LAJSBA
LATIN AMERICAN JOURNAL OF SEDIMENTOLOGY AND BASIN ANALYSIS | VOLUME 32 (1) 2025, 32-43

STRATIGRAPHY OF THE CHUBUT GROUP (CRETACEOUS, GOLFO SAN JORGE BASIN, ARGENTINA): IMPACTS OF ALLOGENIC CONTROLS ON THE ALLUVIAL MACRO-ARCHITECTURE

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ARTICLE INFO

Article history
Received November 13, 2024
Accepted March 3, 2025
Available online April 28, 2025

Handling Editor
José I. Cuitiño

Keywords
Endorheic basin
Cretaceous fluvial systems
Alluvial architecture
Allogenic controls
Patagonia

ABSTRACT

The Chubut Group (Cretaceous, Golfo San Jorge Basin) is a continental succession up to 6,000 meters thick, preserved in an endorheic basin. Its basal depositional system includes the fluvial Matasiete Formation and the lacustrine Pozo D-129 Formation, the main source rock for the hydrocarbons of the basin. The Matasiete Formation (Aptian) represents a high-accommodation, exotic fluvial system with headwaters in the present-day Cañadón Asfalto Basin (CAB), referred to as the Los Adobes Formation. Sediment was transported southward to a saline-alkaline lake (Pozo D-129 Formation) through N-S sedimentary corridors in an extensional setting. The overlying depositional system is integrated by the Castillo and Mina del Carmen formations (Albian-Cenomanian?), and it consists of reworked volcaniclastic particles in drainage catchments within a W-E elongated extensional basin, disconnected from the CAB. The subsequent depositional system includes the Bajo Barreal Formation (Cenomanian-Coniacian?), containing the main hydrocarbon reservoirs. It shows varied stacking density in hundreds of meters thick cycles, linked to climatic cycles. Low net-to-gross fluvial stratigraphy featuring small-scale channel belts and paleosols indicates a temperate, subhumid/humid climate with seasonal rainfall. High net-to-gross fluvial stratigraphy records larger-scale channel belts interbedded with paleosols developed in a warmer, humid climate with perennial rainfall. The uppermost depositional system includes the paleosol-rich Laguna Palacios Formation at basin margins, with maximum thicknesses along syncline axes, and the red-colored, anastomosing fluvial systems of the Maastrichtian Colhué Huapi Formation that fill incised valleys. Both units are equivalent to the upper strata of Meseta Espinosa and El Trébol formations in the subsurface, showing degradational features marking the onset of surface uplift in the San Bernardo Fold Belt.

INTRODUCTION

The Cretaceous Chubut Group in the Golfo San Jorge Basin (GSJB) of central Patagonia was deposited within an endorheic basin, which changed its configuration, boundaries, and alluvial organization throughout its sedimentation history. These issues have been studied due to its significance as a hydrocarbon-producing basin (Figari *et al.*, 1999) and high-quality outcrop analogs along the San Bernardo Fold Belt (Hechem *et al.*, 1990; Paredes, 2023). The GSJB formed in response to the extensional processes associated with the fragmentation of Gondwana in the Late Jurassic. The Mesozoic succession is divided into two groups, differentiated by composition and structural setting, and covered by the marine strata of the Salamanca Formation (Maastrichtian-Danian). The Las Heras Group includes the Pozo Anticlinal Aguada Bandera and the Pozo Anticlinal Cerro Guadal formations in the subsurface, with coeval outcrops on the NNW margin of the basin known as the Puesto Albornoz Formation. This group is a continental siliciclastic succession up to 5,400 meters thick, preserved in half-grabens and grabens, primarily with lacustrine infill. The succession develops mixed and fully marine environments toward the west (Coyhaique Group), linked to an early connection with the Pacific Ocean. Magmatic activity along the incipient Andes Cordillera in the Early Cretaceous (Divisadero Group) provided primary and secondary volcaniclastic particles to the overlying Chubut Group, a continental succession infilling an endorheic basin from Barremian-Aptian to Maastrichtian. The Chubut Group is up to 6,000 meters thick in the deepest subsurface depocenters and comprises six continental formations (Pozo D-129, Matasiete, Castillo, Bajo Barreal, Laguna Palacios, and Lago Colhué Huapi) and its subsurface equivalents (Fig. 1c). The GSJB contains the main source rock in the lacustrine facies of the Pozo D-129 Formation, while the Castillo and Bajo Barreal formations (and coeval subsurface units) currently provide up to 35% of the liquid hydrocarbons of Argentina. This paper summarizes recent research on the role of allogenic forcing factors in the evolution of the endorheic basin, providing a thorough understanding of this complex geological scenario.

ALLUVIAL MACRO-ARCHITECTURE OF THE CHUBUT GROUP

The deposition of the Chubut Group in the GSJB spans about 40 million years and covers over 150,000 km^2 (Fig. 1). Throughout its deposition, the basin's size, organization, and lithological character evolved, influenced by Paleozoic-Jurassic tectonic structures, Cretaceous intrabasin tectonics, and the coeval evolution of the Andes Cordillera to the west (Paredes *et al.*, 2021). The evolution of the Chubut Group is summarized below, considering its main lithological subdivisions and tectonostratigraphic stages within four primary depositional systems: 1) Matasiete-Pozo D-129 depositional system (Barremian-Albian?), 2) Castillo-Mina del Carmen (Albian-Cenomanian?) depositional system, 3) Bajo Barreal (and subsurface units) depositional system (Cenomanian- Coniacian?), and 4) Laguna Palacios-Colhué Huapi (and subsurface units) depositional system (Campanian?-Maastrichtian).

The Matasiete-Pozo D-129 depositional system

The basal units of the Chubut Group comprise red-colored fluvial deposits of the Matasiete Formation (Sciutto, 1981) and extensive lacustrine deposits of the Pozo D-129 Formation (Fig. 2a). Detrital zircons obtained from the uppermost deposits of the Pozo D-129 Formation at Codo del Senguerr anticline indicate late Albian (103.16 ± 5.6 Ma, 103.3 ± 3.8 Ma, Allard *et al.*, 2022), although micropaleontological studies indicate Barremian-Aptian (see Perez Loinaze *et al.*, 2019). Shallowing-upward, deltaic deposits in the Pozo D-129 Formation occur both in outcrop and in the subsurface of the San Bernardo Fold Belt (Paredes *et al.*, 2014; Ferreira *et al.*, 2018), where typical deposits are interpreted as (A) deep lacustrine, (B) sub-littoral lacustrine, and (C) shallow lacustrine environments. The shallow lacustrine deposits include sub-associations of (C.1) carbonate deposits, (C.2) distributary channels, (C.3) mouth bars, and (C.4) interdistributary bay deposits. The Matasiete Formation records exotic rivers originating in the present-day Cañadón Asfalto Basin (CAB), known there as the Los Adobes Formation (Allard *et al.*, 2015). These rivers transported sediments southward (Fig. 2b) to a regional-scale, saline-alkaline lake (Pozo D-129 Formation) via N-S-oriented sedimentary

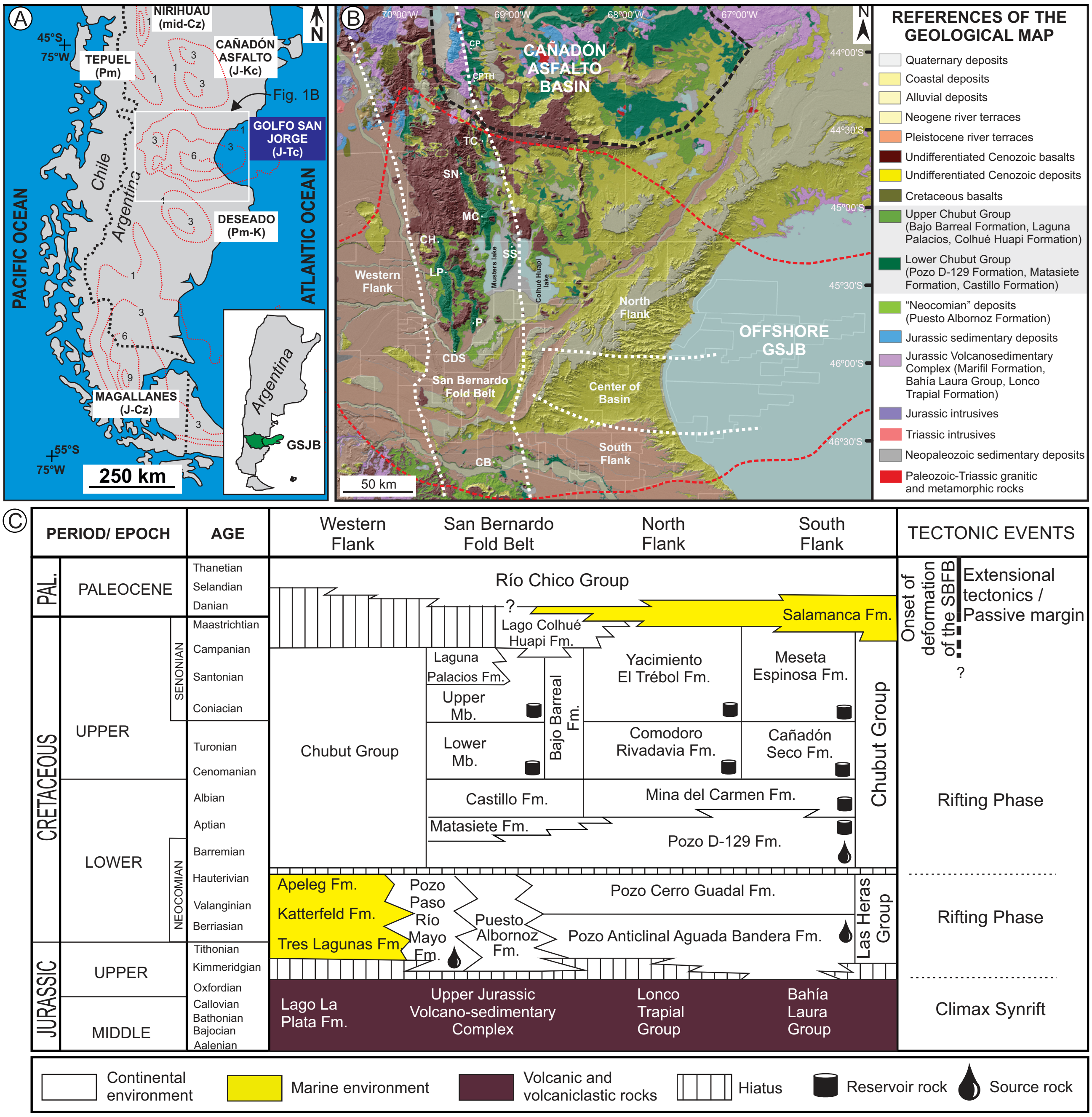


Figure 1. a) Location and thickness map (in Km) of sedimentary basins in central Patagonia, Argentina (after Paredes, 2023). The inset shows the extent of the Golfo San Jorge Basin in green. **b)** Geological map of the Golfo San Jorge Basin, main structural subdivisions and localities mentioned in the text. Key: CP= Cañadón Puelman, CPTH= Cerro Punta Toro Hosco, TC= Tronador Canyon, SN= Sierra Nevada anticline, MC= Matasiete Canyon, SS= Sierra Silva anticline, LP= Las Pulgas anticline, P= Papelía anticline, CDS= Codo del Senguerr anticline, CB= Cerro Ballena anticline. **c)** Mesozoic to Paleogene stratigraphy.

corridors in an extensional setting (Figari and García, 2018), with additional source areas including the Deseado Region at south and the incipient Andes cordillera at west (Figari *et al.*, 1999). This geological context resulted in axial and transverse drainage catchments (Allard *et al.*, 2021), syn-extensional wedges linked to major faults in the San Bernardo Fold Belt (hereafter SBFB) subsurface (Allard *et al.*, 2020), and to the development of a W-E extensional phase identified in multiple oilfields eastward of the SBFB (Figari *et al.*, 1999; Giampaoli, 2019). The thickness distribution of the Pozo D-129 Formation shows (Fig. 2c) a lower seismic sequence with significant thickness variation across fault surfaces and an upper seismic sequence with minor regional variations (Fitzgerald *et al.*, 1990). These features indicate the smoothing of the topography from the previous syn-rift stage of the Las Heras Group. Along exposures of the SBFB, the fluvial systems are part of high-accommodation systems tracts, predominantly containing low sinuosity, fixed channels with ribbon geometries (mean thickness 7.3 m, W/T ratio 14). Stratigraphic intervals with resedimented tuff deposits contain braided rivers with a W/T ratio of up to 90 (Paredes *et al.*, 2024). The channelized sandstones' source area includes neovolcanic and pyroclastic fragments, Upper Jurassic basic-intermediate volcanic components, and minor Paleozoic igneous-metamorphic basement fragments (Olazábal *et al.*, 2020).

The Castillo-Mina del Carmen depositional system

This depositional system, comprising the Castillo and Mina del Carmen formations, overlies the previous system. Radiometric dating (Ar-Ar) of tuff layers in the Castillo Formation indicates deposition during the Late Albian: 100.14 ± 0.32 Ma (Tronador Canyon) and 100.13 ± 0.28 Ma (Cerro Colorado de Galveniz) (Genise *et al.*, 2020), whereas detrital zircons suggest Early Cenomanian (98.3 ± 9.1 Ma) for the base of the unit at Codo del Senguerr anticline (Allard *et al.*, 2022). It features a centripetal fluvial network within a W-E elongated basin, disconnected from the CAB (Fig. 3a), containing up to 70% tuffaceous beds, primarily reworked volcaniclastic particles. These units produce around 10% of the basin's liquid hydrocarbons, extracted from fluvial channel belt deposits and diagenetically altered, ash-rich distal floodplain deposits. Due to low reservoir quality attributed to ash particles in the matrix, hydraulic-fracture stimulation is necessary for hydrocarbon exploitation. The Castillo Formation represents a high-accommodation fluvial system with resedimented tuff beds. Fluvial styles and channel sizes vary along the SBFB (Fig. 3b), with ephemeral rivers in the headwaters and perennial rivers downstream. Systematic measurements of channels (Fig. 3c-d) show a narrow-sheet geometry (~3 m thick, W/T ratio 45) (Paredes *et al.*, 2015) with high dispersion in the external geometry of the channel-belt deposits. Paleosols, paleobotanical, and ichnological data suggest a dry, open woodland or savanna environment under warm-temperate and semiarid conditions (Genise *et al.*, 2020). Extensional tectonic processes in the GSJB and CAB reorganized the basin, disconnecting sedimentary corridors and leading to higher subsidence in the GSJB (Allard *et al.*, 2021). As a result, large-scale Albian lakes are not recorded in the onshore GSJB, but occur in the Centre of Basin and offshore area (Foix *et al.*, 2018). Intra-basin topographic highs associated with renewed extensional activity created drainage divides, partitioning the GSJB into smaller watersheds. Sediment supply reduction in Albian fluvial systems is attributed to river capture, re-routing, and source area contraction, a climate-independent mechanism linked to changes in basin morphology (Paredes *et al.*, 2024). Provenance changes in detrital components reflect reduced pre-Cretaceous sources and increased pumiceous and glass shards from reworked pyroclastic deposits (Tunik *et al.*, 2015).

The Bajo Barreal (and its subsurface equivalents) depositional system

The Bajo Barreal Formation (and subsurface equivalents) spans 300 to 2500 meters in thickness and covers up to 150,000 km^2. It fills inherited depocenters and displays onlap terminations onto basin margins (Hechem and Strelkov, 2002), characterized by centripetal infill of a W-E elongated basin sourced by multiple drainage catchments. Along the SBFB, a Lower Member features channelized sandstones interbedded with fine-grained tuffaceous strata, and the Upper Member contains isolated channel sandbodies surrounded by grey siltstones and mudstones (Umazano *et al.*, 2008). These members correspond to the subsurface Comodoro Rivadavia and El Trébol formations in the North Flank and the Cañadón Seco and Meseta Espinosa formations in the South Flank. However, the upper strata of El Trébol and Meseta Espinosa may be younger than the Bajo Barreal Formation and belong to the Chubut Group's uppermost depositional system (see below).

Radiometric dating (Ar-Ar) of tuff layers in the Bajo Barreal Formation indicates deposition during the Cenomanian–early Turonian: 91 ± 0.49 Ma (Cerro Ballena), 94.2 ± 0.63 Ma (Codo del Senguerr), and 97.9 ± 0.83 Ma, 95.8 ± 0.81 Ma, 91.1 ± 2.85 Ma (Cerro Colorado de Galveniz) (Bridge *et al.*, 2000).

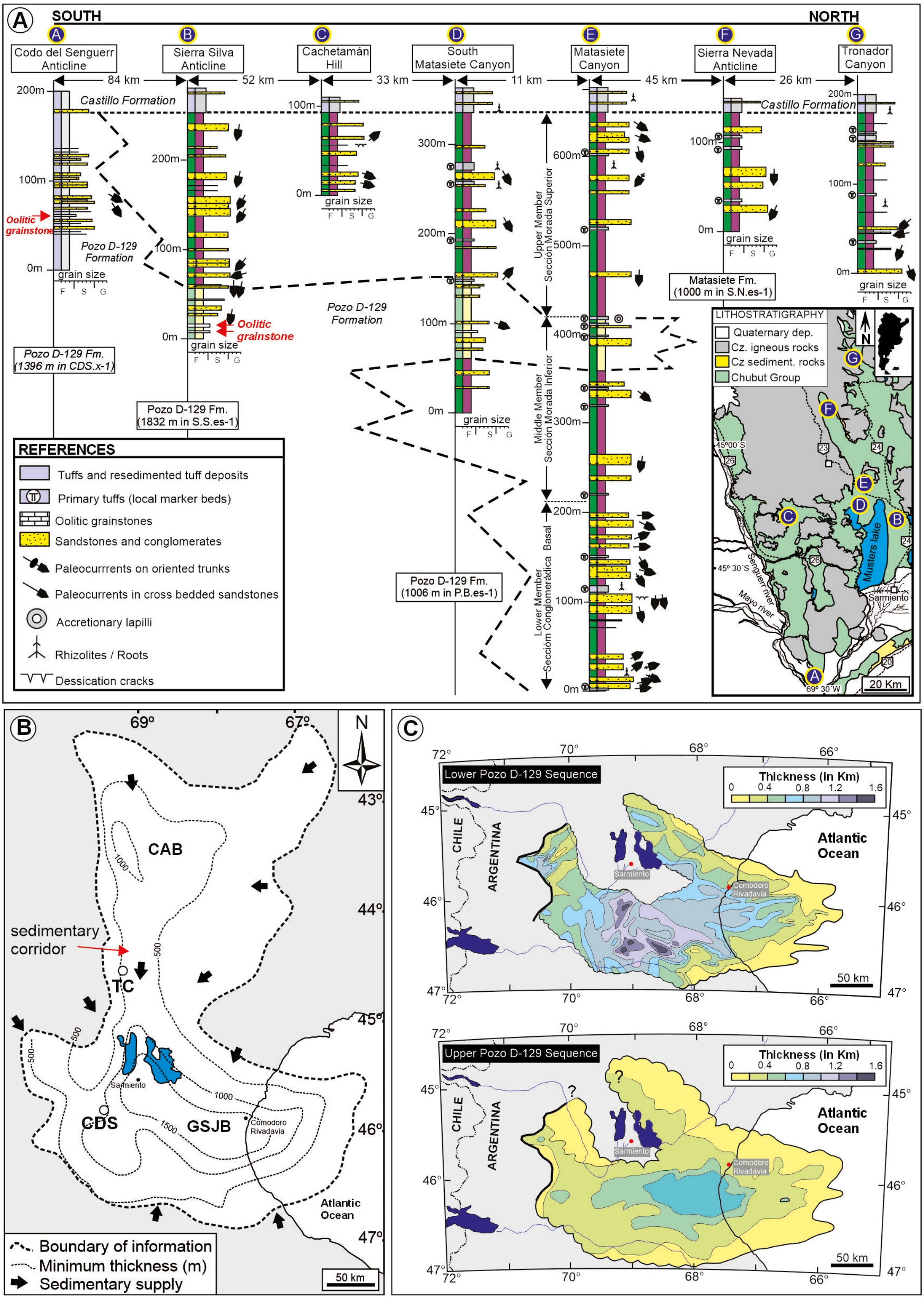
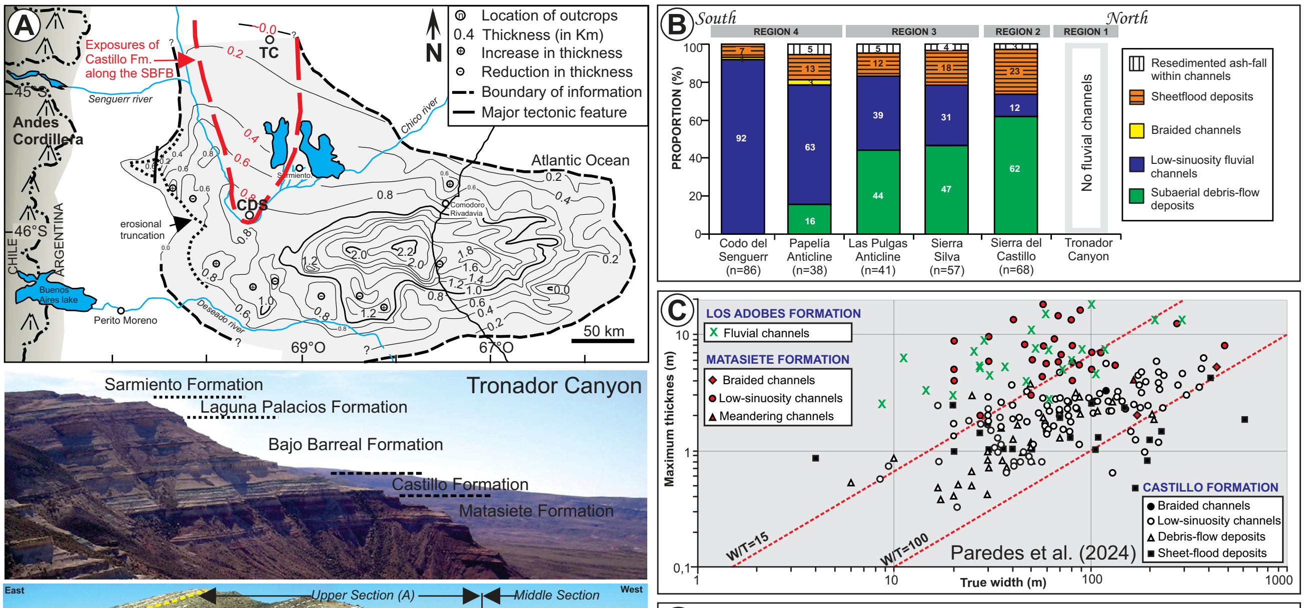


Figure 2. The Matasiete-Pozo D-129 depositional system. **a)** Distribution of the Matasiete and Pozo D-129 formations in San Bernardo Fold Belt exposures. **b)** Simplified thickness map of the depositional system integrated by the Los Adobes Formation (Canadón Asfalto Basin, CAB) and the Matasiete-Pozo D-129 formations in the Golfo San Jorge Basin (GSJB). White circles mark the position of the Codo del Senguerr (CDS) anticline and Tronador Canyon (TC) in the Golfo San Jorge Basin. **c)** Thickness distribution of the two basin-scale seismic sequences identified within the Pozo D-129 Formation in the subsurface of the Golfo San Jorge Basin (after Fitzgerald *et al.*, 1990).



		Locality	N	T (m)	T (max)	StD (m)	W (m)	W (max)	StD (m)	W/T	StD
CHUBUT GROUP	Castillo Formation	Codo del Senguerr	86	2.89	7.70	1.59	114	611.5	102	43	38
		Sierra Silva	36	2.57	5.80	1.30	94	310	82	44	38
		Sierra del Castillo	34	1.29	3.50	0.69	49	199	46	48	46
	Matasiete Formation	Matasiete Canyon	33	7.30	16.5	3.7	103	465	113	14	7
	Los Adobes Formation	PuntaToro Hosco & Puelman Canyon	24	7.30	18.0	4.2	68	294.4	66	9.4	6

Figure 3. The Castillo-Mina del Carmen depositional system. **a)** Thickness distribution in the GSJB (after Fitzgerald *et al.*, 1990). Pictures show typical aspects of the unit at the northern basin margin (Tronador Canyon) and in the Codo del Senguerr anticline. **b)** Spatial variation of the channel types of the Castillo Formation along the SBFB, from exposures of the northern basin margin to the exposures at the Codo del Senguerr anticline. **c)** A scatter log-log plot shows the relationship between maximum thickness and true width (calculated normal to the mean paleoflow direction) of channel deposits of the Los Adobes, Matasiete, and Castillo formations. **d)** Geometrical parameters of fluvial channel belt deposits of the Los Adobes, Matasiete, and Castillo formations in the San Bernardo Fold Belt.

U/Pb SHRIMP zircon data from the Upper Member yield 99.7 ± 0.7 Ma (Cenomanian) and younger grains (94.1 ± 1.1 Ma to 91.7 ± 1.4 Ma, Turonian) (Suárez *et al.*, 2014), whereas detrital zircons suggest Middle Cenomanian (96.8 ± 4.2 Ma) and early Coniacian (88.4 ± 2.4 Ma) ages for the Lower and Upper Members, respectively (Allard *et al.*, 2022).

Up to 90% of the GSJB's liquid hydrocarbons are produced from fluvial channel-belt deposits of the Bajo Barreal Formation. The main hydrocarbon reservoirs are channel belts with high interconnectivity correlating with the Lower Member. These deposits comprise up to 70% of the unit in the North Flank (referred there as Complex III) and up to 40% in the Cañadón Seco Formation of the South Flank (Fig. 4). Synsedimentary extensional faults are widespread in the subsurface of both flanks, reflecting multiple extensional phases during the deposition of the Bajo Barreal Formation (Paredes *et al.*, 2018a; Giampaoli, 2019). The palynological content of the Cañadón Seco Formation suggests temperate to warm and humid conditions (Perez Loinaze *et al.*, 2021).

Fluvial systems along the SBFB are dominated by fine-grained floodplain deposits with low-sinuosity, sheet-like fluvial channels, clustered into several coeval channel belts relocated by avulsion. Depositional interpretations include volcaniclastic alluvial fans, fan-deltas, meandering, braided, and ephemeral rivers (Paredes *et al.*, 2021). Channel belt deposits range from 1 to 10 meters thick (mean 3-4 meters, maximum 25 meters), typically containing two or three stories separated by floodplain deposits. Most Bajo Barreal exposures along the SBFB are high-accommodation systems tracts, with channel deposits rarely exceeding 20% in vertical sections. However, subsurface data show cyclic fluvial architectures in 200-250-meter-thick packages with closely spaced and interconnected channels alternating with floodplain-dominated intervals (Fig. 4).

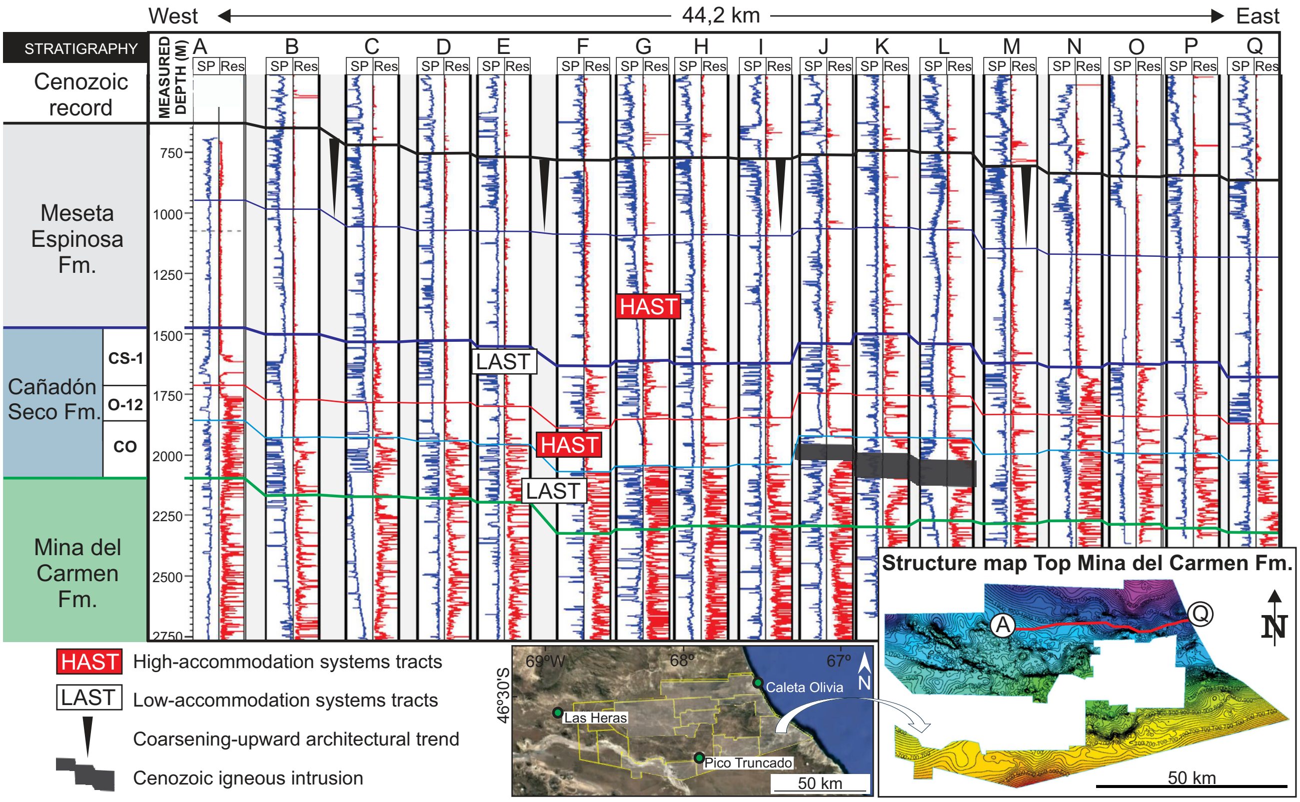


Figure 4. Well-log correlations of the Cañadón Seco and Meseta Espinosa formations, South Flank of the GSJB. Vertical changes in the stacking density of the Cañadón Seco Formation: the Caleta Olivia (CO) and the CS-1 members comprise low-accommodation systems tracts, whereas the O-12 Member represents a high-accommodation systems tracts, dominated by floodplain fines. The upper strata of the Meseta Espinosa Formation show a coarsening-upward log motif, evidencing the progradation of the alluvial systems through time. The inset maps show the structure map of the top of the Mina del Carmen Formation, the location of the well correlation section, and the boundary of oilfield and localities in the South Flank.

The single exposure along the SBFB with contrasting stacking density in the Bajo Barreal Formation is located in the Cerro Ballena anticline (Santa Cruz province, Fig. 5), evidencing two distinctive alluvial architecture styles, referred to as Section A and Section B. Section A is preserved in the core of the anticline. It consists of a 180 m thick succession containing small-scale, isolated channels filled in a siliciclastic floodplain characterized by a sand:mud ratio of ~ 1:6, whereas the overlying Section B has a sand-mud ratio of ~ 1:3, with larger-scale channels and greater inter-connectivity within a volcaniclastic floodplain. GPS data from channel boundaries of Section A indicate a true width of 45 m, whereas Section B averages 61 meters (n=218). Vertical variation in stacking density between Section A and Section B was evaluated using paleohydraulic estimations in channel fills and paleosol-derived climofunctions. The palaeohydrological equations allowed estimating flow depth (d) and true width (Wc) of formative channels of Section A (n=11, d=4.05 m, Wc= 45.5 m) and Section B (n= 30, d=5.76 m, Wc= 69.5 m). Daily discharge estimations in channels of Section A show values of 133 m^3/sec, whereas in Section B, they average 421 m^3/sec; the results indicate more significant discharges and water availability in Section B. These indirect inferences of climatic change were independently corroborated through the study of types of paleosols and paleosol-derived climofunctions. Vertisol-like paleosols and subordinate vertic Alfisol-like paleosols characterize Section A, whereas ultisols and hydromorphic inceptisols occur in the Section B. Climofunctions of mean annual temperature show an average of 11.7 ºC/yr for the Section A, and 13.6 ºC/yr for Section B. Meanwhile, climofunctions of mean annual precipitation show an average of 873 mm/yr for Section A and an average of 1305 mm/yr for Section B (Lizzoli *et al.* 2025). Paleoclimate reconstruction indicates a temperate subhumid/humid climate with seasonal rainfall for Section A and a warmer temperate humid climate with perennial rainfall for Section B.

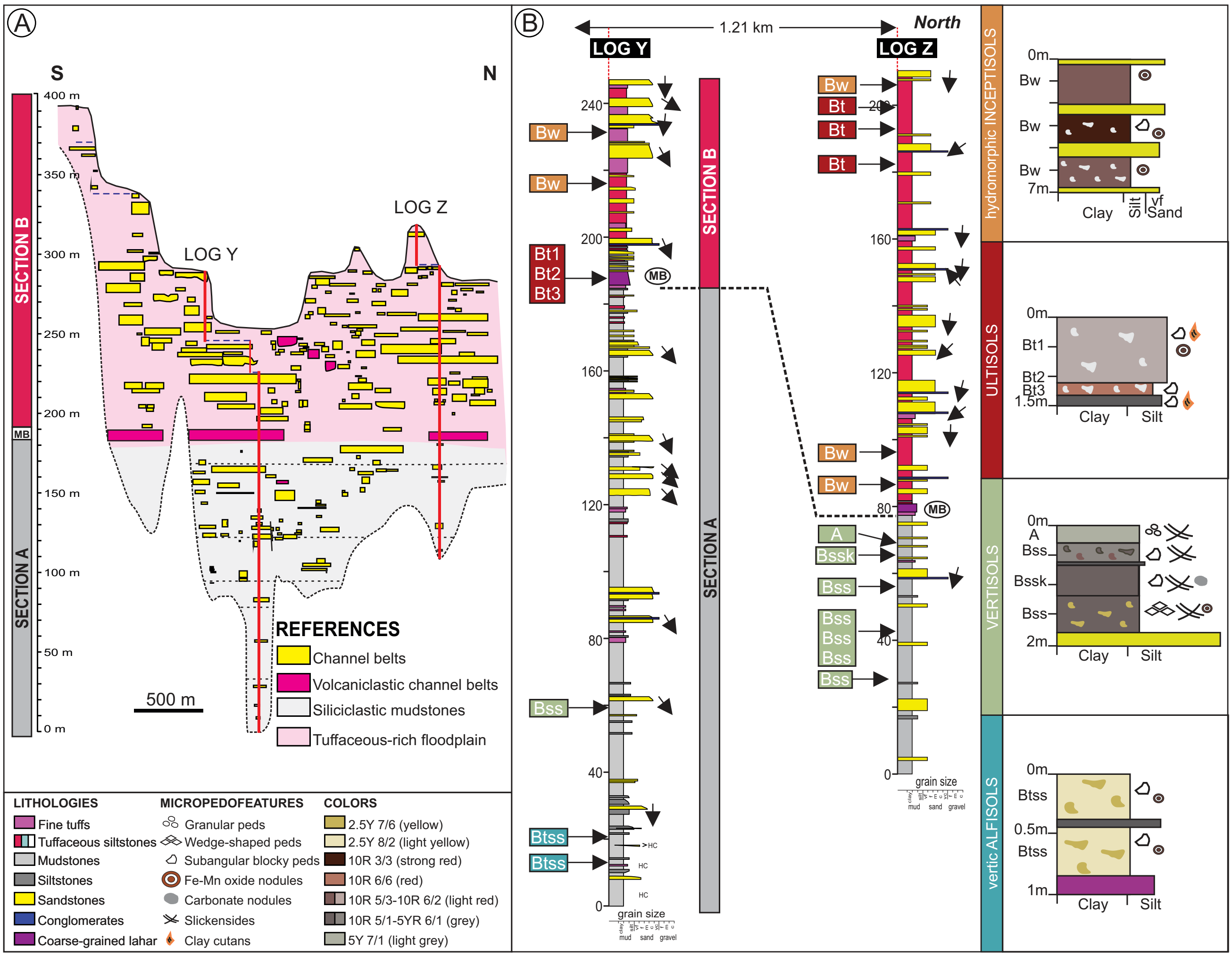


Figure 5. The Bajo Barreal Formation in the Cerro Ballena anticline. **a)** Macro-architecture of the unit and location of sedimentological profiles (after Paredes *et al.*, 2018b). **b)** Sedimentological and paleopedological sections were measured from the Bajo Barreal Formation in the Cerro Ballena (logs Y and Z). The four pedotypes were represented in stratigraphic order of appearance with a representative profile (for details see Lizzoli *et al.*, 2025).

The Laguna Palacios – Lago Colhué Huapi depositional system (and its subsurface equivalents)

The uppermost lithostratigraphic units of the Chubut Group form a complex mosaic of continental formations with varied fluvial architecture, linked to the onset of the SBFB uplift. In this fold belt, the Upper Member of the Bajo Barreal Formation is overlain by the aggradational, paleosol-rich, eolian, and fluvial deposits of the Laguna Palacios Formation (Genise *et al.*, 2002). Radiometric dating (Ar-Ar) of tuff layers at Cerro Colorado de Galveniz indicates deposition during the late Coniacian – early Santonian (85.1 ± 0.79 Ma, Bridge *et al.*, 2000). The Laguna Palacios Formation shows onlap terminations towards the southern basin margin, with maximum thicknesses along syncline axes north of the Codo del Senguerr anticline (Sciutto, 1981), and evidence of progressive unconformities, indicating syn-contractional deformation (Allard *et al.*, 2020). On the eastern margin, the Lago Colhué Huapi Formation (Casal *et al.*, 2015) overlies the Upper Member of the Bajo Barreal Formation. This red, high-accommodation fluvial succession fills 20 m-deep incised valleys and is dated to the Maastrichtian based on palynology (Vallati *et al.*, 2019), correlating with upper levels of the El Trébol Formation.

In the subsurface, the uppermost Chubut Group deposits are represented by the El Trébol (North Flank, 1200 m thick) and Meseta Espinosa (South Flank, 850 m thick) formations, preserved in an aggradational setting with coeval extensional tectonics along W-E normal faults (Paredes *et al.*, 2013, Paredes *et al.*, 2018a). Floodplain fines and low-connectivity channel belts dominate the lower half of these formations, while the upper half shows coarsening-upward trends, correlatable over tens of kilometers, driven by alluvial progradation or compound fan apron deposits from basin margins. In the offshore area, marine deposits with Maastrichtian-Danian foraminifera are found in strata equivalent to the upper El Trébol Formation (Sylwan *et al.*, 2011). Onshore, composite paleovalley fills up to 260 m thick in the upper Meseta Espinosa Formation (Paredes *et al.*, 2021) record base-level changes in a low-accommodation setting before the transgression of the Maastrichtian-Danian Salamanca Formation.

DISCUSSION

The basin-scale alluvial architecture of endorheic basins typically exhibits aggradational stratigraphic architectures regulated by basin subsidence and changes in sediment supply (Nichols, 2012). The formation of large-scale lakes and terminal systems depends on the balance between fluvial discharge and water loss through evaporation or infiltration, with morphology primarily influenced by tectonic processes. A distinctive feature of most modern endorheic basins is the development of distributive channel patterns (Hartley *et al.*, 2010) associated with sediment deposition within the drainage basin, a process that reduces the gradient of the fluvial system and triggers avulsions. However, some rivers terminating on alluvial plains do not develop a distributive pattern (North and Warnick, 2007).

Tectonic Control: Changing Basin Morphology and Coeval Tectonic Scenario

The Los Adobes-Matasiete depositional system is a high-accommodation fluvial system originating in the present-day Cañadón Asfalto Basin, flowing southward to the lake of the Pozo D-129 Formation through N-S oriented tectonic sedimentary corridors. Extensive drainage catchments facilitated large-scale channel belt deposits, averaging 7.3 m of thickness with ribbon geometries. During the Albian, extensional tectonic processes in the CAB and GSJB led to basin reorganization and the disconnection of inherited sedimentary corridors, resulting in higher subsidence in the GSJB. This reorganization reduced drainage catchments and formed intra-basin topographic highs, creating drainage divides and partitioning the GSJB into smaller watersheds. These geomorphological changes impacted the channel network, resulting in small-scale channel belt deposits with narrow-sheet geometries in the Albian-Cenomanian? Castillo Formation.

Alluvial systems are highly sensitive to subtle changes in gradient and sediment supply due to tectonic activity, causing longitudinal or lateral tilting of river profiles, systematic changes in flow direction, aggradation or incision near active tectonic structures, and variations in fluvial styles and channel dimensions in deforming areas. The coeval extensional tectonic processes during the deposition of the Chubut Group largely controlled the organization of the depositional systems. Therefore, integrating outcrop and subsurface data is essential to constrain alternative tectonic interpretations. Despite extensive 3D seismic coverage in the GSJB, there are no mentions of megafan or fluvial fan deposits nor identification of typical facies architecture of alluvial fan deposits within the Chubut Group. Alluvial fan deposits, typically adjacent to mountain fronts, are hard to recognize or absent in the studied successions. Additionally, paleoflow data from channel-fill deposits of the Castillo and Bajo Barreal formations in the Codo del Senguerr anticline shows highly oblique paleoflow trends relative to the anticline axis and relatively straight flow paths, suggesting uplift occurred after deposition (Paredes *et al.*, 2015, Paredes *et al.*, 2016). Both lines of sedimentological evidence do not support the compressional scenario during the deposition of the Castillo and Bajo Barreal formations envisaged by Gianni *et al.* (2015).

Climate Control on Stacking Density of the Bajo Barreal Formation

The vertical, temporal variations in the stacking density of fluvial channel belt deposits are a defining characteristic of ancient stratigraphic successions observed in outcrop and subsurface studies. While it is generally accepted that the development of high- and low-accommodation systems tracts is influenced by sediment supply and available accommodation space, the relative impacts of tectonics (*i.e.*, variations in basin subsidence), base level, and climate (including factors such as water supply, sediment input, paleosols, and vegetation types) remain a subject of debate.

Most exposures in the Bajo Barreal Formation along the San Bernardo Fold Belt appear to represent high-accommodation systems tracts, with channel deposits rarely constituting more than 20% of the vertical section. However, at Cerro Ballena and within much of the basin's subsurface (see Fig. 4), a cyclic alternation of high- and low-accommodation alluvial deposits is preserved in sequences 150-250 meters thick. The Cerro Ballena outcrop, which spans 385 meters in thickness and 2.5 kilometers in width, exhibits a layer-cake geometry without substantial erosional surfaces or fluvial terraces, suggesting that local tectonic activity or base-level fluctuations had minimal influence. Paleohydrological data derived from channel-fill deposits, along with paleosol-based climate indicators (climofunctions) in the Cerro Ballena anticline of the Bajo Barreal Formation, provide critical evidence for the role of climate in influencing stacking density (see Fig. 5). The data indicate that stratigraphic intervals with a low sand-to-mud ratio (Section A) contain small-scale formative rivers and paleosols that reflect a seasonal, sub-humid climate. In contrast, intervals with a higher sand-to-mud ratio (Section B) are associated with higher-discharge rivers, indicative of a warmer, temperate, and humid climate. We interpret the observed upward increase in sand-to-mud ratio as a response to a substantial rise in sediment supply and river discharge, likely resulting in increased channel avulsion frequency or enhanced channel migration rates. Consequently, fluvial successions with variable stacking densities may arise from a complex interplay of climatic changes. This variability is recorded in the basin's oil-bearing reservoirs (refer to Paredes *et al.*, 2020, their Fig. 14), where high sand-to-mud ratio intervals identified through wireline logs correlate via seismic attribute analysis, with large-scale, meandering fluvial channels. Conversely, intervals with a low sand-to-mud ratio are predominantly associated with narrow, low-sinuosity fluvial channels.

Base Level Changes: The Missing Record

Despite an extensive subsurface database, the temporo-spatial evolution of the Pozo D-129 Formation remains largely unknown. Subsurface studies have identified fan-shaped sandstone strata of sub-lacustrine origin, interpreted as volcaniclastic deltas and fan-shaped slope deposits (Lopez-Angriman *et al.*, 2014), with similar features in the upper levels of Pozo D-129 Formation at the Codo del Senguerr anticline (Paredes *et al.*, 2014). However, the large-scale lake dynamics and geometry of the formative lake(s) remain poorly understood, and basin-scale base-level changes have not been documented. The absence of distinctive subsurface geometries characterizing cycles of lake expansion and retraction, along with the lack of documentation of coeval displacement of fluvial successions and coastal deposits (including longshore sand ridges, river deltas, beach ridges, terraces, and spits) limits the study of the temporal evolution of the lacustrine system(s) of the Pozo D-129 Formation (Paredes, 2023). These features are common in present-day endorheic basins (*e.g.*, Chad Basin, Okavango Macrobasin, Paredes *et al.*, 2024) which exhibit: i) multiple drainage catchments of variable orientation with diverse source areas, ii) variable development of fluvial processes (ephemeral, strongly seasonal, perennial) linked by overall precipitation and temperature patterns, and iii) multiple base levels with lakes or ephemeral pans. On a larger scale, these attributes are mainly associated with the interplay of tectonics processes, river capture and climatic cycles.

CONCLUSIONS

The Chubut Group (Barremian to Maastrichtian) deposition occurred within an endorheic basin, whose morphology and organization evolved throughout its history. Subsurface data and outcrop observations enable the subdivision of the Chubut Group into four main depositional systems.

The lower depositional system (Barremian-Albian?) includes the red-colored fluvial deposits of the Los Abobes and Matasiete formations, and lacustrine deposits of the Pozo D-129 Formation. These units were deposited in an extensional tectonic setting with sedimentary corridors linking the CAB with the GSJB.

The Albian-Cenomanian? depositional system, including the Castillo and Mina del Carmen formations, features reworked volcanic ash in extensive floodplain environments. The reconfiguration of basin boundaries, a result of tectonic activity, led to the disconnection of the two basins. Intra-basin extensional tectonics reduced the drainage catchments, consequently diminishing the scale of associated fluvial channel belt deposits, highlighting the role of tectonics in the Chubut Group's depositional history.

The fluvial deposits of the Bajo Barreal Formation (and its subsurface equivalents) represent a Cenomanian-Coniacian? depositional system characterized by high-accommodation system tracts with temporal variations in the channel belt stacking density due to climatic cycles.

The uppermost depositional system includes the Laguna Palacios and Lago Colhué Huapi formations at outcrops, and upper deposits of the El Trébol and Meseta Espinosa formations at subsurface. These units show a complex mosaic of continental formations with varying fluvial architecture. The Laguna Palacios Formation shows onlap terminations towards basin margins, with maximum thicknesses along the syncline axes in the San Bernardo Fold Belt. The Maastrichtian Lago Colhué Huapi Formation is a high-accommodation, multichannelized fluvial system filling incised valleys, overlain by the marine Salamanca Formation. The Meseta Espinosa Formation shows incised valleys and a progradational stacking pattern from the basin margins. The suite of evidence indicates that the uplift of the San Bernardo Fold Belt began in the late Cretaceous.

This study synthesizes the current understanding of the variable influence of allogenic controls on the alluvial macro-architecture of the Chubut Group deposits. Future research should integrate the extensive subsurface database of oil companies with the analysis of outcrop analogs, incorporating virtual outcrop models and advanced AI-assisted algorithms to enhance the accuracy of subsurface models.

ACKNOWLEDGEMENTS

This work was supported by the ANPCyT through PICTO 2021 YPF-GOLFO 00006. The Geology Department of the Universidad Nacional de la Patagonia San Juan Bosco is thanked by logistic support. Compañía General de Combustibles S.A. kindly granted permission for the publication of the well logs presented in Figure 4. The authors thank the detailed review of Dr. Sergio Georgieff and Journal Editor José I. Cuitiño, which have improved the clarity and focus of the manuscript.

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