Journal of South American Earth Sciences 23 (2007) 290–303

Journal of
South American
Earth Sciences

www.elsevier.com/locate/jsames

Preservation of large titanosaur sauropods in overbank fluvial facies: A case study in the Cretaceous of Argentina

Bernardo J. González Riga [a,*], Ricardo A. Astini [b]

[a] Laboratorio de Paleovertebrados, Sección Dinosaurios y Paleoambientes, Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA, CRICYT, CONICET), Avda. Ruiz Leal s/n, Parque Gral. San Martín (5500) Mendoza, Argentina
[b] Cátedra de Estratigrafía y Geología Histórica, Universidad Nacional de Córdoba, Av. V. Sarsfield 1611 (X5016GCA) Córdoba, Argentina

Received 1 May 2005; accepted 1 September 2006

Abstract

Patagonia exhibits a particularly abundant record of Cretaceous dinosaurs with worldwide relevance. Although paleontological studies are relatively numerous, few include taphonomic information about these faunas. This contribution provides the first detailed sedimentological and taphonomical analyses of a dinosaur bone quarry from northern Neuquén Basin. At Arroyo Seco (Mendoza Province, Argentina), a large parautochthonous/autochthonous accumulation of articulated and disarticulated bones that represent several sauropod individuals has been discovered. The fossil remains, assigned to *Mendozasaurus neguyelap* González Riga, correspond to a large (18–27-m long) sauropod titanosaur collected in the strata of the Río Neuquén Subgroup (late Turoronian–late Coniacian). A taphonomic viewpoint recognizes a two-fold division into biostratinomic and fossil-diagenetic processes. Biostratinomic processes include (1) subaerial biodegradation of sauropod carcasses on well-drained floodplains, (2) partial or total skeletal disarticulation, (3) reorientation of bones by sporadic overbank flows, and (4) subaerial weathering. Fossil-diagenetic processes include (1) plastic deformation of bones, (2) initial permineralization with hematite, (3) fracturing and brittle deformation due to lithostatic pressure; (4) secondary permineralization with calcite in vascular canals and fractures, and (5) postfossilization bone weathering. This type of bone concentration, also present in Rincón de los Sauces (northern Patagonia), suggests that overbank facies tended to accumulate large titanosaur bones. This taphonomic mode, referred to as ‘‘overbank bone assemblages’’, outlines the potential of crevasse splay facies as important sources of paleontological data in Cretaceous meandering fluvial systems.

Keywords: Fluvial systems; Taphonomy; Titanosauria; Cretaceous; Argentina

1. Introduction

Both taphonomy and sedimentology are necessary for reconstructing paleoenvironments and original ecological relationships among fossil organisms. In this context, the expansion of taphonomy beyond its traditional role as the study of information loss and palaeoecologic bias into broader problems in palaeobiology has provided a wealth of new possibilities for research and interdisciplinary exchange (Behrensmeyer and Kidwell, 1985).

Cretaceous dinosaurs are particularly abundant and diverse in South America, and most are known from the Neuquén Basin, located near the northwest border of Patagonia, Argentina. This record includes *Argentinosaurus huinculensis*, one of the largest sauropods known (Bonaparte and Coria, 1993); *Amargasaurus cazuai*, a peculiar sauropod with large spines (Salgado and Bonaparte, 1991); and the huge theropod *Giganotosaurus carolinii* (Coria and Salgado, 1995), among others.

In contrast with taxonomic studies (e.g., Salgado and Bonaparte, 1991; Calvo and Bonaparte, 1991; Bonaparte and Coria, 1993; Coria and Salgado, 1995; Calvo and Salgado, 1995; Bonaparte, 1996; Novas, 1998; González Riga, 1999, 2003, 2005; González Riga and Casadío, 2000;

* Corresponding author.
E-mail addresses: bgonriga@lab.cricyt.edu.ar, bgonriga@yahoo.com.ar (B.J. González Riga), raastini@com.uncor.edu (R.A. Astini).

0895-9811/$ - see front matter
doi:10.1016/j.jsames.2007.02.005

Wilson et al., 1999; Coria and Calvo, 2002; Calvo and González Riga, 2003), sedimentological and taphonomical analyses of Cretaceous dinosaur quarries in the Neuquén Basin are relatively scarce. For example, the first sauropod nest sites were recently described (Garrido et al., 2001; Chiappe et al., 2004), and a few bone assemblages have and continue to be studied (Calvo and González Riga, 1999; González Riga, 2002a; González Riga et al., 2004). This situation reduces the possibilities of accurate comparisons of quarries in the Neuquén Basin with other well-known sites from North America and elsewhere.

At Arroyo Seco (Malargue department, Mendoza Province), a new genus and species of large titanosaur sauropod named *Mendozasaurus neguyelap* recently was collected and described by González Riga (2002a, 2003, 2005). This paper presents a detailed palaeoenvironmental and taphonomic study of *Mendozasaurus*'s site from the Neuquén Basin to provide a better understanding of the fossil preservation of large sauropods on overbank fluvial facies. Although overbank deposits have high potential for preservation of vertebrate remains (e.g., Smith, 1993; Behrensmeyer et al., 1995; Cook, 1995; Willis and Behrensmeyer, 1995; White et al., 1998), relatively few examples have been documented in the Cretaceous of South America. In this context, the present work enlarges, through a large sauropod quarry, knowledge on environmental controls in overbank sedimentary successions that bear huge vertebrates.

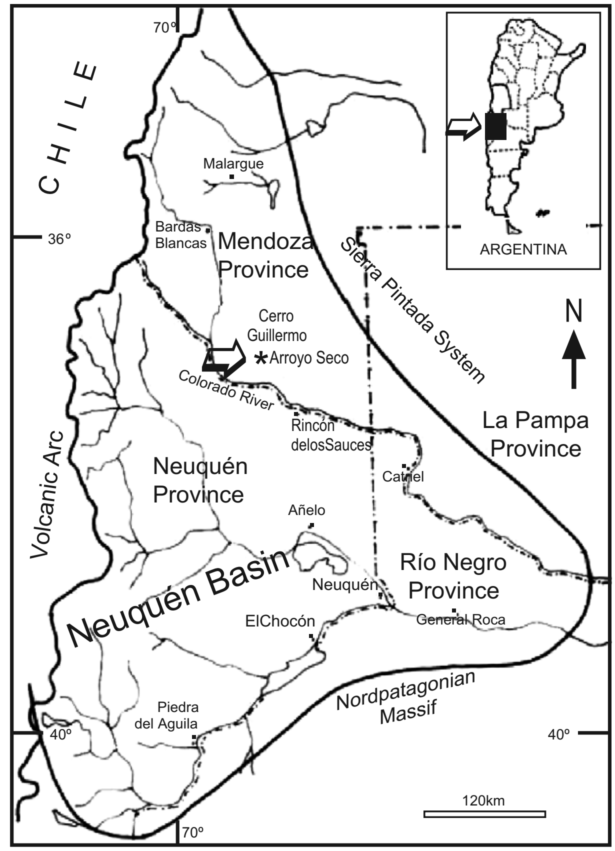

Fig. 1. Location map of the Neuquén Basin showing the Arroyo Seco site in the Cerro Guillermo area, Mendoza Province, Argentina.

2. Methodology

Conventional stratigraphic sections were measured and detailed logs taken after field-based facies analysis. Lateral mapping and photographs indicate the lateral continuity of beds and sedimentary architecture. Sandstones provide samples for petrographical analysis, and a systematic paleocurrent analysis was undertaken. Taphonomical methods include quarry maps generated using a meter grid system and photographs. Orientation measures of elongate skeletal elements employ a Brunton compass. The strike and dip of long axes of appendicular bones (e.g., femora, tibiae, humeri, metacarpals) and anteroposterior axis of articulated vertebrae were plotted in stereoplots. Bone features; evidence of preburial weathering, diagenetic deformation, and exhumation weathering; mineral composition; and bone microstructure were analyzed through thin-sections.

3. Geological setting

The Neuquén Basin, located in northwestern Patagonia (Fig. 1), extends between the active magmatic arc along the Andes to the west and the Sierra Pintada system and North Patagonian Massif to the northeast and southeast, respectively, (Vergani et al., 1995). Distinct sedimentary, tectonic, and faunistic breaks occur within the thick Mesozoic succession of the basin as a result of major paleogeographic shifts (Riccardi, 1988; Legarreta and Gulisano, 1989; Bonaparte, 1996; Novas, 1997). 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 (Fig. 2) is the richest dinosaur-bearing unit of the basin. It comprises a thick continental succession (maximum thickness 1300 m) deposited between the early Cenomanian (97 ± 3 Ma) to the early Campanian (74 ± 3 Ma) (Leanza and Hugo, 1997). Theropods (Coria and Salgado, 1995; Novas, 1998), ornithopods (Coria and Calvo, 2002), and sauropods (Powell, 1986; Calvo and Bonaparte, 1991; Salgado and Bonaparte, 1991; Bonaparte and Coria, 1993; Calvo and Salgado, 1995; Chiappe et al., 1998, 2001; Bonaparte, 1999; González Riga and Calvo, 1999; González Riga, 2002b, 2003) are among the most common fossils. Conglomerates, sandstones, and claystones of the Neuquén Group represent alluvial fans, fluvial systems, and playa-lake environments stacked in recurrent fining-upward sequences (Leanza and Hugo, 2001).

Initially, the Neuquén Group was divided from base to top into the Río Limay, Río Neuquén, and Río Colorado formations (Cazau and Uliana, 1973). Subsequently, these subdivisions were considered subgroups (Ramos, 1981; Leanza and Hugo, 2001). Lateral correlations among the subgroups and formations is problematic because of lateral facies changes related to the fluvial system dynamics (González Riga, 2002a).

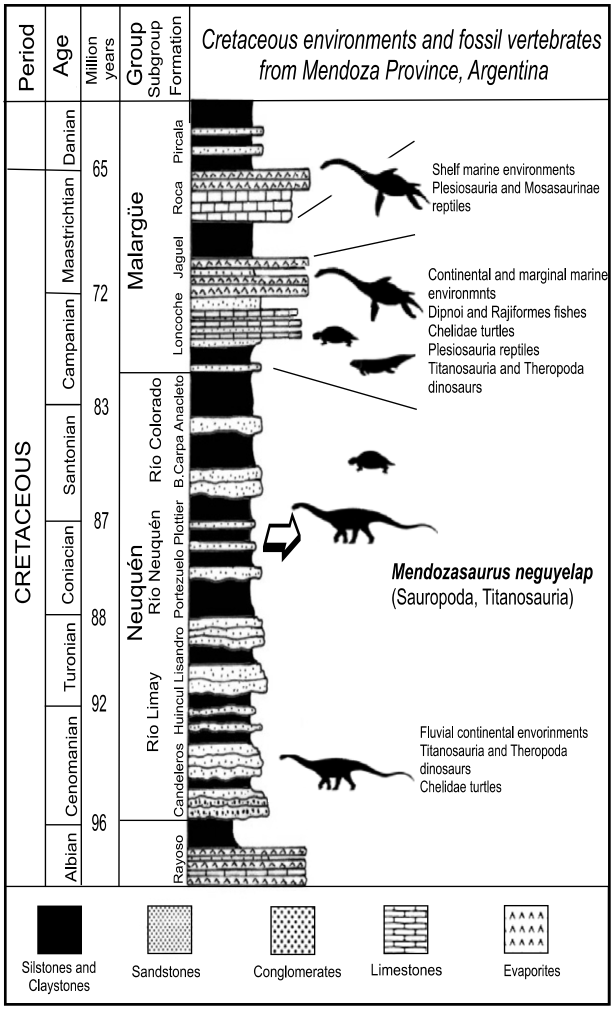

Fig. 2. Schematic stratigraphic column of the Upper Cretaceous in southern Mendoza Province, Argentina (González Riga, 2002b).

In the Cerro Guillermo and Río Colorado areas (south of Mendoza Province), the most ancient outcropping strata of the Neuquén Group are those of the Huincul Formation. The basal levels of the Candeleros Formation do not crop out in the region. From El Pichanal to Cerro de la Teta, a silty–shaly unit (Fig. 3), known as the Lisandro Formation (within the Río Limay subgroup), is covered by sandstones and shales of the Río Neuquén and Río Colorado subgroups (González Riga, 2002a).

Fig. 3. Fluvial deposits of the Neuquén Group outcropping in Cañada del Pichanal, Río Colorado area, southern Mendoza Province.

The Loncoche Formation (late Campanian–early Maastrichtian), the lower unit of the Malargüe Group (Fig. 2), unconformably overlies the Neuquén Group (Legarreta et al., 1989). The Loncoche Formation consists of fluvial, lacustrine, and marginal marine facies (tidal flats, deltas, and sabkhas; Parras et al., 1996; González Riga, 1999) related to a marine incursion from the east that influenced central-northern Patagonia near the end of the Cretaceous (Casadío, 1994).

4. Facies associations and paleoenvironments

Redbeds assigned to the Río Neuquén subgroup (late Turonian–late Coniacian) and the base of the Río Colorado subgroup (Santonian) crop out south of Cerro Guillermo. Continuous outcrops that span several kilometers allowed for detailed analyses of channel morphologies, bounding surfaces, and facies distributions (González Riga, 2002a). Fluvial depositional systems are predominant, as in other parts of the basin (e.g., Cazau and Uliana, 1973; Legarreta and Gulisano, 1989; Cruz, 1993). Two distinct, alternating facies associations (Fig. 3) are recognized within the largely fining- and thinning-upward succession (Fig. 4), which represent floodplain environments and dominantly sandy fluvial channel complexes.

4.1. Floodplain facies association

This association includes deep red to purplish massive and mottled mudstones and siltstones (Fm) and, more rarely, laminated greenish grayish claystones (Fl) interbedded with thin-bedded tabular sandstones (Sm, Sh, Sr).

Within the massive mudstone intervals, intense disruptions of original sedimentary structures and fabrics occur by tubular burrowing (possible pedotubules), infiltrated clay partings, and local abundances of millimeter–centimeter-scale, largely irregular, massive, clay-rich glaebules and calcareous rhizoliths. Less frequent intervals of as much as 0.5 m show laminated fines that locally contain abundant, drifted, organic debris and sinuous, horizontal, meniscated traces, such as *Scoyenia* and *Taenidium*. Horizons with intense color mottling and diffuse boundaries are also present.

Within the dominantly fine-grained sedimentation, tabular, thin-bedded, slightly graded medium- to fine-grained sandstones with various sedimentary structures are present. They may be either grouped into meter-scale cycles or isolated within mottled-laminated fines. From bottom to top, individual sandstone beds range 0.03–0.3 m and show a lower massive (Sm) to laminated interval (Sh) and rippled tops with various sets of cross-lamination (Sr), seldom bioturbated. When overlying shales or silty shales, these sandstones commonly develop a sharp erosive base and incorporate mud chips within the lower interval. These

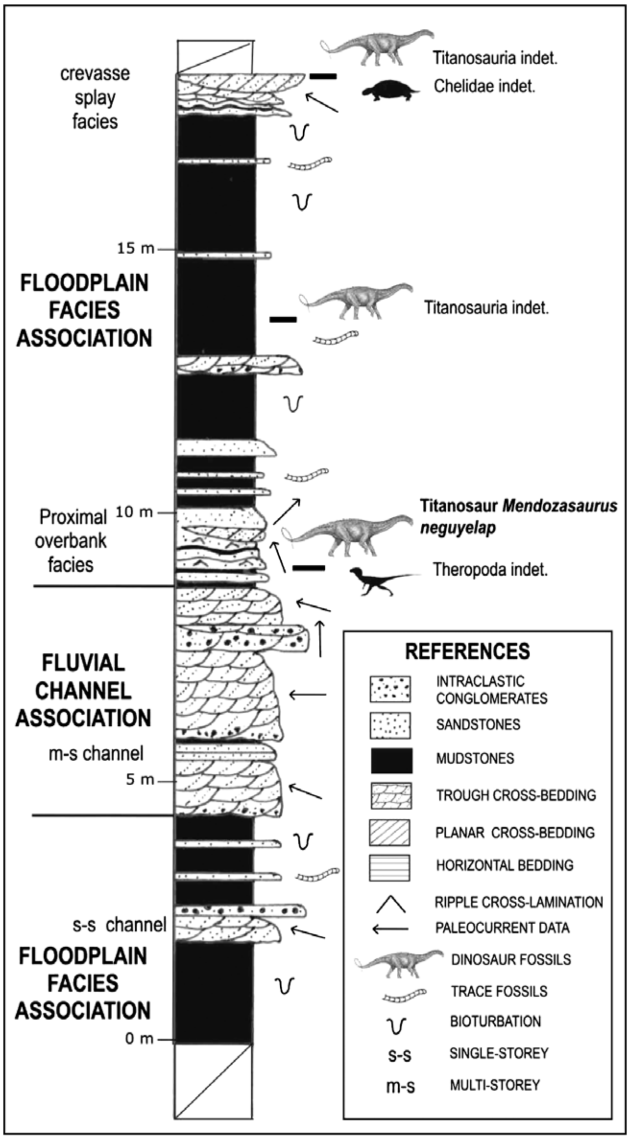

Fig. 4. Stratigraphic column at Arroyo Seco (Mendoza, Argentina) showing fossiliferous levels and different facies associations.

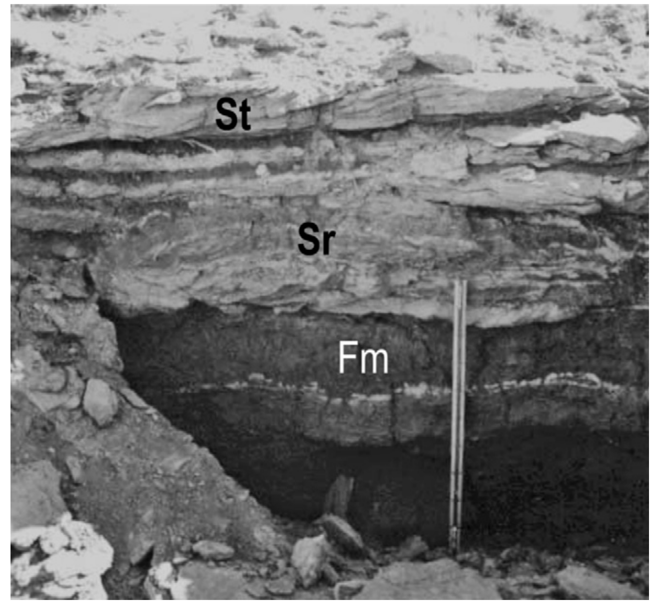

Fig. 5. Overbank facies association from the Arroyo Seco section overlaying massive silty shales (Fm) of the floodplain deposits. Sr: ripple lamination; St: trough cross-bedding. Scale: 1 m.

centimeter- to decimeter-scale sandstones are locally arranged into meter-scale, thickening, and slightly coarsening-upward cycles (Fig. 5). Beds at the top commonly show lenticular geometries and slightly coarser sandstones with medium-scale trough cross-bedding (St) and planar cross-bedding (Sp), as well as lags of gravel-sized mud chips. Low-angle inclined bedding within these beds at the top of cycles is recorded in cross-sections. Under the microscope, the sandstones show relatively good sorting, a laminar fabric of mica flakes and subtle orientation of the coarser grains. Locally, high percentages of clay matrices and disturbances of lamination are observed, particularly in isolated beds.

Cross-bedded sandstone sets (Sp) ranging from 0.1 to 1 m thick are recorded only in the section at Cerro Colorado. Cross-beds are at a high-angle with respect to the horizontal (~35°) and locally show low-angle reactivation surfaces. Near the bottom of the sets, few wedges are recorded within the otherwise smooth terminations. Unfortunately, lateral continuity is limited by poor quality outcrops. Petrographically, they are subfeldespathic arenites and show a remarkable sorting and moderately rounded sand grains compared with any of the other thin-bedded sandstones.

These facies associations record a distinct trace fossil assemblage, together with silicified wood fragments and abundant vertebrate and invertebrate remains. Within the vertebrates, huge herbivorous titanosaurs are recorded in bone accumulations, which are thoroughly analyzed in the taphonomy section. At the Arroyo Seco site, *M. neguyelap*'s holotype and other titanosaur specimens have been recorded (Fig. 3). The fossil-rich level is composed of greenish (10YR 7/2), mica-rich, feldespathic wackes interbedded with mottled red (2.5 YR 4/4) and gray (Fig. 6) shales. Rare bivalves (*Diplodon* sp.) are particularly well preserved in the gray laminated intervals.

4.1.1. Interpretation

The floodplain facies association is comparable to Miall's (1985, 1996) FF architectural element and interpreted as a product of accumulation (vertical-accretion deposits) of fines in variously drained, low-gradient floodplains. Overall, thin-bedded tabular sandstones are interpreted as crevasse splay deposits caused by episodes of deposition when waning floods overtop the river banks. Fall-out of suspended fines after flooding provides most of the silts and clays to the system, with some possible addition from wind-blown dust.

The dominantly massive and mottled structure of mudstones is the result of early diagenetic modification and

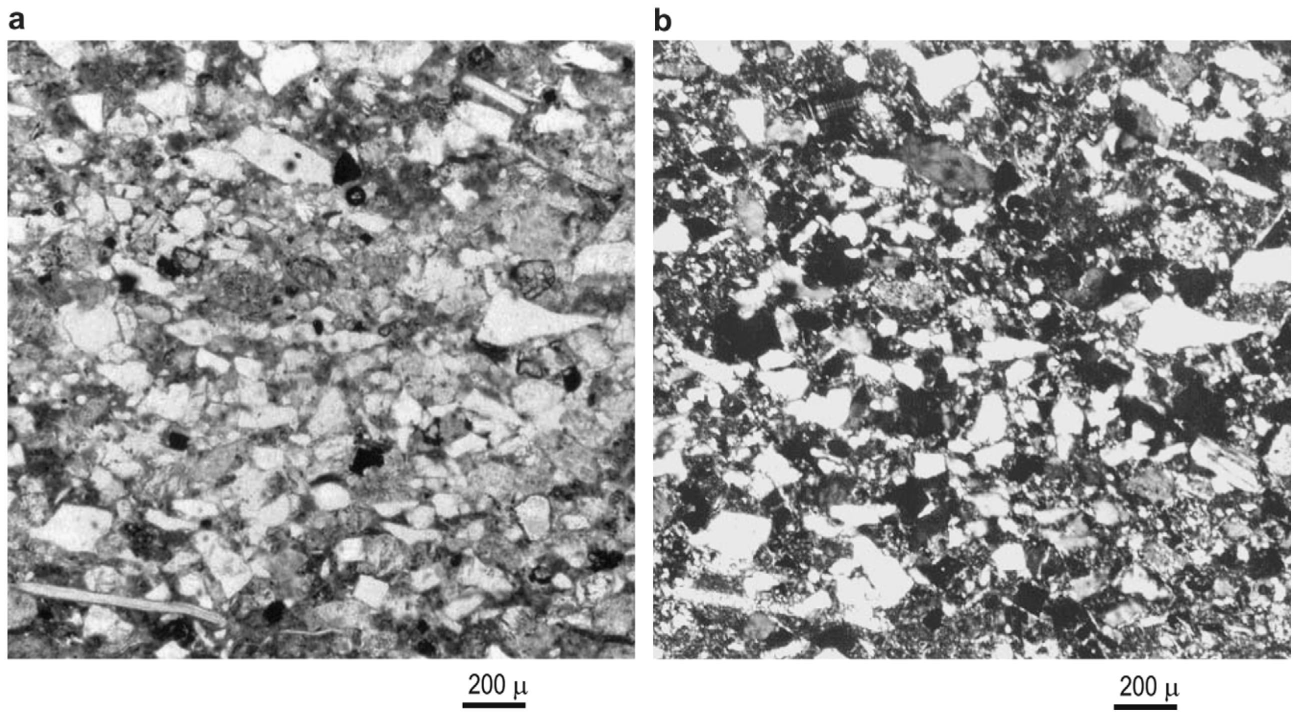

Fig. 6. Sandstone of overbank facies in thin section. Mica-rich feldespathic wackes from the fossiliferous level with *Mendozasaurus neguyelap* (Arroyo Seco site) in (a) plane-polarized light and (b) cross-polarized light. Note the high matrix content, interpreted as a product of early diagenetic infiltrated fines. Scale bar: 200 μm.

soil-forming processes. Physical and biological modification in floodplain deposits commonly result after periods of subaerial exposure. Exposure renders near-surface sediments susceptible to soil-forming processes (Retallack, 1986; Kraus, 1987), which eliminate primary structures. Although true paleosols are not evident, disruptions of original sedimentary structures and fabrics by burrowing organisms, infiltrated textures (a product of illuviation), and local abundances of glaebules and rhizoliths suggest partial soil development. Precise definitions require additional micromorphological and geochemistry studies, but immature soils characterized by root disturbance and animal bioturbation commonly form on temporally exposed surfaces of active aggrading areas (e.g., Collinson, 1996; Bestland, 1997), reflecting some degree of stratigraphic condensation.

Fragments of silicified wood and remains of huge herbivorous vertebrates (titanosaurs) suggest important biological activity in stable and relatively well-drained substrates. Poorly laminated fines bearing abundant drifted organic debris indicates extensive vegetation on the alluvial plains. Local development of trace fossils like *Scoyenia* and *Taenidium* imply periodic flooding and wet muddy substrates (Frey et al., 1984; Buatois and Mangano, 1995, 1996). Local mottling derived from chemical alteration and formation of clay minerals suggest flat topography and poor drainage conditions, especially where a fluctuating water table develops heterogeneous redox conditions that lead to patchy reduction and color-mottled textures. Moreover, bivalves (*Diplodon* sp.) indicate that local swamps and small lakes were important features in the floodplain landscape (González Riga, 2002a).

Sharp-based, tabular, slightly graded, thin-bedded sandstones with silty shale partings and mud drapes clustered into meter-scale thickening- and coarsening-upward cycles record crevasse-splay successions (e.g., O'Brien and Wells, 1986). Increasing amalgamation and more lenticular geometries toward the top, as well as slightly coarser sandstones with abundant mudchips and medium-scale cross-bedding is compatible with progradation and minor channeling at the top. Abundant mudchips at the base are interpreted as scattered, rip-up clasts contained in the stream flow lags. Thickening-upward stacking is a product of projection of the sandy–silty lobes onto the floodplain or eventually standing water ephemeral lakes (e.g., Miall, 1996). The local development of low-angle, inclined bedding records some degree of sinuosity in the crevasse channels that develop lateral accretion surfaces. In contrast, isolated, silty, sandy beds record overbank event-beds that represent discrete waning stage lobes of silty and sandy sediment deposited after floods. These beds are much more common close to the main fluvial channels in mixed-load rivers and constitute important volume in the proximal overbank deposits (levees) within the floodplain.

Regular sorting, laminar fabric of the mica flakes, and the subtle orientation of the coarser grains in thin-sections indicate active hydrodynamic processes during deposition. However, the relative abundance of matrices in some individual beds seems incompatible with tractive processes that primarily deposited arkosic arenites (cf. Pettijohn et al., 1987). This apparent contradiction can be explained by illuviation processes after translocation of clays, accompanying downward pore-water movement through developing soil (cf. Retallack, 2001). Infiltration of clay minerals into the primary pore space of the sandstone may have been promoted by biological activity, which is increasingly more important away from the alluvial ridges or levee complex in the floodplains.

The larger cross-bedded sandstones at Cerro Colorado are interpreted as isolated eolian sand dunes, which in turn may indicate that short-term, relatively arid conditions developed within the floodplains (González Riga, 2002a). Better sorting and rounding of individual components and greater quartz richness than overbank sandstones imply such an origin. Frequent wedge terminations at the bottom of cross-bedded sets within asymptotic terminations may indicate alternating, eolian grain-flow and grain-fall processes. Thin-bedded evaporite beds and nodular gypsum are increasingly more important toward the upper section of the Neuquén Group, which could be related to hypersaline shallow lakes and saline playa-lake systems developed in a more arid environment.

4.2. Fluvial channel association

A variety of distinct, large-scale bodies (meters to tens of meters) of coarser sandstones ranging between lens and sheet-like geometries punctuate the predominantly fine-grained succession at a broader scale. Such packages seen to conform to higher hierarchy elements limited by stratigraphically significant surfaces (third order, after Allen, 1983). These sandstone bodies frequently show internal amalgamation and yield lateral continuity on the order of kilometers. Sharp irregular bases with local concave scour and fill structures (up to 1 m) are present at the base, and large, trough cross-bedding is dominant. Pebble-size mudchip lags are common within the clean, coarse- to medium-grained sandstones. Progressively thinner trough and planar cross-bedded sets (mesoscale St and Sp) are recorded near the top of individual sandstone bodies, which terminate at the top with fining-upward arrangements. In contrast, amalgamated suites within sheet-like bodies include abundant meter-scale wavy sharp surfaces, marked scour and fill features, and frequent intraclastic conglomerate lags. Cross-bedded sets are truncated and range 0.2–0.8 m.

In Arroyo Seco, approximately 8.6 m below the fossiliferous level with *Mendozasaurus*, the measured sandstone body is 38 m wide and 1.7 m thick. Gently inclined surfaces are poorly exposed in this outcrop but have been observed elsewhere in CH sand bodies of the Río Neuquén subgroup.

4.2.1. Interpretation

The variety of large-scale isolated or amalgamated sandstone packages, which at broader scale punctuate the floodplain fines, are interpreted as main fluvial channels or channel belt complexes (CH elements according to Miall, 1985, 1996). Variable external geometries between lens and sheet-like bodies and internal arrangements, particularly the degree of amalgamation and truncation, discriminate multi- and single-story end members. Two distinct channel sets punctuate the predominantly fine-grained succession of the Río Neuquén subgroup. The complex internal mosaic of truncations and amalgamation patterns in the multi-story, multilateral sandstones indicate stratigraphic condensation typical of nested channel associations (cf. Martinsen et al., 1999). These sandstones are considered amalgamated, erosional remnants of originally thicker channel sandstones. The sandstone bodies usually are limited by stratigraphically significant surfaces (Shanley and McCave, 1991). Multi-story or complex fills are mostly interpreted as mobile, broad, shallow channels that generate largely sheet-like geometries, following Friend et al. (1979) and Bridge (1993), common patterns derived from braided streams deposits. However, the absence of true conglomerates and granule-size extraclasts indicate that bottom loads were predominantly sandy. Internal truncation and frequent scour and fill features indicate repeated erosional periods that eliminated the sedimentary record and contributed to amalgamation. Internal intraclastic conglomerates are consistent with this interpretation.

In contrast, single-story bodies show a better developed, fining-upward trend that indicates greater stratigraphic completeness related to available accommodation. Internal mesoscale cross-stratification indicates bedload transport and various types of bed configurations, representing two- and three-dimensional dunes developed on sandy point bars and braid bars at variable flow stages (Allen, 1982; Bridge, 2003). 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. Width/depth ratios of single-story sandstone bodies, similar to the Arroyo Seco section and several meters below the fossiliferous site with *Mendozasaurus*, suggest relatively mobile channels (cf. Miall, 1985) that migrated and suddenly switched or avulsioned within the floodplain.

4.3. Palaeoenvironmental setting

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. However, drainage from the east-southeast to west-northwest and sandstone composition (Legarreta and Gulisano, 1989; Vergani et al., 1995; González Riga, 2002a) indicate that sources were localized toward a cyclically active forebulge, where basement rocks with an important Triassic volcanosedimentary 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 meandering channels, indicates variations in the accommodation/sediment supply rates. 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).

5. Taphonomy

5.1. Taxonomic composition and skeletal representation

Approximately 200 bones and bone fragments that represent three sauropod individuals were recovered from Arroyo Seco. Most remains were recently assigned to a new titanosaur *M. neguyelap* (González Riga, 2003, 2005). This taxon is represented by 22 articulated caudal vertebrae and numerous disarticulated bones that include cervical and dorsal vertebrae, appendicular elements, and large osteoderms corresponding to 2 relatively large adult specimens (~18-m long) (Fig. 7). Disarticulated bones of a large specimen (~27-m long) of the same taxon were also identified (González Riga, 2005). In the same locality, some fragmentary and indeterminate titanosaur specimens (González Riga, 2002a) and a small theropod (Maniraptora indet.) were recovered.

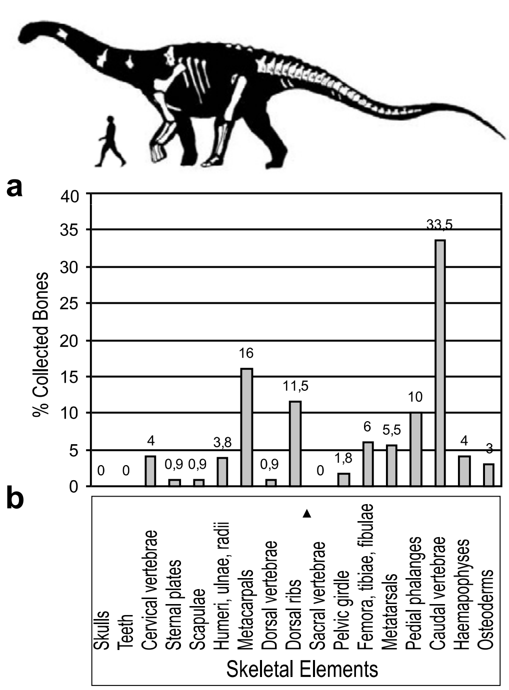

Fig. 7. Frequency of skeletal parts. (a) Skeletal reconstruction of sauropod *Mendozasaurus neguyelap* showing preserved bones (two most complete specimens). (b) Relative abundance of skeletal elements collected from Arroyo Seco ($N = 131$ bones).

Although taphonomy predicts that large animals may be overrepresented in the fossil record, the preservation probability for a complete specimen declines. The largest dinosaurs commonly preserved in the fossil record are about 10-m in length. For this reason, complete large sauropod skeletons are exceedingly rare (Dodson, 1990). At Arroyo Seco, the most abundant remains are caudal vertebrae, dorsal ribs, and large appendicular bones (Fig. 7). Small, brittle, light elements of the titanosaur skeleton (teeth and cranial remains) have not been recovered, perhaps due to differential hydraulic transport and sorting. In contrast, at Loma del Lindero quarry (Neuquén Province), an association of disarticulated sauropod and theropod dinosaurs has yielded, in addition to vertebrae and appendicular bones, cranial fragments and numerous teeth. These fossil remains come from overbank deposits located above channel facies (Calvo and González Riga, 1999, 2005; González Riga et al., 2003).

5.2. Skeletal articulation and spatial patterns

At Arroyo Seco, three types of bone relationships are present: (1) articulated, (2) disarticulated but associated (sensu Behrensmeyer, 1991), and (3) disarticulated. The caudal series of the *Mendozasaurus*-type specimen is preserved in an articulated state (right side of Fig. 8), whereas appendicular bones (humeri, metacarpals, femora, tibiae, fibulae) are disarticulated but associated. In this fossil accumulation, the bones are closely juxtaposed and partly overlapped. After removing interstitial sediments, the bone spatial disposition was developed through mapping (Fig. 9) and plotting orientations into rose diagrams and stereographic projections.

The orientation of elongate bones (humeri, metacarparls, femora, tibiae, fibulae, metatarsals) shows the presence of preferred directions (Fig. 8). The west sector of the quarry (left side of Fig. 8), located 1.8–0.7 m under surface level, shows a dominant northeast–southwest (25°–205°) orientation pattern and two perpendicular secondary components. In the north and south sectors of the quarry (right side of Fig. 8), 1.5–0.2 m under surface level, the bones display a northwest–southeast main orientation with a perpendicular secondary component. Also in the north and south sectors, an accumulation of small bones (metatarsals, metacarpals) appears on the northwest sides of larger bones (1–2-m long) as femora, humeri, and sternal plates.

In a stereographic projection (Fig. 8), the articulated sections of caudal and cervical vertebrae show a north or northwest orientation. In contrast, large and elongated bones (femora, tibiae) dip 20°–40° to the south-southwest with respect to bedding and clearly plot as imbricate bones. Moreover, most bones are oriented with their largest end toward the same dip direction. Small elongate bones (metatarsals, metacarpals) are perpendicularly orientated with respect to large bones, and the ribs show diverse orientations.

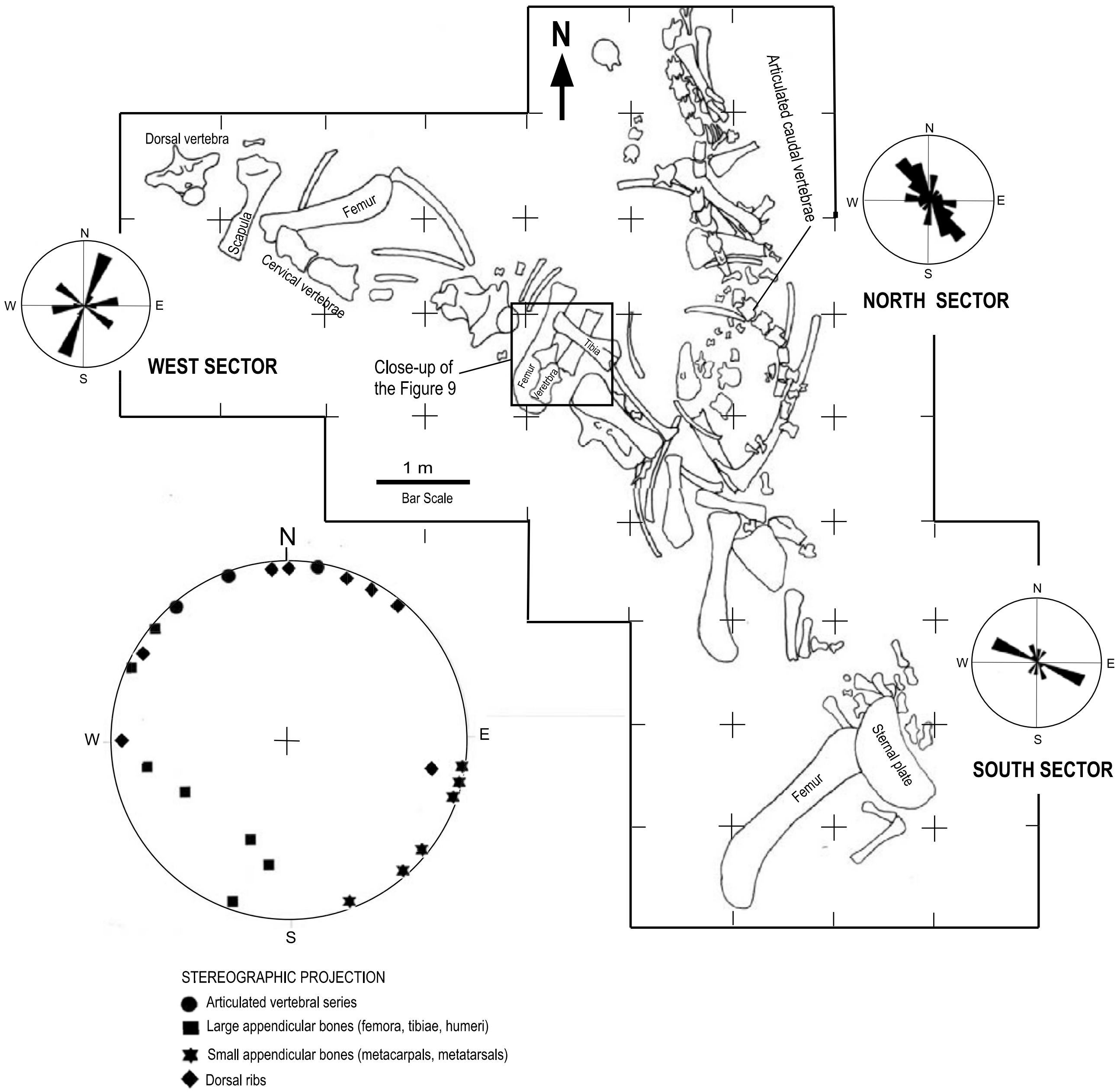

Fig. 8. Quarry map of Arroyo Seco at Cerro Guillermo (Mendoza, Argentina) showing studied fossil accumulation of *Mendozasaurus neguyelap* (González Riga, 2002a). Rose diagrams show orientations of the long axes of elongated bones in west, north, and south sectors of the excavation. Sterographic projection ($N = 31$) includes articulated vertebrae, large appendicular bones (femora, tibiae, humeri), small appendicular bones (metacarpals, metatarsals), and dorsal ribs.

The presence of one strongly preferred direction and a secondary direction normal to it indicates water currents (Voorhies, 1969; Kreutzer, 1988). The orientation and imbrication of the long axis dip of the largest ends of elongated bones (femora, tibiae) directed to the southwest, as well as the accumulation of small bones on the northeast sides of the large bones, suggest several interpretations. First, large bones may act as hydraulic barriers, accumulating smaller bones on their downstream sides. As a consequence of local turbulence, small bones show a secondary orientation and generate their own local orientation pattern normal to the main flow direction. In this context, the major overbank currents flowed north, and slight variations to the northeast and northwest are responsible for the measures (30° fanning, Fig. 8, lower right corner) when plotting the long axis of major femora. Second, the largest bones (femora 1.5–2-m long) located in the base of the accumulation likely were orientated parallel to the flow lines in strong currents. In the more shallow levels of the quarry, smaller bones orientated their long axis in oblique or transversal directions with respect to the main current as a result of rolling effects. This slight change in flow

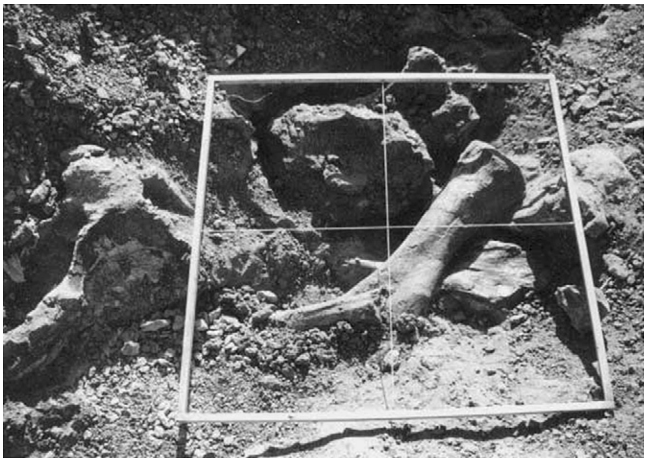

Fig. 9. Close-up of Arroyo Seco from Fig. 8. Note m2 working grid over a tibia and cervical vertebra of *Mendozasaurus neguyelap*.

direction may be related to shallow-water waning stream flows. Several authors (e.g., Voorhies, 1969; Behrensmeyer, 1990) describe that in strong currents, elongate bones orientate their long axis parallel to the flow direction with their heavier ends upstream (anchor effect), whereas in shallow water or weak currents, elongated bones orient perpendicular to the current. Third, the main orientation of water current to the north-northeast is consistent with the flow direction indicated by planar cross-stratification of a crevasse channel located immediately above the fossil level (Fig. 4). However, the flow direction of the overbank currents and the main channel are variable in meandering fluvial systems. Therefore, the orientations described in this quarry might be of local value only.

5.3. Preburial weathering

Most fossil bones (∼92% of the sample) exhibit features commonly assigned to prefossilization weathering. Both vertebrae and appendicular bones show a low grade of preburial cracking and flaking (stages 1, 2 of Behrensmeyer, 1978). Elongate bones exhibit longitudinal cracking parallel to bone fibers, mosaic cracking, and flaking of outer surfaces (Fig. 10a); a few metacarpals exhibit extensive exfoliation (Fig. 10b).Thus, the inner cancellous bone of the epiphyses is exposed (stage 3 of Behrensmeyer, 1978). Some large ribs and metacarpals are differentially weathered. Their upper surface shows longitudinal cracking, whereas the opposite surface is smooth with little indication of preburial cracking or exfoliation. Similar differential weathering was described in dinosaur elements collected in the Two Medicine Formation of Montana (Rogers, 1990) and Cenozoic mammal bones from Nebraska (Fiorillo, 1988).

5.4. Diagenetic deformation and alteration

A particularly notable feature of this assemblage is the intense brittle and plastic deformation of bones due to

Fig. 10. Bone weathering. (a) Metacarpal IV? (col. IANIGLA-PV 071/1) of *Mendozasaurus neguyelap* showing longitudinal cracking parallel to bone fibers, mosaic cracking, and flanking (stage 2 sensu Behrensmeyer, 1978). (b) Proximal end of titanosaur metacarpal (col. IANIGLA-PV 100) showing longitudinal cracking and extensive exfoliation (stage 3 sensu Behrensmeyer, 1978). In both cases, transverse and spiral or oblique non-cemented fractures are presented. Scale bar: 5 cm.

lithostatic compression. Some vertebral centra (Fig. 11) are strongly compressed in comparison with robust appendicular bones, which indicates that the caudal vertebrae of titanosaurs, composed of a spongy structure called somphospondylous (Wedel et al., 2000), had low structural density. Therefore, they can exhibit lateral or dorsoventral intense plastic deformation. However, bone fracture (brittle deformation) occurred after the loss of collagen fibers, because these structural proteins confer toughness, resiliency, and elasticity to bones (Lyman, 1996).

5.5. Exhumation weathering

Various large bones indicate postfossilization weathering. Both femora and sternal plates recovered on the soil surface are splintered and very fragile and exhibit cracking and non-cemented fractures (Fig. 12). They have been exposed to extensive temperature changes, saturation and desiccation, root actions, and torrential rains, which are characteristic of the present dry continental climate in the region. In contrast, bones collected 2–3 m under the topographic surface are better preserved; thus, bone weathering increases toward the present soil surface.

5.6. Mineral composition

Analysis of thin-sections shows well-preserved bone microstructure. Bone tissue is composed of collophane

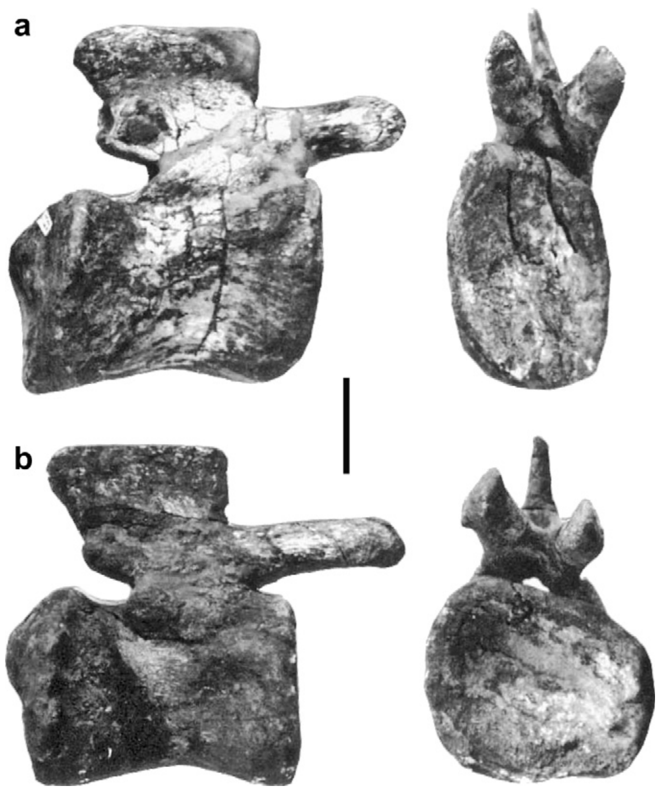

Fig. 11. Plastic deformation of vertebrae. (a,b) Middle-posterior caudal vertebrae of *Mendozasaurus neguyelap* (col. IANIGLA-PV 065/15-16) in lateral (left) and anterior (right) views. Observe lateral compression of the centrum in (a) the 18th caudal in comparison with (b) the 19th caudal. Scale bar: 5 cm.

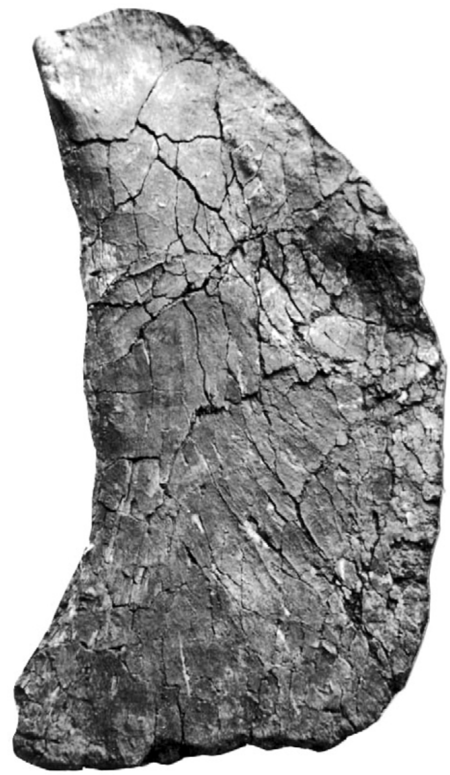

Fig. 12. Bone weathering. Left sternal plate of *Mendozasaurus neguyelap* (col. IANIGLA-PV 067) showing cracking and multiple non-cemented fractures. Scale bar: 10 cm.

(fluorapatite), as has been described in other bones of Cretaceous dinosaurs (Paik et al., 2001). The fluorapatite is isotropic, is colorless in plane-polarized light, and has weak birefringence in bone tissue fibrous structure in cross-polarized light. Transverse sections from the femur of *Mendozasaurus* show two well-defined microstructures (Fig. 13). The external cortex is mainly formed by fibrolamellar bone tissue (laminar or plexiform subtypes), in which primary osteons are embedded in a woven bone matrix (Fig. 13, right side). Toward the inner cortex, secondary osteons dominate, formed by a process termed Haversian reconstruction that involves the removal of bone around a primary vascular canal, followed by subsequent redeposition of bone in the erosion cavity (Chinsamy, 1997). Secondary osteons are recognized from the occurrence of a cement line (CL in Fig. 13). Similar microstructures have been described in other titanosaurs (Salgado, 2000) and sauropods (Curry, 1999). In the histological structure, the main diagenetic process that affected the bones was permineralization (i.e., infiltration of mineral-bearing solutions into pores in skeletal tissue during diagenesis). The original apatite framework (formed by Haversian and Volkmann canals) was filled by hematite and calcite (Fig. 13 and 14). In some bones, lithostatic pressure and consequent deformation of bone tissue cause complex systems of fractures that cut the vascular canals and modify the original structure. In this case (Fig. 14), cross-cutting relationships indicate that the brittle deformation was produced after the first-stage hematite cementation and before late-stage calcareous cementation. Calcite shows a radial growth pattern and iron enrichment (possibly corresponding to ferroan calcite) that indicates local reducing conditions under the water table during precipitation.

6. Discussion

Overbank deposits have high preservation potential for vertebrate remains. Several examples have been documented in the Paleogene of Wyoming (Willis and Behrensmeyer, 1995), the Eocene of Wyoming and Miocene of Pakistan (Behrensmeyer et al., 1995), the Late Permian of South Africa (Smith, 1993), and the Late Cretaceous of Montana and Dakota (White et al., 1998). In contrast, few examples have been documented in the Cretaceous of South America (Chiappe et al., 2004; González Riga et al., 2004).

This taphonomic and sedimentologic study of a new dinosaur assemblage from Neuquén Basin (northwest Patagonia) extends knowledge on environmental controls in overbank sedimentary successions bearing sauropods. At Arroyo Seco (Cerro Guillermo area), a large accumulation of articulated and disarticulated bones belonging to titanosaur individuals of different sizes and ontogenetic states is

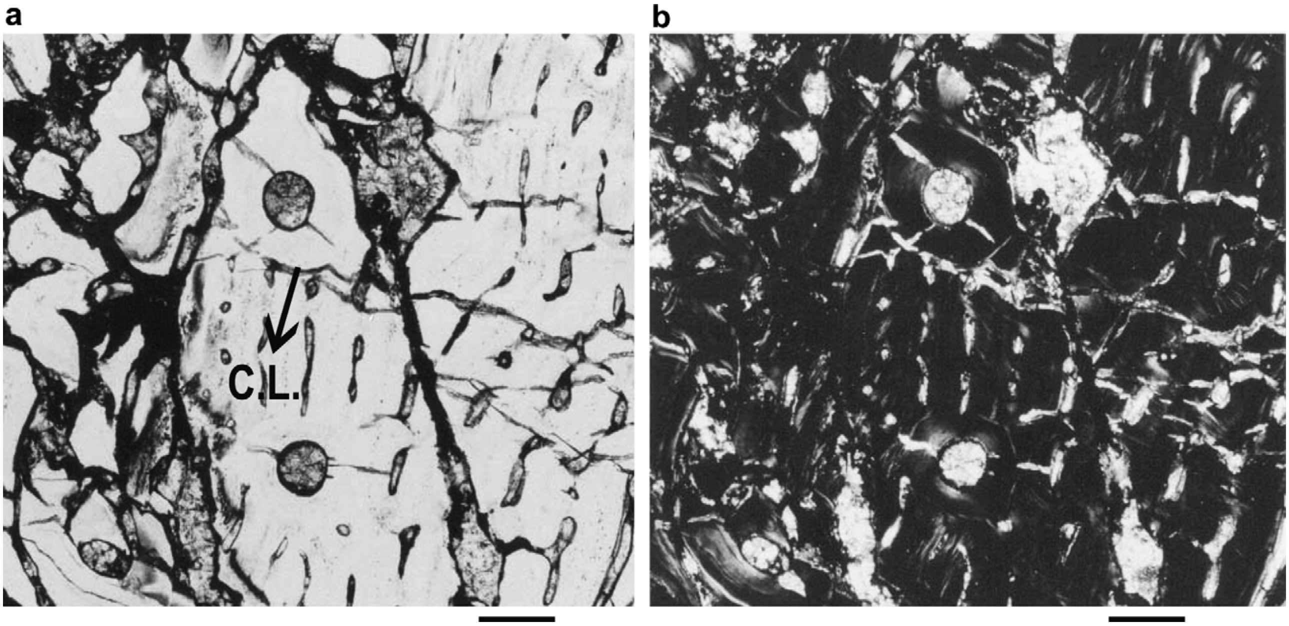

Fig. 13. Bone microstructure in thin section. Transverse section of the femur of *Mendozasaurus neguyelap* in (a) plane-polarized and (b) cross-polarized light. Fibro-lamelar bone (right) and development of secondary osteons (left) limited by a well-marked cementation line (CL). Scale bar: 1 mm.

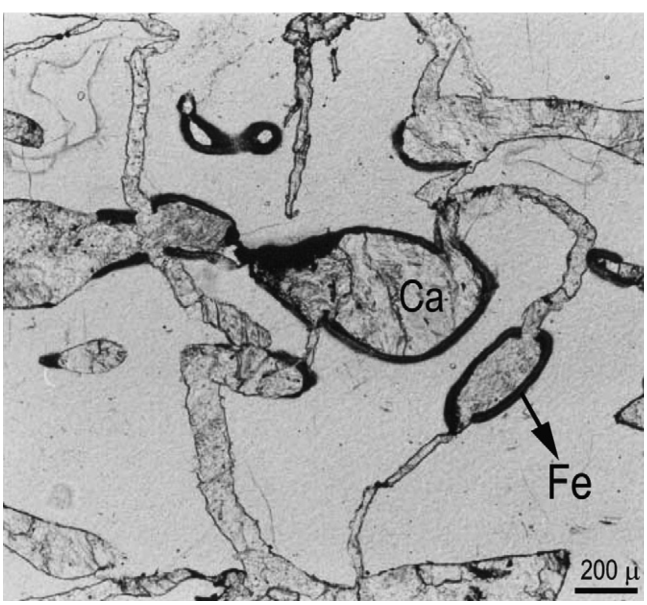

Fig. 14. Bone microstructure in thin section. Transverse section of the femur of *Mendozasaurus neguyelap* showing the sequence of cementation and fracturing. Note hematite cementation (Fe) displaced by fracturing and late-stage calcite (Ca) precipitation. Microphotograph in plane-polarized light. Scale bar: 200 μm.

documented. Most complete remains are type materials of *Mendozausaurus neguyelap*, a large titanosaur (18–27-m long). At Loma del Lindero quarry (Rincón de Los Sauces area), 80 km southeast, 300 bones of four titanosaur individuals and one theropod specimen were collected (Calvo and González Riga, 1999, 2005; González Riga and Calvo, 1999; González Riga et al., 2003). In both sites, the high spatial density (~9 bones for m^2) indicates that the overbank facies of fluvial meandering systems were prone to accumulating titanosaur sauropod bones. These large bone assemblages correspond to a particular taphonomic mode (sensu Behrensmeyer, 1988; Behrensmeyer and Hook, 1992) characterized by disarticulated and partially articulated bone accumulations in floodplain overbank facies.

At Arroyo Seco, the main biostratinomic processes include subaerial biodegradation, disarticulation and necrokynesis, and prefossilization bone weathering. Subaerial biodegradation of sauropod carcasses took place on well-drained floodplains, as depicted by dominant silty–sandy facies without color mottling and the occurrence of pervasive bioturbation. Small theropods associated with large sauropods could suggest the presence of scavenging and the breakdown of bigger remains, as has been described elsewhere (Buffetaut and Suteethorn, 1989; Erickson and Olson, 1996; Chure et al., 1998). However, to confirm this interpretation, complementary studies and surveys of tooth marks in the sauropod remains are necessary.

The partial to total disarticulation of the sauropod carcasses and orientation of bones relates to sporadic overbank flows during the disarticulation and necrokynesis stage. The exceptional occurrence of an articulated vertebral sequence of *Mendozasaurus* indicates relatively rapid burial and low-intensity hydraulic processes. These special conditions characterize the episodic sedimentary mode in floodplains. Preservation style suggests this fossil site is a parautochthonous assemblage. According to Kidwell et al. (1986), in such an assemblage, autochthonous specimens have been reworked to some degree but not transported out of their original habitat.

Prior to burial, bones suffer preburial weathering, such as temperature changes, solar radiation, and saturation and desiccation. Due to these superficial effects, the studied material develops longitudinal cracking parallel to bone fibers and flaking of outer surfaces (Fig. 10). Such features are common in environments with episodic sedimentation and exposure, like proximal floodplains (Bridge, 2003).

Fossil-diagenetic processes observed herein include plastic deformation of bones during the burial history, after the bones have lost their collagen fibers (Fig. 11), and a series of permineralization and cementation stages (Fig. 14) that include (1) a first event of permineralization with hematite cementation on bone vascular canals, (2) later fracturing and brittle deformation (collapse of the spongy tissue) due to lithostatic pressure, and (3) a late-stage permineralization event with pervasive calcite precipitation in bone vascular canals, medular tissue, and fractures. Final exhumation processes involve bone weathering, flaking, and fracturing. These effects can be differentiated from "prior to burial effects" by the development of open fractures, which seldom present associated rootlet growth that contribute to bone weakening and splintering.

The Arroyo Seco paleontological site can be referred to the broadly defined floodplain preservational context (sensu Behrensmeyer and Hook, 1992). This case study further refines the particular taphonomic mode, which we propose to name the "overbank bone assemblage". This mode is characterized by disarticulated and partially articulated accumulations of vertebrate bones, largely oriented, that have been exposed to weathering prior to burial within the proximal overbank deposits of mixed-load fluvial systems. The proximal floodplain preservational context is particularly prone to deposition, trapping of huge bones, and slight removal and exposure of skeletal remains due to the strong influence of crevasse splays.

Similar sauropod bone assemblages have been identified in Rincon de los Sauces and may be present in other paleontological sites in Patagonia. Refinement of this taphonomic mode will enhance comprehension of the habitats in which these huge vertebrates lived.

7. Conclusions

This work refines, through a Late Cretaceous, large, sauropod-bearing case history within the Neuquén Basin, a particular taphonomic mode, referred to as the "overbank bone assemblage", characterized by disarticulated and partially articulated accumulations of vertebrate bones, largely oriented, that have been exposed to weathering prior to burial within the proximal overbank deposits of mixed-load fluvial systems. Within this setting, crevasse splay dynamics control deposition, trap huge bones, lead to slight removal and orientation, and later expose skeletal remains.

Acknowledgments

This paper evolved from discussions of various taphonomic and environmental aspects of the senior author's doctoral dissertation at the National University of Córdoba, Argentina. Wolfgang Volkheimer and José F. Bonaparte provided encouragement to publish this work. Constructive comments from Claudia Marsicano and an anonymous reviewer significantly improved the organization of this paper. Many people and institutions provided assistance and support during both field and laboratory work. This research is supported by the Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (Consejo Nacional de Investigaciones Científicas y Técnicas), and funded by a project of the Agencia Nacional de Promoción Científica y Tecnológica (ANCYT PICT 07-08277) to Jorge O. Calvo.

References

Allen, J.R.L., 1982. Sedimentary structures: Their character and physical basis. Developments in Sedimentology 30. Elsevier Science Publishers, Amsterdam, 593 p.

Allen, J.R.L., 1983. Studies in fluvial sedimentation: Bars, bar complexes and sandstone sheets (low sinuosity braided streams) in the Brownstones (L. Devonian), Welsh Borders. Sedimentary Geology 33, 237–293.

Behrensmeyer, A.K., 1978. Taphonomic and ecologic information from bone weathering. Paleobiology 4, 150–162.

Behrensmeyer, A.K., 1988. Vertebrate preservation in fluvial channels. Palaeogoeography, Palaeoclimatology, Palaeoecology 63, 183–199.

Behrensmeyer, A.K., 1990. Transport-hydrodynamics: Bones. In: Briggs, D.G.G., Crowther, P.R. (Eds.), Paleobiology: A Synthesis. Blackwell Scientific Publications, Oxford, pp. 232–235.

Behrensmeyer, A.K., 1991. Terrestrial vertebrate Accumulations. In: Allison, P.A., Briggs, D.E.G. (Eds.), Topics in Geology. Plenum Press, New York, pp. 291–327.

Behrensmeyer, A.K., Hook, R.W., 1992. Paleoenvironmental contexts and taphonomic modes. In: Behrensmeyer, A.K., Damuth, J.D., DiMichele, W.A., Potts, R., Sues, H.D., Wing, S.L. (Eds.), Terrestrial ecosystems through time: evolutionary paleoecology of terrestrial plants and animals. University of Chicago Press, Chicago, pp. 15–136.

Behrensmeyer, A.K., Kidwell, S.M., 1985. Taphonomy's contributions to paleobiology. Paleobiology 11, 105–119.

Behrensmeyer, A.K., Willis, B.J., Quade J., 1995. Floodplains and Paleosols of Pakistan Neogene and Wyoming Paleogene deposits; a comparative study. In: Badgley, C.; Behrensmeyer, A.K. (Eds.), Long records of continental ecosystems; Paleogene of Wyoming and Neogene of Pakistan. Palaeogeography, Palaeoclimatology, Palaeoecology 115, pp. 37–60.

Bestland, E.A., 1997. Alluvial terraces and paleosols as indicators of Early Oligocene climate change (John Day Formation, Oregon). Journal of Sedimentary Research 67, 840–855.

Bonaparte, J.F., 1996. Cretaceous Tetrapods of Argentina. Münchner Geowissenschaftliche Abhandlungen 30, 73–130.

Bonaparte, J.F., 1999. An armoured sauropod from the Aptian of Northern Patagonia, Argentina. In: Tomida, T.H., Rich Vickers-Rich, P. (Eds.), Proceeding of the Second Gondwanan Dinosaur Symposium. National Science Museum Monographs 15, 1–12.

Bonaparte, J.F., Coria, R.A., 1993. Un nuevo y gigantesco saurópodo Titanosaurio de la Formación Río Limay (Albiano-Cenomaniano) de la provincia del Neuquén, Argentina. Ameghiniana 30, 271–282.

Bridge, J.S., 1993. Descriptive and interpretation of fluvial deposits: a critical perspective. Sedimentology 40, 801–810.

Bridge, J.S., 2003. Rivers and floodplains. Blackwell Publishing, Oxford, 608 p.

Buatois, L.A., Mangano, M.G., 1995. Paleoenvironmental and paleoecological significance of the lacustrine Mermia ichnofacies: and archetypical subaqueous non-marine trace fossil assemblage. Ichnos 4, 151–161.

Buatois, L.A., Mangano, M.G., 1996. Icnología de ambientes continentales: problemas y perspectivas. Asociación Paleontológica Argentina, Publicación Especial 4, 5–30.

Buffetaut, E., Suteethorn, V., 1989. A sauropod skeleton associated with theropod teeth in the Upper Jurassic of Thailand: remarks on the taphonomic and palaeoecological significance of such associations. Palaeogeography, Palaeoclimatology, Palaeoecology 73, 77–83.

Calvo, J.O., Bonaparte, J.F., 1991. *Andesaurus delgadoi* n.g. n.sp. (Saurischia, Sauropoda), dinosaurio Titanosauridae de la Formación Río Limay (Albiano-Cenomaniano), Neuquén, Argentina. Ameghiniana 28, 303–310.

Calvo, J.O., González Riga, B.J., 1999. Hallazgos de Theropoda y Titanosauridae y su paleoambiente en una nueva localidad de Rincón de los Sauces, Neuquén, Argentina. Ameghiniana 36, 97.

Calvo, J.O., González Riga, B.J., 2003. *Rinconsaurus caudamirus* gen. et sp. nov., a new titanosaurid (Dinosauria, Sauropoda) from the Late Cretaceous of Patagonia, Argentina. Revista Geológica de Chile 30 (2), 333–353.

Calvo, J.O., González Riga, B.J., 2005. Hallazgo de un nuevo titanosaurio (Dinosauria, Sauropoda) en Rincón de los Sauces, Patagonia, Argentina. 2° Congreso Latinoamericano de Paleontologia de Vertebrados (Río de Janeiro), Boletim de Resumos, 61–62.

Calvo, J.O., Salgado, L., 1995. *Rebbachisaurus tessonei* sp. nov., a new Sauropoda from the Albain-Cenomanian of Argentina; New evidence on the origin of the Diplodocidae. GAIA 11, 13–33.

Casadío, S.A., 1994. Estratigrafía y Paleontología del intervalo Maastrichtiano-Daniano en el occidente de la Provincia de La Pampa, Argentina. Unpublished Ph.D. Dissertation, Universidad Nacional de Córdoba, Córdoba, 420 pp.

Cazau, L.B., Uliana, M.A., 1973. El Cretácico Superior continental de la cuenca Neuquina. V Congreso Geológico Argentino, Actas 3, 131–163.

Chiappe, L.M., Coria, R.A., Dingus, L., Jackson, F., Chinsamy, A., Fox, M., 1998. Sauropod dinosaur embryos from the Late Cretaceous of Patagonia. Nature 396, 258–261.

Chiappe, L.M., Salgado, L., Coria, R.A., 2001. Embryonic skulls of titanosaur sauropod dinosaurs. Science 293, 2444–2446.

Chiappe, L.M., Schmitt, J.G., Jackson, F.D., Garrido, A., Dingus, L., Grellet-Tinner, G., 2004. Nest Structure for Sauropods: sedimentary Criteria for Recognition of Dinosaur Nesting Traces. Palaios 19 (1), 89–95.

Chinsamy, A., 1997. Assessing the biology of fossil vertebrates through bone histology. Palaeontologia Africana 33, 29–35.

Chure, D.J., Fiorillo, A.R., Jacobsen, A., 1998. Prey bone utilization by predatory dinosaurs in the Late Jurassic of North America, with comments on prey bone use by dinosaurs throughout the Mesozoic. GAIA 15, 227–232.

Collinson, J.D., 1996. Aluvial sediments. In: Reading, H.G. (Ed.), Sedimentary Environments. Blackwell, Science, Oxford, pp. 37–82.

Cook, E., 1995. Taphonomy of two non-marine Lower Cretaceous bone accumulations from southeastern England. Palaeogeography, Palaeoclimatology, Palaeoecology 116, 263–270.

Coria, R.A., Calvo, J.O., 2002. A new Iguanodontian Ornithopod from Neuquén Basin, Patagonia, Argentina. Journal of Vertebrate Paleontology 22, 503–509.

Coria, R.A., Salgado, L., 1995. A new giant carnivorous dinosaur from the Cretaceous of Patagonia. Nature 377, 224–226.

Cruz, C., 1993. Facies y estratigrafía secuencial del Cretácico Superior en la zona del Río Diamante, provincia de Mendoza, Argentina: XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos (Mendoza), Actas I, pp. 46–54.

Curry, K.A., 1999. Ontogenetic histology of *Apatosaurus* (Dinosauria: Sauropoda) new insights on growth rates and longevity. Journal of Vertebrate Paleontology 19, 654–665.

Digregorio, J.H., Uliana, M.A., 1980. Cuenca Neuquina. In: García Castellanos, T. (Ed.), Segundo Simposio de Geología Regional Argentina. Academia Nacional de Ciencias, vol. 2, pp. 985–1032.

Dodson, P., 1990. Sauropod Paleoecology. In: Weishampel, D., Dobson, P., Osmolska, H. (Eds.), The Dinosauria. University of California Press, Berkeley, pp. 402–407.

Erickson, G.M., Olson, K.H., 1996. Bite marks attributable to Tyrannosaurus rex: preliminary description and implications. Journal or Vertebrate Paleontology 16, 175–178.

Fiorillo, A.R., 1988. Taphonomy of Hazard Homestead Quarry (Ogallala Group)Hitchcock County Nebraska, 26. Contribution to Geology, University of Wyoming, pp. 57–97.

Frey, R.W., Pemberton, S.G., Fagerstom, J.A., 1984. Morphological, ethological and environmental significance of the ichnogenera Scoyenia and Ancorichnus. Journal of Paleontology 58, 511–528.

Friend, P.F., Slater, M.J., Williams, R.C., 1979. Vertical and lateral building of river sandstone bodies, Ebro Basin, Spain. Journal of the Geological Society of London 136, 39–46.

Garrido, A.C., Chiappe, L.M., Jackson, F., Schmitt, J., Dingus, L., 2001. First sauropod nest structures. Journal of Vertebrate Paleontology (abstract) 21, supplement to no. 3, 53A.

González Riga, B.J., 1999. Hallazgo de vertebrados fósiles en la Formación Loncoche, Cretácico Superior de la provincia de Mendoza, Argentina. Ameghiniana 36, 401–410.

González Riga, B.J., 2002a. Estratigrafía y Dinosaurios del Cretácico Tardío en el extremo sur de la provincia de Mendoza, Argentina. Unpublished Ph.D. Dissertation. National University of Córdoba (Argentina), 280 pp.

González Riga, B.J., 2002b, Dinosaurs and environments from the Cretaceous of the province of Mendoza, Argentina. In: Trombotto, D.T., Villalba, R. (Eds.), IANIGLA, 30 Years of basic and applied research on environmental sciences. Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales. Special Publication, pp. 197–202.

González Riga, B.J., 2003. A new titanosaur (Dinosauria, Sauropoda) from the Upper Cretaceous of Mendoza Province, Argentina. Ameghiniana 40, 155–172.

González Riga, B.J., 2005. Nuevos restos fósiles de *Mendozasaurus neguyelap* (Sauropoda: Titanosauridae) del Cretácico Tardío de Mendoza, Argentina. Ameghiniana 42 (3), 535–548.

González Riga, B.J., Calvo, J.O., 1999. Unusual caudal series of Titanosauridae of the Late Cretaceous in the Río Colorado Formation, border between the Neuquén and Mendoza provinces, Argentina: VIIth International Symposium on Mesozoic Terrestrial Ecosystems (Buenos Aires), Abstracts, pp. 29–30.

González Riga, B.J., Casadío, S., 2000. Primer registro de Dinosauria (Ornithischia, Hadrosauridae) para la provincia de La Pampa (Argentina) y sus implicancias paleobiogeográficas. Ameghiniana 37, 341–351.

GonzálezRiga, B.J., Calvo, J.O., Astini, R.A., Parras, A.M., 2003. Preservación tafonómica de titanosaurios (Dinosauria, Sauropoda) en facies fluviales del sector septentrional de la Cuenca Neuquina. Ameghiniana 40 (4), 102R.

GonzálezRiga, B.J., Calvo, J.O., Londero, S., Piccolella, F., Bourguet, M., Previtera, M.E., Pirrone, C.E., Sancho, C., 2004. Hallazgo de dinosaurios saurópodos en la región de Cañadón Amarillo (Mendoza, Argentina) y su relación con los ambientes fluviales. Ameghiniana 41 (4), 49–50R.

Kidwell, S.M., Fürsich, F.T., Aigner, T., 1986. Conceptual framework for the analisys and classification of fossil concentrations. Palaios 1, 228–238.

Kraus, M.J., 1987. Integration of channel and floodplain suites, II. Vertical relation of alluvial paleosols. Journal of Sedimentary Petrology 57, 602–612.

Kreutzer, L.A., 1988. Megafaunal butchering at Lubbock Lake, Texas: a taphonomic reanalysis. Quaternary Research 30, 221–231.

Leanza, H.A., Hugo, C.A., 1997. Hoja Geológica 3969-III Picún Leufú, Geología. Servicio Geológico Minero Argentino, Boletín 218, 11–99.

Leanza, H.A., Hugo, C.A., 2001. Cretaceous red beds from southern Neuquén Basin (Argentina): age, distribution and stratigraphic discontinuities. Asociación Paleontológica Argentina, Publicación Especial 7, 117–122.

Legarreta, L., Gulisano, C., 1989. Análisis estratigráfico secuencial de la cuenca Neuquina (Triásico Superior- Terciario inferior). In: Chebli, G., Spalletti, L. (Eds.), Cuencas Sedimentarias Argentinas, Serie Correlación Geológica, Universidad Nacional de Tucumán, vol. 6, pp. 221–243.

Legarreta, L., Uliana, M.A., 1991. Jurassic-Cretaceous marine oscillations and geometry of back-arc basin fill, central Argentine AndesInternational Association of Sedimentology, vol. 12. Special Publication, pp. 429-450.

Legarreta, L., Kokogian, D.A., Boggetti, D.A., 1989. Depositional sequences of de Malargüe Group (Upper Cretaceous-Lower Tertiary), Neuquén Basin, Argentina. Cretaceous Research 10, 337–356.

Lyman, R.L., 1996. Vertebrate Taphonomy. Cambridge University Press, Cambridge, 524 pp.

Martinsen, O.J., Ryseth, A., Helland-Hansen, W., Flesche, H., Idil, S., Torkildsen, G., 1999. Stratigraphic base level and fluvial architecture. Ericson Sandstone (Campanian), Rock Spring Uplift., SW Wyoming, USA. Sedimentology 46, 235–259.

Miall, A.D., 1985. Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. Earth Science Review 22, 261–308.

Miall, A.D., 1996. The Geology of Fluvial Deposits. Springer-Verlag Berlin Heidelberg, New York, 583 pp.

Novas, F.E., 1997. South American Dinosaurs. In: Currie, P., Padian, K. (Eds.), Encyclopedia of Dinosaurs. Academic Press, New York, pp. 678–688.

Novas, F.E., 1998. *Megaraptor namunhuaiquii*, gen. et sp. nov., a large-clawed, Late Cretaceous Theropod from Patagonia. Journal of Vertebrate Paleontology 18, 4–9.

O'Brien, P.E., Wells, A.T., 1986. A small, alluvial crevasse splay. Journal of Sedimentary Petrology 56, 876–879.

Paik, I.S., Kim, H.J., Park, K.H., Song, Y.S., Lee, Y.I., Hwang, J.Y., Huh, M., 2001. Paleoenvironments and taphonomic preservation of dinosaur bone-bearing deposits in the Lower Cretaceous Hasandong Formation, Korea. Cretaceous Research 22, 627–642.

Parras, A.M., Casadío S., Pires, M., 1996. Secuencias depositacionales del Grupo Malargüe y El límite Cretácico-Paleógeno, en el sur de la provincia de Mendoza, Argentina. Asociación Paleontológica Argentina, Publicación Especial 5, Paleógeno de América del Sur y Península Antártica, pp. 61–69.

Pettijohn, F.J., Potter, P.E., Siever, R., 1987. Sand and Sandstone. Springer-Verlag, New York, 553 pp.

Plint, A.G., Browne, G.H., 1994. Tectonic event stratigraphy in a fluvio-lacustrine, strike-slip setting: the Boss Point Formation (Westphalian A), Cumberland Basin, Maritime Canada. Journal Sedimentary Research B64, 341–364.

Powell, J.E., 1986. Revisión de los Titanosáuridos de América del Sur: Ph.D. Dissertation. National University of Tucumán (Argentina), 340 pp.

Ramos, V., 1981. Descripción geológica de la Hoja 33c, Los Chihuidos Norte. Servicio Geológico Nacional (Buenos Aires), Boletín 182, 1–103.

Retallack, G.J., 1986. Fossil soils as a ground for interpreting long time controls on ancient rivers. Journal of Sedimentary Petrology 56, 1–18.

Retallack, G.J., 2001. Soils of the Past. An introduction to Paleopedology. Blackwell Science, Oxford, 404 pp.

Riccardi, A.C., 1988. The Cretaceous System of Southern South America, vol. 168. Geological Society of America, Memoir, 161 pp.

Rogers, R.R., 1990. Taphonomy of the Dinosaur bone beds in the Upper Cretaceous Two medicine Formation of Northwestern Montana: Evidence for Drought-Releated Mortality. Palaios 5, 394–413.

Salgado, L., 2000. Evolución y Paleobiología de los saurópodos Titanosauridae. Ph.D. Dissertation. National University of La Plata (Argentina), 300 pp.

Salgado, L., Bonaparte, J.F., 1991. Un nuevo saurópodo Dicraeosauridae, Amargasaurus cazaui gen. et sp. nov., de la Formación La Amarga, Neocomiano de la provincia de Neuquén, Argentina. Ameghiniana 28, 333–346.

Shanley, K.W., McCave, P.J., 1991. Predicting facies architecture through sequence stratigraphy – an example from the Kaiporowits Plateau, Utah. Geology 19, 742–745.

Smith, R.M.H., 1993. Vertebrate taphonomy of Late Permian Floodplain deposits in the southwestern Karoo Basin of South Africa. Palaios 8 (1), 45–67.

Vergani, G.D., Tankard, A.J., Belotti, H.J., Welsink, H.J., 1995. Tectonic evolution and paleogeography of the Neuquén Basin, Argentina. In: Tankard, A.J., Suarez, R., Welsink, H.J. (Eds.), Petroleum Basins of South America, vol. 62. American Association of Petroleum Geologists, Memoir, pp. 383–402.

Voorhies, M.R., 1969. Taphonomy and population dynamics of an early Pliocene Vertebrate Fauna, Knox County, Nebraska. Contributions to Geology, University of Wyoming, Special Paper 1, 69 pp.

Wedel, M.J., Cifelli, R.L., Kent Sanders, R., 2000. Osteology, paleobiology and relationships of the sauropod dinosaur Sauroposeidon. Acta Palaeontologica Polonica 45, 343–388.

White, P.D., Fastovsky, D.E., Sheehan, P.M., 1998. Taphonomy and suggested structure of the dinosaurian assemblage fo the Hell Creek Formation (Maastrichtian), eastern Montana and western North Dakota. Palaios 13 (1), 41–51.

Willis, B.J., Behrensmeyer, A.K., 1995. Fluvial systems in the Siwalik Miocene and Wyoming Paleogene in Long records of continental ecosystems. In: Badgley, C; Behrensmeyer, A.K. (Eds.), Paleogene of Wyoming-Montana and Neogene of Pakistan. Palaeogeography, Palaeoclimatology, Palaeoecology 115, pp. 13–35.

Wilson, J.A., Martínez, R.N., Alcober, O., 1999. Distal tail segment of a Titanosaur (Dinosauria: Sauropoda) from the Upper Cretaceous of Mendoza, Argentina. Journal of Vertebrate Paleontology 19, 591–594.