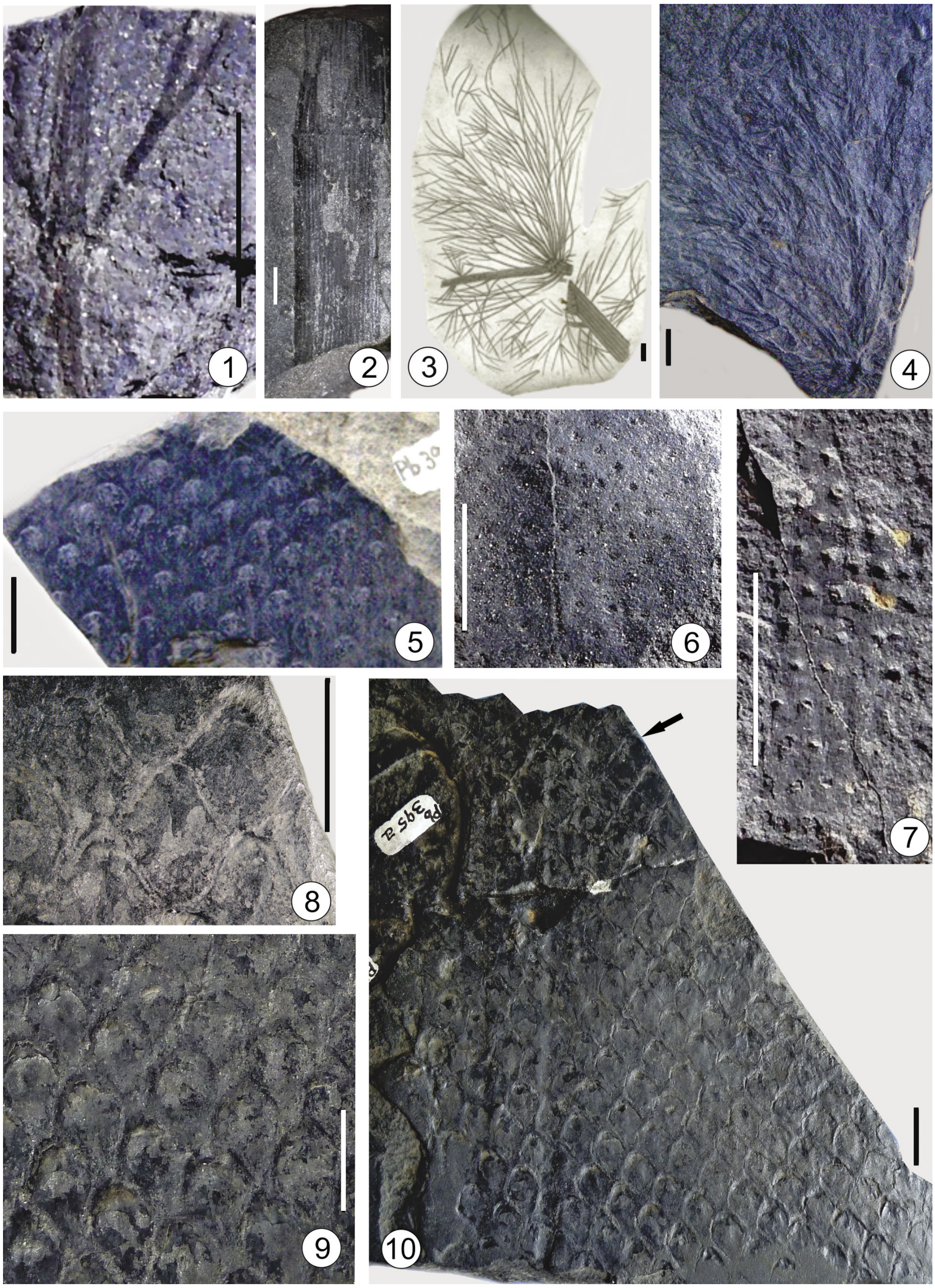

Plate 1. **1–4**. *Gondwanites subtilis*. **1**. PBSJ 1475; **2**. CORD-PB 874; **3**. Reproduction of figure 5, plate XXXVI from Kurtz (1921); **4**. CORD-PB 394. **5, 8–10**. *Brasilodendron* cf. *B. pedroanum*. **5**. CORD-PB 395; **8**. Detail of leaf cushions at arrow in 10, CORD-PB 396; **9**. Detail of leaf cushions in 10; **10**. CORD-PB 396; **6–7**. *Malanzania nana*. **6**. PBSJ 1476; **7**. PBSJ 1477. Scale bar: 1 cm

impressions of the outer surface of the bark at its upper end, one well-protruding, approximately crescent-shaped depression which stands out on the outer surface of the bark fragment as a rather sharply outlined scar". Archangelsky et al. (1981) suggested that the specimen figured by Szajnocha (1891: pl. II, figs 2, 3) may be assigned to *Bumbudendron paganzianum* Archangelsky, Azcuy & Wagner, although the leaf cushions are wider and the interareas narrower. Another species illustrated by Szajnocha (1891: pl. II, fig. 1), *Lepidodendron* ex gr. *L. nothum* Unger, with closely arranged, rhombic leaf cushions, is poorly preserved, impeding a precise identification according to Archangelsky et al. (1981).

Similar specimens were mentioned by Kurtz (1894, 1921) as *Lepidodendron pedroanum* (Carruthers) Szajnocha and re-illustrated by Archangelsky et al. (1995).

Arrondo and Petriella (1979) described the specimens CORD PB 395a and 396 of Kurtz's collection deposited at Córdoba University as *Lycopodiopsis pedroanus* (Carruthers) Edwards emend. Kräusel. These specimens were also revised by Archangelsky et al. (1981, 1995) and considered to be a new species of *Bumbudendron* (the lycophyte that characterizes the Pennsylvanian flora of western Argentina) and similar to "*Lepidodendropsis peruviana*" (Gothan) Jongmans.

Frenguelli (1944) suggested that the lycophytes illustrated by Szajnocha (1891) and Kurtz (1921) belong to *Lepidodendron peruvianum* Gothan. Archangelsky et al. (1981) stated that the specimen illustrated by Frenguelli (1944: pl. 10, fig. 1) from Retamito as *L. peruvianum* is similar to *Bumbudendron paganzianum* Archangelsky, Azcuy & Wagner. However, its poor preservation prevents precise identification of the decorticated stem.

In our revision of specimens CORD PB 395 and 396 (Pl. 1, figs 5, 10) analyzed by Kurtz and illustrated by Archangelsky et al. (1995), we describe them as incomplete and decorticated fragments up to 16 cm wide. These stems show closely spaced subrhombic leaf cushions arranged in lepidodendroid phyllotaxis, up to 10 mm high at 7 mm maximum width (halfway up the leaf cushion), with a rounded apex. There are no distinctive leaf scars but the leaf insertion seems to have been subapical (Pl. 1, fig. 9). They are similar to the sample illustrated by Szajnocha (1891: pl. I, fig. 2), which was described by Archangelsky et al. (1981) as a possible representative of *B. paganzianum,* segregating the specimen illustrated in Szajnocha's plate I, fig. 1 by its rhombic leaf cushions. However, similar rhombic leaf cushions are recognized in CORD PB 396 (Pl. 1, figs 8, 10, see arrow), where their morphology varies, as is usual in lycophytes, by ontogeny and degree of decortication.

Among the species that have been compared with the lycophytes found in the Retamito Formation, we agree in part with the proposal of Arrondo and Petriella (1979), who referred them to *Lycopodiopsis pedroanum* (Carruthers) Edwards emend. Kräusel. They coincide in the shape of decorticated leaf cushions as described by those authors. Chaloner et al. (1979) restricted *Lycopodiopsis* to material with preserved anatomy and proposed *Brasilodendron* for imprints and compressions bearing leaf cushions lacking evidence of leaf abscissions and ligule pits. Therefore, we assign to *Brasilodendron* the lycophytes from Retamito, which are also similar to its type species.

Remains of lycophytes up to 15 cm in width, suggesting a subarborescent habit, have also been described in northwestern Argentina in the Tupe and Solca formations (Césari 1982, Coturel et al. 2009).

Genus ***Malanzania***
Archangelsky, Azcuy & Wagner 1981

Malanzania nana
Archangelsky, Azcuy & Wagner 1981
Pl. 1, figs 6, 7

Description. This species includes small unbranched stems with widely spaced, small, subcircular false leaf scars with a fairly regular disposition in a steep spiral (ca 60°), without clear evidence of a leaf trace. The fragments 2–3 cm long recovered from the Retamito Formation (PBSJ 1476, 1477) show subcircular false leaf scars, equidistant vertically and subhorizontally (Pl. 1, figs 6, 7), similar to *M. nana* as described from the Malanzán, Trampeadero and Jejenes formations (Archangelsky et al. 1981).

This is the first record of the species in the Retamito Formation.

Class PTERIDOSPERMOPSIDA

Order PTERIDOSPERMALES

Genus ***Botrychiopsis*** Kurtz 1894

Botrychiopsis weissiana Kurtz emend.
Archangelsky & Arrondo 1971
Pl. 2, figs 1–4, 8–10

Comments. Kurtz (1984) studied a sample provided by Brackebush from the Retamito Formation and defined the new taxon *Botrychiopsis*, which was characterized as: "Robust fern, widely linear frond, mono-pinnate, rachis stout, bi-sulcate, with a few striae (2–3) separated by thin sulcus. Pinnae alternate imbricate, deeply

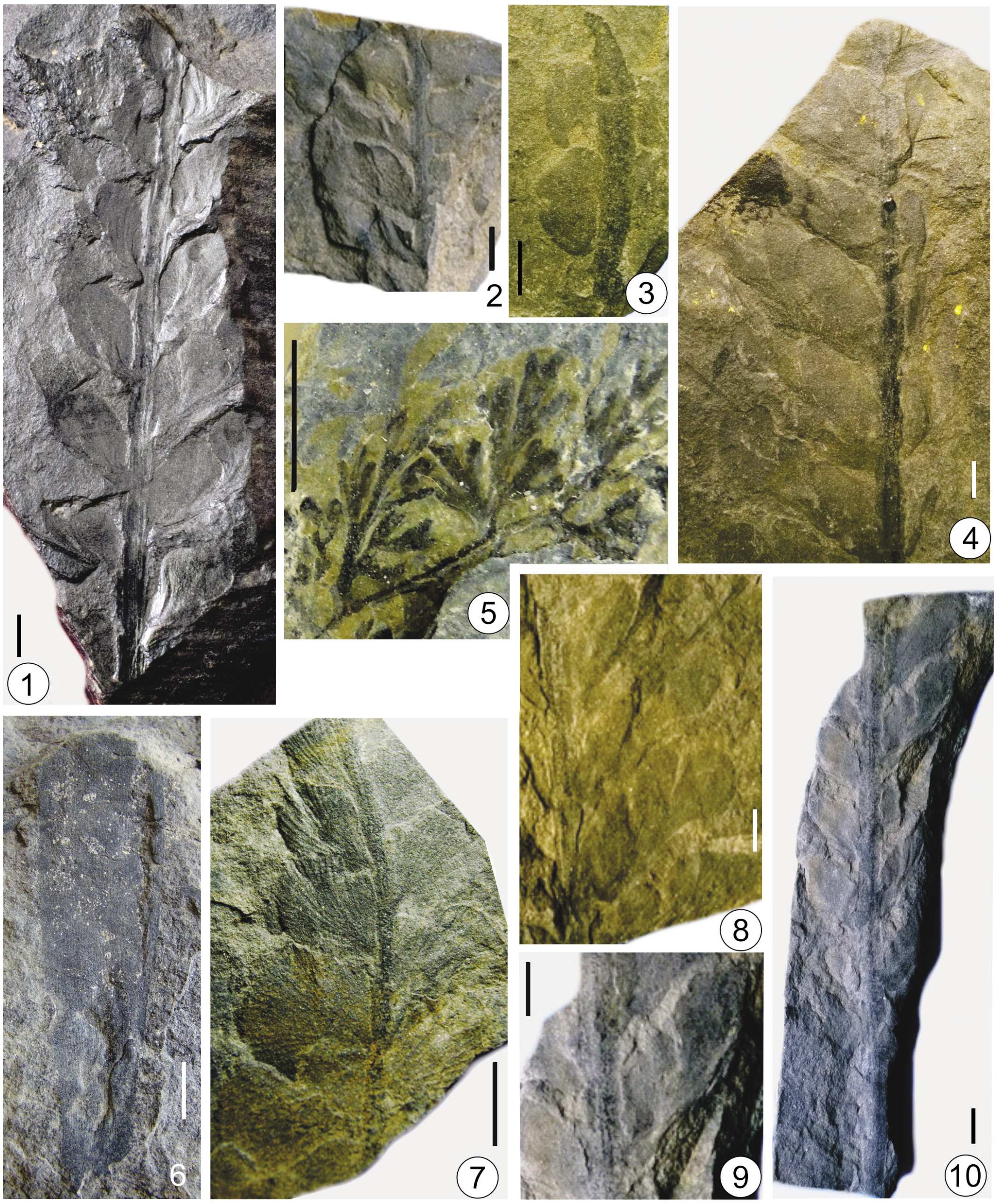

Plate 2. **1–4**, **8–10**. *Botrychiopsis weissiana*. **1**. CORD-PB 874, holotype; **2**. Specimen illustrated by Frenguelli (1944), LPPB 10763; **3**. Basal foliar expansions, LPPB10745; **4**. Detail of pinna, LPPB 4302 counterpart; **8**. Bipinnate fragment, LPPB 4302; **9–10**. LPPB 4303; **5**. *Diplothmema bodenbenderi*, PBSJ 1478; **6**. *Cordaites riojanus* PBSJ 1480; **7**. *Nothorhacopteris argentinica* PBSJ 1479. Scale bar: 1 cm

trilobate; apical lobe with cuneiform base and wider square-obcordate apex, veins uniform, divergent and dichotomous, emerging from the rachis; lateral lobes rhomboid". Archangelsky and Arrondo (1971) revised the holotype CORD PB 874 of the type species *B. weissiana* illustrated by Kurtz (1894: pl. I, fig. 1). The specimen, 14.5 cm long and 5 cm wide, possesses a rachis 5 mm wide bearing six pinnae inserted at 45–60° alternately on each side. The pinnae are sunken in the sediment, showing only the anadromous pinnules (Pl. 2, fig. 1). Archangelsky and Arrondo (1971) emended the diagnosis of *B. weissiana* by revising specimens from other localities, adding the morphology of the basal part of the frond with sessile foliar expansions that develop to pinnules, becoming bipinnate in the medial and distal sections.

Frenguelli (1944: pl. IX, fig. 3) also illustrated a specimen (LPPB 10763) of *B. weissiana* from Río del Agua, which is poorly preserved, as well as the holotype, showing catadromic pinnules sunken in the sediment (Pl. 2, fig. 2). The same author determined as *Gondwanidium plantianum* specimen LPPB 10745 (Pl. 2, fig. 3), which represents basal pinnules of *B. weissiana* according to Archangelsky and Arrondo (1971). Two other specimens deposited in the La Plata Museum, LPPB 4302 and 4303 from the Retamito Formation, are here illustrated in Pl. 2, figs 4, 8 and 9–10, respectively.

Genus ***Diplothmema*** Stur 1877

Diplothmema bodenbenderi
(Kurtz) Césari 1987
Pl. 2, fig. 5

Comments. A specimen collected at the Río del Agua locality is referred to *D. bodenbenderi*, a species originally described by Kurtz (1921) as *Sphenopteris bodenbenderi* from the Agua Colorada and Jejenes formations. It was characterized by Césari (1987) as having quadripinnate fronds, main rachis dichotomous, pinnae inserted at nearly 90°, pinnules deeply dissected in narrow cuneate segments with emarginate or shortly bilobate apex. Pinnule base with a single vein which dichotomizes successively in each lobe. Césari (1987) described ovules in organic connection with *D. bodenbenderi*-type foliage from Mississippian strata, erecting the new taxon *Eonotosperma arrondoi*, which was proposed only for fertile foliage of that age.

Specimen PBSJ 1478 illustrated in Pl. 2, fig. 5 displays all the characters of *D. bodenbenderi* and is the first mention of this taxon in the Retamito Formation.

Family AUSTROCALYXACEAE
Vega & Archangelsky 2001

Genus ***Nothorhacopteris***
Archangelsky 1983

Nothorhacopteris argentinica
(Geinitz) Archangelsky 1983
Pl. 2, fig. 7

Comments. Szajnocha (1891) described but did not illustrate *Rhacopteris* cf. *machaneki* Stur, from two poorly preserved specimens. This northern species was combined to *Anisopteris* by Oberste-Brink (1914). A new specimen (PBSJ 1479) collected from the Retamito Formation (Pl. 2, fig. 7) is very similar to the type specimen of *N. argentinica* illustrated by Archangelsky (1983), showing a main rachis bearing sessile, cuneate pinnules with a rounded apical margin. Pinnules alternate to subopposed, obliquely inserted, with dichotomous veins radiating from the base. Archangelsky (1983) erected *Nothorhacopteris,* which was applied to Gondwanan monopinnate fronds bearing sessile or shortly petiolate cuneate or subcircular pinnules with radiating, dichotomous venation. The type species, *N. argentinica* (Geinitz) Archangelsky, was based on specimens wrongly described as Triassic in age by Geinitz (1876) from Carboniferous deposits today known as the Agua Colorada Formation.

This is the first mention of this key species of the *Nothorhacopteris*/*Botrychiopsis*/*Ginkgophyllum* (NBG) Biozone for this locality.

Class GYMNOSPERMOPSIDA

Order CORDAITALES

Genus ***Cordaites*** Unger 1850

Cordaites riojanus
Archangelsky & Leguizamón 1980
Pl. 2, fig. 6

Comments. Szajnocha (1891, pl. II, fig. 4) reported *Cordaites* cf. *borassifolius* Brongniart, a species characteristic of the European Carboniferous. Kurtz (1894) also recognized cordaitalean leaves in the palaeoflora of the Retamito Formation.

A new specimen (PBSJ 1480) collected at Río del Agua is illustrated in Pl. 2, fig. 6, which is a leaf 10 cm long and a maximum 2.7 cm wide at the distal part, with ca 20 parallel veins per cm. These morphological characters correspond to those of *Cordaites riojanus* Archangelsky & Leguizamón, a species described for small cordaitalean leaves from the Pennsylvanian flora of Argentina (Archangelsky & Leguizamón 1980). However, it must be considered that leaf morphology and venation are of little taxonomic value, as demonstrated by Šimůnek (2007) and Šimůnek and Florjan (2013).

PALYNOLOGY

The first palynological studies of the Retamito Formation were those of González Amicón (1973), based on seven samples from carbonaceous strata with plant remains. Gutiérrez and Césari (1987) added to the palynological content of the unit, mentioning the presence of monosaccate pollen.

Recently, new sampling of the sequence allowed us to identify abundant and well-preserved assemblages containing monolete and trilete spores, together with monosaccate and taeniate bisaccate pollen (Vázquez et al. 2016). The following species have been identified in the Retamito Formation in the three palynological contributions mentioned above:

Spores:

Ahrensisporites cristatus Playford & Powis (Pl. 1, fig. 8)

Apiculatasporites caperatus Menéndez & Azcuy

Apiculatasporites spinolistratus (Loose) Ibrahim (Pl. 1, fig. 2)

Apiculiretusispora ralla (Menéndez & Azcuy) Menéndez & Azcuy

Apiculiretusispora cf. *A. papillata* Menéndez & Azcuy

Apiculiretusispora sparsa Menéndez & Azcuy

Apiculiretusispora variornata (M. & A.) Menéndez & Azcuy

Convolutispora muriornata Menéndez (Pl. 1, fig. 9)

Convolutispora sinuosa Menéndez

Cristatisporites mendendezii (Menéndez & Azcuy) Playford

Cristatisporites scabiosus Menéndez

C. verrucosus González Amicón

Dictyotriletes diversiluminis González Amicón

Granulatisporites varigranifer Menéndez & Azcuy

Grossusporites microgranulatus (Menéndez & Azcuy) Perez Loinaze & Césari (Pl. 1, fig. 3)

Horriditriletes uruguaiensis (Marques Toigo) Archangelsky & Gamerro (Pl. 1, fig. 1)

H. ramosus (Balme & Hennelly) Bharadwaj & Salujha

H. superbus (Foster) Césari, Archangelsky & V. de Seoane. Remarks: Césari et al. (1995) included in this species the specimens originally described by González Amicón (1973) as *Acanthotriletes menendezii*.

H. curvibaculosus Bharadwaj & Salhuja

Irmosporites circumpolaris Menéndez & Azcuy

Lophotriletes discordis Gutiérrez & Césari

Lundbladispora braziliensis (Pant & Srivastava) Marques-Toigo & Pons emend. Marques Toigo & Picarelli (Pl. 1, fig. 10)

Pustulatisporites papillosus (Knox) Potonié & Kremp

Raistrickia densa Menéndez (Pl. 1, fig. 6)

Retusotriletes anfractus Menéndez & Azcuy

Spelaeotriletes ybertii (Marques-Toigo) Playford & Powis (Pl. 1, fig. 7)

Striatosporites heyleri (Doubinger) Playford & Dino (Pl. 1, fig. 5)

Laevigatosporites vulgaris (Ibrahim) Ibrahim (Pl. 1, fig. 4)

Vallatisporites cf. *V. arcuatus* (Marques-Toigo) Archangelsky & Gamerro

Waltzispora polita (Hoffmeister, Staplin & Malloy) Smith & Butterworth,

Portalites gondwanensis Nahuys, Alpern & Ybert

Pollen:

Caheniasaccites densus Lele & Karim

Cannanoropollis densus (Lele) Bose & Maheshwari

Florinites verrucosus González Amicón (Pl. 1, fig. 19)

Limitisporites hexagonalis Bose & Maheshwari (Pl. 1, fig. 16)

Limitisporites rectus Leschik (Pl. 1, fig. 18)

Potonieisporites magnus Lele & Karim

Potonieisporites neglectus Potonié & Lele (Pl. 1, fig. 11)

Potonieisporites novicus Bharadwaj

Potonieisporites seorsus Playford & Dino 2000 (Pl. 1, fig. 17)

Plicatipollenites malabarensis (Potonié & Sah) Foster (Pl. 1, fig. 12)

Striatoabieites multistriatus (Balme & Hennelly) Hart (Pl. 1, fig. 15)

Striatopodocarpites cf. *S. gondwanensis* Lakhanpal, Sah & Duve (Pl. 1, fig. 13)

Striatopodocarpites cf. *S. pantii* (Jansonius) Balme 1970 (Pl. 1, fig. 14)

Striatopodocarpites sp. (Pl. 1, fig. 20)

COMPARISONS AND AGE

The palynological assemblages can be referred to Subzone B of the *Raistrickia densa / Convolutispora muriornata* Biozone (DM) proposed by Césari and Gutiérrez (2000) for the upper Palaeozoic of central-western Argentina. The three subzones of the DM Biozone are characterized by an abundance of monosaccate pollen. The palynofloras from Río del Agua contain the two species that give the name to the biozone,

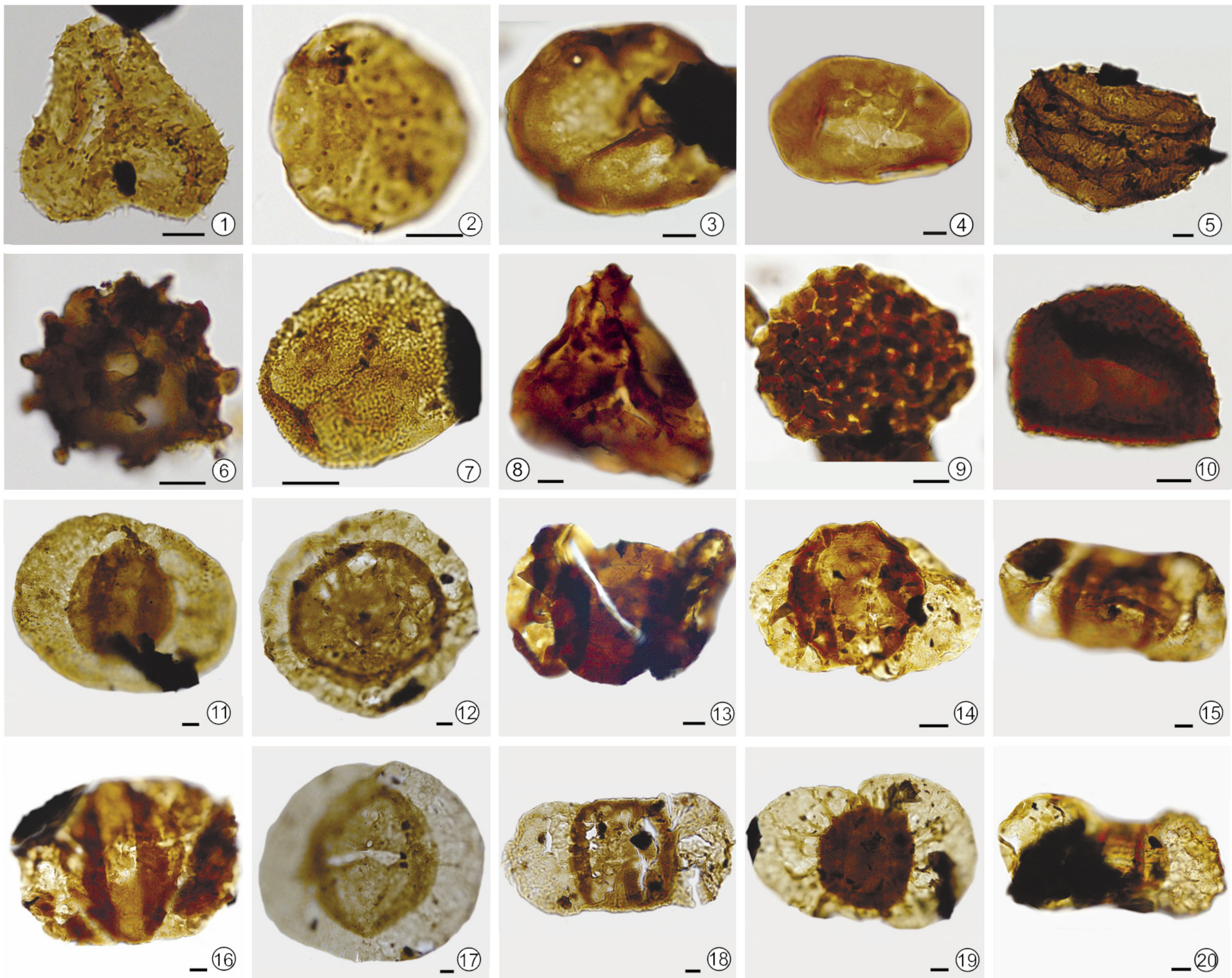

Plate 3. **1**. *Horriditriletes uruguaiensis*; **2**. *Apiculatasporites spinolistratus*; **3**. *Grossusporites microgranulatus*; **4**. *Laevigatosporites vulgaris*; **5**. *Striatosporites heyleri*; **6**. *Raistrickia densa*; **7**. *Spelaeotriletes ybertii*; **8**. *Ahrensisporites cristatus*; **9**. *Convolutispora muriornata*; **10**. *Lundbladispora braziliensis*; **11**. *Potonieisporites neglectus*; **12**. *Plicatipollenites malabarensis*; **13**. *Striatopodocarpites* cf. *S. gondwanensis*; **14**. *Striatopodocarpites* cf. *S. pantii*; **15**. *Striatoabieites multistriatus*; **16**. *Limitisporites hexagonalis*; **17**. *Potonieisporites seorsus*; **18**. *Limitisporites rectus*; **19**. *Florinites verrucosus*; **20**. *Striatopodocarpites* sp. Scale bar: 10 µm

and other diagnostic species such as *Spelaeotriletes ybertii*, *Grossusporites microgranulatus* and *Lundbladispora braziliensis.* The presence of taeniate bisaccate pollen allows comparisons with Subzones B and C. Moreover, the recognition of *Striatosporites heyleri* indicates at least a Moscovian or younger age for the deposits (see Playford & Dino 2000). In the same way, the smooth specimens of *S. heyleri* that can be described as *Laevigatosporites vulgaris* have their worldwide first occurrence in the Moscovian. Argentinian Subzones B and C were referred to the late Bashkirian and Moscovian by ^{206}Pb/^{238}U zircon dating (Césari et al. 2011). Subzone B is constrained between 318.79 ± 0.10 Ma at the base and 315.46 ± 0.07 Ma at the top. Transgressive successions related to Subzone C probably were deposited in the interval of ^{206}Pb/^{238}U ages 312.82 ± 0.11 Ma and 310.71 ± 0.1 Ma (Gulbranson et al. 2010, Césari et al. 2011).

Macrofloristic remains identified in the Retamito Formation belong to the *Nothorhacopteris/Botrychiopsis/Ginkgophyllum* Biozone (NBG), which expands in the late Serpukhovian–Bashkirian in northwestern Argentina (Césari et al. 2011). This monotonous and not very diverse flora includes assemblages preserved in glacial and postglacial deposits of the widespread Guandacol and Tupe formations and their local equivalents. The younger *Krauselcladus–Asterotheca* Biozone (Carrizo & Azcuy 2015) includes the latest Carboniferous assemblages where the first occurrences of conifer and fern remains are identified and glossopterid leaves are absent. Although this megafloristic biozone, identified in the upper section of the Libertad Formation, has been considered coeval with the palynological Subzone C, few palynological controls exist. At the type locality, palynofloras were recovered from the basal section of the Libertad Formation and referred to Subzone B, whereas the overlying Los Sauces Formation provides assemblages of the *Pakhapites fusus–Vittatina subsaccata* Biozone (FS) (Di Pasquo et al. 2010) referred to the Ghzelian–Cisuralian (Césari & Chiesa 2017). Other palaeofloras considered to undoubtedly belong to the KA Biozone (by the presence of the two key taxa) associated with palynofloras have not been described up to now in northwestern Argentina. Moreover, Gutiérrez and Barreda (2006) proposed that the stratigraphic range of *Krauselcladus argentinus* Archangelsky must be extended to the early Pennsylvanian. Therefore, the precise age of this biozone remains uncertain until further studies permit its age to be constrained to the late Pennsylvanian.

STRATIGRAPHIC CORRELATIONS IN THE AREA

To the north of the Río del Agua site, the Jejenes Formation (Amos 1954) crops out in a large area between Las Lajas and Los Berros creeks, on the eastern margin of the Sierra Chica de Zonda. Amos (1954) described the section of reference at Quebrada Grande – Jejenes and La Mina creeks, with glacial deposits at the base and plant remains at the top.

The Río del Agua outcrops have been described as the Jejenes Formation by some authors (Gutiérrez & Césari 1987, Archangelsky et al. 1995) but there are differences between the Retamito and Jejenes formations that make it possible to separate them. Although they share some plant species assigned to the NBG Biozone, there are differences in their palaeoenvironmental sedimentation and palynological assemblages.

Kneller et al. (2004) and Dykstra et al. (2006) described the Jejenes Formation as filling of a glacial valley and its tributaries in a palaeofjord environment with catastrophic sedimentation at Quebrada Grande Creek. They mentioned the presence of large wood fragments in silty mudstones lacking dropstones. Anatomically preserved trunks were described by Pujana (2005) at La Mina Creek (Cladera et al. 2000) a few kilometers to the south of Quebrada Grande. Gymnosperm wood *Abietopitys petriellae* (Brea & Césari) Pujana is associated at La Mina Creek with a rich palaeofloristic assemblage characterized by the presence of: *Nothorhacopteris argentinica* (Geinitz) Archangelsky, *Sphenopteris sarmientoi* Vega & Iannuzzi, *Fedekurtzia argentina* (Kurtz) Archangelsky, *Diplothmema bodenbenderi* (Kurtz) Césari, *Rhacopteris szajnochai* Kurtz, *Eusphenopteris sanjuanina* (Kurtz) Césari emend. Césari et al., *Ginkgophyllum diazii* Archangelsky & Arrondo and *Cordaites* sp., together with reproductive structures such as *Rinconadia archangelskyi* Vega, *Austrocalyx jejenensis* Vega & Archangelsky and *Polycalyx laterale* Vega & Archangelsky. Brea and Césari (1995) have also described *A. petriellae* wood in high-density flows of lacustrine deposits outcropping at Las Lajas Creek.

Gutiérrez and Césari (1987) described sparse palynofloras dominated by monosaccate pollen from the Jejenes Formation at the La Mina Creek locality. Later, Césari and Bercowski (1997) analyzed 21 palynological samples from the basal section of the Jejenes Formation at Las Lajas Creek, suggesting a nearshore marine environment. Those assemblages, not very well preserved, have several species in common with those analyzed here (*Ahrensisporites cristatus, Lundbladispora braziliensis*, *Raistrickia densa*) but taeniate pollen is absent.

Recently, Valdez Buso et al. (2017) presented new data for the Jejenes Formation at Quebrada Grande Creek. U-Pb SHRIMP analysis of twelve zircon grains from a tuff level provided two populations: (1) three zircons yielding ages from 1088 ± 24 to 1204 ± 32 Ma, and (2) nine zircon grains yielding ages from 347 ± 8.4 to 311 ± 7.2 Ma. The mean age calculated from seven concordant younger zircon grains was 321.3 ± 5.3 Ma. Despite the 5 My uncertainty of these data, Valdez Buso et al. (2017) suggested an early Bashkirian age for the strata. From these deposits they recovered poorly preserved small lycophyte stems with leaf cushions missing details, in helicoidal phyllotaxis. These stems were compared with *Frenguellia eximia* (Frenguelli) Arrondo et al., a diagnostic Mississippian lycophyte from western Argentina. Imprints of platyspermic seeds without significant biostratigraphic value complete the floristic assemblage represented by *Cordaicarpus cesariae* Gutiérrez et al. emend. Archangelsky and *Cordaicarpus famatinensis* Gutiérrez et al.

Valdez Buso et al. (2017) reported recovery of eight palynological samples providing poorly preserved palynomorphs (three samples containing only 1–3% palynomorphs). Most of the illustrated specimens are very fragmentary and their taxonomic assignments are uncertain: for example, *Plicatipollenites malabarensis* Fig. 14.M, *Lundbladispora braziliensis* Fig. 14.L. However, based on the presence of *Cristatisporites*-like spores, *Vallatisporites ciliaris* and *Circumplicatipollis plicatus* (with a large stratigraphic range throughout the Pennsylvanian) and indeterminate monosaccate pollen, Valdez Buso et al. (2017) compared the palynofloras with other assemblages from Argentina and concluded similitude with Subzone A of the DM Biozone. This agrees with the previous correlation proposed by Césari and Gutiérrez (2001) for the basal part of the Jejenes Formation based on the most abundant palynofloras described by Césari and Bercowski (1997). The age of Subzone A was considered late Serpukhovian–early Bashkirian by Césari et al. (2011).

The absence of late Serpukhovian–early Bashkirian glacial deposits in the Retamito Formation, which characterized a key stratigraphic level of correlation in northwestern Argentina, supports a younger age for this unit. Moreover, the available data on the palaeontological content of the Jejenes Formation also suggest its older age, based mainly on the absence of taeniate pollen in the palynofloras up to now known for that unit.

The Andapaico Formation, another upper Palaeozoic stratigraphic unit in the region (Fig. 1), was analyzed by Correa et al. (2012) at its outcrops (430 m thick) near the Bachongo site. At the basal section of the unit they recognized plant remains including conifers (*Ferugliocladus patagonicus*) and palynological assemblages containing taeniate pollen (*Protohaploxypinus, Illinites*), together with spores such as *Converrucosisporites confluens*, a key species of the late Carboniferous/ early Cisuralian boundary (Stephenson 2009, Césari & Chiesa 2017). Therefore, the Andapaico Formation is younger than the Retamito Formation.

CONCLUSIONS

Our revision of the first Carboniferous palaeoflora recognized in Argentina by Szajnocha in 1891 confirmed its Pennsylvanian age. Plant remains are preserved in coal-bearing strata of the Retamito Formation at the Río del Agua locality, including lycopsids, pteridosperms, cordaites and sphenopsids. Lycopsids are represented by *Brasilodendron* cf. *B. pedroanum* and *Malanzania nana*, probably indicating sub-arborescent and herbaceous habits respectively. Pteridosperms are represented by foliage of *Botrychiopsis weissiana, Diplothmema bodenbenderi* and *Nothorhacopteris argentinica*, which characterize the NBG Biozone from Argentina. Small leaves of *Cordaites riojanus* confirm the presence of cordaitalean plants in the flora. Finally, sphenopsids are represented by narrow branches of *Gondwanites subtilis*, characterized by its divided leaves.

The palynological assemblages are dominated by spores and monosaccate pollen, together with subordinate bisaccate taeniate grains. The presence of sparse taeniate *Protohaploxypinus* and *Striatoabieites* specimens and the monolete spores *Laevigatosporites vulgaris* and *Striatosporites heyleri* suggests an early Moscovian age for the Retamito Formation.

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