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The Oko Limestones: a Late Miocene-Pliocene fluvial to palustrine-lacustrine carbonate wetland enclosed in the South-Pyrenean Thrust Front (Navarre, Spain)

Las Calizas de Oko: un humedal fluvial a palustre-lacustre carbonático del Mioceno tardío-Plioceno encajado en el Frente Cabalgante Surpirenaico (Navarra, España)

Asier Valenzuela[1]*, Zuriñe Larena[1], Xabier Murelaga[1] and Juan Ignacio Baceta[1]

[1] Dept. of Geology, Faculty of Science and Technology, University of the Basque Country (UPV/EHU), Bº Sarriena, s/n, 48940 Leioa (Bizkaia).
asiervalenzuela5@gmail.com, zurine.larena@ehu.eus, xabier.murelaga@ehu.eus, juanignacio.baceta@ehu.eus.
Corresponding author

ABSTRACT

This work presents the sedimentological study of the Upper Miocene-Pliocene Oko Limestones, exposed in the Antzin-Murieta Basin, in Navarre. Two stratigraphic sections of the carbonate unit have been studied: the Oko cemetery and Ega road sections. The former exposes facies that characterize a fluvial carbonate environment, with a distinct development of microbial oncolitic deposits. The coeval deposits exposed in the Ega road section, instead, largely represent a palustrine-lacustrine setting that evolved under alternating conditions of ponding and desiccation. Data integration from these sections and the intermediate areas, allows the interpretation of a fluvial to palustrine-lacustrine wetland with a marked east-southeast trend, which developed coevally to the uplift of the Piedramillera thrust sheet.

Key-words: *Oko Limestones, Upper Miocene-Pliocene, fluvial to palustrine-lacustrine environments, South-Pyrenean Thrust Front.*

RESUMEN

Este trabajo presenta el estudio sedimentológico de las Calizas de Oko del Mioceno Superior-Plioceno, expuestas en la Cubeta de Antzin-Murieta, en Navarra. Se han estudiado dos secciones estratigráficas de la unidad carbonática: las secciones del cementerio de Oko y de la carretera del Ega. La primera comprende facies que caracterizan un ambiente fluvial carbonático, con un notable desarrollo de depósitos oncolíticos microbianos. Los depósitos coetáneos expuestos en la sección de la carretera Ega, en cambio, representan en gran medida un entorno palustre-lacustre que evolucionó bajo condiciones alternas de encharcamiento y desecación. La integración de datos de estas secciones y de las zonas intermedias, permite la interpretación de un humedal fluvial a palustre-lacustre con una marcada tendencia este-sureste, que se desarrolló coetáneamente al levantamiento de la lámina cabalgante de Piedramillera.

Palabras clave: *Calizas de Oko, Mioceno Superior-Plioceno, ambientes fluviales a palustres-lacustres, Frente Cabalgante Surpirenaico.*

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Introduction

Pre-Quaternary fluvial to palustrine-lacustrine carbonate systems are well known in the geological record (see Arenas-Abad et al., 2010). In Spain, some excellent examples from different tectonic settings have been documented in the Jurassic of Asturias, Oligocene of Mallorca and Upper Miocene of the Ebro Basin (Arenas et al., 2007, 2015; Vázquez-Urbez et al., 2013).

Here, we document the preliminary sedimentological analysis of the Upper Miocene-Pliocene Oko Limestones (Baceta et al., 1997; López-Horgue and Olivé, 1998), representing the last depositional stage during the emplacement of the South-Pyrenean Thrust Front (SPTF), to the west of the Pamplona transfer fault system.

Geological setting

In western Navarre, the boundary between the Pyrenean fold and thrust belt and the Ebro foreland basin is defined at surface by the Piedramillera and Learza-Monjardín thrust sheets, which can be traced in continuity east-west along 20 km from the Estella diapir to the Kodes mountain ridge (Fig. 1). The integration of data from outcrops and several seismic lines, documents that both tectonic features represent the surface tips of the SPTF. At depth, the SPTF occurs as a single basal thrust rooted at 5500-6000 m subsea, with an estimated tectonic shortening of about 15 km (Bravo, 2022). The growth of the Piedramillera thrust sheet during Early-Middle Miocene times, determined the formation of a series of small depositional troughs on the hanging block to the north, among which the Antzin-Murieta Basin is the most representative (Fig. 1). This is a small syncline basin that was infilled by ca. 500 m thick alluvial to palustrine deposits, unconformably onto folded Upper Cretaceous marine strata (Fig. 2).

The infilling succession consists of four informal lithological units, including (1) the basal conglomerates, (2) the lower mudstone unit, (3) the Oko Limestones and (4) the upper mudstone unit. Detailed mapping of this sedimentary fill documents the irregular physiography of the basal unconformity, and the lateral interfingering of the four main units in both north-south and east-west oriented sections (Fig. 2). Based on regional criteria, the succession was deposited during Late Miocene-Pliocene times (Baceta et al., 1997; López-Horgue and Olivé, 1998).

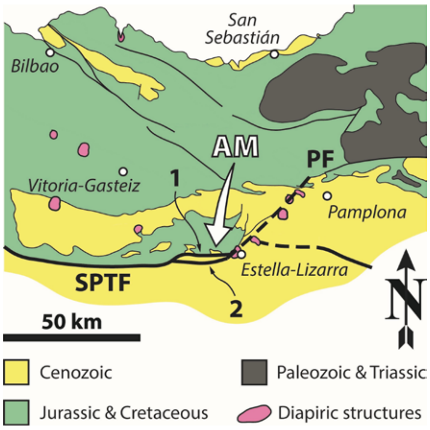

Fig. 1.- Synthetic geological map of the Western Pyrenees. AM: Antzin-Murieta Basin; 1: Piedramillera thrust; 2: Learza-Monjardín thrust; SPTF: South-Pyrenean Thrust Front; PF: Pamplona Fault. See color figure on the web.

Fig. 1.- Mapa geológico sintético de los Pirineos Occidentales. AM: Cubeta de Antzin-Murieta; 1: cabalgamiento de Piedramillera; 2: cabalgamiento de Learza-Monjardín; SPTF: Frente Cabalgante Surpirenaico; PF: Falla de Pamplona. Ver figura en color en la web.

Facies analysis

Two stratigraphic sections of the Oko Limestones were studied in detail: the Oko cemetery section, on the southern flank of the basin, and the Ega road section, along the road NA 132-A (kilometre point 9+800), separated 3.2 km from each other (Fig. 2).

Oko cemetery section

At this site, the upper 65 m of the Oko Limestones are exposed dipping 20-25° to the north-northeast (Fig. 2). The succession is defined by m-thick beds and bed packages of indurated carbonates, alternating with poorly exposed marl intervals. The indurated carbonates exhibit irregular erosional bases and laterally pinch and swell over distances of 50-200 m. According to composition and texture, these channel-like carbonate bodies consist of two distinct facies deposited in vertical succession: the oncoid rudstone-floatstones and the oncoid-intraclast packstone to wackestones (Fig. 3).

The oncoid rudstone-floatstones are 20-60 cm thick accumulations of ovoid to cylindrical microbial oncoids, ranging 0.5-5 cm in size, commonly in fining-upward arrangement (Figs. 3 and 4A). Individual oncoids display empty or calcite spar-filled nuclei, with morphologies that resemble to plant stems. Alternatively, the nuclei consist of dark-grey micrite intraclasts, oncoid fragments or bioclasts (gastropod shells). Oncoid cortices vary in thickness from a few mm to 2 cm, and consist of 200-500 μm thick laminae that surround symmetrically the nuclei. Matrix, if present, is of wackestone to grainstone texture comprising micrite, intraclasts and broken oncoids.

The oncoid-intraclast packstone-wackestones form continuous but heterogeneous intervals up to 1 m thick, in gradual vertical transition from the oncoid rudstone-floatstones, or defining the base of the sharp-based carbonate beds (Fig. 3). They mainly consist of packstone-wackestones with floating micritic intraclasts, broken oncoids and very sparse fragments of ostracods and gastropods (Fig. 4B). The intraclasts are diverse in size, rounding degree and coloration, features indicative of reworking and mixing of material from different levels or sources. Most beds show randomly-oriented cracks, non-recognised microbial remains and irregular fenestrae infilled of calcite spar and microspar.

The tops of the beds and bed packages are defined by thin intervals of charophyte-ostracod wackestones and/or intraclastic wackestone-mudstones, with the latter exhibiting sub-vertical to irregular spar-filled root traces. The marl interbeds are usually laminated, lack fossil remains and comprise sparse to abundant root traces (Fig. 3). The succession exposed at the Oko cemetery extends with similar characteristic across the southern flank of the Antzin-Murieta Basin (Fig. 2).

Ega road section

At this section, the Oko Limestones display facies that differ significantly from those exposed at Oko (Fig. 2). The unit, up to 210 m thick, is dominated by limestones of two main facies types: charophyte-gastropod wackestones and intraclastic wackestone-mudstones (Fig. 3).

The charophyte-gastropod wackestones crop out as massive to slightly laminated beds, 10-80 cm thick, with sharp to gradual undulating bases and tops. Most beds show sub-vertical root traces up to 20 cm high, more conspicuous at their tops (Fig. 3). These limestones are made of sparse to abundant gastropod shells, charophyte stems and oogonia averaging 1-2 mm in size, and to a lesser extent, of tiny ostracods and micritic intraclasts (Fig. 4C). The charophytes and gastropods are commonly broken by bioturbation and compactional processes, and show dissolution or neomorphism to calcite microspar. Moldic and fenestral porosity are noticeable in these deposits (Fig. 4C).

The intraclastic wackestone-mudstones occur as beds of 10-80 cm thick, also with sharp to gradual wavy bases and

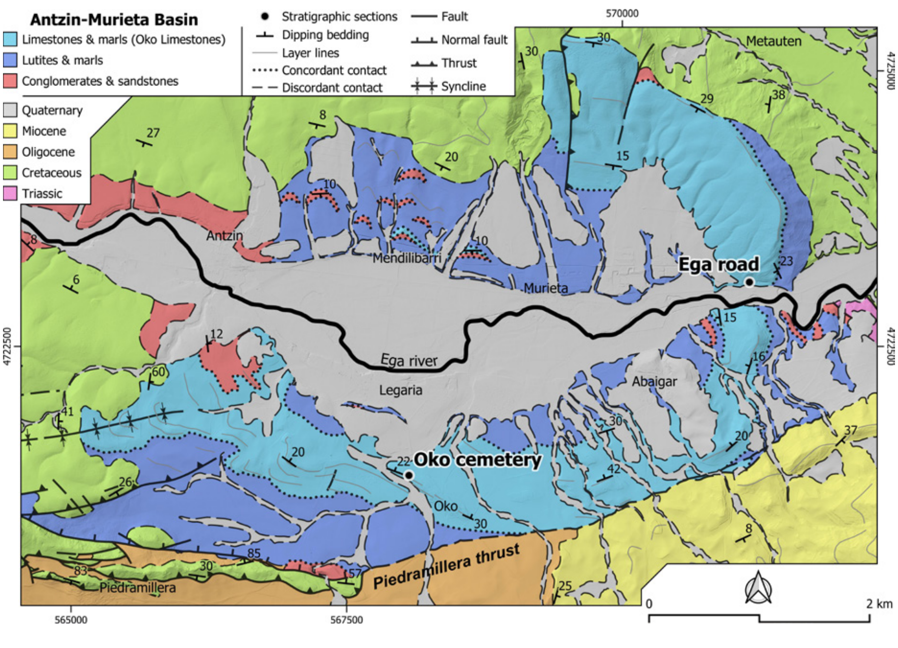

Fig. 2.- Geological map of the Antzin-Murieta Basin. Note the position of the two sections studied in detail. CRS: ETRS89 / UTM zone 30N (EPSG:25830). See color figure on the web.

Fig. 2.- Mapa geológico de la Cubeta de Antzin-Murieta. Nótese la posición de las dos secciones estudiadas en detalle. SRC: ETRS89 / UTM zone 30N (EPSG: 25830). Ver figura en color en la web.

tops. A nodular fabric is distinct in many beds, given by the abundant root marks, rhizocretions and desiccation cracks (Fig. 3). In thin section, different generations of cracking, brecciation, and void filling by calcite spar and minute intraclasts are visible (Fig. 4D). Some beds show moderate to intense neomorphism.

The two main facies described above are interbedded with thin, massive to laminated marls that include root traces and very sparse charophytes. No vertical arrangements indicative of facies cyclicity is evident in the section (Fig. 3). The facies succession exposed at the Ega road section is characteristic of all outcrops of the Oko Limestones across the northeast and southeast of the basin (Fig. 2).

Facies model

Considering the sedimentological features of the Oko Limestones across the Antzin-Murieta Basin, a fluvial to palustrine-lacustrine carbonate environment is proposed. According to Arenas et al. (2007, 2015) and Arenas-Abad et al. (2010), the beds and bed packages consisting of oncoid rudstone-floatstones and/or oncoid-intraclast packstone-wackestones found at the Oko cemetery section, likely represent deposits that infilled a series of stacked, shallow, low-energy fluvial channels, which trended towards the east and southeast. These channels developed over a flat marly alluvial plain, during episodes of increased discharge, eroding previous deposits and pulling out plant fragments that acted as nuclei for the oncoidal growths. The fining-upward sequences are indicative of a progressive decrease in energy levels, succeeded by the subsequent ponding and final abandonment of the channeled areas. This final filling stage is represented by the vertical transition to bioclastic wackestones and/or intraclastic wackestone-mudstones with abundant root traces, suggesting the establishment of full palustrine conditions.

The facies of the Ega road section attest the persistence of palustrine-lacustrine conditions in the areas to the east of the western fluvial channelled domain. According to Alonso-Zarza and Wright (2010), the charophyte-gastropod wackestones represent shallow, semi-permanent subaquatic conditions. The interbedding of this facies with intraclastic wackestone-mudstones with abundant root traces and minor massive to laminated marls, is indicative of stages of oscillating water table conditions, punctuated by episodes of partial exposure and active plant recolonization. The persistent but random superposition of facies found in the Ega road section, indicates alternating phases of ponding and desiccation, which is fully consistent with the episodes of increasing then decreasing water discharge, channelling and subsequent abandonment recorded in the Oko cementery section.

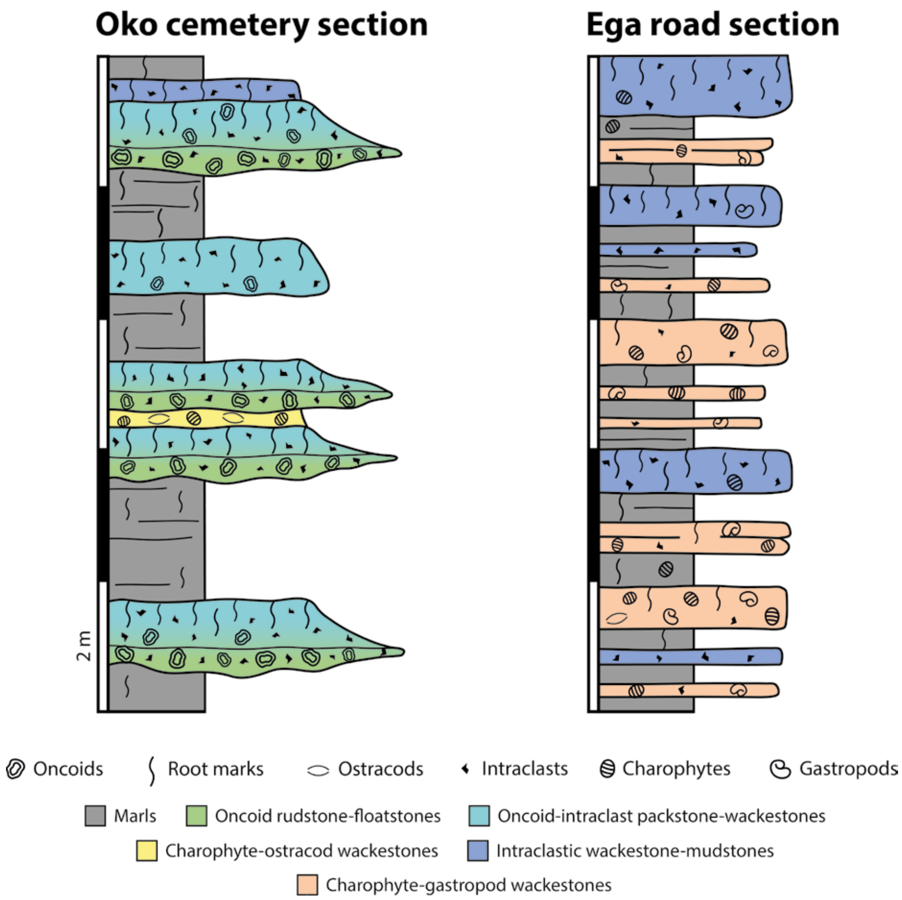

Fig. 3.- Synthetic stratigraphic columns showing the general characteristics of the two sections studied in detail of the Oko Limestones. See color figure on the web.

Fig. 3.- Columnas estratigráficas sintéticas que muestran las características generales de las dos secciones estudiadas en detalle de las Calizas de Oko. Ver figura en color en la web.

Conclusions

The sedimentological study carried out on the Oko Limestones provides significant data about the facies types, distribution and depositional conditions that prevailed in the Antzin-Murieta Basin during Late Miocene-Pliocene times. The integration of the facies analysis and cartographic data, suggests that this carbonate unit was deposited across a small endorheic depression, developed between the hanging block of the Piedramillera thrust sheet and the rising Estella diapir to the east. The fluvial to palustrine-lacustrine environment was mainly fed by the alluvial systems developed along the west and northwest margins of the basin.

The Oko Limestones have potential for future sedimentological studies, since its microbialite facies can provide significant environmental data of past continental wetland environments. Detailed age dating of the Oko Limestones will be essential to accurately constraint its chronostratigraphic position.

Author contributions

Field work (mapping, logging and sampling): all authors. Sedimentology and microfacies analysis: AV, ZL and JIB. Palaeontology: AV and XM. Synthesis and interpretations: all authors.

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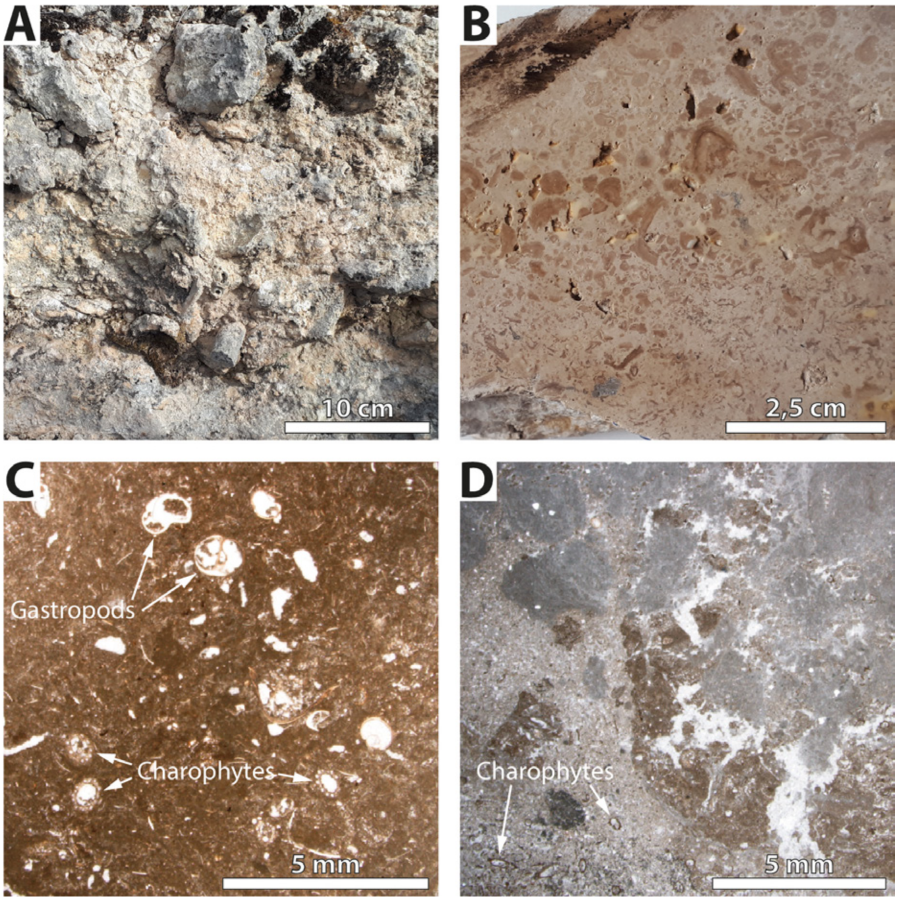

Fig. 4.- Field, hand sample and thin section photographs of the main facies of the studied Oko Limestones. A) Oncoid rudstone-floatstone. B) Oncoid-intraclast packstone-wackestone; in this case, most intraclasts are oncoid fragments. C) Charophyte-gastropod wackestone. D) Intraclastic wackestone-mudstone; different generations of cracking, brecciation and void filling can be recognised. See color figure on the web.

Fig. 4.- Fotografías de campo, muestra de mano y láminas delgadas de las principales facies de las estudiadas Calizas de Oko. A) Rudstone-floatstone de oncoides. B) Packstone-wackestone de oncoides-intraclastos; en este caso, la mayoría de los intraclastos son fragmentos de oncoides. C) Wackestone de carofitas-gasterópodos. D) Wackestone-mudstone intraclástica; pueden reconocerse diferentes generaciones de agrietamiento, brechificación y relleno de huecos. Ver figura en color en la web.

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