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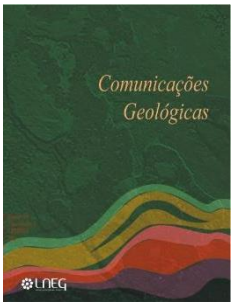
Updating the geological and stratigraphic occurrences of La Rioja dinosaur sites. Palaeobiodiversity of the Lower Cretaceous Enciso Group at Peña Cárcena (Igea, Spain)

Atualização da informação geológica e estratigráfica das jazidas de dinossáurios de La Rioja. Paleodiversidade do Cretácico Inferior do Grupo Enciso em Peña Cárcena (Igea, Espanha)



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Abstract: The discovery of new vertebrate fossil sites with skeletal remains in the Enciso Group of Igea (La Rioja) is showing the relevance of the area to study the palaeobiodiversity of Early Cretaceous vertebrate faunas from the Iberian Peninsula. At Peña Cárcena hill two sedimentary environments have been inferred: a mixed siliciclastic-carbonate lacustrine environment that is dominant at the outcrops, overlaid by a splay delta in an avulsion-belt. The vertebrate remains are especially abundant in the mixed siliciclastic-carbonate lacustrine deposits with two partially articulated skeletons (a theropod and a large-sized dinosaur), teeth and a fragment of a left maxilla of baryonychines, a pterosaur tooth that differs from those of *Prejanopterus*, a *Goniopholis* tooth, chelonian shell fragments that might belong to *Camerochelys*, a fairly complete lepisosteiform, teeth and dorsal fin spines of hybodontiforms. At the delta deposits, vertebrate fossils are rather scarce, with a single lepisosteiform skeleton and indeterminate bone fragments.

Keywords: Cameros Basin, Early Cretaceous, dinosaur, palaeontological sites, vertebrate fauna.

Resumo: A descoberta de novas jazidas com restos osteológicos de vertebrados no Grupo Enciso em Igea (La Rioja) comprova a importância da região para o estudo da paleobiodiversidade das faunas de vertebrados do Cretácico Inferior da Península Ibérica. Na colina de Peña-Cárcena, tem-se inferido dois ambientes sedimentares: o predominante nos afloramentos corresponde a um ambiente lacustre, siliciclástico-carbonatado misto, que se encontra sobreposto por depósitos de transbordo deltaico em cinturão abandonado. Restos de vertebrados são abundantes nos depósitos lacustres, incluindo dois esqueletos parciais articulados (de um terópode e de outro dinossáurio de grande porte), dentes e um fragmento de maxila esquerda de barionicinos, um dente de pterossáurio distinto de *Prejanopterus*, um dente de *Goniopholis*, fragmentos da carapaça de quelónios que poderão pertencer a *Camerochelys*, um lepisosteiforme praticamente completo, dentes e espinhos de barbatanas de hybodontiformes. Fósseis de vertebrados são escassos nos depósitos deltaicos, com apenas um esqueleto de lepisosteiforme e fragmentos indeterminados.

Palavras-chave: Bacia de Cameros, Cretácico Inferior, dinossáurios, jazidas paleontológicas, fauna de vertebrados.

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1. Introduction

The riojan sector of the Cameros Basin is well known by its palaeoichnological record. Indeed, according to the last census, there are 186 ichnological sites in La Rioja and, up till now, around 8,000 to 25,000 ichnites have been identified in the area (Díaz-Martínez, 2013; Pérez-Lorente, 2015; García Ortíz de Landaluce, 2016). In addition, new vertebrate-bearing fossil sites with skeletal remains have recently been discovered in the Enciso Group, especially in the locality of Igea (La Rioja, Spain).

The vertebrate fauna of the Enciso Group is mainly represented by aquatic or semiaquatic taxa. These comprise lepisosteiform, pycnodontiform and hybodontiform fishes (Viera and Torres, 2013), the crocodyliforms *Bernissartia*, *Goniopholis* and *Pholidosaurus* (Ortega *et al*., 1996, 2010; Viera and Torres, 1996, 2013), and the chelonian *Camerochelys* (Pérez-García and Murelaga, 2013). Furthermore, the pterosaur *Prejanopterus* has also been described in the same depositional sequence (Fuentes-Vidarte and Mejide Calvo, 2010; Pereda-Suberbiola *et al*., 2012; Witton, 2013). The dinosaur record mainly consists of theropod remains, including spinosaurid bones and teeth, and carcharodontosaurid teeth (Viera and Torres, 1995, 2013; Navarro-Lorbés and Torices, 2018; Isasmendi *et al*., 2020). A partially articulated theropod skeleton is currently under study (Isasmendi *et al*., 2019).

Most of the vertebrate remains of Igea are located in several sites found at Peña Cárcena hill. However, little is known about

their stratigraphic occurrence and specific depositional environment. Therefore, the aim of this paper is to update the stratigraphy and sedimentology of the vertebrate-bearing beds found at Peña Cárcena. Furthermore, the palaeobiodiversity of the vertebrate fauna is studied.

2. Geographical and geological setting

The vertebrate fossil sites and skeletal remains here reported were found in Igea (southeast of La Rioja, Spain) (Fig. 1). The sites are specifically located at the Peña Cárcena hill, which is situated between the main town of Igea and the Virgen del Villar hermitage. The sites are called Colladillos 1 to 5, La Cañada 1, Marino 1 and 2, Peña Cárcena 1 and 2 (Fig. 1D and E, Table 1).

The Peña Cárcena hill is located in northeastern Cameros Basin. This basin was developed during the Late Jurassic and Early Cretaceous when the second rifting stage took place in the Iberian Mesozoic Rift (Mas *et al*., 2002). The deposits of the Cameros Basin, dated as Tithonian-early Aptian, exceed 5,000 m in thickness (Martín-Chivelet *et al*., 2019 and references therein). These have been traditionally divided into Tera, Oncala, Urbión, Enciso and Oliván groups (Tischer, 1966), or eight depositional sequences (DS1-8) by Mas *et al*. (2002) (Fig. 1C).

The Peña Cárcena hill stratigraphic succession is situated in the upper part of DS 7 of Mas *et al*. (2002). The DS 7 is composed by the Jubera and Leza formations in the northeastern Cameros Basin and by the Enciso Group in the central sector of the basin. The studied section belongs to the Enciso Group (Fig. 1C). This group is represented by more than 2,000 m of mixed siliciclastic-carbonate deposits in the main depocentre of the Cameros Basin (Clemente, 2010; Suárez-González *et al*., 2013), and has been interpreted as a siliciclastic-influenced carbonate lacustrine and palustrine environment (Mas *et al*., 1993, 2002, 2011). However, fluvial and deltaic environments have also been inferred (*e.g.* Hernán, 2018). The Enciso Group has been dated for the most part as early Aptian (*e.g.* Suárez-González *et al*., 2013, 2015) (Fig. 1C), but also as late Barremian-late Aptian (Hernán, 2018).

3. Material and methods

For the stratigraphic and sedimentologic study of the Peña Cárcena outcrops, three stratigraphic columns were built: one in the carbonate rich section and two in the siliciclastic upper part of the hill due to the lateral changes of the observed lithofacies. The sedimentary environments were interpreted after data processing, taking into account the work of Hernán (2018).

The fossil material mentioned in this work was recovered in previous prospection campaigns during the last decades and palaeontological excavations carried out in 2018 and 2019. The fossil sites are indicated in the stratigraphic columns (Fig. 1D and E). This material is curated at the Centro de Interpretación Paleontológica de La Rioja in Igea.

4. Sedimentary environments of the Enciso Group at Peña Cárcena

In the Peña Cárcena hill a 64.5 m thick stratigraphic section is found, composed mainly of carbonates and marls but also of siliciclastic-dominated facies in its upper part.

4.1. Carbonate-dominated section

In the lower and middle part of the hill, mainly carbonate rocks crop out, showing a thickness of 57.5 m (Fig. 1E). These are marly and lutitic facies, and limestones and marly limestones that are arranged within an overall trend of carbonate-enrichment upwards, leading to thicker intervals of marls and limestones towards the upper part of the succession. Overall, in this part, it can be noticed that fine-grained lithofacies dominate the section and these show a hectometre-scale lateral extension.

Four lithofacies have been differentiated: (1) massive grey marls with occasional parallel laminations; (2) massive ochreish, whitish and orangish marls and lutites, sometimes parallel laminated; (3) massive mudstone to wackestone limestones and marly limestones, which sometimes show packstone texture; and (4) nodular limestones or nodular marly limestones (Fig. 1E).

The overall shape of the strata of all the lithofacies is tabular, but in some cases the massive limestones show irregular bases; in these limestones ostracod accumulations are common, as well as structures such as micritic nodules, desiccation cracks, brecciated parts and dissolved gypsum casts at the top of the strata. The ochreish lutites show ferruginization processes and, sometimes, high gypsum content. Furthermore, the ochreish lutites and marls sometimes show vertical and lateral transitions to the grey marls.

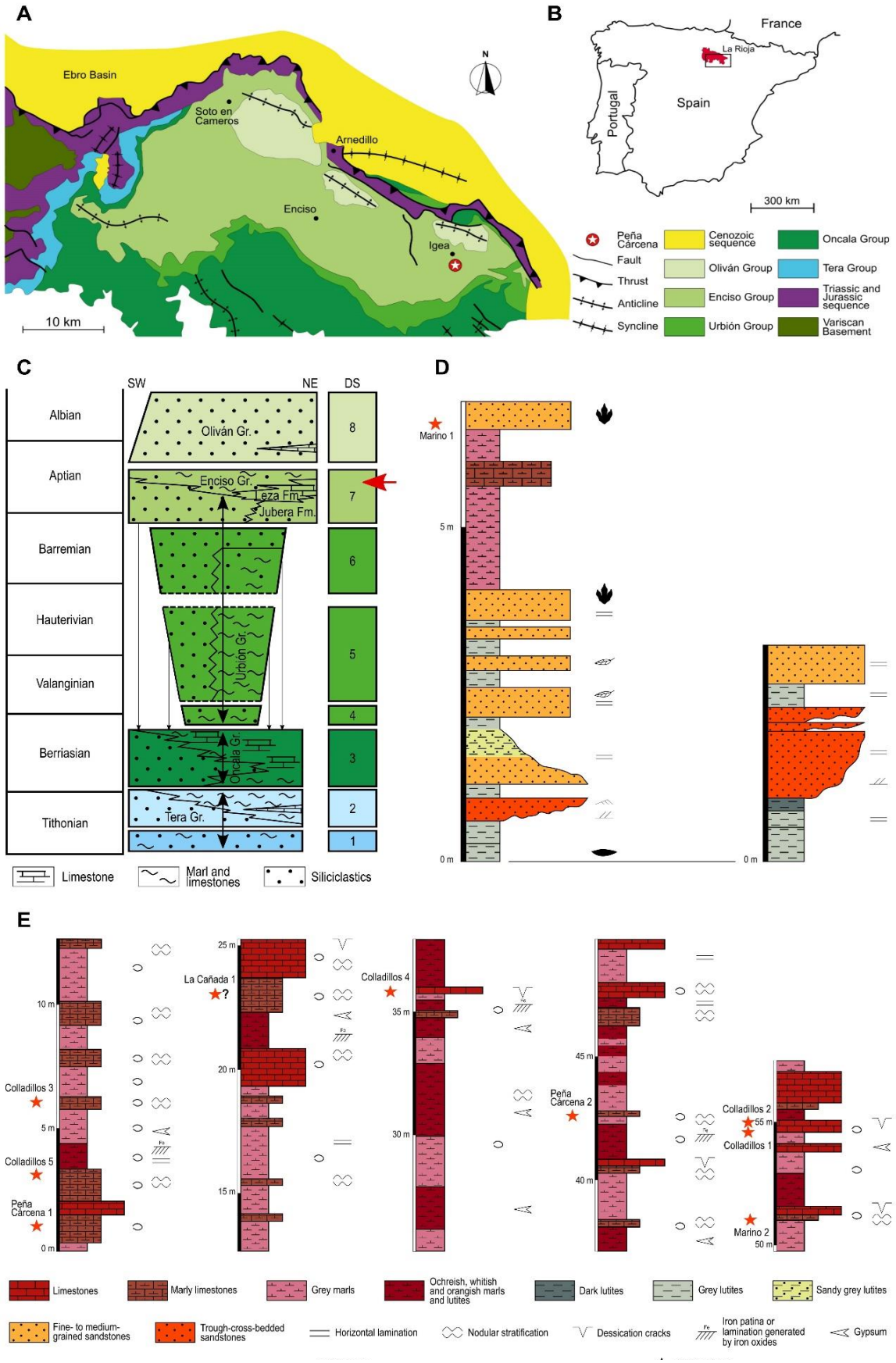
4.2. Siliciclastic-dominated section

Siliciclastic deposits dominate the upper part of the Peña Cárcena hill. This siliciclastic interval is 7-8 m thick and shows a large lateral extension of several hundred metres, whereas the extension of most of the lithofacies that comprise it ranges from few to several tens of metres, passing laterally to other siliciclastic lithofacies. This is not the case for the carbonate facies that crop out, which show high lateral extension.

Eight lithofacies have been distinguished: (1) dark coloured massive lutites with tabular bedding; (2) grey massive lutites with tabular bedding; (3) sandy grey lutites with parallel lamination; (4) fine- to medium-grained massive sandstones with tabular bedding; (5) fine- to medium-grained sandstones with parallel lamination and tabular bedding; (6) trough-cross-bedded sandstones

Figure 1. (next page) (A) simplified geological map of northeastern Cameros Basin showing the location of the Peña Cárcena hill (modified from Suárez-González *et al*., 2013). (B) geographical map of the Iberian Peninsula. (C) chronostratigraphic scheme of Eastern Cameros Basin, showing the ages of the different formations and groups as well as the eight depositional sequences (modified from Suárez-González *et al*., 2013). The red arrow indicates the position of Peña Cárcena hill along the Enciso Group. (D) stratigraphic columns of the siliciclastic-dominated section of Peña Cárcena hill (Igea, Spain), interpreted as splay delta deposits in an avulsion-belt. Both columns were correlated at the base where the carbonate-dominated deposits pass upwards to the siliciclastic-dominated deposits. (E) stratigraphic column of the carbonate-dominated section of Peña Cárcena hill (Igea, Spain), interpreted as a mixed carbonate-siliciclastic lacustrine environment. The vertebrate-bearing fossil sites and their names are indicated by a red star. Note that (D) and (E) do not follow the standard colours for geologic maps.

Figura 1. (próxima página) (A) mapa geológico simplificado do setor norte da Bacia de Cameros, mostrando a localização da colina de Peña Cárcena (modificado de Suárez-González *et al*., 2013). (B) mapa geográfico da Península Ibérica. (C) esquema cronoestratigráfico do setor Oriental da Bacia de Cameros, mostrando as idades das diferentes formações e grupos, bem como as oito sequências deposicionais (modificado de Suárez-González *et al*., 2013). As setas vermelhas indicam a posição da colina de Peña Cárcena ao longo do Grupo Enciso. (D) colunas estratigráficas da secção predominantemente silicicástica da colina de Peña Cárcena (Igea, Espanha), interpretada como depósitos de transbordo deltaico num cinturão abandonado. Ambas as colunas estão correlacionadas na base, onde os depósitos predominantemente carbonatados passam superiormente a depósitos predominantemente silicicásticos. (E) coluna estratigráfica da seção predominantemente carbonatada da colina de Peña Cárcena (Igea, Espanha), interpretada como depósitos de ambiente lacustre misto carbonato-silicicástico. Os locais com fósseis de vertebrados e os respetivos nomes são indicados pela estrela vermelha. Note que (D) e (E) não seguem as cores padrão para mapas geológicos.


A
Ebro Basin
Soto en Cameros
Arnedillo
Enciso
Igea
10 km
N
B
France
La Rioja
Portugal
Spain
300 km
Peña Cárcena
Fault
Thrust
Anticline
Syncline
Cenozoic sequence
Oliván Group
Enciso Group
Urbión Group
Oncala Group
Tera Group
Triassic and Jurassic sequence
Variscan Basement
C
SW
NE
DS
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Tithonian
Oliván Gr.
Enciso Gr.
Leza Fm.
Jubera Fm.
Urbión Gr.
Oncala Gr.
Tera Gr.
8
7
6
5
4
3
2
1
Limestone
Marl and limestones
Siliciclastics
D
Marino 1
5 m
0 m
0 m
E
Colladillos 3
10 m
5 m
Colladillos 5
Peña Cárcena 1
0 m
La Cañada 1
25 m
20 m
15 m
Colladillos 4
35 m
30 m
Peña Cárcena 2
45 m
40 m
Colladillos 2
55 m
Colladillos 1
Marino 2
50 m
Limestones
Marly limestones
Grey marls
Ochreish, whitish and orangish marls and lutites
Dark lutites
Grey lutites
Sandy grey lutites
Fine- to medium-grained sandstones
Trough-cross-bedded sandstones
Horizontal lamination
Nodular stratification
Dessication cracks
Iron patina or lamination generated by iron oxides
Gypsum

composed of fine- to medium-sized grains; (7) grey massive marls with scarce parallel laminations; and (8) marly nodular limestones (Fig. 1D).

In some of the massive grey lutites, centimetre to decimetre long lenses of dark coloured lutites can be observed. In the massive tabular sandstones, plant fragments are quite common. Furthermore, the trough-cross-bedded sandstones may be either internally massive or with sedimentary structures, such as asymmetric ripples, climbing-ripple cross-lamination, and low-angled parallel cross-lamination to parallel lamination. Load structures, which are usual in the sandstones of the top of the sections, could be interpreted as natural casts since they have been found below clear dinosaur ichnites occurring atop of the deformed bed (Fig. 1D).

5. Palaeobiodiversity of the Enciso Group at Peña Cárcena

In the carbonate-rich deposits of the lower and middle part of the hill two partially articulated skeletons belonging to an indeterminate theropod and to other mid- to large-sized dinosaur have been recovered from Marino 2 and Colladillos 1 sites, respectively (Fig. 1E and 2A).

These deposits have also yielded other theropod remains, consisting of a fragment of a left maxilla from La Cañada 1, assigned to Baryonyx walkeri by Viera and Torres (1995) (Fig. 2F), and two baryonychine isolated teeth found in Peña Cárcena 1 and 2 sites, which have been referred to Baryonychinae indet. 1 morphotype (Isasmendi *et al*., 2020) (Fig. 2B and C, Table 1). The maxilla fragment has eight alveoli. All of them lack teeth but in the first preserved alveolus two teeth are present (Viera and Torres, 1995). No comparison is possible to make with the isolated baryonychine teeth already found in the Enciso Group.

One isolated tooth belonging to a pterosaur has been found in Colladillos 3 site. The pterosaur tooth is conidont, elongate and does not show any ornamentation. The only formerly reported pterosaur in the DS 7 is *Prejanopterus curvirostris* (Fuentes-Vidarte and Meijide Calvo, 2010; Pereda-Suberbiola *et al*., 2012) (Table 1). Comparing to those of *Prejanopterus*, the pterosaur tooth found at Peña Cárcena is larger, more elongate, and apically pointed. Therefore, the isolated tooth probably belongs to a different pterosaur taxon.

Besides the dinosaur and pterosaur remains, a turtle shell fragment that might belong to the genus *Camerochelys* (Fig. 2E), an isolated tooth of crocodyliform *Goniopholis* and a partial skeleton of a lepisosteiform fish have been found in the nearby sites. Other scattered vertebrate remains have also been found in Peña Cárcena, such as hybodontiform teeth and dorsal fin spines, as well as archosaur rib fragments (Table 1).

Among the associated biota, ostracods, gastropods and bivalves are quite common on the deposits formed in the mixed carbonate-siliciclastic lacustrine system. In addition, conifer trunk fragments and fern remains are also usual. The conifers could belong to *Dadoxylon* (*Araucaryoxylon*) *riojense* and the ferns to *Tempskya riojana* (Viera and Torres, 2013).

The vertebrate fossil record at the upper siliciclastic part of the Peña Cárcena hill is, up to date, rather scarce bearing only a single quite complete lepisosteiform (Fig. 2D) and some archosaur bone fragments. Nonetheless, fern and indeterminate plant remains are quite abundant in the sandstones. These ferns may also belong to *Tempskya riojana* (Viera and Torres, 2013). Alongside these remains, casts of dinosaur footprints are abundant in the sandstones (Fig. 1D). Invertebrate fossils in the siliciclastic deposits at Peña Cárcena have yet been found.

Isasmendi *et al*. (2019) mentioned the presence of an articulated hindlimb found at Peña Cárcena, which was tentatively attributed to *Baryonyx* by Viera and Torres (2013). Nevertheless, these remains were recovered from the Virgen del Villar 1 site.

6. Discussion

Differences in the nature of the lithofacies that crop out in the Peña Cárcena hill suggest that two depositional environments could be distinguished: a carbonate-dominated environment and a siliciclastic-dominated environment. Taking into account both the facies diversity and their lateral extension in the carbonate-rich section, a mixed siliciclastic-carbonate lacustrine model can be inferred. The massive grey marls would have been deposited in open and infralittoral lacustrine areas due to the decantation of mud particles in a carbonate-rich water column (Street-Perrott *et al*., 1993; Gierlowski-Kordesch, 2010). The massive ochreish, whitish and orangish marls and lutites could be the result of palustrine pedogenic processes in the grey marls (Platt, 1989 ; Luzón *et al*., 2002). Massive limestones that are relatively rich in ostracods would have been deposited in a littoral area (*e.g.* Arp, 1995). Desiccation cracks and nodules in limestones suggest sediment emersion and pedogenesis (Freytet, 1973; Freytet and Verrecchia, 2002, Alonso-Zarza and Wright, 2010) indicating they have been formed in the eulittoral area of the lake (Hernán, 2018). In any case, the limestones originated in subaquatic conditions in areas out of the siliciclastic inputs; massive limestones are indicative of shallow lacustrine settings starved of clastic sediments (*e.g.* Talbot and Allen, 1996). The siliciclastic lithofacies indicate the sediment input by alluvial (fluvial to deltaic) systems. The thickness and lateral extension of lithosomes as well as their stratigraphic occurrence in the Enciso Group suggest these siliciclastic levels may be interpreted as a splay delta deposit in an avulsion-belt (J. Hernán, Pers. Comm. 2021).

The trough-cross-bedded sandstones would represent the distributary channels in the deltaic spill (Tye and Coleman, 1989; Smith and Pérez-Arlucea, 1994; Pérez-Arlucea and Smith, 1999). The sandstones with parallel laminations and the massive sandstones could be interpreted as mouth bars (Tye and Coleman, 1989; Pérez-Arlucea and Smith, 1999). However, structureless lithofacies could also be generated by bioturbating organisms (Hernán, 2018). Although different interpretations for the massive dark lutites can be inferred, the lateral extension and thickness of those found in the siliciclastic section may represent prodelta deposits. The same may be inferred for the grey lutites either with or without parallel lamination in a deltaic spill (Smith and Pérez-Arlucea, 1994; Pérez-Arlucea and Smith, 1999). The mixed siliciclastic-carbonate lacustrine environment dominated most of the studied outcrops at Peña Cárcena. Upwards, the transition to a siliciclastic environment may indicate the progradation of a delta lobe in an avulsion belt. Finally, the large lateral extension of the grey marls and nodular marly limestones found along the siliciclastic section suggest the return to the lacustrine environment rather than to a more confined pond or floodplain lake.

Although it has been assumed that the vertebrate fossils are scarce in the Enciso Group, former publications (*e.g.* Viera and Torres, 2013) and this study have shown that they are quite frequent and diverse, with remains belonging to different groups. At Peña Cárcena, the vertebrate fauna consists of hybodontiform and lepisosteiforms fishes, turtles that could correspond to the pan-cryptodiran *Camerochelys* (Pérez-García and Murelaga, 2013), the goniopholidid crocodyliform *Goniopholis*, baryonychine theropods

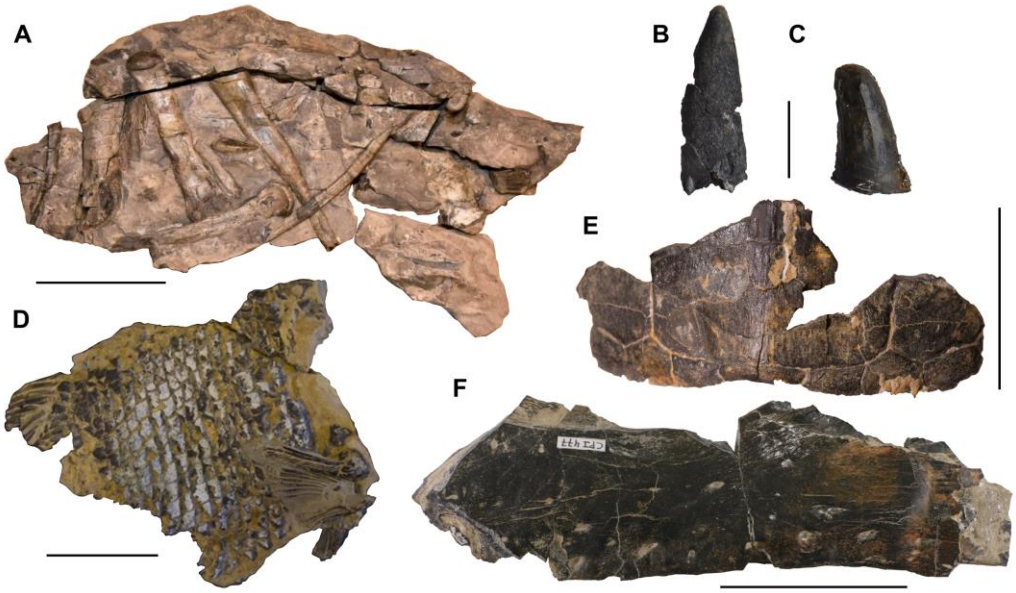


Figure 2. Fossil remains recovered from the Peña Cárcena sites. (A) remains of a partially articulated indeterminate theropod, (B) CPI 1623 (former ICIPLR 35), Baryonychinae indet. 1 tooth, (C) CPI 1616 (former ICIPLR 28), Baryonychinae indet. 1 tooth, (D) CPI 310, fairly complete lepisosteiform skeleton, (E) CPI 405, turtle shell fragment that could belong to Camerochelys, (F) CPI 477, *Baryonyx walkeri* left maxilla fragment. Scale bar 20 cm for (A), 1 cm for (B) and (C), and 5 cm for (D-F).

Figure 2. Restos fósseis recuperados em diferentes localidades na área de Peña Cárcena. (A) parte do esqueleto parcialmente articulado de um terópode indeterminado, (B) CPI 1623 (anteriormente ICIPLR 35), Baryonychinae indet. 1 dente, (C), CPI 1616 (anteriormente ICIPLR 28), Baryonychinae indet. 1 dente, (D), CPI 310, esqueleto praticamente completo de lepisosteiforme, (E), CPI 405, carapaça de tartaruga possivelmente relacionada a Camerochelys, (F), CPI 477, fragmento de maxila esquerda de *Baryonyx walkeri*. Escala 20 cm para (A), 1 cm para (B) e (C) e 5 cm para (D-F).

Table 1. Vertebrate-bearing sites and vertebrate fossil record at Peña Cárcena hill (Igea, Spain).

Tabela 1. Locais com restos de vertebrados e registo de vertebrados da colina de Peña Cárcena (Igea, Espanha).

Fossil site	Taxa	Referred material	Environment	Reference
Marino 1	Lepisosteiformes indet.	Fairly complete skeleton	Avulsion-belt in splay delta	This study
Marino 2	Theropoda indet.	Partially articulated skeleton	Mixed carbonate-siliciclastic lacustrine system	Isasmendi *et al.*, 2019
Colladillos 1	Dinosauria indet.	Partially articulated skeleton	Mixed carbonate-siliciclastic lacustrine system	This study
Colladillos 2	cf. *Camerochelys*	Shell fragment	Mixed carbonate-siliciclastic lacustrine system	This study
Colladillos 3	Pterosauria indet.	Isolated tooth	Mixed carbonate-siliciclastic lacustrine system	This study
Colladillos 4	Lepisosteiformes indet.	Fairly complete skeleton	Mixed carbonate-siliciclastic lacustrine system	This study
Colladillos 5	*Goniopholis* sp.	Isolated tooth	Mixed carbonate-siliciclastic lacustrine system	This study
La Cañada 1	*Baryonyx walkeri*	Partial left maxilla	Mixed carbonate-siliciclastic lacustrine system	Viera and Torres, 1995
Peña Cárcena 1	Baryonychinae indet. 1	Isolated tooth	Mixed carbonate-siliciclastic lacustrine system	Isasmendi *et al.*, 2020
Peña Cárcena 2	Baryonychinae indet. 1	Isolated tooth	Mixed carbonate-siliciclastic lacustrine system	Isasmendi *et al.*, 2020

and an indeterminate theropod, a large-sized dinosaur whose affinities are yet to be determined, and a pterosaur different from *Prejanopterus*. Most of the vertebrate remains heve been found in the deposits of the mixed siliciclastic-carbonate system, with only one partial skeleton of a lepisosteiform and scattered atchosaur bone fragments found in the splay delta deposits. This could be due either to a habitat preference of these taxa or to a shorter depositional time-span and high-energy of the inferred siliciclastic system.

7. Conclusions

The present study conducted in the Enciso Group at the Peña Cárcena hill (Igea, La Rioja) suggests that two different depositional environments developed during the Early Cretaceous in the area. The mixed siliciclastic-carbonate lacustrine system dominates the outcrop with an upwards change to a splay delta environment in an avulsion-belt. The deposits above the deltaic sediments atop of the hill would suggest the return of the mixed siliciclastic-carbonate lacustrine system. At Peña Cárcena, the fossil beds as a whole, show a highly diverse vertebrate fauna comprising hybodontiform and lepisosteiforms fishes, turtles, goniopholidid crocodyliforms, spinosaurid theropods and pterosaurs. Most of the vertebrate remains have been found in the mixed siliciclastic-carbonate lacustrine deposits.

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