Rev. Mus. Argentino Cienc. Nat., n.s.
26(1): 1-10, 2024
ISSN 1514-5158 (impresa)
ISSN 1853-0400 (en línea)

New paleobotanical data from the Puntudo Chico Formation (uppermost Cretaceous), Chubut Province, Argentina

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Abstract: The Puntudo Chico Formation is a continental unit cropping out in central and northern region of the Chubut Province in Argentina. It is one of the units that overlays the Chubut Group and its age is currently regarded as Campanian to lower Maastrichtian. The previously reported paleontological content of this unit essentially consist of silicified conifer trunks of *Podocarpoxylon mazzonii*, *Agathoxylon antarcticum* and *Brachyoxylon* sp. cf. *B. currumilii* (reported from El Quiosco locality), and palms and the dicot *Aextoxicoxylon kawasianum* identified at Estancia María de las Nieves locality. In this contribution, new conifer woods are reported from the latter locality. *Podocarpoxylon mazzonii* is identified as the most abundant taxon in this locality, as in El Quiosco. A second taxon is *Cupressinoxylon austrocedroides* Nishida, representing the first record of the genus for the unit. Finally, a third wood type is recognized, which can be separated from the other two taxa here identified, but given its deficient preservation remains with unclear taxonomic placement. The shared presence of *P. mazzonii* and *C. austrocedroides* in the Puntudo Chico Formation and in a Danian unit cropping out in the region (*i.e.*, the Salamanca Formation) is discussed.

Keywords: *Podocarpoxylon*, *Cupressinoxylon*, Campanian, Maastrichtian, fossil woods, Patagonia

Resumen: Nuevos datos paleobotánicos para la Formación Puntudo Chico (Cretácico superior alto, provincia del Chubut, Argentina). La Formación Puntudo Chico es una secuencia continental aflorante en la región central y norte de la provincia del Chubut en Argentina. Es una de las unidades que suprayace al Grupo Chubut, y su edad es actualmente considerada campaniana a maastrichtiana inferior. El contenido paleontológico previamente reportado consiste esencialmente de troncos de coníferas silicificadas de *Podocarpoxylon mazzonii*, *Agathoxylon antarcticum* y *Brachyoxylon* sp. cf. *B. currumilii* (reportadas en la localidad El Quiosco), y la dicotiledónea *Aextoxicoxylon kawasianum* y palmeras identificadas en la localidad Estancia María de las Nieves. En esta contribución se reportan nuevas maderas de coníferas procedentes de esta última localidad. *Podocarpoxylon mazzonii* es identificado como el taxón más abundante en la localidad, como también ocurre en El Quiosco. Un segundo taxón reconocido es *Cupressinoxylon austrocedroides* Nishida, representando el primer registro del género para la unidad. Finalmente, se ha identificado un tercer tipo de leño, cuyos rasgos anatómicos permiten separarlo de los otros dos taxones reconocidos, pero su deficiente preservación no permite una ubicación taxonómica precisa. La presencia compartida de *P. mazzonii* y *C. austrocedroides* en la Formación Puntudo Chico y en una unidad daniana aflorante en la región (*i.e.*, la Formación Salamanca) es discutida.

Palabras clave: *Podocarpoxylon*, *Cupressinoxylon*, Campaniano, Maastrichtiano, maderas fósiles, Patagonia

INTRODUCTION

The Puntudo Chico Formation is a continental unit exposed in the Cañadón Asfalto Basin, central region of the Chubut Province, Argentina (Pesce, 1979, Lapido & Page, 1978; Page, 1987; Anselmi *et al*., 2004; Silva Nieto *et al*., 2020). Recent age estimations place the top of the unit in the lower Maastrichtian (Clyde *et al*., 2021), while its deposition probably initiated during the Campanian (Vera *et al*., 2019, and cites therein). The fossil record of the unit consists of silicified plants, including three taxa of conifer woods (Vera *et al*., 2019), identified

at El Quiosco locality, the dicot *Aextoxicoxylon kawasianum* Vera, Perez Loinaze, Llorens et Passalia (Vera *et al.*, 2020) identified at the Estancia María de las Nieves, and fragmentary remains of *Palmoxylon* Schenk, 1882 described preliminarily (Vera *et al.*, 2017) collected from the latter locality. Palynological assemblages, algae, and fungi remains were also recovered from undescribed outcrops, probably belonging to the Puntudo Chico Formation (Llorens & Pérez Pincheira, 2021; Nuñez Otaño *et al.*, 2022). The uppermost Cretaceous age of the Puntudo Chico Formation and the presence of fossil woods in several Danian/Selandian assemblages in the region (*e.g.*, from the Allen, Salamanca/Bororó and Peñas Coloradas formations; Petriella, 1972; Del Fueyo, 1998; Raigemborn *et al.*, 2009; Brea *et al.*, 2011; Passalia *et al.*, 2023) make the Puntudo Chico Formation a relevant unit to evaluate similarities and differences (and probable causes) between assemblages across the K/Pg limit. To allow more precise comparisons, new data on the Puntudo Chico flora coming from different localities is necessary to have a more complete picture of the latest Cretaceous assemblages. In this sense, the objective of this work is to describe new fossil taxa of silicified wood recovered from the Puntudo Chico Formation at Estancia María de las Nieves locality, and evaluate its significance in the floristic assemblages of the latest Cretaceous to early Paleocene interval in northern-central Patagonia.

GEOLOGICAL SETTING

The Puntudo Chico Formation comprises sandstones and conglomerates deposited in a high energy fluvial system, geographically restricted to the Chubut Province (Pesce, 1978; Lapido & Page, 1978; Page, 1987; Anselmi *et al.*, 2004; Silva Nieto *et al.*, 2020). Outcrops of this unit have been considered by some authors as a lower section of the La Colonia Formation (*e.g.*, Pascual *et al.*, 2000; Gasparini *et al.*, 2015), but its nature as a separate lithostratigraphic unit is currently accepted (*e.g.*, Vera *et al.*, 2019; Clyde *et al.*, 2021).

At the study area (*i.e.*, the Estancia María de las Nieves), the Puntudo Chico Formation overlies the Upper Triassic–Middle Jurassic Marifil Formation (Ardolino *et al.*, 1996). In some sectors of the locality, the Puntudo Chico Formation is covered by the marine deposits of the Paleogene Arroyo Verde Formation (Ardolino *et al.*, 1996). Other localities show the Puntudo Chico Formation outcrops overlain by the Maastrichtian to Danian La Colonia Formation (Anselmi *et al.*, 2004; Clyde *et al.*, 2021). Outcrops of the Puntudo Chico Formation in the region (Fig. 1) were in part originally mapped as Chubut Group by Ardolino *et al.* (1996), a proposal not followed here based on field observations.

The Puntudo Chico Formation is commonly regarded as Campanian–Maastrichtian. Vera *et al.* (2019) briefly discussed the age of the unit, comparing its fossil record with other Late Cretaceous to Danian Patagonian floristic assemblages, and suggested a middle to upper Campanian to Maastrichtian age for this unit. Recently, Clyde *et al.* (2021) obtained absolute ages using detrital zircons from rocks located at the top of the Puntudo Chico Formation, immediately below the base of the La Colonia Formation. An age of 71.71 ± 0.33 My obtained by these authors implying that the upper limit of the Puntudo Chico Formation in the area can be constrained to the lowermost Maastrichtian.

MATERIAL AND METHODS

Fifteen wood remains were collected from the Puntudo Chico Formation at the Estancia María de las Nieves locality, Chubut Province, Argentina. Collection was carried out at a site located at the north of the main buildings of the Estancia (42°25′36″S 66°19′51″W) (Fig. 1). Remains are silicified and consist exclusively of secondary xylem. The studied specimens are housed in the paleobotanical collection of the Museo Paleontológico Egidio Feruglio (Trelew, Argentina), under the MPEF-PB acronym. The fossil woods were thin sectioned in transverse (TS), longitudinal tangential (LTS), and longitudinal radial (LRS) sections, and studied using light microscopy (Olympus BX51). Descriptive terminology used here for conifer woods follows the IAWA list of microscopic features for softwood identification (Richter *et al.* 2004), with the addition of terms defined in Philippe & Bamford (2008) and Boura *et al.* (2021). Pit counting method follows Philippe *et al.* (2014). Seriation and contiguity indices proposed by Pujana *et al.* (2016) were also estimated when possible.

SYSTEMATIC PALEONTOLOGY

Fossil Genus. *Podocarpoxylon* Gothan, 1905
Type species. *Podocarpoxylon juniperoides* Gothan, 1906 (in Gagel, 1906)

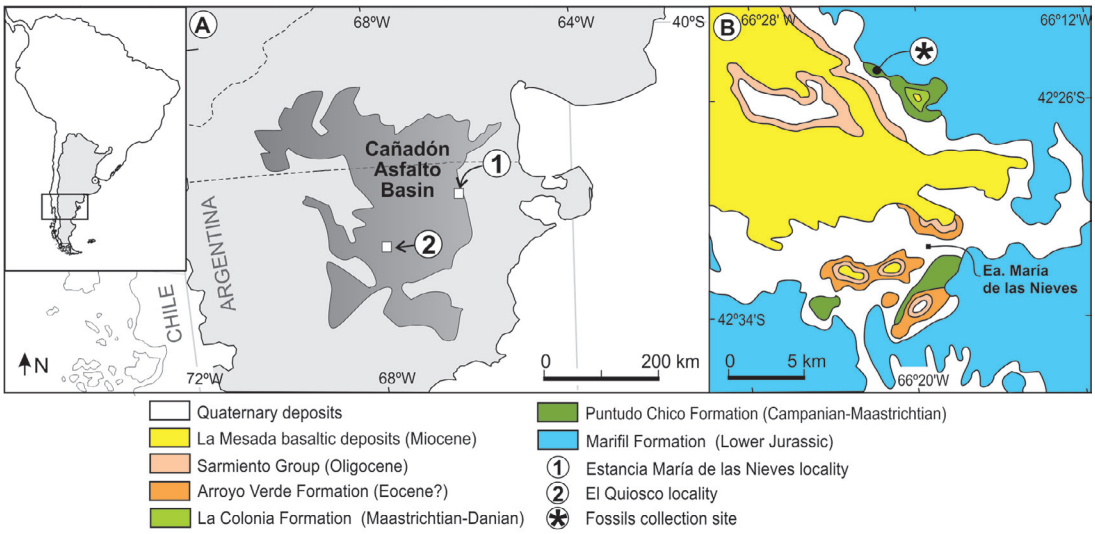

Fig. 1. Location map. Modified from Vera *et al.* (2020). (A) Puntudo Chico Formation outcrops at Estancia María de las Nieves (1) and El Quiosco (2) fossiliferous localities. (B) Detail of the Estancia María de las Nieves showing the fossil collection site.

Podocarpoxylon mazzonii (Petriella) Müller-Stoll et Schultze-Motel, 1990
(Fig. 2)

Basionym
1972 *Messembrioxylon mazzonii* Petriella, p. 173, fig. 3, Pl. 3, A–E
Synonymy
1998 *Circoporoxylon gregussii* Del Fueyo, p. 45, Pl. 1

Studied specimens. MPEF-PB 13010, 13011, 13012, 13013, 13014, 13015, 13016, 13017, 13018, 13019, and 13020.
Locality. Estancia María de las Nieves, Telsen Department, Chubut Province.
Stratigraphic horizon. Puntudo Chico Formation; Upper Cretaceous (middle–upper Campanian to lower Maastrichtian).
Description. Growth ring boundaries distinct. Latewood consisting of 1–4 tracheids with reduced diameter. Transition from earlywood to latewood abrupt. In longitudinal section tracheids usually contain septa-like structures. Tracheid radial pitting abietinean, uniseriate (74–90%) to biseriate/partially biseriate (10–26%). The 5–16% is uniseriate contiguous, 58–85% uniseriate separate and 10–26% biseriate opposite; Si=1.10–1.26, with Cp=2.5–11.5%. Radial pits circular 14.2 (11.6–23) μm in vertical diameter. Tracheid tangential diameter 24 (17.5-33.5) μm. Intercellular spaces rare to absent. Tangential pits and axial parenchyma not observed. Cross-field pitting podocarpoid, with a single circular to pointed half-bordered pit per cross field, with oblique apertures, 8.5 (7–9.6) μm in vertical diameter. Rays homogeneous, parenchymatous, with cells 22.1 (14.2–27.2) μm in vertical diameter. Rays medium, 11 (4–21) cells high, to high, 17.1 (6–29) cells high, partially biseriate (rarely triseriate) and with a frequency of 5.25 (2–10) rays per mm.
Comparisons and remarks. *Podocarpoxylon mazzonii* (Petriella) Müller-Stoll et Schultze-Motel, 1990 is probably one of the most easily recognizable taxa among South American Mesozoic tracheydoxyls, due to its abundant biseriate (to triseriate) rays, uni- to biseriate opposite abietinean pitting, and septa-like structures in the tracheids (Petriella, 1972; Pujana & Ruiz, 2017; Vera *et al.*, 2019). The specimens described here fall within the diagnostic characters of the species (Petriella, 1972).

Podocarpoxylon mazzonii is a species previously reported in the Puntudo Chico Formation at El Quiosco locality (Vera *et al.*, 2019), where it was found in association with *Agathoxylon antarcticum* (Poole et Cantrill) Pujana, Santillana et Marenssi, 2014 and *Brachyoxylon* sp. cf. *B. curumilii* Bodnar, Escapa, Cúneo et Gnaedinger, 2013 (probably referable to *Brachyoxylon patagonicum* Rombola, Greppi et Pujana, 2022 from the Upper Cretaceous Cerro Fortaleza Formation; see discussion in Rombola *et al.*, 2022, and in Greppi *et al.*, 2023).

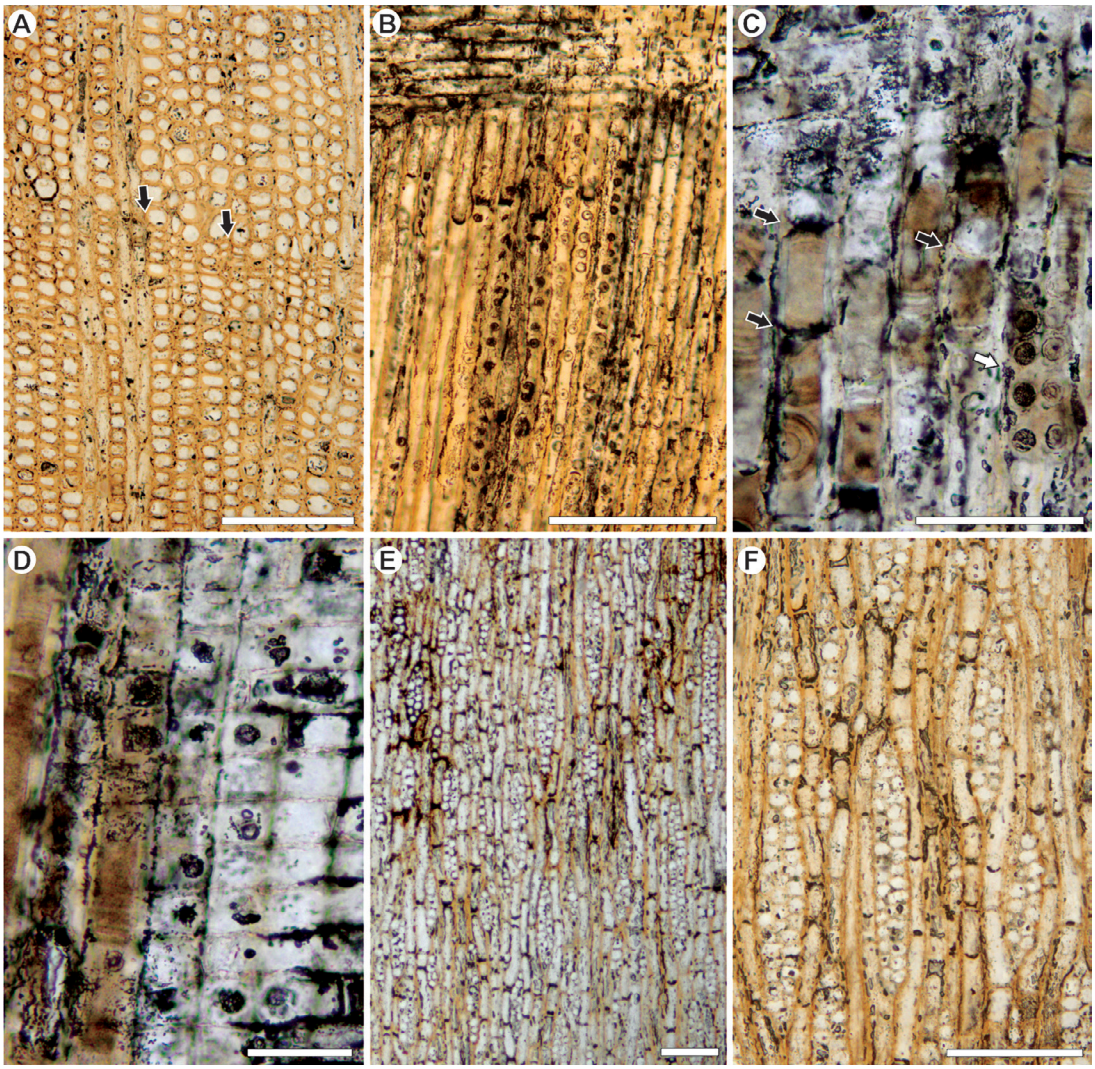

Fig. 2. *Podocarpoxylon mazzonii* (Petriella) Müller-Stoll et Schultze-Motel, 1990. MPEF-PB 13015. (A) TS showing growth ring (arrow). (B) LRS showing uniseriate separate pits. (C) LRS showing biseriate opposite spaced pits (white arrow) and septa-like structures (black arrows). (D) LRS showing cross fields with single circular to pointed half-bordered pit. (E) LTS showing rays. (F) Detail of LTS, showing biseriate partially triseriate rays. Scale bars = 200 μm (A, B, E and F), 100 μm (C), and 50 μm (D).

Podocarpoxylon mazzonii is a taxon recognized mostly from uppermost Cretaceous to Danian assemblages from the Chubut and Río Negro Provinces (Allen, Puntudo Chico, Bororó, Salamanca and Peñas Coloradas Formations; Petriella, 1972; Raigemborn *et al.*, 2009; Brea *et al.*, 2011; Vera *et al.*, 2019; Passalia *et al.*, 2023), Argentinian Patagonia. *Circoporoxylon gregussii*, recognized in the Allen Formation (Del Fueyo, 1998), was later referred to this species of *Podocarpoxylon* (Vera *et al.*, 2019). Recently, Rombola *et al.* (2021) reported the presence of this taxon from the Cardiel Formation in the Cardiel Lake area, Santa Cruz Province, Argentina. Given this unit is considered Cenomanian in age, this could represent the oldest record of this species. Nevertheless, the age of the Cardiel Formation was challenged by some authors, suggesting that it may have a younger age (Panza *et al.*, 2018, Passalia *et al.*, 2023, and cites therein). In any case, the presence of *P. mazzonii*, typically found in younger assemblages, may be a clue to reevaluate the Cenomanian age postulated for the Cardiel Formation.

Affinities. Most of the features of *Podocarpoxylon mazzonii* can be commonly found in conifers of the Family Podocarpaceae, except for bi to triseriate rays which are present in the fossil taxon. This feature is not present in extant Podocarpaceae, and is also rare in fossil *Podocarpoxylon* woods (see revision in Pujana & Ruiz, 2017). Thus, although it may represent an extinct lineage of Podocarpaceae, affinities with this family should be considered as tentative.

Fossil Genus. *Cupressinoxylon* Göppert nom. cons. prop. (Bamford *et al.*, 2002)
Type species. *Cupressinoxylon subaequale* Göppert, 1850

Cupressinoxylon austrocedroides Nishida 1984
(Fig. 3A–F)

Studied specimens. MPEF-PB 13021, 13022, and 13023.
Locality. Estancia María de las Nieves, Telsen Department, Chubut Province.
Stratigraphic horizon. Puntudo Chico Formation; Upper Cretaceous (middle–upper Campanian to lower Maastrichtian).
Description. Growth ring boundaries distinct but poorly defined. Latewood consisting of 1–3 tracheids with reduced diameter (Fig. 3A). Transition from earlywood to latewood abrupt. Earlywood tracheid tangential diameter 37.5 (19–53) μm. Latewood tracheids thin walled. Intercellular spaces rare to absent. Tracheid radial pitting abietinean, uniseriate separate (78%) to biseriate opposite (22%), sometimes portions of biseriate pits present alternating with uniseriate pits in the same tracheid (Fig. 3C), very rarely and locally alternate pitting, Si=1.2, pits always separate (Fig. 3. B–C). Radial pits circular 13.1 (9.3–16.2) μm in vertical diameter. Tangential pits not observed. Axial parenchyma abundant, diffuse, and frequently tangentially zonate (2–6 cell strands) with cells 168 (57.4–287.6) μm in height (Fig. 3A, B). Cross-field pitting cupressoid, 1, rarely 2, pits per cross field, 7.5 (6.5–9.2) μm in vertical diameter, with slits narrower than borders, obliquely oriented (Fig. 3D–E). Rays homogeneous, parenchymatous, with cells 23.2 (14.2–33.2) μm in vertical diameter. Rays medium, 6 (1–14) cells high, uniseriate and with a frequency of 8 (6–10) rays per mm (Fig. 3F).
Comparison and remarks. Göppert (1850) characterized the fossil genus *Cupressinoxylon* using features not only belonging to the secondary xylem, but also its pith and bark. Nevertheless, Philippe & Bamford (2008) proposed that it could be used for tracheidoxyls, and characterized it as having abietinean radial pitting and cross fields with cupressoid pits, usually not contiguous, and ordered in rows and columns (Key 3.3. Group C "abietinean radial pitting", Philippe & Bamford, 2008). Given all these features are recognized in the studied fossils, we include them in this genus.

Within this genus, Nishida (1984) proposed the species *Cupressinoxylon austrocedroides* for remains described from probably Miocene strata from Chile. This taxon is similar to the specimen here described but differs in having exclusively uniseriate radial pitting of the tracheids, and sparsely distributed pits in the tangential walls of the tracheids. Later, this species was reported by Ruiz *et al.* (2017) from the Paleocene Salamanca Formation at Chubut Province, Argentina. The Salamanca Formation *Cupressinoxylon austrocedroides* woods are described as having uniseriate, rarely biseriate radial pitting of the tracheids, and lacking pits on the tangential walls of the tracheids (Ruiz *et al.*, 2017). As such, these Paleocene fossils are closer to the Puntudo Chico Formation woods than the original specimen described by Nishida (1984). We believe these differences are not enough to justify segregating them in different species.
Affinities. Woods with abietinean radial pitting and cupressoid cross-fields are found in conifers of the families Cupressaceae and Podocarpaceae (Richter *et al.*, 2004; Vasquez Correa *et al.*, 2010; Pujana *et al.*, 2014; Ruiz *et al.*, 2017).

Xylotype indet.
(Fig. 4A–D)

Studied specimen. MPEF-PB 13024.
Locality. Estancia María de las Nieves, Telsen Department, Chubut Province.
Stratigraphic horizon. Puntudo Chico Formation; Upper Cretaceous (middle–upper Campanian to lower Maastrichtian).
Description. Growth ring boundaries somewhat indistinct. Bands of apparently small tracheids in cross section probably corresponding to deformation (Fig. 4A). Tracheid radial pitting unclear due to preservation quality. Scarce observed radial pitting series almost all uniseriate (only two biseriate opposite pits observed), observed pits typically separate (Fig. 4B), although some radial series are contiguous (Fig. 4C). Radial pits circular 9.9 (7.6–12.5) μm in vertical diameter.

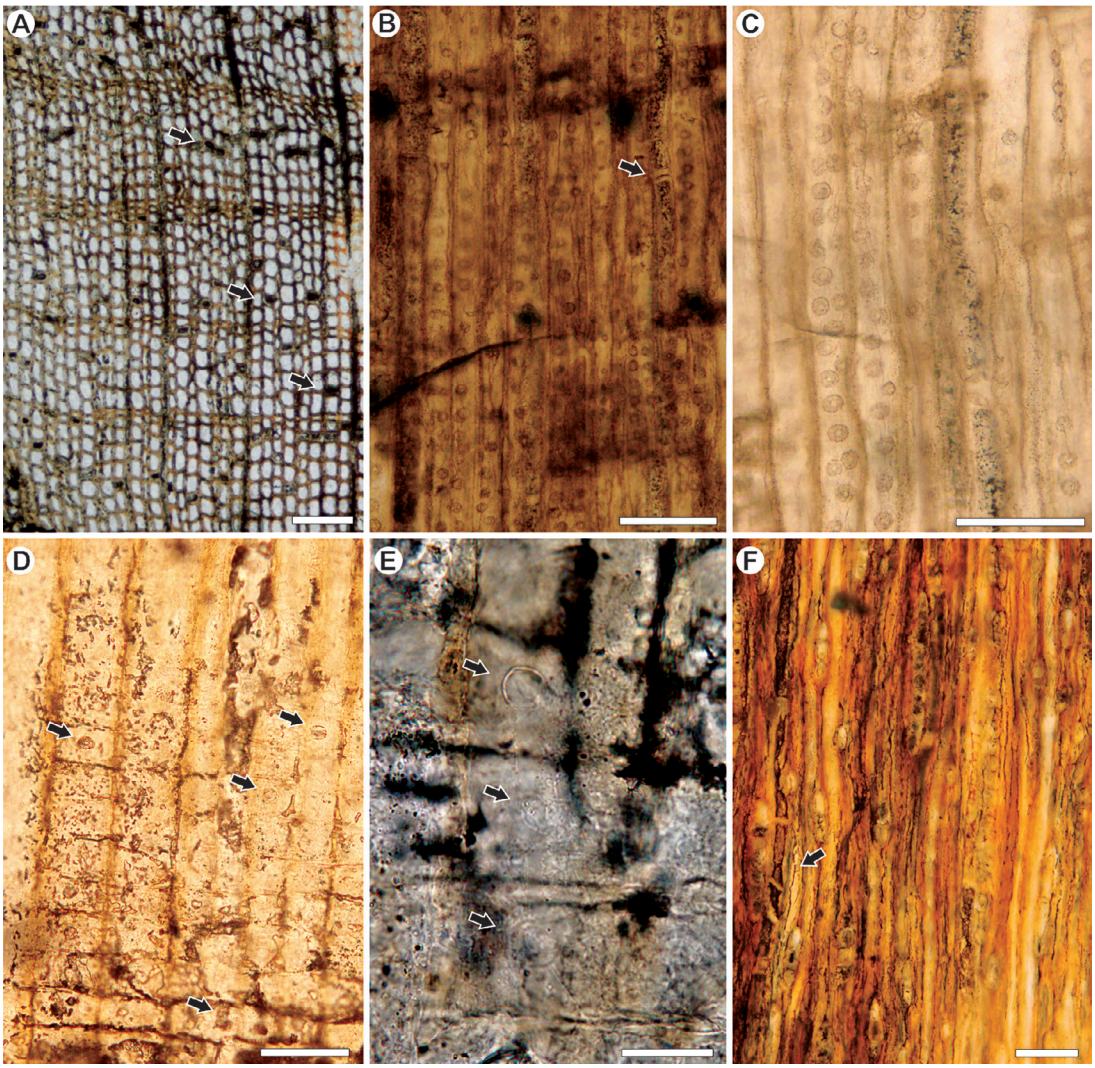

Fig. 3. *Cupressinoxylon austrocedroides* Nishida, 1984. (A) TS showing growth rings and axial parenchyma (arrows) (MPEF-PB 13022). (B), (C) LRS showing uniseriate and biseriate spaced pits, and axial parenchyma strand (arrow) (MPEF-PB 13021). (D) LRS showing cross fields (MPEF-PB 13021). (E) LRS showing detail of cross fields with cupressoid pits (arrows) (MPEF-PB 13021). (F) LTS showing uniseriate rays and axial parenchyma (arrow) (MPEF-PB 13022). Scale bars = 200 μm (A); 100 μm (B, C and F), 50 μm (D), and 20 μm (E).

Tracheid tangential diameter 31.4 (23–41.1) μm. Intercellular spaces common. Tangential pits not observed. Axial parenchyma not observed. Cross-field pitting without preserved pits. Rays homogeneous, parenchymatous, with cells 23.2 (14.2–33.2) μm in vertical diameter. Rays medium, 14 (3–30) cells high, uniseriate and with a frequency of 8 (6–10) rays per mm (Fig. 4D).

Comparisons and remarks. It is impossible to assign these remains to a particular fossil wood genus, due to its deficient preservation, in particular due to its lack of preserved cross-fields. Nevertheless, it can be separated from other taxa here described. This xylotype differs from *Podocarpoxylon mazzonii* by the lack of bi- and triseriate rays, as well as the lack of septa-like structures. The other taxon here described, *Cupressinoxylon austrocedroides,* has abundant axial parenchyma, diffuse and tangentially zonate in short bands, while this xylotype lacks axial parenchyma. On the other hand, it is not possible to segregate this xylotype from other coniferous taxa reported from the Puntudo Chico Formation at El Quiosco locality (*Agathoxylon*

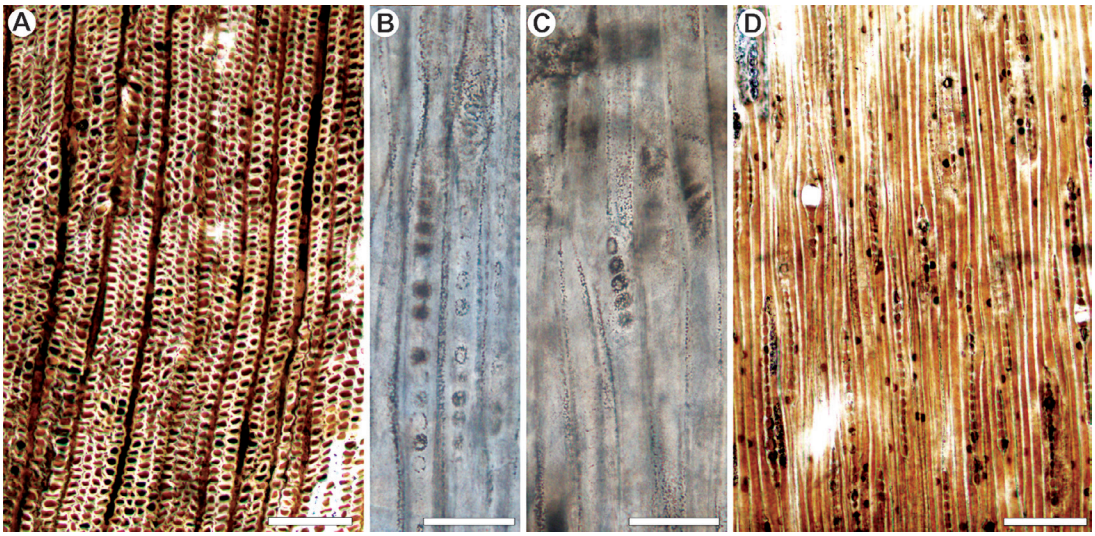

Fig. 4. Xylotype indet. MPEF-PB 13024. (A) TS showing growth ring. (B) LRS showing uniseriate spaced pits. (C) LRS showing uniseriate contiguous pits. (D) LTS showing uniseriate rays. Scale bars = 200 μm (A and D), and 50 μm (B and C).

antarcticum and *Brachyoxylon* sp. cf. *B. currumilii*) as key features are unpreserved in the wood here described, as cross-field pits and more data on the type of radial pitting and the proportion of spaced and contiguous pits. Both *Agathoxylon antarcticum* and *Brachyoxylon* sp. cf. *B. currumilii* may have some proportion of spaced uniseriate radial pits, as the wood here studied, and thus more complete specimens would be necessary to evaluate the degree of overlap with these previously reported taxa, or maybe recognize a different taxon.

Affinities. Undeterminable, due its poor preservation.

DISCUSSION

The new data presented here increase the knowledge on fossil floras that inhabited the region during the latest Cretaceous. *Podocarpoxylon mazzonii* is recognized again as the most abundant taxon among the studied collection of woods, as previously reported in the Puntudo Chico Formation at El Quiosco Locality (Vera *et al.*, 2019). In the latter locality, this taxon was found accompanied by woods assigned to the genera *Agathoxylon* Hartig and *Brachyoxylon* Hollick et Jeffrey, both apparently absent in the assemblage here studied. Noteworthy, *P. mazzonii* is also present as the most abundant (or even the unique) wood taxon in other upper Cretaceous to Paleocene localities from central and northern Patagonia (Petriella, 1972; Del Fueyo, 1998; Raigemborn *et al.*, 2009; Brea *et al.*, 2011; Vera *et al.*, 2019; Passalia *et al.*, 2023), suggesting that the distribution of this taxon may have been linked to some type of spatial and/or climatic conditions that developed relatively close to shallow seas during the latest Cretaceous, and persisted during the Danian/Selandian (Vera *et al.*, 2019; Passalia *et al.*, 2023).

The report of *Cupressinoxylon austrocedroides* is interesting not only because it represents the first record of the genus in the Puntudo Chico Formation, but also due its presence in the Danian deposits of the Salamanca Formation. This unit is not found overlying the Puntudo Chico Formation in all its extension, as rocks of the La Colonia Formation are often found bracketed between the Puntudo Chico and Salamanca (=Cerro Bororó) formations (see Anselmi *et al.*, 2004 and Clyde *et al.*, 2021). However, in some parts of the Cañadón Asfalto Basin, the Salamanca (=Cerro Bororó) Formation is found directly overlying the Puntudo Chico Formation, even suggesting that the age of this latter unit can be comparable to the one of the La Colonia Formation (Clyde *et al.*, 2021, and cites therein). This stratigraphic relationship between both units (Puntudo Chico and Salamanca formations) can be tentatively used to evaluate the continuity of the wood taxa across the K/Pg limit. In this sense, *C. austrocedroides* is the second wood taxon shared with the Salamanca

Formation, the other one being *Podocarpoxylon mazzonii*, and they represent taxa that traverse the K/Pg extinction event. Noteworthy, wood assemblages of the Salamanca Formation do not feature both taxa in the same paleontological sites. In some localities, as the Bororó Hill or the Ameghino Petrified Forest, *Podocarpoxylon mazzonii* is found as a monotypic element of the assemblage (Petriella, 1972; Brea *et al.*, 2011), while *Cupressinoxylon austrocedroides* is found at Las Violetas locality in the same stratigraphic level as *Podocarpoxylon multiparenchymatosum* Pujana et Ruiz, *Cupressinoxylon artabeae* Ruiz, Brea, Raigemborn et Matheos, and a probable *Cupressinoxylon* (Ruiz *et al.*, 2017), and approximately 2 meters below a level with several dicot woods (Ruiz *et al.*, 2020). Future works dealing with reconstructing climatic conditions using the paleontological content of the Puntudo Chico Formation may provide clues regarding the floristic changes that happened in the region during the latest Cretaceous to early Paleocene interval.

CONCLUSIONS

New reports of fossil woods are presented for the Puntudo Chico Formation, collected from Estancia María de las Nieves locality. The taxonomic content reveals the presence of the ubiquitous *Podocarpoxylon mazzonii* (already identified at El Quiosco locality) along with *Cupressinoxylon austrocedroides* (representing the first report of the genus from the unit) and an indeterminate xylotype. While the recognized *Cupressinoxylon austrocedroides* specimens fall within the limits of the taxon, they are anatomically closer to the reports of this species from the Salamanca Formation, than from the originally described from Chile. This taxon represents the second shared wood species —*P. mazzonii* is the other— between the Puntudo Chico Formation and the Salamanca Formation, although they have not been found at the same locality in the Danian unit. Future work dealing with climatic reconstructions on the Puntudo Chico Formation will provide more sources of information to compare changes on wood floristic assemblages across the K/Pg limit.

ACKNOWLEDGMENTS

The authors want to thank the comments of two anonymous reviewers, who greatly improved the final version of the manuscript. We make extensive our gratitude to the hospitality of Zulma Iglesias and Andrés Horteloup, farmer owners of the Estancia María de las Nieves, and to Miss Cecilia Bau, for her collaboration in the field. We also thank the Secretaría de Cultura del Chubut for land access. This work was partially funded with the research grant PIP 1814 (CONICET).

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Doi: 10.22179/REVMACN.26.819

Recibido: 1-III-2023
Aceptado: 1-IX-2023