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Molluscs from the fossil site of "Lo Hueco" (Upper Cretaceous, Cuenca, Spain): Palaeoenvironmental and sequential implications

Moluscos del yacimiento paleontológico de "Lo Hueco" (Cretácico Superior, Cuenca, España): Implicaciones paleoambientales y secuenciales

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ABSTRACT

In the exceptional site of "Lo Hueco" (Cuenca, Spain) more than 8500 macroremains of plants, invertebrates and vertebrates, including titanosaur sauropod dinosaurs, have been collected in a succession of Upper Cretaceous "Garumn" facies. This work describes the molluscs found together, interpreting their palaeoenvironmental and sequential meaning. The sample is comparatively scarce due to the urgency of the excavation, and to constraints of the preservational scenario, seemingly not ideal for the fossilization of carbonated remains. Thus, the absence of well preserved shells has motivated the use of open nomenclature. Bivalves are recorded by unarticulated marly mudstone moulds of *Margaritifera* sp., *Anodonta* sp., ?*Corbicula* sp. and *Pisidium* sp., and most gastropods by gypsum moulds of *Faunus* sp. This association indicates a typical freshwater palaeofauna, where the presence of Melanopsidae gastropods can suggest the sporadic influence of moderately brackish-water episodes. These data confirm previous palaeoenvironmental interpretations proposed for the site. Additionally, the presence of the terrestrial gastropod *Palaeocyclophorus* sp. in underlying beds with high proportion of vegetal terrestrial organic matter, and situated over an important erosive discordance, has allowed to locate the beginning of the depositional sequence of "Lo Hueco".

Key words: Mollusca, Systematics, Continental palaeoenvironments, Sequential stratigraphy, Upper Cretaceous, "Lo Hueco", Spain

RESUMEN

En el excepcional yacimiento paleontológico de "Lo Hueco" (Cuenca, España) se han obtenido más de 8500 macrorrestos de plantas, invertebrados y vertebrados, incluyendo dinosaurios saurópodos titanosaurios, en una sección del Cretácico Superior en facies "Garumn". El presente trabajo describe los moluscos recogidos, interpretando su significado paleoambiental y secuencial. La muestra obtenida resulta relativamente reducida debido a la urgencia de la excavación, y a que las condiciones diagenéticas posiblemente no han favorecido la preservación de restos carbonatados. En consecuencia, la ausencia de conchas bien preservadas ha obligado a la utilización de nomenclatura abierta. Los bivalvos identificados se encuentran representados por moldes margosos desarticulados de *Margaritifera* sp., *Anodonta* sp., ?*Corbicula* sp. y *Pisidium* sp., y la mayoría de los gasterópodos por moldes de yeso de *Faunus* sp. Esta asociación corresponde a una típica paleofauna de agua dulce, en la que la presencia de gasterópodos melanópsidos parece sugerir la influencia esporádica de episodios de agua salobre. Estos datos confirman las interpretaciones paleoambientales previas propuestas para el yacimiento. Adicionalmente, la presencia del gasterópodo terrestre *Palaeocyclophorus* sp. en niveles infrayacentes con una elevada proporción de materia orgánica vegetal, situados sobre una importante discordancia erosiva, ha permitido localizar el inicio de la secuencia deposicional correspondiente a "Lo Hueco".

Palabras clave: Mollusca, Sistemática, Paleoambientes continentales, Estratigrafía Secuencial, Cretácico Superior, "Lo Hueco", España

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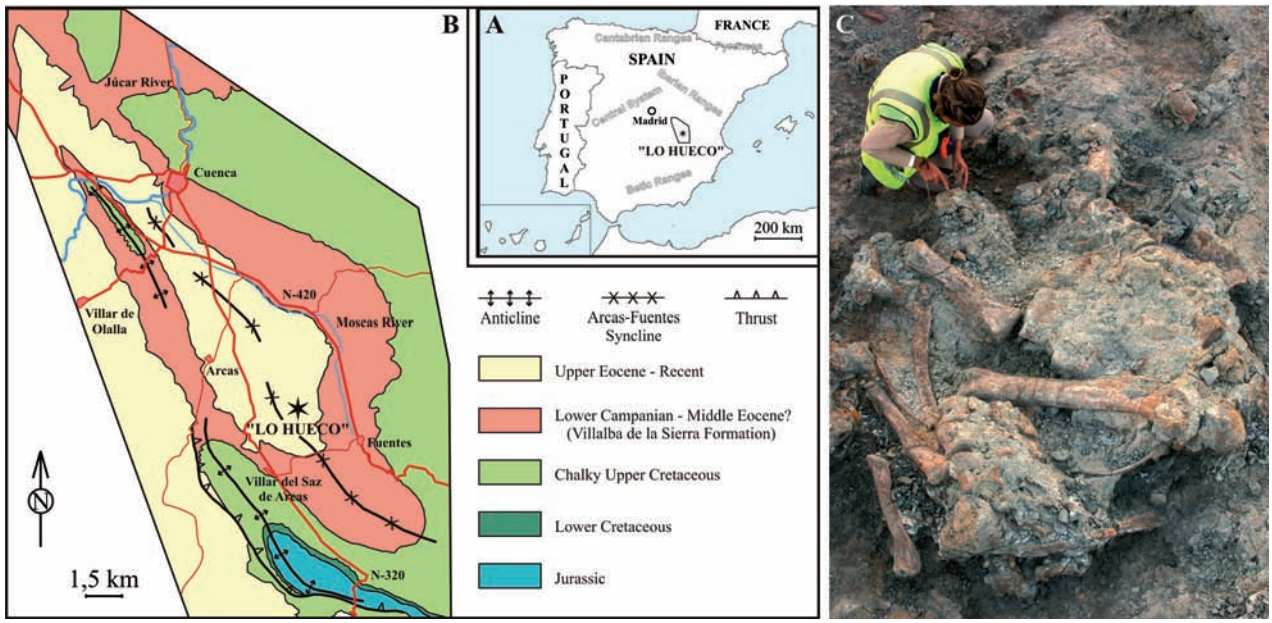

Fig. 1.—General setting and palaeontology of the fossil site of "Lo Hueco" and surrounding area. A, Geographical location. B, Detailed geological situation inside the Arcas-Fuentes Syncline. C, Bone accumulation of a titanosaur sauropod dinosaur.

Introduction

The exceptional site of "Lo Hueco" was discovered in 2007 in Cuenca, Spain, during the cutting of a little hill due to the construction of the Madrid-Levante highspeed railway, under Cenozoic conglomerates, in Upper Cretaceous marly mudstones (Fig. 1A-B). It includes a succession in "Garumn" facies of versicolor marly mudstone levels, partially cut by a sandy channel structure and two sulphated intervals. This site contains an extraordinary richness and diversity of fossils that constitutes a singular accumulation not only for the Spanish record but also for the whole upper Campanian-lower Maastrichtian European palaeontological record. To date, it has provided more than 8500 macroremains, mainly of vertebrates, such as actinopterygians (lepisosteids) and teleosteans fishes, amphibians, panpleurodiran (bothremydids) and pancryptodiran turtles, squamate lizards, eusuchian crocodiles, pterosaurs, and euornithopod (rhabdodontids), theropod (mainly dromaeosaurids) and sauropod (titanosaurs, some of them with nearly complete skeletons) dinosaurs, but also of plants and invertebrates (Ortega *et al.,* 2008; Barroso-Barcenilla *et al.,* 2009; Carenas *et al.,* 2011; Cambra-Moo *et al.,* 2012) (Fig. 1C). In order to a better characterization of the palaeoenvironmental and stratigraphical context of this important site, a detailed analysis of the collected sample with continental molluscs has been achieved here.

In "Lo Hueco" and surrounding area, the molluscan palaeofauna is represented by a limited number of small specimens, which have been preserved nearly all as composite and internal moulds with relicts of shell ornamentation. The scarceness of sampled molluscs results from the extreme urgency of the excavation (with the use of heavy machinery to recover the largest possible number of fossil remains and thus, the lack of methodical sieving procedure of molluscs), but can also be due to the fact that the preservational scenario was not the ideal for the fossilization of these thin and fragile carbonated remains. Both factors surely biased the real abundance and diversity values of these invertebrates in the original palaeoenvironment.

Nevertheless, the continental molluscs, including many families of land snails and freshwater bivalves and gastropods, are common guests in many Upper Cretaceous vertebrate sites, where they usually occur inside a variety of fine-grained siliciclastic rocks related with alluvial plain, lake or marsh palaeoenvironments, and can be used as useful palaeoecologic indicators when combined with other interdisciplinary data. Since the early works of Vidal (1874), Matheron (1876) and Tournouer (1879), among others, many of these molluscs have been described from the so called "Garumn" facies, an informal term

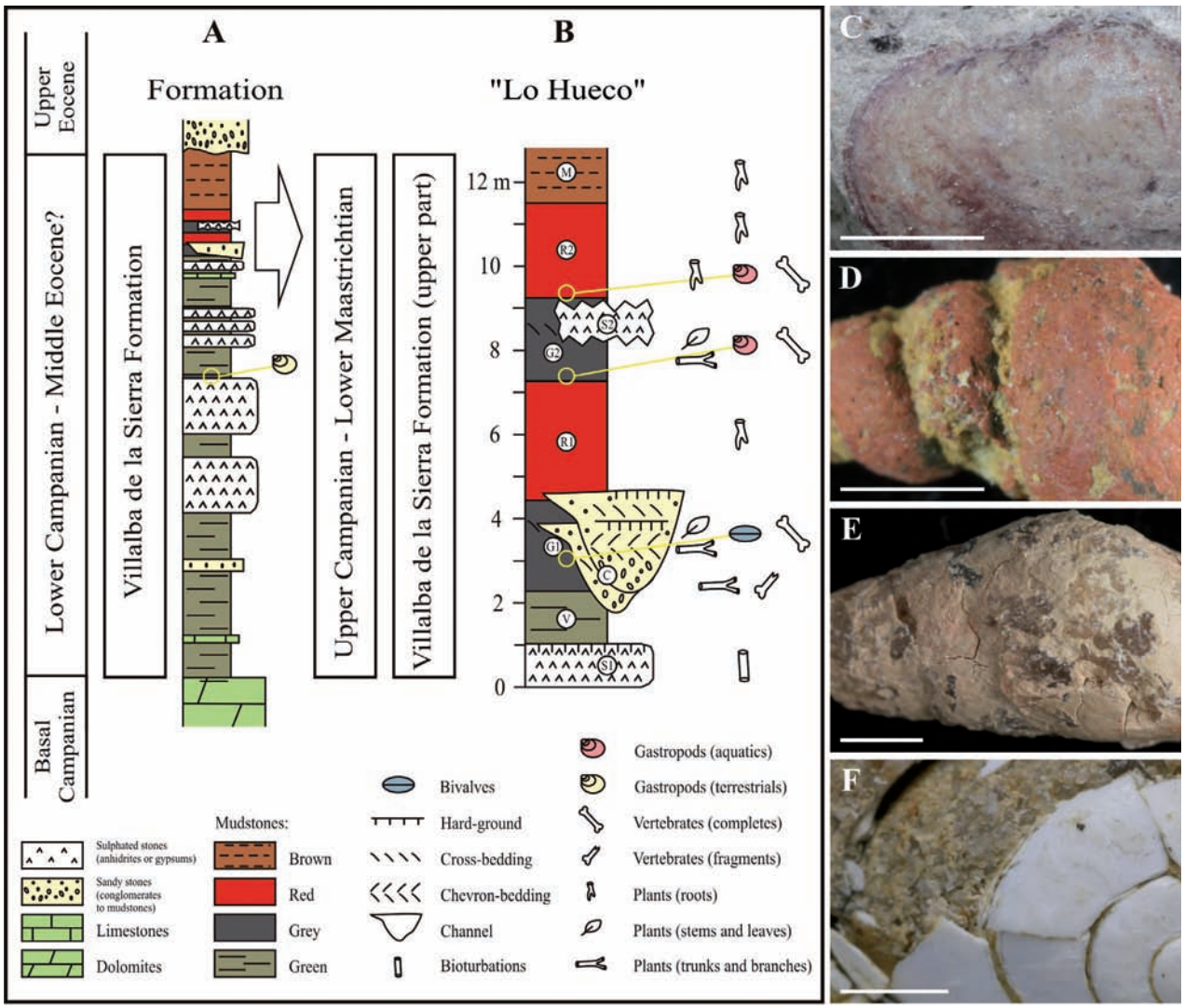

Fig. 2.—Geology of "Lo Hueco" and surrounding area, and taphonomy of their molluscs. A-B, Sections of the Villalba de la Sierra Formation (schematic, 2A), and of the site (detailed, 2B). C-F, Detailed views of a marly mudstone composite mould of bivalve from the G1 level (2C), a marly mudstone internal mould of gastropod from the base of the G2 level (2D), a gypsum composite mould of gastropod from the lower part of the R2 level (2E), and a sandy internal mould of gastropod with shell fragments from the base of the upper part of the Villalba de la Sierra Formation (2F). Scale bars are 2 mm.

for marls, clays and gypsums, mainly of reddish coloration, deposited in shallow marine, coastal or continental environments of south-western Europe during Latest Cretaceous and Early Palaeogene. Thick series of these clayey and reddish materials have been widely recorded in the South of France (Provence and Northern Pyrenees), Centre and North of Spain (Iberian Ranges, Ebro Basin and Southern Pyrenees) and West Portugal (Beira Littoral and Estremadura), sometimes with remarkable invertebrate faunas (Oppenheim, 1895; Cotter, 1901; Repelin, 1906-1907; Roman, 1917; Bataller, 1949; Fabre-Taxy, 1951, 1959; Antunes & Pais, 1978; Antunes, 1979; Antunes & Broin, 1988; Antunes & Russel, 1996; García *et al.,* 2000), suggesting a long interval of continental stability on the sedimentary systems, and a significant absence of marginal relieves.

It is very interesting to note that the freshwater bivalve assemblages already known from these environments are markedly conservative, showing many taxonomic similarities with Cenozoic palaeofaunas of Western Europe. On the contrary, the terrestrial and freshwater gastropod palaeofaunas are significantly different, mixing a combination of

Cretaceous relict families and genera, with other taxa also recorded from Paleogene deposits, and a few families with more recent ranges outside the Palearctic areas of Europe. Even though a satisfactory knowledge of the mollusc palaeofaunas of the "Garumn" facies will need further researches, which will be certainly confronted with the scarcity of well-preserved specimens, the bivalves and gastropods here presented from "Lo Hueco" can be seen as an additional case study for the resolution of this complex puzzling.

Geographical and geological setting

The "Lo Hueco" site is located in the middle east of Spain, in the centre of the province of Cuenca, close to the village of Fuentes. It is situated in the south-western branch of the Iberian Ranges, on the Arcas-Fuentes Syncline, and includes a stratigraphic interval in the "Garumn" facies belonging to the upper part of the "Margas, Arcillas y Yesos de Villalba de la Sierra" Formation (Vilas *et al.,* 1982) (Fig. 1A-B). As detailed by Barroso-Barcenilla *et al.* (2009) and Carenas *et al.* (2011), the heterolithic and little known Villalba de la Sierra Formation has a thickness that varies widely, but in the areas where this marly, muddy and gypsiferous unit is thicker, it reaches up to 500 m (Vilas *et al.,* 1982) and seems to range from the lower Campanian (Gil *et al.,* 2004) to the middle Eocene (Ramírez-Merino, 1989). The Villalba de la Sierra Formation has been interpreted as deposited in a coastal marsh with distributary channels of terrigenous materials that suffered the sporadic establishment of sebkhas, the accumulation of clastics, mainly due to storms, and the draining of certain areas (Albert-Colomer & Ferreiro-Padín, 1998; Lendínez-González *et al.,* 1998) (Fig. 2A).

This lithostratigraphic unit can be divided into three intervals. The lower one consists of green marly mudstones with chalky and terrigenous canalized interbeds, probably formed in a coastal plain or marsh. The middle interval, informally defined as the "Bascuñana member" (Meléndez-Hevia, 1971), consists of massive or nodular anhydrite and gypsum beds with thin dolomitic and calcitic bioclastic interbeds. It can be related to a coastal sebkha with periodical influence of storms. The upper interval, to which belongs the stratigraphic succession of "Lo Hueco", consists of versicolor marly mudstones with chalky and sandy interbeds. It seems to correspond to a muddy coastal flood plain crossed by distributary sandy channels, exposed to brackish to fresh water aquatic influences, and with edaphic intervals (Albert-Colomer & Ferreiro-Padín, 1998; Lendínez-González *et al.,* 1998; Barroso-Barcenilla *et al.,* 2009) (Fig. 2A).

Specifically, in "Lo Hueco", a stratigraphic succession of green (V), grey (G1), red (R1), grey (G2), red (R2) and brown (M) levels of marly mudstones separated by gradual boundaries can be identified. This succession becomes partially modified in the eastern area of the outcrop by a first sulphated interval (S1) that cuts the V level by means of a net boundary, in the southern area of the outcrop by a sandy channel structure (C) that interrupts the V, G1 and R1 levels by means of an erosive surface, and in the north-eastern area of the outcrop by a second sulphated interval (S2) that distorts at least part of the G2 level by means of a net boundary. Most of macrofossils are concentrated in only four of these lithosomes: the C structure, the G1 and G2 levels and the lower part of the R2 level (Barroso-Barcenilla *et al.,* 2009; Carenas *et al.,* 2011; Cambra-Moo *et al.,* 2012) (Fig. 2B).

Taphonomy

Taking into account first palaeoecological approximation relating to "Lo Hueco" fossil site (Barroso-Barcenilla *et al.,* 2009), and recently published preliminary taphonomic analysis (Cambra-Moo *et al., in press.*), herein are presented the first detailed data relating mollusc preservation. Molluscs (bivalves and gastropods) were mainly recovered from different parts of the outcrop and surrounding area during excavation phase.

Specifically, bivalves were recovered in the southern area of the outcrop from the G1 level (Fig. 2B), corresponding to the proximal part of a flooded muddy plain (close to the distributary channels). Specimens are of small size, ranging from 0.5 to 3.6 centimetres, and are preserved as composite moulds of marly mudstone partially covered with an iron oxide film formed by sedimentary infilling (sedimentary pseudomorphism *sensu* Fernández-López, 2000, Fig. 2C). Unfortunately, these moulds do not preserve evidences of internal structures or hinge details. No shell remains have been found within these specimens, and nearly all of them have been recovered as isolated valves, it is said, always disarticulated. These features indicate that bivalve's soft tissues were

probably decayed before or during biostratinomic transformation (they were disarticulated before burial). After that, diagenetic alteration degraded carbonated shell until been completely disappeared. As denoted in previous works, other carbonated remains, such as charophytes, small fragments of mollusc shells and faecal pellets, also are scarce, whereas to date, ostracods have not been found in the outcrop, suggesting the disappearance of almost all carbonated fossils.

A single gastropod was obtained from screen-washing and picking of sediments for vertebrate microfossil analyses from the base of the G2 level (Fig. 2B) and is preserved as an internal mould of marly mudstone (Fig. 2D). Nevertheless, the remaining gastropods from "Lo Hueco" came out from the lower part of the R2 level (Fig. 2B), interpreted as the transition between a distal part of a flooded muddy plain (distant from the distributary channels) and the partially or totally dried part of a muddy plain. These specimens, smaller than 1 centimetre, were recovered in the northeast part of the outcrop and appear preserved as composite moulds of gypsum. Unlike what happened with bivalves, these gastropods seem not to be biostratinomic altered, and probably they were trapped in life position or after a short transport, losing their organic tissues after been finally buried. Ulterior gypsum precipitation filled the shell cavities (chemical precipitation of colloidal substances that coat the internal cavities *sensu* Fernández-López, 2000, Fig. 2E). As described for bivalves, no shells have been found and details of ornamentation have also been preserved as impressions on these composite moulds of gypsum.

Additional gastropods were recovered from stratigraphically underlying beds, in the base of the upper interval of the Villalba de la Sierra Formation (Fig. 2A), interpreted as a terrigenous canalized interbed with high proportion of terrestrial organic matter. These gastropods are slightly larger than the previous specimens, close to 1,5 centimetres, and are preserved as slightly crushed sandy internal moulds partially covered by shell fragments (Fig. 2F).

Systematic Palaeontology

Due to the extreme urgency of the excavation process and to the fact that the preservational scenario was not the ideal for the fossilization of carbonated remains, the number of collected specimens is low and do not reflect the original abundance and diversity of these invertebrates in the palaeoenvironment. The sample consists of a scarce number of 15 specimens preserved with relicts of shell ornamentation. Specifically, eight disarticulated bivalves belonging to four genera and families of freshwater environments, six specimens from two fresh- or brackish-water gastropods species and a land-snail have been identified. Nowadays, these specimens are temporarily housed in Cuenca, at a storehouse rented by the Museo de las Ciencias de Castilla-La Mancha.

The systematic layout used for the taxonomic categories above the genus and family ranks was based in Moore (1969) and Bieler *et al.* (2010) for the bivalves, and Wenz (1938-44), Bouchet & Rocroi (2005) and Bandel, (2006) for the gastropods. Nevertheless, the small sample and the incomplete preservation of specimens have motivated the use of open nomenclature, but is likely that some of these specimens belong to yet undescribed species, at least for the Upper Cretaceous palaeofaunas of Spain.

Phylum MOLLUSCA (Linné, 1758) Cuvier, 1795
Class BIVALVIA Linné, 1758
Superorder HETEROCONCHIA Cox, 1960
Clade PALAEOHETERODONTA Newell, 1965
Order UNIONIDA Stoliczka, 1871
Family *Margaritiferidae* Haas, 1940
Genus *Margaritifera* Schumacher, 1815
Margaritifera sp.
(Figure 3A)

Studied material: A composite mould of right-valve partly spotted by a thin film of iron oxide.

Description: Elongated valve with a rather subrectangular and compressed shape, and a slightly concave ventral margin. The posterior half side of the dorsal margin is almost straight, and shows a large ligamental area. The anterior margin is rounded. There are a significant number of concentric growth lines, closer over the ventral flanks of the valve. The umbonal area and the posterior end are incomplete. Valve length of approximately 35 mm and 15 mm of height.

Remarks: Despite the lack of the hinge area, the concave ventral margin and the overall shape of the studied specimen suggest that we are in presence of a Margaritiferidae. The genus *Margaritifera* is known at least since the Late Cretaceous, and has a large Palearctic and Nearctic distribution in fresh-water environments that reaches to the Iberian Peninsula (Nobre, 1941; Reis, 2006).

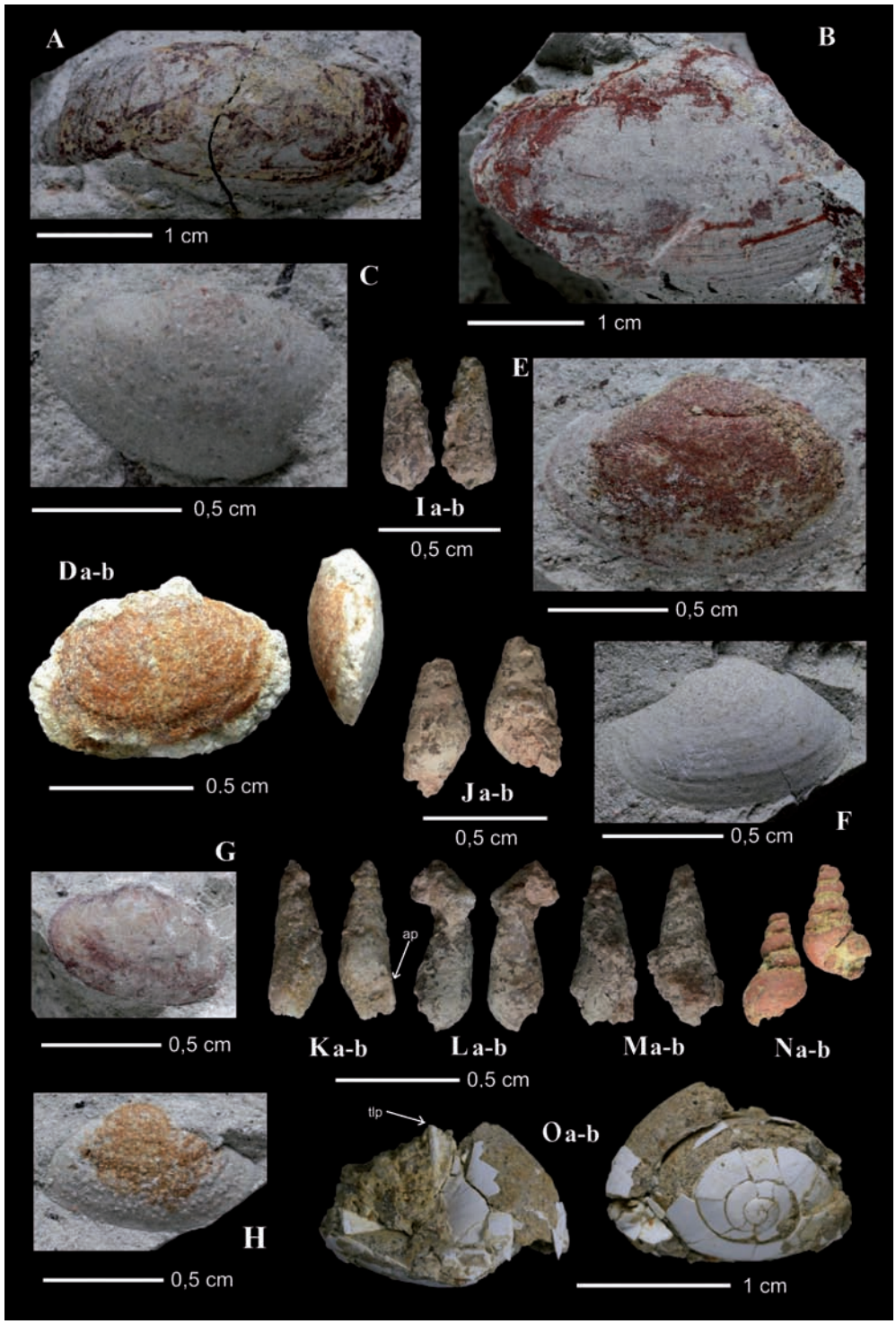

Fig. 3.—Bivalves and gastropods of "Lo Hueco" and surrounding area. A, *Margaritifera* sp. Composite mould of a right valve (note the slightly inflected ventral side). B-C, *Anodonta* sp. Composite moulds of a right valve (fragment, 3B), and of a left valve from a young specimen (3C). D, ?*Corbicula* sp. Composite mould of a right valve with well-impressed concentric folds: frontal (a) and lateral (b) views. E-H, *Pisidium* sp. Composite moulds of left valves (3E-F, H), and of a right valve (fragment, 3G). I-M, *Faunus* sp. A. Composite moulds of gypsum mineralization: abapertural (a) and apertural (b) views (ap - note the melanopsid like aperture in 3K). N, ?*Faunus* sp. B. Internal mould with reddish matrix: abapertural (a) and apertural (b) views. O, *Palaeocyclophorus* sp. Crushed shell and internal mould: basal (a) and upper (b) views (tlp - note the thick and slightly reflected outer lip).

Family Unionidae Fleming, 1828
Subfamily Anodontinae Ortmann, 1910
Genus *Anodonta* Lamarck, 1799
Anodonta sp.
(Figure 3B-C)

Studied material: A left valve mould of a juvenile specimen (Fig. 3B) and a fragment of right valve (Fig. 3C).

Description: The smaller valve has a rounded, elliptical, slightly inflated shape and 11 mm of length, and 7 mm of height. The dorsal hinge line is moderately curve, with an acute anterior end. The surface is almost smooth with exception for several concentric growth lines. The additional fragment is an inflated composite mould of right valve, with 36 mm of length and well-marked growth lines.

Remarks: This unionid genus is widespread on northern Hemisphere, from the Upper Cretaceous onwards (Moore,1969). The hinge area of the studied valves is not visible, but the rounded, elliptical shape and simple ornamentation are diagnostic of *Anodonta*.

Clade HETERODONTA Neumayr, 1883
Order VENERIDA H. & A. Adams, 1854
Superfamily Corbiculacea Gray, 1847
Family Corbiculidae Gray, 1847
Genus *Corbicula* Mühlfeld, 1811
?*Corbicula* sp.
(Figure 3D)

Studied material: A small mould of right-valve sampled at the lower part of the R2 level of "Lo Hueco".

Description: A slightly asymmetric, ovate mould of right valve with a well-defined ornamentation of rather strong concentric folds.

Remarks: This kind of shape and strong ornamentation are found in many fossil and recent forms of Corbiculacea, including the Lower Cretaceous to recent type genus *Corbicula*. However, with the hinge details unpreserved, there is no way to confirm if the typical strong and serrate lateral teeth are present. *Corbicula* is a cosmopolitan genus with a large and widespread fossil record. Most species inhabit in freshwater environments, but some others can support brackish conditions.

Family Pisidiidae Gray, 1857
Genus *Pisidium* Pfeiffer, 1821
Pisidium sp.
(Figure 3E-H)

Studied material: Three small moulds of left valve and a mould of right valve.

Description: Valve moulds are small, slightly convex, with a rounded and ovate shape, and surfaces covered by numerous, weak, concentric growth lines.

Remarks: The overall shape and ornamentation are indicative of the Pisidiidae, a widespread family of freshwater bivalves known since the Upper Cretaceous (Moore, 1969). The mould of Fig. 3H is a typical example of *Pisidium*, identical to several Cenozoic species of this morphologically conservative genus. The Pisidiidae is a cosmopolitan family of bivalves adapted to freshwater conditions, sometimes very restricted.

Class GASTROPODA Cuvier, 1795
Clade CAENOGASTROPODA Cox, 1960
Superfamily *Cerithioidea* Fleming, 1822
Family Melanopsidae H. & A. Adams, 1854
Genus *Faunus* Montfort, 1810
Faunus sp. A
(Figure 3I-M)

Studied material: Five composite moulds filled with gypsum and remains of aperture and spiral ornamentation preserved.

Description: The overall shape is conical elongated, with a moderately high spire composed by 7-8 slightly rounded whorls and a shallow suture line. From specimen of Fig. 3J it can be seen that the aperture is a melanopsid like pear-shaped, narrow and angled at the top, and rounded at the base. The ornamentation is partly preserved on specimen of Fig. 3L as five regularly spaced spiral bands perceptible on the periphery of body-whorl.

Remarks: The morphologic details are close to the Melanopsidae, namely to the genus *Faunus* known from the Upper Cretaceous of Europe, and worldwide widespread during the Cenozoic (Wenz, 1938-44). The studied material comes from the lower part of the R2 level of "Lo Hueco". It likely belongs to a new species, but the preservation is not enough for a specific description.

?*Faunus* sp. B
(Figure 3N)

Studied material: A single internal mould of reddish mudstone.

Description: Internal mould of a small shell with conical shape, comprising a spire with 5-6 whorls, an expanded body whorl with a slightly marked median carina, and an aperture rounded at the base and sharply angular at the top.

Remarks: This specimen comes from the base of the G2 level of "Lo Hueco". Preservation is deficient but the overall shape and the aperture contour suggest an additional Melanopsidae species related with the previous taxon.

Superfamily Cyclophoroidea Gray, 1847
Family Cyclophoridae Gray, 1847
Genus *Palaeocyclophorus* Wenz, 1923
Palaeocyclophorus sp.
(Figure 3O)

Studied material: Two crushed specimens with internal mould and partial shell, collected at the lower part of the studied section, equivalent to the base of the upper interval of the Villalba de la Sierra Formation.

Description: The morphologic details show a slightly depressed globular, rather keeled species of terrestrial gastropod, with a low convex spire of 4 whorls. On the lower half of the crushed shell a considerably thick and slightly reflected outer lip is preserved, as part of a round mouth. The external ornamentation is poorly preserved, but fine growth-lines are visible. The overall diameters reach 15 mm.

Remarks: According to Wenz (1938-44), *Palaeocyclophorus* is a Late Cretaceous to Eocene genus with a type species known from the Thanetian of France, *P. helicinaeformis* (Boissy, 1848), and mentioned in the *Prodrome* of d'Orbigny (Pacaud, 2007). More recently, *Palaeocyclophorus* has been found in several sections of vertebrate sites from the Maastrichtian of Provence, France (Kerourio, 1987; García *et al.,* 1999; García, 2000). Most of these specimens were collected in beds with food-plain and channel belt facies, analogous to the palaeonvironments of "Lo Hueco". In the same way, the shell shape and the rounded mouth with the thick and reflected outer lip of the here studied specimens are diagnostic features of *Palaeocyclophorus* yet poorly known from the Iberian Upper Cretaceous continental series.

In the review of the Maastrichtian faunas of Provence, Fabre-Taxy (1959) also describes at least 5 species of *Cyclophorus* Montfort, 1810, from diverse localities. Nevertheless, these taxa should be assigned to *Palaeocyclophorus* or other closely related genera, since *Cyclophorus* is a more recent genus with a Late Cenozoic range. The same is probably true for several other examples of "*Helix*" or *Cyclophorus* cited in older works dealing with the "Garumn" facies of southwest Europe.

Bandel (2002) proposed the family Palaeocyclophoridae to group these Late Cretaceous, Paleocene and Eocene gastropods. According to Bouchet *et al.* (2005) this name cannot be available since there is not citation of the name of the type genus. Thus, family Cyclophoridae is here used in a broad sense.

Palaeoenvironmental and sequential significance

Most of the studied mollusc specimens from "Lo Hueco" (Fig. 4A-B) are representative of a freshwater palaeofauna dominated by unionid and heterodontid bivalves. The occurrence of some melanopsid gastropods also suggests the sporadic influence of moderately brackish-water episodes. These interpretations are consistent with an autecological analysis based on taxonomically related modern representatives. They also confirm previous interpretations of the sedimentologic, taphonomic and palaeontological data from the fossil site (Barroso-Barcenilla *et al.,* 2009; Cambra-Moo *et al.,* 2012).

At the same time, the single occurrence of disarticulated bivalves, some of them belonging to genera with relatively robust hinges, could be related with more energetic local events lying on the dependence of distributary channels with significant flows (and floods). Much possibly, the oligohaline to mesohaline brackish gastropod Faunus, is here interpreted as an indicator of some sporadic influence of marine conditions related with a rather close communication with the seashore and the stronger tidal streams.

A preliminary sequential analysis of the whole of the Villalba de la Sierra Formation, which has been partially or totally related to the UZA-4 second order eustatic cycle of Haq *et al.* (1988) by Segura *et al.* (2002, 2006), Gil *et al.* (2004) and Torres *et al.* (2006), among others, reveals the presence of sandy grey mudstones with terrestrial gastropods (*Palaeocyclophorus*) and high proportion of terrestrial organic matter of vegetal origin (Fig. 4A, C), in underlying beds to "Lo Hueco", located immediately over a marked erosive discordance. This fact has allowed to confirm the existence of an important sedimentary discontinuity that limits two major transgressive-regressive depositional sequences. The same main boundary was formed by a process of subaerial exposition and subsequent erosion ("karstification") of sulphated beds and infilling of the more depressed areas with sandy mudstones, during a main regression with strong terrestrial influence.

This sedimentary discontinuity limits a first major transgressive-regressive depositional sequence, corresponding to the lower and middle ("Bascuñana member") part of the Villalba de la Sierra Formation. It is composed mainly by green marly mudstones (lower interval) and anhydrites and gypsums (upper interval). The second major depositional sequence, coinciding to the upper part of the Villalba de la Sierra Formation, is mainly constituted by versicolor marly mudstones, and contains, among others, the materials corresponding to the "Lo Hueco" fossil site. As suggested by Meléndez-Hevia (1971) and Viallard (1973), both intervals could be divided in several minor depositional sequences with a clear regressive and shallowing tendency.

Laterally, the main part of the Villalba de la Sierra Formation seems to be related northward to the "Calizas, Arcillas y Arenas rojas de Santibáñez del Val" Formation (Floquet *et al.,* 1982) in the Iberian Ranges, and to the "Margas de Sedano", "Calizas de Valdenoceda" (both Floquet *et al.,* 1982) and "Sobrepeña" formations (Floquet, 1991) in the Cantabrian Ranges, and south-eastward, probably to

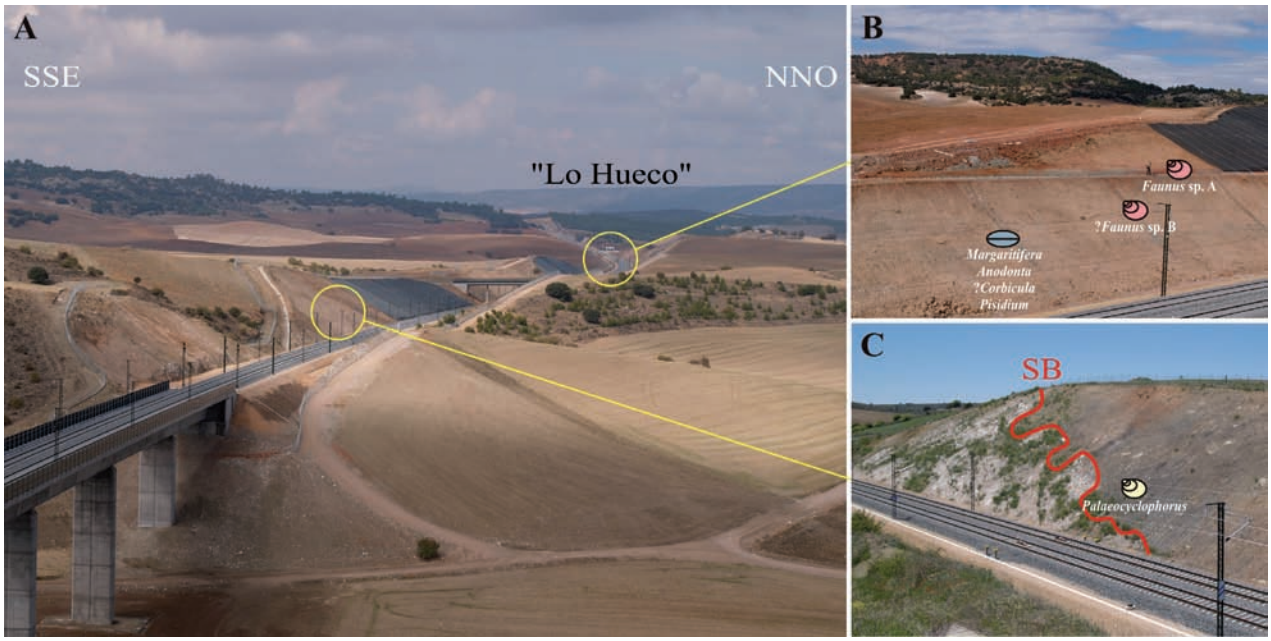

Fig. 4.—Photographic view of the Madrid-Levante highspeed railway in "Lo Hueco" and surrounding area. A. General view with the origin of the collected molluscs. B. Detailed view of "Lo Hueco", indicating the beds that have provided bivalves and aquatic gastropods. C. Detailed view of the base of the upper part of the Villalba de la Sierra Formation, with the boundary between two depositional sequences (SB), indicating the beds which have provided terrestrial gastropods.

the "Calizas y Margas de la Sierra Perenchiza" Formation (Vilas *et al.,* 1982). Precisely, the base of Valdenoceda Formation has been described as an erosive unconformity (cycle boundary) tied to siliciclastic inputs, followed by a generally thin transgressive systems tract and by a thick highstand (regressive) systems tract (Berreteaga, 2011), and seems to coincide to the sequence boundary (seemingly of third order *sensu* Haq *et al.,* 1988) identified in the here presented research (Fig. 4C).

Conclusions

It is known that molluscan associations with bivalves and gastropods are useful for integrated palaeoenvironmental reconstructions. This is true for many examples of fossil sites with remains of terrestrial vertebrates, including dinosaurs (Callapez, 2003a, 2003b), since many Meso-Cenozoic continental taxa have close modern representatives. This fact makes easier the application of palaeoecologic analysis to complete the data inferred from the vertebrate groups.

For the exceptional palaeontological site of "Lo Hueco" it has been possible to sample only a small collection of freshwater bivalves and, possibly, low brackish-water gastropods. Specifically, bivalves are recorded by marly mudstone composite moulds belonging to freshwater unionids of families Margaritiferidae (*Margaritifera*) and Unionidae (*Anodonta*), and heterodontids of families Corbiculidae (?*Corbicula*) and Pisidiidae (*Pisidium*). Gastropods are mostly known by composite moulds of gypsum corresponding to, at least, two species of Melanopsidae (*Faunus*) that suggest some influence of moderately brackish conditions. All bivalves have been found disarticulated, a fact that can be related with some energetic flooding episodes on the palaeoenvironment. These systematic and palaeoecologic data on molluscs from this site are in accordance with an upper Campanian-lower Maastrichtian near-coast continental muddy flood plain crossed by distributary sandy channels, exposed intermittently to brackish or marine tidal influx, freshwater flooding, and partial or total desiccation.

The presence of terrestrial gastropods (*Palaeocyclophorus*) in stratigraphically underlying beds with high proportion of vegetal terrestrial organic matter, over an important sedimentary discontinuity (erosive discordance), has allowed the location of the

beginning of the depositional sequence corresponding to "Lo Hueco".

In spite of the scarceness of specimens and the lack of better conditions of preservation, these bivalves and gastropods have been studied as part of the integrated palaeontologic analysis in course for the more than 8500 fossil remains already collected, proving that molluscs can be an useful additional indicator for ecologic, palaeoenvironmental and sequential purposes.

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