Latin American Journal of Sedimentology and Basin Analysis

ISSN 1851-4979
Published by the Asociación Argentina de Sedimentología

ACCEPTED MANUSCRIPT

Charophyte record of the Early Cretaceous Cañadón Asfalto Basin (central Patagonia, Argentina): biostratigraphic and paleoenvironmental synthesis

Andrea De Sosa Tomas, *Carles Martín-Closas*

https://doi.org/10.67355/f5r6nm92

Received date: 16-05-2026
Accepted date: 24-10-2026
Available online: 06-11-2026

Handling (guest) Editor: Aldo Martín Umazano

Please cite this article as

De Sosa Tomas, A. and Martín-Closas, C. Charophyte record of the early Cretaceous Cañadón Asfalto Basin (central Patagonia, Argentina): biostratigraphic and paleoenvironmental synthesis (in press). *Latin American Journal of Sedimentology and Basin Analysis*. https://doi.org/10.67355/f5r6nm92

This is a preliminary version of the manuscript accepted for publication in the Latin American Journal of Sedimentology and Basin Analysis. This version will be revised before final publication. Please note that some errors may be found during the final revision process. The same disclaimers as for printed and final versions apply for this early online version.

This work is licensed under Creative Commons Attribution-NonCommercial 2.5 Argentina License

De Sosa Tomas and Martín-Closas, in press. Latin American Journal of Sedimentology and Basin Analysis

Charophyte record of the Early Cretaceous Cañadón Asfalto Basin (central Patagonia, Argentina): biostratigraphic and paleoenvironmental synthesis

De Sosa Tomas, A. [1*] and Martín-Closas, C. [2]

1 – Laboratorio de Bioestratigrafía "Dr. Eduardo Musacchio", Departamento de Geología, Universidad Nacional de la Patagonia San Juan Bosco, Ciudad Universitaria Km. 4, Comodoro Rivadavia, Chubut, 9000, Argentina.

2 – Departament de Dinàmica de la Terra i de l'Oceà, Facultat de Ciències de la Terra, Universitat de Barcelona-UB, c/ Martí i Franqués s/n, Barcelona, Catalonia, 08028, Spain.

**Corresponding author*: adesosatomas@gmail.com

ABSTRACT

This contribution presents an integrated synthesis of the freshwater calcareous microfossil record preserved in Lower Cretaceous continental successions of north-central Patagonia, focusing on two stratigraphically successive units of the Cañadón Asfalto Basin. Based on previously published data and the results synthesized herein, this review includes the taxonomic composition, biostratigraphic framework, paleoenvironmental evolution, and paleobiogeographic significance of the recorded assemblages.

Charophytes from the lower unit (Los Adobes Formation) are characterized by distinctive *Mesochara*-dominated floras that developed in shallow freshwater settings within low-energy floodplains during the Barremian, the most probable age for the charophyte-bearing deposits studied herein. This vegetation inhabited temporary ponds and small lacustrine depressions that were subject to frequent water-level fluctuations and episodic sediment influx. The overlying unit (Cerro Barcino Formation) records species-rich assemblages, including both early characeans and clavatoraceans. These

charophyte floras reflect Aptian–early Albian freshwater habitats established in volcaniclastic floodplains affected by recurrent volcanic disturbance and variable hydrological regimes. The higher diversity observed in this interval may partly reflect the occurrence of taxa with different ecological tolerances, some of which were able to persist under fluctuating hydrological and physicochemical conditions. Together, these records highlight the importance of the Cañadón Asfalto Basin for understanding the early diversification of Charoidae in southern Gondwana and provide new insights into the evolution of dynamic freshwater ecosystems in volcanically influenced continental settings during the Early Cretaceous.

Keywords: Freshwater microfossils, characean evolution, volcaniclastic sedimentation, fluvial-lacustrine environments, Gondwana, paleobiogeography

INTRODUCTION

Charophytes are non-marine aquatic plants with a long and well-documented fossil record ranging from the Silurian to the present (Feist *et al.*, 2005; Martín-Closas *et al.*, 2024) and are widely recognized for their value in biostratigraphic correlation and paleoenvironmental reconstruction of continental deposits. Their relatively rapid evolutionary rates, ecological sensitivity, and restricted environmental tolerances make charophyte assemblages particularly useful for refining chronostratigraphic frameworks and reconstructing freshwater paleoecosystems. During the Early Cretaceous, charophyte floras underwent major evolutionary and biogeographic changes, including the diversification of clavatoraceans and the early radiation of characeans that ultimately gave rise to the Charoidae-dominated floras characteristic of the Late Cretaceous and Cenozoic (Grambast, 1974).

In Patagonia, the study of fossil charophytes has a long tradition, initiated by the pioneering contributions of Eduardo Musacchio. His work established taxonomic, biostratigraphic, and paleoenvironmental foundations for the interpretation of charophyte assemblages from Cretaceous continental basins of southern South America (*e.g.*, Musacchio, 1979, 1989, 1993, 2000). At a broader Gondwanan scale, and particularly in southern South America, the charophyte record remains unequally documented. Isolated occurrences were reported from some Cretaceous intervals in

Brazilian basins, including the Santos and Potiguar basins (Musacchio, 2000), whereas large areas of the continent remain poorly documented for charophytes.

In Patagonia the Cañadón Asfalto Basin is notable for the preservation and taxonomic particularity of its Early Cretaceous charophyte floras. Recent regional syntheses of plant microfossils from the Chubut Group in adjacent basins, such as the Golfo San Jorge Basin (De Sosa Tomas *et al.*, 2023; De Sosa Tomas and Vallati, 2025), have further emphasized the stratigraphic and paleoenvironmental value of freshwater microfloras in central Patagonia, highlighting the need for basin-focused integrations.

Previous studies have documented the occurrence of charophyte assemblages in the Los Adobes and Cerro Barcino formations (Musacchio, 1972; Musacchio and Chebli, 1975; Musacchio *et al.*, 1986; Musacchio, 1995), mainly within broader stratigraphic frameworks or regional syntheses (Musacchio, 2000). Although these contributions provided valuable initial taxonomic identifications and general paleoenvironmental interpretations, detailed formation-scale analyses remained limited. More recent formation-scale studies have provided refined taxonomic revisions and improved stratigraphic resolution for the Los Adobes (De Sosa Tomas *et al.*, 2022; De Sosa Tomas, 2025) and the Cerro Barcino (De Sosa Tomas *et al.*, 2017; De Sosa Tomas, 2025) formations. However, the available information remains scattered across individual publications, and to date, no study has explicitly integrated the charophyte record of both formations at the basin scale.

The aim of this contribution is to provide an integrated synthesis of the charophyte assemblages from the Los Adobes and Cerro Barcino formations of the Cañadón Asfalto Basin, emphasizing their biostratigraphic significance, paleoenvironmental implications, and paleobiogeographic relevance. By integrating pioneering studies on the charophyte record of the basin (*e.g.*, Musacchio, 1972; Musacchio and Chebli, 1975; Musacchio *et al.*, 1986; Musacchio, 1995, 2000) with more recent stratigraphic and micropaleontological contributions (*e.g.*, De Sosa Tomas *et al.*, 2017, 2022; De Sosa Tomas, 2025), this synthesis provides an updated, basin-focused perspective on the evolution of Early Cretaceous freshwater systems in central Patagonia.

THE CHUBUT GROUP IN THE CAÑADÓN ASFALTO BASIN

The Cañadón Asfalto Basin is located in central Patagonia, Argentina, between approximately 42°00′ and 44°30′ S latitude and 68°30′ and 70°00′ W longitude (Fig. 1a). It represents a continental basin developed along the western margin of the North Patagonian Massif and is tectonically distinct from the adjacent Golfo San Jorge Basin, although episodic hydrological connections between the two basins during the Early Cretaceous have been proposed (Allard *et al.,* 2021 and references cited therein).

The Mesozoic basin infill comprises a thick succession of Jurassic to Cretaceous continental deposits, traditionally divided into syn-rift and post-rift stages. The syn-rift stage is dominated by Jurassic lava flows and volcaniclastic rocks, both primary and secondary; whereas the post-rift stage is characterized by Cretaceous fluvial, alluvial, and lacustrine deposits with variable volcaniclastic input (Figari, 2005; Villegas and Umazano, 2024 among others). Within this post-rift succession, the Los Adobes and Cerro Barcino formations belong to the Chubut Group and record the Early Cretaceous continental evolution of the basin (Fig. 1b).

The Los Adobes Formation represents the lower unit of the Chubut Group and includes the Arroyo del Pajarito and Bardas Coloradas members. The lower one is coarse-grained and epiclastic, while the overlying Bardas Coloradas Member is composed of fine-grained siliciclastic deposits including mudstones, claystones, and siltstones, locally interbedded with fine-grained sandstones and paleosols. Volcaniclastic material is present but remains subordinate, occurring mostly as reworked tuffaceous components within floodplain deposits, a characteristic that is accentuated in the upper part of the Bardas Coloradas Member.

The Los Adobes Formation has traditionally been assigned to the Hauterivian–Aptian interval (Tasch and Volkheimer, 1970; Turner, 1983), although an Albian age was subsequently proposed for its lower member based on palynological evidence from subsurface deposits (Marveggio and Llorens, 2013). More recently, Krause *et al.* (2020) reported an early Aptian U-Pb age using zircons from a tuffaceous level near the base of the overlying Cerro Barcino Formation, providing a chronological constraint for the stratigraphic boundary with the underlying Bardas Coloradas Member (Los Adobes Formation).

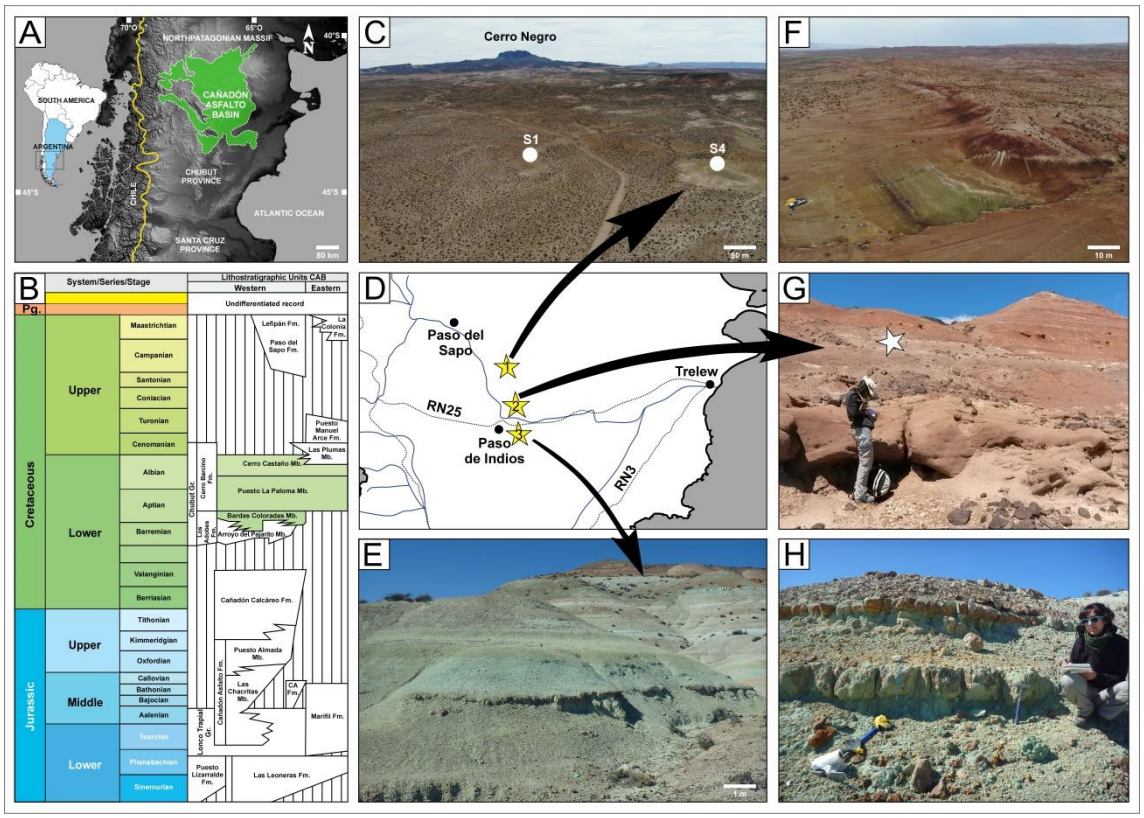


Figure 1. a) Geographic location of the Cañadón Asfalto Basin in central Patagonia, Argentina. **b)** Stratigraphic framework of the basin (modified from Allard et al., 2021). Colored lithostratigraphic units are those containing charophytes. **c)** Aerial view of selected sampling sites (S1 and S4) at Sierra de la Manea (see D), within the Bardas Coloradas Member, Los Adobes Formation. **d)** Location map of the studied sections. Green stars indicate sampling sites: (1) Sierra de La Manea, (2) Cerro Castaño, and (3) Paso de Indios sections. **e)** Photograph of the studied outcrop next to Paso de Indios (see D), showing greenish tuffaceous sandstones and mudstones of the Puesto La Paloma Member overlain by reddish deposits of the Cerro Castaño Member, Cerro Barcino Formation. **f)** Aerial view of one of the studied sections of the Bardas Coloradas Member, Los Adobes Formation, at Sierra de la Manea. **g)** Outcrop of reddish channelized deposits of the Cerro Castaño Member, Cerro Barcino Formation, illustrating the fluvial depositional context of the studied succession. The white star indicates the approximate stratigraphic position of the sampled charophyte-bearing level. Person for scale is 1.7 m. **h)** Detail of the outcrop shown in e, showing paleosol horizons within the Puesto La Paloma Member, Cerro Barcino Formation. Charophyte-bearing levels occur in fine-grained deposits interbedded between the paleosol horizons. Hammer is 30 cm long.

The Cerro Barcino Formation conformably overlies the Los Adobes Formation and comprises a more heterogeneous succession formally subdivided into the Puesto La Paloma, Cerro Castaño, and Las Plumas members (*sensu* Krause *et al.*, 2020). The formation spans an Aptian–Cenomanian interval. In contrast to the underlying unit, the Cerro Barcino Formation is characterized by markedly higher volcaniclastic content,

including fluvial-channel sandstones interbedded with tuffaceous-rich siltstones and mudstones.

The stratigraphic architecture of the basin reflects the combined influence of tectonic subsidence, volcanism related to the proto-Andean margin, and continental sedimentation under fluctuating climatic conditions, with volcaniclastic sediment supply playing a central role in modulating floodplain dynamics and depositional patterns (Villegas and Umazano, 2024). Volcaniclastic material, particularly abundant in the Cerro Barcino Formation, occurs either as primary ash-fall deposits or as reworked tuffaceous sediments and it strongly influenced sediment composition, water chemistry, and depositional processes.

CHAROPHYTE ASSEMBLAGES OF THE LOS ADOBES FORMATION

Stratigraphic and sedimentological context

Charophyte assemblages from the Los Adobes Formation are restricted to the fine-grained intervals of the Bardas Coloradas Member, within the lower part of the Chubut Group, and were recovered from several sampled sites at Sierra de La Manea (Fig. 1c–d, f). These levels occur in mudstones and siltstones with scarce tuffaceous content, interbedded with paleosols and fine-grained sandstones, reflecting sedimentation in distal sectors of a fluvial floodplain system (further details on sampling and stratigraphic position are provided in De Sosa Tomas *et al.,* 2022 and De Sosa Tomas, 2025).

The charophyte-bearing horizons are associated with low-energy depositional settings within the fluvial floodplain. Since volcaniclastic material is less abundant than in the overlying Cerro Barcino Formation, the reworked tuffaceous components had a comparatively minor influence on sediment composition and water chemistry. Charophytes are known to thrive in alkaline freshwater bodies where carbonate precipitation is favored, and the abundance and good preservation of gyrogonites indicate that pond waters periodically reached sufficient alkalinity and carbonate saturation to allow calcification. In these distal floodplain settings, such geochemical conditions were probably enhanced by evaporation and limited water circulation in

shallow, temporary ponds. The association of charophytes with ostracods and palynomorphs further supports the interpretation of freshwater environments characterized by temporally variable hydrological conditions rather than permanent lacustrine systems (De Sosa Tomas *et al.*, 2022; De Sosa Tomas, 2025).

Taxonomic composition and biostratigraphic significance

The charophyte assemblages of the Los Adobes Formation are remarkable for their unusual taxonomic composition, with gyrogonites exclusively attributable to species of the genus *Mesochara* (Fig. 2a–j). Several species have been recognized including *Mesochara maruchoensis*, *Mesochara stipitata*, *Mesochara aff. harrisii*, and *Mesochara adobensis* (De Sosa Tomas *et al.*, 2022). This composition is exceptional for Early Cretaceous charophyte floras, which elsewhere are typically dominated by clavatoraceans or mixed assemblages. In addition to gyrogonites, hundreds of fragments of ecorticate thalli were recovered from the Bardas Coloradas Member (Fig. 2k–l).

The dominance and diversity of *Mesochara*, which is the earliest representative of the Charoidae, suggest an early radiation of this group in southern Gondwana, predating by approximately 30 million years the widespread development of homogeneous Charoidae-dominated floras that became characteristic during the Late Cretaceous and Cenozoic (De Sosa Tomas *et al.*, 2022). From a biostratigraphic perspective, a Barremian age is considered the most probable for charophyte-bearing levels, based primarily on stratigraphic relationships and regional chronostratigraphic evidence, and is consistent with the stratigraphic distribution of the identified charophyte species (De Sosa Tomas *et al.*, 2022). This interpretation is also consistent with palynological assemblages, characterized by the absence of early angiosperm pollen and the predominance of gymnosperm pollen (De Sosa Tomas, 2025).

Paleoenvironmental interpretation

The *Mesochara*-dominated assemblages of the Los Adobes Formation are interpreted as predominantly autochthonous floras developed in shallow freshwater bodies established on distal floodplains. The abundance of well-preserved gyrogonites and the limited evidence of transport indicate predominantly *in situ* growth within temporary ponds that developed in poorly drained sectors of the floodplain. These water bodies were hydrologically variable, experiencing recurrent fluctuations in water level and

periodic desiccation, as supported by the presence of paleosols in the studied section. Sedimentological and paleopedological evidence, including gleying interpreted as reflecting seasonal alternation between a high-water table and subaerial exposure, supports seasonal hydrological variability under warm, semi-arid climatic conditions (De Sosa Tomas *et al.*, 2022). In this unit, the volcanic input was minor relative to the overlying Cerro Barcino Formation. Thus, environmental variability was mainly related to climatic and floodplain dynamics rather than to recurrent volcanic disturbance.

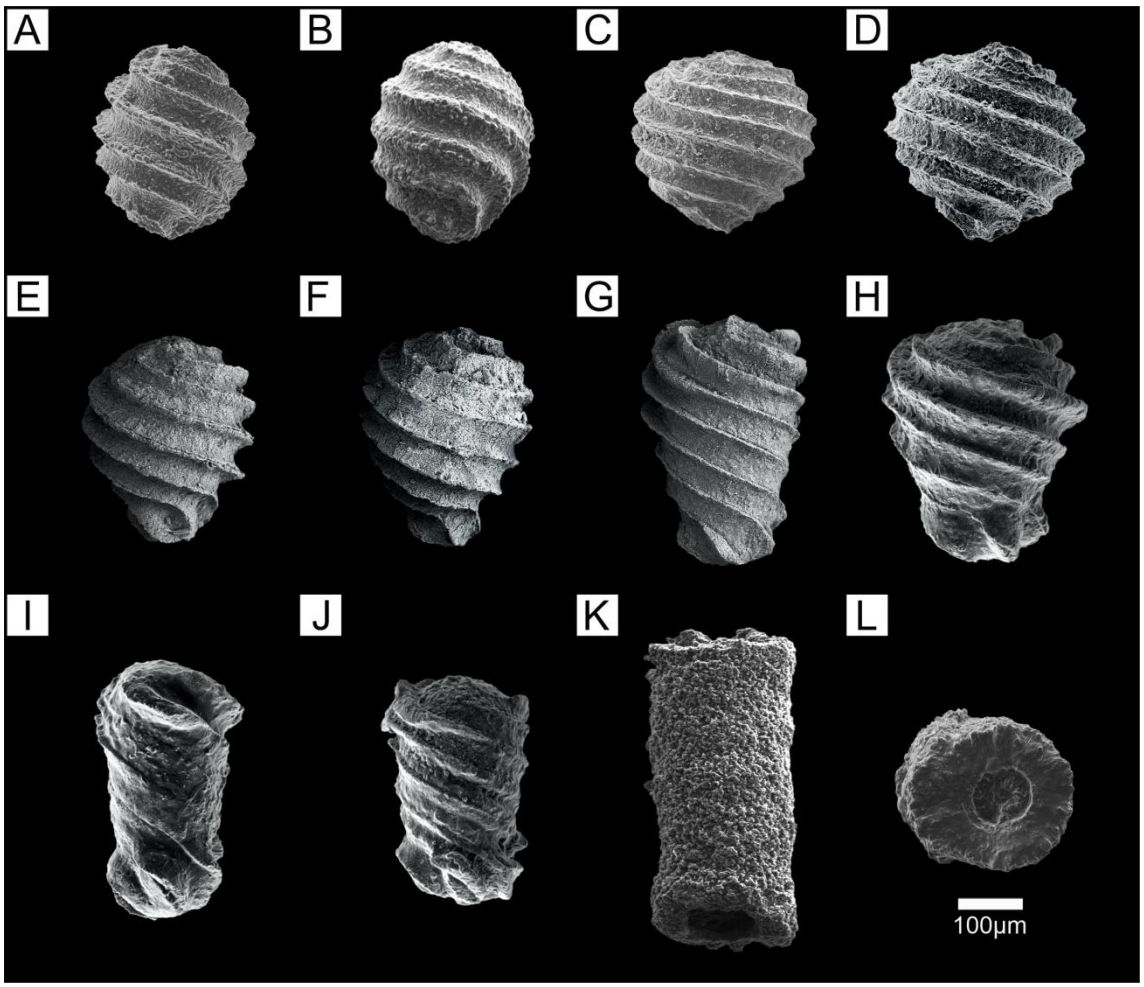


Figure 2. SEM micrographs of the charophyte assemblage from the Bardas Coloradas Member, Los Adobes Formation (Barremian), Cañadón Asfalto Basin. Representative gyrogonites of Mesochara illustrating the taxonomic composition of the assemblage. **a-b)** aff. *Mesochara harrisii*, UNPSJB-MFC 252, 225. **c-d)** *Mesochara maruchoensis*, UNPSJB-MFC 226, 331. **e-f)** *Mesochara stipitata*, UNPSJB-MFC 227, 332. **g-h)** *Mesochara adobensis*, UNPSJB-MFC 231, 234, 236, 237. **k-l)** Longitudinal and transverse views of internodes of indeterminate ecorticate thalli, UNPSJB-MFC 229.

The dominance of *Mesochara* and the absence of clavatoraceans may reflect paleoenvironmental conditions considering that clavatoraceans were already present and

dominated the charophyte assemblages during the Barremian in lacustrine deposits of the La Amarga Formation in the Neuquén Basin (Musacchio, 1971). The Los Adobes Formation microflora is consistent with warm, seasonally dry climatic settings in which temporary ponds repeatedly formed and disappeared across distal floodplains. A comparable paleoecological preference has been reported for *Mesochara* in the Barremian of the Tethyan domain (Vicente and Martín-Closas, 2013). In other Barremian assemblages, M. *harrisii* has also been recorded in permanent lacustrine environments, although in this case as a subordinate component of the clavatoracean-dominated charophyte flora (Pérez-Cano *et al.*, 2022). In this context, charophytes function as sensitive indicators of hydrological variability within continental systems with subordinate volcaniclastic input.

CHAROPHYTE ASSEMBLAGES OF THE CERRO BARCINO FORMATION

Stratigraphic and sedimentological context

Charophyte assemblages have been recorded primarily from the Puesto La Paloma and Cerro Castaño members and provide biostratigraphic constraints for the fossil-bearing intervals, which are assigned to the Aptian–early Albian (De Sosa Tomas *et al.*, 2017; De Sosa Tomas, 2025). These assemblages represent key intervals in the micropaleontological record of the basin and were studied in sections exposed at Cerro Castaño and Paso de Indios (Fig. 1d–e, g–h), including several fossiliferous levels in the Puesto La Paloma Member and a more limited record from the Cerro Castaño Member (detailed information regarding the sampled sections, stratigraphic position, and fossiliferous levels is provided in De Sosa Tomas *et al.*, 2017).

The Puesto La Paloma member is dominated by volcaniclastic sandstones deposited mainly in alluvial environments, while the Cerro Castaño Member consists of fluvial channel sandstones interbedded with volcaniclastic-rich floodplain deposits. In contrast to the underlying Los Adobes Formation, volcaniclastic input is markedly higher, particularly in the Puesto La Paloma Member, where the studied charophyte-bearing deposits show a stronger pyroclastic influence than those of the overlying Cerro Castaño Member (De Sosa Tomas, 2025). The occurrence of analcime in the Puesto La Paloma Member, interpreted as a diagenetic modification of volcanic glass, provides additional

mineralogical evidence of this influence (Iñiguez Rodríguez *et al.*, 1987; De Sosa Tomas, 2025). Sedimentation in the Puesto La Paloma Member took place mainly within ephemeral, unconfined volcaniclastic-rich alluvial systems dominated by sheet-flood deposits, locally associated with aeolian dunes, interdune areas, and shallow lacustrine environments (Umazano *et al.*, 2017; Villegas and Umazano, 2024). In contrast, the Cerro Castaño Member records predominantly perennial, channelized fluvial systems, with meandering to locally low-sinuosity channels interbedded with volcaniclastic-rich floodplain deposits (Umazano *et al.*, 2017). Temporary ponds developed in distal areas of volcaniclastic sheet-flood systems in the Puesto La Paloma Member and on fluvial floodplains in the Cerro Castaño Member. These habitats were subject to variable volcaniclastic sediment input, generating dynamic freshwater conditions (De Sosa Tomas *et al.*, 2017; Umazano *et al.*, 2017; Villegas and Umazano, 2024).

Taxonomic composition and biostratigraphic significance

Compared with the Los Adobes Formation, the charophyte assemblages from the Cerro Barcino Formation show higher taxonomic diversity, with fructifications representing both early characeans and clavatoraceans (Fig. 3a–l). Hundreds of vegetative thalli assigned to *Clavatoraxis* sp. were also recovered from the studied deposits (Fig. 3m–p).

Differences are also observed between the two sampled members: the Puesto La Paloma Member yielded more abundant charophyte remains, with *Lamprothamnium? barcinensis* and *Clavator harrisii* var. *harrisii* particularly well represented, whereas the more limited record from the Cerro Castaño Member includes C. *harrisii* var. *zavialensis*, which has not been recognized in the Puesto La Paloma Member (De Sosa Tomas *et al.*, 2017).

The presence of two cosmopolitan taxa, *Clavator harrisii* var. *harrisii* and *Clavator harrisii* var. *zavialensis* provides robust biostratigraphic constraints, allowing correlation with Aptian–lower Albian charophyte biozones recognized in Europe and other regions (De Sosa Tomas, 2025). The persistence of cosmopolitan clavatoracean taxa indicates that, during this time interval, large-scale dispersal pathways were still

effective, and that Patagonia participated in broader Gondwanan and peri-Tethyan biogeographic networks.

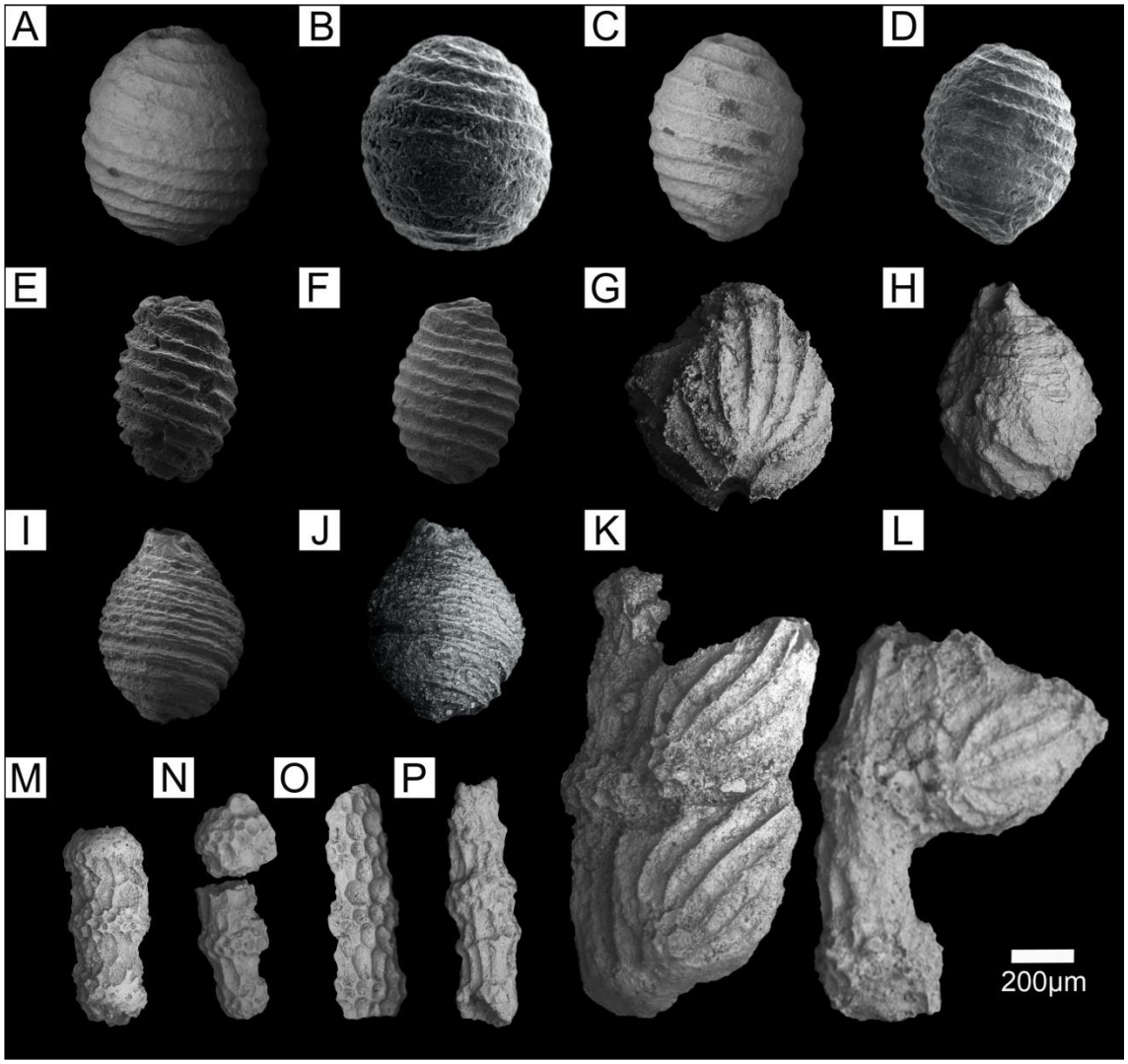


Figure 3. SEM micrographs of the charophyte assemblage from the Cerro Barcino Formation (Aptian–lower Albian), Cañadón Asfalto Basin. Representative gyrogonites illustrating the increased taxonomic diversity of the assemblage, including characeans and clavatoraceans. **a-b)** *Sphaerochara verticillata*, UNPSJB-MFC 78, 401. **c-d)** *Mesochara symmetrica*, UNPSJB-MFC 120, 400. **e-f)** *Lamprothamnium? barcinensis*, UNPSJB-MFC 71, 127. **g-h, k-l)** *Clavator harrisii* var. *harrisii*, UNPSJB-MFC 127, 83, 94, 93. **i-j)** *Clavator harrisii* var. *zavialensis*, UNPSJB-MFC 96, 343. **m-p)** *Clavatoraxis* sp., UNPSJB-MFC 123–126.

Paleoenvironmental interpretation

The charophyte assemblages of the Cerro Barcino Formation reflect freshwater habitats developed in distal areas of unconfined volcaniclastic flows and on fluvial floodplains in the Puesto La Paloma and Cerro Castaño members, respectively, subject

to recurrent environmental disturbance. The occurrence of *Lamprothamnium? barcinensis* within these assemblages provides additional paleoenvironmental insights. This species is particularly abundant in the Puesto La Paloma Member, whereas it is less abundant in the Cerro Castaño Member, where charophyte fructifications are generally scarce (De Sosa Tomas, 2025). Living species of the genus *Lamprothamnium* generally thrive in brackish environments with a high seasonal fluctuation in salinity. By way of comparison, *Lamprothamnium papulosum* requires oligohaline water to germinate but 20–40‰ dissolved NaCl to fructify and produce gyrogonites (*e.g.*, Soulié-Märsche, 2008). The presence of this genus in the Cerro Barcino Formation likely records episodic increases in salinity linked to evaporation and water-level fall in shallow floodplain ponds. In this context, diagenetic analcime in the Puesto La Paloma Member, interpreted as a product of volcanic glass alteration, is also consistent with the development of shallow, intermittently saline-alkaline water bodies (Iñiguez Rodríguez *et al.*, 1987; De Sosa Tomas, 2025). This interpretation is consistent with the coexistence of hydromorphic and calcic features in associated paleosols, which indicates alternating wetter and drier conditions (Krause *et al.*, 2014). Despite recurrent volcaniclastic disturbance, the presence of well-calcified gyrogonites indicates that water chemistry periodically reached alkaline conditions favorable for charophyte growth and carbonate precipitation.

Compared to the Los Adobes Formation, the Cerro Barcino system records a stronger influence of recurrent volcaniclastic input superimposed on hydrologically variable paleoenvironmental conditions, resulting in greater physicochemical variability of freshwater habitats. These factors generated spatially heterogeneous freshwater habitats with differing physicochemical characteristics, potentially favoring the establishment of taxa with different ecological tolerances, including cosmopolitan clavatoraceans.

INTEGRATED BIOSTRATIGRAPHIC AND PALEOENVIRONMENTAL EVOLUTION OF THE CAÑADÓN ASFALTO BASIN

The integrated charophyte record of the Los Adobes and Cerro Barcino formations reflects changes in taxonomic composition and paleoenvironmental conditions during the Early Cretaceous, as illustrated by the stratigraphic distribution of the recorded taxa

(Fig. 4). *Mesochara*-dominated assemblages from the Los Adobes Formation are associated with distal floodplain settings characterized by shallow temporary freshwater ponds subject to seasonal water-level fluctuations and periodic desiccation. Although volcaniclastic material was present, environmental variability in this unit appears to have been primarily controlled by seasonal hydrological dynamics rather than by intense volcanic disturbance. The presence of calcified gyrogonites indicates that these ponds periodically attained alkaline conditions favorable for carbonate precipitation. Such conditions, together with seasonal hydrological fluctuations, may have favored the establishment of charophyte assemblages dominated by *Mesochara*.

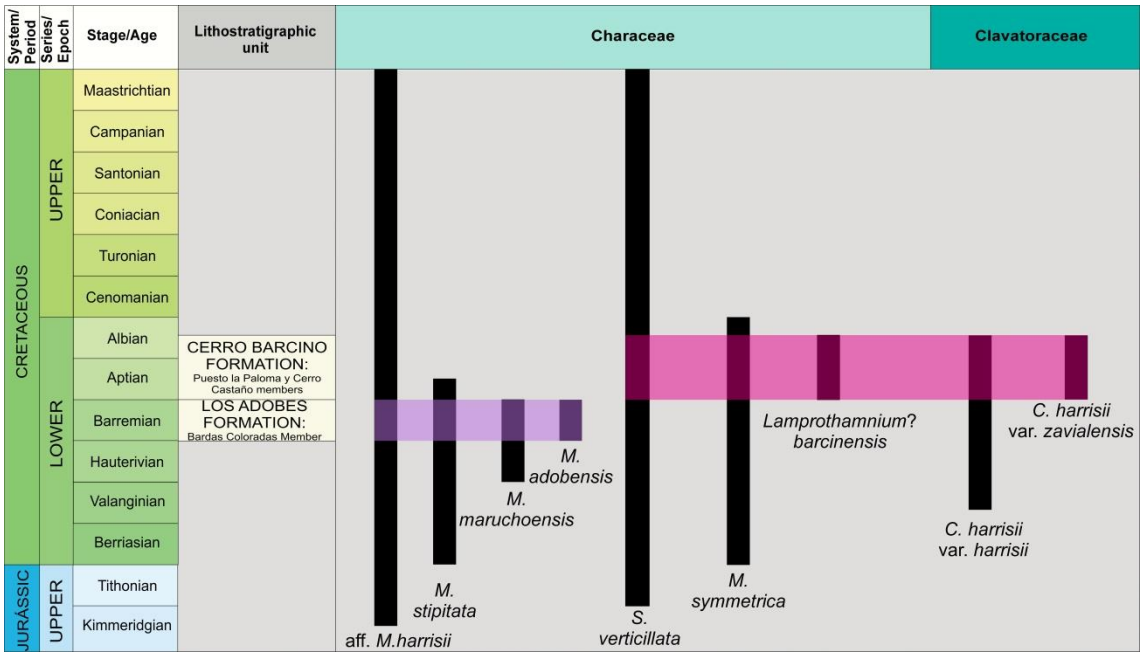


Figure 4. Stratigraphic distribution of the charophyte taxa recorded in the studied localities of the Los Adobes and Cerro Barcino formations, Cañadón Asfalto Basin. Black bars indicate the known stratigraphic ranges of the taxa. The colored bands indicate the interpreted ages of the charophyte-bearing intervals studied in each formation (modified from De Sosa Tomas et al., 2023, with data synthesized in De Sosa Tomas, 2025).

In contrast, the Cerro Barcino Formation records a markedly stronger influence of repeated volcaniclastic input on similar freshwater floodplain environments. Its higher taxonomic diversity, including clavatoraceans and characeans, coincides with greater sedimentary and physicochemical variability. In particular, the presence of *Lamprothamnium? barcinensis* suggests episodic increases in salinity, while the small size of gyrogonites recorded in the Puesto La Paloma Member may reflect a reproductive response to fluctuating environmental conditions in shallow, temporary,

alkaline ponds (De Sosa Tomas, 2025). Furthermore, *Clavator harrisii* has been characterized as tolerant of lacustrine environments with abundant clastic input (Pérez-Cano *et al.*, 2022), consistent with its occurrence in these volcaniclastic-influenced freshwater systems. The combined effects of recurrent sedimentary input and hydrological fluctuations may have contributed to the development of spatially variable aquatic habitats, potentially favoring taxa with different ecological tolerances. However, the available evidence does not allow a direct causal relationship to be established between volcanic disturbance and increased charophyte diversity.

Taken together, the charophyte assemblages indicate the persistence of shallow freshwater ponds within floodplain environments throughout the Barremian–early Albian, subject to fluctuating hydrological conditions. The succession records changes in the intensity of volcaniclastic input and associated physicochemical conditions, with episodic increases in salinity inferred for the Cerro Barcino Formation.

PALEOBIOGEOGRAPHIC IMPLICATIONS

The charophyte floras of the Cañadón Asfalto Basin (Fig. 5) provide key insights into Early Cretaceous freshwater paleobiogeography in western Gondwana. Assemblages from the Los Adobes Formation (Fig. 5a) are dominated exclusively by species of *Mesochara*, including both endemic taxa restricted to Patagonia (*Mesochara adobensis* and *Mesochara maruchoensis*) and species with a wider, cosmopolitan or subcosmopolitan distribution (*Mesochara stipitata* and *Mesochara* aff. *harrisii*). This combination highlights Patagonia as a region with an unusual diversity of *Mesochara* species, an ancestral characean genus considered a precursor of modern Charoidae, suggesting an important role in their early evolutionary diversification while maintaining broader intercontinental biogeographic connections during the Barremian.

In contrast, charophyte assemblages from the Cerro Barcino Formation (Fig. 5b) include clavatoraceans with well-established cosmopolitan distributions (Martín-Closas, 2015), such as *Clavator harrisii*, reflecting a shift toward floras more comparable to those documented in other Gondwanan and peri-Tethyan regions during the Aptian–early Albian. The occurrence of wide-distributed taxa under unstable environments

suggests that dispersal and establishment of cosmopolitan taxa were compatible with dynamic and volcanically influenced continental systems.

Taken together, the charophyte record of the Cañadón Asfalto Basin supports the interpretation of Patagonia as a center of endemism for early characeans and an integral component of global biogeographic networks during the Early Cretaceous. These floras highlight the role of southern South America in the early evolutionary history and paleobiogeographic expansion of charophytes, particularly during the transition from *Mesochara*-dominated assemblages to more taxonomically diverse floras including clavatoraceans.

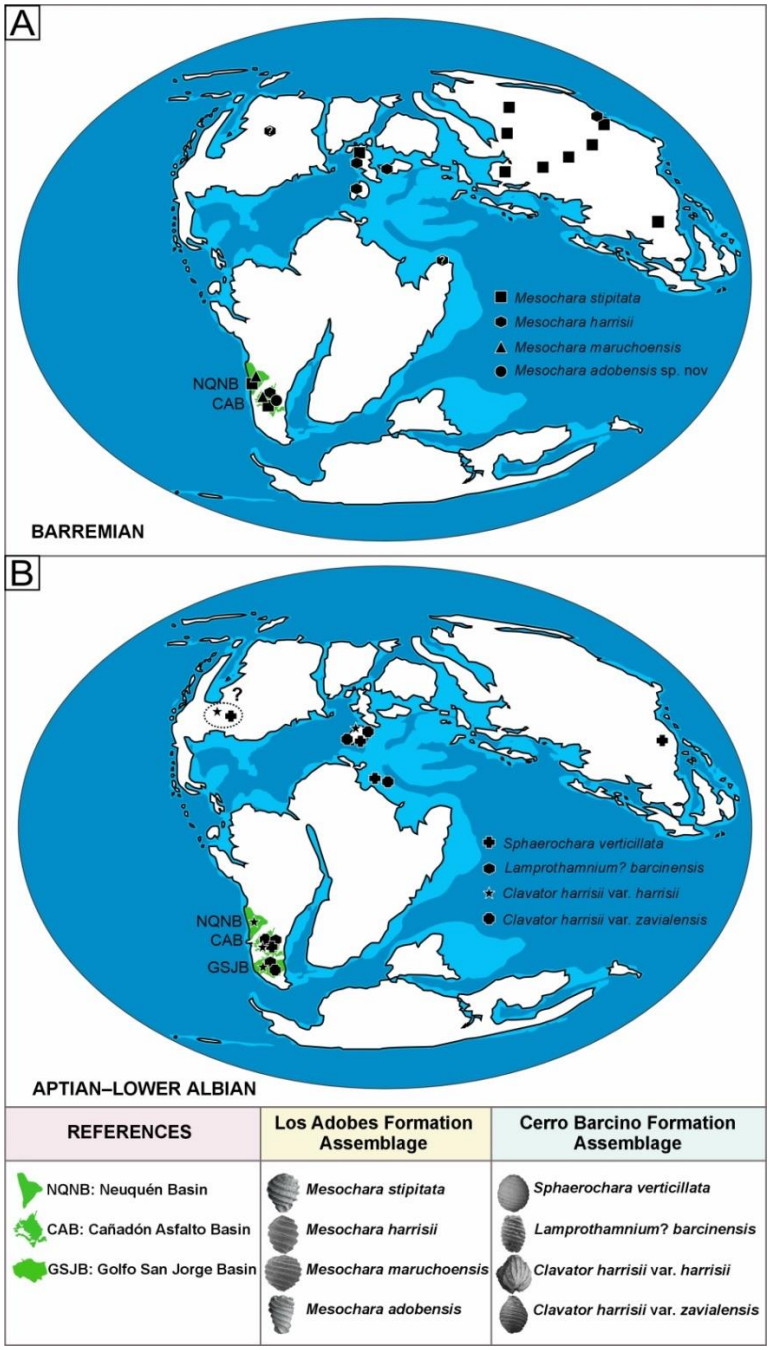


Figure 5. Paleogeographic distribution of charophyte species recorded in the Cañadón Asfalto Basin during the Early Cretaceous. **a)** Barremian distribution of *Mesochara* species recovered from the Bardas Coloradas Member of the Los Adobes Formation. **b)** Aptian–early Albian distribution of charophyte species recorded in the Puesto La Paloma and Cerro Castaño members of the Cerro Barcino Formation. Symbols indicate the geographic occurrences of each taxon, as identified in the corresponding legends. The dashed line and question mark indicate uncertain occurrences within the considered interval (modified from De Sosa Tomas et al., 2017, 2022).

FINAL CONSIDERATIONS

The synthesis presented here emphasizes the Cañadón Asfalto Basin as an important record of Early Cretaceous freshwater ecosystems in southern Gondwana. Charophyte assemblages from the Los Adobes and Cerro Barcino formations document changes in taxonomic composition and provide some biostratigraphic constraints for the Barremian–early Albian succession of central Patagonia. In particular, the remarkable species diversity of *Mesochara* in the Los Adobes Formation provides significant evidence for understanding the early evolutionary history of the Charoidae.

By integrating previous studies, from the pioneering investigations of Patagonian charophytes to more recent stratigraphic and micropaleontological contributions, this contribution provides an updated synthesis and interpretation of the available record. The combined sedimentological and micropaleontological evidence contributes to a better understanding of the paleoenvironmental evolution of freshwater floodplain systems in the Cañadón Asfalto Basin during the Early Cretaceous.

The charophyte record in this basin thus contributes to understanding the early evolutionary diversification of the Charoidae and their paleobiogeographic relationships, revealing the coexistence of endemic and widely distributed taxa during the Early Cretaceous. Future multidisciplinary studies integrating high-resolution stratigraphy, sedimentology, micropaleontology, and geochronology will help refine basin-scale correlations and improve our understanding of the evolution of continental freshwater ecosystems in southern Gondwana.

Acknowledgments. We acknowledge Dr. Aldo Martín Umazano and the journal Editors of the special issue for inviting us to participate with this review paper. We are

also grateful to Dr. Alba Vicente and Dr. Eduardo Bellosi for their comments and suggestions, which helped improve the manuscript.

REFERENCES

Allard, J., Foix, N., Paredes, J., Giacosa, R., Bueti, S., and Sánchez, F. (2021). Estratigrafía de la Cuenca de Cañadón Asfalto. In R. Giacosa (Ed.), *Relatorio del XXI Congreso Geológico Argentino: Geología y Recursos Naturales de la Provincia de Chubut* (187–266). Asociación Geológica Argentina.

De Sosa Tomas, A. (2025). *Bioestratigrafía (carofitas) del Cretácico de las cuencas del Golfo San Jorge y Cañadón Asfalto (Chubut)* [Unpublished doctoral thesis]. Facultad de Ciencias Naturales y Ciencias de la Salud, Universidad Nacional de la Patagonia San Juan Bosco, 239 pp. https://rdi.unp.edu.ar/handle/123456789/364

De Sosa Tomas, A., Martín-Closas, C., and Vallati, P. (2017). Biostratigraphy and biogeography of charophytes from the Cerro Barcino Formation (upper Aptian–lower Albian), Cañadón Asfalto Basin, central Patagonia, Argentina. *Cretaceous Research*, *79*, 1–11. http://dx.doi.org/10.1016/j.cretres.2017.07.004

De Sosa Tomas, A., Martín-Closas, C., Vallati, P., and Krause, J. M. (2022). Early Cretaceous Mesochara-rich assemblages from central Patagonia, Argentina, predate the origin of homogenous Charoidean floras by about 30 million years. *Cretaceous Research*, *129*, 1–18. https://doi.org/10.1016/j.cretres.2021.105017

De Sosa Tomas, A., Martín-Closas, C., and Vallati, P. (2023). Charophytes from the Pozo D-129 Formation (lower Aptian, Lower Cretaceous), source rock in the Golfo San Jorge Basin, Patagonia, Argentina. *Cretaceous Research, 151*, 105652. https://doi.org/10.1016/j.cretres.2023.105652

De Sosa Tomas, A., and Vallati, P. (2025). Insight into Cretaceous floras: A synthesis from plant microfossils of the Chubut Group in the Golfo San Jorge Basin. *Latin American Journal of Sedimentology and Basin Analysis*, *32*(1), 91–102.

Feist, M., Grambast-Fessard, N., Guerlesquin, M., Karol, K., Lu, H. N., McCourt, R. M., Wang, Q. F., and Zhang, S. (2005). *Treatise on Invertebrate Paleontology, Part B: Protoctista (Charophyta)* (Vol. 1). The Geological Society of America and University of Kansas Press.

Figari, E. G. (2005). *Evolución tectónica de la Cuenca de Cañadón Asfalto* [Unpublished doctoral thesis]. Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, 197 pp.

Grambast, L. (1974). Phylogeny of the Charophyta. *Taxon*, *23*, 463–481.

Iñiguez Rodríguez, A. M., Zalba, P. E., and Maggi, J. H. (1987). *Clinoptilolita y analcima en miembros del Grupo Chubut entre Paso de Indios y Las Plumas, provincia de Chubut, Argentina* [Abstract]. X Congreso Geológico Argentino (Vol. 1), 75–78. San Miguel de Tucumán.

Krause, J. M., Umazano, A. M., Bellosi, E. S., and White, T. S. (2014). *Hydromorphic paleosols in the upper Puesto La Paloma Member, Cerro Barcino Formation, mid Cretaceous, Patagonia Argentina:*

Environmental and stratigraphic significance [Abstract]. XIV Reunión Argentina de Sedimentología Actas, 146–147. Puerto Madryn.

Krause, J. M., Ramezani, J., Umazano, A. M., Pol, D., Carballido, J. L., Sterli, J., Puerta, P., Cúneo, N. R., and Bellosi, E. S. (2020). High-resolution chronostratigraphy of the Cerro Barcino Formation (Patagonia): Paleobiologic implications for the mid-Cretaceous dinosaur-rich fauna of South America. *Gondwana Research, 80*, 33–49. https://doi.org/10.1016/j.gr.2019.10.005

Martín-Closas, C. (2015). Cosmopolitanism in Northern Hemisphere Cretaceous Charophyta (Clavatoroidae). *Palaeogeography, Palaeoclimatology, Palaeoecology, 438*, 9–23. http://dx.doi.org/10.1016/j.palaeo.2015.07.029

Martín-Closas, C., Soulié-Märsche, I., and Sanjuan, J. (2024). The Fossil record and evolution of Charophytes from European data. In H. Schubert, I. Blindow, E. Nat, H. Korsch, T. Gregor, L. Denys, N. Stewart, K. van de Weyer, R. Romanov, and M. T. Casanova (Eds.). *Charophytes of Europe*. Springer Nature, 153–175. https://doi.org/10.1007/978-3-031-31898-6

Marveggio, N., and Llorens, M. (2013). Nueva edad de la base del Grupo Chubut en la mena uranífera Cerro Solo, provincia del Chubut. *Revista de la Asociación Geológica Argentina, 70*(3), 318–326.

Musacchio, E. A. (1971). Charophytas de la Formación La Amarga (Cretácico Inferior), provincia de Neuquén, Argentina. *Revista del Museo de La Plata, 6*(37), 19–38.

Musacchio, E. A. (1972). Carofitas del Cretácico Inferior en sedimentitas "chubutenses" al este de La Herrería, Chubut. *Ameghiniana, 9*(4), 354–356.

Musacchio, E. A. (1979). Datos paleobiogeográficos de algunas asociaciones de foraminíferos, ostrácodos y carofitos del Jurásico y el Cretácico inferior de Argentina. *Ameghiniana, 16*(3–4), 247–271.

Musacchio, E. A. (1989). Biostratigraphy of the non-marine Cretaceous of Argentina based on calcareous microfossils. In J. Weidmann (Ed.), *Cretaceous of the Western Tethys*. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 811–850.

Musacchio, E. A. (1993). Use of global time scale in correlating nonmarine Cretaceous rocks in southern South America. *Cretaceous Research, 14*, 113–126. https://doi.org/10.1006/cres.1993.1010

Musacchio, E. A. (1995). *Estratigrafía y micropaleontología del Jurásico y el Cretácico en la comarca del valle medio del río Chubut, Argentina*. VI Congreso Argentino de Paleontología y Bioestratigrafía Actas, 179–187, Trelew, Chubut.

Musacchio, E. A. (2000). Biostratigraphy and biogeography of Cretaceous charophytes from South America. *Cretaceous Research, 21*, 211–220. https://doi.org/10.1006/cres.1999.0197

Musacchio, E. A., and Chebli, G. (1975). Ostrácodos no marinos y carofitas del Cretácico Inferior en las provincias de Chubut y Neuquén, Argentina. *Ameghiniana, 12*, 70–96.

Musacchio, E. A., Beros, C., and Pujana, I. (1986). Microfósiles continentales del Jurásico y Cretácico del Chubut y su contribución a la bioestratigrafía de la Cuenca del Golfo San Jorge. In W. Volkheimer (Ed.), *Bioestratigrafía de los sistemas regionales del Jurásico y Cretácico de América del Sur* (Vol. 2), 355–383.

Pérez-Cano, J., Bover-Arnal, T., and Martín-Closas, C. (2022). Charophyte communities in Barremian Iberian wetlands. *Facies*, 68, 13, 1–38. https://doi.org/10.1007/s10347-022-00651-6

Soulié-Märsche, I. (2008). Charophytes, indicators for low salinity phases in North African sebkhet. *Journal of African Earth Sciences, 51*, 69–76.

Tasch, P., and Volkheimer, W. (1970). Jurassic conchostracons from Patagonia. *University of Kansas Paleontological Contributions, 50*, 1–23.

Turner, J. C. (1983). *Hoja Geológica 44 Colan Conhué, Provincia del Chubut escala 1:200.000.* 79 pp. (Boletín 197). Servicio Geológico Nacional.

Umazano, A. M., Krause, J. M., Bellosi, E. S., Perez, M., Visconti, G., and Melchor, R. N. (2017). Changing fluvial styles in volcaniclastic successions: A Cretaceous example from the Cerro Barcino Formation, Patagonia. *Journal of South American Earth Sciences, 77*, 185–205. https://doi.org/10.1016/j.jsames.2017.05.005

Vicente, A., and Martín-Closas, C. (2013). Lower Cretaceous charophytes from the Serranía de Cuenca, Iberian Chain: Taxonomy, biostratigraphy and palaeoecology. *Cretaceous Research, 40*, 227–242. https://doi.org/10.1016/j.cretres.2012.07.006

Villegas, P., and Umazano, A. M. (2024). Volcaniclastic sediment input and environmental responses of fluvial systems: Exploring a Cretaceous example from Patagonia. *Latin American Journal of Sedimentology and Basin Analysis*, *31*(1), 13–24.