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Carbonate platform margin facies evolution: the Aptian of Mundaka (Bizkaia, Northern Spain)

Evolución de facies de margen de plataforma carbonatada: el Aptiense de Mundaka (Bizkaia, Norte de España)

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ABSTRACT

Platform margin as well as foreslope settings are heterogeneous and constitute key elements to understand carbonate platform system dynamics. Aptian outcrop exposures along the Mundaka cliffs in the Basque-Cantabrian basin were investigated to assess the development of a variety of facies in carbonate margin and foreslope settings. The measured Santa Catalina section displays a series of rudist-coral bioherms revealing changes in water depth together with significant variations in turbidity. Relative sea-level trends were inferred from facies associations, which helped indentify three transgressive-regressive cycles. This depositional record provides baseline data to predict margin and foreslope evolution, geometry and heterogeneity in sedimentary basins with prospective hydrocarbon targets.

Key-words: *Aptian, carbonate platform, reef, rudists, corals.*

RESUMEN

El margen y su talud son ambientes heterogéneos y fundamentales para entender la dinámica de los sistemas de plataforma carbonatada. Los afloramientos aptienses de los acantilados de Mundaka pertenecientes a la Cuenca Vasco-Cantábrica han sido investigados para descifrar el desarrollo de un amplio abanico de facies en estos ambientes. La sección de Santa Catalina muestra diversos biohermos de rudistas y corales que revelan cambios de batimetría así como grados variables de turbidez en las aguas. Las asociaciones de facies han permitido sintetizar una curva del nivel del mar e identificar tres ciclos transgresivos-regresivos. Este registro sedimentario proporciona información clave para predecir la evolución, geometría y heterogeneidad de márgenes y taludes de plataformas carbonatadas en cuencas con fines de prospección de hidrocarburos.

Palabras clave: *Aptiense, plataforma carbonatada, arrecife, rudistas, corales.*

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Introduction

Carbonate margins are excellent recorders of carbonate platform evolution. Over the last years numerous case studies and compilations of modern, outcrop and subsurface carbonate margin depositional systems have enhanced our understanding of the facies spectrum, sedimentary architectures, variability, organization and controls. Despite this progress, challenges remain in developing predictive facies models in these heterogeneous settings.

We have reviewed and investigated the urgonian succession in the western limb of the Gernika anticline to decipher the vertical and lateral evolution of depositional systems. The study area lies in the northwestern end of the North-Biscay Anticlinorium (Fig. 1A), within the Basque Arc domain (Barnolas and Pujalte, 2004). It was located in the southern margin of the European Plate during Aptian times. Urgonian facies of the Gernika anticline consist of intertonguing limestone and mixed carbonate-terrigenous deposits. The Urgonian Complex in the Basque-Cantabrian Basin (Fig. 1A) was defined by Rat (1959) as sedimentary units coeval with deposits of shallow marine limestones containing *Toucasia* requieniid rudists. Robador (1984) and García-Mondéjar and Robador (1986-1987) analysed Aptian-Albian sedimentary facies in the Forua section of the Gernika anticline and interpreted them as shallow marine based on the presence of red algae, *Bacinella* and the association of corals and rudists, whereas further north towards Mundaka a progressive deepening was noted. These authors identified *Orbitolina (Mesorbitolina) parva*, *Orbitolina (Mesorbitolina) texana* and *Pseudochofattella* sp., and proposed an upper Aptian – lower Albian depositional slope environment for the Mundaka succession.

The current study is focused on the Santa Catalina section, which is located north of Mundaka near the Santa Catalina hermitage (Fig. 1B). The section provides continuous and well-preserved outcrops along coastal cliffs in an E-W transect. These outcrops are unique in terms of coastal exposure quality, and are age-equivalent and stratigraphically comparable to producing oil fields in the Middle East (*e.g.*, Van Buchem *et al.*, 2010). The section presents remarkable benthic metazoan reefal associations that can be used to elaborate referential models for global correlations in the Cretaceous.

Results

We present here results of an introductory research of a 293-m-thick section with emphasis on stratigraphical and sedimentological analyses. The succession is divided into three major units based on facies distribution (Fig. 2): 1) a lower marl and limestone alternation from metre 0 to 64, 2) a middle limestone-dominated unit from metre 64 to 171, and 3) upper interspersed limestones and marls from metre 171 to 293. Each of the three units is subdivided into facies associations which define different stratigraphic members characteristic of specific depositional environments (Fig. 1B). Based on sedimentological analyses a relative sea-level variation curve is proposed to clarify the tem-

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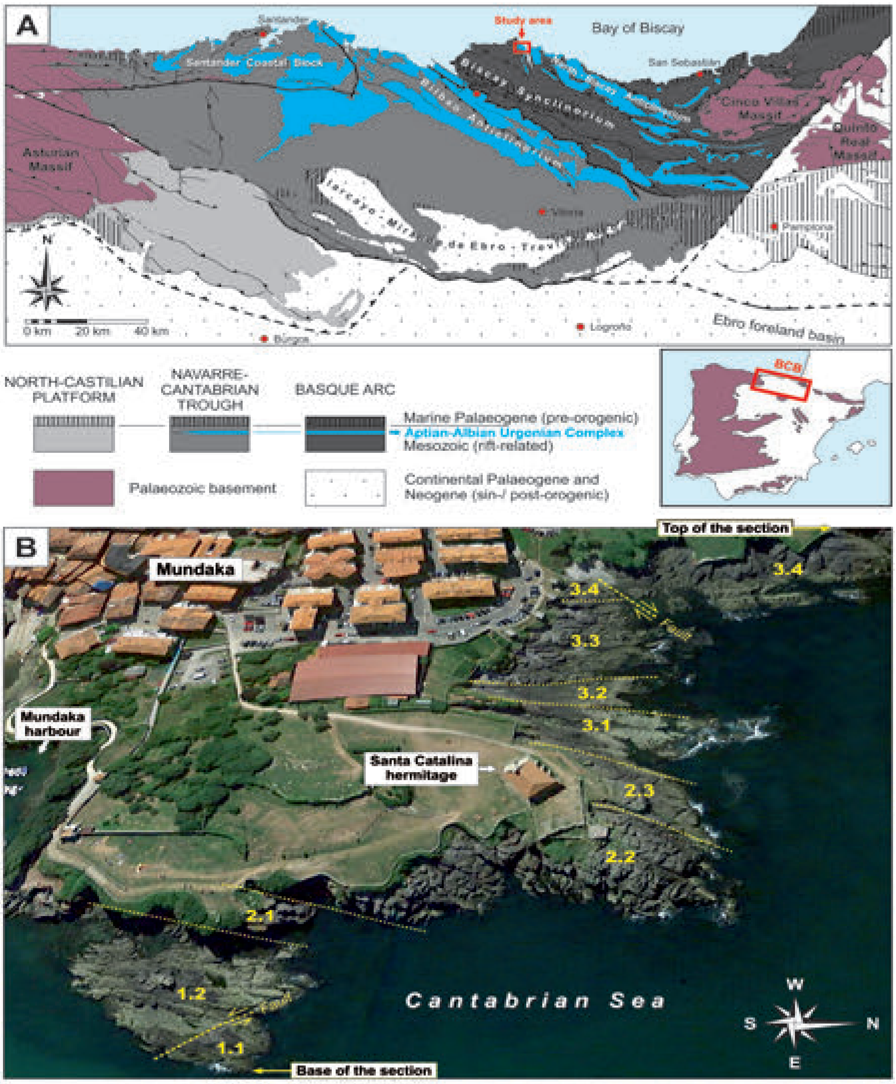

Fig. 1.- A) Simplified geological map of the Basque-Cantabrian Basin, including the study area location and the Urgonian facies distribution (Pérez-Malo *et al*., 2017). B) Aerial view of the Santa Catalina section showing stratigraphic members (from 1.1 to 3.4) and their boundaries.

Fig. 1.- A) Mapa geológico de la Cuenca Vasco-Cantábrica, con los afloramientos urgonianos destacados en azul y la ubicación de la zona de estudio (tomado de Pérez-Malo et al., *2017). B) Vista aérea del sector de estudio, en la que se indican los distintos miembros estratigráficos definidos en este trabajo.*

poral evolution of such sedimentary facies and palaeoenvironments (Fig. 2).

Unit 1

The first unit is subdivided into two members separated by a minor fault: a lower calcarenitic package (member 1.1, 19 m thick) and an upper marl-dominated interval (member 1.2, from metre 19 to 64).

Member 1.1 includes fine-grained calcarenites and high-energy coarse grainstones and rudstones with abundant orbitolinids and echinoderm fragments that display NE-directed cross stratification and fill channeled scours up to 0.5 m deep. Member 1.2 consists of dominant marls that contain ferruginous and calcareous nodules, sponges and belemnites, as well as interlayered thin-bedded calcarenites rich in orbitolinids, echinoderms and brachiopods.

Unit 1 contains *Palorbitolina lenticularis* and *Chofatella decipiens* of early Aptian age. It was deposited in a calcarenitic ramp, where middle ramp facies of member 1.1 were overlain by outer ramp sediments of member 1.2.

Unit 2

The second unit is partitioned into three subunits spanning from metres 64 to 77, 77 to 135 and 135 to 171 (respectively): the lower coral-rich member 2.1, the middle rudist-coral-dominated member 2.2, and the upper coral-rich member 2.3. Member 2.1 is made up of marls with planar and massive corals, which evolve upwards to nodular limestones showing more tightly packed massive corals. This evolution records a shoaling trend along a slope.

Member 2.2 comprises micritic limestones of polyconitid-requieniid rudists and massive corals that often constitute carbonate buildups. Radiolitids, ostreids, *Chondrodonta* and ramose corals occur as secondary contributors to the reef system. Several limestone beds are capped by palaeoexposure surfaces with palaeokarst development. In some cases the overlaying sandstone layers fill subaerial dissolution cavities reaching depths up to 4 m, and contain occasional limestone cobbles up to 12 cm in diameter. The facies association of member 2.2 is attributed to open platform and upper foreslope depositional settings with intermittent subaerial exposure phases and terrigenous input.

Member 2.3 is composed of micritic limestones, massive coral boundstones (with large coral heads up to 1 m in diameter) and sparse flat lenses of rudists. Nodular marly intercalations with orbitolinids and radiolitids are also common within this interval. This facies association corresponds to an upper foreslope environment. The presence of densely packed plate-like coral colonies and terrigenous silty matrix at the top of this member represents a transition to a middle foreslope setting.

Unit 3

The third unit is split into four members. Member 3.1 spans from metre 171 to 190 and is characterized by bioturbated marls with iron-oxide/ calcareous nodules and orbitolinids, as well as by minor sponges and *Rastellum*-type ostreids. It is interpreted as formed in the deepest palaeoenvironment of the entire stratigraphic succession, a shallow basin adjacent to the carbonate platform margin.

The beginning of member 3.2 is marked by coral bioherm development at metre 190. Small patch reefs 0.5 to 2.3 metres-thick grade laterally into orbitolinid marls. Platy and delicate ramose corals appear to be particularly abundant in these reefal communities enveloped within a marly matrix.

Member 3.3 (metre 205 to 254) is composed of rudist, coral and mixed rudist-coral bioconstructions separated by inter-reef orbitolinid marls. These limestones are represented by a high-diversity fauna, including polyconitids, requieniids, massive corals, monopleurids, ramose corals, brachiopods and gastropods. This reef development took place on open platform and upper foreslope settings.

Member 3.4 consists of orbitolinid marls and interspersed lens-shaped coral buildups do-

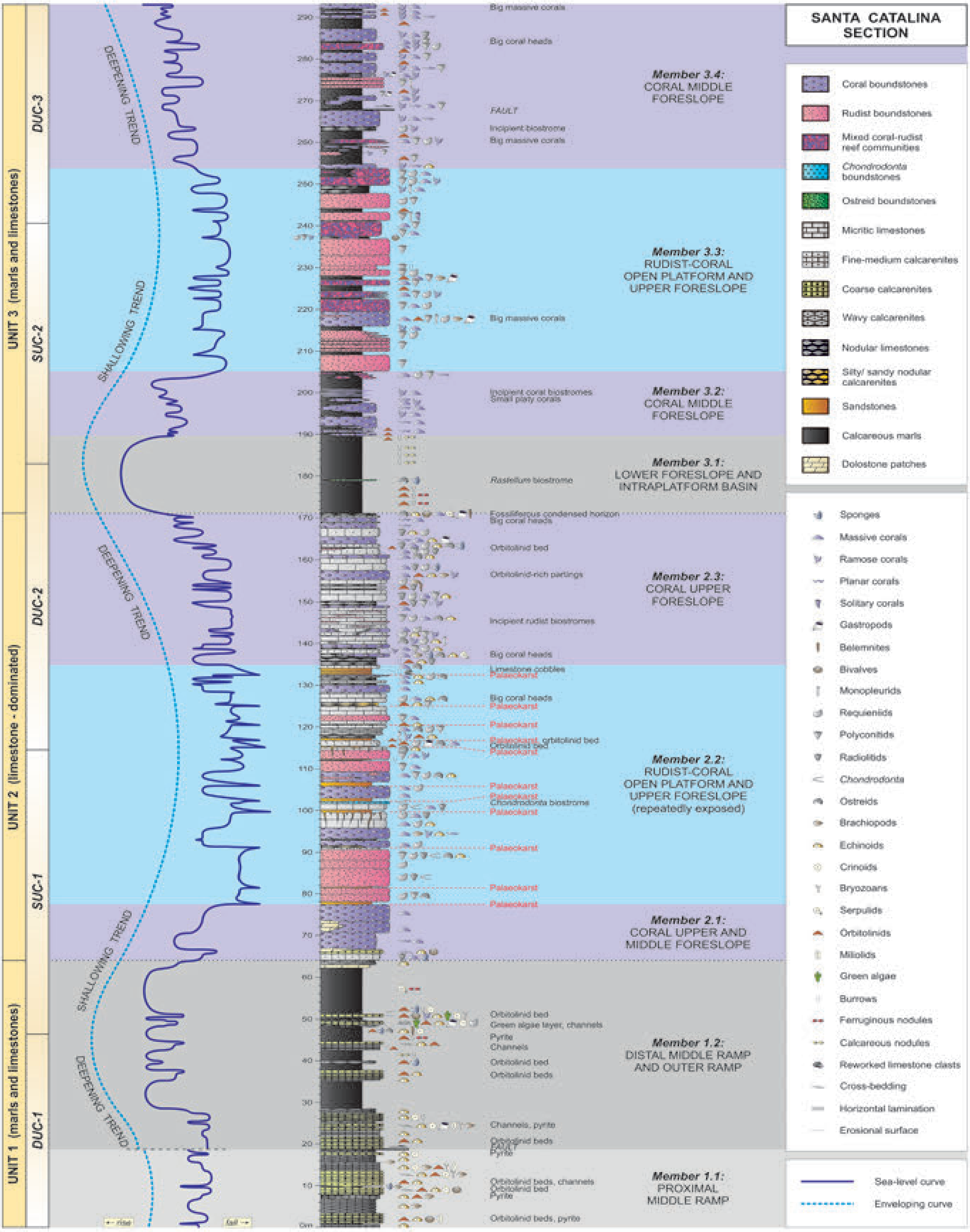

Fig. 2.- Stratigraphic column of the Santa Catalina section. The relative sea-level curve and transgressive-regressive cycles (DUC: Deepening Upward Cycle/ SUC: Shallowing Upward Cycle) are based on facies evolution.

Fig.2.- Columna estratigráfica de la sección de Santa Catalina, junto con la curva del nivel del mar (interpretada a partir de la evolución de facies) y los ciclos transgresivo-regresivos establecidos.

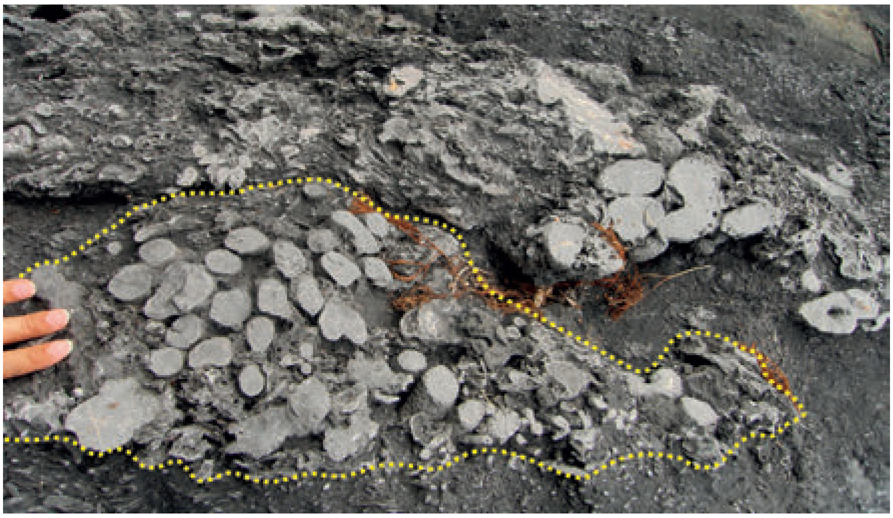

Fig. 3.- Coral patch reefs characteristic of stratigraphic member 3.4, dominated by delicate and robust branching forms surrounded by a marly matrix.

Fig. 3.- Parches arrecifales de matriz margosa característicos del miembro estratigráfico 3.4, en los que predominan las colonias de corales ramosos.

minated by ramose specimens and marly matrix (Fig. 3). Both member 3.2 and member 3.4 reflect intermittent reef growth on marly substrates, under relatively quiet and turbid water conditions in a middle foreslope environment.

Discussion

Sedimentary evolution

The vertical succession of Mundaka reveals a complex history of carbonate margin development. It records a great variety of palaeoenvironments ranging from a homoclinal ramp devoid of reef structures (Unit 1) to a carbonate platform with depositional margins, including shallow-marine open platform, foreslope and adjacent basin settings. Unit 2 indicates the shallowest water conditions, whereas Unit 3 contains the deepest facies association. Basinal environments are envisaged to have reached water depths of a few tens of metres, based on platform configuration and lack of high-angle platform margin clinoforms.

The overall evolution of the platform margin reflects middle ramp high-energy calcarenitic facies of Unit 1 evolving upwards to slightly deeper outer ramp marls (Deepening-Upward Cycle DUC-1). DUC-1 is followed by a shoaling upward cycle at the transition from Unit 1 to Unit 2 (Shallowing Upward Cycle SUC-1). DUC-2 occurs throughout the upper part of Unit 2 and the base of Unit 3, ranging from rudist-coral limestones to intraplatform basin deposits. SUC-2 is accompanied by a gradual increase in reef production along the foreslope and platform margin, which finally experiences a deepening trend (DUC-3) that extends further into the overlying marly unit above member 3.4.

Reefal communities

Facies associations along this margin reflect variations in palaeo-water depth and turbidity. These factors controlled bioconstruction characteristics. Reefs grew under both limpid and turbid water conditions. Cleaner waters from shallow platform and upper foreslope settings were suitable for the development of rudist biostromes and massive coral colonies. On the contrary, turbid-water environments such as deeper middle foreslope favored the formation of small-scale bioherms composed of ramose and platy corals. Analogous turbid-water coral assemblages have been reported in the coeval Laga section (Bonilla-González *et al.*, 2017). The diversity and palaeoecological zonation of reefal communities of Mundaka can be tied to similar coetaneous buildups described around the Gulf of Mexico (Scott, 1984a, b). There, rudist reefs characterized inner platforms, whereas coral-rudist associations dominated platform margins and coral frameworks developed on foreslope settings.

Conclusions

The facies associations of the Santa Catalina section reveal a carbonate platform depositional margin with low angle slopes fluctuating between shallow-marine and basinal environments. A relative sea-level curve with three main transgressive-regressive cycles is inferred from sedimentological interpretation.

Facies analysis of the sedimentary succession in Mundaka offers the opportunity to understand the genetic processes that controlled the distribution pattern of reefal communities in platform margins. The influence of palaeobathymetry and turbidity on the reef type is highlighted. Rudist and massive coral reefs occupied open platform and upper foreslope settings, whereas ramose and platy coral bioherms developed in middle foreslope environments characterized by more turbid water conditions.

Identification of key elements in reefal facies along the carbonate margin of Mundaka will help future exploration and production of hydrocarbons from modern analogs such as the Middle East and coeval basin fills worldwide.

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