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Coralgal buildup in a mixed carbonate-siliciclastic succession of the Upper Eocene Sant Martí Xic formation (Orís, Vic, SE Ebro basin, Spain)

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ABSTRACT

Coralgal buildups from the mixed carbonate siliciclastic succession of the upper Eocene Sant Martí Xic Formation (Orís, Vic, SE Ebro basin, Spain) were studied. During the upper Eocene, the sedimentation in the Orís area was strongly influenced by global and local factors associated with the evolution of the Ebro Basin. The stratigraphic series in Orís shows first a transgressive sedimentary sequence characterized by floatstone to rudstone limestone with Discocyclina and Nummulites, which developed in a deeper and oligophotic environment and in a general context of humid climate conditions. The second sequence is formed by progradational deltaic deposits rich in Nummulites and developed under more arid climate conditions. Coralgal buildups occur interdigitated with these deltaic deposits forming two different lens-shaped bioherms that resulted in a coalescent buildup, with coral colonies sparse in a skeletal matrix of different grain-size. Corals grew in the mesophotic zone of the deltaic system affected by light fluctuations during periods of low siliciclastic input. The coralgal buildups of Sant Martí Xic Formation were thus influenced both by climatic changes and by the local detrital input from a deltaic system, associated with the uplift of the Catalan Coastal Range, highlighting the resilience of Eocene corals to environmental change.

KEYWORDS **Cluster reef. Mesophotic corals. Priabonian. Delta. Climate change.**

INTRODUCTION

Priabonian coralgal buildups from the Ebro Basin (Spain) are represented by nodular limestone that crops out especially in the Igualada (La Tossa de Montbui; Salas, 1979) and Vic areas (Centelles, La Trona; Álvarez *et al.*, 1994, 1995, 1999; Barnolas *et al.*, 1983; Santisteban and Taberner, 1988). These beds are among the last marine deposits of the Ebro Basin (Costa *et al.*, 2013; Garcés *et al.*, 2020) and were previously interpreted as fringing reefs or coral mounds developed in a deltaic complex, under high hydrodynamic conditions (Ferrer *et al.*, 1968; Santisteban and Taberner, 1988; Barnolas, 1992; Álvarez *et al.*, 1999; Taberner and Bosence, 1995). Several authors that studied coeval/similar successions characterized by the same lithofacies rich in coralgal buildups from the Southern central Pyrenees and Alpine Foreland Basin (Bosellini and Trevisani, 1992; Bosellini and Papazzoni, 2003; Nebelsick *et al.*, 2005; Rasser, 2009; Morsilli *et al.*, 2011; Pomar *et al.*, 2017), concluded that such hermatypic corals were developed under relatively high sedimentation rates, and associated to turbid water and in mesotrophic conditions. In

general, the Bartonian-Priabonian coral buildups represent one of the four major episodes of extensive coral buildup development during the Cenozoic (Pomar *et al.,* 2017). These buildups were formed during global cooling phases, as evidenced by positive trends in $\delta^{18}O$ values, which also coincide with periods of reduced oceanic fertility reflected in lower $\delta^{13}C$ values. Pomar *et al.* (2017) highlight two distinct drops in the global temperature, which align well with two distinct key stages in the evolution of the symbiotic zooxanthellae. During the first Cenozoic interval, lasting until the Lutetian, coral buildups retained affinities with Cretaceous assemblages. The first significant cooling event occurred in the Bartonian-Priabonian transition and corresponded to the initial diversification of the *Symbiodinium* group of zooxanthellae (Pochon and Pawlowski, 2006). In addition, Bartonian-Priabonian corals often developed under mesophotic and high turbidity conditions (Taberner and Bosence, 1995; Morsilli et al., 2012; Pomar *et al.,* 2017).

Recently, coral reefs exposed to high turbidity, reduced light penetration, and significant sediment input have attracted considerable scientific attention (see Zweifler *et al.*, 2021 and Bosellini *et al.*, 2024 for a review), challenging the long-held idea that clear, warm, and oligotrophic waters are essential for optimal coral reef growth. Evidence from modern oceans shows that turbid-water reefs may be more resilient to the impacts of climate change, particularly during prolonged periods of elevated sea-surface temperatures leading to severe bleaching events (Morgan *et al.*, 2017; Sully and van Woesik, 2020; Rosedy *et al.*, 2023; Bosellini *et al.*, 2024). As a result, this type of reefs was positioned as a potential ecological refugium (Beger *et al.*, 2014). In the geological record, many coral reefs and coral assemblages are found in association with marly and mixed carbonate-siliciclastic sediments (Wilson and Lokier, 2002; Sanders and Baron-Szabo, 2005; Morsilli *et al.*, 2011; Santodomingo *et al.*, 2015, 2016; Pomar *et al.*, 2017; Reuter *et al.*, 2019; Woolfe and Larcombe, 1998; Perry and Smithers, 2006; Lesser *et al.*, 2009; Tomassetti *et al.*, 2013; Bosellini *et al.*, 2024), often related to deltaic systems (Lokier *et al.*, 2009; Morsilli *et al.*, 2011). Thus, the development of coral buildups is clearly influenced by a combination of global and local factors. In this study, we aim to disentangle the contributions of these various influences, with a particular focus on the climatic conditions that governed terrigenous input.

GEOLOGICAL SETTING

The investigated area (Orís) is located in the eastern margin of the Ebro Basin (Spain) and shows autochthonous deposits extending from the Vic area in the west to the Camós-Celrà extensional fault to the east (Saula *et al.*, 1994). To the north, the study area is bounded by the South Pyrenean frontal thrust (Muñoz *et al.*, 1986). From the Paleocene to the late Eocene the Ebro basin and the Vic area recorded sedimentation mostly in marine environments, as a result of subsidence related to the collision of Iberia with the European plate (Vergès *et al.*, 2002) (Fig. 1). During this period, the Ebro Basin was connected to the Atlantic Ocean. Subsequently, reduced marine connection led to the deposition of evaporites in two different depocenters: the Catalan Basin to the east and the Navarra Basin to the west, separated by the central-southern Pyrenees thrust system. After the closure of the basin in the uppermost Eocene, the sedimentation evolved into alluvial-lacustrine sediments in the basin and conglomeratic sediments near the range margins (Garcés *et al.*, 2020). The studied succession represents the final evolution of marine sedimentation in the autochthonous part of the southern Pyrenees foreland basin.

From the early Eocene to the Oligocene, the south-eastern margin of the Ebro Basin was strongly influenced by the uplift of the Catalan Coastal Range thrust. The central part of this zone shows the most pronounced deformation, which took place from the middle to late Eocene accompanied by the syn-sedimentary evolution of deltaic systems (Cabello *et al.*, 2010; López-Blanco *et al.*, 2000). These deposits gradually evolved into basinal sedimentation with shallow marine limestones and clastic sediments (*e.g.* in the Igualada area, Serra-Kiel *et al.*, 2003a, b).

From the stratigraphic viewpoint the study area (Orís) shows a complete Priabonian succession (Fig. 1) formed by two sedimentary sequences (Costa *et al.*, 2013; Sanjuan *et al.*, 2012; Serra-Kiel *et al.*, 1998, 2003a, b). The first one was a transgressive sequence, with a maximum flooding surface represented locally by bryozoans and *Discocyclina* marls that developed in a deep and oligophotic environment (Serra-Kiel *et al.*, 2003a), while the subsequent regressive sequence shows instead coralgal facies of the Sant Martí Xic Formation interdigitated with progradational deltaic sediments (*Upper deltaic reefal complex* in Serra-Kiel *et al.*, 2003b). These deposits where covered by the Terminal Complex carbonates defined by Travé *et al.* (1996) that evolved into the transitional and non-marine sediments of the Sant Boi de Lluçanès and Artés formations (Sanjuan *et al.*, 2012). This transition corresponds to the last marine event of the eastern Ebro Basin.

MATERIAL AND METHODS

Seven stratigraphic logs were studied, with logs 1, 2, 3, 5 and 7 representing the lateral part of the coralgal buildups, while logs 4 and 6 represent their central part. A detailed by sedimentological analysis and lithofacies characterization was performed. The stratigraphic logs, ranging 65–70m in

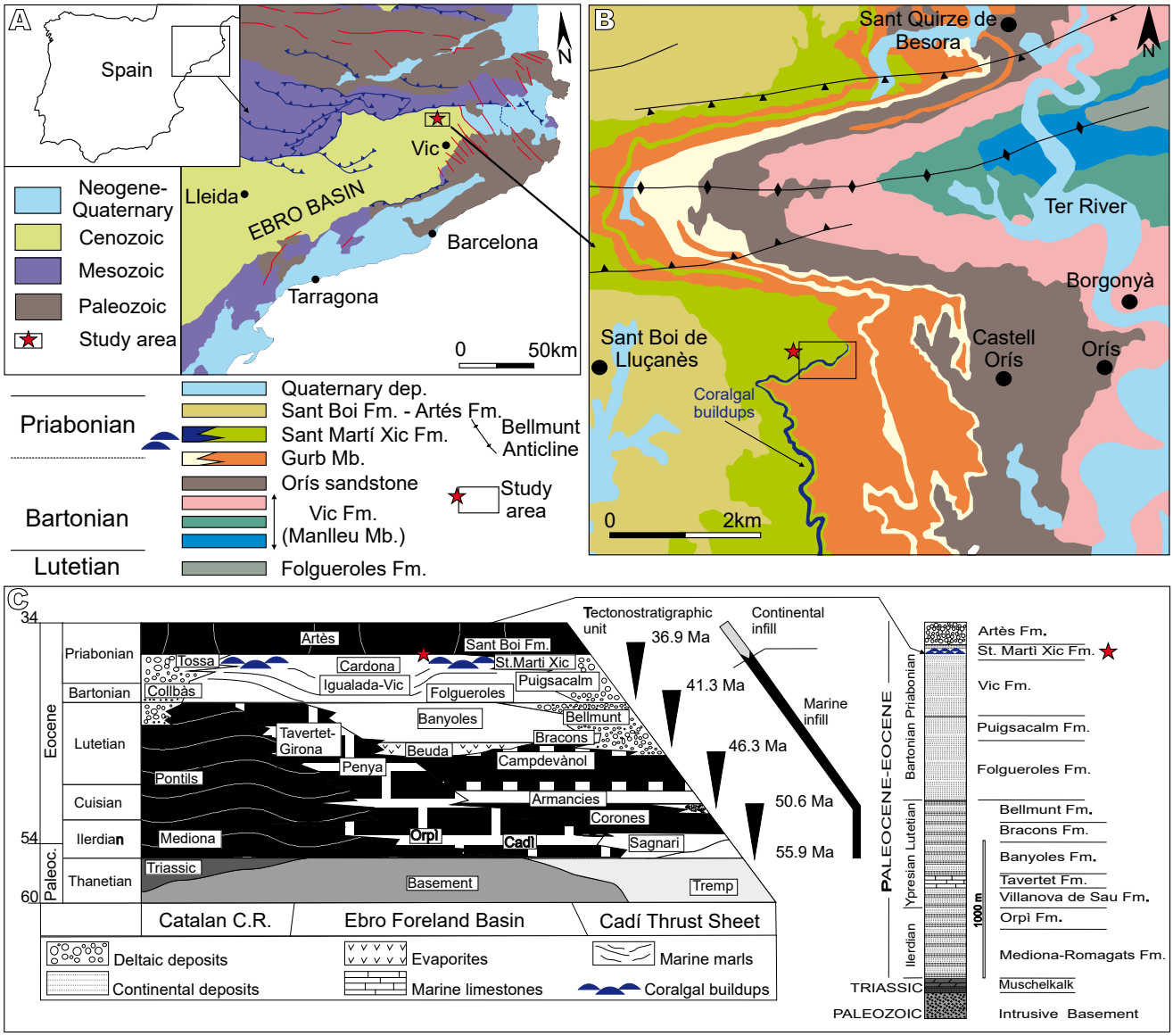

FIGURE 1. Geological setting of the study area. A) Geological map of the eastern Ebro Basin. B) Geological map of the study area. C) Stratigraphic units of the Ebro Basin, showing the lateral relationships from the Catalan Coastal Range to the Cadí thrust sheet, the tectonostratigraphic units, and the change from marieto continental sedimentation (modified from Vergés *et al.*, 2003; Sanjuan and Martín-Closas, 2012).

thickness (Fig. 2), were measured in the Orís hill, located at Serrat dels Bous hills near Sant Salvador de Bellver church (18.8km north of Vic). Microfacies analysis, texture characterization and identification of skeletal components was based on the study of 40 thin section, following the texture classification given in Dunham (1962) and Insalaco (1998). Carbonate content was measured to evaluate the terrigenous percentage of the different lithofacies analysed. Up to 21 samples for the determination of the $CaCO_3$ fraction were collected. A weighted amount (some grams) of each sample was dissolved in a 5M HCl solution. Each solution was filtered with a cellulose acetate 0.45mm membrane filters and the insoluble residue was dried and weighted. The carbonate fraction of each sample has been computed from:

$$f\,CaCO_3 = (Wi - Wr)/Wi$$

where Wi is the initial weight and Wr the weight of the insoluble fraction.

RESULTS

Lithofacies

The studied succession, detailed in seven stratigraphic logs, was divided in six lithofacies, which are reported below from base to top. They characterize two sedimentary sequences, divided in stratigraphic intervals (Fig. 2;

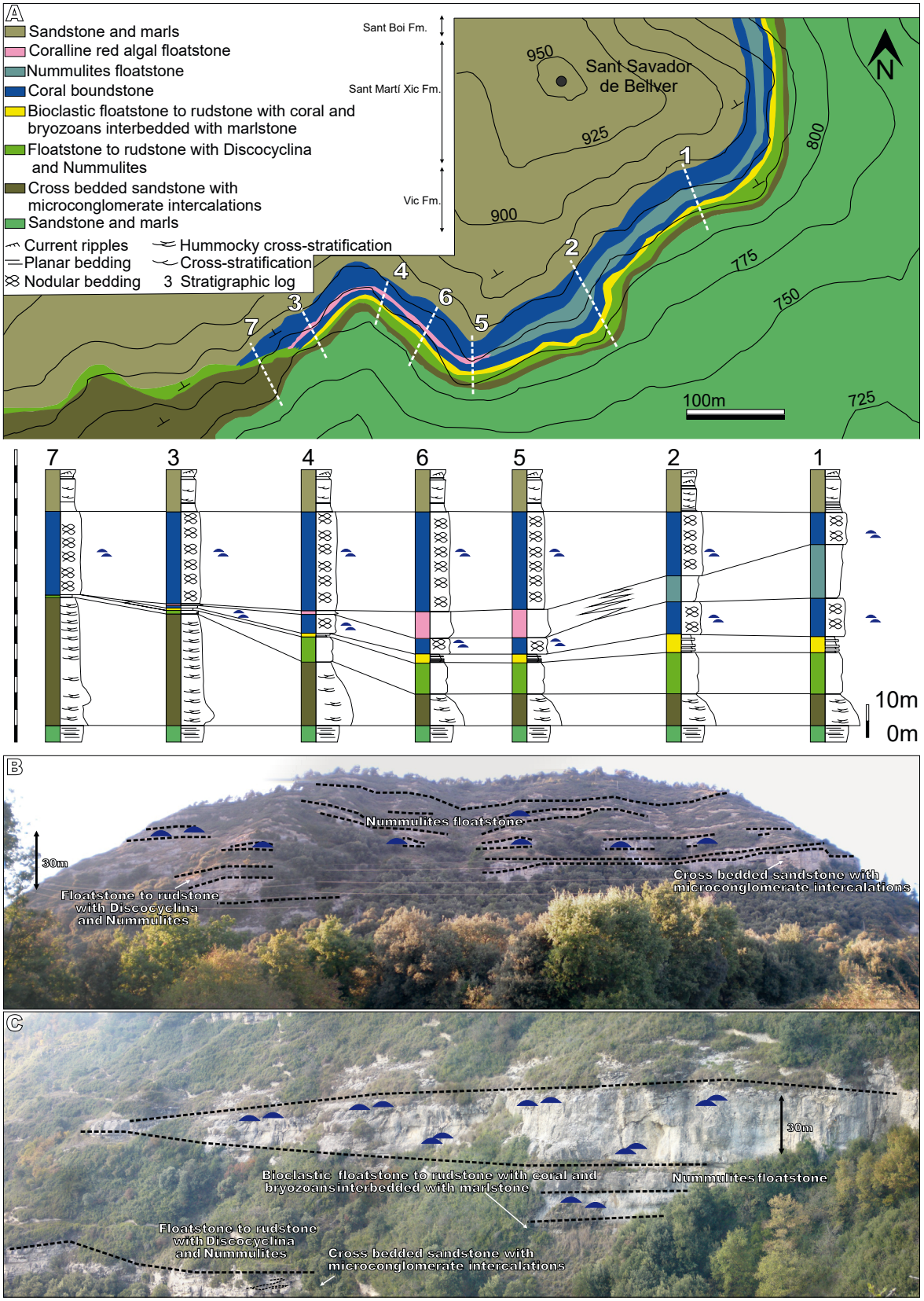

FIGURE 2. Stratigraphic setting of the study area. A) Detailed geological map with location of stratigraphic logs and their correlation. B-C) Panoramic view of the study area showing the geometries of the stratigraphic interval studied (stri.e.to the depositional profile. The blue shapes indicate the coralgal buildups.

3). The boundaries between the different stratigraphic intervals are characterized by vertical abrupt changes in lithofacies associated to non-planar contact surfaces with important thickness variations (see also Fig. 2). The only lateral heteropic change observable in the study area is represented by the *Nummulites* and coralline red algal floatstone lithofacies.

Cross bedded sandstone with microconglomerate intercalations

This lithofacies, 5–10m thick, is characterized by yellow fine sandstone with intercalation of microconglomerate beds several decimetres thick. The sediment shows a variable amount of quartz. Other undetermined components are well-rounded. Hummocky cross-stratification occurred especially at the top of the level (Fig. 3A).

Floatstone to rudstone with Discocyclina and Nummulites

This lithofacies forms a grey lens-shaped interval, 0.5–13m thick, which develops on top of the cross-bedded sandstone with microconglomerate intercalations (Fig. 3B). Bed thickness varies between 1.5–10m, being sometimes difficult to observe due to amalgamation, especially in the thickest part of the interval. The $CaCO_3$ content amounts 98%. Bioclastic floatstone to rudstone (Fig. 4A) is characterized by the main occurrence of *Discocyclina* sp. and sparse *Nummulites* (*N. incrassatus* DE LA HARPE, *N.* ex. gr. *fabianii* (PREVER in Fabiani), and *N.* ex. gr. *striatus* BRUGUIÈRE, *Assilina* sp. and abundant fragments of echinoids, bryozoans and bivalves (oysters). The presence of *N. incrassatus* indicates a Bartonian-Priabonian age and the shallow benthic zones SB 17-18 of Serra-Kiel *et al.* (2003a). Vertical and horizontal bioturbation is common.

Bioclastic floatstone to rudstone with coral and bryozoans interbedded with marlstone

This interval, 0.5–5m thick, is characterized by alternating grey marlstone and nodular limestone (78% of $CaCO_3$ content), organized in tabular beds, 0.10–0.30m thick (Fig. 3C). Grey marlstone is laminated or structureless. The nodular limestone intervals are instead characterized by bioclastic floatstone to rudstone (Fig. 4B) with bryozoans, coralline red algae, fragments of bivalves (oysters), foraminifera (miliolids, *Gypsina moussaviani* BRUGNATTI & UNGARO, *Fabiania cassis* OPPENHEIM, *Haddonia heissigi* HAGN, *Asterigerina rotula* (Kaufmann), *Gyroidinella magna* LE CALVEZ, rare *Nummulites* ex. gr. *fabianii* and corals. Coral fragments are bioeroded by sponges (*Entobia* ichsp.) and bivalves (*Gastrochaenolites* ichsp.) and encrusted by coralline red algae and serpulids and sometimes are completely re-crystallized.

Coral boundstone

Coral boundstone lithofacies (Fig. 3C, D) forms two different lens-shaped intervals separated by *Nummulites* and coralline red algal floatstone (see description below). Coral colonies are sparse in a skeletal matrix characterized by different lithofacies (Fig. 4C, D; Fig. 5A-L). Grainstone with fragments of intensively bioeroded corals, coralline red algae, *Nummulites* ex. gr. *fabianii*, *Gypsina moussaviani* and miliolids, characterizes the central part of the interval (Fig 5E-F), while rudstone to packstone/wackestone and bafflestone (Fig. 5A, B, C, D, G, H, I, J, K, L) with corals encrusted by *Fabiania cassis*, coralline red algae, miliolids, rhodoliths, *Nummulites* (*N.* ex. gr. *fabianii*, *N.* ex. gr. *striatus*), gastropods, *G. moussaviani*, victoriellids, gastropods, serpulids, rare fragments of bryozoans, oysters and intraclasts characterizes instead the marginal part. The thickness of the first interval varies 1–7m, while the second is up to 32m thick. The first coral interval is not well-organised laterally and vertically, whereas the second one is highly organised with larger coral colonies. The colonies show different growth patterns (branching, thick-branched, phaceloid, rare platy and dome) organised in a "mixstone" (*sensu* INSALACO, 1998). Relatively few coral taxa are present in either layer: *Cereiphylila*, *Ellipsocoenia*, *Goniopora*, *Caulastrea* and *Actinacis* (Fig. 6A, B, C, D). The largest colonies are 55–80cm (mean 26.8cm) in diameter and 14–25cm (mean 12.8cm) high. Corals are fragmented and abraded, whereas bioerosion values are variable, with higher values in logs 1 and 7, which correspond to marginal parts of the intervals. The bioerosion corresponds to sponges (*Entobia* ichsp.) and bivalves (*Gastrochaenolites* ichsp.) and several colonies are encrusted by coralline red algae and foraminifera (*Solenomeris*). Secondary processes are related to diagenesis and neomorphism (substitution of aragonite by calcite). In the Orís colonies, these processes are invasive and principally affect the *Actinacis* colonies, entirely replacing the internal structure and preserving only the exterior shape. The $CaCO_3$ content varies between 78% in the lower part of the intervals, to 98% in the upper part.

Nummulites floatstone

This lithofacies (Fig. 3E) separates the two coralgal buildups described above. It displays a variable thickness from 8m in the central part of the coral boundstone to 17.5m in its marginal part. Beds show planar stratification and sometimes are completely amalgamated. $CaCO_3$ content amounts 87%. Occasional bioturbations are observed in the lower part of the beds, while thin strata of microconglomerates may occur in the upper part. The poorly sorted floatstone (Fig. 4E) is dominated by *Nummulites* (*N.* ex. gr. *fabianii*, *N.* ex. gr. *striatus*, *N.* ex. gr. *incrassatus*), *G. moussaviani*, *Assilina schwageri* (SILVESTRI), *Assilina alpina* (H. DOUVILLÉ), *Asterigerina*

FIGURE 3. Lithofacies and outcrops of the study area. A) Cross-bedded sandstone with microconglomerate intercalations. B) Floatstone to rudstone with *Discocyclina* and *Nummulites*. C) Contact between the bioclastic floatstone-rudstone with corals and bryozoans interbedded with marlstone, and the first interval of coral boundstone. D) Contact between the coralline red algal floatstone and the second coral boundstone interval. E) Outcrop showing the characteristics of the Nummulites floatstone lithofacies. F) Outcrop view of coralline red algal floatstone.

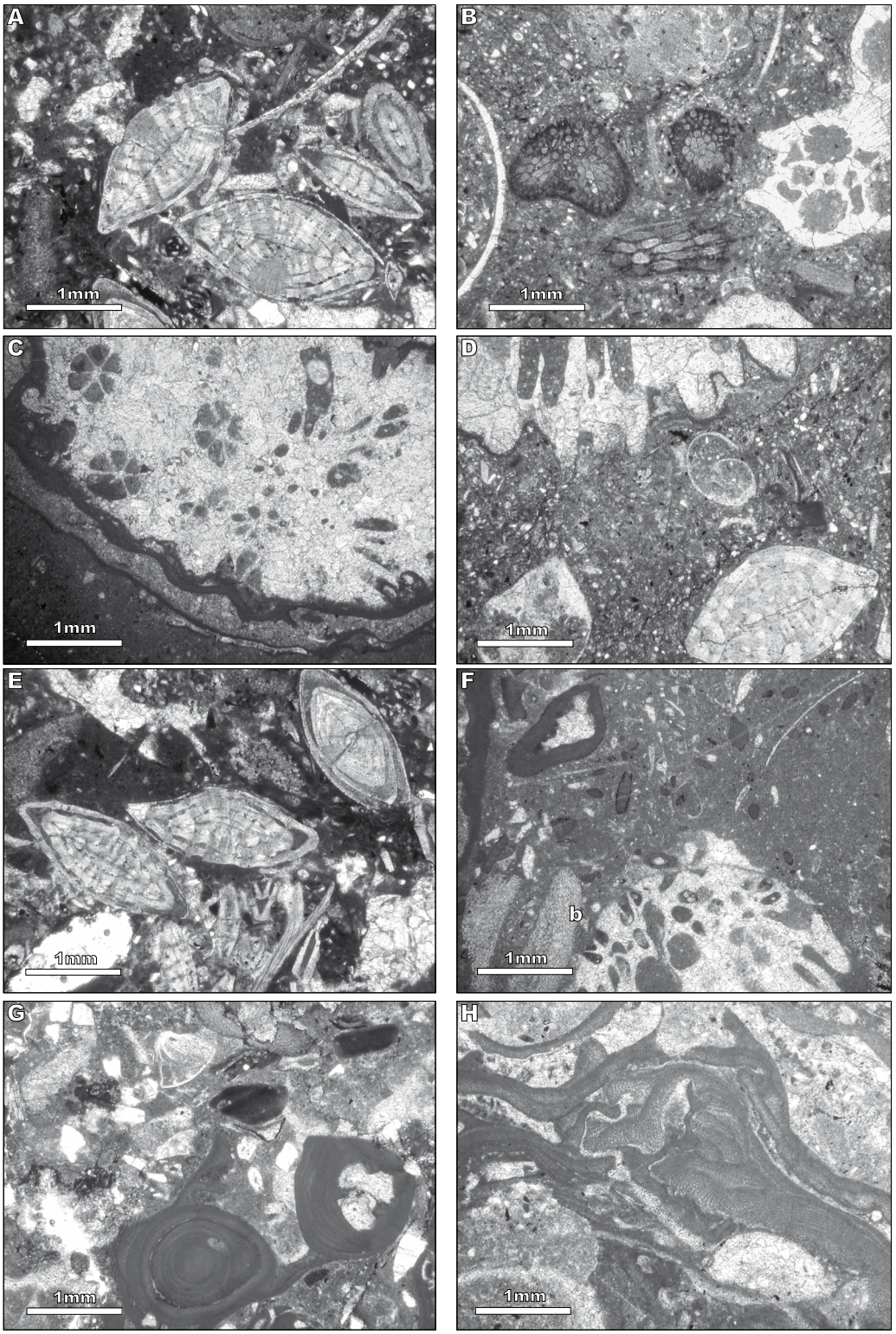

FIGURE 4. Microfacies of the lithofacies studied. A) Bioclastic floatstone with Nummulites and bivalve fragments from "Floatstone to rudstone with Discocyclina and Nummulites lithofacies"; B) Bioclastic rudstone with bryozoans from "Floatstone to rudstone with coral and bryozoans interbedded with marlstone lithofacies"; C) Bioeroded coral fragment encrusted by coralline coralline red algae from "Coral boundstone lithofacies"; D) Bioclastic floatstone with coral fragments and *Nummulites* (*N.* ex. gr. *fabianii*) from "Coral boundstone lithofacies"; E) Floatstone with *Nummulites* (*N. incrassatus* and *N.* ex. gr. *fabianii* from "Floatstone with Nummulites lithofacies"; F-G) Bioclastic floatstone with coralline red algae and bioeroded coral fragments from "Coralline red algal floatstone lithofacies". To note the variability in the growth type of the coralline red algae (branching, encrusting or nodular) and the presence of *Gypsina moussaviani* (b in subfigure F), indicating a vegetated seafloor; H) Coralline red algal bindstone encrusting unidentified bioclasts from "Coralline red algal floatstone lithofacies".

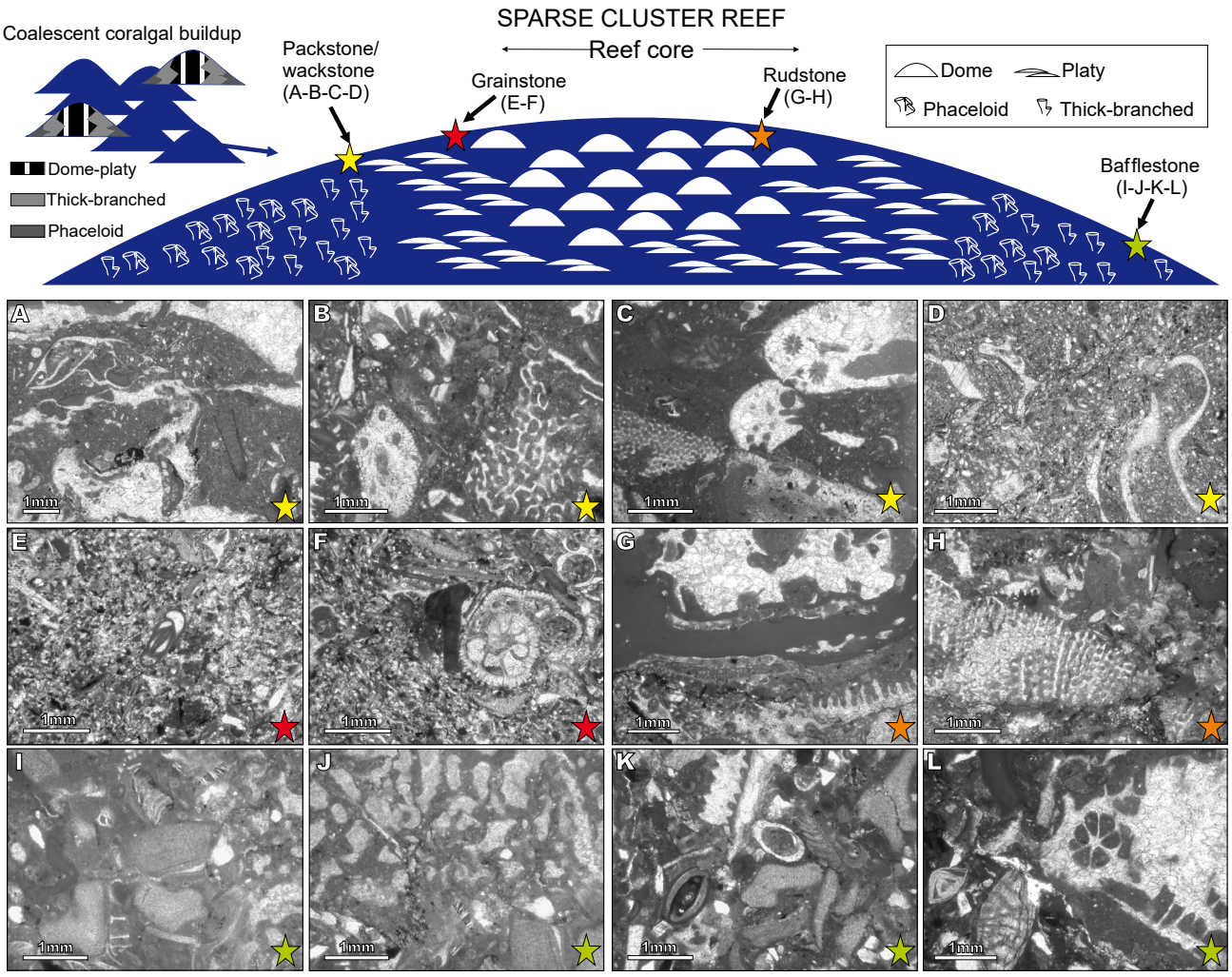

FIGURE 5. Distribution of the matrix fabrics in coral boundstone lithofacies. The coralgal buildups form two different lithosomes, which are characterized by small lens-shaped bioherms organized in a coalescent buildup, which develops on top of previous reliefs, maintaining the same distribution of coral growth-forms in each interval. A) Bioclastic packstone to wackestone with coral fragments, *Gypsina moussaviani*, bryozoans and coralline red algae; B-C) Wackestone with coralline red algae, bryozoans, miliolids, fragments of bivalves and bioeroded coral; D) Packstone to wackestone with fragments of bioeroded and encrsuted corals (*Fabiania cassis*), bryozoans, fragments of gastropods, coralline red algae, *Nummulites ptukhiani–fabiani*, quartz and serpulids; E) Grainstone with fragments of corals, *Nummulites ptukhiani–fabiani*, miliolids, coralline red algae and *Gypsina moussaviani*; F) Grainstone with fragments of corals, coralline red algae, gastropods, *Nummulites* sp., *Gypsina* sp., cibicides, serpulids and *Gyroidinella magna*; G-H) Rudstone with fragments of corals encrusted by *Fabiania cassis*; I-J-K-L) Bafflestone with fragments of bioeroded corals, gastropods, serpulids, miliolids, coralline red algae and *Gypsina moussaviani*.

rotula (KAUFMANN), miliolids, fragments of coralline red algae, bivalves, and gastropods (*Campanile* sp.).

Coralline red algal floatstone

This lithofacies displays a lenticular geometry and is characterized by a variable thickness of 0.5–8m, replacing laterally the *Nummulites* floatstone (Fig. 3F). The tabular beds are characterized by floatstone (rare bindstone) fabrics with abundant coralline red algae and *Nummulites* (Fig. 4F, G, H). $CaCO_3$ content amounts 97%. Coralline red algae vary from encrusting to branched. Crusts were principally built on bioclasts of corals and molluscs, while branches may be thick (up to 2cm long), to thin. The skeletal components include *Asterigerina rotula*, *Fabiania cassis*, epiphytic foraminifera such as *Planorbulina bronnimanni* BIGNOT & DECROUEZ and *Gypsina moussaviani* (Fig. 4F), miliolids, vermetids, rare encrusting bryozoans and fragments of corals, sometimes bioeroded (*Entobia* ichsp.).

DEPOSITIONAL MODEL

Facies analysis performed on the two sedimentary sequences of the Orís succession allows reconstructing the evolution of depositional settings passing from a lower

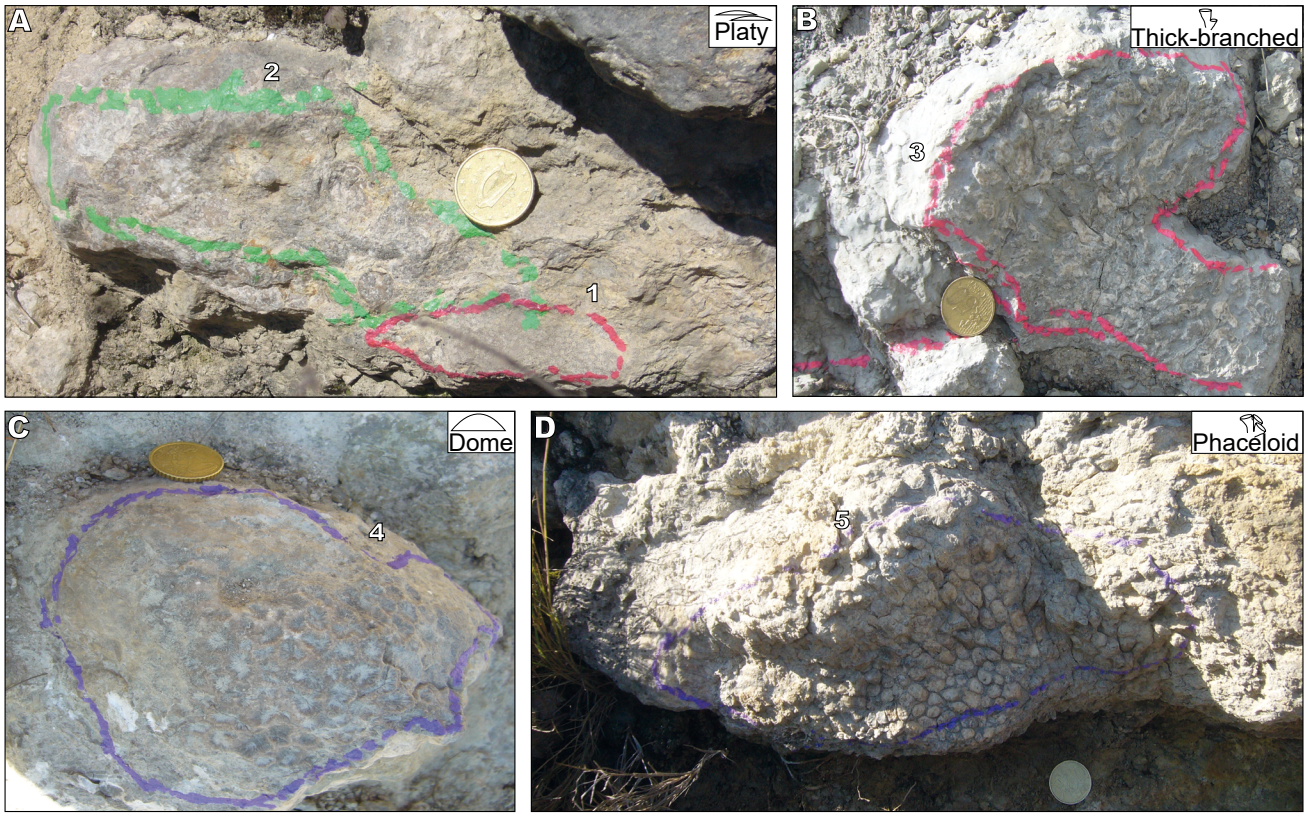

FIGURE 6. Growth types of coral colonies; A) Platy; B) Thick-branched; C) Dome; D) Phaceloid. Legend: 1= *Goniopora* sp.; 2-3= *Actinacis* sp.; 4= *Ellipsocoenia* sp.; 5= *Cereiphylila* sp.

transgressive sequence (Fig. 7, stages 1-2) to the upper regressive sequence (Fig. 7, stages 3-5), as also reported by Serra-Kiel *et al.* (2003a, b). In particular, the lithofacies observed on the lower part of the succession (Fig. 7, stage 1) attests for a depositional environment mainly associated to pro-delta (Ferrer, 1971), sometimes affected by episodic high energy events related to the activity of the delta front system and testified by the cross bedded sandstone with microconglomerate intercalations. Above previous facies, rudstone to floatstone with *Discocyclina* and *Nummulites* suggests deposition in a deeper environment (Fig. 7, stage 1), probably below the fair-weather wave-base level. In particular, *Discocyclina* is usually interpreted as inhabiting deeper water (outer ramp or lower photic zone (*e.g.* Beavington-Penney and Racey 2004; Romero *et al.*, 2002), since it is commonly associated to marls and shows morphological adaptations to low light intensity (*e.g.* Ferràndez-Cañadell and Serra-Kiel, 1992; Romero *et al.*, 2002). The absence of tractive structures excludes transport and accumulation of these larger foraminifera under the action of sea-bottom currents. Analogous facies, with similar foraminiferal assemblages, have been also described in the Alpine foreland basin (*e.g.* the "nummulitid and orthophragminid" biofacies of Coletti *et al.*, 2021), in the Eocene Foraminiferal Limestone of Pag (Croatia; Mariani *et al.*, 2024), and in the upper Eocene Nago limestone, Trento, Northern Italy (Bassi, 1998). The lack of shallow-water skeletal biota indicates minimal reworking processes, supporting the conclusion that the components were autochthonous in the depositional setting.

Bioclastic floatstone to rudstone with corals and bryozoans and marlstone deposited above the rudstone to floatstone with *Discocyclina* and *Nummulites,* suggest a transgression and a change in the hydrodynamic conditions to a low energy environment (Fig. 7, stage 2), as also reported in Barnolas *et al.* (1988) and Serra-Kiel *et al.* (2003a). The coral boundstone lithofacies developed in this deltaic complex and on top of the floatstone to rudstone with coral and bryozoans interbedded with marlstone (Fig. 7, stage 2) is associated to deposition below the wave-base level in a prodelta setting. A similar situation was described in the Ainsa Basin, in the South-Central Pyrenean zone (Morsilli *et al.*, 2011). The coralgal buildups form two different lithosomes with the same texture and lithofacies. In particular, corals develop into small, lens-shaped bioherms organized in a coalescent buildup (Fig. 5). This larger buildup grew on top of previous reliefs with the grainstone facies occupying the central part of the reef core (Fig. 5E, F), the packstone-wackestone facies placed

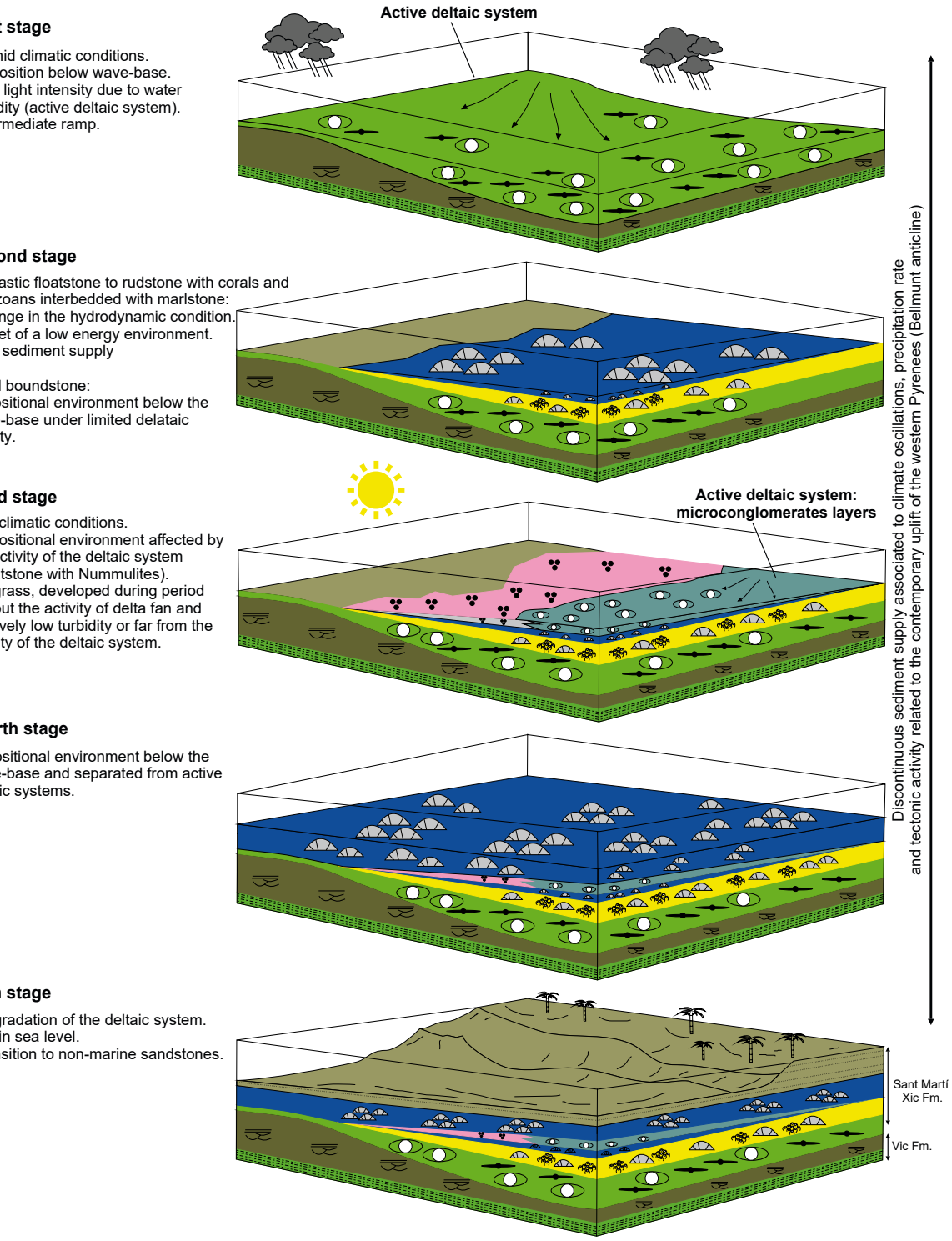

FIGURE 7. Palaeoenvironmental reconstruction of the studied succession (not to scale).

in the transition area from the reef core to the marginal part, and the rudstone/bafflestone facies occurring in the marginal part of the reef core (Fig. 5A, B, C, D, G, H, I, J, K, L). Moreover, the scarce lateral continuity of the coral boundstone lithosomes suggests that they were constrained by the morphology of the underlying active deltaic deposits. Sometimes such environment was affected by episodic high-hydrodynamic pulses, allowing the skeletal sediments to be reworked. From this viewpoint, such coral lithosomes could be classified as sparse cluster-reefs *sensu* Riding (2002). Reefs on the delta fan system were submitted to important light fluctuations in mesophotic to aphotic zones and developed probably during periods with limited or without siliciclastic input. A similar situation was documented by Morsilli *et al.* (2011) in the coeval succession of Ainsa Basin (South Central Pyrenean zone). The two coral boundstone intervals are separated by *Nummulites* floatstone that passes laterally to coralline red algal floatstone. In particular, the thick- to thin-branching growth of coralline red algae and the abundance of *Gypsina moussaviani* with hooked morphologies suggests the occurrence of seagrass on the sea-bottom (Beavington-Penney *et al.*, 2004; Sola *et al.*, 2013). This would attest for a period with an unactive deltaic system and relatively low water turbidity (Fig. 7, stage 3). In contrast, the presence of several beds of microconglomerate toward the top of the sequence probably indicates the increase of fluvial input preceding the origin of the second coral buildup. Finally, the progradation of the deltaic system was related to a fall in sea level (Fig. 7, stage 5), as attested by the transition to the non-marine sandstones of the Sant Boi de Lluçanès and Artés Formations (Serra-Kiel *et al.*, 2003a, b; Sanjuan *et al.*, 2012).

DISCUSSION

The Priabonian coralgal buildup of the studied Orís sedimentary succession in the NE part of the Ebro Basin was related by Barnolas *et al.* (1988) and Serra-Kiel *et al.* (2003a) to the second Bartonian regressive cycle (Sant Martí Xic Formation). It consists of an alternation of offlap episodes, represented by deltaic deposits, and onlap episodes associated to marine deposits with larger foraminifera and coralgal facies. Costa *et al.* (2013), using integrated bio- and magnetostratigraphic data, re-assigned this cycle to the Priabonian.

The sedimentary succession is organized in two sedimentary sequences. The first is a transgressive sequence that starts with floatstone to rudstone with *Discocyclina* and *Nummulites* covered by coral boundstone, while the second, a regressive sequence, is characterized by *Nummulites* and coralline red algal floatstone overlain by the second coral boundstone (second buildup). The cyclicity of the studied succession would be related both to local and global factors. Upper Eocene to lower Oligocene sedimentary successions follows worldwide (*e.g.* in European basins, Antarctica, East Asia and North America) a general climatic trend towards more arid climatic conditions (Sheldon and Retallack, 2004; Dupont-Nivet *et al.*, 2008; Passchier *et al.*, 2013; Utescher *et al.*, 2015). Such a climatic trend is also recognized in the Ebro Basin and testified by a modification in the composition of plant biomes (Cavagnetto and Anadón, 1996; Bauer *et al.*, 2016). However, the change in plant biomes did not correspond to a linear process but rather to short-term paleoclimatic fluctuations, in part related to orbital cyclicity influencing the precipitation rates (Postigo Mijarra *et al.*, 2009; Tosal *et al.*, 2019). The succession studied at Orís may be also influenced by similar short-term fluctuations.

During the Priabonian, the precipitation regime was relatively low and irregular, with a trend toward more arid conditions, mainly recorded in the coastal area and probably associated to oceanic regression. This lead finally to an increased continentalization of the Eurasian climate and a global temperature decrease (Postigo Mijarra *et al.*, 2009). In Orís, this climate change might correspond to the replacement of *Discocyclina*-rich assemblages by *Nummulites*-dominated assemblages and is also testified by the decrease in carbonate content of the *Nummulites* floatstone in comparison with the second coral boundstone interval.

From the early Eocene climatic optimum (50–52Ma) until the start of the Oligocene (34Ma), a 17Myr-long abrupt fall in temperature occurred, culminating around 34Ma with the EOT events (Postigo Mijarra *et al.*, 2009; Gandolfi *et al.*, 2024). This temperature cooling was associated to an important glaciation (400kyr - Oi-1) and resulted in the development of the first Cenozoic Antarctic ice cap (Miller *et al.*, 1991; Zachos *et al.*, 2001). In the Ebro Basin important palynological changes were recorded at the boundary between Bartonian and Priabonian. Mangroves disappeared and plant associations shifted to biomes better adapted to drier climates, including savannahs (Cavagnetto and Anadon, 1996; Tosal *et al.*, 2019). However, despite this climatic trend, several marine and continental palaeotropical species survived better in the Iberian Peninsula than in other areas of Europe, suggesting that the peninsula may have acted as a biogeographic refuge thanks to its southern palaeolatitude, to its varied orography and microclimatic diversity (Tosal *et al.*, 2024, and references therein). Also, the influence of the Tethyan and Atlantic oceans, providing constant humidity across several peninsular areas, must be considered as a significant factor of temperature attenuation (Postigo Mijarra *et al.*, 2009).

This climatic situation may have also affected the development of the coral buildups studied. The architecture of the coralgal buildups suggests adaptation to low light intensity, showing coral colonies growing wider than higher in order to increase the surface exposed to sunlight. Alternatively, they grew on top of pseudocolonial forms (phaceloid shapes) to avoid being covered by sediment, with platy corals serving as ground for more complex colonies, such as rare domes (Fig. 6A). Unstable environments resulted in low coral biodiversity with *Cereiphylla* sp., *Ellipsocoenia* sp., *Goniopora* sp., *Caulastrea* sp., and *Actinacis* sp. being the main components.

In this view, the coralgal buildups studied here represent a good example of reefs developed under turbid water conditions in the sense of Sanders and Baron-Szabo (2005). These reefs were influenced by discontinuous sediment supply associated to climate oscillations, unstable precipitation rate (*e.g.* Gómez-Paccard *et al.*, 2012) and possibly also active tectonics, related to the contemporary uplift of the western Pyrenees and the nearby Bellmunt anticline (Vilà-Vinyet, 2010) (Fig. 1).

Similar environmental scenarios were described in other localities. In the Upper Austrian Alpine foreland basin, Rasser (2009) reported coeval deposits to the Orís buildups with corals sharing similar patterns of poor diversity and growth morphology. Coralline red algae lithofacies attested for an environment mainly controlled by good light conditions and associated to inactive deltaic systems covered by seagrass (Nebelsick *et al.*, 2005). The adaptation of corals to similar environments was also described by Bosellini and Trevisani (1992), Bosellini (1998), Bosellini and Papazzoni (2003) in the succession of the Nago Limestone (Venetian region, North Italy) and by Morsilli *et al.* (2011) in coeval examples of the Ainsa Basin (southern central Pyrenees). The coralgal buildups of the Orís section show limited lateral extension and thickness when compared with the coeval deposits of the Ainsa Basin. This space limitation could result from the growth of corals upon a small, pre-existing deltaic lobe.

Further examples of corals adapted to similar environmental conditions and palaeotopographic constraints were described in non-coeval records. Thus, during the Late Oligocene Warming Event in the Piedmont Basin (NW Italy) Bosellini *et al.* (2024) describe a deltaic system developed in a narrow palaeovalley, where discontinuous coral buildups grew in the pro-delta under mesophotic conditions. These coral buildups grew during periods of inactive deltaic systems or thanks to a by-pass of the fluvial sediment.

Another important factor to be considered to interpret correctly the growth of coral buildups is the Cenozoic change in marine water circulation proposed by Pomar *et al.* (2017). This was related to new thermal gradients that induced the formation of waves or currents at different depths and latitudes. The increase of such currents and waves changed the nutrient supply, feeding in particular the plankton catchers, such as corals, and limiting the distribution of larger benthic foraminifera. Although such currents might not have reached the easternmost Ebro basin, the fact that occurrence of larger benthic foraminifera (*Discocyclina/Nummulites*) in the Orís section was reduced in the areas where the succession of coral boundstone was developed, suggest similar patterns to those described by Pomar *et al.* (2017).

All these considerations suggest that the studied sedimentary succession at Orís was influenced by simultaneous processes, such as light fluctuation, high sedimentary rates and increase in nutrient supply, leading to mesotrophic conditions. In particular the deposition of floatstone to rudstone with *Discocyclina* and *Nummulites*, suggests a period of stronger activity of the deltaic system associated to more humid conditions, while the deposition of the *Nummulites* floatstone and coralline red algal floatstone, suggest deltaic systems with variable water turbidity and developed under drier climatic conditions. This view is supported by the absence of *Discocyclina*. Coral boundstone displays lens-shaped bioherms, with geometries being possibly controlled by the pre-existing deltaic morphology and nutrient distribution, rather than by climatic constraints (*e.g.* Pomar *et al.*, 2017). Nutrient distribution was related to marine currents, hydrodynamic conditions and the palaeotopography, the latter being strictly linked to the uplift of the Catalan Coastal Range (Vergès *et al.*, 2002). The interaction of the local and global factors reported above reveal the complexity of sedimentary successions in a shallow water setting and document the resilience of Eocene corals to environmental change.

CONCLUSIONS

The sedimentary successions in both continental and marine environments are a valuable tool to recognize how biotas responded to global and local environmental factors with varying adaptive strategies. In particular, different lithofacies and biofacies are directly indicative of the environmental conditions preserved within the sedimentary record. The upper Eocene Sant Martí Xic Formation and its sedimentary succession studied at Orís, (Vic, SE Ebro basin, Spain), is characterized by different depositional stages.

The first stage, represented by the deposition of the rudstone to floatstone with *Discocyclina* and *Nummulites*,

testifies for an environment below the fair-weather wave-base level, related to the middle ramp. This environment, with low light intensity, was associated to turbid water and humid climate conditions. The second stage, that includes the first coral boundstone interval, reveals instead a low energy environment below the fair-weather wave-base characterized by low sediment supply due to the inactive deltaic system or to deposition in an area away from deltaic influence. The third stage was instead associated to two different environmental settings associated to dry climate conditions. The first one was represented by *Nummulites* floatstone and suggests an environment affected by the active deltaic system with low light intensities. In contrast, the second environmental setting reveals low water turbidity in a period when the deltaic system was not active (coralline red algae floatstone). Microconglomerates overlaying the third stage lithofacies suggest the onset of the fluvial input and the progradation of the deltaic system, stopped during the development of the second coral boundstone layer (fourth stage). This stage displays similar conditions to those described by the second stage. Finally, a fall in sea level determined the transition to the continental sandstones of the Sant Boi and Artés formations (fifth stage).

The two coralgal buildups interdigitated with deltaic system deposits studied at Orís, were influenced two main large-scale factors, firstly the tectonic activity, related to the uplift of the western Pyrenees, and secondly the climatic fluctuations with discontinuous sediment supply mainly related to precipitation rate. The cyclicity in the appearance of these buildups is linked to short-term paleoclimatic fluctuations during the Priabonian, a period characterized by low and irregular precipitation, with a trend towards increasingly arid conditions. Despite these environmental shifts the studied buildups represent the resilience of Eocene corals to both climatic and local environmental changes.

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