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The Campo section (Pyrenees, Spain) revisited: Implications for changing benthic carbonate assemblages across the Paleocene–Eocene boundary

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Abstract

The Campo section is a parastratotype section for the shallow-water Ilerdian and Cuisian stages. Although a lot of work has been concentrated during the last years on biostratigraphy, sequence stratigraphy, magnetostratigraphy, and geochemistry, surprisingly little work has been published on the facies development. Here we evaluate the facies evolution with particular emphasis on the biogenic assemblages of the latest Paleocene (shallow benthic zonation 4) to the earliest Eocene (shallow benthic zonations 5 and 6) of the Campo and the nearby Serraduy section. Overall, the facies show a deepening in the Paleocene and the Eocene, interrupted by a terrestrial interval across the newly defined Paleocene/Eocene boundary. In the late Paleocene altogether seven microfacies types were distinguished. These are dominated by various algal taxa and subordinate corals and larger foraminifera. The lower Eocene carbonate platform is characterised by twelve microfacies types, which are dominated by larger foraminifera such as alveolinids, orbitolitids and nummulitids and subordinate corals. This facies dichotomy recognized in the Campo and Serraduy sections can be extrapolated to the whole Pyrenean region in the early Paleogene and is even found in Egypt. The comparison of the two regions shows that the facies dichotomy is less pronounced in the Pyrenean region. This is interpreted to reflect a latitudinal trend, where corals are absent in the low latitudes, while in the middle latitudes they occur subordinately. This gradient within the facies distribution can be explained by latitudinal temperature changes and by the long-time warming in the early Paleogene and the short-time warming of the Paleocene Eocene Thermal Maximum. Hot temperatures in the low latitudes hamper the growth of temperature sensitive corals, while in the middle latitudes the temperatures were still in a favourable temperature range.

Keywords: Paleocene; Eocene; Campo; Serraduy; Platform evolution; Larger foraminifera; Corals; Microfacies

1. Introduction

During the last few years, the Paleocene/Eocene boundary time interval has been the focus of several studies, which have dealt mainly with the timing of the Paleocene/Eocene Thermal Maximum (PETM) (Norris

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and Röhl, 1999; Röhl et al., 2000) and its impact on marine and terrestrial environments. The PETM is associated with a sharp negative δ^{13}C excursion (carbon isotopic excursion, CIE; e.g., Dickens, 1999) that probably resulted from rapid dissociation of methane at the sea floor (Dickens et al., 1995; Bains et al., 1999). Open marine microfossils (planktic and benthic foraminifera, dinoflagellates, calcareous nannofossils) show extinction and diversification patterns (e.g., Thomas, 1998; Crouch et al., 2001; Kelly, 2002; Bralower, 2002), the most prominent being the benthic foraminifera extinction event (BEE; Pak and Miller, 1992), during which approximately 40% of all smaller benthic foraminifera became extinct. On land the terrestrial vertebrates show a well-documented rejuvenation (Maas et al., 1995).

In contrast to studies on the impact of the PETM on open marine and terrestrial environments, only few studies exist regarding its impact on shallow marine environments. Orue-Etxebarria et al. (2001) and Pujalte et al. (2003a) investigated this time interval in the Pyrenees (northern Tethys) and concluded that the impact of the PETM on the evolution of the benthic faunas in shallow-water environments may have been greater than previously thought, but did not state any possible causes for this relationship. Recently, Scheibner et al. (2005) analysed Paleocene/Eocene sections in the Galala Mountains in Egypt (southern Tethys) and suggested an interplay between rising temperatures and changes in the trophic resource regime and their effects on biota (especially corals and larger foraminifera) and long-term evolutional changes in larger foraminifera as the main causes for the changes in shallow-water facies. Furthermore, for the Egyptian platform they postulated an evolution of the shallow-water platform across the Paleocene/Eocene boundary in three successive stages, characterised by changing biota. The two Paleocene stages are characterised first by a coralgal-dominated platform and second by a larger foraminifera-dominated platform (mainly *Miscellanea* and *Ranikothalia*). The boundary between the second and the third stage is the newly defined Paleocene/Eocene boundary. The third platform stage is characterised by abundant alveolinids, nummultids and orbitolitids (Scheibner et al., 2005).

Apart from studies on the ecological impact of the PETM, several old and new sections around the world, especially in Spain, have been investigated over the last few years to establish the Global Stratotype Section and Point (GSSP) for the Paleocene/Eocene boundary. Particularly, the Campo section in the Spanish Pyrenees has been investigated in great detail concerning this potential selection. The Campo section in Spain is the Ilerdian and Cuisian parastratotype (Schaub, 1966; Molina et al., 1992; Schaub, 1992): Hottinger and Schaub (1960) described the Larger Foraminiferal Turnover (LFT, Orue-Etxebarria et al., 2001) for the first time in Campo. The LFT marks the base of the Ilerdian (Hottinger and Schaub, 1960; Hottinger, 1998) and is characterised by the start of adult dimorphism and a large shell size in the larger foraminifera especially the nummulitids and alveolinids. Because of the importance of this shallow-marine section and the search for a GSSP, the Campo section was recently re-examined magnetostratigraphically by Pujalte et al. (2003b),

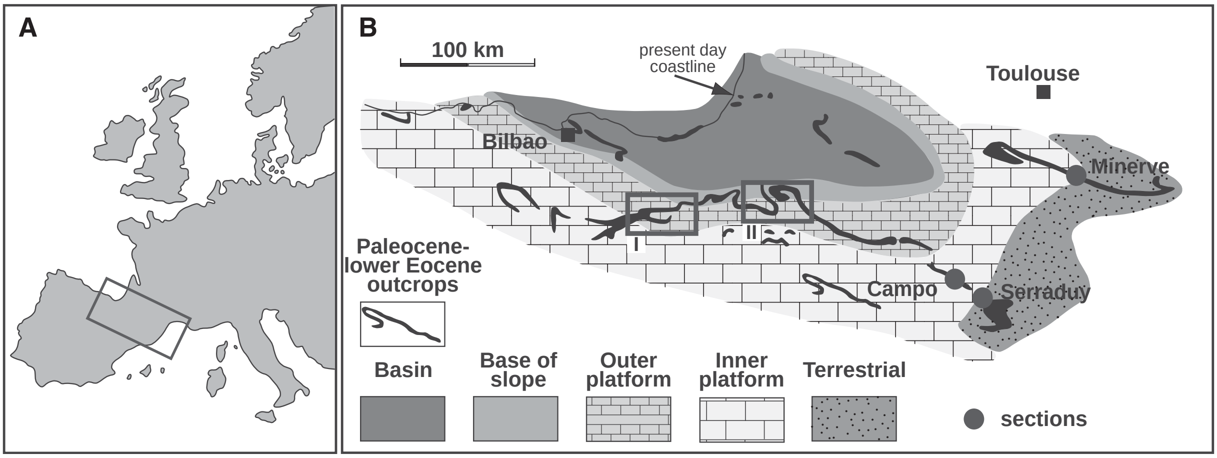

Fig. 1. Location and paleogeography of the Pyrenean area, modified after Orue-Etxebarria et al. (2001); A: recent location of the Pyrenees, the rectangle marks the position of the Pyrenees; B: paleogeographic reconstruction of the Pyrenean basin. I: Reefs of the Urbasa–Andia plateau (Baceta et al., 2005; see Fig. 6), II: location of the Urrobi and Mintxate sections of Pujalte et al. (2003a). The two sections of this study, Campo and Serraduy and the section of Minerve from Rasser et al. (2005) are indicated by dots.

isotopically by Schmitz and Pujalte (2003), biostratigraphically (planktic foraminifera, calcareous nannoplankton and dinoflagellate cysts) by Orue-Etxebarria et al. (2001), Molina et al. (2003), and lithostratigraphically and sequence stratigraphically by Payros et al. (2000). The current GSSP for the Paleocene/Eocene boundary is located in Dababiya (Egypt): the position of the carbon isotopic excursion is used as the boundary criterion (Luterbacher et al., 2004). In this study we present new sedimentological and microfacies data from two Pyrenean (Spain) late Paleocene–early Eocene inner-platform sections, Campo and Serraduy to better constrain the evolution of sedimentary environments and biogenic assemblages. The Paleocene/Eocene boundary in these sections is located within a short terrestrial interval and separates Paleocene environments, dominated by red algae, from Eocene environments, dominated by abundant larger foraminifera (alveolinids, nummulitids and orbitolitids). These results, in combination with literature data from other Pyrenean sections, enabled us to propose a platform subdivision for the Pyrenees in the northern Tethys, similar to that established by Scheibner et al. (2005) in Egypt for a southern Tethyan platform.

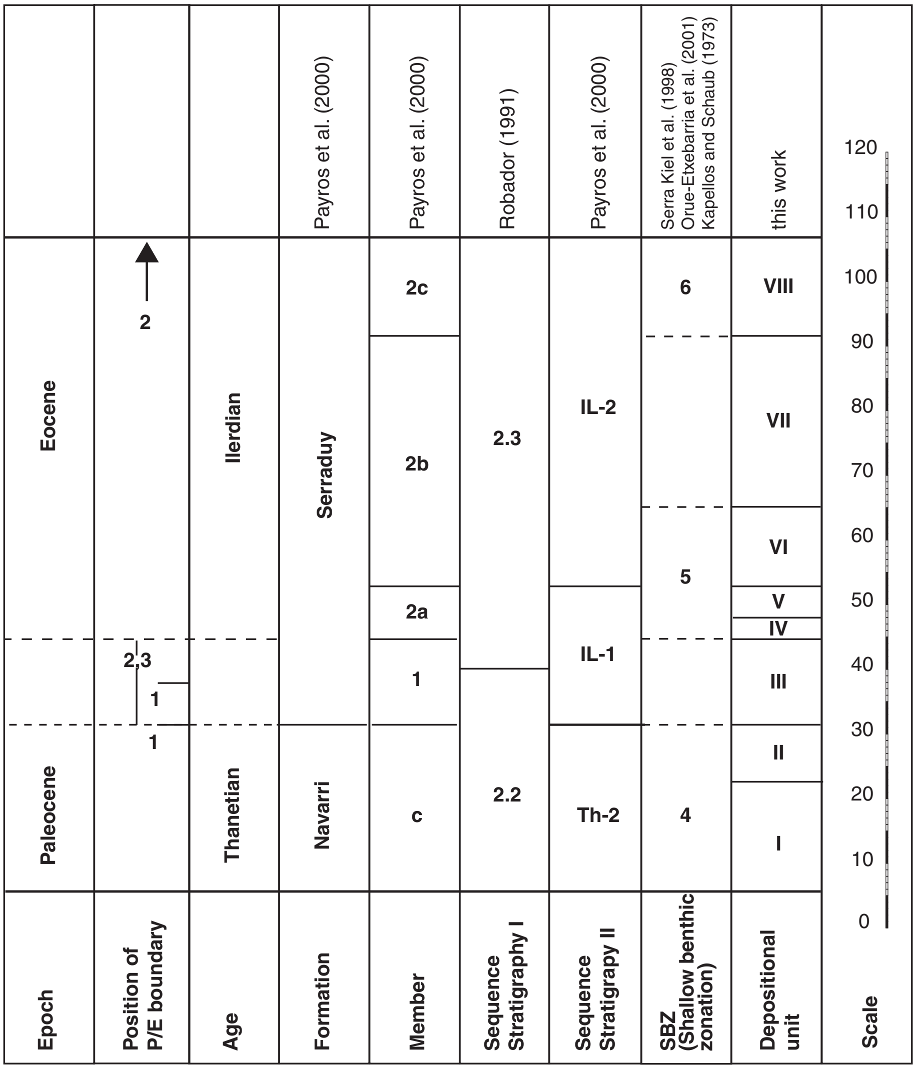

Fig. 2. Chronostratigraphy, lithostratigraphy, biostratigraphy and sequence stratigraphy of the Campo section. The position of the numbers in the P/E boundary column refers to the different opinions for the location of the P/E boundary: 1. Schmitz and Pujalte (2003), 2. Molina et al. (2003), 3. Orue-Etxebarria et al. (2001). We follow Schmitz and Pujalte (2003). The boundary between SBZ5 and SBZ6 is uncertain, as literature data either give different positions for this boundary or the scale of the literature sections is too small to compare it with our scale (Robador et al., 1991; Schaub, 1992; Molina et al., 1992; Serra-Kiel et al., 1993; Orue-Etxebarria et al., 2001; Molina et al., 2003).

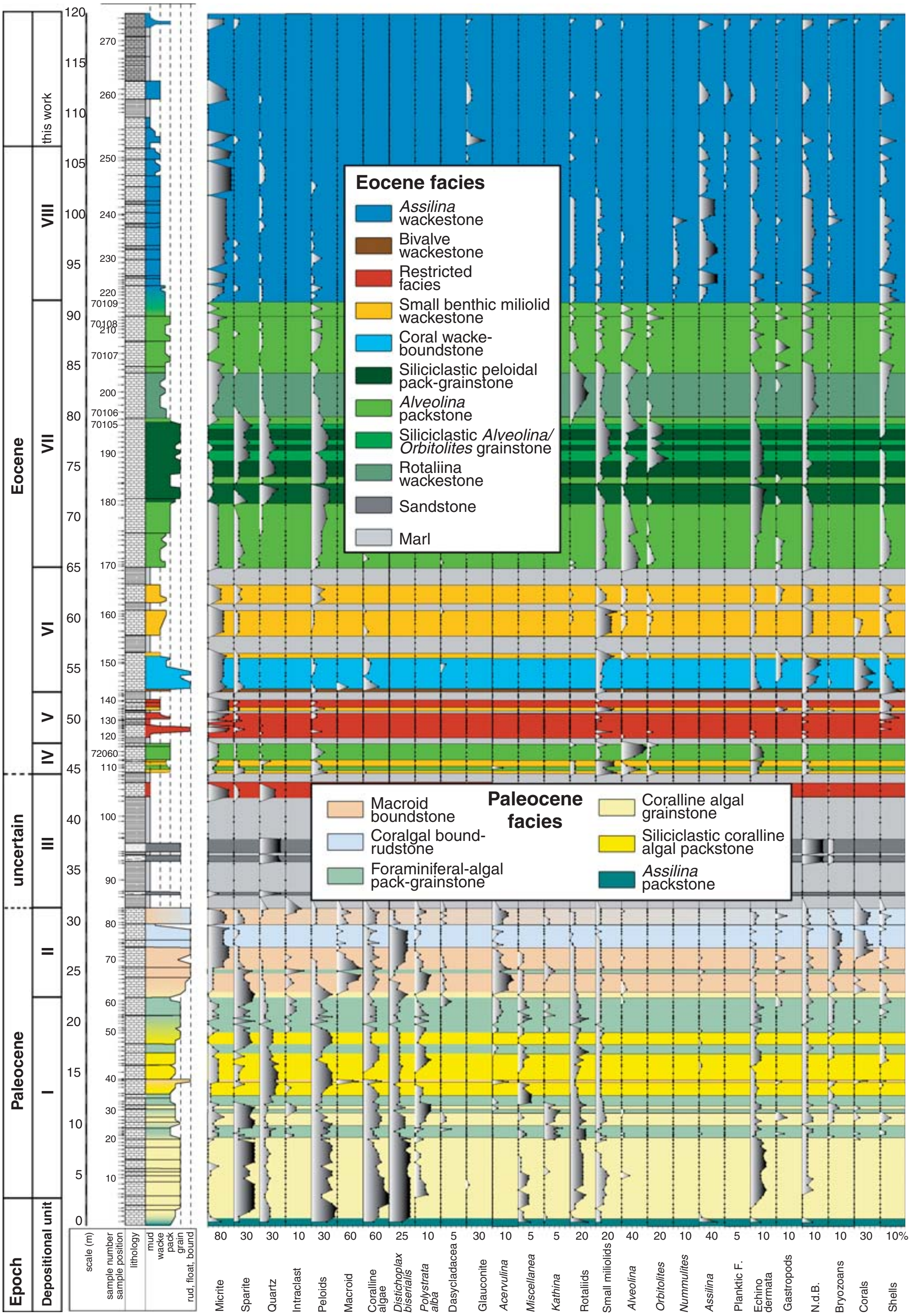

Fig. 3. Stratigraphy, depositional units, lithology, components, and microfacies types of the Campo section. The sample numbers with 5 digits are the sample positions of Kapellos and Schaub (1973), Schaub (1992) and are painted on the rocks within the section. The distribution curves behind the legends have values of zero. The percent values at the bottom of every curve indicate the maximum values of each scale.

2. Geologic overview

During the Early Paleogene, the region that now forms the Pyrenees, comprised an elongated east–west trending gulf, which opened westward into the paleo Bay of Biscay and is positioned at a paleolatitude of 38° N (Hay et al., 1999; Fig. 1). Terrestrial red beds, carbonate platform limestones and deep basinal marls surrounded this gulf. Tectonically this time interval is characterised by the development of a foreland basin (Paleocene) and the migration of foreland basins (Eocene; Puigdefabregas and Souquet, 1986).

The carbonate platform-to-basin strata of the Pyrenees, especially in the Campo section, are one of the classical and best-studied deposits of the early Paleogene worldwide. Numerous paleontological studies have focused on various fossil groups, including planktic foraminifera (Orue-Etxebarria et al., 2001), larger foraminifera (Hottinger, 1960; Schaub, 1966, 1981, 1992; Serra-Kiel et al., 1993), calcareous nannofossils (Kapellos and Schaub, 1973; Wilcoxon, 1973), and dinoflagellates (Caro, 1973). A number of regional studies have addressed lithostratigraphy (Payros et al., 2000), stable isotope analyses (Molina et al., 2000, 2003; Schmitz and Pujalte, 2003) and the overall paleogeography and depositional history of the Pyrenees (Plaziat, 1981; Puigdefabregas and Souquet, 1986; Eichenseer and Luterbacher, 1992; Pujalte et al., 1993, 2000, 2003a; Baceta et al., 2005).

During the early to middle Eocene, the time of the development and migration of a foreland basin, three main carbonate platform units (Ilerdian, Cusian, Lutetian) existed in the Pyrenees. These platform units were interrupted by phases of collapse and drowning (Barnolas and Teixell, 1994). The platform collapse events resulted in a retreat of the platform and are associated with 8 megaturbidite beds, whereas the drowning is documented by glauconite limestones and marls (Barnolas and Teixell, 1994). During times of tectonic quiescence, the platforms could grow, while during times of major overthrust loading, collapse and drowning of the carbonate platform occurred (Barnolas and Teixell, 1994). The onset of this thrusting began with the collapse and drowning of the Ilerdian platform. Therefore, the Ilerdian platform itself can be regarded as mostly unaffected by the tectonic influence. The development and subsequent drowning of the Ilerdian platform is reflected by the early Eocene *Alveolina* limestone and the *Assilina* wackestone with glauconites, investigated in this study. From middle Eocene time onwards this depositional environment was uplifted and eroded during the Pyrenean orogeny.

2.1. Stratigraphic correlation in the Campo section

Orue-Etxebarria et al. (2001) proposed the synchronicity of the larger foraminifera turnover (LFT), the benthic foraminifera extinction (BEE), and the carbon isotopic excursion (CIE) in the Campo section, although the identification of these events and their correlation remain ambiguous. Molina et al. (2003) give two possible intervals for the Paleocene/Eocene boundary, the first interval coincides with the siliciclastic interval, mentioned by Schmitz and Pujalte (2003), Orue-Etxebarria et al. (2001), while the other is a level within the Ilerdian limestones approximately 80 m above the siliciclastic interval (Figs. 2, 3). There have been more suggestions for placing the P/E boundary, even much more higher in the section than those mentioned here; a summary of all the suggested locations for the P/E boundary in Campo is covered by Orue-Etxebarria et al. (2001). We follow Schmitz and Pujalte (2003) and place the P/E boundary within the siliciclastic interval above the marine Thanetian and below the marine Ilerdian.

The definition and biostratigraphic assignment of the different members within the Campo section from previous studies is given below:

I. Part c of the Navarri Formation: Payros et al. (2000) gives a thickness of 32 m for the last interval of the Navarri Formation, which ends with the prominent karstic horizon. Part c of the Navarri Formation belongs to SBZ4 (Payros et al., 2000; Pujalte et al., 2003a).
II. Member 1 of the Serraduy Formation: Payros et al. (2000) measured 12 m and Orue-Etxebarria et al. (2001) measured 14 m for this unit. Both authors transferred member 1 to the Serraduy Formation because of the gradational transition to the overlying Ilerdian limestones. In contrast to this Serraduy Formation assignment Molina et al. (2003) measured 11 m and attributed this part to the Navarri Formation. According to the latest isotopic studies by Schmitz and Pujalte (2003) the Paleocene/Eocene boundary delineated by the carbon isotopic excursion lies within this interval, either on top of the sandstones in the middle of this interval or at the karstic horizon at the base (Figs. 2, 3).
III. Member 2a of the Serraduy Formation: Payros et al. (2000) measured 11 m and Orue-Etxebarria et al. (2001) measured 9 m for this unit. This unit belongs to SBZ5.

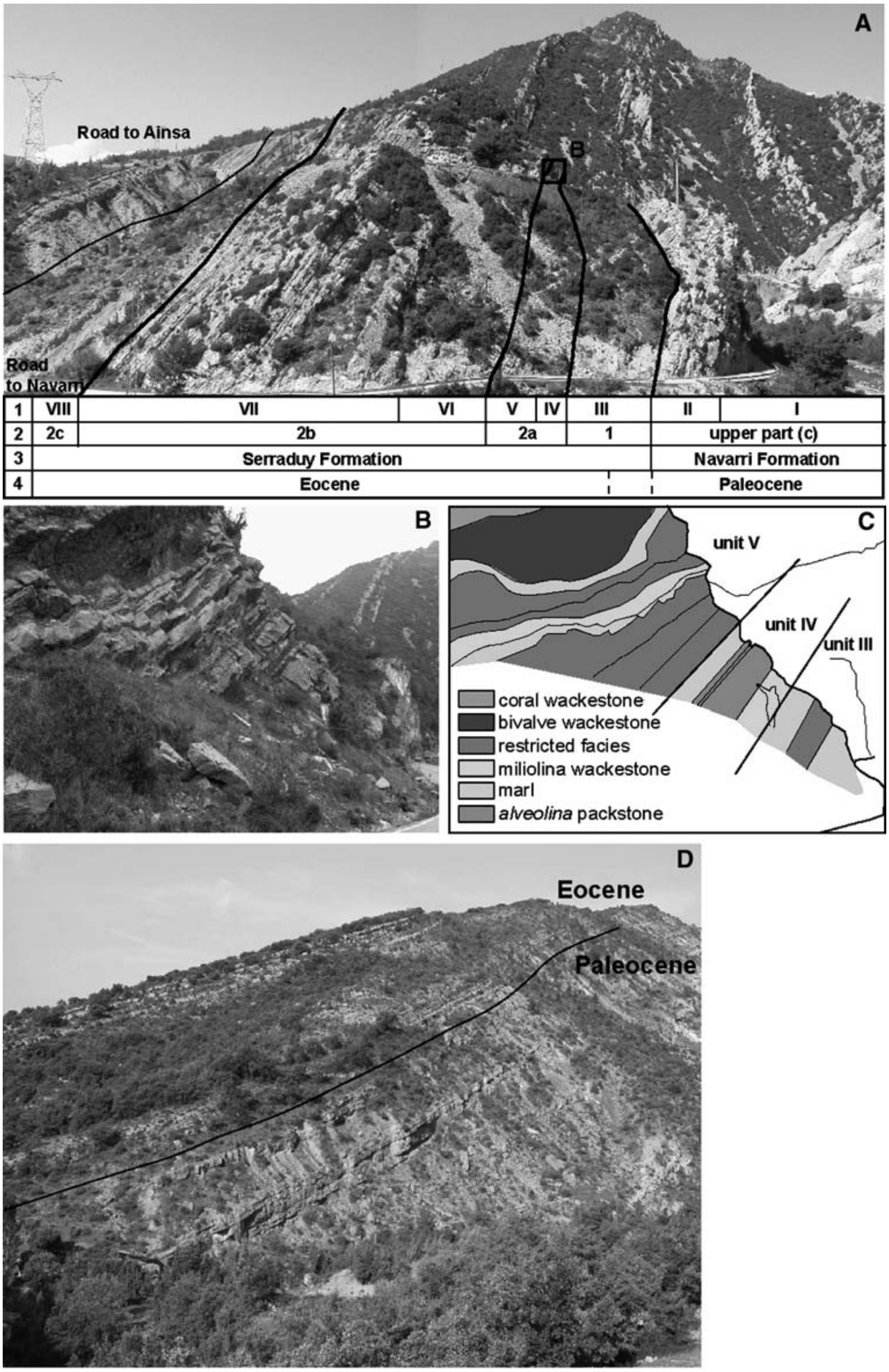

Fig. 4. Sections of Campo and Serraduy in the Pyrenees. A: Campo section, the rectangle marks the area of Fig. 4B, 1: depositional units, 2: members of Payros et al. (2000), 3: formations, 4: epochs; B: the first Ilerdian limestones (restricted to inner platform facies; units III and IV), the person is pointing directly at the first massive *Alveolina* beds; C: sketch of Fig. 4B with the interpretation of the microfacies types; D: Serraduy section, red terrestrial sediments dominate the Paleocene part of the section.

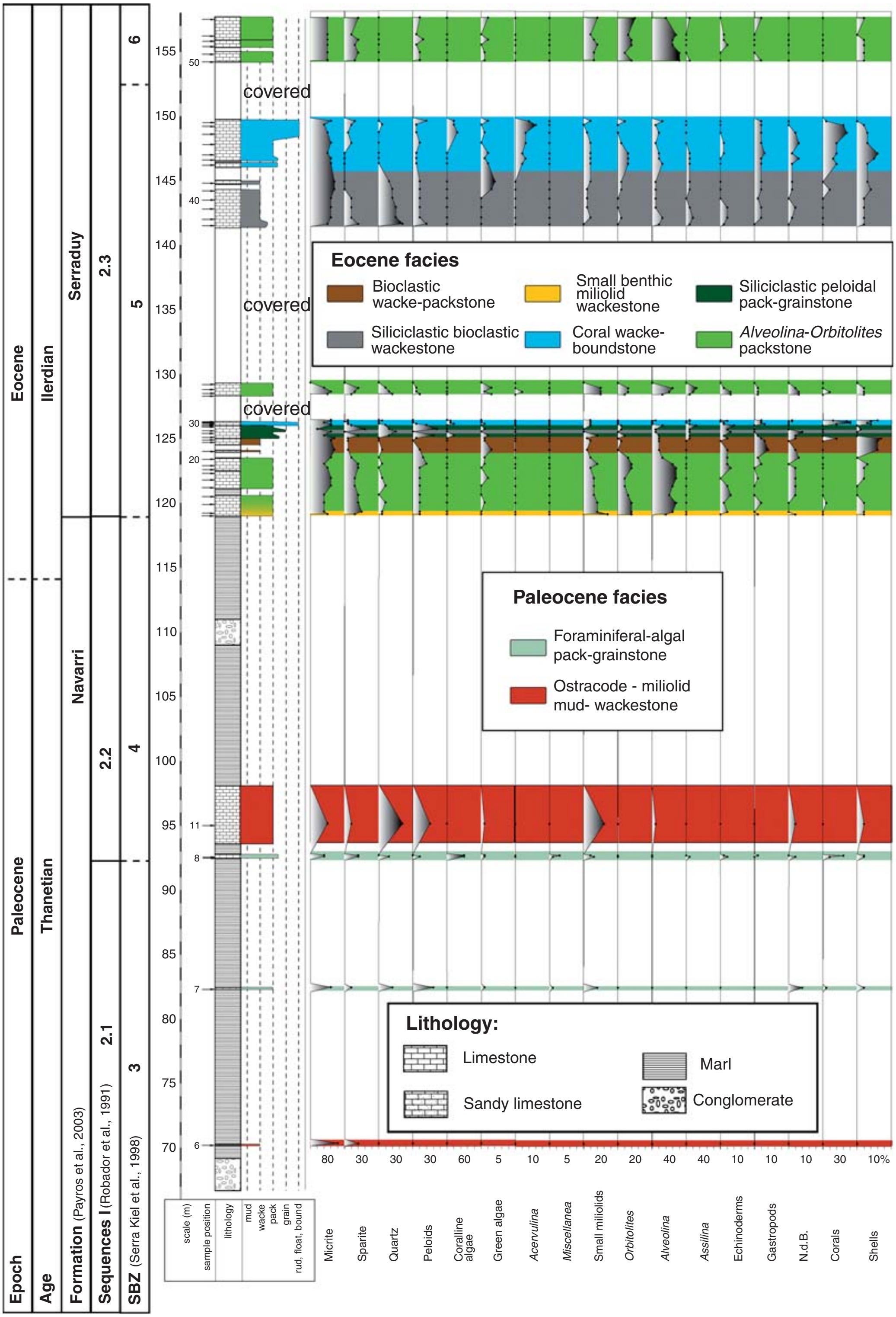

Fig. 5. Stratigraphy, lithology, components and microfacies types of the Serraduy section. The percent values at the bottom of every curve indicate the maximum values of each scale.

IV. Member 2b of the Serraduy Formation: Orue-Etxebarria et al. (2001) measured 41 m for member 2b, while Payros et al. (2000) measured 35 m. According to Schaub (1992) and Kapellos and Schaub (1973) the complete member 2b belongs to SBZ5 (for comparison we used their painted sample numbers 70105–70109 within the section, Figs. 2, 3). In contrast to the assignment of member 2b to SBZ5 Orue-Etxebarria et al. (2001) attributed the lower 12 m to SBZ5 and the upper part to SBZ6 (Figs. 2, 3).

V. Member 2c of the Serraduy Formation: Orue-Etxebarria et al. (2001), Payros et al. (2000) measured 23 m and 28 m for this interval, respectively. This unit belongs to SBZ6.

3. Materials and methods

This paper presents microfacies data on two sections, Campo and Serraduy (Fig. 1). The Campo section is a composite section, constructed along the road exposures from Campo to Navarri (Paleocene part) and from Campo to Ainsa (Eocene part; Figs. 3, 4A). The interval considered in this study spans 120 m and altogether 280 samples (86 for the Paleocene, 194 for the Eocene) were collected, of which nearly 80% are lithified rocks for thin sections and the rest marls. The Paleocene part was sampled along the road to Navarri, while the karstified horizon upwards was sampled along the road to Ainsa.

The section of Serraduy was taken west of the Isabena River at the northern end of the village Serraduy. This location is identical to the one in the study by Robador (1991; Figs. 4D, 5). It has a thickness of about 150 m: 55 limestone samples were collected, from which 44 were sampled from Eocene limestones. Within the Paleocene there are only two small fossiliferous limestone layers. The Eocene limestones are partly covered by vegetation, which is the reason for the scattered sample intervals. Both the scarcity of Paleocene limestones and the scattered Eocene sample intervals are the reason for using the Serraduy section only as support for the Campo section.

In this study we investigated only the thin sections, without concentrating on the loose material. The thin sections of our study have 3 different sizes. The thin sections of the Serraduy section have dimensions of 7.5 cm * 10 cm, while the thin sections of the Campo section are smaller (2.8 cm * 4.8 cm and 5 cm * 5 cm). The modal distribution of the components in the thin sections was estimated by using a classifying system with 6 subgroups (absent, very rare, rare, common, abundant, very abundant), customised for each individual component. In a second step, a maximum value for each individual curve was determined (Figs. 3, 5).

4. Depositional units in the Campo and Serraduy sections (Pyrenees)

Campo (Figs. 2–4): The investigated section can be subdivided into eight depositional units: two in the Paleocene and six in the Eocene. Preliminary interpretation of the depositional environments is given here, but the detailed discussion will follow in the next chapters.

I. The first depositional unit is 22 m thick and composed of medium to thick-bedded (20 cm–100 cm) limestones, which are bundled into 1-m to 3-m thick packages and partly show large-scale cross-bedding. Rounded to angular clasts appear at the base of some beds. The colour of the different packages varies from bright to dark grey, partly reflecting the four different algal to foraminiferal assemblages, which are affected by varying terrestrial input and by different energy regimes. This unit belongs to the lower two-thirds of part c of the Navarri Formation (Payros et al., 2000, Fig. v2).

II. The second depositional unit is composed of very thick (1 m–2 m) limestones with abundant macroids and corals and has a total thickness of 9 m. This unit belongs to the upper one-third of part c of the Navarri Formation (Payros et al., 2000, Fig. 2). The Navarri Formation terminates with a prominent karstic horizon with abundant *Microcodium*.

The age determination of the Paleocene units I and II is only possible with *Assilina* in the first sample and very rare glomalveolinids. They indicate SBZ4, although other characteristic foraminifera for SBZ4 such as *Hottingerina lukasi* and several types of *Miscellanea* and *Ranikothalia* are missing.

III. Unit III is identical to member 1 of the Serraduy Formation of Payros et al. (2000, Fig. 2): this member is 13 m thick and composed primarily of calcareous shales intercalated with a calcareous channel-fill sandstone and a 1-m thick calcareous sandstone with cross-bedding. In the upper part, a characteristic yellow, 1-m thick non-fossiliferous mudstone occurs, followed by 1-m thick shales with rhizolites. This unit reflects the terrestrial interval between the marine Thanetian of the Navarri Formation and the marine Ilerdian of the Serraduy Formation.

According to the latest isotopic studies by Schmitz and Pujalte (2003) the newly defined Paleocene/Eocene boundary lies within this interval, either on top of the sandstones in the middle of this interval or at the karstic

Table 1
Summary of the microfacies types for the Campo and Serraduy sections

Number	MFT	Sub MFT	Age	Occurrence	Unit	Main components	Texture	Environment
1	Ostracode — small benthic miliolid wackestone		Paleocene	Serraduy		Ostracods, small benthic miliolids, charophytes	Thick bedded, moderately sorted	Restricted to inner platform
2	*Assilina* packstone		Paleocene	Campo	I	*Assilina*, small *Miscellanea*	Only one sample	Back-reef
3	Coralline algal grainstone		Paleocene	Campo	I	*D. biserialis*, fragments of coralline algae	Large scale cross-bedding, well sorted	High energetic inner platform
4	Siliciclastic coralline algal packstone		Paleocene	Campo	I	*D. biserialis*, fragments of coralline algae, quartz	Large scale cross-bedding, well sorted	High energetic inner platform
5	Foraminiferal–algal pack-grainstone		Paleocene	Campo, Serraduy	I	Larger foraminifera, red algae	Thick bedded, moderately sorted	Inner platform
6	Coralgal boundstone–rudstone		Paleocene	Campo	II	Corals, *D. biserialis*	Thick bedded, poorly sorted	Small coral patches
7	Macroid boundstone		Paleocene	Campo	II	Red algae, encrusting foraminifera, bryozoan	Thick bedded, poorly sorted	Deeper inner platform
8	Restricted facies	1 Ostracode wackestone	Eocene	Campo	V	Ostracods, small benthic miliolids	Medium bedded	Restricted, tidal flat
		2 Algal bindstone	Eocene	Campo		Algal laminae	Laminae	
		3 Mudstone	Eocene	Campo		No components		
		4 Siliciclastic mudstone	Eocene	Campo		Quartz		
9	Small benthic miliolid wackestone		Eocene	Campo	IV, V, VI	Small benthic miliolids, *Alveolina*, *Orbitolites*	Thin–thick bedded, moderately sorted	Inner platform
10	*Alveolina–Orbitolites* packstone	1	Eocene	Serraduy		*Alveolina*, *Orbitolites*	Nodular to thick bedded	Inner platform
		2	Eocene	Serraduy		*Alveolina*, *Orbitolites*, small benthic miliolids		
11	Siliciclastic peloidal pack-grainstone		Eocene	Campo, Serraduy	VII	Peloids, quartz	Large scale cross-bedding, well sorted	High energetic inner platform
12	Siliciclastic *Alveolina–Orbitolites* grainstone		Eocene	Campo	VII	*Alveolina*, *Orbitolites*, small benthic miliolids, quartz	Large scale cross-bedding	High energetic inner platform
13	*Alveolina* packstone	1	Eocene	Campo	IV	Dominated by *Alveolina*	Thick bedded, moderately sorted	Inner platform
		2	Eocene	Campo	VII	Less frequent *Alveolina*		
		3	Eocene	Campo	VII	Less frequent *Alveolina* and small rotaliids		
14	Rotaliina wackestone		Eocene	Campo	VII	Small rotaliids	Thick bedded, moderately to well sorted	Inner platform
15	Bioclastic wackestone–packstone		Eocene	Serraduy		Shell fragments, gastropods	Nodular to thick bedded	Inner platform

(continued on next page)

Table 1 (*continued*)

Number	MFT	Sub MFT	Age	Occurrence	Unit	Main components	Texture	Environment
16	Siliciclastic bioclastic wackestone		Eocene	Serraduy		Quartz, bioclastic fragments	Well–moderately sorted	Inner platform
17	Bivalve wackestone		Eocene	Campo	VII	Oysters	Poorly sorted	Inner platform
18	Coral wackestone–boundstone	1	Eocene	Campo	VI	Corals	Nodular to thick bedded, poorly sorted	Platform margin, inner platform coral patches
		2	Eocene	Serraduy		Encrusting foraminifera, corals		
19	*Assilina* wackestone		Eocene	Campo	VIII	*Assilina*, *Nummulites*	Medium bedded, debris flows, moderately sorted	Middle platform

horizon at the base. A biostratigraphic assignment is not possible because of the absence of age-indicative fossils.

IV. Unit IV is the smallest depositional unit of the whole section with a total thickness of 3 m. It is composed of 2 wacke- to packstone beds; the lower one is dominated by small benthic miliolids, while the upper one is rich in alveolinids deposited in layers, patches and lenses. They belong to the lower part of member 2a of the Serraduy Formation (Payros et al., 2000, Fig. 2). The occurrence of the first true alveolinids in this interval clearly indicates an Eocene age.

V. This depositional unit has a thickness of 5 m and is composed of marly intervals at the base and at the top. The limestone intervals in-between consist of mudstone-wackestones and are very thin to medium bedded. They are either non-fossiliferous or dominated by algal mats or ostracods, (Table 1). Occasionally thin layers of chert are intercalated and small benthic miliolids occur in some beds. In the lower part, a yellowish to reddish 1-m thick interval is thought to represent a karstic horizon with root traces. This unit represents the upper part of member 2a of the Serraduy Formation (Payros et al., 2000, Fig. 2).

VI: This unit is composed of 12 medium to thick-bedded wacke-boundstones beds with abundant corals in the first 4 m. At the base of this interval there is an accumulation of bivalves, probably oysters. The second interval is 8 m thick and built by an intercalation of two medium to thick-bedded limestone beds with small benthic miliolids and bivalves, and shales and marls. This unit belongs to the lower part of member 2b of the Serraduy Formation of Payros et al. (2000, Fig. 2).

VII. Unit VII is built of 28 m of massive, mainly *Alveolina*-rich limestones without any marly intervals, which can be subdivided into 3 parts. The lower section is composed of *Alveolina*-rich limestones with some bivalves, the middle section is composed of large-scale cross-bedded grainstones with abundant quartz and the upper section is again dominated by alveolinids with an increasing content of large bivalves. This unit represents the well-known *Alveolina* limestones and belongs to the upper part of member 2b of the Serraduy Formation of Payros et al. (2000, Fig. 2).

VIII. Depositional unit VIII is identical with member 2c of the Serraduy Formation. It is 28 m thick and composed of medium to thick-bedded (20 cm–100 cm) limestones to marly limestones and marls which are bundled in 1-m to 4-m thick packages composed of middle shelf *Assilina* wackestone (Table 1). From bottom to top, the marly intervals become more abundant and in the upper half of this member four 1-m to 3-m thick slumped intervals occur, with the uppermost slumped interval enriched in bryozoans. In the upper half there is also a 10-m thick horizon dominated by glauconite. In the field, larger foraminifera and bivalves are the main visible components while echinoderms occur only subordinately.

Serraduy (Figs. 4, 5): The ca. 150-m thick section is dominated by Paleocene terrestrial red beds with roots and up to 2-m thick conglomerates. In the upper part of the Paleocene, marine ingressions expressed by marine carbonate beds are intercalated in the red beds and have been attributed by Robador et al. (1991) to SBZ3 and SBZ4. According to Eichenseer and Luterbacher (1992) the newly defined Paleocene/Eocene boundary is located below the massive siliciclastic conglomerates, which they interpret as braided river deposits. These conglomerates are age-equivalent to the sandstones of member 1 in the Campo section (Eichenseer and Luterbacher, 1992).

The Eocene marine deposits can be subdivided into three intervals separated by vegetation cover (Figs. 4, 5). The first interval is dominated by medium to thick-bedded *Alveolina* packstones with an internal wavy structure, which exhibit a bulbous weathering. Coral- and bivalve-dominated wacke- to boundstones and siliciclastic peloidal grainstones occur subordinately. The middle part of this section is composed of medium to thick-bedded bulbous weathering wacke- to boundstones with quartz, corals, and bivalves. The upper part is dominated by *Alveolina*-rich massive packstones.

The massive, up to 10-m thick, large-scale cross-bedded tidal channel unit (Eichenseer and Luterbacher, 1992) composed of *Alveolina*-rich grainstones typical of the eastern side of the Isabena River is missing in the section investigated in this study, located on the western side of the Isabena River.

5. Paleocene and Eocene microfacies of Campo and Serraduy

In the course of a detailed thin-section analysis of about 280 thin-sections we estimated the relative abundance of about 30 different elements throughout the two sections. We plotted 27 elements in Figs. 4 and 5. Apart from micrite, sparite, quartz, and glauconite, the elements are mainly biogenic components, belonging predominantly to different types of algae and foraminifera. Altogether, we established six categories for each individual element, ranging from not present in the thin-section to very abundant. A total of 19 microfacies types (MFT) could be distinguished. Their distribution within the Campo and Serraduy sections shows a clear dichotomy in which the boundary is marked by the terrestrial interval across the Paleocene–Eocene boundary. The microfacies types are presented separately for the Paleocene and the Eocene. The 19 different microfacies types are documented on 3 plates (Plates 1–3) and their characteristics and relationship to the depositional units are summarized in Table 1.

5.1. Paleocene microfacies

The marine Paleocene of Campo and Serraduy is dominated by red algae that occur isolated, encrusting or as macroid. Apart from different types of red algae, rotaliid foraminifera, corals, and quartz grains appear in varying amounts. Altogether seven microfacies types could be identified within the Paleocene, which are compared with the microfacies types of Baceta et al. (2005) from their study from the southern margin of the Pyrenean basin (Fig. 1).

5.1.1. Ostracode — small benthic miliolid mud-wackestone

The microfacies type is characterised by ostracods, small benthic miliolids, charophytes and quartz grains in a dismicritic matrix. *Microcodium* fragments occur rarely.

Occurrence and interpretation: This MFT occurs in the lower parts of the Serraduy section. The presence of ostracods and charophytes together with small benthic miliolids are indicators of a restricted, probably peritidal setting. However, no evidence for supratidal features such as exposure surfaces and desiccation features were recognized in the field.

5.1.2. Assilina packstone

The *Assilina* packstone is characterised by abundant *Assilina* (*A. azilensis* or *A. yvettae*), which are the largest components in this MFT. The matrix is composed of micrite, while little sparite is present. Additionally, small *Miscellanea*, other rotaliid foraminifera, small benthic miliolids, fragments of *Distichoplax biserialis*, fragments of coralline algae, algal peloids, echinoderms, and quartz grains are present (Plate 1, fig. 1).

Occurrence and interpretation: This MFT occurs only in the lowermost sample of the Campo section (unit I) and indicates SBZ4. Apart from *Assilina*, this MFT has similarities with the foraminiferal–algal pack-grainstone and the siliciclastic coralline algal packstone. The composition of this MFT with larger foraminifera, algae and quartz grains and the relation to other inner platform microfacies types suggest a similar depositional environment. An analog facies type is described by Baceta et al. (2005) as back-reef bioclastic facies of the Thanetian, with abundant fragments of geniculate and non-geniculate corallinaceans, bryozoans and small and large benthic foraminifera.

5.1.3. Coralline algal grainstone

The coralline algal grainstone is dominated by small fragments of *D. biserialis*, fragments of geniculate coralline algae and peloids (algal peloids), which are well sorted. Interparticle pore space is now filled with sparry calcite. Additionally small benthic miliolids, small rotaliids, small *Miscellanea*, echinoderms, peyssonelid algae (*Polystrata alba*), udoteacean algae (*Halimeda nana*) and quartz grains are present (Plate 1, fig. 2; Plate 3, fig. 6).

Occurrence and interpretation: The first ten metres of the Campo section (unit I) are nearly entirely composed of this MFT. Transitional microfacies types to the foraminiferal–algal pack-grainstones and the siliciclastic coralline algal packstone are present. Geniculate corallines prefer intertidal to shallow-subtidal rocky substrates, thus indicating a position close to the shore-line (Riosmena-Rodrigues and Siqueiros-Beltrones, 1995, 1996). The grainy texture, the small fragments of *D. biserialis*, and the well-sorted components suggest deposition in a high-energy environment. In their facies description of Paleocene coral reefs and related facies in the Pyrenean region, Baceta et al. (2005) described different species of coralline algae as the dominant group of organisms in the Thanetian reefs without mentioning *D. biserialis*. In contrast, Aguirre and Braga (personal communication) found them in great abundance in the Basque-Cantabrian region, W Pyrenean. A similar dominance of *D. biserialis* has been described from Paleocene back-reef sediments from Oman (Racz, 1979) and from the Northern Calcareous Alps (Moussavian, 1984).

5.1.4. Siliciclastic coralline algal packstone

This microfacies type is dominated by small fragments of *D. biserialis*, rounded fragments of geniculate coralline algae, peloids, and quartz grains. In contrast to the coralline algal grainstone, this MFT comprises micritic matrix. Peloids, rotaliid and small benthic miliolid foraminifera, small *Miscellanea*, *P. alba* and echinoderms are additional components (Plate 1, fig. 3).

Occurrence and interpretation: This MFT occurs in unit I of the Campo section. Transitional microfacies types exist to the foraminiferal–algal pack-grainstones and the coralline algal packstone. The main difference of this MFT in comparison to the coralline algal grainstone is

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Plate I. Paleocene microfacies types from the Campo section. (see page 157)

1. *Assilina* packstone, This facies is present only at the lowermost sample (sample E1-1).
2. Coralline algal grainstone, This facies is composed of fragments of non-geniculate red algae (a) and fragments of *Distichoplax biserialis*, rotaliid foraminifera are rare (sample E1-7).
3. Siliciclastic coralline algal packstone, Apart from quartz grains dark fragments of coralline algae are present, the brighter fragments (a) belong to *Polystrata alba* (sample E1-45).
4. Foraminiferal–algal pack-grainstone, the foraminifera are represented by a: *Kathina* sp. and other rotaliids and b: *Discocyclina* sp. The dark particles are mainly fragments of coralline algae (sample E1-21).
5. Macroid boundstone, In this slide all four encrusting organisms are present: a: *Acervulina* sp.; b: bryozoans; c: *Polystrata alba*; d: coralline algae (sample E1-69).
6. Coralgal boundstone–rudstone, On the left side corals are visible, while the right side is dominated by long fragments of the red algae *Distichoplax biserialis*. The inlay shows different cross-sections of *D. biserialis* and a planktonic foraminifer (sample E1-73; inlay: sample E1-75).
7. Macroid boundstone, a: encrusting foraminifer *Acervulina* sp.; b: encrusting coralline algae. On the right corner a fragment of a coral is visible (sample E1-83).
8. The karstification on the top 50 cm of the Paleocene Navarri limestones (macroid boundstone) is indicated by *Microcodium*; a: area dominated by *Microcodium* prisms; b: intact *Microcodium*, the prisms are oriented in a ring-like structure (sample E1-85).

Plate II. Eocene microfacies types from the Campo and Serraduy sections. (see page 158)

1. Restricted facies, Algal bindstone (sample E1-124).
2. Restricted facies, Ostracode wackestone (sample E1-133).
3. Restricted facies, Charophytes (a) (sample E1-134).
4. Small benthic miliolid wackestone: (sample E1-112).
5. *Alveolina* packstone, (sample E1-117).
6. Siliciclastic peloidal pack-grainstone, (sample E1-181).
7. *Alveolina–Orbitolites* packstone, (sample I1-13).
8. Siliciclastic *Alveolina*/*Orbitolites* grainstone (sample E1-189).

Plate III. Eocene microfacies types from the Campo and Serraduy sections (1–5); Paleocene algae from the Campo section (6–8). (see page 159)

1. Rotaliina wackestone, (sample E1-200).
2. Bivalve wackestone, (sample E1-144).
3. Bioclastic wacke- to packstone, This microfacies type is present only in the Serraduy section and it is dominated by shell fragments (a) and gastropods (b). Green algae (c) occasionally occur (sample I1-21).
4. Coral wacke- to boundstone, (sample E1-149).
5. *Assilina* wackestone, (sample E1-226).
6. Coralline algal grainstone, fragments of geniculate red algae (a) and *Distichoplax biserialis* (b) (sample E1-6).
7. Foraminiferal–algal pack-grainstone, A non-geniculate red algae (*Lithothamnion*-type) is growing around rotaliid foraminifera (sample E1-22).
8. Macroid boundstone, alternating encrustation of the foraminifer *Acervulina ogormani* (a) and coralline red algae (*Sporolithon*) (b) (sample E1-65).

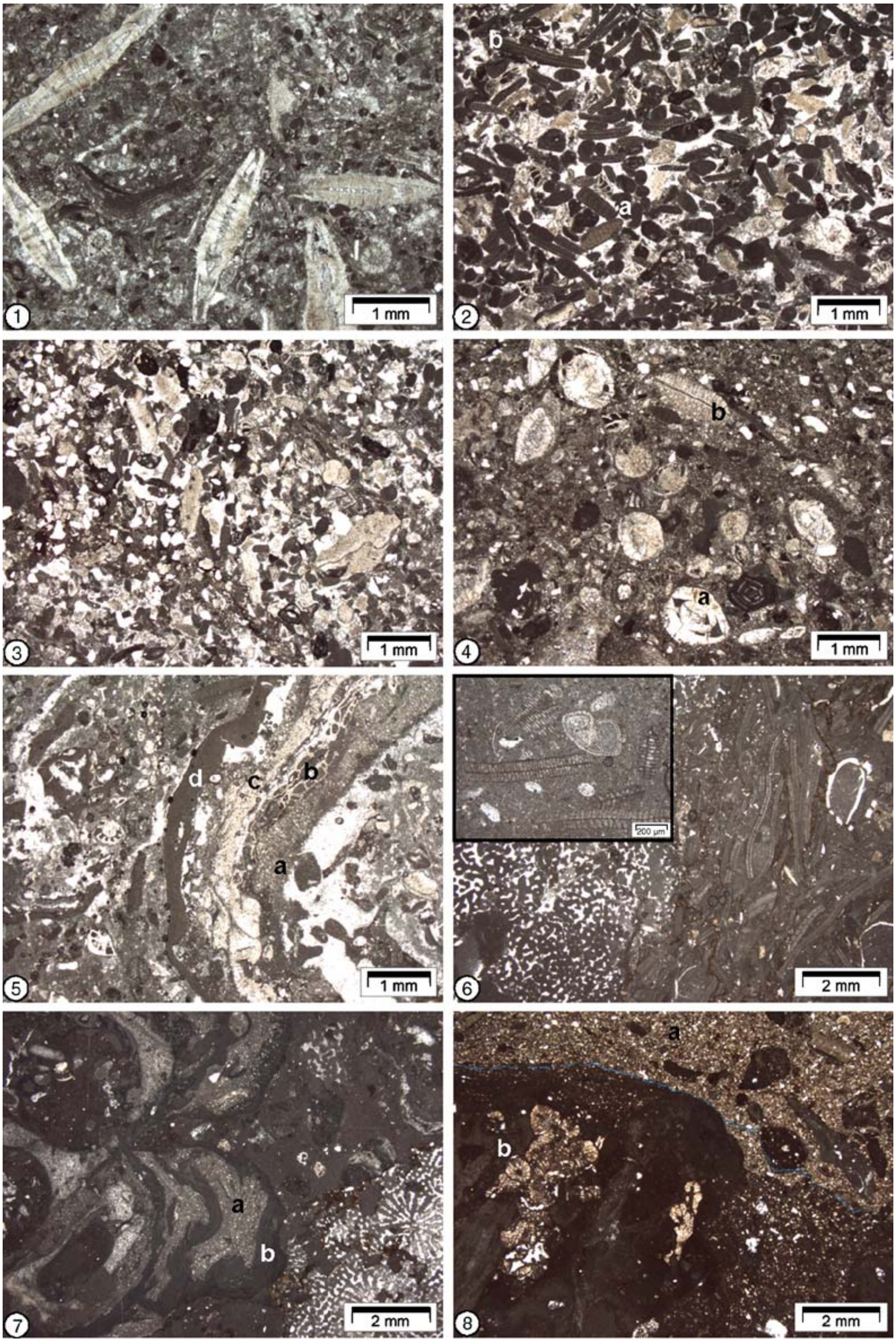

Plate I (*caption on page 156*).

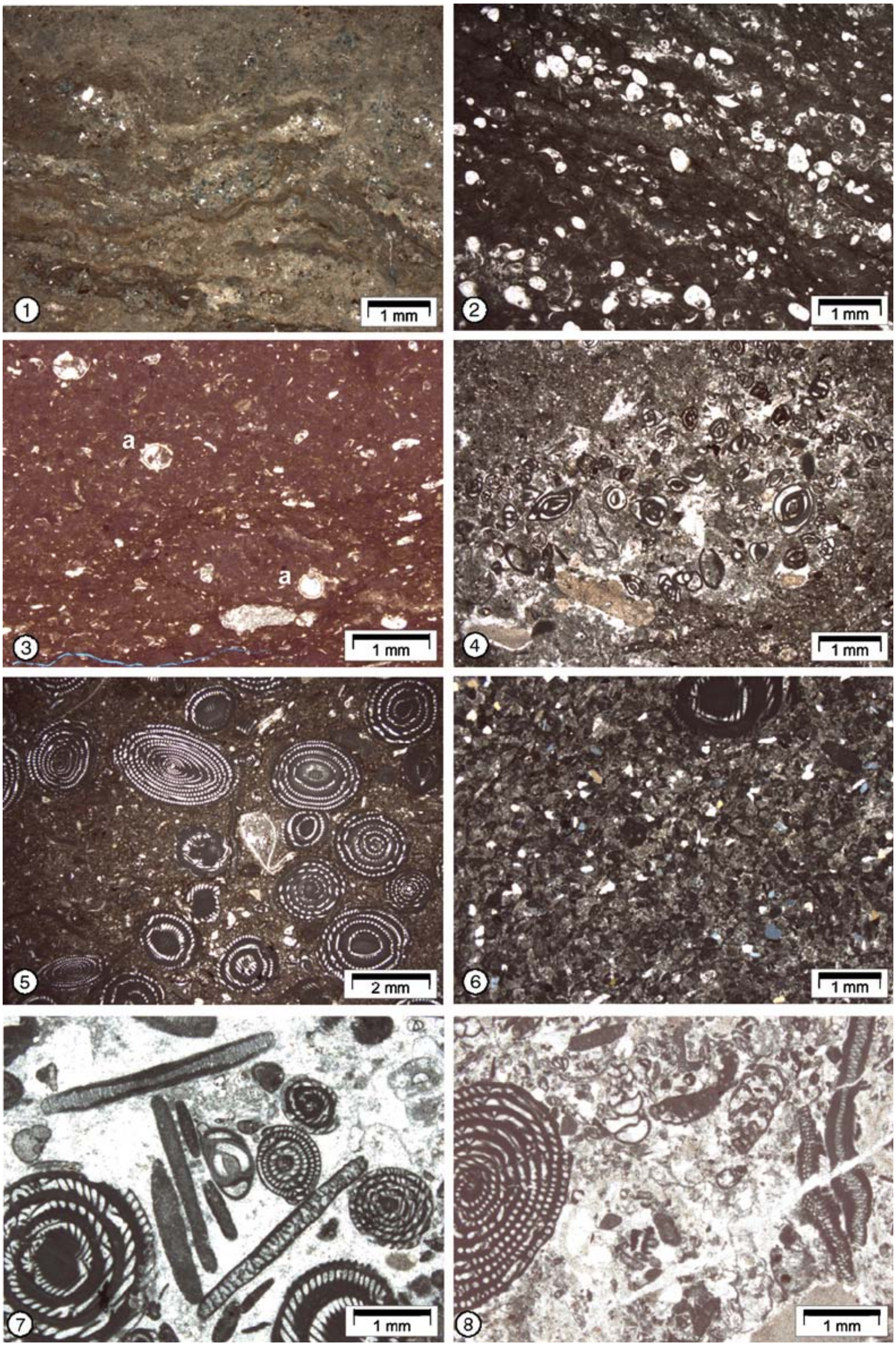

Plate II (*caption on page 156*).

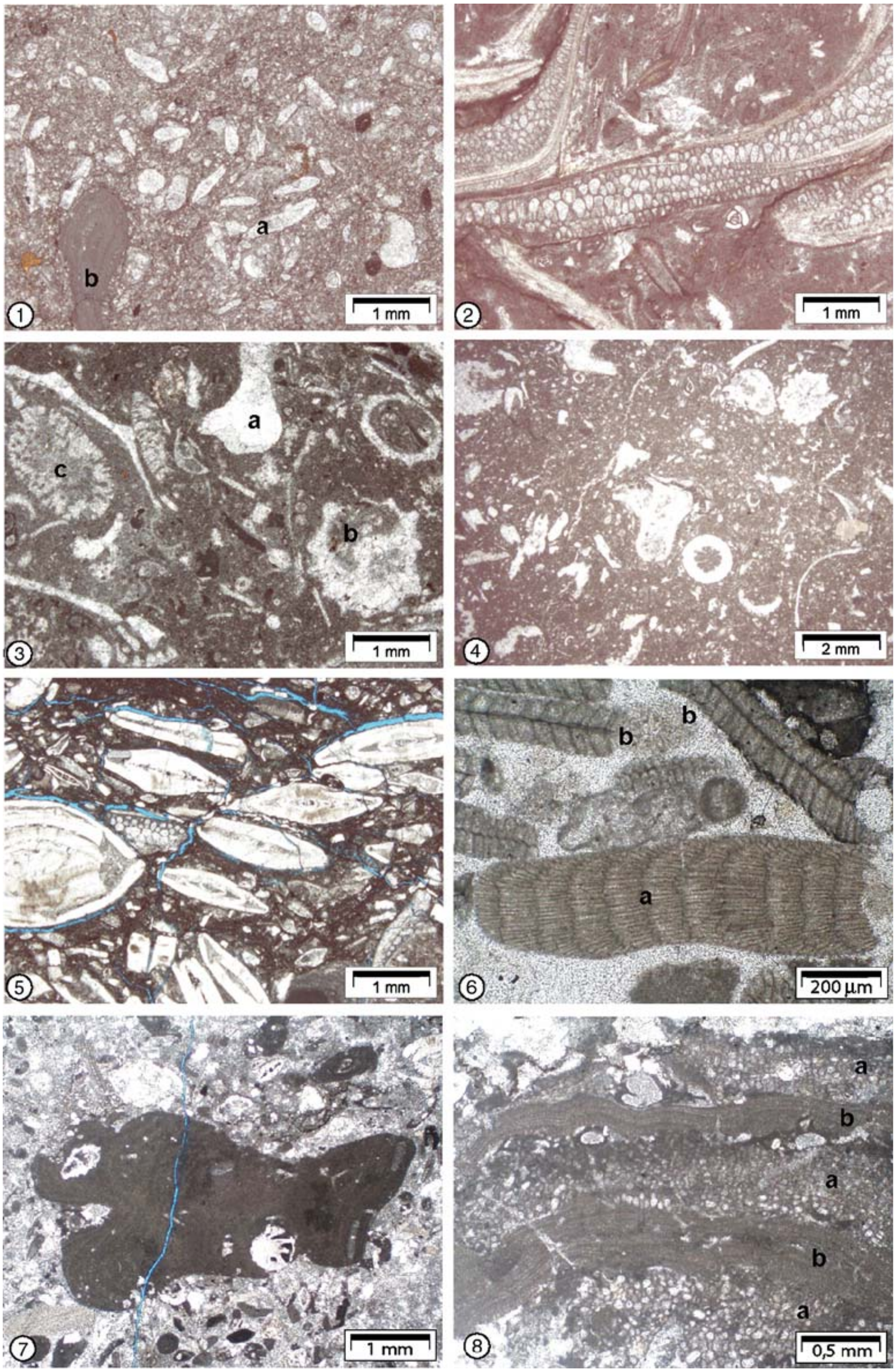

Plate III (*caption on page 156*).

the common occurrence of quartz grains and of micrite. The similarity of both microfacies types suggests a similar depositional environment, but in this case probably less energetic and closer to a siliciclastic source. The combined occurrence of *D. biserialis* and quartz is described from back-reef sediments from the Northern Calcareous Alps (Moussavian, 1984).

5.1.5. Foraminiferal–algal pack-grainstone

The foraminiferal–algal pack-grainstone is characterised by different types of foraminifera (rotaliids, *Miscellanea*, *Kathina*) and red algae (*D. biserialis*, geniculate and non-geniculate forms (*Sporolithon*, *Lithothamnion*-type, *P. alba*). Subordinate components are peloids, intraclasts, small benthic miliolids, echinoderms, and bryozoans. The groundmass is dominated by sparite. In one sample *Discocyclina* is abundant. This MFT is moderately sorted and the components, especially the non-geniculate coralline algal fragments, are larger than in the two coralline algal facies types (Plate 1, fig. 4; Plate 3, fig. 7).

Occurrence and interpretation: This MFT occurs in the middle of the Paleocene part of the Campo section (unit I) and in the Serraduy section. The foraminiferal–algal pack-grainstone has a somewhat intermediate position between the coralline algal packstones and the two boundstone MFTs, as it has similarities to both of them. The presence of geniculate red algae, fragments of *D. biserialis* and quartz grains suggest a relationship to both coralline algal packstones while the larger fragments of the coralline algae (*Sporolithon*, *Lithothamnion*-type) resembles the coralline algae of the boundstone MFTs. The depositional environment probably lies between the shallow intertidal to shallow-subtidal rocky substrates of the coralline algal packstones and the deeper reef-related microfacies types. A similar facies type with abundant fragments of non-geniculate and geniculate corallinaceans, *P. alba*, and larger foraminifera is described as reef crest/back-reef deposits by Baceta et al. (2005).

5.1.6. Coralgal boundstone–rudstone

The coralgal boundstone–rudstone is characterised by different types of coral species, which were probably reworked, and large, unfragmented specimens of *D. biserialis* within a micritic matrix. The corals are encrusted to some extent by red algae (*P. alba*, non-geniculate coralline algae), encrusting foraminifera (*Acervulina ogormani*) and bryozoans. Other components like echinoderms or shell fragments are present only in very small amounts (Plate 1, fig. 6).

Occurrence and interpretation: This MFT occurs in the upper part of the Paleocene (unit II). The micritic matrix and the unfragmented specimens of *D. biserialis* suggest a low-energy environment, probably below wave base. The reworked corals suggest that this MFT was deposited in close vicinity of coralgal associations. Eichenseer and Luterbacher (1992) and Pujalte et al. (1993) found similar coralgal associations at the platform margin. In contrast to the Danian reefs that are dominated by corals in the Pyrenean area, suggesting a very shallow water position, the Thanetian reefs are algal-dominated, allowing for a deeper water setting (Baceta et al., 2005). A modern example for this depth gradient are the Flower Garden Banks in the Gulf of Mexico, where coralline algae dominate the deeper water (Minnery, 1990). The last one-and-a-half-metres of the Paleocene part of the Campo section is dominated by a mixture of this coralgal bound-rudstone and the macroid boundstone described below.

5.1.7. Macroid boundstone

The macroid boundstone is dominated by encrusting algae (coralline, *Polystrata alba*), encrusting foraminifera (*Acervulina ogormani*) and encrusting bryozoans. Quite often the encrusting organisms do not form real macroids but grow as authochthonous crusts directly on the sediment. Similar to the coralgal boundstone, large specimens of *D. biserialis* are abundant. Rotaliid and small benthic miliolid foraminifera, *Miscellanea*, green algae and echinoderms are present in smaller amounts (Plate 1, figs. 5, 7; Plate 3, fig. 8).

The uppermost Paleocene part of the Campo section is characterised by a karstic surface with dissolution pipes extending into the upper 50 cm and in-filled with yellow crystalline carbonate. *Microcodium* (Plate 1, fig. 8) occurs commonly in the upper 50 cm.

Occurrence and interpretation: This MFT occurs in the upper part of the Paleocene of the Campo section (unit II). In contrast to the coralgal boundstone, which is only subordinately encrusted by *Acervulina ogormani*, the macroid boundstone is formed to a great extent by *A. ogormani*. Both facies types probably occur in the same facies belt, below wave base, as *A. ogormani* is able to build small reefs and can substitute corals as the main reef builder. This substitution is conspicuous in the early Eocene of the Pyrenean basin (Plaziat and Perrin, 1992). Both types of boundstones are deposited in deeper water depth than the coralline and foraminiferal–algal packstones because the increasing amount of peyssonneliacean algae (*P. alba*) and acervulinid foraminifera (Rasser, 2000). Acervulinid foraminifera are an indicator for a reduced competition for substrate encrustation, which could be related to a decrease in light intensity (Perrin, 1992).

According to Baceta et al. (2005) rhodolith boundstones, which probably reflect our macroids, are typical for inter-reef facies.

5.2. Eocene microfacies

The Eocene is dominated by larger foraminifera (*Alveolina, Orbitolites*, *Assilina*), which were living at different depths. We utilize the general analyses of Hottinger (1973, 1997) and the specialised study of Rasser et al. (2005) to arrange the depth zonations of the larger foraminifera facies types. Subordinate restricted, bioclastic and coral-dominated facies occur in the Campo and Serraduy sections. In total, twelve microfacies types have been identified, which have been compared with the facies types of Rasser et al. (2005). They describe a shallow-water inner platform paleoenvironmental standard section for the early Ilerdian in Minerve (France), which at that time belonged to the northern part of the Pyrenean carbonate platform. They describe nine facies types, from which seven facies types can be identified in our sections also. The two missing types are transitional facies types that do not exist in our successions. The additional five facies types in this study result from the broader environmental lateral changes from restricted to middle platform facies.

5.2.1. Restricted facies

The restricted facies is very heterogenous and composed of at least 4 different subtypes but because of the similar depositional environment in which they occur and their small thickness (about 4 m; Fig. 3) they are combined into this one MFT. The most common subtype is ostracode wackestone, characterised by the presence of abundant ostracods within a micritic matrix, with occasional charophytes. The second subtype is algal bindstone, which is composed of undulating micritic layers. Besides ostracods, rare small benthic miliolids, rare small benthic foraminifera, very rare echinoderms and peloids are present. In some samples gypsum crystal ghosts occur, replaced by sparite. Transitions occur between both subtypes. Mudstones and siliciclastic mudstones without any biogenic/abiogenic components are the third and fourth subtypes (Plate 2, figs. 2, 3; Plate 2, fig. 1).

Occurrence and interpretation: This MFT occurs in units III and V of the Campo section and starts above the siliciclastic Paleocene/Eocene interval. The monospecific character of this facies, together with the occurrence of ostracods, charophytes, algal mats, evaporitic crystals and the absence of any open marine organisms suggest sedimentation in a restricted, evaporitic environment in the intertidal zone. The non-fossiliferous mudstones, which have been found together within this facies are also indicators of a restricted environment. Eichenseer and Luterbacher (1992) interpret these facies types as carbonate tidal flats.

5.2.2. Small benthic miliolid wackestone

This MFT is dominated by the occurrence of small benthic miliolid foraminifera in a micritic matrix. Other components are *Alveolina*, *Orbitolites*, echinoderms, shell fragments and peloids (Plate 2, fig. 4).

Occurrence and interpretation: This MFT occurs in units IV, V, and VI of the Campo section. In some parts of the section it interfingers with, and shows transitions to, the restricted facies and the *Alveolina* packstone while in other parts entire intervals, separated by marls from other microfacies types, are composed by this MFT. The abundance of small benthic miliolids and the transitional status between the restricted facies and the alveolinid- and orbitolitid-dominated facies attribute this facies type to the proximal facies of the inner platform. Eichenseer and Luterbacher (1992) interpret this facies together with the alveolinid-dominated *Alveolina* packstone as lagoonal deposits.

5.2.3. *Alveolina*–*Orbitolites* packstone

This MFT can be subdivided into two subtypes. The first subtype is characterised by alveolinids and orbitolitids as the most prominent components, the alveolinids having a slightly higher relevance. The second subtype is dominated, apart from alveolinids and orbitolitids, by small benthic miliolids. Other important components are green algae, shell and gastropod fragments (Plate 2, fig. 7).

Occurrence and interpretation: The first MFT-subtype is characteristic for the lower and upper parts of the Serraduy section, whereas the second subtype is restricted to a 1-m thick interval in the lower part of the Eocene Serraduy section. The high abundance of orbitolitids and small benthic miliolids together with the presence of green algae suggests a very proximal inner platform setting. According to Hottinger (1973, 1997), *Orbitolites* occurs in the shallowest parts of carbonate platforms. For Minerve, a comparable facies type was attributed to the shallowest (inner lagoonal) part of a carbonate ramp (Rasser et al., 2005).

5.2.4. Siliciclastic peloidal pack-grainstone

The siliciclastic peloidal pack-grainstone is well sorted and dominated by peloids, quartz grains, and echinoderm fragments. Other components are small benthic miliolids, *Alveolina*, *Orbitolites*, shell fragments, and small rotaliid foraminifera. In contrast to the peloids present in the Paleocene part of the section, which are mainly derived from algal remnants, the origin of the peloids are micritised biogenic fragments. Within layers composed of this facies type, large-scale cross-bedding is visible (Plate 2, fig. 6).

Occurrence and interpretation: This MFT occurs in unit VII of the Campo section and in the lower part of the Serraduy section. In some parts it interfingers with and shows transition to the *Alveolina* packstone and the siliciclastic *Alveolina*/*Orbitolites* grainstone. The sorting, the large-scale cross-bedding and the lack of depositional mud suggest a high-energy environment. This facies type has no equivalent in the Minerve section of Rasser et al. (2005).

5.2.5. Siliciclastic Alveolina/Orbitolites grainstone

This MFT is characterised by the presence of *Alveolina*, *Orbitolites*, small benthic miliolids, and quartz grains groundmass. Other components are echinoderms and shell fragments (Plate 2, fig. 8).

Occurrence and interpretation: This MFT occurs in VII of the Campo section. In some parts it interfingers with, and shows transition to, the *Alveolina* packstone and the siliciclastic peloidal pack-grainstone. The dominance of alveolinids and orbitolitids suggests a deposition in the open waters of the inner platform, while the quartz grains suggest a position close to a source area. The grainy texture hints at a high-energy environment. A similar facies type has been described in Minerve (Rasser et al., 2005) as the terrigenous alveolinid facies, although in Minerve *Orbitolites* are much scarcer than in Campo.

5.2.6. Alveolina packstone

The *Alveolina* packstone can be subdivided into three subtypes. The first subtype is dominated by *Alveolina*, in the second subtype alveolinids occur less frequently, whereas the third subtype is similar to the second but contains small rotaliids. Associated with the alveolinids are small benthic miliolids, *Orbitolites*, peloids, echinoderms, gastropods, and peloids (Plate 2, fig. 5).

Occurrence and interpretation: The three subtypes of this MFT occur in unit IV (subtype 1), and unit VII (subtypes 2 and 3) of the Campo section. In some parts it interfingers with, and shows transitions to, the small benthic miliolid wackestone, the siliciclastic *Alveolina*/*Orbitolites* grainstone, siliciclastic peloidal grainstone and the rotaliina wackestone. Alveolinids are important faunal contributors to open water sediments of the inner platform. They have a slightly deeper depth range than orbitolitids (Hottinger, 1997). This facies is comparable with the alveolinid facies of Minerve (Rasser et al., 2005), which is the most prominent of that section.

5.2.7. Rotaliina wackestone

The rotaliina wackestone is characterised by abundant small rotaliid foraminifera within a predominantly micritic matrix. Other components are *Alveolina*, *Orbitolites*, small benthic miliolids, green algae, echinoderms, gastropods, shell fragments, and peloids (Plate 3, fig. 1).

Occurrence and interpretation: This MFT occurs in unit VII of the Campo section. The difference of this MFT to the third subtype of the *Alveolina* packstone is the more frequent occurrence of small rotaliid foraminifera and the less frequent occurrence of *Alveolina* and *Orbitolites*. The dominance of micrite in combination with the above mentioned bioclasts suggests a deposition in the protected part of the inner platform. This facies type has no equivalent in the Minerve section of Rasser et al. (2005).

5.2.8. Bioclastic wackestone–packstone

Large recrystallised shell fragments and gastropods dominate the bioclastic wacke–packstone facies. Rotaliid and small benthic miliolid foraminifera, green algae and alveolinids are present in minor percentages. Corals are present in one thin-section out of three. Echinoids have been found in situ within the interval composed of this MFT (Plate 3, fig. 3).

Occurrence and interpretation: This MFT is restricted to a 1-m interval in the lower part of the Eocene Serraduy section. The organisms present suggest deposition on the inner platform with moderate circulation and wave energy. A similar facies type in Minerve is the bioclast facies, although pack-grainstones dominate this facies type (Rasser et al., 2005) and suggest deposition in a higher energy environment than that of the bioclastic wacke-packstones of this study.

5.2.9. Siliciclastic bioclastic wackestone

This MFT is characterised by moderate to high amounts of quartz within a dominantly micritic matrix. Small bioclastic fragments (small benthic miliolids, alveolinids, recrystallised shell fragments, gastropods) occur in low numbers. In two thin-sections significant quantities of green algae occur.

Occurrence and interpretation: The siliciclastic bioclastic wackestone is present in the upper part of the Eocene Serraduy section. It differs from the bioclastic wacke-packstone in the smaller size and the small numbers of the individual components. Similar to the bioclastic wacke-packstone the depositional environment of this MFT is the inner platform, but within a low energy environment. This facies type has no equivalent in the Minerve section of Rasser et al. (2005).

5.2.10. Bivalve wackestone

Large bivalves with a vesicular shell structure are the dominant components in the bivalve wackestone. Other components are small benthic miliolids (Plate 3, fig. 2).

Occurrence and interpretation: This MFT is very rare (only one sample) and occurs at the base of unit VI of the Campo section. It forms the base of the three-and-a-half-metre coral wackestone–boundstone bed. The dominance of bivalves, most certainly oysters, together with small benthic miliolids in a micritic matrix in the absence of outer platform biota suggests an in situ deposition as oyster banks on the inner platform. These oyster banks occasionally served as hard substrates for small coral patch-reefs.

5.2.11. Coral wackestone–boundstone

The first subtype of this MFT is characterised by various types of corals in a micritic matrix. Additional components are shell debris, gastropods, and encrusting coralline algae. The second subtype is characterised, apart from corals, by very abundant encrusting acervulinid foraminifera. One thin-section is composed completely of acervulinid foraminifera (Plate 3, fig. 4).

Occurrence and interpretation: The first subtype occurs in a three-and-a-half-metre thick bed within the lower part of unit VI in the Campo section and in a 30 cm thin layer on top of the siliciclastic peloidal pack-grainstones in the Eocene Serraduy section. The second subtype is present in a three-and-a-half-metre thick bed in the upper part of the Eocene Serraduy section. According to Eichenseer and Luterbacher (1992) and Pujalte et al. (1993), coral reefs in the Pyrenees grow at the carbonate platform margin. A further depositional setting of coral reefs could be as small patch reefs within the open inner platform, as the coral-dominated interval in Campo is sandwiched between the restricted facies and the miliolid wackestones. Eichenseer and Luterbacher (1992) described foraminiferal reef mounds of "*Solenomeris*" (the former name of the genus *Acervulina*) from the study area. Such foraminiferal mounds are typical for the Early Eocene and have been described by Plaziat and Perrin (1992) from the northern rim of the paleo Gulf of Biscay (SW-France). A similar facies type in Minerve is the coral facies that is restricted in that section to one sample (Rasser et al., 2005).

5.2.12. *Assilina* wackestone

Associated with abundant *Assilina* are *Nummulites*, shell fragments, bryozoans, planktic foraminifera, *Discocyclina*, small rotaliids and echinoderms. Compared to other MFTs, small benthic miliolids and *Alveolina* are rare to absent. Within the *Assilina* wackestone there is a 10 m interval (section m 103–113) with a glauconite accumulation. The uppermost samples of the Campo section are dominated by bryozoans (Plate 3, fig. 5).

Occurrence and interpretation: The *Assilina* wackestone occurs in unit VIII of the Campo section without transition to other MFTs. The dominance of assilinids and the occurrence of *Discocyclina* and planktic foraminifera in a micritic matrix together with the absence of inner platform organisms suggest a deposition on the middle platform, while the glauconite hint to low sedimentation rates. The nummulitid facies in Minerve (Rasser et al., 2005) is a comparable facies type, although in Minerve it was probably deposited in shallower water-depths than the *Assilina* wackestone of Campo, due to the existence of small benthic miliolids, corals and lack of depositional micrite.

6. Environmental interpretation of the Campo and Serraduy sections

Both the late Paleocene and the early Eocene successions reflect a deepening shelf, interrupted by the terrestrial siliciclastic interval across the Paleocene/Eocene boundary.

6.1. Paleocene

The latest Paleocene (SBZ4) in the Campo section is dominated by different algae species that show columnar/protuberated or crustose growth forms. Other components are larger foraminifera, corals, bryozoans, peloids, and quartz grains. The deepening upward is reflected by the succession from grainstones rich in geniculate coralline algae at the base (coralline algal grainstone, siliciclastic coralline algal packstone), to facies types dominated by non-geniculate corallines, peyssonneliacean algae, and acervulinid foraminifera (coralgal boundstone, macroid boundstone). Geniculate corallines thrived in intertidal to shallow-subtidal rocky shorelines and were reworked in high-energy, shallow-marine grainstones. Probably, the problematic alga *Distichoplax biserialis* preferred the same environments. The decreasing abundance of geniculate corallines upsection as well as the increasing abundance of peyssonneliacean algae and – especially – acervulinid foraminifera reflect a characteristical deepening-upward succession (e.g., Reid and Macintyre, 1988; Perrin, 1992; Rasser and Piller, 1997; Rasser, 2000).

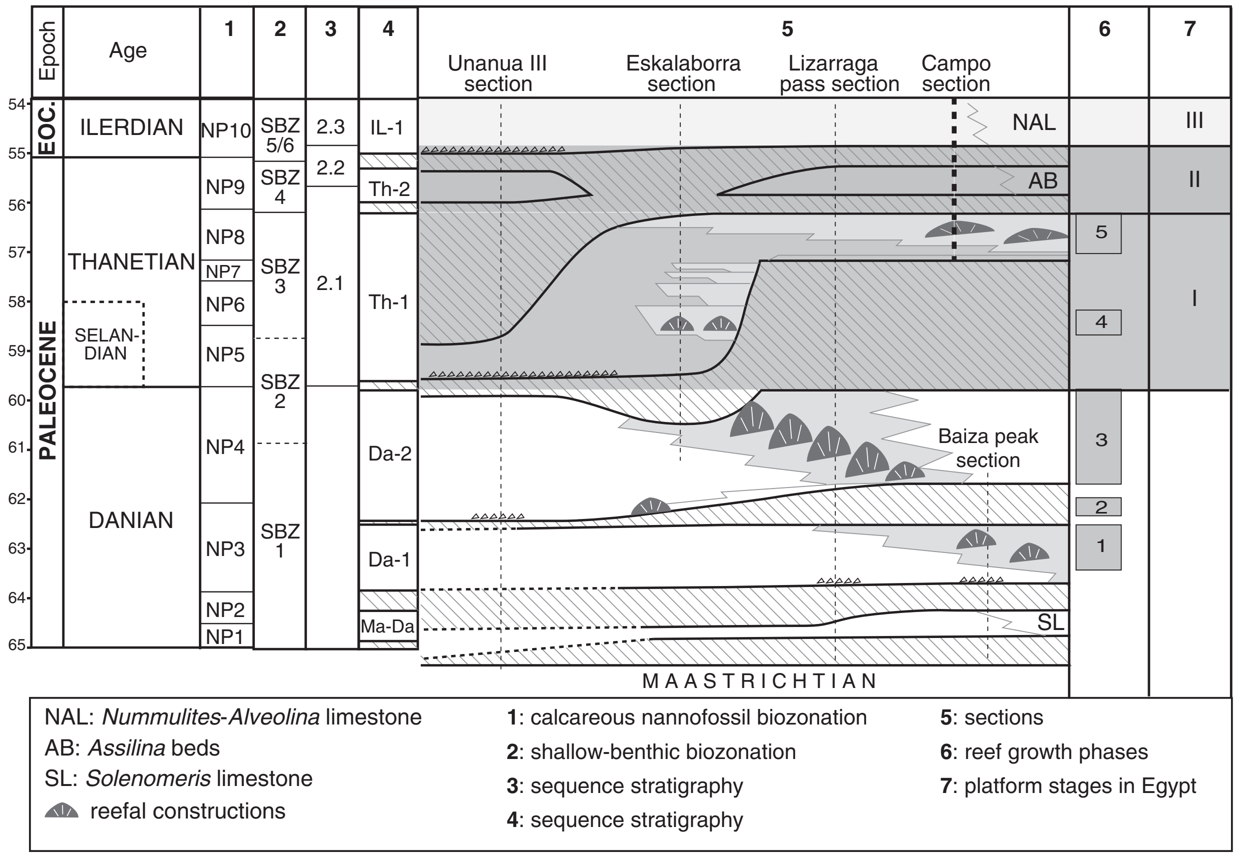

Fig. 6. Biostratigraphy, sequences, reef growth phases and platform stages in the Urbasa-Andia plateau (Pyrenees), modified after Baceta et al., (2005). Column 1 after Martini (1971); column 2 after Serra-Kiel et al. (1998); column 3 after Pujalte et al. (1993); columns 4, 5, 6 after Baceta et al. (2005); column 7 after Scheibner et al. (2005).

The last 8 m of the Paleocene carbonates form coralgal associations, which have been described by Baceta et al. (2005) from other areas in the Pyrenees as typical for the Thanetian: according to Baceta et al. (2005) the dominance of red algae over corals is also a sign for a deeper water setting. A recent analogy for depth dependence of corals and red algae are the Flower Garden Banks in the north-western Gulf of Mexico, where coralline algae are the dominant sediment contributors below 50 m (Minnery, 1990). In comparison, corals with a subordinate abundance of red algae dominated the Danian reefs in the Pyrenees, which indicate reef growth in very shallow waters (Baceta et al., 2005). In contrast to this deepening trend in part C of the upper part of the Navarri Formation that we concluded from the change in algal associations, Payros et al. (2000) proposed a shallowing-upwards character for this interval, from larger foraminiferal grainstones to algae-dominated limestones and stated that the organisms are arranged in several metre-thick sequences with nummulitids in their lower parts and alveolinids and small benthic miliolids in the upper ones. In the Serraduy section, a deepening or shallowing trend in the Paleocene is not obvious, because of the scarcity of marine intervals.

6.2. Eocene

The precise position of the Paleocene/Eocene boundary is uncertain but according to Schmitz and Pujalte (2003) it lies within the siliciclastic interval, either on top of the sandstones or at the karstified horizon on top of the Paleocene limestones of the Navarri Formation. In the Eocene of the Campo section, the overall deepening trend is even more obvious than in the Paleocene part. After the terrestrial siliciclastic interval around the Paleocene/Eocene boundary (unit III), the first marine sediments are deposited in lagoonal and restricted environments with a slight terrestrial influence (charophytes, unit V). The following *Alveolina*-dominated facies types (member 2b) are characteristic for an inner platform setting, while the *Assilina* wackestone in the upper part of the section (unit VIII) is characteristic for a middle platform setting and probably formed as a response to increased subsidence during the middle to late Ilerdian, due to the onset of thrust loading in the foreland basin. This thrust loading resulted in the collapse and retreat of the Ilerdian carbonate platform, for which the slumped beds in the upper part of the *Assilina* wackestone may be the first evidence, followed by subsequent drowning of the Ilerdian carbonate platform (Barnolas and Teixell, 1994). The glauconitic limestones in this interval probably reflect low sedimentation rates during periods of increased deepening.

In Serraduy a similar overall deepening is not visible as it is dominated at the bottom and at the top by inner platform *Alveolina*–*Orbitolites* packstone. Only the coral wacke- to boundstone with abundant encrusting foraminifera (*Acervulina*) could indicate a deepening. The overall facies distribution in the Eocene sections of Serraduy and Campo suggest a more landward paleogeographical position of the Serraduy section in comparison with the Campo section. A partly comparable deepening-upward succession was described from Minerve (Rasser et al., 2005), which lacks, however, middle platform environments.

7. Facies changes across the Paleocene/Eocene boundary in Spain

The sections of Campo and Serraduy in the Spanish Pyrenees show a clear dichotomy at the newly defined Paleocene/Eocene boundary. The uppermost part of the Paleocene (depositional units I and II, member c of the Navarri Formation) is dominated by red algae, with minor appearance of benthic foraminifera (rotaliids) and corals, whereas the Eocene is characterised by larger foraminifera (alveolinids, nummulitids, orbitolitids), with minor appearance of corals and bivalves. In contrast to all other studies in the Pyrenees that mention geniculate (*Jania*) and non-geniculate (*Lithothamnion*-type, *Sporolithon*, *Mesophylum*) corallines as the important red algae genera, the Campo section is dominated by *D. biserialis*, a species, not mentioned in other studies. Probably, other authors interpreted this species as geniculate coralline alga, although Aguirre and Braga (personal communication) found high amounts of *D. biserialis* in the Basque-Cantabrian region (W. Pyrenean). In contrast to the dominance of red algae in Campo and the subordinate occurrence of corals, other Pyrenean sections are marked during this time interval by larger foraminifera, often of the type *Assilina* (*Assilina* beds of Pujalte et al., 2003a; Baceta et al., 2005; Fig. 6). Furthermore, Baceta et al. (2005) stated in their study on Pyrenean coralgal-reefs that the uppermost Paleocene is devoid of reef bioconstructions. An explanation for the deviation of the facies of the Campo section may be the fact that all other Pyrenean sections are situated on the outer platform, whereas the Campo section is situated on the inner platform.

The facies dichotomy at the Paleocene/Eocene boundary can be observed in all Pyrenean sections, in fact, the dominance of larger foraminifera in the latest Paleocene to earliest Eocene can be traced Tethyan-wide (Scheibner et al., 2005). They presented a three-fold platform subdivision in the southern Tethys (Galala Mountains, Egypt; 20°N paleolatitude) across the Paleocene/Eocene boundary. In Egypt, platform stage I is dominated by coralgal associations, which are time equivalent to the Thanetian reef phases 4 and 5 (Baceta et al., 2005) of the Pyrenean region (Fig. 6), a time interval not investigated in this study. Platform stage II, as defined in Egypt, correlates with depositional units I and II of the Paleocene part of the Campo section. According to Scheibner et al. (2005), platform stage II is dominated in Egypt by larger foraminifera shoals (*Miscellanea* and *Ranikothalia*) and is characterised by the absence of coralgal associations or even corals. Baceta et al. (2005) described for the Pyreneans a similar dominance of larger foraminifera (*Assilina* beds). In contrast to Egypt, the Pyrenean region during this time interval is not totally devoid of corals as this study reveals. The deposits of platform stage III in Egypt and those of the Eocene in Campo (unit III to unit VIII) and Serraduy are very similar, time equivalent and are dominated by different depth-dependant larger foraminifera species (*Orbitolites*, *Alveolina*, *Nummulites, Assilina*). However, the Egyptian lower Eocene strata studied in the Galala Mountains (Scheibner et al., 2005) is more or less devoid of corals, whereas in Campo and Serraduy coral-associated facies types occur subordinately.

According to Baceta et al. (2005) the conditions for coralgal-reef systems in the Pyrenees deteriorated from middle Thanetian times onwards, caused by a global cooling of about 3–4 °C in mid to low latitudes, whereas the late Paleocene absence of reefs is interpreted as a regional feature caused by the increase of siliciclastic input. In contrast to this global cooling as the reason for the demise of the coral reefs, Scheibner et al. (2005) proposed, apart from varying trophic resource regimes and the overall long-term evolution of larger foraminifera, a global warming as the reason for the changes in Late Paleocene to Early Eocene platform settings in Egypt. The warming trend started at 59 Ma (Zachos et al., 2001), which corresponds with the base of coral reef phases 4 and 5 in Spain and the base of platform stage I in Egypt (Scheibner et al., 2005). The mid Paleocene cooling that according to Baceta et al. (2005) resulted in the demise of the coralgal-reefs, appeared in an already very warm climate, so that this cooling was most probably not the reason for the disappearance of corals in the low latitudes, as in Egypt (Scheibner et al., 2003, 2005). For the Pyrenean region this short-term cooling might be a reason for the demise of coralgal-reefs, as this region has no direct connection to the Tethys, but opens to the paleo Bay of Biscay (Atlantic; Pujalte et al., 1993) and could therefore be influenced by cooler waters than the Tethyan regions.

The early Eocene larger foraminifera dominance of platform stage III, at least in low latitudes such as Egypt (Scheibner et al., 2005), but to some extent also in higher latitudes like Spain, has several reasons (Scheibner et al., 2005). Apart from changes in the trophic resource regime, the long-term evolution of larger foraminifera, the dominance of larger foraminifera is the result of long-time and short-time warming, as corals are more sensitive than larger foraminifera to temperature increase, which may cause symbiont loss, bleaching and subsequently the death (Hallock, 2000; Gattuso and Buddemeier, 2000), while larger foraminifers and their photosynthetic symbionts appear to be less sensitive to elevated summer temperatures (Hallock et al., 2006). The long-time warming culminated in the Early Eocene Climatic Optimum around 52 Ma, the time of the highest temperatures in the Cenozoic. The start of platform stage III also coincides with the onset of the Paleocene Eocene Thermal Maximum, characterised by a rise in sea-surface temperature of 8 °C to 10 °C in high latitudes and 4 °C to 5 °C in low latitudes (Zachos et al., 2003).

Upon comparison of the Egyptian strata from low latitudes at the southern Tethys (Scheibner et al., 2003, 2005) with the Pyrenean succession from the middle latitudes at the northern Tethys (this study) the overall trend within the three platform stages is the same, while latitudinal differences exist, especially in platform stages II and III. The Egyptian succession at the Galala Mountains is devoid of corals in both platform stages II and III. This overall trend of a less frequent coral occurrence is also apparent in the Pyrenean area (Baceta et al., 2005), but this study clearly shows the presence of small coral patches in the late Paleocene platform stage II as well as in the early Eocene platform stage III. In both regions the reasons for the evolution of the platform stages were probably the same, but consequences were less severe in the middle latitudes of the Pyrenees, thus representing a latitudinal effect. In the low latitudes (Egypt) apart from reasons mentioned above, temperatures were too warm to sustain the growth of coral reefs and enabled the larger foraminifera to occupy this niche and flourish during the early Paleogene. In the middle latitudes (Pyrenees) the temperatures were cooler than in the tropics, so that coral reefs still could grow, but played only a minor role beside the dominant larger foraminifera.

8. Conclusions

The Late Paleocene–Early Eocene Pyrenean sections of Campo and Serraduy are characterised both in the Paleocene and in the Eocene by a deepening. The Paleocene deepening is marked by a facies change from intertidal to shallow-subtidal rocky substrates rich in geniculate coralline algae to algal and coralgal facies comprising non-geniculate algae, peyssonneliacean algae, and acervulinid foraminifera. This deepening is interrupted by a terrestrial interval across the Paleocene/Eocene boundary. The investigated Eocene part of the Campo section show a well-defined deepening from terrestrial to restricted facies, followed by *Alveolina*- and *Orbitolites*-dominated inner platform facies and nummulitid-dominated middle platform facies. This Eocene deepening is triggered by the onset of the tectonic thrusting in the foreland basin.

The late Paleocene and early Eocene sediments are characterised in Campo by a well-pronounced dichotomy with red-algae-dominated Paleocene facies and larger foraminifera-dominated Eocene facies, although corals have a minor appearance in both time intervals. This dichotomy is not only apparent in other middle latitude Pyrenean sections but also in southern Tethyan low latitude sections in Egypt, although in the Campo section it is not as pronounced as in Egyptian sections. The main difference is the occurrence of corals in the middle latitude Campo and Serraduy sections, while the low latitude Egyptian sections are apparently devoid of coral reefs or corals. This facies distribution pattern probably reflects a latitudinal temperature gradient from warmer temperatures in the low latitudes to cooler temperatures in the middle latitudes during a time of overall warm temperatures and the onset of the short-time warming at the Paleocene Eocene Thermal Maximum.

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References

Baceta, J.I., Pujalte, V., Bernaola, G., 2005. Paleocene coralgal reefs of the western Pyrenean basin, northern Spain: new evidence supporting an earliest Paleogene recovery of reefal systems. Palaeogeography, Palaeoclimatology, Palaeoecology 224, 117–143.

Bains, S., Corfield, R.M., Norris, R.D., 1999. Mechanisms of climate warming at the end of the Paleocene. Science 285, 724–727.

Barnolas, A., Teixell, A., 1994. Platform sedimentation and collapse in a carbonate-dominated margin of a foreland basin (Jaca Basin, Eocene, southern Pyrenees). Geology 22, 1107–1110.

Bralower, T.J., 2002. Evidence of surface water oligotrophy during the Paleocene–Eocene thermal maximum: nannofossil assemblage data from the Ocean Drilling Program Site 690, Maud Rise, Weddell Sea. Paleoceanography 17. doi:10.1029/2001PA000662.

Caro, Y., 1973. Contribution à la connaissance des dinoflagellés du Paléocène–Éocène inférior des Pyrénées espagnoles. Revista Espanola de Micropaleontologia 5, 329–372.

Crouch, E.M., Heilmann-Clausen, C., Brinkhuis, H., Morgans, H.E.G., Rogers, K.M., Egger, H., Schmitz, B., 2001. Global dinoflagellate event associated with the late Paleocene thermal maximum. Geology 29, 315–318.

Dickens, G.R., 1999. The blast in the past. Nature 401, 752–755.

Dickens, G.R., O'Neil, J.R., Rea, D.K., Owen, R.M., 1995. Dissociation of oceanic methane hydrate gas as a cause of the carbon isotope excursion at the end of the Paleocene. Paleoceanography 10, 965–971.

Eichenseer, H., Luterbacher, H., 1992. The marine Paleogene of the Tremp Region (NE Spain) — depositional sequences, facies history, biostratigraphy and controlling factors. Facies 27, 119–152.

Gattuso, J.P., Buddemeier, R.W., 2000. Calcification and CO_2. Nature 407, 311–313.

Hallock, P., 2000. Symbiont-bearing foraminifera: harbingers of global change? Micropaleontology 46 (supplement 1), 95–104.

Hallock, P., Williams, D.E., Fisher, E.M., Toler, S.K., 2006. Bleaching in foraminifera with algal symbionts: implications for reef monitoring and risk assessment. Anuário do Instituto de Geociências 29, 108–128.

Hay, W.W., DeConto, R., Wold, C.N., Wilson, K.M., Voigt, S., Schulz, M., Wold-Rossby, A., Dullo, W.C., Ronov, A.B., Balukhovsky, A.N., Soeding, E., 1999. Alternative global Cretaceous paleogeography. In: Barrera, E., Johnson, C. (Eds.), The Evolution of Cretaceous Ocean/Climate Systems. Geological Society of America Special Paper, vol. 332. The Geological Society of America, Boulder, pp. 1–47.

Hottinger, L., 1960. Recherches sur les Alvéolines du Paléocène et de l'Eocène. Schweizerische Palaeontologische Abhandlungen 75/76, 1–243.

Hottinger, L., 1973. Selected Paleogene larger foraminifera. In: Hallam, A. (Ed.), Atlas of Palaeobiogeography. Elsevier, Amsterdam, pp. 443–452.

Hottinger, L., 1997. Shallow benthic foraminiferal assemblages as signals for depth of their deposition and their limitations. Bulletin de la Societé Géologique de France 168, 491–505.

Hottinger, L., 1998. Shallow benthic foraminifera at the Paleocene–Eocene boundary. Strata. Serie 1, Communications 9, 61–64.

Hottinger, L., Schaub, H., 1960. Zur Stufeneinteilung des Paleocaens und des Eocaens. Eclogae Geologicae Helveticae 53, 453–479.

Kapellos, C., Schaub, H., 1973. Zur Korrelation von Biozonierungen mit Grossforaminiferen und Nannoplankton im Paläogen der Pyrenäen. Eclogae Geologicae Helveticae 66, 687–737.

Kelly, D.C., 2002. Response of Antarctic (ODP Site 690) planktonic foraminifera to the Paleocene–Eocene thermal maximum: faunal evidence for ocean/climate change. Paleoceanography 17, 1071. doi:10.1029/2002PA000761.

Luterbacher, H.P., Ali, J.R., Brinkhuis, H., Gradstein, F.M., Hooker, J.J., Monechi, S., Ogg, J.G., Powell, J., Röhl, U., Sanfilippo, A., Schmitz, B., 2004. The Paleogene period. In: Gradstein, F., Ogg, J., Smith, A. (Eds.), A Geologic Time Scale 2004. Cambridge University Press, Cambridge, pp. 384–408.

Maas, M.C., Anthony, M.R.L., Gingerich, P.D., Gunnell, G.F., Krause, D.W., 1995. Mammalian generic diversity and turnover in the Late Paleocene and Early Eocene of the Bighorn and Crazy Mountains Basins, Wyoming and Montana (USA). Palaeogeography, Palaeoclimatology, Palaeoecology 115, 181–207.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A. (Ed.), Proceedings of the II Plankton Conference, Roma. Edizioni Tecnoscienza Rome, Roma, pp. 739–785.

Minnery, G.A., 1990. Crustose coralline algae from the Flower Garden Banks, northwestern Gulf of Mexico: controls on distribution and growth morphology. Journal of Sedimentary Petrology 60, 992–1007.

Molina, E., Canudo, J.I., Guernet, C., McDougall, K., Ortiz, N., Pascual, J.O., Pares, J.M., Samso, J.M., Serra-Kiel, J., Tosquella, J., 1992. The stratotypic Ilerdian revisited: integrated stratigraphy across the Paleocene/Eocene boundary. Revue de Micropaléontologie 35, 143–156.

Molina, E., Angori, E., Arenillas, I., Monechi, S., Schmitz, B., 2000. Integrated stratigraphy across the Paleocene/Eocene boundary at Campo, Spain. GFF 122, 106–107.

Molina, E., Angori, E., Arenillas, I., Brinkhuis, H., Crouch, E.M., Luterbacher, H., Monechi, S., Schmitz, B., 2003. Correlation between the Paleocene/Eocene boundary and the Ilerdian at Campo, Spain. Revue de Micropaléontologie 46, 95–109.

Moussavian, E., 1984. Die Gosau-und Alttertiär-Gerölle der Angerberg-Schichten (Höheres Oligozän, Unterinntal, Nördliche Kalkalpen). Facies 10, 1–86.

Norris, R.D., Röhl, U., 1999. Carbon cycling and chronology of climate warming during the Palaeocene/Eocene transition. Nature 401, 775–778.

Orue-Etxebarria, X., Pujalte, V., Bernaola, G., Apellaniz, E., Baceta, J.I., Payros, A., Nunez-Betelu, K., Serra-Kiel, J., Tosquella, J., 2001. Did the Late Paleocene thermal maximum affect the evolution of larger foraminifers? Evidence from calcareous plankton of the Campo Section (Pyrenees, Spain). Marine Micropaleontology 41, 45–71.

Pak, D.K., Miller, K.G., 1992. Paleocene to Eocene benthic foraminiferal isotopes and assemblages: implications for deep water circulation. Paleoceanography 7, 405–422.

Payros, A., Pujalte, V., Baceta, J.I., Bernaola, G., Orue-Etxebarria, X., Apellaniz, E., Caballero, F., Ferrandez, C., 2000. Lithostratigraphy and sequence stratigraphy of the upper Thanetian to middle Ilerdian strata of the Campo section (southern Pyrenees, Spain): revision and new data. Revista de la Sociedad Geologica de Espana 13, 213–226.

Perrin, C., 1992. Signification Écologique des foraminifères acervulinidés et leur role dans la formation de faciès récifaux et organogènes depuis le Paléocène. Geobios 25, 725–751.

Plaziat, J.C., 1981. Late Cretaceous to late Eocene palaeogeographic evolution of southwest Europe. Palaeogeography, Palaeoclimatology, Palaeoecology 36, 263–320.

Plaziat, J.C., Perrin, C., 1992. Multikilometer-sized reefs built by foraminifera (*Solenomeris*) from the early Eocene of the Pyrenean domain (S. France, N. Spain): palaeoecologic relations with coral reefs. Palaeogeography, Palaeoclimatology, Palaeoecology 96, 195–231.

Puigdefabregas, C., Souquet, P., 1986. Tecto-sedimentary cycles and depositional sequences of the Mesozoic and Tertiary from the Pyrenees. Tectonophysics 129, 173–203.

Pujalte, V., Robles, S., Robador, A., Baceta, J.I., Orue-Etxebarria, X., 1993. Shelf-to-basin Palaeocene palaeogeography and depositional sequences, western Pyrenees, north Spain. In: Posamentier, H.W., Summerhayes, C.P., Haq, B.U., Allen, G.P. (Eds.), Sequence Stratigraphy and Facies Association. Blackwell, Oxford, pp. 369–395.

Pujalte, V., Robles, S., Orue-Etxebarria, X., Baceta, J.I., Payros, A., Larruzea, I.F., 2000. Uppermost Cretaceous–middle Eocene strata of the Basque-Cantabrian region and western Pyrenees: a sequence stratigraphic perspective. Revista de la Sociedad Geologica de Espana 13, 191–211.

Pujalte, V., Orue-Etxebarria, X., Schmitz, B., Tosquella, J., Baceta, J.I., Payros, A., Bernaola, G., Caballero, F., Apellaniz, E., 2003a. Basal Ilerdian (earliest Eocene) turnover of larger foraminifera: age constraints based on calcareous plankton and δ^{13}C isotopic profiles from new southern Pyrenean sections (Spain). In: Wing, S.L., Gingerich, P.D., Schmitz, B., Thomas, E. (Eds.), Causes and Consequences of Globally Warm Climates in the Early Paleogene. GSA Special Paper. The Geological Society of America, Boulder, pp. 205–221.

Pujalte, V., Dinares-Turell, J., Bernaola, G., Baceta, J.O., Payros, A., 2003b. A reappraisal of the position of Chron C25n in the Campo section (Huesca province, south-central Pyrenees). Geogaceta 34, 155–158.

Racz, L., 1979. Paleocene carbonate development of Ras al Hamra, Oman. Bull. Cent. Rech. Explor. Prod. Elf-Aquitaine 3, 767–779.

Rasser, M.W., 2000. Coralline red algal limestones of the Late Eocene alpine foreland basin in upper Austria: component analysis, facies and palecology. Facies 42, 59–92.

Rasser, M.W., Piller, W.E., 1997. Depth distribution of calcareous encrusting associations in the Northern Red Sea (Safaga, Egypt) and their geological implications. Proceedings of the 8th International Coral Reef Symposium, pp. 743–748.

Rasser, M.W., Scheibner, C., Mutti, M., 2005. A paleoenvironmental standard section for Lower Ilerdian tropical carbonate factories (Pyrenees, Spain; Corbieres, France). Facies 51, 217–232.

Reid, R.P., Macintyre, I.G., 1988. Foraminiferal–algal nodules from the Eastern Caribbean: growth history and implications on the value of nodules as paleoenvironmental indicators. Palaios 3, 424–435.

Riosmena-Rodrigues, R., Siqueiros-Beltrones, D.A., 1995. Morfologia y distribucion de *Corallina vancouverensis* (Corallinales, Rhodophyta) en el noroeste de Mexico. Cienc. Mar. 21, 187–199.

Riosmena-Rodrigues, R., Siqueiros-Beltrones, D.A., 1996. Taxonomy of the genus *Amphiroa* (Corallinales, Rhodophyta) in the southern Baja California Peninsula, Mexico. Phycologia 35, 135–147.

Robador, A., 1991. Early Paleogene stratigraphy. In: Barnolas, A., Robador, A., Serra-Kiel, J., Caus, E. (Eds.), Introduction to the Early Paleogene of the South Pyrenean Basin. Field-trip guidebook 1st Meeting IGCP Project 286, Jaca 1990. Instituto Tecnológico Geominero de España, Barcelona, pp. 41–87.

Robador, A., Samso, J.M., Serra-Kiel, J., Tosquella, J., 1991. Field guide. In: Barnolas, A., Robador, A., Serra-Kiel, J., Caus, E. (Eds.), Introduction to the Early Paleogene of the South Pyrenean Basin. Field-trip guidebook 1st Meeting IGCP Project 286, Jaca 1990. Instituto Tecnológico Geominero de España, Barcelona, pp. 131–159.

Röhl, U., Bralower, T.J., Norris, R.D., Wefer, G., 2000. New chronology for the late Paleocene thermal maximum and its environmental implications. Geology 28, 927–930.

Schaub, H., 1966. Über die Grossforaminiferen im Untereocaen von Campo (Ober-Aragonien). Eclogae Geol. Helv. 59, 355–377.

Schaub, H., 1981. Nummulites et Assilines de la Téthys paléogène. Taxinomie, phylogenèse et biostratigraphie. Schweiz. Palaontol. Abh. 104/105/106, 1–238.

Schaub, H., 1992. The Campo Section (NE Spain) a Tethyan parastratotype of the Cuisian. Neues Jahrb. Geol. Palaontol. Abh. 186, 63–70.

Scheibner, C., Reijmer, J.J.G., Marzouk, A.M., Speijer, R.P., Kuss, J., 2003. From platform to basin: the evolution of a Paleocene carbonate margin (Eastern Desert, Egypt). Int. J. Earth Sci. 92, 624–640.

Scheibner, C., Speijer, R.P., Marzouk, A., 2005. Larger foraminiferal turnover during the Paleocene/Eocene thermal maximum and paleoclimatic control on the evolution of platform ecosystems. Geology 33, 493–496.

Schmitz, B., Pujalte, V., 2003. Sea-level, humidity, and land-erosion records across the initial Eocene thermal maximum from a continental–marine transect in northern Spain. Geology 31, 689–692.

Serra-Kiel, J., Canudo, J.I., Dinares, J., Molina, E., Ortiz, N., Pascual, J.O., Samso, J.M., Tosquella, J., 1993. Cronoestratigrafia de los sedimentos marinos del Terciario inferior de la Cuenca de Graus-Tremp (Zona Central Surpirenaica). Rev. Soc. Geol. Esp. 7, 273–297.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferrandez, C., Jauhri, A.K., Less, G., Pavlovec, R., Pignatti, J., Samso, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J., Zakrevskaya, E., 1998. Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. Bull. Soc. Geol. Fr. 169, 281–299.

Thomas, E., 1998. Biogeography of the Late Paleocene benthic foraminiferal extinction. In: Aubry, M.P., Lucas, S., Berggren, W.A. (Eds.), Late Paleocene–Early Eocene Climatic and Biotic Events in the Marine and Terrestrial Records. Columbia University Press, New York, pp. 214–243.

Wilcoxon, J.A., 1973. Paleogene calcareous nannoplankton from the Campo and Tremp sections of the Ilerdian stage in NE-Spain. Rev. Esp. Micropaleontol. 5, 107–112.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., Billups, K., 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present. Science 292, 686–693.

Zachos, J.C., Wara, M.W., Bohaty, S., Delaney, M.L., Petrizzo, M.R., Brill, A., Bralower, T.J., Premoli-Silva, I., 2003. A transient rise in tropical sea surface temperature during the Paleocene–Eocene Thermal Maximum. Science 302, 1551–1554.