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Upper Campanian continental oncolites in the Montalbán subbasin (Allueva Fm, Iberian Chain)

Oncolitos continentales en el Campaniense superior de la Cuenca de Montalbán (Allueva Fm, Cordillera Ibérica)

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ABSTRACT

This study focuses on the analysis of the oncolites found in the Allueva Fm, an uppermost Cretaceous (middle-upper Campanian) alluvial unit deposited during the initial stages of development of the compressional Montalbán Subbasin (Iberian Chain). Successive oncolitic levels are found in the upper part of the formation, westwards the locality of Fonfría (northern Teruel province). There, the 45 m-thick succession logged consists of an association of oncolitic limestones, mudstones and marlstones. Oncoid sampling has been done for petrographic description and isotopic analysis. Oncoids are accumulated in up to 1 m-thick lenticular levels, and show spherical to elliptical shapes with sizes ranging between 1 and 15 cm, the smallest being oncoids dominant. Oncoid lamination is concentrical with almost no irregularities (SS-C oncoids), indicating constant movement. A preliminary isotopic study performed of successive oncoid laminations is coherent with a fresh-water environment with sub-humid climatic conditions.

Key-words: *Oncoid, isotopes $\delta^{18}O$ $\delta^{13}C$, Cretaceous, Allueva, Alluvial.*

RESUMEN

Este estudio se centra en el análisis de niveles oncolíticos encontrados en la Formación Allueva, una unidad aluvial de edad Campaniense medio a superior depositada durante las etapas iniciales de desarrollo de la subcuenca compresiva de Montalbán (Cordillera Ibérica). La acumulación de oncoides se encuentra en la parte superior de la formación, y aflora hacia el oeste de la localidad de Fonfría (norte de la provincia de Teruel). Allí, la sucesión de 45 m de espesor consiste en una asociación de calizas oncolíticas, lutitas y margas. Se ha realizado un muestreo de los oncoides para su descripción petrográfica y análisis isotópico. Los oncoides se acumulan en capas lenticulares de hasta 1 m de espesor, y presentan formas esféricas a elípticas con tamaños que oscilan entre 1 y 15 cm, dominando los oncoides de menor tamaño. La laminación es concéntrica con casi ninguna irregularidad (oncoides SS-C), lo que indica condiciones de movimiento constante. Un estudio isotópico preliminar llevado a cabo en láminas sucesivas de oncoides es coherente con un ambiente de agua dulce bajo condiciones climáticas subhúmedas.

Palabras clave: *Oncoide, isótopos $\delta^{18}O$ $\delta^{13}C$, Cretácico, Allueva, Aluvial.*

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Introduction and geological setting

The Montalbán subbasin is a narrow intramountain compressional trough located between the Montalbán anticline and the Utrillas thrust, in the northern Teruel province (Fig. 1A, B). This subbasin records a c. 2 km-thick uppermost Cretaceous-Paleogene syntectonic terrigenous-dominated succession of alluvial deposits, varying from conglomerates and sandstones at the basin margins to lacustrine carbonate-dominated succession at the basin center (e.g. Casas *et al*., 2000). In the lower part of this continental succession, the 500–700 m-thick uppermost Cretaceous (middle-late Campanian) Allueva Fm records the initial stages of evolution of the Montalbán subbasin, coeval to the onset of the uplift of the Montalbán anticline (Aurell *et al*., 2022).

The Allueva Fm is mostly dominated by reddish mudstones, cross-bedded or bioturbated sandstones and conglomerates. The formation was subdivided in 4 subunits (A1-A4 after Aurell *et al*., 2022). Of particular interest is the subunit A2, which includes several vertebrate sites with abundance of titanosaur sauropod dinosaurs as well as the presence of ornithopod dinosaurs and crocodylomorphs (Aurell *et al*., 2022). These sites are concentrated around the carbonate-dominated successions found around the localities of Allueva and Fonfría, which consist of up to 80 m-thick alternating limestones and mudstones/marlstones. Locally, near Fonfría (Fig. 1C), the subunit A2 contains beds with strong accumulation of semi-spherical oncoids. The presence of oncolitic levels here opens the door to more detailed palaeoenvironmental studies in the lacustrine deposits found locally in the Allueva Fm. The occurrence of oncoids in the latest stages of the Cretaceous has already been studied in the Pyrenees (Freeman *et al*., 1982; Ayera *et al*., 2012). Therefore, this work provides a great opportunity to start deciphering the origin and significance of oncoids locally recorded in the uppermost Cretaceous successions of the Iberian Ranges.

Methodology

A 45 m-thick stratigraphic log has been done westwards the locality of Fonfría (Fig.1C), in the fossil site known as Carramatilla. Figure 2 shows the schematic log with indication of main textures,

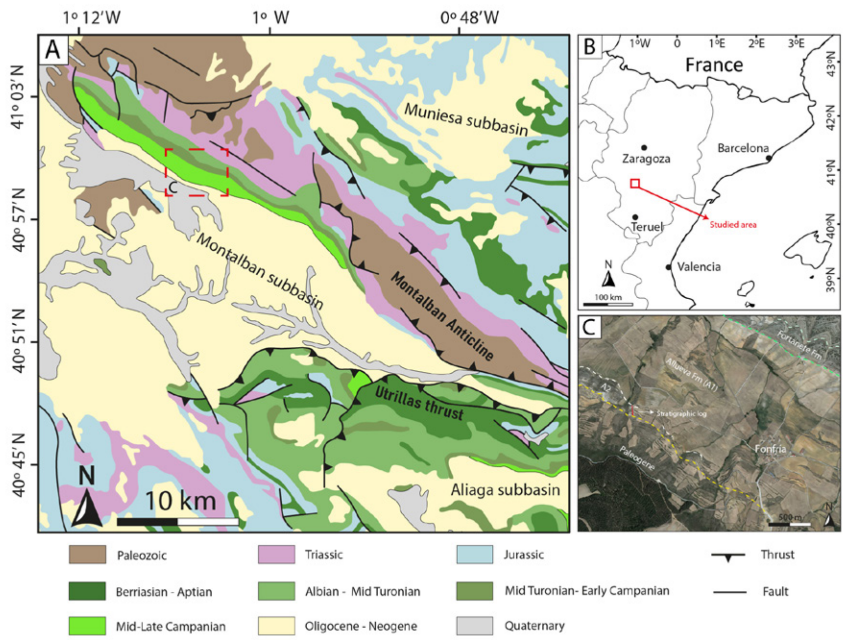

Fig. 1.- A) Geological map of Montalbán subbasin (modified after Torromé *et al*., 2022). B) Geographical location of the study area. C) Satellite view of the area indicating boundaries between the different units and the location of the stratigraphic log (see Fig.2)

Fig. 1.- A) Mapa geológico de la cubeta de Montalbán (modificado de Torromé et al., 2022). B) Localización geográfica del área de estudio. C) Imagen satélite del área indicando los límites entre las diferentes unidades y la localización de la columna estratigráfica (ver Fig.2).

lithologies and location of dinosaur bones and oncolitic levels where sampling was performed. 10 samples of oncoids of different size were taken and cut in half with a diamond blade and polished in order to analyse the internal structure in a binocular microscope. Two thin sections from a single oncoid were analyzed with a petrographic microscope. Additionally, some small slabs were observed under scanning electron microscope (SEM), and also went under EDS analysis in ZRC SAZU, Ljubliana.

A $\delta^{13}C$ and $\delta^{18}O$ isotopic analysis has been carried out in a 13 cm-size oncoid from the collected 10 samples, targeting successive concentric layers. Powder samples (>0.1g) were taken using a microdrill Supershu Marathon N3S S05 and saved in vials. Isotopic analysis was performed in the "Servicio de análisis de isótopos estables" from University of Salamanca.

Description of the outcrop and oncoids

Limestone beds in the analysed Fonfría log range between dms- to 1 m-thick. The log starts with laterally continuous slightly-tabular to irregular beds, which are dominated by mudstone-wackestone textures with gastropods and charophyte fragments (Fig. 2). Upwards, beds containing accumulation of oncoids are highly irregular with lenticular shapes (Fig. 3A), laterally disappearing or abruptly changing to more clastic facies. Furthermore, these irregular beds can also display microbial mounds. The m-thick oncolitic beds are normally graded (Fig. 3B), being the most common pattern accumulation of small oncoids (<1cm), which progressively changes upwards to an accumulation of bigger cm-size oncoids at the top of the beds. The opposite pattern, an eroding base of big oncoids decreasing size towards to the top has been identified in one isolated bed.

An oncoid is a type of microbialite formed on a mobile substrate (Riding, 2000). Diameter of oncoids ranges between less than 1 cm to 15 cm. However, most oncoids are smaller than 5 cm in diameter and always show semi-spherical to slightly elliptical shapes (Fig. 3C, D). The oncoids found in Fonfría show micrite-rich textures, lamination and rare microbial remains (Flügel, 2004). These oncoids can also be classified as SS oncoids (Logan *et al*., 1964). SS are subdivided in different recognizable modes, being mode SS-C (concentrically stacked spheroids), the most common pattern found in this study. However, some oncoids display internal micro-unconformities, so mode SS-R (randomly stacked hemispheroids) is also present.

The internal structure of these oncoids mainly consists of alternating smooth and dense concentric layers that normally ranges between 100 to 500µ (SS-C, Fig. 3C-F), but in some cases can reach 1 to 2 mm. Unbranched micrite filamentous bodies extend across some laminae that could correspond to cyanobacterial remains resembling modern genus Calothrix and Phormidium. Furthermore, irregular and fragmented layers are recognizable at polished slab scale (Fig. 3D) and at thin section scale (Fig. 3E), but never predominates in a single oncoid, representing isolated episodes. Other la-

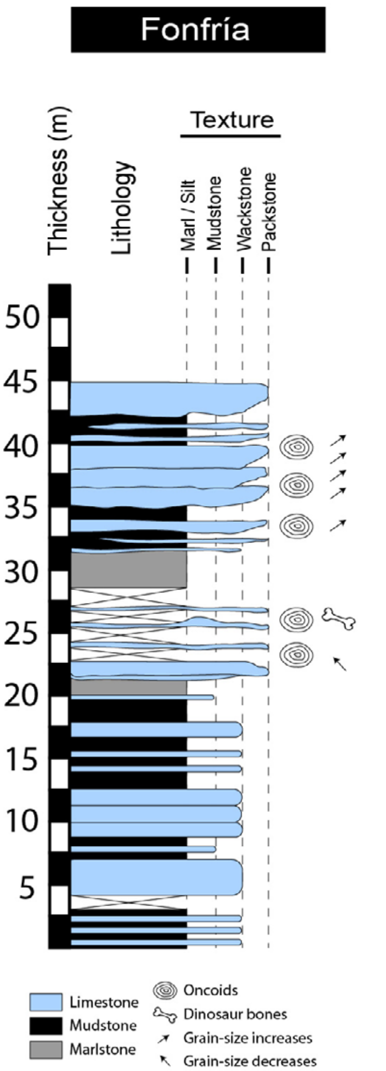

Fig. 2.- Schematic stratigraphic log of the upper part of the Allueva Fm (A2 Unit) including successive oncolitic levels.

Fig. 2.- Columna estratigráfica esquemática de la parte superior de la Fm Allueva (Ubidad A2) que incluyen sucesivos niveles oncoliticos.

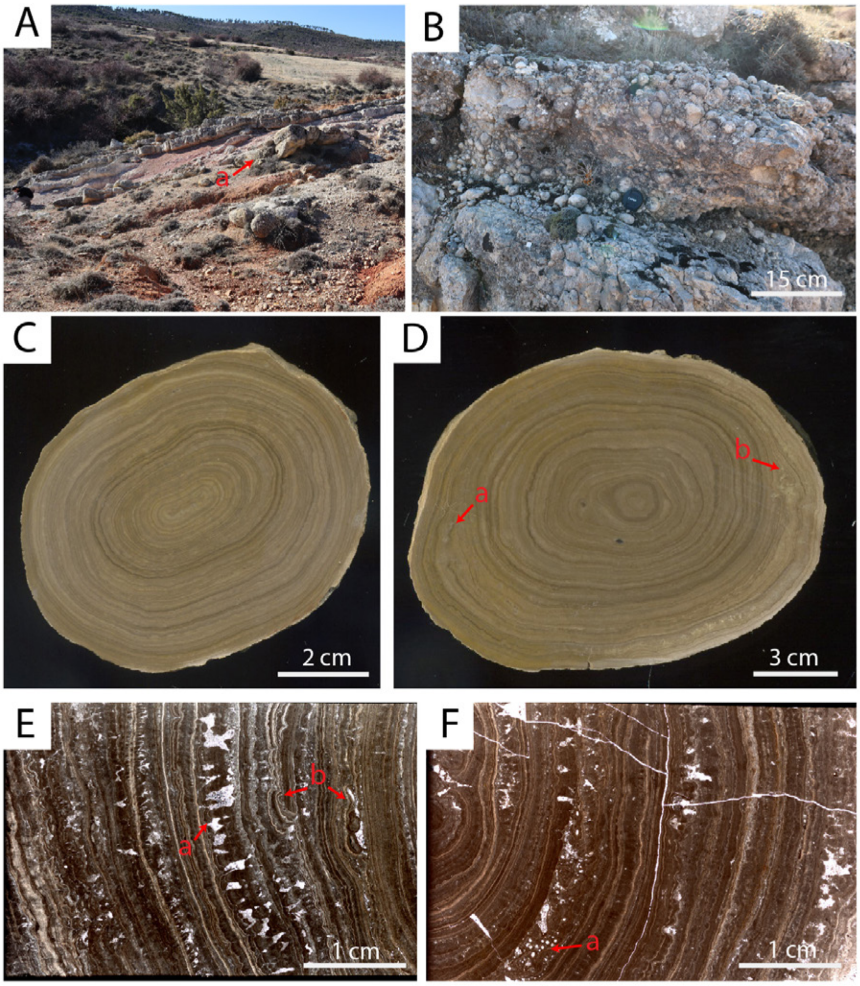

Fig. 3.- A) Outcrop-view of part of the studied Fonfría section, showing alternance of mudstones and limestones, with irregular-channelized bed rich in oncoids (a). B) Close view of a graded level of oncolitic limestones. C) Cut-in-a-half slab of an oncoid showing an almost perfect concentric pattern. D) Cut-in-a-half slab of an oncoid, with some minor irregularities (a, b). E) Thin-section view of an oncoid with knobbly-like shapes due to partial dissolution (a), and some minor irregularities (b). F) Thin-section view of an oncoid with tubiform recognizable filaments probably related to algal remains (a).

Fig. 3.- A) Foto de campo de una parte de la sección de Fonfría, mostrando una alternancia de lutitas y calizas. (a) muestra una capa con morfología irregular de canal rica en oncoides. B) Vista cercana de un nivel gradado de calizas oncolíticas. C) Corte por la mitad de un oncoide que muestra un patrón concéntrico casi perfecto. D) Corte por la mitad de un oncoide, (a) y (b) indican irregularidades menores. E) Lámina delgada de un oncoide, (a) señala a estructuras nudosas debidas a disolución parcial. (b) señala a pequeñas irregularidades. F) Lámina delgada de un oncoide. (a) señala a pequeños filamentos tubulares cuyo origen está probablemente relacionado con algas.

yers present more porous micrite due to less calcification during the formation of the oncoid and/or partial dissolution, sometimes even developing knobbly-like shapes (Fig. 3E). Exceptionally, 5-20µ tubiform shapes probably related to algal filaments are recognizable (Fig. 3F). Oncoids are commonly nucleated on other oncoid fragments, but detrital grains and even dinosaur bones also appear as nucleus. Finally, SEM analysis does not show visible composition differences between layers, and EDS analysis gave no relevant information more than an expected low-magnesium calcite composition.

Isotopic analysis

The isotopic ($\delta^{18}O$ and $\delta^{13}C$) analysis may provide relevant data for paleoenvironmental studies (Leng and Marsall, 2004). The correlation plot between $\delta^{18}O$ and $\delta^{13}C$ obtained from different layers of a single oncoid is represented in figure 4. On one hand, points fit well with the zone defined by Leng and Marshall (2004) for continental fresh-water lakes ($\delta^{18}O$ and $\delta^{13}C$ values approximately between -10 and 0 ‰), and is similar to the isotopic data from other lacustrine studies in the Mesozoic of the Iberian Basin (Delvene *et al*., 2019) and to values associated with sub-humid climatic conditions (Leng and Marshall 2004). On the other hand, covariance (r) is high; however, this r value should be approached with caution since the values are limited and almost equal, being the average value more relevant than any possible correlation. Additionally, isotopic data from a single oncoid serves as a useful complement for the interpretation but should not be taken as a strong paleoclimatic reference.

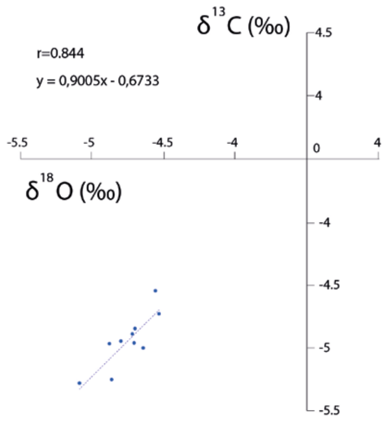

Fig. 4.- $\delta^{18}O$ and $\delta^{13}C$ plot of the samples taken from the successive layers of a single oncoid. The value of covariance (r) and lineal ecuation (y) are indicated.

Fig. 4.- Gráfica de los valores de $\delta^{18}O$ y $\delta^{13}C$ obtenidos de las láminas de un oncoide. Se indica el valor de covarianza (r) y la ecuación lineal (y).

Paleoenvironmental interpretation and discussion

The association from the Fonfría log (Fig. 2), mainly consisting of oncoidal limestones with mudstones and marlstones, along with absence of any marine feature, indicates that the carbonates found in subunit A2 of the Allueva Fm correspond to a continental fresh-water environment located in the distal areas of an alluvial setting (Aurell *et al*., 2022). Furthermore, oncoids are a typical grain found in lakes, fluvial and freshwater tufa (Platt 1989).

In contrast to other stromatolitic structures, SS structures are formed under permanently submerged water areas (Ginsburg, 1960).

SS oncoids do not necessarily need high-energy conditions to form, however movement accomplished by wave and current action help their formation. SS-C oncoids indicate moderately constant motion that results in the growth of concentrically stacked spheroidal lamination (Logan *et al*., 1964). In addition, scarcity of microbial remains support high energy conditions (Peryt, 1983). Thus SS-C is restricted to areas that are permanently under water and with enough energy in the system to keep the oncoids in almost permanent motion. On the other hand, SS-R, not common but slightly recognizable in the Fonfría area, is associated to intervals of less water agitation in which the oncoid is not moved and the structure lies in a different position each time the oncoid rest on the bottom. SS-I (inverted stacked hemispheroids) oncoids have not been recognized in the Allueva Fm, these biconvex structures are associated to long periods of extremely low agitation of waters. Thus, despite short low-energy episodes were likely to happen in this setting, long low-energy episodes can be discarded for the paleo-environmental analysis.

Stratigraphically, lenticular and eroding surfaces evidence the existence of channels with enough energy to both form and transport oncoids. Moreover, accumulation of <1cm oncoids also found here need less restrictive conditions to form (Alonso-Zarza and Calvo, 2000). Therefore, these limestone levels could have been deposited in lower-energy isolated ponds or even in the same stream flows of the alluvial system during slightly less-energy episodes, which if followed by a turbulence increment, could explain the origin of the graded levels. The largest oncoids (>5cm size) were probably formed near the junction of the alluvial flows and the distal lakes system, where high-energy conditions would be constant over time.

Regarding the isotopic study, obtained data is similar to those obtained for fresh-water environments. However, isotopic data is scarce, taken from a single sample and the isotopic signal may incorporate some diagenetic overprint. Therefore, despite it seems to indicate sub-humid paleoenvironmental conditions, here it is difficult to infer, and more isotopic information is needed.

Finally, low isotopic disparity of values from successive layers should suggest low impact of climatic variations on layering, but a more complete study on these microbialites is needed to reach to this conclusion. On the other hand, SEM analysis indicates that compositional differences did not influence layering either. Hence, other factors such as water chemistry variation or organic matter oxidation should be considered.

Conclusions

The subunit A2 of the Allueva Fm exposed west to the locality of Fonfría includes successive levels of oncolitic limestones interbedded with mudstones and marlstones. Facies association along with oncoid sampling, description and isotopic study helped to propose a fresh-water lake environment for these rocks, located in the distal areas of an alluvial setting. Biggest oncoid physical properties suggest moderately and constant energy conditions that allowed the formation of mostly-spherical oncoids with a regular concentrical layering pattern (SS-C). Oncoid formation was probably concentrated near the junction of alluvial flows and small lakes.

Contribution of authors

DT and MA conceived the idea and organized the structure and content of the publication. DT wrote the manuscript and prepared the figures. DT and MA carried out the stratigraphic log and took pictures from the outcrop. DT and MA took the samples from the field and organized their preparation in thin sections. DT and MA reviewed the final version of the manuscript.

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