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A synthesis of palynological data recovered from "Neocomian" deposits of the Golfo San Jorge Basin

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ABSTRACT

This contribution provides a synthesis of the palynological studies carried out on "Neocomian" units of the Golfo San Jorge Basin. Additionally, a revision of the palynological zones established for these units in previous works is presented, incorporating insights from new contributions and recent taxonomic novelties. Based on the palynological record, the age of the Las Heras Group is considered as not younger than Hauterivian at the northern and southern flanks of the Golfo San Jorge Basin. In contrast, the age of this group extends to the Aptian in the western area. Nevertheless, more detailed palynological studies and an evaluation of the current status of the stratigraphic units recognized in the analyzed wells are needed to confirm and expand these results.

Keywords: Lower Cretaceous, Las Heras Group, Palynology, Patagonia

INTRODUCTION

The Golfo San Jorge Basin (GSJB) is located in the central region of Argentinian Patagonia, between 45° and 47° South and 65° and 71° West, in

Chubut and Santa Cruz provinces, and extending eastward onto the Continental Platform (Fig. 1). This basin has the distinction of being the oldest and most productive petroleum sedimentary basin in Argentina (Barcat et al., 1989). The GSJB is an intracratonic structure with predominantly extensional characteristics, stretching in an east-west direction from the Andean belt to the Atlantic Ocean. Its sedimentary succession comprises deposits ranging from the Upper Jurassic to the Neogene. The Cretaceous sedimentary record of the basin is included in two successions. The first comprises the formally defined Las Heras Group and the informally named "Neocomian" deposits (and other equivalent formal and informal units; Lesta et al., 1980) dated as Upper Jurassic to Lower Cretaceous. The second consists of the Chubut Group, which includes Barremian? to upper Maastrichtian units (Allard et al., 2018). Despite the basin's extensive geographical extent and wide stratigraphic range, palynological studies of its succession remain scarce, particularly for the Lower Cretaceous (Archangeslky et al., 1981, 1983, 1984; Vallati, 1993, 2013; Barreda *et al.*, 2003; Perez Loinaze *et al.*, 2019, 2024).

This work aims to provide an updated review of the contributions of palynology from "Neocomian" unit of the GSJB. Additionally, a revision of the paleontological zones is presented, incorporating insights from updated records and recent taxonomic novelties.



Figure 1. Location map of the Golfo San Jorge Basin, showing the location of the sites referred in the text. 1. UN.OIL.OS-1 (Union Oil) well, 2. YPF.CH.F.x-1 (F) well, 3. YPF.PRM.es-1 (Paso Río Mayo=PRM) well, 4. YPF.CH.EC x-1 (Estancia Centeno) well, 5. YPF.CH.CS.x-1 well, 6. YPF.CRM.es-1 (Confluencia Río Mayo=CRM) well, 7. SC.CEP.x-1 (Cordón El Pluma=CEP) well, 8. Co.Ba.x-1 (Cerro Bagual), 9. EZ.x-1 (El Zanjón) well, 10. D-129 well, 11. YPF.SC.PL.x-2 (Puesto Luden) well, 12. Puesto Albornoz locality.

LAS HERAS GROUP AND EQUIVALENT DEPOSITS

The "Neocomian" deposits fill grabens and half-grabens formed during the Gondwana break-up (Figari *et al.*, 1996). These deposits reach maximum thickness in the western part of the basin. The Las Heras Group overlies, in angular unconformity, the Lower to Upper Jurassic Complejo Volcánico Sedimentario (*sensu* Clavijo, 1986), a succession of volcanic, volcaniclastic, and, to a lesser degree, sedimentary rocks of different stratigraphic units.

The "Neocomian" sequences present in the eastern zone of the basin, and at Sierra de San Bernardo, are referred to as the Pozo Anticlinal Aguada Bandera and Pozo Cerro Guadal formations in the subsurface (Fig. 2). These successions are also recognized under different names throughout the basin. The Shale Member of the Pozo Paso Río Mayo Formation in the Río Mayo area, the "Pelitas Laminares" in the central basin, and the "Sección Pelítica Basal" in the Lago Colhué Huapí sector are all correlatable with the Pozo Anticlinal Aguada de Bandera Formation. On the other hand, the Sandy Member of the Pozo Paso Río Mayo Formation can be correlated with the Pozo Cerro Guadal Formation. Additionally, the Tres Lagunas, Katterfeld, and Apeleg formations, located near Lago Fontana at the Río Mayo sub-basin and western area, as well as the Puesto Albornoz Formation outcropping in the northwestern part of the basin, are correlatable with the Las Heras Group (Sylwan *et al.*, 2011; Fig. 1 and 2).

The Pozo Anticlinal Aguada Bandera Formation consists mainly of black shales with intercalations of sandstones (Lesta *et al.*, 1980) deposited in a low salinity and anoxic lacustrine environment (Peroni *et al.*, 1995). However, marine elements have been reported in the western sector, suggesting influence from a Pacific transgression (Laffitte and Villar, 1982). The fossil record of this unit includes palynomorphs, scales and other skeletal remains of fishes, foraminifers, conchostracans, and ostracods (Lesta *et al.*, 1980; Laffitte and Villar, 1982).

The age of the Pozo Anticlinal Aguada Bandera Formation has been estimated as Tithonian to lower Valanginian, based on its paleontological content (Barcat *et al.*, 1989). Fitzgerald *et al.* (1990), using biostratigraphic information and correlations with the eustatic cycle chart of Haq *et al.* (1987), proposed an age range from Callovian to Berriasian for the unit. Masiuk and Viña (1987; in Barcat *et al.*, 1989) also assigned a lower Berriasian-lower Valanginian age to the unit, based on non-marine ostracodes and charophytes. Furthermore, this unit has yielded a Late Jurassic foraminifer assemblage (Laffitte and Villar, 1982) and Early Cretaceous palynomorphs (Archangelsky *et al.*, 1984).



Figure 2. Stratigraphic column of Lower Cretaceous unit of the Golfo San Jorge Basin. Modified from Sylwan *et al.* (2011). PAAB: Puesto Anticlinal Aguada Bandera Formation, PCG: Puesto Cerro Guadal Formation, SB: San Bernardo hill.

Overlying the Pozo Anticlinal Aguada Bandera Formation is the Puesto Cerro Guadal Formation. The contact between both units is unconformable (Sylwan, 2001). The Puesto Cerro Guadal Formation is composed of sandstones, tuffaceous siltstones, and silicified black shales, deposited in marine and transitional paleoenvironments to the west and lacustrine settings to the east (Clavijo, 1986; Figari *et al.*, 1999). This unit represents the moment of maximum flooding of the basin, influenced by marine incursions from the Pacific (Barcat *et al.*, 1989; Figari *et al.*, 1999).

The biostratigraphic record of the Puesto Cerro Guadal Formation is sparse, partly due to the fact that few wells penetrate the interval, and partly because most samples are sterile (Sylwan, 2001). Consequently, there is no consensus regarding the age of this unit. Barcat *et al.* (1989) inferred a Valanginian-Hauterivian age based on marine fauna. Fitzgerald et al. (1990) constrained its age to the Valangianian, based on the Hauterivian-Barremian age assigned to the overlying Pozo D-129 Formation. On the other hand, based on palynological data from EZ.x-1 (El Zanjón) well, Seiler and Viña (1996, in Sylwan, 2001) suggested a Berriasian age for the Puesto Cerro Guadal Formation.

Based on the cephalopod fauna as well as foraminifera, recovered from the Katterfeld Formation, a Valanginian-Hauterivian age was suggested for this unit (Russo and Flores, 1953 in Clavijo, 1986). The Pozo Paso Río Mayo Formation has been subdivided into two members: the lower Shale Member and the upper Sandy Member (Clavijo, 1986). The Shale Member consists of mudstones and black shales deposited in a lacustrine environment, while the Sandy Member comprises mudstones, sandstones, and tuffs deposited in both marine and continental conditions. Due to the presence of marine deposits, as well as the similarity in age, these levels have been correlated with the Katterfeld Formation (Ramos, 1976). Based on the foraminiferal content, a Berriasian to lower Valanginian age has been proposed for the Pozo Paso Río Mayo Formation (Clavijo, 1986).

PALYNOLOGICAL RECORD

The Las Heras Group and other formal and informal correlatable units from the GSJB have yielded limited palynological data (Perez Loinaze *et al.*, 2019). These palynofloras are characterized by the presence of pioneering cyanobacterial species *Celyphus rallus* (*e.g.*, Archangelsky and Seiler, 1980, Archangelsky *et al.*, 1984; Figari *et al.*, 1999; Peroni *et al.*, 1995; Bellosi *et al.*, 2002; Barreda *et al.*, 2003). However, Archangelsky *et al.* (1984) studied palynofloras from "Neocomian" without *Celyphus rallus*, and Barreda *et al.* (2003) present palynofloras with this taxon referred to Pozo D-129 Formation.

Archangelsky et al. (1981, 1983, 1984) analyzed palynofloras recovered from the Pozo Anticlinal Aguada Bandera, Puesto Cerro Guadal and Paso Río Mayo formations and undifferentiated "Neocomian" deposits from several wells of the GSJB (Fig. 2). In the first contribution, Archangelsky et al. (1981) presented the relative abundances of the different recovered paleofloristic groups. Later, the authors systematically studied the assemblages, proposing several new taxa (Archangelsky et al., 1983). Finally, Archangelsky et al. (1984), based on the distribution of 67 palynomorph species from YPF.CH.F.x-1, CRM.es-1, PRM.es-1, CBA.x-1, YPF.SC.CEP.x-1 and UN.Oil.OS-1 wells, proposed four palynological zones. These zones, in ascending stratigraphic Callialasporites-Contignisporites-Staplinisporites order, are the flate Berriasian-early Valanginian), Interulobites-Foraminisporis (late Valanginian-Hauterivian), *tectifera-corrugatus* (Barremian), and Antulsporites-Clavatipollenites (Aptian; Fig. 3).

The authors only recognized the first zone in strata referred to as the Springhill Formation of the Austral Basin, whereas the remaining three zones were identified in "Neocomian" units from the GSJB (Archangelsky *et al.*, 1984).

According to Archangelsky et al. (1984), the Interulobites-Foraminisporis Zone identification is based on the exclusive presence of Foraminisporis variornatus, F. microgranulatus, Interulobites pseudoreticulatus, I. distannulatus, Klukisporites tuberosus, Polycingulatisporites trabeculatus, and Taurocusporites sp. in Archangelsky et al. (1983). This zone also records the first appearances of Balmeiopsis limbatus and Cicatricosisporites sp. 3 in Archangelsky et al. (1983), and Cyclusphaera psilata, C. patagonica, C. Perez Loinaze, in press. Latin American Journal of Sedimentology and Basin Analysis

radiata, Foraminisporis wonthaggiensis, Impardecispora apiverrucatus, Laevigatosporites belfordii, Taurocusporites segmentatus, Triporoletes reticulatus among other continental taxa and the algae Microfasta evansii and Celyphus rallus (Archangelsky et al., 1984).



Figure 3. Biostratigraphic framework of Lower Cretaceous palynozones at the austral basins of Argentina, with detail of the stratigraphic ranges of recognized taxa. (*): in Archangelsky and Archangelsky (2010).

Among taxa characteristic of the Interulobites-Foraminisporis Zone as defined by Archangelsky et al. (1984), it is worth mentioning the presence of *Cyclusphaera psilata*, a species first recorded from upper Valanginian strata (Volkheimer, 1980; Quattrocchio et al., 2003), which allows defining the oldest temporal range of the zone, and separating it from the *Callialasporites-Contignisporites-Staplinisporites* Zone, where this species is absent. The presumed freshwater algal form *Microfasta evansii* is recorded from Berriasian to Aptian deposits in Australia (Morgan et al., 2002). *Celyphus rallus* is recorded from Upper Jurassic to Lower Cretaceous non-marine deposits (Batten et al., 1994 and references therein) whereas in Argentina, this taxon is known only from late Valanginian to Barremian assemblages (Barreda et al., 2003; Quattrocchio *et al.*, 2003 and references therein). However, the presence of *Celyphus rallus* is constrained by the paleoenvironmental conditions and, as such, has limited stratigraphic value.

Archangelsky *et al.* (1984) correlated the section between 2050 to 2600 m in depth of the YPF.SC.CEP.x-1 well with the *Interulobites-Foraminisporis* Zone (Fig. 4). These levels were referred to the Pelitas laminares (currently named Pozo Anticlinal Aguada Bandera Formation) and Puesto Cerro Guadal Formation (although the authors do not clarify the boundary between both units). However, Clavijo (1986) noted that in the YPF.SC.CEP.x-1 well, only the Puesto Anticlinal Aguada Bandera Formation is recorded, as the erosive contact with the overlying Pozo D-129 Formation resulted in the absence of the Puesto Cerro Guadal Formation.

The *Interulobites-Foraminisporis* Zone is also identified from the YPF.CH.F.x-1 well at a depth of 2220-2320 m, referred to as undifferentiated "Neocomian", and at the UN.Oil.OS-1 well (probably from 1314-1926 m, but this is not clearly stated; Archangelsky *et al.*, 1984).

The tectifera-corrugatus Zone was characterized by Archangelsky et al. (1984) by the appearance of *Cicatricosisporites* sp. 9 in Archangelsky et al. (1983), *Cyatheacidites tectifera*, *Densoisporites corrugatus*, *Leptolepidites macroverrucosus*, and *Trilobosporites purverulentus*. Several taxa present in minor proportions in the older assemblages become more common in this zone, such as *Cicatricosisporites* sp. 1 in Archangelsky et al. (1983), *C*. sp. 2 in Archangelsky et al. (1983), *C*. sp. 4 in Archangelsky et al. (1983), *C*. sp. 5 in Archangelsky et al. (1983), and *Foraminisporis dayli*. On the other hand, *Celyphus rallus*, *Cyclusphaera radiata*, *Interulobites pseudoreticulatus*, *Laevigatosporites belfordii*, *Microfasta evansii*, and *Trilobosporites canadensis* have their last appearances in this zone (Archangelsky et al., 1984).

Recently, the species *Cyclusphaera radiata* was found in younger units (Vallati *et al.*, 2013; Perez Loinaze *et al.*, 2019, 2021). Archangelsky and Archangelsky (2010) systematic review of the genera *Cicatricosisporites* and *Ruffordiaspora* recovered from Lower Cretaceous units from Argentina and

proposed new taxonomic combinations. In this context, *Cicatricosisporites* sp. 9 was referred to *Ruffordiaspora ludbrokiae*, *Cicatricosisporites* sp. 1 and *C*. sp. 2 to *C. cuneiformis*, and *C.* sp. 4, *C.* sp. 5 was assigned to *Ruffordiaspora cardielensis* (Fig. 3).

Palynological assemblages referred to the *tectifera-corrugatus* Zone were identified by Archangelsky *et al.* (1984) from the upper part of Puesto Cerro Guadal Formation at the CRM.es-1, PRM.es-1 well (2200-2400 m), the Shale Member of the Paso Río Mayo Formation at the PRM.es-1 well (1350-1685 m), the upper levels of the UN.Oil.OS-1 well (1281-1314 m), and from the undifferentiated "Neocomian" at the YPF.CH.F.x-1 well (1940-2220 m). Based on dinoflagellate cysts, Seiler (1979) suggested an age not older than upper Hauterivian and not younger than upper Aptian for the 1281-1290 m levels of the UN.Oil.OS-1 well, not contradicting the Barremian age of the *tectifera-corrugatus* zone as proposed by Archangelsky *et al.* (1984).

The Antulsporites-Clavatipollenites Zone was defined by Archangelsky et al. (1984) as characterized by the first appearance of angiosperm pollen grains (Clavatipollenites spp.), along with Antulsporites baculatus, Cyclusphaera crassa, Coptospora striata, and Contignisporites fornicatus.

More recent studies have shown that the species *Antulsporites baculatus* and *Cyclusphaera crassa* are also present in older units (upper Valanginian to Barremian; Guler *et al.*, 2015; Perez Loinaze *et al.*, 2019, 2024). Additionally, primitive angiosperm pollen grains have been recorded from older strata, dated as upper Barremian (Springhill Formation; Quattrocchio *et al.*, 2006; Guler *et al.*, 2015) and upper Barremian-lower Aptian (Pozo D-129 Formation; Vallati, 2013; Perez Loinaze *et al.*, 2019; Fig. 3).

This zone was recognized by Archangelsky *et al.* (1984) from the upper part of the Shale Member (correlated with the Puesto Anticlinal Aguada Bandera Formation by Clavijo, 1986) and the lower part of the Sandy Member (considered equivalent to the Puesto Cerro Guadal by Clavijo, 1986) of the Paso Río Mayo Formation at the PRM.es-1 well (1160-1350 m), and the upper part of Puesto Cerro Guadal Formation from the CRM.es-1 well (2200-2400 m).



Figure 4. a) Aequitriradites vertucosus, BA Pal 6011-2:F56/2. b) Aequitriradites spinulosus, BA Pal 6025-2:B50/4. c) Cicatricosisporites cuneiformis, BA Pal 6021-1:W45/0. d) Contignisporites cooksoniae, BA Pal 6011-1:P43/1. e) Densoisporites velatus, BA Pal 6022:G31/4. f-g) Foraminisporis variornatus, BA Pal 6024:D31/4. h) Impardecispora apiverrucata, BA Pal 6011-2:J43/4. i) Klukisporites sp., BA Pal 6012-1:F53/1. j) Polycingulatisporites trabeculatus, BA Pal 6022:R30/1. k) Nevesisporites radiatus, BA Pal 6023:O24/1. l) Interulobites pseudoreticulatus, BA Pal 6017:U51/1. m) Ruffordiaspora ludbrookiae, BA Pal 6015-2:X33/1. n) Staplinisporites caminus, BA Pal 6017:E45/0. o) Taurocusporites segmentatus, BA Pal 6021-1:K50/0. p) Triporoletes reticulatus, BA Pal 6020-2:D41/4. q) Verrucosisporites sp., BA Pal 6016:U40/4. r) Callialasporites trilobatus, BA PAL 6019:B26/0. s) Classopollis sp., BA PAL 6016:F56/2. t) Cyclusphaera psilata, BA PAL 6019:H28/0. u) Araucariacites australis, BA PAL 6012:Y28/0. x) Celyphus rallus, BA PAL 6018:E43/4. y) Microfasta evansii, BA PAL 6012-1:F53/4. Scale bar: 10 µm.

Based on the palynozones defined by Archangelsky *et al.* (1984), the Las Heras Group and equivalent formal and informal units would reach the Aptian, at least in the western sector of the GSJB, where the wells that provided the palynological assemblages studied by Archangelsky *et al.* (1984) are located.

Barreda *et al.* (2003) studied palynological samples recovered from 3059-3570 m of the D-129 well (Fig. 2), the type locality of Pozo D-129 Formation, on the northeast flank of GSJB. These authors reassigned the interval of 3335-3570 m, previously referred to as the Pozo D-129 Formation, to the Las Heras Group. These palynofloras of the Las Heras Group are characterized by the dominance of *Celyphus rallus*, associated with *Aequitriradites verrucosus*, *Cyclusphaera psilata*, *Densoisporites velatus*, *Foraminisporis wonthaggiensis* and *Taurocusporites segmentatus*, among others. Barreda *et al.* (2003) included this interval in the *Interulobites-Foraminisporis* Zone and referred it to the Hauterivian.

More recently, Perez Loinaze *et al.* (2019) studied palynological assemblages recovered from cutting samples of the YPF.SC.PL.x-2, from sections referred to the Las Heras Group (2534–2936 m) and the Pozo D-129 Formation (1584–2330) on the southeast flank of GSJB (Fig. 2). Among the species identified from the Las Heras Group are *Cyclusphaera psilata, C. radiata, Foraminisporis variornatus, Impardecispora apiverrucata, Laevigatosporites belfordii* and *Celyphus rallus, being the latter taxon present in most samples without being dominant. These palynological assemblages were correlated by Perez Loinaze <i>et al.* (2019) with the late Valanginian–Hauterivian *Interulobites-Foraminisporis* Zone.

The fossil record from the Puesto Cerro Guadal Formation recovered by Seiler and Viña (1996; in Sylwan, 2001) from the EZ.x-1 (El Zanjón) well (3019-3196 m) on the northeast flank of the GSJB (Fig. 2), is composed of *Coptospora striata, Cyclusphaera psilata, Ruffordiaspora australiensis,* along with ostracods of the genus *Candona*. These levels were dated as Berriasian by Seiler and Viña (1996; in Sylwan, 2001). Similar palynofloras to the El Zanjón well have been also identified at the YPF.SC.AAB.x-1 ("Anticlinal Aguada Bandera"), YPF.CH.AdP.es-1 ("Anticlinal de Papelía"), and YPF.CH.CDS.x-1 ("Codo del Senguerr") wells, and all correlated by these authors. Nevertheless, the presence of *Cyclusphaera psilata* in the assemblages suggests an age not older than late Valanginian (Volkheimer, 1980; Quattrocchio *et al.*, 2003). Additionally, *Coptospora striata* has only been recorded for the Aptian *Antulsporites-Clavatipollenites* Zone in Argentina (Archangelsky *et al.*, 1984). A more detailed study is necessary to clarify the age of these deposits.

Seiler and Moroni (1984) presented a preliminary study of palynological assemblages recovered from the YPF.CH.EC.x-1 and YPF.CH.CS.X-1 wells, located in the western area of the GSJB (Fig. 2), which are not associated with a formal stratigraphic unit. Among the identified species are Araucariacites australis, Balmeiopsis limbatus, Cyclusphaera psilata, *Callialasporites* trilobatus, **Podocarpidites** ellipticus, segmentatus, С. **Taurocusporites** segmentatus, and Vitreisporites signatus, along with dinoflagellate cysts (Seiler and Moroni, 1984). Based on the recognized taxa, an Early Cretaceous age, and probably Hauterivian to Barremian age, was suggested for these assemblages. However, as recognized taxa can be found in both the Interulobites-Foraminisporis and tectifera-corrugatus zones, a proposal of a conclusive Hauterivian to Barremian age is not supported, only suggesting that these assemblages cannot be older than late Valanginian. More detailed studies are necessary to assign a more precise age.

The first palynological record from the Puesto Albornoz Formation was presented by Vallati (1993). The author conducted a detailed palynological study, recognizing 36 taxa, though most of them were presented under open nomenclature. Among the palynomorphs Vallati (1993)identified senonicus, Interulobites intraverrucatus, Gleicheniidites *Callialasporites* segmentatus, and Cyclusphaera spp. An upper Valanginian to Aptian age, more likely Hauterivian to Barremian, was suggested for this unit (Vallati, 1993). More recently, Perez Loinaze et al. (2024) presented new palynological assemblages from the Puesto Albornoz Formation, expanding the list of

known taxa for the unit with the recognition of the spore taxa as Antulsporites baculatus, Cicatricosisporites cuneiformis, C. hughesi, Densoisporites velatus, wonthaggiensis, along with pollen grains Foraminisporites such as Cyclusphaera radiata, Ticoites gamerroi, among others. Interestingly, the algae Celyphus rallus was also recorded. The palynological assemblages from Puesto Albornoz Formation were correlated with the Interulobites-Foraminisporis Zone (Perez Loinaze et al., 2024), given the record of many taxa that first appear or are exclusive of this zone. Additionally, species that first appear in the overlying tectifera-corrugatus Zone, such as Trilobosporites purverulentus and Densosporites corrugatus, were not found in the Puesto Albornoz assemblages. Cyatheacidites tectifera is also considered as having its oldest records in the *tectifera-corrugatus* Zone and was identified in the assemblage by a single specimen. The palynofloras from the Puesto Albornoz Formation are closely comparable to those studied by Perez Loinaze et al. (2019) from the Las Heras Group, which were correlated to the Interulobites-Foraminisporis Zone.

Based on palynological record, the Las Heras Group's age is considered upper Valanginian to Hauterivian on the northern and southern flanks of GSJB (Fig. 1). However, this unit presents levels older based on another paleontological record. In contrast, the age of this group extends to the Aptian in the western area, where palynological assemblages from the upper levels of the Puesto Cerro Guadal Formation, the upper part of Shale Member, and the lower part of the Sandy Member of the Paso Río Mayo Formation are referred to the *Antulsporites-Clavatipollenites* Zone.

PALEOENVIRONMENTAL INFERENCES

The genus *Classopollis*, a pollen type related to the extinct conifer family Cheirolepidiaceae, is the dominant pollen form in most samples from the palynofloras studied by Archangelsky *et al.* (1981), mainly from levels referred to the *Interulobites-Foraminisporis* Zone in the YPF.CH.F.x-1 and YPF.SC.CEP.x-1 wells. The genus *Callialasporites*, related to the Podocarpaceae, co-dominates, while spores are in low abundances. In the levels of the YPF.CH.F.x-1, PRM.es-1, and CRM.es-1 wells referred to the *tectifera-corrugatus* Zone, *Classopollis* remains dominant, but the abundance of spores increases, while *Callialasporites* decreases. Finally, in the levels of the PRM.es-1 and CRM.es-1 wells assigned to the *Antulsporites-Clavatipollenites* Zone, *Classopollis* continues being the dominant taxon. In these levels, spores show either abundances similar to the previous Zone (CRM.es-1 well), or an increase in proportion (PRM.es-1 well; Archangelsky *et al.*, 1981).

Many studies have linked the high abundance of Cheirolepidiaceae to arid climates, citing the xeromorphic traits of their vegetative structures (*e.g.*, Vakhrameev, 1991). Nevertheless, more recent studies indicate that this family might have thrived in a broader range of environments (Tosolini *et al.*, 2015). In addition to its ecological requirements, the high relative abundance of *Classopollis* pollen grains could be influenced by several factors, including the high production of parent plants, the abundance of these plants in the assemblage, and transportation sorting (Schrank, 2010). Therefore, high percentages of *Classopollis* are not always indicative of xeric conditions in Gondwanan palynological assemblages, necessitating other climatic proxies to support or contrast this hypothesis (Perez Loinaze *et al.*, 2024). Additionally, the increase in spores may reflect more humid conditions. A rise in Podocarpaceae is also considered a paleoclimatic indicator of an increase in humidity as representatives of the family are, with few exceptions, typically found in humid climates (Zhang *et al.*, 2021).

The increased abundance of spores in the *tectifera-corrugatus* and *Antulsporites-Clavatipollenites* zones could suggest a rise in humidity during the deposition of the bearing strata. Based on apparent vertical changes in organic matter type and richness within lacustrine depositional systems in the GSJB, Peroni *et al.* (1995) suggested that the uppermost Jurassic-lower "Neocomian" organic-rich accumulations (Puesto Anticlinal Aguada Bandera Formation) developed in deeper, anoxic, and mildly brackish conditions, likely in humid climates with little seasonal contrast. On the other hand, the

upper "Neocomian" organic facies (Puesto Cerro Guadal Formation) seem to represent shallower lakes with ooidal benches, containing brackish to saline (alkaline) waters, which were likely promoted by semiarid climates. More detailed palynological studies are necessary to better understand the condition under which the Las Heras Group was deposited.

Algae in the palynofloras from the Las Heras Group and other correlatable deposits from the GSJB, referred to as the *Interulobites-Foraminisporis* and *tectifera-corrugatus* zones, are mainly represented by *Celyphus rallus* and *Microfasta evansii. Celyphus rallus* is a probable pioneering blue-green algae belonging to the family Rivulariaceae, adapted to brackish to freshwater transitional environments (Batten and Van Geel, 1985). Local abundances of this algae may reflect "blooms" in neutral or slightly alkaline conditions, but they could also be related to seasonal changes in productivity. The presence of abundant *Celyphus rallus* occurs mainly in shale deposits, which typically show good oil-generation potential (Figari *et al.*, 1999; Sylwan, 2001). In addition, the presence of the presumed freshwater algal form *Microfasta evansii* suggests deposition in a lacustrine environment and supports the potential for oil-prone source rocks (Morgan *et al.*, 2002).

FINAL COMMENTS AND PERSPECTIVES

Despite the economic importance of the "Neocomian" units of GSJB, their palynological knowledge remains scarce. The age of the Las Heras Group is inferred to be not younger than Hauterivian at the northern and southern flanks of GSJB. However, this unit is suggested to reach the Aptian in the western area of the GSJB. Nevertheless, more detailed palynological studies and an evaluation of the current status of the stratigraphic units recognized in the studied wells are needed to confirm these results.

Another issue observed in the scarcely available palynological studies is that palynofloras recovered from the Las Heras Group are not always segregated between the Puesto Anticlinal Aguada Bandera and Puesto Cerro Guadal formations. Better characterization of these units results critical to clarify the biostratigraphy of the group, and future studies should focus on addressing this topic.

While the *Antulsporites-Clavatipollenites* Zone needs revision, as some of the diagnostic species have been found in older strata, it is worth mentioning that the pioneering studies carried out by Archangelsky *et al.* (1981, 1983, 1984), as well as the biostratigraphic scheme proposed by these authors, continue, four decades later, to be a valuable tool for understanding the stratigraphy and relationship of these "Neocomian" units.

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