

Taphonomic analysis of saurischian dinosaurs from the Plottier Formation (Upper Cretaceous), Mendoza, Argentina

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ABSTRACT. The uppermost Cretaceous continental deposits of the Neuquén Basin (west-central Argentina) have yielded a high diversity vertebrate assemblage, including numerous dinosaur species. The Neuquén Group is the richest unit in remains of dinosaur of the basin and comprises the Río Limay, the Río Neuquén and the Río Colorado subgroups. In this group, there is abundance of isolated, disarticulated or partially articulated sauropods and theropods. However, little is known about the taphonomic history of fossil assemblages. In this study, dinosaur remains from the Plottier Formation (late Coniacian-early Santonian) found in the Cerro Guillermo area in southern Mendoza are examined. The investigation of fossil occurrences within the study area revealed the existence of different taphonomic modes, from isolated bones until partially articulated skeletons preserved in deposits of floodplain and fluvial channel settings. SEM-EDS analysis showed the substitution of hydroxyapatite by francolite in the bone microstructure. The presence of fluorine in one of the cases suggested a link between the elemental composition and depositional environments: floodplain and fluvial channel. The survey of the vertebrate accumulation types and their sedimentary context allowed documenting a wide range of processes responsible for their genesis, operating within a meandering fluvial environment. This contribution represents a holistic approach about taphonomic history of Cretaceous dinosaurs for assessing the differential preservation of fossil assemblages in fluvial environments.

Keywords: Taphonomy, Dinosaurs, Upper Cretaceous, Neuquén Basin, Neuquén Group, Palaeoenvironments, Argentina.

RESUMEN. Análisis tafonómico de dinosaurios saurisquios de la Formación Plottier (Cretácico Superior) de Mendoza, Argentina. Los depósitos continentales del Cretácico Superior de la Cuenca Neuquina (centro-oeste de Argentina) han producido una gran diversidad de vertebrados, incluidas numerosas especies de dinosaurios. El Grupo Neuquén es la unidad de la cuenca más rica en restos de dinosaurios y comprende los subgrupos Río Limay, Río Neuquén y Río Colorado. En este grupo, hay abundancia de saurópodos y terópodos aislados, desarticulados o parcialmente articulados. Sin embargo, se sabe poco sobre la historia tafonómica de los asociaciones fósiles. En este estudio, se examinan restos de dinosaurios de la Formación Plottier (Coniaciano tardío-Santoniano temprano) hallados en el área de cerro Guillermo en el sur de Mendoza. La investigación de las ocurrencias de fósiles dentro del área de estudio reveló la existencia de diferentes modos tafonómicos, desde huesos aislados hasta esqueletos parcialmente articulados preservados en depósitos de llanura de inundación y de canal fluvial. El análisis SEM-EDS mostró la sustitución de hidroxipatita por francolita en la microestructura ósea. La presencia de flúor en uno de los casos sugirió un vínculo entre la composición elemental y los ambientes depositacionales: llanura de inundación y canal fluvial. El estudio de los tipos de acumulación de vertebrados y su contexto sedimentario permitió documentar una amplia gama de procesos responsables de su génesis, operando dentro de un ambiente fluvial meandriforme. Esta contribución representa un enfoque holístico sobre la historia tafonómica de los dinosaurios cretácicos para evaluar la preservación diferencial de las asociaciones fósiles en ambientes fluviales.

Palabras clave: Tafonomía, Dinosaurios, Cretácico Superior, Cuenca Neuquina, Grupo Neuquén, Argentina.

1. Introduction

The quality of the fossil record is controlled by different extrinsic and intrinsic factors (physical, chemical and biological) that modify the diversity, abundance and distribution of the preserved fossil assemblages. In this sense, taphonomy is extremely useful for the understanding of the biases that introduce these processes. It thus serves a broader role in incentivizing research over all types of biases that affected, on the one hand, paleontological information during collecting; publication and curation methods and stratigraphic incompleteness on the other (Lyman, 1994; Donovan and Paul, 1998).

Both taphonomy and sedimentology are essential for the reconstruction of the ecological relations among fossil organisms. Only by considering geological-sedimentological and taphonomical data, it is possible to acknowledge the original ecological relationships among fossil organisms (Csiki *et al.*, 2010). Taphonomic research in Mesozoic reptiles is increasing worldwide contributing to clarify palaeoenvironmental, paleontological and biostratigraphic interpretations (*e.g.*, Paik *et al.*, 2001; Britt *et al.*, 2004; Eberth *et al.*, 2006; Britt *et al.*, 2009; Eberth and Currie, 2010; Brown *et al.*, 2013; Casal *et al.*, 2014; Smith *et al.*, 2015; Dai *et al.*, 2015; Canudo *et al.*, 2016, among others).

The remains of cretaceous dinosaurs are plenty and diverse in South America mainly in the Neuquén Basin, located in the northwest Patagonia, Argentina. Most of dinosaur species have been found in Upper Cretaceous strata of the Neuquén Group. This record includes abundant sauropods and theropods of considerable significance from both systematic and phylogenetic viewpoints (*e.g.*, Bonaparte, 1991; Novas, 1996, 1997; Novas and Puerta, 1997; Salgado *et al.*, 1997; Powell, 2003; González Riga, 2003; Wilson, 2002; Calvo and González Riga, 2003; Calvo *et al.*, 2004; Curry Rogers, 2005; Coria and Currie, 2006; Calvo *et al.*, 2007; González Riga *et al.*, 2008, 2009; González Riga and Ortiz David, 2014; Casal *et al.*, 2014; González Riga *et al.*, 2016, among others). Unlike the numerous systematic studies published, sedimentological and taphonomic analyses have been poorly documented (*e.g.*, Garrido *et al.*, 2001; Chiappe *et al.*, 2004; González Riga and Astini, 2007; Previtera, 2011, 2017) and they are lagging behind taxonomic and palaeobiogeographic researches. The paucity of taphonomic studies

diminishes not only the option of accurate comparisons among different vertebrate assemblages but their stratigraphic provenance as well. Additionally, it reduces the possibility of studying the disposition in the sedimentary deposit of fossil specimens often unknown or undocumented. However, in Patagonia, a detailed study from a taphonomic point of view was made to the sauropod *Aeolosaurus colhuehuapensis* Casal *et al.* (2014).

This work reports a detailed taphonomic analysis about dinosaur-bearing intervals from the Plottier Formation (Neuquén Group) in the Cerro Guillermo area (southern Mendoza, Argentina) that integrates sedimentary facies descriptions with preservation taphonomic modes so as to reconstruct burial environments.

2. Geological setting

The Neuquén Basin is considered one of the most important sites in South America on account of its occurrences in terrestrial and marine fossils. This basin is located at the eastern side of the Andes in west-central Argentina between 32° and 40° S latitude (Fig. 1). It spreads between the active magmatic arc along the Andes Range to the west, the Sierra Pintada System to the northeast, and the North Patagonian Massif to the southeast (Legarreta and Gulisano, 1989; Vergani *et al.*, 1995). It covers an area of over 120,000 km² and comprises a nearly continuous record of up to 6,000 m of stratigraphic thickness from the late Triassic to early Cenozoic (Schwarz, 2012). This sedimentary record includes continental and marine siliciclastics, carbonates and evaporites accumulated under a variety of basin styles, including syn-rift, post-rift/sag and foreland phases (Legarreta and Uliana, 1991; Howell *et al.*, 2005). At a large scale (100-1000 m), marine and continental deposits alternate, representing transgressive-regressive episodes (Digregorio and Uliana, 1980; Legarreta and Uliana, 1991).

The Neuquén Group (early Cenomanian-middle Campanian) *sensu* Cohen *et al.* (2013) (Fig. 2) constitutes a sequence of continental sediments deposited during the initial foreland stage of the Neuquén Basin (Franzese *et al.*, 2003). It is the richest dinosaur-bearing unit of the basin, including sauropods, ornithopods and theropods, as well as other vertebrate groups (Leanza *et al.*, 2004). This group reaches ~1,200 m of maximum thickness (Cazau

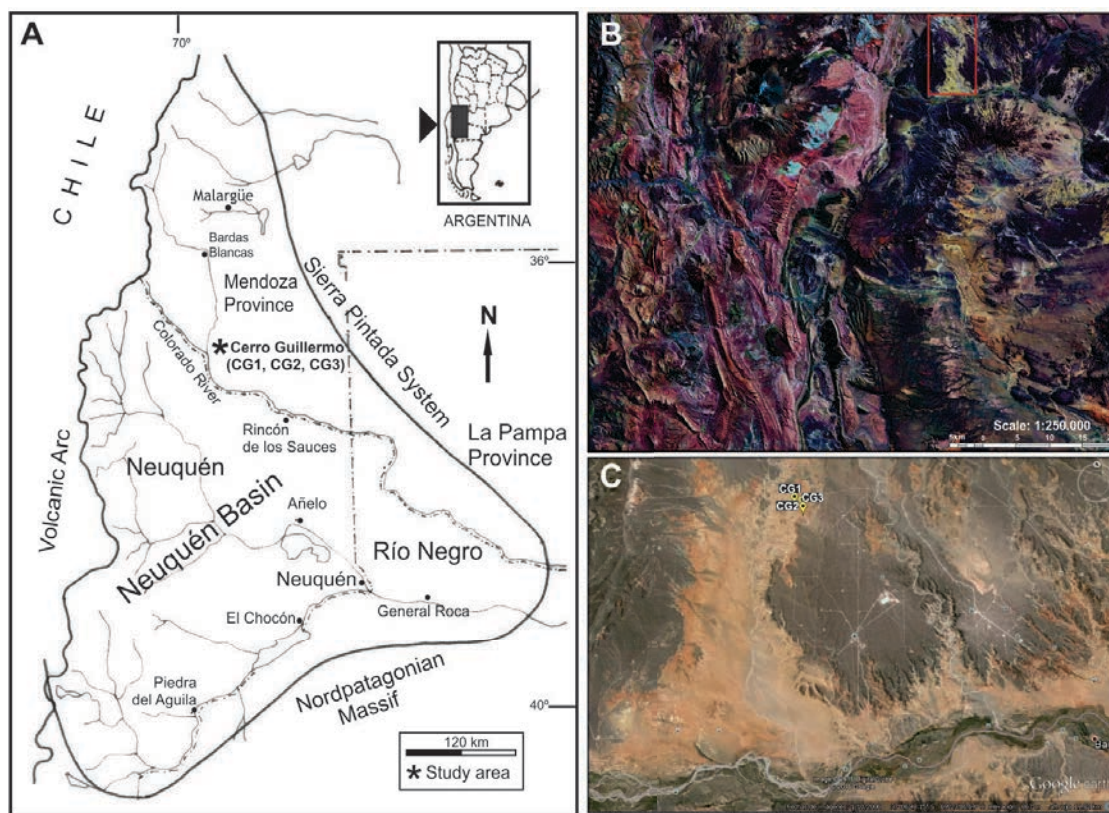


FIG. 1. A. Location map of the Neuquén Basin showing the Cerro Guillermo study area (modified from Previtera, 2017); B. Satellite image of the Chos Malal, 3769 III (data from Groeber, 1946) indicating within a red rectangle the Cretaceous outcrops of the Cerro Guillermo in the southern Mendoza; C. Google Earth image indicating the paleontological sites (CG1, CG2 and CG3).

and Uliana, 1973) being bounded at the base by the Patagonidican unconformity (Keidel, 1917; Leanza, 2009) and at the top by the Huantraiquian unconformity (Méndez *et al.*, 1987) separating it from the Loncoche Formation (late Campanian-early Maastrichtian), the lower unit of Malargüe Group (Andreis *et al.*, 1974; Digregorio and Uliana, 1980; Legarreta *et al.*, 1989). These unconformities have been located at the base of the Cenomanian (Leanza, 2009; Tunik *et al.*, 2010) and in the middle Campanian (Dingus *et al.*, 2009) respectively (Fig. 2). Lithologically, this group comprises a succession of sandstones, conglomerates and claystones which represent alluvial fans; fluvial systems and playa-lake environments stacked in recurrent fining-upward sequences (Leanza and Hugo, 2001). The Neuquén Group is divided-from bottom to top-into the Río Limay (de Ferrariis, 1968), the Río Neuquén (de Ferrariis, 1968; Cazau and Uliana, 1973) and the Río Colorado (Cazau and Uliana, 1973) subgroups (Ramos, 1981). The current lithostratigraphic model

of the Neuquén Group proposed by Garrido (2010) regards a subdivision of these subgroups into seven formations according to the following scheme: Río Limay Subgroup (Candeleros and Huincul formations); Río Neuquén Subgroup (Cerro Lisandro, Portezuelo, Los Bastos, Sierra Barrosa and Plottier formations), and Río Colorado Subgroup (Bajo de la Carpa and Anacleto formations).

In southern Mendoza, in the Cerro Guillermo (CG) study area, the most ancient outcropping strata of the Neuquén Group correspond to the Cerro Lisandro Formation (middle-late Turonian), Río Neuquén Subgroup. The Río Neuquén Subgroup (middle Turonian-early Santonian) comprises an interbedded succession of muddy and sandy deposits. It is covered by sandstones, shales and conglomerates of the Río Colorado (Santonian-early Campanian) Subgroup (Garrido, 2010). The Río Neuquén and Río Colorado subgroups include sedimentary sequences composed of alluvial plains and channel complexes

System	Series	Stage Age	Group	Subgroup	Formation
Cretaceous	Upper	-75 Ma	Neuquén Group	Unconformity	
		Campanian		Río Colorado	Anacleto
		83.6+/-0.2 Ma			Bajo de la Carpa
		Santonian		Río Neuquén	Plottier
		86.3+/-0.5 Ma			Sierra Barrosa
		Coniacian			Los Bastos
		89.8+/-0.3 Ma			Portezuelo
		Turonian			Cerro Lisandro
		93.9 Ma			
		Cenomanian		Río Limay	Huincul
	Candeleros				
		100.5 Ma	Unconformity		

FIG. 2. Lithostratigraphic scheme of the Neuquén Group. Chronostratigraphic scale according to Cohen *et al.*, 2013.

that periodically alternate, forming two distinct facies associations (González Riga and Astini, 2007). According to Previtera (2011), the basal levels of the outcrops here described and that are located northwards and eastwards of the CG were assigned to the Plottier Formation (late Coniacian-early Santonian) (Hugo and Leanza, 2001; Garrido, 2010), Río Neuquén Subgroup. Whereas that the cuspidal levels outcropping in the CG were correlated with the Bajo de la Carpa (Santonian) (Hugo and Leanza, 2001; Garrido, 2010) and Anacleto (early Campanian) (Legarreta and Gulisano, 1989) formations, Río Colorado Subgroup.

3. Materials and methods

The materials used for this study comprise an associated partial skeleton of *Notocolossus gonzalezparejasi* (González Riga *et al.*, 2016) UNCUYO-LD.301, and a specimen referred to this UNCUYO-LD.302, that includes an associated partial skeleton

of a second, smaller-bodied individual. Additionally, here it is described disarticulated but associated indeterminate sauropod bones IANIGLA-PV.113. All the sauropod specimens were collected in the Plottier Formation (Neuquén Group) in three fossiliferous sites of CG area (CG1, CG2 and CG3). Dinosaur specimens were discovered by the Bernardo González Riga in paleontological fieldworks in which the author of this work (E.P.) actively participated. The skeletons of the *Notocolossus* are housed at the Universidad Nacional de Cuyo, whereas that the indeterminate sauropod bones are housed at the IANIGLA, both repositories located in Mendoza, Argentina.

3.1. Fieldworks

Conventional stratigraphic sections were measured and detailed logs were taken after field-based facies analysis. Lateral mapping and photographs indicate the lateral continuity of beds and sedimentary

architecture. Detailed facies and architectural element analysis was performed following the Miall (1996). For evaluation of taphonomic signature followed the methods defined by Behrensmeier (1978, 1991); Behrensmeier and Hook (1992); Alcalá Martínez (1994) and Rogers *et al.*, 2007. These methods included quarry maps generated with a meter grid system and photographs, as well as the description of taphonomic modes and attributes. For the orientation measures of elongate skeletal elements it was employed a Brunton compass. The strike and dip of long axes of appendicular bones (*e.g.*, femur, tibiae and humerus) and anteroposterior axis of articulated vertebrae were plotted in stereoplots.

3.2. SEM-Energy Dispersive X-ray Spectra (EDS)

The elemental composition of the carbon-coated bone sample IANIGLA-PV.113-7 was obtained using a scanning electron microscope (SEM) JEOL JSM-6610 LV equipped with an energy dispersive spectrometer (Thermo Scientific Ultra Dry Noran Sysytem 7) in MEBYM, IANIGLA-CONICET. For the EDS maps, it was used an acquisition live time of 30 seconds, the energy of the excitation beam was set equal to 15 keV, 35.1 deg take off angle and 10 mm working distance. Results provided by the standard procedure are qualitative. The Proza Phi-Rho-Z algorithmic correction method (Bastin *et al.*, 1986) was used to perform matrix correction. Map-scans were performed from the bone's edge through the cortex towards the medullary cavity. Two categories were used referring to the concentrations of elements present in the sample: major and minor elements. The weight percentage of major components (C, O, F, P, Ca, Si) and minor components (Al, Mg, Na, K, S, Cl) were determined at each point. They were selected in order to differentiate major pore fillers and/or bone substituents (*e.g.*, Si, Mg, Ca, F) of the original bone composition represented by carbonates and phosphates.

Institutional Abbreviations: UNCUYO-LD:

Universidad Nacional de Cuyo, Laboratorio de Dinosaurios; **IANIGLA-PV:** Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales, Mendoza, Argentina, Paleontología de Vertebrados.

4. Facies associations and paleoenvironments

Red beds outcropping in the Plottier Formation at the CG area include three different fossiliferous sites

(CG1, CG2 and CG3, previously shown in figure 1) here analyzed. The architectural arrangement of these units shows the development of the fluvial system (Fig. 3). Sedimentary features of these deposits refer to tractive high energy fluvial facies (channels and bars) interbedded with fine floodplain facies. Based on the codes and definitions summarized by Miall (1996), distinct alternating facies associations are recognized within the succession in CG. These associations represent floodplain environments and sandy fluvial channel complexes (Fig. 3), whose lithofacies and architectural elements are summarized in table 1. Facies associations are described below as (A) floodplain and (B) fluvial channel.

4.1. Facies association A: Floodplain

This association includes red massive and mottled mudstones, claystones and siltstones (Fm), rarely laminated (Fl) interbedded with tabular or lenticular sandstones (Sm, Sh, Sr, St, Sp) and paleosol levels (P). Within the massive intervals (Fig. 4A), intense disruptions of original sedimentary structures and fabrics occur by tubular burrowing (possible pedotubules), infiltrated clay partings, and local abundance of irregular, massive clay-rich glaeboles and calcareous nodules composed mainly of calcite and quartz (Fig. 4B). Less frequent intervals of 0.5 m show fine sandstones that locally contain pelitic intraclasts and ripple cross-lamination (Fig. 4C). Horizons with intense greenish grayish mottling and diffuse boundaries are also present. The paleosol levels (P) comprise red, whitish and visibly mottled sandy mudstones with proportions of fine to medium-grained 5-10% (Fig. 4D).

Within the dominantly fine-grained sedimentation, tabular, thin-bedded, slightly graded medium-to fine-grained sandstones with various sedimentary structures are present. From bottom to top, individual sandstone beds range 0.03-0.3 m and show a lower massive (Sm) to laminated interval (Sh), rippled tops with sets of cross-lamination (Sr) bioturbated and conglomeratic. Beds at the top commonly show lenticular geometries and slightly coarser sandstones with trough cross-bedding (St) and planar cross-bedding (Sp), as well as lags and intraclasts.

These facies associations contain diverse trace fossil together with vertebrate remains. The ichnological record exhibits typical characteristics of floodplain ichnofaunas such as a low to moderate

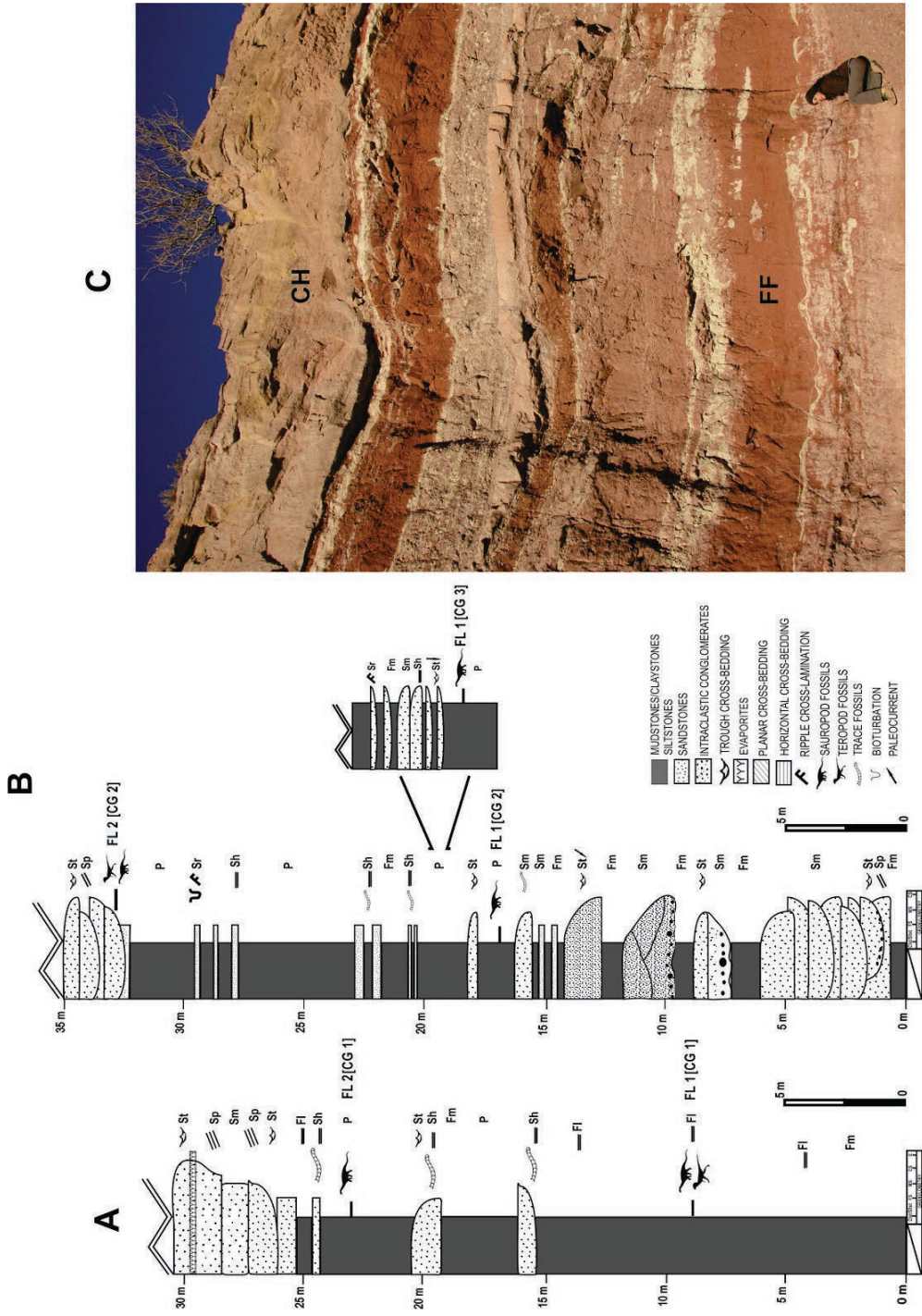


FIG. 3. **A-B.** Stratigraphic columns of the Plotier Formation at Cerro Guillermo showing lithofacies and fossiliferous levels (A) CG1 site; (B) CG2 and CG3 sites; C. Photograph of the fluvial deposits in the study area showing facies associations with architectural elements: floodplain fines (FF) and channel belt complexes (CH). See text for further explanation. **CH**: fluvial channel; **FF**: floodplain fines; **FL**: fossil level; **FL**: pelite horizontal lamination; **Fm**: pelite massive; **P**: paleosol; **P**: pebble massive; **P**: pebble massive; **Sm**: sandstone horizontal lamination; **Sm**: sandstone massive; **Sp**: sandstone planar cross-lamination; **St**: sandstone ripple cross-lamination; **St**: sandstone trough cross-lamination.

TABLE 1. LITHOFACIES AND ARCHITECTURAL ELEMENTS RECOGNIZED IN THE CERRO GUILLERMO, MENDOZA, ARGENTINA (MODIFIED FROM PREVITERA, 2017).

Cody	Lithology	Geometry	Sedimentary structures	Interpretation	Architectural elements	Fluvial sub-environments
Fm	Claystones Siltstones	Tabular	Massive	Deposits of decantation, Overbank deposits	FF (Floodplain fines)	Floodplain and floodbasin deposits
Fl	Siltstones	Tabular	Fine horizontal lamination	Overbank deposits or flood deposits	FF (Floodplain fines)	Distal/proximal deposits
P	Sandy/Mud carbonates	Fine irregular horizon	Pedogenic features: concretions and calcareous nodules	Soil with chemical precipitation	FF (Floodplain fines)	Paleosols
Sm	Fine to coarse-grained sandstones	Tabular to lenticular	Massive	Varied tractive deposits intense biological activity	CR (Crevasse channel) CH (Channel)	Overflow deposits Sandy fluvial channels
Sh	Fine to medium-sandstones	Tabular	Horizontal Lamination	Plane-bed deposits (critical flow)	CS (Crevasse splay)	Overflow deposits
St	Fine to coarse-grained sandstones	Lenticular	Trough cross stratification	3D bedforms (lower flow regimen)	CS/CR (Crevasse) CH (Channel)	Overflow deposits Channel belt complexes
Sr	Fine to medium-grained sandstones	Tabular	Ripple cross lamination	Ripple (lower flow regime)	CS (Crevasse splay)	Sheet-flood, distal crevasse splay deposits
Sp	Fine to coarse-grained sandstones	Tabular to lenticular	Planar cross lamination	2D bedforms (lower flow regime)	CS/CR (Crevasse) CH (Channel)	Overflow deposits Fluvial channel complexes

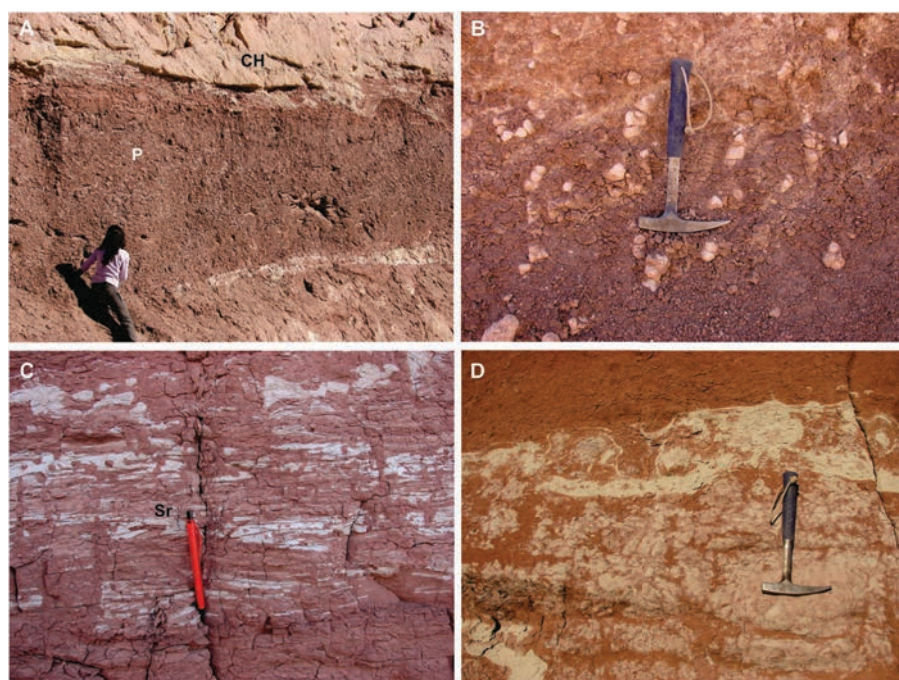


FIG. 4. Detailed photographs of the floodplain facies from the Cerro Guillermo area. **A.** Paleosol horizons underlying the channel belt; **B.** Detail of the paleosol level showing abundant calcareous nodules; **C.** Fine sandstones containing pelitic intraclasts and ripple cross-lamination; **D.** Red sandy mudstones with whitish mottled. **CH:** fluvial channel; **P:** paleosol; **Sr:** sandstone ripple cross-lamination.

diversity and dominance of locomotion and feeding structures generated by detritivorous organisms (Ekdale *et al.*, 1984; Frey *et al.*, 1984) or mainly produced by arthropods in ephemeral lakes and floodplains (Bridge, 2006). Although this record is relatively scarce, its good preservation allow recognize the representative features of the *Scoyenia* ichnofacies (Buatois and Mangano, 1996) with low ichnodiversity and dominance of meniscate structures associated with stress conditions. Vertebrates include mainly remains of sauropods which are thoroughly analyzed in the taphonomy section.

The floodplain facies association is comparable to Miall's (1985, 1996) FF architectural element and is interpreted as a product of accumulation (vertical-accretion deposits) of fines in variously drained, low-gradient floodplains. These deposits were formed from subaqueous sedimentation dominant processes associated with shallow lacustrine bodies. However, part of this association could also have eolian origin "paleoloess". Overall, thin-bedded tabular sandstones are interpreted as crevasse splay deposits caused by episodes of deposition when waning floods overtop the river banks (Miall, 1996; Bridge, 2003; Fisher *et al.*, 2007). These sandy facies reflect the origin of overflows caused by episodic flooding and flood irregular sheets (Miall, 1996) fed from the crevasse channel (CR).

The dominantly massive and mottled structure of mudstones is the result of early diagenetic modification and soil-forming processes. Physical and biological modification in floodplain deposits commonly results after periods of subaerial exposure. Exposure renders near-surface sediments susceptible to soil-forming processes that eliminate primary structures (Retallack, 2001). Disruptions of original sedimentary structures and fabrics by burrowing organisms, infiltrated textures -a product of illuviation- and local abundances of glaeboles and rhizoliths suggest paleosols development.

The presence of trace fossils like *Scoyenia* implies environments subject to periodic flooding and drying (Frey *et al.*, 1984; Buatois and Mangano, 1995, 1996). However, the absence of sedimentary structures in the majority of the pelitic facies, together with the record of dinosaurs; concretions; calcareous nodules, and traces of invertebrates evidence a significant biological activity in the floodplains subject to intense bioturbation and development of surrounding vegetation.

4.2. Facies association B: Fluvial channel

A variety of distinct, large-scale bodies (1-5 m) of coarse sandstones ranging in size from lens to sheet-like geometries, predominantly fine-grained succession at a broader scale. Such packages conform a higher hierarchy elements that are limited by significant stratigraphically surfaces (third order, *sensu* Miall, 1996). These sandstone bodies frequently show internal amalgamation and yield lateral continuity of several kilometers (Fig. 5A). The individual channels have an irregular base and a series of structures reflecting a gradual decrease in the flow regime. Progressively thinner trough and planar cross-bedded sets (mesoscale St and Sp) are recorded near the top of individual sandstone bodies, which end up at the top with fining-upward arrangements. Within this association, it is frequently observed lateral accretion surfaces (Fig. 5B). Between each deposit of individual sandy channels, there are fine facies deposits reflecting episodes of decantation (Fig. 5C). This facies is composed of coarse-grained sandstones with abundant pelitic intraclasts that can reach 1 m in diameter (Fig. 5D) arranged in banks of up to 2 m thick and lenticular geometry. Also, this association contains isolated bones of indeterminate sauropod and theropod dinosaurs transported as basal lag deposits.

The variety of large-scale isolated or amalgamated sandstone packages are interpreted as main fluvial channels or channel belt complexes (CH elements according to Miall, 1996). The internal arrangements, particularly the degree of amalgamation, discriminate multi-story and single-story end members. Two distinct channel sets the predominantly fine-grained succession of the Río Colorado subgroup. Amalgamation patterns in the multi-story, multilateral sandstones indicate stratigraphic condensation. Multi-story or complex fills are mostly interpreted as mobile, broad, shallow channels that generate largely sheet-like geometries (Friend *et al.*, 1979; Bridge, 1993).

In contrast, single-story bodies show a fining-upward trend that indicates greater stratigraphic completeness related to available accommodation. Fining-upward trends indicate progressive abandonment or lateral migration. Meter-scale, gently inclined surfaces observed within CH sandstone bodies and oblique to perpendicularly oriented paleoflows are interpreted as lateral accretion surfaces deposited by high sinuosity rivers through low-gradient plains.

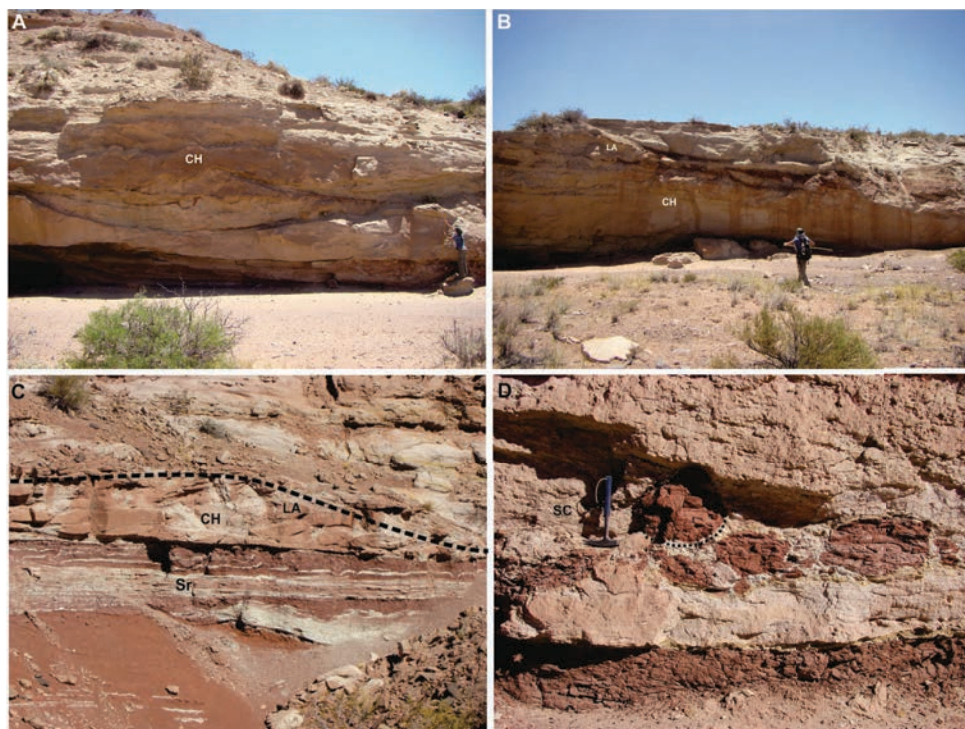


FIG. 5. Detailed photographs of the fluvial channel facies from the Cerro Guillermo area. **A.** Multi-story amalgamated fluvial channels; **B.** Channel belt complexes with lateral continuity; **C.** Detail of fluvial channel showing lateral accretion surfaces interbedded with sandstones ripple cross-lamination; **D.** Coarse-grained sandstones with abundant pelitic intraclasts. **CH:** fluvial channel; **LA:** lateral accretion; **SC:** coarse-grained sandstone; **Sr:** sandstone ripple cross-lamination.

4.3. Palaeoenvironmental setting

The facies of the Río Neuquén Subgroup include a variable suite of alluvial plain facies and channel complexes that periodically alternate, forming the two distinct facies associations. Low-gradient fluvial plains with developed mixed-load meander belts within extensive floodplains are consistent with slow subsidence in the external position of the Neuquén Basin (González Riga and Astini, 2007). However, drainage from the east-southeast to west-northwest and sandstone composition (Vergani *et al.*, 1995; González Riga, 2002; Previtera, 2011) indicates that sources were localized toward a cyclically active forebulge where basement rocks with an important Triassic volcano-sedimentary cover were intermittently exposed. At a larger scale within the Río Neuquén Subgroup, the alternating and contrasted stacking pattern of sheet-like fluvial belts and alluvial plain intervals, dominated by fine accumulation and isolated channels, indicates variations in the accommodation/

sediment supply rates (González Riga and Astini, 2007). This recurrent pattern probably relates to tectonic activity that periodically contributed to readjust the longitudinal gradient and the stratigraphic base level in the basin (*e.g.*, Plint and Browne, 1994; Martinsen *et al.*, 1999).

At the base of the Cerro Guillermo (CG1, CG2 and CG3 sites) outcrops show a low relation of channel/floodplain with a strong aggradation of pelitic deposits in the floodplain, where the proportions of fines are high relative to the proportions of sand. This shows a rate of return of the channels relatively low, with a predominance of floodplain deposits compatible with good accommodation space (Previtera, 2011). This fact suggests the development of isolated lenticular channels in floodplain deposits and levees, crevasse splays and sheet floods events (Sánchez *et al.*, 2006). The restriction of the channel systems can be related to the climatic conditions probably combined with subsidence that have temporarily controlled the development of the system.

Subsequently, water supply conditions and a more stable sediment allowed the development of more extensive and powerful channels, enabling the gradual passage in the upper sectors toward a fluvial moderate/high sinuosity meandering type. Gradually, an increasing on the channel/floodplain relation is recorder. This pattern accompanied by the location of the channels in the most stable alluvial-belt. This situation favored the development of avulsion episodes associated with crevasse channels (Previtera, 2011).

According to Sánchez *et al.* (2006), the evolution of fluvial system in the Plottier Formation shows a large scale geometry of styles I and II. Style I characterized by an ephemeral fluvial system, and the style II with the development of fluvial pattern braided, which are pointing out a progressive decrease on the accommodation/supply. Weather probably varied from sub-humid or semi-arid to humid climatic conditions with strong seasonal variations. These provoked important changes on the water and sediment discharge onto the fluvial system. In opposite to Sánchez *et al.* (2006), Garrido (2010) proposes for the Plottier Formation, the development of mixed-load fluvial systems constituted by distal floodplains rich in paleosols associated with small ephemeral canals, until to areas with large isolated paleochannels, simple of mixed charge "ribbon bodies" (Friend, 1983). The recurrent presence of lateral accretion macroforms in these channels indicates the predominant development of high sinuosity fluvial systems (Miall, 1996), criteria adopted in this work. The dinosaur remains here studied were preserved mostly in the floodplain deposits subject to intense pedogenic activity, whereas that a less proportion was registered in the fluvial channels.

The facies associations described in this work have many similarities with the stratigraphic arrangement of facies associations (floodplain and fluvial channel) described by González Riga and Astini (2007), in the paleontological site of *Mendozasaurus neguyelap*, at the Arroyo Seco locality (Sierra Barrosa Formation) in southern Mendoza (González Riga *et al.*, 2018). The latter is possible due to the close spatio-temporal proximity of the paleontological sites.

5. SEM-EDS analysis

Images and maps were performed in the thin-section of the femoral fragment IANIGLA-PV.113 to monitor trends in elemental distributions (Fig. 6).

The EDS recognized the following elements: C, O, F, P, Ca, Si, Al, Mg, Na, K, S, Cl, which were mapped to show their qualitative distribution patterns. The major elements include C, O, F, P, Ca, Si, whereas the minor are Al, Mg, Na, K, S, Cl. Two areas (cortical bone/medullary cavity) were illustrated with the combination of the informative elements (P, Ca, F, Mg) to recognize the original bone composition and the interaction of fillers and/or substituents components. It is possible to note some differences between cortex and medullary zone in the SEM image and EDS maps. P and Ca show a similar concentration in both areas, although in the medullary zone present a highest concentration and more homogeneous distribution. The Ca conforms the bone original composition as well as the diagenetic mineral infilling the pore spaces. The high concentration of F is evident in all the sample. This confirms an ionic substitution of the hydroxyapatite by francolite (carbonate-fluorapatite) in the bone microstructure. Finally, the Si that represents a sedimentary component, is more concentrated in the transition of the cortical bone and the host rock. However, the presence of Si in the bone matrix is mainly located in the infilling points. In general, the Al shows a similar distribution to the Si that supports the sandy mudstone rock matrix.

6. Vertebrate taphonomy

6.1. Taphonomic site 1

In sedimentary units from the Plottier Formation in the CG1 site (see Fig. 3, FL 2), disarticulated but associated bones corresponding to a sauropod *indet.* IANIGLA-PV.113 were found (Table 2). The bones were recovered from a single horizon and there were no duplicated elements. Skeletal elements included the proximal end of humerus, the distal end of femur, one scapula, one fibula, two incomplete appendicular bones, two dorsal ribs, one coracoid, and one neural arch.

The skeletal elements showed a general SW to NW trend (185°-340°). The long bones (*e.g.*, femur, humerus and fibula) do not showed preferential orientation patterns according to the morphology since they were arranged in both directions (Fig. 7A). However, some bones (*e.g.*, scapula, neural arch and dorsal ribs) displayed a clear SW trend.

The bones exhibited inclinations ranging between 9° and 42° in relation to the horizontal stratigraphic plane. This inclination is interpreted as a product of

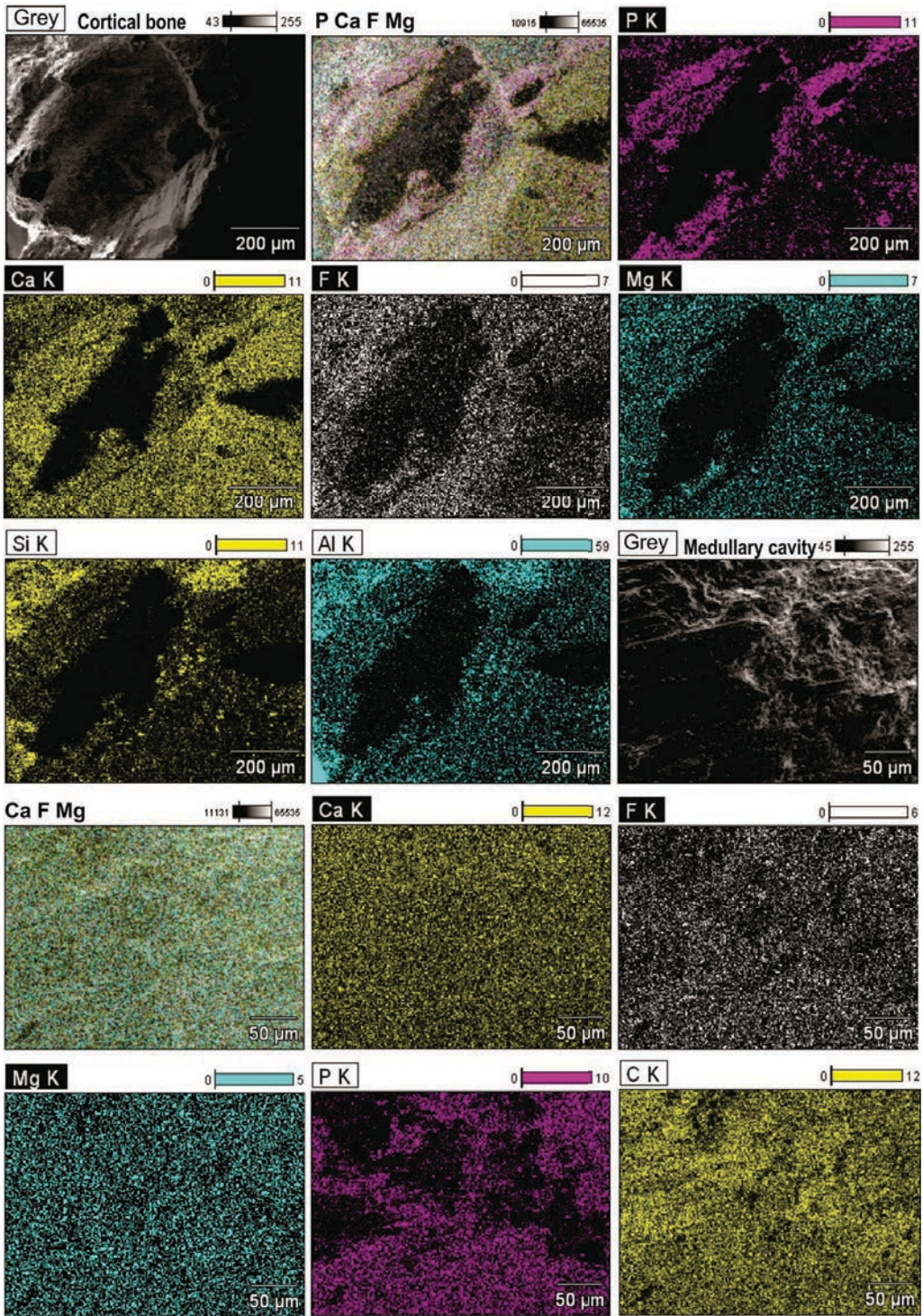


FIG. 6. SEM images and EDS maps of the femoral fragment IANIGLA-PV.113 in a thin-section. Grey photos are the SEM image in different points of the sample. The multicolour images are the superimposition of the grey with the P, Ca, F and Mg mapping. The colour differences in the maps show the distribution of the different elements in the analyzed points. See text for further explanation. **AlK**: aluminum; **CK**: carbon; **CaK**: calcium; **FK**: Fluorine; **MgK**: magnesium; **PK**: phosphorus; **SiK**: silica.

TABLE 2. SUMMARY OF THE MAIN TAPHONOMIC FEATURES OF THE CERRO GUILLERMO DINOSAURS.

Sites	Taxonomic composition	Description	Taphonomic features	Taphonomic modes
CG1	Sauropoda indet. IANIGLA-PV.113	Incomplete skeleton composed of associated bones corresponding to the single taxon.	Complete disarticulation, sorting, distortion, weathering, abrasion high, absence of crusting.	Disarticulated-associated bones Preserved in well-drained floodplains deposits.
CG2	<i>Notocolossus</i> <i>Gonzalezparejasi</i> UNCUYO-LD. 301	Co-occurrence of two or more skeletal elements belonging to the same individual, in various degrees of completeness and articulation.	Partial articulation, weathering, abrasion and breakage low to moderate presence of bioerosion and crusting, absence of sorting.	Associated specimen Partial skeleton Preserved in well-drained floodplain deposits.
	Accumulation of saurischian remains	Accumulation of small-sized skeletal elements. More than one taxon, high diversity.	Complete disarticulation sorting, weathering abrasion and breakage moderate to high.	Isolated bones Preserved in channel deposits.
CG3	<i>Notocolossus</i> <i>Gonzalezparejasi</i> UNCUYO-LD. 302	Co-occurrence of two or more bones belonging to the same specimen in variable degree of articulation.	Partial articulation, low weathering, absence of abrasion, presence of crusting and distortion, absence of sorting and bioerosion.	Associated specimen Partial skeleton Preserved in well-drained floodplain deposits.

soil compaction by lithostatic load. This phenomenon is common in environments characterized by pelitic deposits susceptible to physical processes of compaction and compression. This is consistent with the degree of distortion or plastic deformation evinced by fossils. The paleoenvironmental context suggests that the bones were oriented horizontally or sub horizontally by shallow and sporadic currents.

In the CG1 site the fossils are mainly large elongated bones (scapula, femur, humerus) together to medians (fibula) and small (dorsal ribs). However, their incompleteness condition determined that they behaved like elements of similar sizes, being able to be selected and transported together by hydraulic currents that occurred during flood. The absence of cranial elements, teeth and phalanges suggests some hydraulic sorting processes. Hence, the smaller and lighter parts could be transported away from the site of accumulation of the remains (Behrensmeyer, 1991).

Moderate cracking of the periosteum is observed in the preserved elements. Long bones have longitudinal fractures parallel to the bone fibers which is associated with the subaerial exposure experienced before the burial -biostratigraphic stages- (Fig. 8A). These

cracks were subsequently filled by minerals during permineralization events occurring within the sediment -diagenetic stages- as described by the author (see Previtera, 2017). Appendicular bones, dorsal ribs and the scapula show transverse and oblique fractures with smooth edges (Fig. 8B-F). These fractures are typical of dry or slightly weathered bones (Marshall, 1989).

The bones show (1-3) weathering degrees according to Behrensmeyer (1978). The following skeletal elements: scapula, humerus, fibula, femur and appendicular bones exhibit (1, 2 stages of weathering) "slightly weathered" with loss of compact tissue; while the dorsal ribs, the coracoid and the neural arch show (3 stage of weathering) "weathered" with loss of spongy tissue and exfoliation their ends. In some long bones absence of epiphysis is observed (Smith, 1993).

In the neural arch, appendicular bones and dorsal ribs, moderate abrasion exhibiting smoothly rounded ends is recognized (category 2 of Alcalá Martínez, 1994). This wearing is associated with a certain degree of sorting by hydraulic transport. In contrast to the remains from CG2 and CG3 sites, the bones of CG1 do not have calcareous crusting in their outer surface.

Signs of bioerosion associated with plant root activity are recognized in the scapula and long bones. Sinuous roots are also observed with polished and filled by “U”-shaped cross-sections sediments (Andrews, 1990). In most elements, root marks are present on the fracture surface; this indicates that the bone was fractured prior to etching and perhaps prior to burial (White *et al.*, 1998).

In addition, the presence of tubular fossil traces developed on the external surface of appendicular bones and the scapula is recorded (Fig. 8B, D, F). These tubes generated by detritivores organisms, with a diameter of ~0.5 mm, are curved and filled by sandy mudstones. These horizontal structures type *Taenidium* sp. (Heer, 1877) are burrows filled with well-defined meniscus, typical of environments exposed to floods and episodic desiccations (González Riga *et al.*, 2009). Similar bioerosion features have been reported in a sternal plate of Titanosauridae from Arroyo Seco site (González Riga, 2002).

6.2. Taphonomic site 2

In outcrops from the Plottier Formation exposed in the CG2 site (see Fig. 3, FL 1), it was found an associated partial skeleton of a very large individual denominated *Notocolossus gonzalezparejasi* (González Riga *et al.*, 2016) UNCUYO-LD. 301 (Table 2). The skeleton consists of the right humerus, the proximal end of the left pubis, one anterior dorsal vertebra, and one anterior caudal vertebra. The bones were found within an area of 8 m by 8 m at the same stratigraphic level. These elements represent a single titanosaurian individual because they are of the appropriate size and morphology of a single skeleton (González Riga *et al.*, 2016) (Fig. 7B).

The bones showed three different orientations. The right humerus was oriented to southwest, the vertebrae (anterior dorsal and anterior caudal) to the northwest and the proximal end of the left pubis has southeast direction. The values showed a generalized dispersion. The absence of bone sorting by shape and size as well as of preferential orientations indicate non-intense hydraulic processes and of short-term. Therefore, the dispersion of the remains can be attributed to the intervention of biological agents during the biostratinomic stage. However, to achieve a greater certainty about of the phenomenon that caused the scattering of the bone remains, a highest relative abundance is required.

The humerus and dorsal vertebra (Fig. 8G-K) show slight cracking of the periosteum. The humerus exhibits bioerosion attributes (Fig. 8I, J) related to the activity of roots as well as described in CG1. In the humerus (Fig. 8G-J) it can be recognize two types of fractures: (1) cemented longitudinal fractures parallel to the bone fibers (pre-burial weathering); (2) non-cemented transverse fractures (post-burial or exhumation), both with smooth edges and orthogonal designs “cracked”.

Some bones present borings which can be attributed to the action of scavengers or carnivores, that could be linked to the disarticulation and dispersion mentioned above, although this assertion needs further analysis. The fossils are covered by an outer calcareous crust, which could have inhibited the influence of alterative agents (*e.g.*, abrasion).

6.3. Taphonomic site 3

In the outcrops from the Plottier Formation in the CG3 site (see Fig. 3, FL 1), it was found an associated partial skeleton of a second, smaller-bodied individual UNCUYO-LD.302 (Table 2) also referred to as *Notocolossus gonzalezparejasi* (González Riga *et al.*, 2016). The bones include an articulated anterior caudal series (consisting of seven partial vertebrae and haemal arches), the complete and articulated right astragalus and pes and appendicular bones. As in the holotype mentioned above, these elements are considered to represent a single titanosaurian individual because they were found within an area of 5 m by 5 m at the same stratigraphic level. They are of the appropriate size and morphology to belong to a single skeleton (González Riga *et al.*, 2016) (Fig. 7C).

The anterior caudal section (Fig. 8L) exhibits slight weathering stage 1 of Behrensmeyer (1978) in relation to the articulated foot (Fig. 8M, N), that shows no evidence of weathering and is attributed to the stage 0 of intact bone. This situation is due to the foot bones were extracted at greater depth (~2 m) below ground level, therefore, they are less weathered with respect to the other bones exposed in the surface. The skeletal elements show no evidence of abrasion attributed the category 1 of Alcalá Martínez (1994).

All the bones analyzed are covered by a calcareous crust. Some of them, as the foot, have carbonate

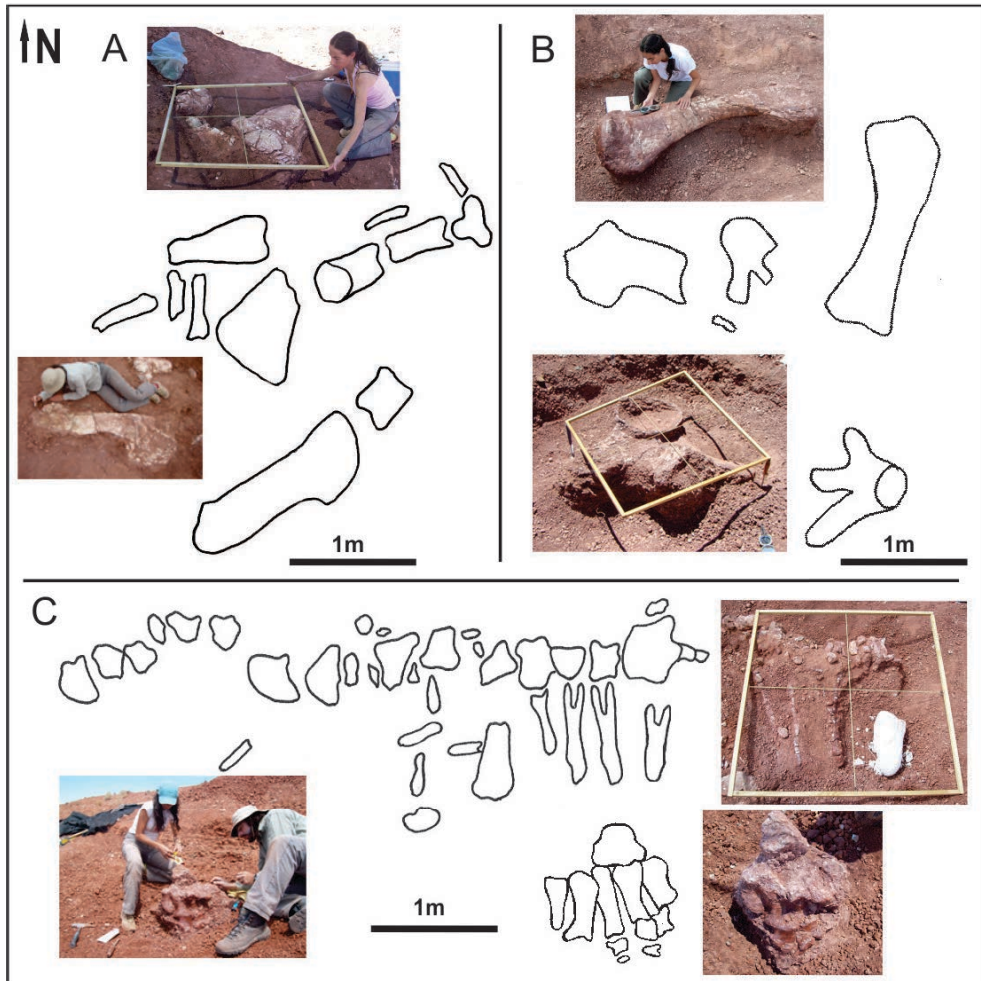


FIG. 7. Quarry maps of Cerro Guillermo (Mendoza, Argentina) showing the spatial distribution of dinosaur remains. **A.** CG1 site; **B.** CG2 site; **C.** CG3 site. See text for further explanation.

concretions adhered to its external surface. These concretions are very abundant in the fossil-bearing floodplain facies and were subjected to intense pedogenetic processes. This type of crusting masks the existence of borings or bioerosion signals that may have affected the remains during the biostratinomic stage.

The distortions observed in the bones occurred during the early diagenetic stages, when skeletal elements were susceptible to be deformed plastically, because they still conserved organic matter. It can be observed a horizontal thrust of the metatarsals I and II in the articulated foot (Fig. 8M, N). This distortion is interpreted as the product of soil compaction by lithostatic load on pelitic facies.

7. Discussion

7.1. Taphonomic modes of vertebrates

Behrensmeyer and Hook (1992) observed that terrestrial organisms conserved in specific sedimentary contexts show similar fossil preservation patterns. They define these recurring types of preservation as “taphonomic modes” integrating sedimentological and taphonomic data in order to expand the knowledge of each paleontological site. Several taphonomic modes have been recognized by previous authors such as isolated complete skulls of macrovertebrates, complete articulated and disarticulated skeletons, associated partial specimens, large monospecific

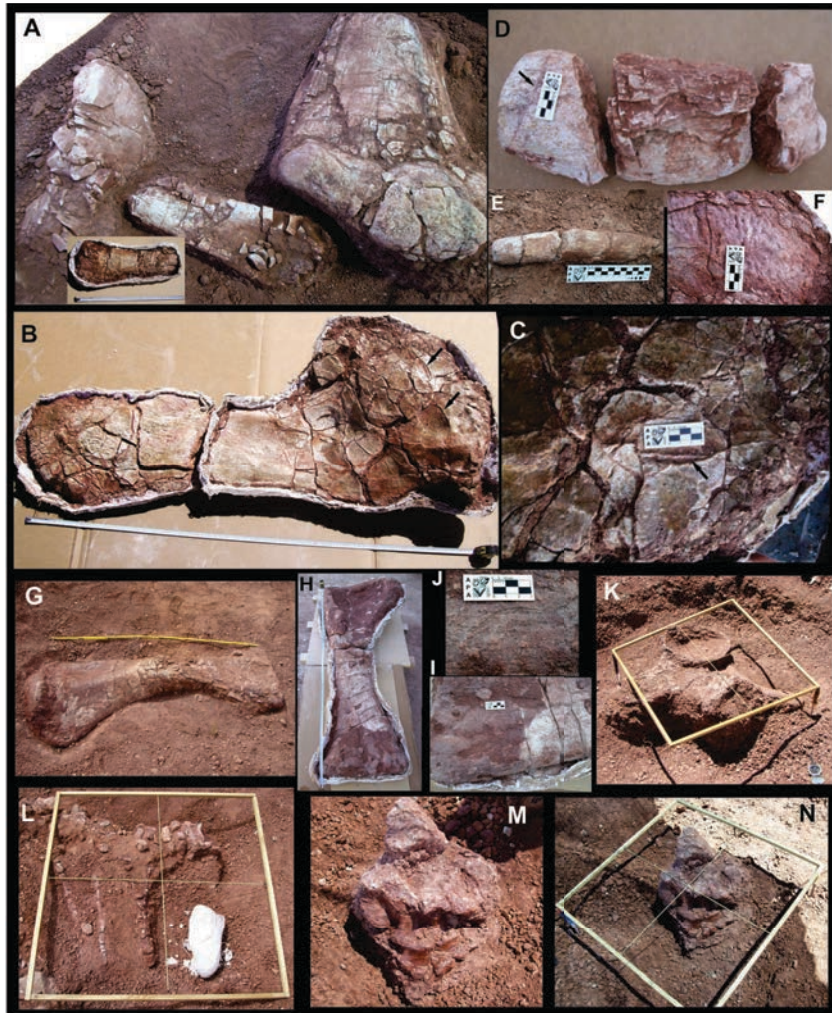


FIG. 8. Taphonomic modifications in dinosaur remains from the Cerro Guillermo area. A-F. Skeletal remains of a sauropod *indet.* IANIGLA-PV.113 from the CG1 site, FL 2. A. Associated bones (distal end of femur, fibula and proximal end of humerus) showing the longitudinal cracks that suggest advanced weathering; B-F. Appendicular bones, dorsal ribs and the scapula show transverse, oblique fractures and tubular fossil traces on the external surface; G-K. Skeleton remains of *Notocolossus gonzalezparejasi* UNCUYO-LD. 301 from the CG2 site, FL 1. The right humerus and dorsal vertebra display slight cracking of the periosteum; I, J. The right humerus showing bioerosion attributes on its external surface; L-N. Skeleton remains of *Notocolossus gonzalezparejasi* UNCUYO-LD. 302 from the CG3 site, FL 1. L. The anterior caudal section shows slight weathering before burial; M, N. The foot displays slightly horizontal thrust of the metatarsals I and II due to compaction phenomena. See text for further explanation.

bonebeds and isolated bones (*e.g.*, Varricchio and Horner, 1993; Varricchio, 1995; Heinrich, 1999; Eberth and Currie, 2005; Csiki *et al.*, 2010; Smith *et al.*, 2015).

The dinosaurs of Cerro Guillermo (CG1, CG2 and CG3 sites) from the Plottier Formation occur in three distinctive taphonomic modes within mudrock and sandstones of the facies associations

(A-B) accumulated on a floodplain, and also complexes of channels, respectively. Most of the dinosaur remains found correspond to sauropods recovered in facies of floodplains. In contrast, the isolated bones of sauropod and theropod transported together through fluvial channels are scarce. Every taphonomic mode reflects the interactions between taphonomic attributes of fossils and the sedimentary

context prevailing between death and final burial. Each dinosaur taxon was assigned a taphonomic mode modified from those proposed by Eberth and Currie (2005) according to the following criteria: (1) Disarticulated/Articulated (complete or partial), (2) Associated, or (3) Isolated. The taphonomic modes derived from Cerro Guillermo (CG1, CG2 and CG3) assemblages are described below.

7.1.1. Taphonomic mode 1. Disarticulated-associated bones in well-drained floodplains

Associated specimens are frequently found and they represent the most common preservation mode in the studied sites. Disarticulated but still associated bones of a sauropod *indet.* were preserved in the sandy mudstones deposited on the floodplain in the (CG1 site, fossil level (FL 2)). These lithofacies show scarce development of paleosol horizons and the sedimentation rate was slow and essentially episodic.

The bones were found close to the death site, within the same area, disarticulated and somewhat scattered. However, the elements remained in association confirming their parautochthonous condition, such as it was found in other dinosaur sites at Neuquén Group (MT1 from González Riga *et al.*, 2003, 2007). They showed evidence of partial disarticulation, subaerial biodegradation, weathering and cracking. Some bones displayed processes of preferential orientation, hydraulic sorting and sedimentary abrasion. This fact indicates that they were oriented and dispersed by shallow currents during flood episodes of the alluvial plain. Although the bones were reworked by processes of disarticulation and dispersion, they remained within the area of death. On the other hand, the absence of calcareous crusting favored the intense abrasion.

7.1.2. Taphonomic mode 2. Associated partial skeletons in well-drained floodplains

Incomplete skeletons usually include associated remains of the axial and appendicular skeleton, ranging from 2 to 3 disarticulated bones to accumulations of partly articulated remains from various body parts (*e.g.*, Smith *et al.*, 2002; Van Itterbeeck *et al.*, 2004; González Riga *et al.*, 2007; Csiki *et al.*, 2010; Smith *et al.*, 2015). This taphonomic mode is registered in the fossil level (FL1) in both CG2 and CG3 sites and comprises two associated partial skeletons assigned to *Notocolossus*

gonzalezparejasi. The dinosaur remains also were preserved in the sandy mudstones deposited on the floodplain facies, but in this case, the lithofacies show a well-developed paleosols. In the dinosaur-bearing lithofacies, the processes of bioturbation and pedogenesis were very intense and contributed to the oxidation of sediments and recycling of organic matter. The carbonates and other minerals available in this depositional environment caused the rapid permineralization and partially articulated preservation of the specimens.

The specimen found in the CG2 site was preserved very close to the death site, within the same area, with a short pre-burial phase. Since the bones remained for some time on the surface, they underwent processes of dispersion, subaerial biodegradation, weathering, bioerosion and crusting. The absence of sorting by shape and size in the bones as well as of preferential orientations indicate scarce hydraulic transport processes. In this case, evidences suggest biological intervention (predators and/or scavengers) as dispersing agents. These parautochthonous fossil assemblages resulted from the decay and burial of partially complete carcasses.

The specimen of the CG3 site was preserved at the site of death, without evidence of transport and with a very short pre-burial time period favoring articulated conservation. The absence of skeletal parts, which are easily destroyed and/or removed, suggests that these skeletons were subjected to short-distance transport, limited and selective dispersal and/or removal of the elements. The most portion of the skeleton it disappeared, possibly result of predatory or scavenging activity, as hydraulic transport seemed an unlikely cause. The skeletal elements do not evidence weathering either intense or slight, abrasion, bioerosion, and orientation produced by sporadic currents. They exhibit a calcareous crusting, calcareous concretions and distortions. The articulated preservation without evidence of weathering together with the sedimentary context suggests the absence of hydraulic action. Based on the available evidence so far, it is considered that biological organisms (predators or scavengers) acted as dispersing agents during the burial history. However, for to confirm this interpretation, further studies are necessary. This mode of occurrence confirms their autochthonous condition.

7.1.3. Taphonomic mode 3. Isolated bones in fluvial channels

Isolated bones represent the less frequent occurrence of dinosaur remains in the Cerro Guillermo area. The saurischian remains (sauropods and theropods) were preserved in the coarse-grained sandstones deposited on the *channel* floor as “lag deposits” formed under extreme flow conditions (*i.e.*, high-energy and large transport capacity). This taphonomic mode is registered in the (CG2 site, fossil level (FL 2)) and comprise bones preserved away from the site of death. These isolated bones show highly fragmentary nature and are usually weathered and abraded, such as it was found in other taphonomic sites in the Neuquén Group (MT2 of González Riga *et al.*, 2003). They show pre-burial signs like complete disarticulation, weathering, fracturing, abrasion and sorting by hydraulic processes.

Phenomena of sorting and abrasion in skeletal parts, in channel lags and bars, generally indicate some degree of transport and hydraulic selection. Therefore, the bones are considered allochthonous which were transported together by high-energy currents, mixed and reworked. The skeletal remains of different specimens, time intervals and origin areas were preserved together within the same area. This fact confirmed the existence of “time averaging” in these fossiliferous concentrations.

7.2. Taphonomic pathways

The genesis of the bone accumulations recognized in the Cretaceous deposits of Cerro Guillermo (CG1, CG2 and CG3 sites) can be explained within a relatively simple scenario. After death, the carcasses were subjected to sequences of biostratinomic processes (vertebrate taphonomy; Table 2) leading to the formation of the above described taphonomic modes. These different taphonomic pathways were dependent on the cause of death; place of death; local depositional environment; climate cycle as well as anatomy and preservational potential of the different organisms (Csiki *et al.*, 2010).

Prior to burial, the sauropod bones found in the floodplain likely undergone processes of pre-fossilization weathering as temperature changes, solar radiation, saturation and desiccation, all common in environments with episodic sedimentation (Bridge, 2003). The carcasses were sometimes subaerially exposed for long time periods, leading to the almost

complete removal of the soft tissue and weathering as well as dispersal and fragmentation of the bones. Biostratinomic processes were favored by the development of sub-arid episodes within the floodplain. These episodes are confirmed by the presence of eolian sandstones at the Cerro Colorado section -Río Neuquén Subgroup- (González Riga, 2002) laterally correlated to the study area. Behrensmeier (1978) described similar features in bones under arid or saline conditions.

Moreover, the periods of flooding with high sediment input into the floodplain were favourable to concentration and burial of partial carcasses and isolated bones, concentrating the fragmentary remains in fluvial channels. The presence of articulated remains can be explained by transport of the respective skeletal parts into the place of burial as partial carcasses or by rapid *in situ* burial in still soft sediments deposited on the floodplain. Well-drained floodplain fossil assemblages, especially the common incomplete and partial skeletons are characterized by a higher degree of articulation. On the other hand, parautochthonous burial of partial skeletons in, or very close to, the site of death might have also occurred in these distal floodplain settings, leading to the formation of taphocoenoses dominated by the associated remains of one single individual (Csiki *et al.*, 2010).

In the associated specimens, the taphonomic signatures are more constant suggesting a similar taphonomic history. The sauropod remains were preserved in the sandy mudstones in well-drained floodplains with different degree of paleosols development, from a lesser level of develop as seen in CG1 site, until higher levels as observed in CG2 and CG3 sites. Well-drained bearing floodplains fossils were sites of intense bioturbation and pedogenesis in which organic debris were readily oxidized (Bridge, 2006). This type of environment was optimal for the preservation of organic remains (*e.g.*, root traces, burrows and articulated/disarticulated bones) in the study area.

In contrast, the isolated saurischian bones preserved in the coarse-grained sandstones of the CG2 site, and transported through the fluvial channel-lag formed under extreme flow conditions, experienced complete disarticulation, weathering, fracturing, abrasion and sorting due to hydrodynamic processes. These bones are considered allochthonous because that they were transported together by high-energy currents, mixed and reworked. This type of occurrence showed that taphocoenoses was accumulated and

reworked during several years because multiple events confirming “time averaging” of remains (*sensu* Kidwell and Behrensmeyer, 1993). Frequently, advanced weathering and abrasion stages characterize bones preserved in coarse-grained deposits, while these modifications are usually less profound in floodplain deposits.

Furthermore, diagenetic processes, mineralization and compaction, which occurred in the burial environments (floodplain and fluvial channel) has been recognized in a previous study (Previtera, 2017). According to this study, after the burial, the main diagenetic processes that affected the dinosaur bones were compaction, plastic deformation, permineralization and substitution. The ionic substitution of the hydroxyapatite by francolite -in the bone microstructure- was confirmed, in the first moment through the XRD analysis (see Previtera, 2017), and also by the SEM-EDS method performed here. This is a typical mineral replacement of fossilized bone (Lucas and Prévôt, 1991; Kolodny *et al.*, 1996; Elorza *et al.*, 1999) and it is common in many other dinosaur sites (*e.g.*, Hubert *et al.*, 1996; Pereda-Suberbiola *et al.*, 2000; Paik *et al.*, 2001; Luque *et al.*, 2009; Rogers *et al.*, 2010; Piga *et al.*, 2011; among others).

Especially, the existence of “open fractures” in saurischian bones indicates post-fossilization weathering processes -subaerial exposure- flaking and fracturing occurred during exhumation events (telodiagenesis). These processes are the result of the differences in burial depth, temperature and geostatic pressure suffered by the fossils in each burial environment (Previtera, 2017). Similar fossil-diagenetic features have been identified in other cretaceous tetrapod assemblages of Patagonia (González Riga and Astini, 2007; González Riga *et al.*, 2009; Casal *et al.*, 2013; Previtera, 2011, 2013).

Changes in the preservation of fluvial transported fossils over time has been influenced not only by evolution of life on land but also by changes in climate and tectonic activity. Variations in these latter cause modifications also in the depositional environments and hence in the types of organisms present and their modes of preservation. Some important stages in the evolution of life on land relating to fossil preservation are given in previous investigations (*e.g.*, Behrensmeyer and Hook, 1992; Buatois *et al.*, 1998; Driese *et al.*, 2000; Shear and Selden, 2001).

In summary, the most of the dinosaur remains analyzed here come from facies of distal floodplains

of meandering fluvial systems, in contrast to the observed in other localities of Mendoza as Arroyo Seco (González Riga, 2003; González Riga and Astini, 2007), and northern Patagonia such as Rincón de los Sauces (Calvo and González Riga, 2003) in which the dinosaur remains come mostly from overbank facies of these systems.

8. Conclusions

The study of the CG1, CG2 and CG3 fossiliferous sites from the Plottier Formation allowed the recognition of different taphonomic modes within these deposits, from isolated bones to partially articulated skeletons of dinosaurs preserved in meandering fluvial systems. The distribution of the different taphonomic modes within sedimentary facies in Cerro Guillermo is uneven. Isolated bones commonly occurred in channel deposits, whereas associated partial skeletons were dominantly found in distal floodplain deposits (especially well-drained ones). Although the composition of these modes might seem unexpected in the light of previous studies, their genesis can be explained as result of taphonomic processes that operated within a fluvial environment under a semi-arid climate, seasonally variable, linked to periods of water deficit. This multidisciplinary survey represents an interesting local taphonomic pattern about saurischian dinosaurs preservation in different burial environments during the Upper Cretaceous.

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