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RECONSTRUCTING THE LATE MIOCENE PALEOENVIRONMENT OF NORTHWESTERN ARGENTINA: NEW SEDIMENTOLOGICAL AND FAUNISTIC EVIDENCE FROM THE PALO PINTADO FORMATION

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Abstract. The sedimentological characteristics and fossil vertebrates studies are notoriously increasing in the earth sciences field, as a way to infer reliable information about the biota and the paleoenvironmental and paleoclimatic context. In this framework, we establish relationships among the flora, fauna and the depositional environment during the Late Miocene in Northwestern Argentina. The sedimentology features are described in detail from sediments collected in the Quebrada Salta section, and the Xenarthra Cingulata *Kraglievichia paranensis* (Pampatheriidae) and *Cranithlastus xibiensis* (Glyptodontidae) are recorded for the first time in the Palo Pintado Formation (Salta Province, Argentina). The sedimentary observations support the presence of a sinuous sandy-gravel fluvial system with swamps and lacustrine, under a wet tropical climate. In this environment, the vertebrates here described would have inhabited open zones close to these freshwater bodies, predominated by xeric vegetation, mainly represented by grasses and sedges with scarce arboreous elements.

Introduction

In recent years, several late Neogene fossiliferous localities with a rich paleofauna have been reported along the Andean and sub-Andean areas of northwestern Argentina, including Catamarca, Jujuy, and Salta provinces (e.g. Candela et al. 2013; Ortiz et al. 2012; Bonini et al. 2017; Zurita et al. 2017; Zimicz et al. 2018; Quiñones et al. 2019, Ercoli et al. 2019, 2021).

Among them, the fossiliferous Palo Pintado Formation (Upper Miocene-earliest Pliocene), which crops out in southern Salta Province (Argentina), comprises one of the largest stratigraph-

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ic sequences of the Northwestern, including the Late Miocene-Early Pliocene transition (Galli et al. 2011a). Due to these unique characteristics, this unit has been widely studied from distinct perspectives, including the sedimentology (Coutand et al. 2006; Bywater-Reyes et al. 2010; Galli et al. 2010, 2011a, 2019; Pingel et al. 2016, Rohrmann et al. 2016), the mega and microflora (Herbst et al. 1987; Anzótegui 1998; 2006; Acevedo et al. 1997; Anzótegui & Horn 2011; Garralla et al. 2016; Anzótegui et al., 2017, 2019; Robledo et al. 2021, Mautino & Garralla 2021), the ichnology (Horn et al. 2011; Robledo 2017a,b; Robledo et al. 2015, 2016, 2018), and the paleofauna (Miserendino Fuentes & Díaz 1988; Bona et al. 2014; Zimicz et al. 2018; Barasoain et al. 2020; Candela et al. 2021).

The sediments of the Palo Pintado Formation were deposited while the region was affected by major changes regarding the hydric regime, with a transition from a wet phase (Late Miocene) to a drier one (Pliocene), mainly due to the establishment of an intermountain basin (Angastaco Basin), limited to the West by the Sierra de Quilmes and to the East by the uprising of the Sierras Los Colorados and León Muerto (Starck & Anzótegui 2001; Bywater-Reyes et al. 2010; Rohrmann et al. 2016). More precisely, foliar physiognomy studies for the basal and medial sections of the formation suggest a Mean Annual Temperature (MAT)= 23.98 °C and Mean Annual Precipitation (MAP)= 330.8 mm during its deposition (Robledo et al. 2020).

In this scenario, the fossil-bearing levels of the Palo Pintado Formation have provided several vertebrate remains, including fishes, amphibians, turtles, and caimans (Díaz 1985; Bona et al. 2014). However, previous mammal remains are scarce and usually very fragmentary. Records include Notoungulata (*Paedotherium kakai, Andinotoxodon*, *Paedotherium* cf. *minor*, *Protypotherium*, *Typotheriopsis*) and Rodentia (Caviidae indet., cf. *Ferigolomys*, cf. *"Eumysops" parodii,* cf. *Microsteiromys*, cf. *Thrichomys, Procardiomys*, *Protabrocoma paranensis*, *Prolagostomus*, *Lagostomus*) (Reguero et al. 2015; Armella et al. 2016; Zimicz et al. 2018; Candela et al. 2021). Focusing on Xenarthra, the first records were reported by Miserendino Fuentes & Díaz (1988), represented by the pampathere *Kraglievichia* sp. and the glyptodont *Plohophorus* sp. In turn, Starck & Vergani (1996) and Armella et al. (2016) mentioned remains belonging to Glyptodontidae indet., without further details. Later on, contributions reported several taxa of Cingulata Dasypodidae, including *Macroeuphractus morenoi*, *Chorobates villossisimus*, *Chasicotatus* sp., cf. *Paraeuphractus* sp., *Macrochorobates* sp., *Vetelia* cf. *V. gandhii* and Euphractini gen. et sp. indet. a and b (see Armella et al. 2016; Zimicz et al. 2018).

In this contribution, we infer the paleoenvironment of the Palo Pintado Formation in Quebrada Salta locality (Salta, Argentina), through the analysis of the sedimentary lithofacies, geometry, hierarchical organization of the elements, vertebrate remains, and flora. Moreover, we report and describe new remains of Cingulata Pampatheriidae and Glyptodontidae exhumed from this locality. These fossils represent the most complete specimen of Glyptodontidae, allowing to provide the first accurate specific determinations for the formation. Additionally, we carry out a comprehensive analysis about the relationships between these taxa, the paleoflora and the depositional environment at the locality of Quebrada Salta.

Paleobotanical Context

The Palo Pintado Formation crops out at seven different localities in Salta Province, and has provided about a hundred plant taxa, including macro and microfossils (Anzótegui et al. 2017, 2019; Mautino & Garralla 2021; Robledo et al. 2021). These records suggest five distinct vegetal paleocommunities: aquatic, marsh, riparian forest, xeric, and mountain forest (Anzótegui 2006; Galli et al. 2011b; Anzótegui et al. 2019); four of them are present in Quebrada Salta (see Anzótegui et al. 2015). These assemblages developed in an environment with fresh or brackish permanent water, with the following characteristics: (1), the aquatic paleocommunity comprised floating (*Azolla filiculoides*, *Salvinia graui* and *S*. cf. *S. minima*), submersible (*Cabomba* aff. *C. caroliniana* and *Mayaca* aff. *M. fluviatilis*) and rooted (*Sagittaria montevidensis*) plants (Herbst et al. 1987; Anzótegui & Horn 2011; Horn 2014; Robledo et al. 2021). This paleocommunity would have originated in vast floodplains, formed by the river system, with lakes from floods or river overflows (from exceptional rainfall) (Galli et al. 2011b; Horn 2014); (2), the marsh paleocommunity was characterized by herbaceous species, such as the ferns *Acrostichum palaeoaureum* Anzótegui & Horn, 2011, *Blechnum serrulatiformis* Anzótegui & Horn, 2011, *Lycopodiella* aff. *L. cernua* Anzótegui & Horn, 2011, *Equisetum* sp. and several taxa of Cyperaceae, which would have been placed on the littoral zone of the lakes, mainly in those in the process of clogging (Galli et al. 2011a); (3), the riverside forests, related to the banks of a river or streams, which included trees such as *Cedrela fissiliformis* Anzótegui & Horn, 2011, *Ficus tressensae* Anzótegui, 1998, *Nectandra saltensis* Anzótegui, 1998, *Schinus herbstii* Anzótegui, 1998 and *Sapium haematospermoides* Anzótegui & Horn, 2011 and a climbing plant such as *Ranunculodendron anzoteguiae* Lutz & Martínez, 2007 (Anzótegui 1998, 2006; Anzótegui & Horn 2011); (4), finally, the xerophytic paleocommunity occupied more remote areas to the water bodies (Anzótegui et al. 2017), represented mostly by *Caesalpinia* aff. *C. stuckerti* (Herbst et al. 2000; Anzótegui & Horn 2011). According to Galli et al. (2011a), these communities would have developed under a warm subtropical climate with dry seasonality.

Geological Setting

The study area is located in the Eastern Cordillera, from 25°30’ S to 66°15’ W and 25°45’S to 66º00’ W, approximately 200 km south of the city of Salta in Northwestern Argentina (Fig. 1). Cenozoic sedimentary strata outcrop in the Calchaquí Valley as part of the regional Andean foreland basin that extended into the Eastern Cordillera. The synorogenic deposits of the Cenozoic are represented by the Payogastilla Group in the Calchaquí Valley and are composed of continental deposits, from base to top: Los Colorados (middle Eocene to Oligocene), Angastaco (middle to upper Miocene), Palo Pintado (upper Miocene) and San Felipe (Pliocene to lower Pleistocene) formations (Díaz & Malizzia 1983).

The Palo Pintado Formation is ~800 m thick and contains a tuff level dated at 10.29 ± 0.11 Ma (K/Ar) by Galli et al. (2008). Near the top, another pyroclastic level was dated at 5.27 ± 0.28 Ma (^{206}Pb/^{238}U) by Coutand et al. (2006) and at 5.98 ± 0.32 Ma by Bywater-Reyes et al. (2010). The unit comprises thickening and coarsening-upward cycles, including matrix-supported conglomerates, fine to medium sandstone, and fine-grained sublithic sandstones that end in levels of green, brown and gray siltstones. These deposits are related to a transitional style between low and high sinuosity rivers, including wandering sand-gravel fluvial systems with small lakes. The geometry and the fluvial architectural characteristics are a direct consequence of allogenic controls, such as tectonic activity, under constant climatic conditions (Galli et al. 2011b; Galli & Reynolds 2012).

During the Late Miocene, the uplift of the basin caused an increase in the sedimentary accommodation/deposition (A/D) rate, also associated with changes in the petrologic/mineralogic composition of the deposits (Galli et al. 2011b, Galli et al. 2017). The resulting orographic barriers produced a warmer and more humid climate (Stark & Anzótegui 2001).

The deposits of the San Felipe Formation at the top of the Payogastilla Group in the southeastern Calchaquí Valley are more than 600 meters thick, and are affected by numerous faults and folds. The transition between the Palo Pintado Formation and the San Felipe Formation is sharp and unconformable, involving considerable clast-supported conglomerates with overlapping clasts and a lower proportion of sandstones and siltstones, which are interpreted as a gravel-braided fluvial system (Galli & Reynolds 2012). Evidence in deposits of Palo Pintado Formation, such as the presence of clay minerals (illite, smectite and kaolinite) in the floodplain sub-environment, indicates a generation by hydrolysis in a temperate-humid climate (Galli et al. 2011a). In turn, stable isotope data from pedogenic carbonates reflected relatively more humid conditions between 10 to 6 Ma (Bywater-Reyes et al. 2010). Paleomagnetism studies in Palo Pintado Formation deposits indicate an increase in the rate of sedimentation of 0.11 mm/yr to 0.66 mm/yr, associated with a higher percentage of Salta Group clasts at approximately 6.6 Ma. Paleocurrents from the south to the southeast indicate tectonic reactivation of the deposition area from the Sierra León Muerto and its continuation to the north as the Sierra Los Colorados (Galli et al. 2014). Isotopes analysis of δD_g revealed that between ~6.5 to 5.3 Ma, values from the Angastaco Basin decreased by −23 ± 6‰ (absolute δD_g = −95‰), which is interpreted as the result of a surface uplift in this area, with altitude and aridization in an environment similar to current (Pingel et al. 2016).

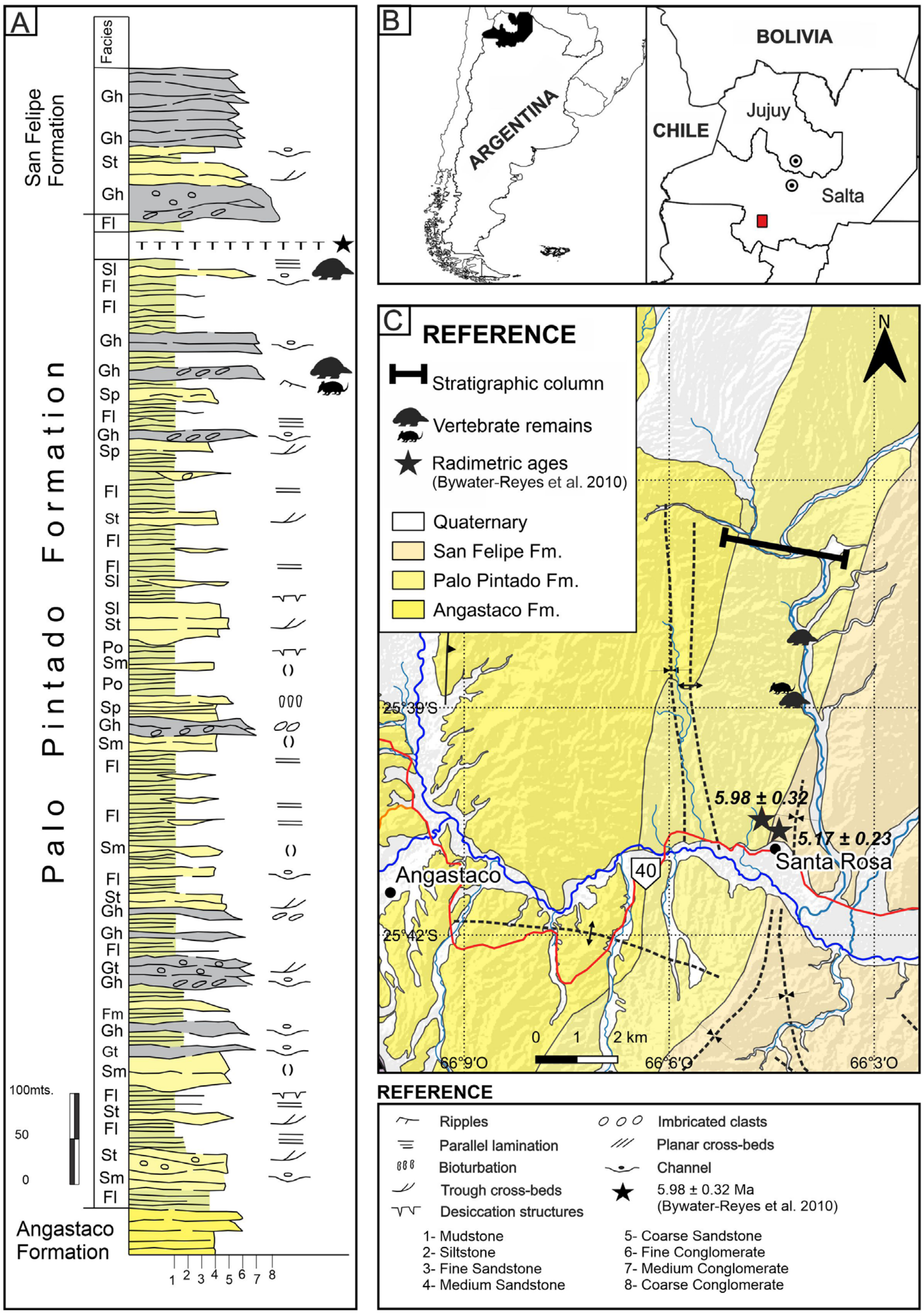


Fig. 1 - A) Palo Pintado Formation stratigraphic column at the Quebrada Salta section including facies and fossils stratigraphic location. B) Geographic location of the study area (southern Calchaquí Valley, Salta Province). C) Geological map of the study area with the stratigraphic column, radiometric ages, and fossil location.

Materials and Methods

Sedimentological profiles

The sedimentological profiles from the Quebrada Salta of the Palo Pintado Formation were analyzed at a scale of 1:500. Thicknesses were determined using Jacob's staff. This procedure, in addition to the rock descriptions with an emphasis on lithology types (including texture and composition) and sedimentary structures, allowed the characterization of the different sedimentary facies, discontinuity features and hierarchy. Field studies enabled the recognition of the geometry of the bed sets.

The geometry and hierarchical organization of the element limits was examined in the vertical and lateral associations. Sedimentary lithofacies were defined (Fig. 2), and the various architectural elements were analyzed (Fig. 3). The definition of facies and their associations were used to discriminate against the paleoenvironment of the Palo Pintado Formation in the study area.

Fossils analyzed

The fossils here analyzed were collected in the year 2013 by two of us (J.M.R and C.I.G), during a series of fieldwork campaigns in the fos-

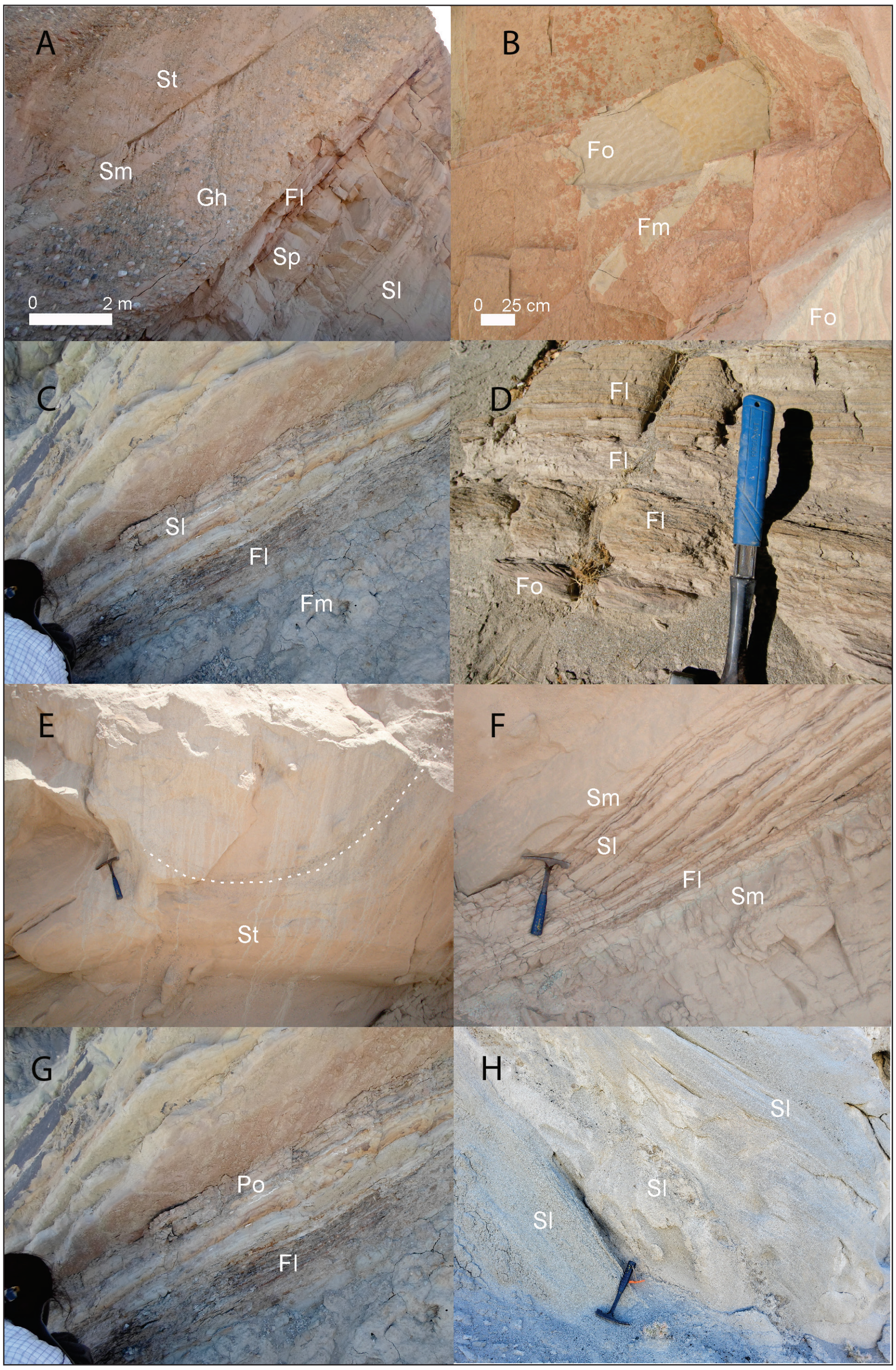


Fig. 2 - Lithofacies code of the Palo Pintado Formation deposits in Quebrada Salta, A) (Gh) clast-supported conglomerate, (St) very coarse-grained sandstone sets of trough cross-beds, (Sm) fine- to coarse-grained sandstone massive, (Sp) very coarse-grained sandstone sets of planar cross-beds, (Sl) fine- to coarse-grained sandstone with planar lamination, (Fl) laminated siltstone; B) (Fo) Siltstone and mudstone with ripples and very thin laminations, (Fm) massive siltstone and mudstone; C) (Sl) fine- to coarse-grained sandstone with planar lamination, (Fl) laminated siltstone; (Fm) massive siltstone; D) (Fl) laminated siltstone, (Fo) siltstone with ripples; E) (St) very coarse-grained sandstone sets of trough cross-beds; F) (Sm) fine- to coarse-grained sandstone massive, (Fl) laminated siltstone, (Sl) fine laminate sandstone; G) (Fl) laminate siltstone, (Po) paleosol and H) (Sl) laminate sandstone.

siliferous area of Quebrada Salta (25°38'58,60"S, 66°4'9,10"W), southern Salta Province, Argentina. Remains are currently housed at the Paleontological Vertebrates Natural Collection of the National University of Salta, Salta Province, Argentina.

For the systematics we partially follow the schemes proposed by Gois (2013) and Jiménez-Lara (2020) for pampatheres, and McKenna & Bell (1997) and Barasoain et al. (2022) for glyptodonts. The terminology adopted in the anatomical descriptions follows Gois et al. (2013, 2015) for Pampatheriidae osteoderms and Krmpotic et al. (2009) and Porpino et al. (2014) for Glyptodontidae osteoderms, caudal rings and caudal tube. The relative position within the carapace of the described osteoderms of *Cranithlastus xibiensis* was inferred through direct comparisons with the carapace of the type material (CNS-V10014), housed in the paleontological collection of the Museo de Ciencias Naturales de Salta (Salta Province, Argentina).

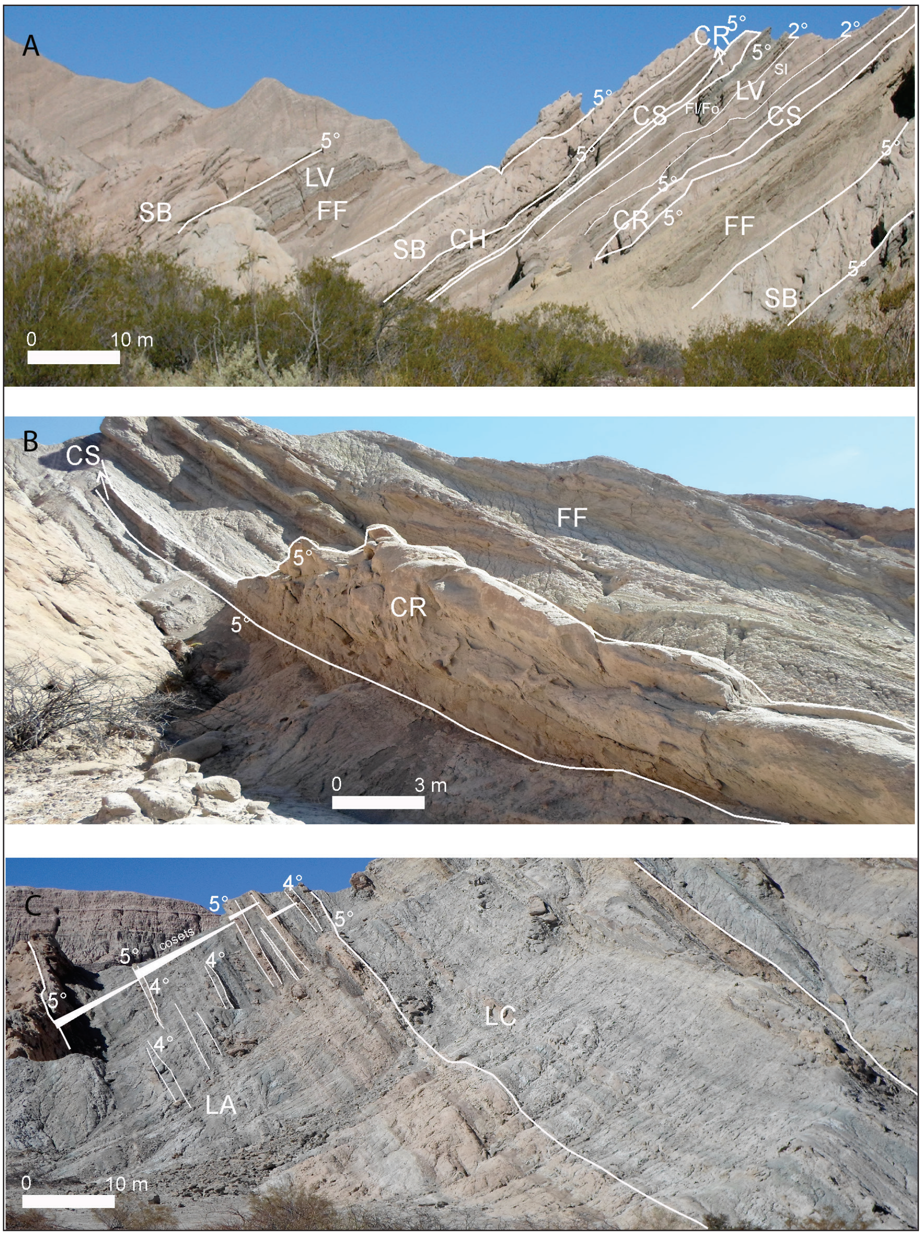


Fig. 3 - Architectural analysis of the Palo Pintado Formation in Quebrada Salta: A) SB sandy bedforms, FF floodplain deposits, CR crevasse channel, CS crevasse splay, LV levee and CH tabular and sheet-like channel with packages of sediment represent in-channel deposits, separated by fifth-order surfaces; B) CS crevasse splay, CR crevasse channel and FF floodplain deposits separated by fifth-order surfaces; C) LA cosets lateral-accretion macroform ordered in cycles separated by fifth-order surfaces and LC floodplain lake.

Results

Lithofacies, architectural elements, and interpretation of the Palo Pintado Formation

Ten lithofacies and eight architectural elements were recognized for the Palo Pintado Formation at the Quebrada Salta locality. The lithofacies described in Tab. 1 are presented using the codes of Miall (2006) and Colombera et al. (2013). Tab. 2 presents architectural elements recognized in the formation.

The fluvial-lacustrine associated lithofacies and architectural characteristics for the Palo Pintado Formation define a fluvial system with intrachannel and overbank deposits with great development of floodplains, swamps and lagoons (Galli et al. 2012). The CH elements have a tabular and sheet-like geometries, sizes up to 2 to 6 m thick and external boundaries lower and upper fifth-order surfaces are erosional, internal boundaries first-order bounding surfaces (Figs. 3A, 4A, B). The element SB represents slack water deposits, such as abandoned-channel fills or bar-edge sand wedges (Rust 1972; Miall 1977). These sheet-like tabular elements (Tab. 2), with a thickness of 0.5-2 m, are bound by lower fifth-order surfaces that are erosive (Figs. 2A, 3A). The tops of the elements are typically marked by erosive surfaces at the bases of successive elements of floodplain, also including fields of ripples and dunes that represent bedform migration down channels, across bar top, or in crevasse splays (Fig. 3A) (Miall 2006). Horizontally laminated sandstone was deposited under

Tab. 1 - Major lithofacies identified in the Palo Pintado Formation in Quebrada Salta (modified from Galli et al. 2014).

Code	Lithofacies	Interpretation
Gh	Clast-supported conglomerate, crudely bedded, with well-sorted and rounded clasts, sparse matrix, imbrication.	Longitudinal bars, lag deposits.
Gt	Matrix-supported conglomerate with trough cross-bedding.	Minor channel fills.
St	Very coarse-grained sandstone sets of trough cross-beds. Wedge-shaped strata with residual lag.	Linguoid (3D) dunes.
Sp	Very coarse-grained sandstone sets of planar cross-beds, and lag deposits. Beds with erosional bases.	Transverse and linguoid bedforms (2D dunes).
Sl	Fine- to coarse-grained sandstone, planar lamination, lag deposits. Tabular beds and wedge up.	High flow conditions. Flash flood. Overbank flooding.
Sm	Fine- to coarse-grained sandstone, poorly sorted, massive, with clastic wedges and beds with erosional bases.	Upper flow regime and poorly sorted deposits.
Fl	Very fine-grained sandstone, siltstone, and mudstone, fine lamination, desiccation cracks, roots, and bioturbation.	Overbank, abandoned channel, or waning flood deposits.
Fm	Massive siltstone and mudstone, very thin beds.	Overbank or abandoned channel deposits.
Fo	Siltstone and mudstone, very small ripples and very thin laminations.	Swamp and lacustrine in the floodplain.
Po	Very fine-grained sandstone, siltstone and mudstone, massive with calcified rhizoliths.	Paleosols.

Tab. 2 - Code of the major architectural elements defined for the Palo Pintado Formation with their characteristic lithofacies (modified from Galli et al. 2014).

Element	Description	Facies Association
CH	Tabular and sheet-like channel. Packages of sediment represent in-channel deposits.	Gh - Gt - Sm Sl - Sp - St - Sm - Fl
SB	Sandy bedforms	Gh - Gt - Sl - Sp - St
CR	Crevasse channel	St - Sl -
CS	Crevasse splay	Sp - Sl - Sm
LV	Levee	Sl - Fl
FF	Floodplain deposits	Fm - Fo - Po
LA	Lateral-accretion macroform	Sm - Sl - Fm - Fo
LC	Floodplain lake	Fl - Fo - Sm

upper flow regime conditions (Ghazi & Mountney 2009) when the gravel bars were fully submerged. Facies of these elements compose an ordered succession, with beds up to 50 cm thick of parallel-bedded fine sandstone (Sl), overlying stacked 30 cm cosets of cross-laminated sandstone (St and Sp, Fig. 2A, E, H).

The overbank deposits are frequent in the Quebrada Salta section, represented by: (a) Crevasse channel deposits (CR), (b) crevasse splay deposits (CS), (c) lateral-accretion macroform (LA), (d) levee deposits (LV), (e) floodplain deposits (FF), and (f) floodplain lake (LC) (Tab. 2, Fig. 3).

The crevasse channel deposits (CR element) incise levee, and other backswamp deposits and the bounding are classified as fourth-order surfaces when preserved, or generally fifth-order (Fig. 3A, B). These elements represent ribbon-like bodies typically consisting mainly of St and Sl facies. The crevasse splay deposits (CS element) have a typical wedge-shaped architecture, with slopes of 2° (Fig. 3) and appear to have prograded over floodplain mud and silt.

The LV element levee deposits is mainly composed of sheet or wedge-shaped bodies, up to 1 m thick, consisting of fine to coarse-grained sandstone, planar lamination, lag deposits (Sl facies), claystone and siltstone with lamination, desiccation cracks (Fl and Fo facies), and bioturbation (Fig. 3A). These levee deposits consist in rhythmically bedded units of 0.20 to 0.30 cm of thickness.

The LV element is interpreted as proximal overflow environments in a wide floodplain, where sediment was supplied through sheet overflow during unconfined flooding (Ghazi & Mountney 2009). The units dominated by clays and siltstones are interpreted as vertical accretion deposits, accumulated through repeated flooding and sedimentation along the banks of the canals (Bridge 2006).

The FF element represents geometrical genetic bodies interpreted as deposited out of channel floods (Miall 1996; Bridge 2006). The vertical facies association is variable, reflecting a flat depositional surface and readily susceptible to small changes in depositional processes (Miall 2006). This element occurs in the form of a blanket with a thickness of more than 15 m, which extends laterally for more than 200 m in the strata (Figures 3A, B). The predominant facies associations are Fm, Fo and Po, resulting of a continuous slow settling of fine-grained sediment from suspension in permanent swamps with seasonal or longer term drying out of the floodplain, in which there are desiccation and pedogenic processes, such as paleosols and desiccation cracks (Fig. 2 G).

The LA element, indicative of lateral accretion, is larger and more common than their downstream-oriented counterparts (Fig. 3C). It is characterized by 0.5 to 0.8 m thick and more than 30 m wide units dominated by fining-upward packages composed of fine to very fine sandstones (Sm and Sl facies), with massive siltstone and mudstone, and very thin beds (Fm facies). These elements present fifth-order surfaces in the base and top of each coset and fourth-orden surfaces in the top transverse bars (Sl and Sm facies). Low angle-inclined compound cosets of planar cross-bedding are abundant (Fig. 3C), and smaller scale structures including ripple cross-lamination are developed (Fig. 2B). The inclination of the large-scale strata varies from 2° to 5°. The LA elements units are interpreted to have deposited under a constant flow regime during normal river discharge, and likely represent a succession of mid-channel transverse bars within the central parts of a sinuous channel (Smith 1970, 1990; Halfar et al. 1998; Platt & Keller 1999; Ghazi & Mountney 2009). The convex-up macroform bounding surfaces (fourth order surfaces), together with a lack of features otherwise indicative of lateral accretion, suggest a frequent lateral shifting of the down current-migrating sand dunes or channel bars (Ghazi & Mountney 2009).

The LC element is represented by a facies association mainly composed of gray mudstones, massive (Fm), laminated, organic black shales (Fl) and current ripple (Fo), arranged in packages of 15-20 m thick (Figure 3C), extending laterally for distances greater than 100 m. Fossil content is abundant, including invertebrates (ostracods, bivalves) and plant remains (leaves, seeds, fruits and woods). Lithofacies Fm and Fl are dominant in these elements with minor occurrences of Sm (Figs. 2B and D). Rootlets and calcareous nodules are commonly recorded perpendicular to bedding. In a few places, horizontal laminations and a small degree of bioturbation are visible in the mudstone, though the mudstone is mainly massive. This facies association also comprises fine to very fine-grained sandstones, 10 to 40 cm thick, massive (Sm) or with faint ripple cross-lamination (Fo) (Figure 2D).

The mud-dominated nature of this association is indicative of deposition in a low energy-water environment, with low sedimentation rates. The presence of gray to black mudstones, with abundant organic matter, invertebrate shells and plant remains, suggests that these deposits were accumulated and preserved in an anoxic environment. The thick and laterally continuous packages of the facies association suggest the presence of a large lake. However, the absence of roots and desiccation features indicates a perennial lake, with no subaerial exposure. The absence of any preserved evaporite facies suggests an abundant supply of fresh water to the lake, where precipitation exceeds evaporation and the concentration of salts was low (Talbot & Allen 1996; Fielding & Webb 1996; Platt & Keller 1999). The Sm sediments were likely carried into the lakes via low-energy traction currents.

Systematic Paleontology

Superorder **Xenarthra** Cope, 1889
Order **Cingulata** Illiger, 1811
Family Pampatheriidae Paula Couto
Genus *Kraglievichia* Castellanos, 1927

Kraglievichia paranensis (Ameghino, 1883)
Fig. 4

Material: Analyzed materials (CNS-PV 041) were found in close association, and include one fragmented and one complete fixed osteoderms of the scapular shield, one fixed osteoderm of the pelvic shield, and one proximal fragment of a mobile osteoderm.

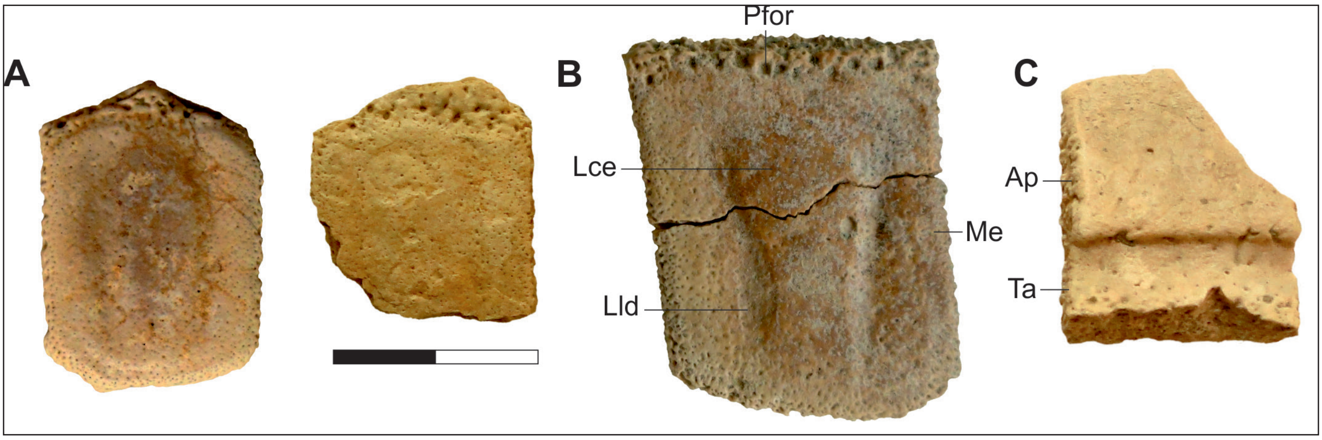


Fig. 4 - Osteoderms (CNS-PV 041) of *Kraglievichia paranensis*: A) fixed osteoderms of the scapular shield; B) fixed osteoderm of the pelvic shield; C) fragmented osteoderm of the mobile bands. Abbreviations: Ap, articular portion; Lce, longitudinal central elevation; Lld, longitudinal lateral depression; Me, marginal elevation; Pfor, piliferous foramina; Ta, transitional area. Scale bar represents 2 cm.

Descriptions

Fixed osteoderm of the scapular shield: the complete recovered osteoderm is subpentagonal in outline, longer than wide. The totality of the exposed surface is covered by very small foramina. In lateral view, it maintains a constant thickness along its entire length. The ornamentation pattern of the exposed surface shows a longitudinal central elevation, a pair of lateral longitudinal depressions and a marginal elevation. The central elevation has an elliptical contour, with its major axis anteroposteriorly oriented. It is depressed at its anterior and posterior endings, so that the lateral longitudinal depressions are connected, and totally surround the central elevation. These depressions have a similar width to that of the central elevation, and become progressively shallower towards the lateral margins of the osteoderm, until reaching the marginal elevation. The marginal elevation is relatively narrow and low, and it is placed close to the margins of the osteoderm, being better developed at the posterior margin, but almost disappearing at the anterior margin. At the anterior margin, there are two rows of piliferous foramina. One is placed in the lower area of the anterior margin and is composed of eight large foramina of homogeneous size, which are horizontally oriented. The other row is placed in the more dorsal area of the anterior margin, and is composed of six smaller foramina which are dorsally oriented. At the posterior margin of the osteoderm, there is a single row of 11 small sized foramina with an horizontal orientation. Foramina in the lateral margins are scarce and large, and placed along the proximal half of the osteoderm.

Fixed osteoderm of the pelvic shield: this osteoderm is subrectangular, slightly longer than wide, and much larger than that of the scapular shield. The exposed surface is covered by very small foramina, which get slightly larger towards the lateral margins. In lateral view, it maintains a constant thickness. The central elevation has a subrectangular contour, with its major axis anteroposteriorly oriented, and gets much thinner towards the posterior margin. Unlike in the described scapular osteoderm, it is depressed only at its anterior ending, so that the lateral longitudinal depressions are anteriorly connected, but not posteriorly. These depressions have approximately half the width of the central figure, and become progressively shallower towards the lateral margins of the osteoderm. The marginal elevation is poorly developed and can be differentiated just at some areas next to the lateral margins. At the anterior margin, there is a single row of 12 large and dorsally oriented piliferous foramina. At the posterior margin, foramina are scarce and much smaller, while they are absent in the lateral margins.

Mobile osteoderm: this osteoderm is fragmented and only its most proximal area is preserved. It includes the articular portion and most part of the transitional area. The articular portion is totally flat and unornamented: it has the function of articulating with the adjacent osteoderm row, overlapping to allow some flexibility to the set of mobile bands. In turn, the transitional area has a rough surface, due to the insertion of tissues, and separates the articular portion from the ornamented portion, which is not preserved.

Remarks. Wthin the Neogene Pampatheriidae diversity, the genus *Kraglievichia* gathers the type species, *K. paranensis*, and *K. carinatum* (Gois et al. 2013; Jiménez-Lara 2020). The described material is assigned to *K. paranensis* for having a convex and anteriorly depressed longitudinal central elevation, unlike *K. carinatum* in which it is higher and sharper, and begins far anteriorly, next to the foramina of the anterior margin; and for having a more convex and wide marginal elevation (Gois et al. 2013). Other Late Miocene genera include *Scirrotherium* Edmund & Theodor, 1997, *Plaina* Castellanos, 1937 and *Vasallia* Castellanos, 1927. The described material differs from *Scirrotherium* in developing much less pronounced lateral margins (Gois et al. 2013) and lacking a uniformly narrow longitudinal central elevation (Jiménez-Lara 2020). It differs also from *Plaina* in having deeper longitudinal depressions and from *Vasallia* in being much larger. Additionally, *Vasallia* develops a much wider and poorly defined longitudinal central elevation (Gois 2013).

Family Glyptodontidae Gray, 1869
Genus *Cranithlastus* Arias, Alonso & Malanca, 1979

Cranithlastus xibiensis Arias, Alonso & Malanca, 1979
Fig. 5

Materials: CNS-PV 037, several associated osteoderms of the dorsal carapace, osteoderms of the caudal rings, and caudal tube fragments; CNS-PV 040, several osteoderms of the dorsal carapace belonging to different regions, fragments and osteoderms of the caudal rings, an almost complete caudal tube and several very fragmented postcranial remains of a single individual, which was originally partially articulated prior to its extraction.

Descriptions

Dorsal carapace: the osteoderms show in its exposed surface a "rosette" ornamentation pattern, in which a subcircular and large central figure is surrounded by several much smaller peripheral figures. As observed in all glyptodonts having this "rosette" pattern, there are some differences according to the different regions of the dorsal carapace (Zurita 2007).

In the antero-dorsal region (Fig. 5A) osteoderms belonging to the second row next to the cephalic notch are preserved. They are circular to subcircular in outline, having a well-developed subcircular and flat central figure, which is surrounded by 14-15 small peripheral figures, and some accessories that compose an incomplete second row. Towards the laterals of the antero-dorsal region, osteoderms (Fig. 5B) are antero-posteriorly elongated, showing a subelliptic and slightly concave central figure, surrounded by one row composed of 12-15 peripheral figures.

In turn, osteoderms of the most antero-lateral region (Fig. 5C) have a pentagonal to hexagonal morphology with a large central figure surrounded by 12-13 small peripheral figures, which are circular in outline and slightly convex surface; in some osteoderms it is possible to observe large foramina at the intersection between the radials and annular sulci, including 1 to 3 accessory peripheral figures.

The osteoderms of the dorso-medial region (Fig. 5D) have a very large and flat circular central figure, surrounded by one complete row of 14-18 pentagonal peripheral figures; in some osteoderms, an incomplete second row is also observable.

Towards the latero-medial region (Fig. 5E), the osteoderms show a rectangular or pentagonal contour, elongated antero-posteriorly. The central figure tends to be more circular when compared to those osteoderms belonging to the most anterolateral region; in addition, this central figure has a slightly concave surface, and is posteriorly displaced. It is surrounded by a complete row of 11-12 polygonal peripheral figures, more developed in its anterior margin, where it is possible to see 6-8 accessory peripheral figures. This particular morphology shows some resemblance with the glypateline glyptodonts (see Hoffstetter 1958).

In turn, osteoderms belonging to the posterior region of the carapace show a more quadrangular contour, with a larger central figure compared to the other regions of the carapace, and there is a low number of peripheral figures.

Caudal rings: some osteoderms correspond to the most anterior caudal rings (Fig. 5F). These osteoderms are rectangular in outline, with their proximal margin modified into a small articular surface to articulate with the next caudal ring. Posterior to this area, the exposed surface has a "rosette" ornamentation pattern, very similar to that described for the dorsal carapace. The central figure is surrounded by numerous peripheral figures, being larger than those placed next to the central figure. At the intersection between the rugose and ornamented areas, there are several large foramina. In another preserved fragment (Fig. 5G) it is possible to observe a proximal

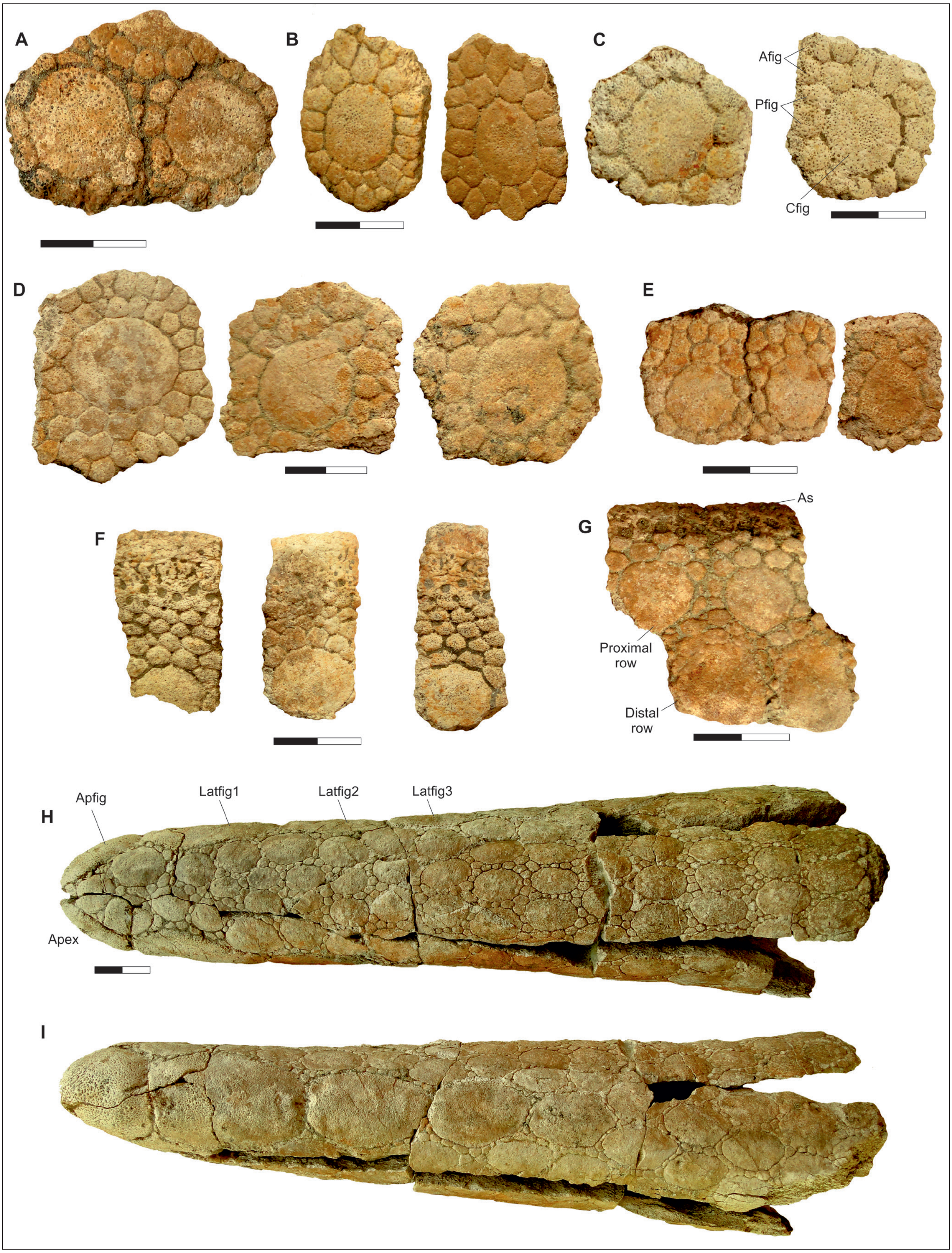


Fig. 5 - Dorsal and caudal armour elements (CNS-PV 040) of *Cranithlastus xibiensis*: A) osteoderms of the antero-dorsal region of the carapace; B) osteoderms of a more lateral antero-dorsal region of the carapace; C) osteoderms of the antero-lateral region of the carapace; D) osteoderms of the dorso-medial region of the carapace; E) osteoderms of the latero-medial region of the carapace; F) osteoderms of the caudal rings; G) caudal ring articulated fragment; H) caudal tube in dorsal view; I) caudal tube in lateral view. Abbreviations: Afig, accessory figure; Apfig, apical figure; As, articular surface; Cfig, central figure; Latfig, lateral figure; Pfig, peripheral figure. Scale bars represent 2 cm.

row of osteoderms that shows a similar morphology to previously described, but the distal row is composed of pentagonal and smaller osteoderms. In this row the osteoderms show a subcircular or subelliptical contour central figure, slightly convex and of flat surface, surrounded by 11-12 peripheral figures placed at anterior the lateral and margins, being this latter shared with the contiguous osteoderms.

Caudal tube: this structure is almost complete (Fig. 5H), being almost identical to that of the type material of *Cranithlastus xibiensis* (CNS-V10014). It presents a cylindrical-conical morphology. In lateral view (Fig. 5I), it is observed that it shows a slight curvature with a lesser dorso-ventral diameter at its distal end. The apex is slightly asymmetric, being the left lateral terminal figure more elongated when compared to the right one. The remaining lateral figures show an oval outline and a quite convex surface; limiting two figures, there exists a deep groove. On the distal margin, and over both lateral faces, there are three large figures that decrease in size distal-proximally. These figures show an oval outline, with the dorsal and lateral margins surrounded by a row of small peripheral figures. On the dorsal surface of the caudal tube, the osteoderms show a clear "rosette" ornamentation pattern, almost identical to those of the dorsal carapace. The central figures are proximo-distally oval, and surrounded by one row of peripheral figures that are shared by the lateral osteoderms. At the proximal end of the caudal tube, these peripheral figures vary between 14 to 17, being of variable form and size. Toward the distal end, it is noted that the peripheral figures surrounding the central figure get smaller and even they can disappear in the osteoderms close to the apex, generating direct contact among central figures. On the ventral surface, the ornamentation pattern is quite similar to that of the dorsal surface but less evident. In general, the central figures are larger, and the peripherals are scarcer in number; in consequence, the central figures are most often in contact among them.

Remarks. *Cranithlastus* is a monospecific genus including the species *C. xibiensis*. The comparative study with the type material (CNS-V10014) reveals almost identical morphologies. The analyzed material is referred to this species for being a medium to small-sized glyptodont, the presence of hexagonal osteoderms with circular central figures and a caudal tube with relatively small apical figures, an acute apex and a diffuse ornamentation pattern in the ventral surface. It differs from other late Neogene glyptodonts from northwestern Argentina, including *Stromaphorus* Castellanos, 1926 and *Phlyctaenopyga* Cabrera, 1944, because in these genera the central figure of the osteoderms belonging to the caudal region is clearly convex (Cabrera, 1944), while flat in *C. xibiensis*. In turn, the caudal tube has three large and elliptical lateral figures, instead of four observed in *Plohophorus*, and *Neosclerocalyptus*. It also differs from *Eosclerocalyptus proximus* (Moreno & Mercerat, 1891) and *E. lineatus* (Ameghino, 1888) by having more peripheral figures that in turn are clearly much smaller at the level of the caudal tube and dorsal carapace (see Zurita 2007), and from *Kelenkura* Barasoain, Zurita, Croft, Montalvo, Contreras, Miño-Boilini & Tomassini, 2022 in having much numerous peripheral figures (Barasoain et al. 2022a). Finally, it is different when compared to *Plophophorus figuratus* Ameghino, 1887 because this species shows a lower number of peripheral figures that are usually more rounded and larger compared to *C. xibiensis*.

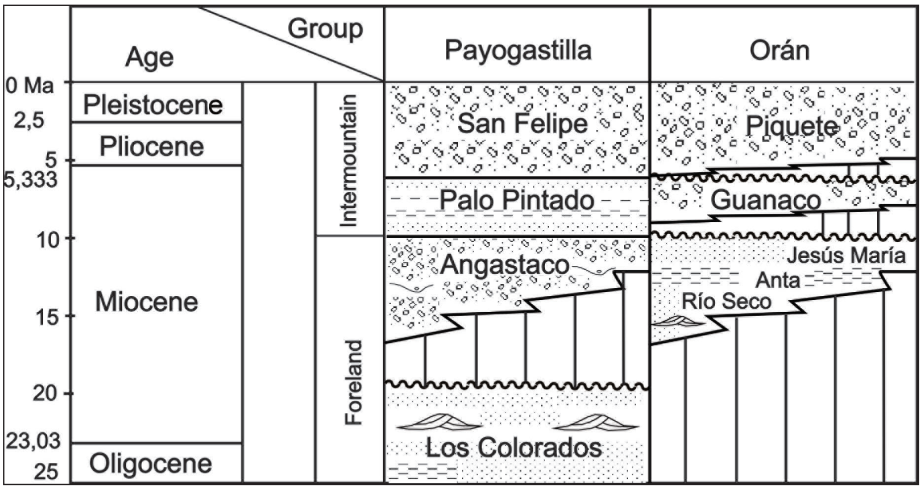
Discussion

Depositional model for the Palo Pintado Formation in Quebrada Salta

The sedimentary observations support the presence of a fluvial system where the transport and deposition of sediment took place as a sinuous sandy-gravel fluvial system with swamps and lacustrine (Galli et al. 2011a), under a wet tropical climate (Starck & Anzótegui 2001; Galli et al. 2017). In the southern area of the Angastaco Basin, there is a higher accumulation of pebble-dominated intervals (Quebradas El Estanque and Peñas Blancas), which have been deposited in wandering gravel-bed rivers with sinuosity intermediate to medium. The development of these two distinct fluvial styles may indicate a decrease in the northward slope.

The deposits of Palo Pintado Formation have been accumulated in an elongated basin with south north direction, and the fluvial system drained approximately parallel to the Los Colorados Range from 10 Ma to 5 Ma. Fine-grained (sand and mud-dominated) parts of the system appear to have been deposited on low-gradient floodplains characterized

Fig. 6 - Lithostratigraphic column of the Payogastilla Group and Oran Group.



by high-constructive single and multi-story channel systems with further development of the swamp and lacustrine deposits system with major development in the Quebrada Salta. These deposits are arranged into a series of fining-upward cycles from the base to the top. The succession is characterized by ten distinctive lithofacies types (Gh, Gt, St, Sp, Sl, Sm, Fl, Fm, Fo, and Po), each of them occurring in a predictable order within the individual fining-upward cycles. A range of sedimentary structures indicate deposition in a subaqueous setting, predominantly under lower flow regime conditions. Additional structures, including desiccation cracks, raindrop imprints, and caliche nodules indicate episodes of subaerial exposure. Eight distinct architectural elements, each with distinctive geometries and associations of facies, are recognized, reflecting the presence of tabular and sheet-like channels, sandy bedforms, crevasse channel, crevasse splay, levee, floodplain deposits, lateral-accretion macroforms and floodplain lakes. The lateral persistence of channelized sandstone elements suggests high rates of lateral channel migration and associated lateral accretion surfaces document the growth of point bars.

These interpretations are concordant with those of the temporal equivalent and geographically close of the Guanaco Formation (*ca*. 10.9-6.9 Ma: Viramonte et al. 1994; Reynolds et al. 2000; Coira et al. 2018) (Fig. 6) outcropping in Jujuy Province, north of the study area. This formation was interpreted as a fluvial system associated with an environment of alluvial fans dominated by flowing currents. The proximal deposits are located in the western zone (Valle de Lerma) and the middle and distal sector is located in the central and distal zone (González Villa 2002), associated with a large river system under hot and wet climate conditions (Starck & Vergani 1996).

About the Cingulata of Quebrada Salta within the xenarthrans diversity of Palo Pintado Formation

The record of xenarthrans from the Palo Pintado Formation is scarce, very fragmentary and currently restricted to Cingulata. According to Zimicz et al. (2018) the lack of records of Pilosa could be due to taphonomic bias. The records of *Kraglievichia paranensis* and *Cranithlastus xibiensis* here described increase the diversity known for this unit and constitute the first specific determinations of pampatheres and glyptodonts, previously limited to Dasypodidae (Armella et al. 2016; Zimicz et al. 2018)

Kraglievichia paranensis is the most widespread and more frequently recorded pampathere during the Late Miocene, more specifically for the Chasicoan and Huayquerian Ages/Stages (Tortonian-Messinian) (Gois 2013). In Argentina, it is known by cranial, postcranial and carapace elements (Gois et al. 2013) recorded from the "Conglomerado osífero" of the Ituzaingó Formation (Huayquerian) in Entre Ríos Province (Scillato-Yané et al. 2013), the Arroyo Chasicó Formation (Chasicoan, *ca*. 9.43 Ma, *sensu* Zárate et al. 2007) in Buenos Aires Province (Scillato-Yané 1982; Gois & Scillato-Yané 2010), and the Loma de Las Tapias Formation (Chasicoan/Huayquerian, *ca*. 9 Ma *sensu* Contreras & Baraldo 2011) in San Juan Province (Ciancio et al. 2006). In turn, *Kraglievichia* sp. was reported for El Palo Formation (Huayquerian) in Río Negro Province (Gois & Scillato-Yané 2010). According

Fig. 7 - Hypothetical reconstruction of Quebrada Salta, including the pampathere *Kraglievichia paranensis* (left) and the glyptodont *Cranithlastus xibiensis* (right). Artwork by P. Cuaranta.

to Gois et al. (2013) and Scillato-Yané et al. (2013), this record may also belong to *K. paranensis*. In Uruguay, *K. paranensis* is known from the Kiyú Formation (Huayquerian) in San José Department (Perea 1993). In Bolivia, it is known for the deposits of the Mauri Formation (Huayquerian) of the fossiliferous localities of Achiri, Camacho, Rosario and Jankojakhe in La Paz Department (Gois et al. 2013; Scillato-Yané et al. 2013). This way, the materials analyzed herein represent the northern records of this taxon in Argentina, extending the biogeographical range of this species. The presence of *K. paranensis* suggests a late Miocene age for the bearing levels of Quebrada Salta locality.

Cranithlastus xibiensis is a small sized glyptodont compared to Pleistocene taxa (i.e., *Glyptodon* Owen, 1839, *Panochthus* Burmeister, 1866, and *Neosclerocalyptus* Paula Couto, 1957) (Fig. 7), which records were, previously to this contribution, restricted to the Neogene deposits of the Orán Group (including the Piquete and Guanaco formations, see Starck & Vergani 1996) in Jujuy Province, Argentina. Records of this species are rare, and the specimen here analyzed (CNS-PV 040) represents the third record referred to this taxon, and the first one out of Jujuy Province.

The species *C. xibiensis* was defined on the basis of a very complete and well-preserved specimen (including complete skull, mandible, carapace and caudal tube) coming from the deposits of the Piquete Formation in Jujuy Province, Argentina (Arias et al. 1979). Reynolds et al. (1994, 2000) indicated an age of ~5 Ma for the lower levels of this formation, while Malamud et al. (1995) indicated an age of 1.3 ± 0.2 for the upper section, inferring a late Pliocene-Pleistocene age. Recently, a second specimen of *C. xibiensis* (including an almost complete cranium and fragments of the dorsal carapace and cephalic shield) was reported for the fluvial deposits of the Guanaco Formation in Jujuy Province, Argentina (Ercoli et al. 2021). The Guanaco Formation underlies the deposits of the Piquete Formation and has an estimated depositional age between 10 and 5 Ma, including the Late Miocene-early Pliocene lapse (Reynolds et al. 2000; Hain et al. 2011; Coira et al. 2018), but the remains of this glyptodont came from the middle section of the Guanaco Formation, Late Miocene (*ca.* 6.3 Ma), according to Ercoli et al. (2021). Both the Piquete and Guanaco formations are considered to represent subtropical patch-forested environments, and the vertebrate bearing levels indicate the presence of low energy rivers to lacustrine lowland environments (Galli et al. 2019; Ercoli et al. 2021).

Traditionally, the faunal assemblage of these formations has been related to the Huayquerian age/stage (Arias et al. 1979; Coira et al. 2018; Ercoli et al. 2019, 2021).

In turn, the deposits of the Palo Pintado Formation in Salta Province have an estimated age of 10.29 to 5.27 Ma (Late Miocene-early Pliocene, see Coutand et al. 2006; Galli et al. 2008; Bywater-Reyes et al. 2010), representing an approximately similar lapse to that of the Guanaco Formation in Jujuy Province. The record of *C. xibiensis* from Quebrada Salta locality here described extends the biogeographical range of this species, which remains are still restricted to northwestern Argentina, and may represent an endemic species to this region according to the current evidence. Additionally, this is the most complete Glyptodontidae recovered for the Palo Pintado Formation. In this context, the materials previously referred to *Plohophorus* sp. by Miserendino Fuentes & Díaz (1988) and Glyptodontidae indet. by Armella et al. (2016) should be reviewed under a new taxonomical perspective, particularly since both Arias et al. (1979) and Ercoli et al. (2021) remarked strong morphological affinities between *C. xibiensis* and the "Plohophorini" glyptodonts.

On the other hand, our comparative analyses with other localities where the Palo Pintado Formation outcrops, particularly at Tonco Valley, reveal that at Xenarthra level no common taxa are found, since Zimicz et al. (2018) reported the presence of the Dasypodidae *Macrochorobates* sp., *Vetelia* cf. *ghandii* and Euphractini indet. This taxonomic difference could be due to the fact that Cingulata at Tonco Valley come from the lower levels of the unit (100 m basal), while glyptodonts and pampatheres here reported come from the upper levels (between 900 m to 1000 m on the top). Other locality, Angastaco, shows a larger diversity of Cingulata, but also limited to Dasypodidae, including *Macroeuphractus morenoi*, *Chorobates villosissimus*, *Chasicotatus* sp., and *Paraeuphractus* (Armella et al. 2016). This Dasypodidae diversity reported for both Tonco Valley and Agastaco localities is composed of taxa that characterize sediments of the Late Miocene-Early Pliocene lapse along the Cuyo and Northwestern regions in Argentina (Scillato-Yané 1982; Barasoain et al. 2022b). In this sense, the current absence of Dasypodidae remains in Quebrada Salta may be due to chronological differences between the different localities of the Palo Pintado Formation or a taphonomical bias, which will be enlightened by future fieldwork.

Conclusions

The features of the sedimentology and faunistic assemblage of the Palo Pintado Formation, in the Quebrada Salta section of Calchaquí Valley, indicate the presence of a fluvial system where the transport and deposition of sediment took place as a sinuous sandy-gravel fluvial system with swamps and lacustrine in a subtropical forested environment. The paleoenvironmental study suggests that the sequence thickness of Palo Pintado Formation in Quebrada Salta is lesser than previously recognized, considering a higher development of lacustrine and swamps deposits for this locality. Probably, the incipient uplift of the Sierra de Los Colorados to the east made possible the more development of lagoons and swamps in the study area.

Fossils come from levels close to the 5.98 Ma tuff. The upper fossiliferous levels here studied come from nearly 100 m and 20 m above the 5.98 Ma tuff, and 5 m below the limit between the Palo Pintado and San Felipe formations. The vertebrates here reported, including the glyptodont *C. xibiensis* and the pampathere *K. paranensis,* are first mentioned for this unit, significantly increasing the diversity known for the Palo Pintado Formation. Previous reports suggest that they would have inhabited open areas close to these freshwater bodies, predominated by xeric vegetation, mainly represented by grasses and sedges with scarce arboreous elements. In particular, the small-sized glyptodont *Cranithlastus xibiensis* is also recorded in the Piquete and Guanaco formations (Jujuy province) in a similar paleoenvironmental scenario, and could be endemic to this area. In turn, the pampathere *Kraglievichia paranensis* has a wide latitudinal distribution in Argentina, and it is traditionally also related to humid and tropical palaeoenvironmental scenarios such as the "Mesopotamian" (Late Miocene) of northeastern Argentina.

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