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Rudist Biostratigraphy in the Campanian-Maastrichtian of the south-central Pyrenees, Spain

with 10 figures

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Abstract

The Campanian-Maastrichtian shallow-marine strata of the south-central Pyrenees include eight calcarenite horizons, interstratified within thick siliciclastic deposits, that contain characteristic rudist associations. From older to younger, they are listed below.

1 - *Hippurites lamarcki* horizon
2 - Rudist-free horizon
3 - *Hippurites radiosus* horizon
4 - *Radiolitella pulchella* horizon
5 - *Hippuritella castroi* lower horizon
6 - *Hippuritella castroi sensu stricto* horizon
7 - *Biradiolites moroi* horizon
8 - *Biradiolites chaperi* horizon

The recognition of these horizons within the basin has proven to be useful to resolve classical problems of correlation, and has provided a local rudist biostratigraphic scale, which has been calibrated by means of planktonic foraminifera, that are present in equivalent basinal rocks. In this work, we provide a detailed description of the rudist-bearing horizons and their rudist faunas.

Keywords: Rudists, Campanian-Maastrichtian, south-central Pyrenees, biostratigraphy

Introduction

The studied area comprises a wide region between the Segre and Ribagorçana rivers in the South-Central Pyrenean thrust unit (fig. 1).

In this region, the Campanian-Maastrichtian shallow-marine strata are exposed along the limbs of two E-W – trending synclines (Tremp and Ager) separated by a major thrust anticline (Montsec). This present-day disposition reflects the former configuration of an elongate foredeep basin that deepens northwestward to the Atlantic ocean (DERAMOND et al. 1993). The foredeep was filled by basinal turbidites, shelfal and deltaic deposits, and continental red beds that range in age from Santonian to Maastrichtian. Coeval shelf sandstones and calcarenites and red beds were deposited on the southern margin.

For description purposes, the studied area has been divided in five geographic sectors (fig. 1). The northern sector is the northern limb of the Tremp syncline (fig. 2); the eastern sector is the western end of the Isona anticline; the central sector is the southern limb of the Tremp syncline (fig. 3); and the southern sector is the southern limb of the Ager syncline, while its northern limb is overthrusted. The northern and eastern sectors were part of the foredeep axis, while the central and southern sectors were part of the passive southern margin. Farther east outcrops are considered as the most easter sector (Sallent area).

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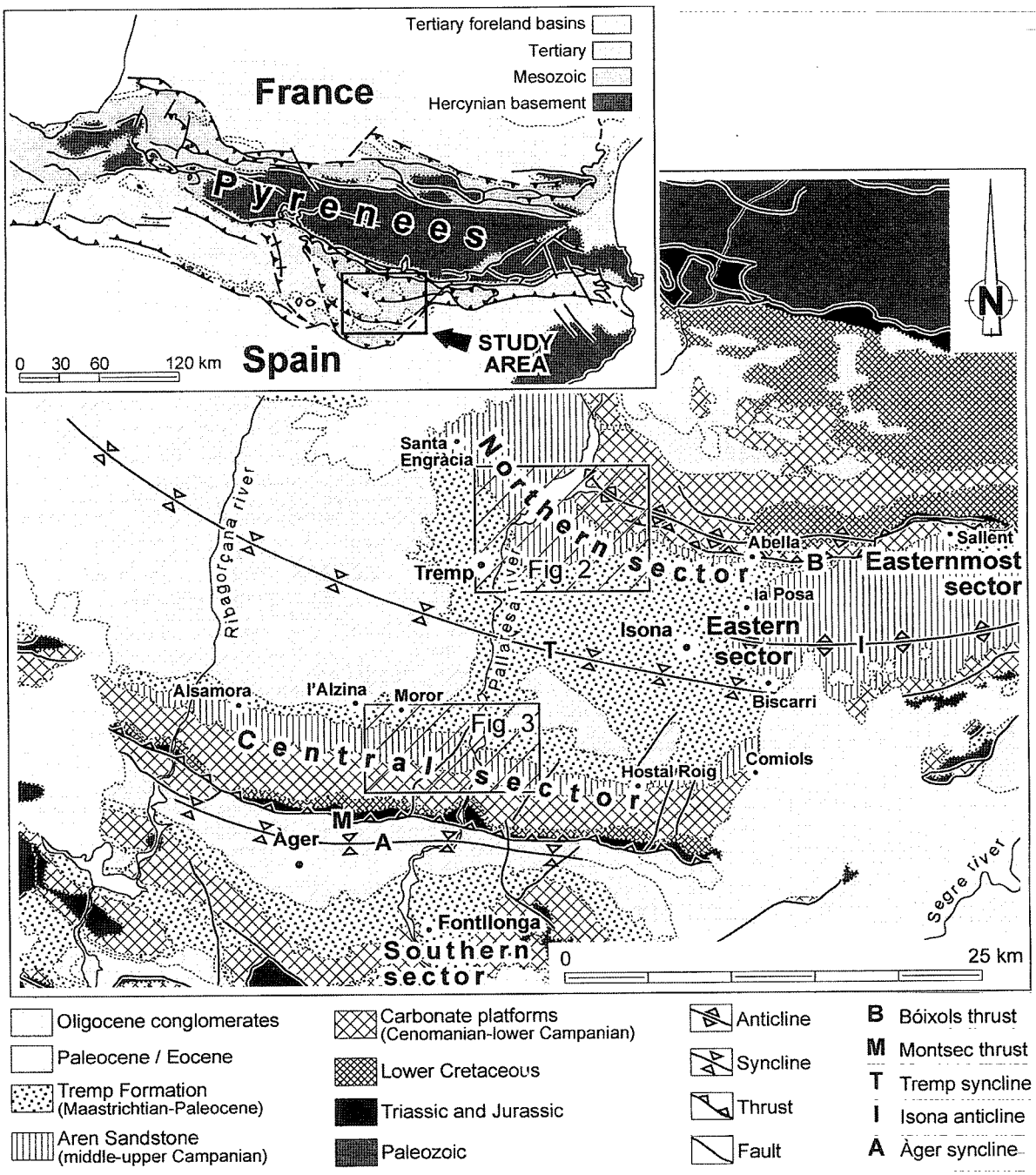

Fig. 1: Geologic map of the study area in the south-central Pyrenees. The maps are modified from BERÁSTEGUI et al. (1993) & LOSANTOS et al. (1989) The boxes show the location of the maps in figs. 2 and 3.

The stratigraphic correlation among the defined sectors of the Upper Cretaceous foredeep has been classically problematic. The difficulties in correlation are mostly related to the lack of physical continuity of beds and considerable lateral facies changes. The accurate dating of these rocks, mainly based on benthic foraminifera, has also been uncertain. Field mapping, construction of stratigraphic sections, and collecting of a number of rudist specimens has been carried out in order (1) to establish detailed correlations among the different sectors of the basin, and (2) evaluate the potential of rudists as a biostratigraphic tool.

The rudist fossil faunas in the south-central Pyrenees have been extensively studied. The area is the type locality of many species described by VIDAL (1874, 1878) and DOUVILLÉ (1895). further studies were provided, among others, by ASTRE (1932), ALIBERT (1933), BAUDELOT & SOUQUET (1962), LIEBAU (1973), PONS (1977), and PASCUAL et al. (1989).

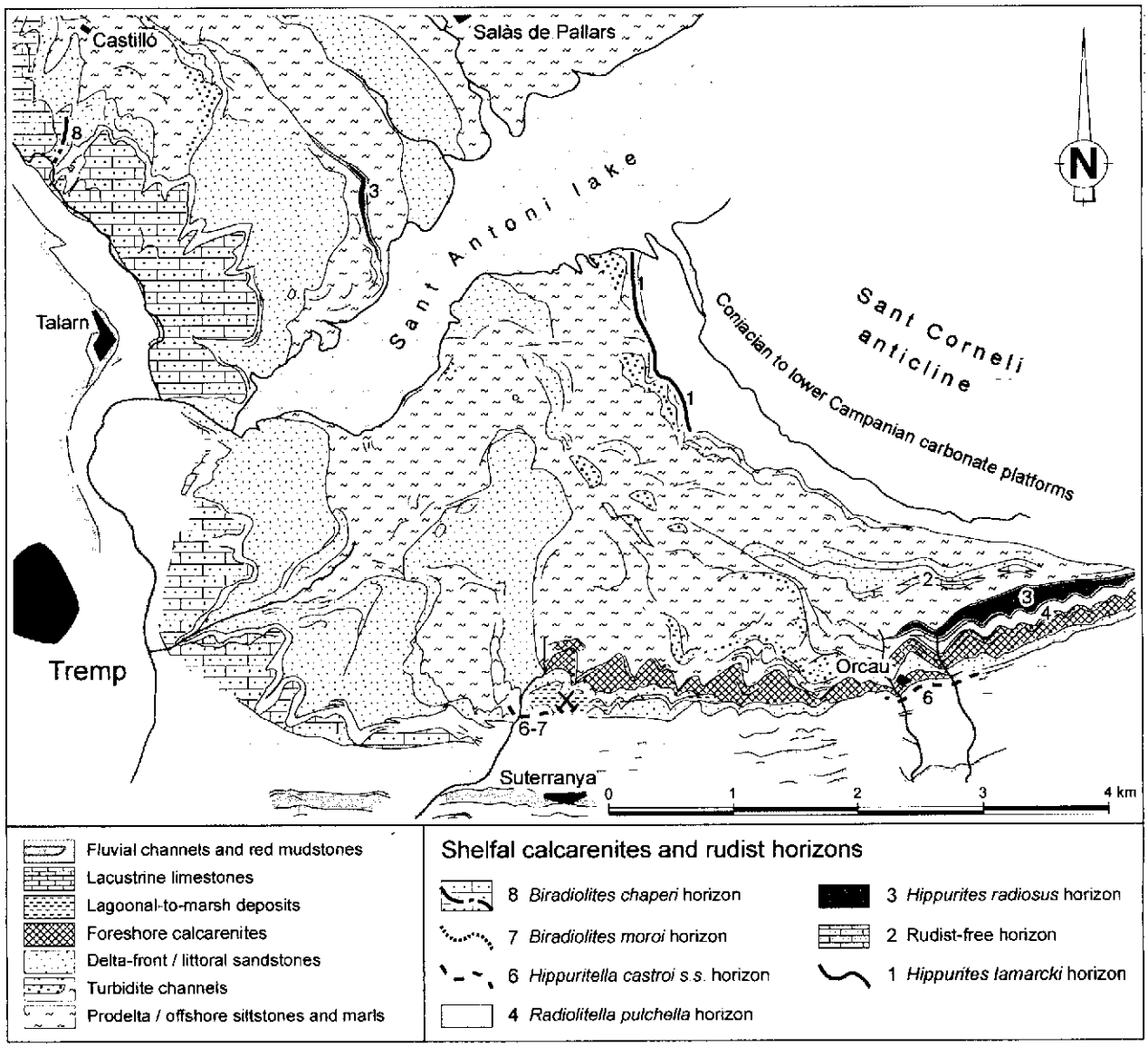

Fig. 2: Geologic map of the northern sector of the basin, along the northern limb of the Tremp syncline.

The rudist-bearing horizons

The correlation of the stratigraphic sections within each sector has led to the definition of a minimum of seven rudist-bearing horizons (fig. 4).

These horizons consist of calcarenite intervals, that range from tens of decimetres to tens of metres in thickness, and may reach several kilometres in lateral extension. The rudist horizons are intercalated within shallow-marine and coastal deposits, which thickness varies between few hundreds of metres in the southern sector and 1500 m in the northern sector. These deposits are formally known as the Aren Sandstone and Tremp Formation, respectively (MEY et al. 1968).

The Aren Sandstone was mostly deposited in shelfal and deltaic environments (central and northern sectors, respectively). The interstratified calcarenite horizons consist of medium-bedded bioclastic grainstones (with fragments of red algae, echinoids, rudists, bryozoans, and foraminifers such as *Orbitoides*) with terrigenous sediment (quartz, feldspar, volcanics, chert, mica) that varies between 20% in the northern sector and 10% in the central sector. The calcarenite bodies show mostly low-angle large-scale cross bedding, interpreted as a structure related to foreshore deposition. The lower part of the Tremp Formation was deposited in coastal and delta-plain environments. The interstratified calcareous horizons consist of packstones/wackestones that generally contain charophytes, gastropods, ostracods and foraminifers.

Because of rudist faunas are locally associated with the horizons, especially in the central sector, the horizons are defined from their rudist associations and named after their most characteristic rudist species. The specimens

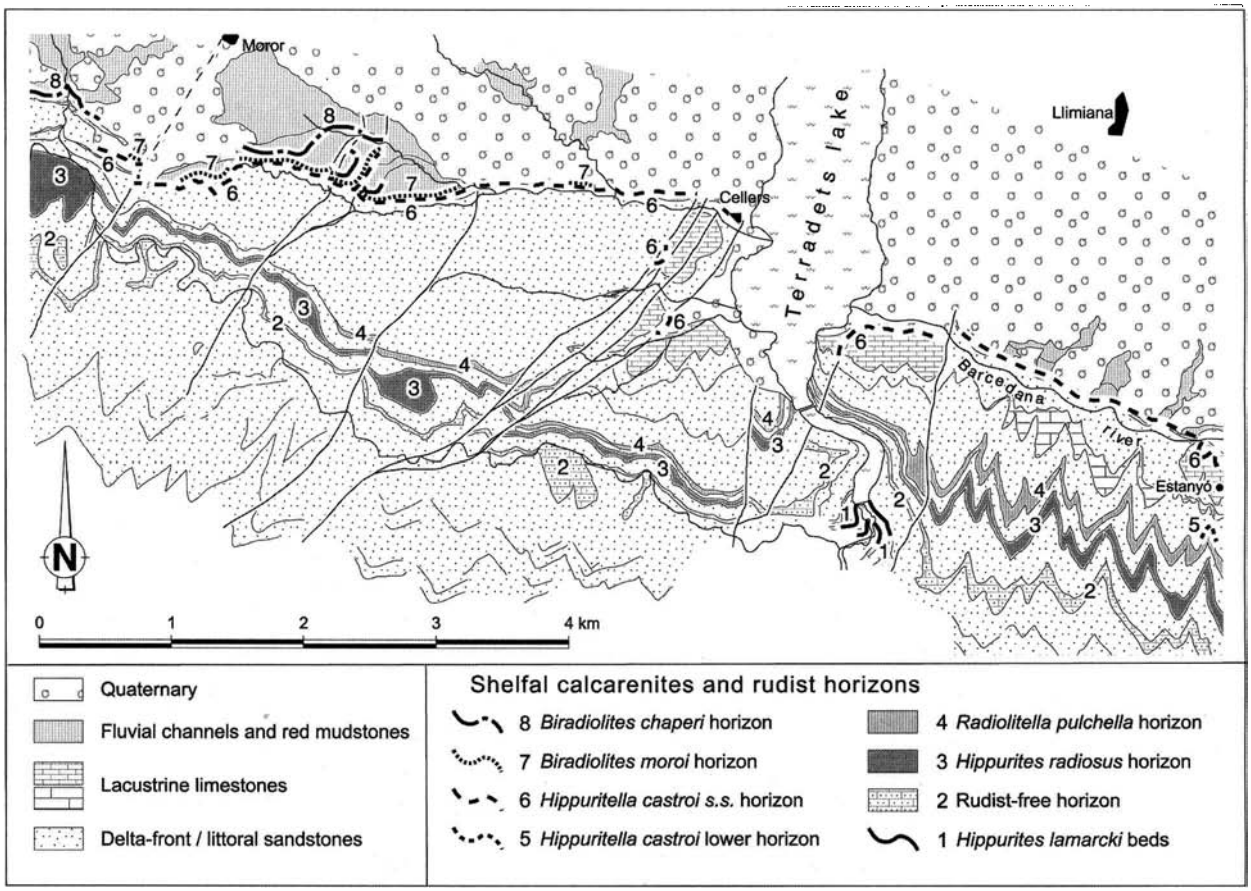

Fig. 3: Geologic map of the central sector of the basin, along the southern limb of the Tremp syncline.

are commonly found in life position, although they can also be transported, or may be absent. In an ascending stratigraphic order, the rudist-bearing horizons are described below. Their component rudist species are listed in fig. 4.

1. *Hippurites lamarcki* horizon

The most lower *Hippurites lamarcki* horizon, is recognised in the northern and central sectors, although further studies are needed for its characterization. In the northern sector, the horizon consists of slope deposits disturbed by slumping (Puimanyons member, MEY et al. 1968). The rudists have been resedimented there. In the central sector, this level is correlated to a minimum of two calcarenite layers exposed in the basal part of the section.

2. Rudist-free horizon

This horizon consists of a continuous calcarenite interval, well recognised in the northern and central sectors. No identifiable rudists have yet been found, therefore, further studies are needed. In the northern sector, the horizon is correlated to two calcarenite layers exposed in the upper part of a thick section of deltaic sandstones (lower part of the Aren Sandstone). In the central sector, the level has a lateral continuity of several kilometres and a regular thickness of several metres.

3. *Hippurites radiosus* horizon

The *Hippurites radiosus* horizon is recognised in the northern, central, and southern sectors. In the northern sector, the horizon extends from Abella to Santa Engràcia but it is not present in the middle part of this fringe, due to submarine canyon erosion (ARDÈVOL et al. 2000, fig. 1). These authors interpret the level as a calcarenite shelf as thick as 50 m, with echinoids, rudists and corals. The rudists have been found in Santa Engràcia and Orcau (SOUQUET 1967, figs. 1,2).

In the central sector, the horizon extends between Hostal Roig and Moror (LIEBAU 1971, figs. 1,3). Farther west, the horizon becomes sandy and free of rudists but they appear again in Alsamora. At Terradets, the horizon consists of two limestone layers separated by a 15m-thick interval of sandstones and sandy limestones. The *Hippurites radiosus* horizon has not been found in the eastern sector but is present in the easternmost sector, where it consists of two layers separated by pebbly sandstones (WILLEMS 1985, ULLASTRE et al. 1987).

RUDIST HORIZONS	Southern sector	Central sector	Eastern sector	Easternmost sector	Northern sector
Biradiolites chaperi	NOT OBSERVED	*M.* cf. *falgasi* Vidal *M.* cf. *figolina* Vidal *B. ara* Pons *B. chaperi* Toucas *B.* aff. *osensis* (Vidal) *P. boucheroni* Toucas	NOT OBSERVED	NOT OBSERVED	*P. boucheroni* Toucas
Biradiolites moroi	NOT OBSERVED	*M. moroi* (Vidal) *B. moroi* (Vidal)	NOT OBSERVED	NOT OBSERVED	*M. moroi* (Vidal) *M.* aff. *moroi* (Vidal) *Hl. castroi* (Vidal) *B. moroi* (Vidal) *B. sellesi* (Baudelot) *P. boucheroni* Toucas
Hippuritella castroi s.s.	NOT OBSERVED	*M.* cf. *falgasi* Vidal *M. moroi* (Vidal) *M.* aff. *moroi* (Vidal) *Hl. castroi* (Vidal) *B. ara* Pons *B. sellesi* (Baudelot) *P. boucheroni* Toucas	*Hl. castroi* (Vidal) *P. leymeriei* (Bayle) *Rosellia* sp.	NOT OBSERVED	
Lower Hippuritella castroi	NOT OBSERVED	*B. chaperi* Toucas *B. osensis* (Vidal) *P. boucheroni* Toucas	*M.* cf. *falgasi* Vidal *Hl. castroi* (Vidal) *P. boucheroni* Toucas *P. leymeriei* (Bayle) *Rosellia* sp. *Apricardia* sp.	NOT OBSERVED	NOT OBSERVED
Radiolitella pulchella	*B. chaperi* Toucas *P. boucheroni* Toucas *Ra. pulchella* (Vidal)	*Hl. lapeirousei* (Goldfuss) *Hl.* aff. *castroi* (Vidal) *B. chaperi* Toucas *B. lameracensis* Toucas *B. osensis* (Vidal) *B.* nov. sp. *Bournonia* sp. *Lapeirousia* sp. *P. boucheroni* Toucas *Ra. pulchella* (Vidal) *Apricardia* sp. *Mitrocaprina* sp.	*Hl.* aff. *castroi* (Vidal) *B. chaperi* Toucas *Lapeirousia* sp. *P. boucheroni* Toucas *Ra. pulchella* (Vidal) *Apricardia* sp.	NOT OBSERVED	NOT OBSERVED
Hippurites radiosus	*Hl. lapeirousei* (Goldfuss) *H. radiosus* des Moulins *B. chaperi* Toucas *P. boucheroni* Toucas *Ra. pulchella* (Vidal)	*H. radiosus* des Moulins *B. fumanyae* (Vidal) *P. boucheroni* Toucas *Mitrocaprina* sp.	NOT OBSERVED	*Hl. lapeirousei* (Goldfuss) *Hl.* aff. *castroi* (Vidal) *H. radiosus* des Moulins *P. boucheroni* Toucas	*H. radiosus* des Moulins
Hippurites lamarcki	NOT OBSERVED	*H. lamarcki* Douvillé *B. lameracensis* Toucas *P. boucheroni* Toucas	NOT OBSERVED	NOT OBSERVED	*H. lamarcki* Douvillé (plus 8 species more)

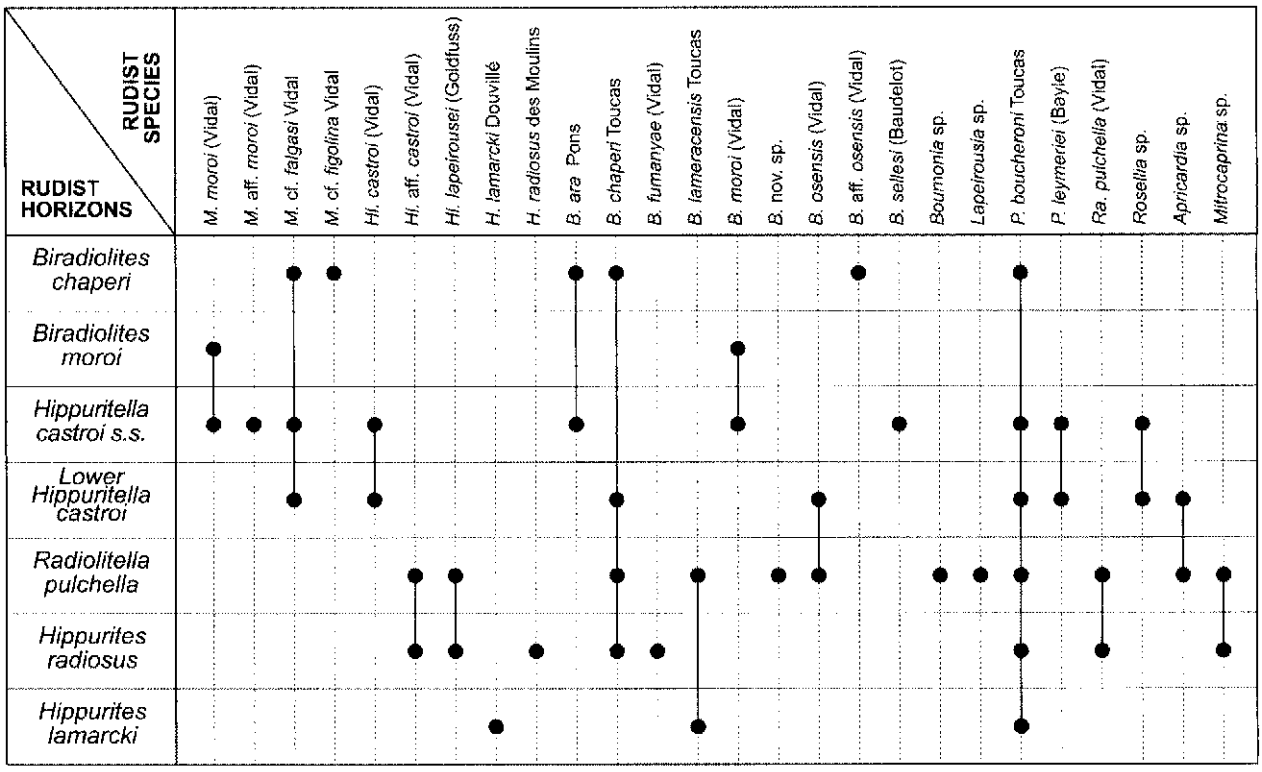

Fig. 4: The rudist-bearing horizons and their rudist faunas, showing the distribution within the geographic sectors (up) and the local ranges (down).

4. *Radiolitella pulchella* horizon

The *Radiolitella pulchella* horizon largely crops out in the eastern, central, and southern sectors. In the northern sector, two calcarenite layers are correlated to the horizon but rudists have not yet been found. In the eastern sector, the level extends along a 12 km fringe between la Posa church and Biscarri (fig. 1). The horizon is 1m thick at la Posa and increases its thickness southward reaching 12 m in 3 km.

In the central sector, the horizon has more than 20 km of lateral continuity between Comiols and Moror where it pinches out into sandstone beds (figs. 1, 3). The level is 20m thick at Terradets. In the southern sector, the horizon is identified by a thin calcarenite layer. In both, eastern and southern sectors, it contains colonial corals.

5. *Hippuritella castroi* lower horizon

The *Hippuritella castroi* lower horizon is reduced in extension and appears locally in the eastern and central sectors. In the eastern sector, the level is 1m thick and has less than 1 km of lateral extension near la Posa church (fig. 1). In the central sector, the horizon has been correlated to two beds as thick as 1 and 0.2 m at l'Estanyó (fig. 3).

6. *Hippuritella castroi sensu stricto* horizon

The *Hippuritella castroi s.s.* horizon is well developed in the northern, eastern, and central sectors. In the northern sector, the level is 0.7 m thick and has less than 1 km of lateral continuity at Orcau (fig. 2). Eastward, the horizon pinches out into red beds; westward, it may disappear eroded by sandstones but it is exposed at Suterranya, according to our correlation. At this locality, two rudist beds are recognised.

In the eastern sector, the horizon is less than 1m thick and extends southward for 3 km from la Posa church (fig. 1). The rudists are associated with an abundant coral fauna (LIEBAU 1973, MIMÓ 1993). Localised exposures are also found eastward. In the central sector, the horizon has more than 9 km of lateral continuity between the Barcedana river and Moror (fig. 3). The horizon is 1.5m thick and thins out westward before being eroded by conglomerates. The rudists are mostly found in life position within a muddy matrix.

7. *Biradiolites moroi* horizon

The *Biradiolites moroi* horizon is recognised in the northern and central sectors. In the northern sector, the level extends for some hundreds of metres in Suterranya (fig. 2). In the central sector, it extends for 3.5 km between Cellers and Moror and has a thickness of 0.5 m (fig. 3). Eastward, the horizon disappears under a Quaternary cover; westward, its eroded top is overlain by Tertiary conglomerates. The rudists are mostly found in life position within a muddy matrix.

8. *Biradiolites chaperi* horizon

The uppermost horizon in the rock record of the study area, the *Biradiolites chaperi* horizon, is recognised in the northern and central sectors. In the northern sector, the level is exposed at Castilló (LIEBAU 1984, fig. 2). The rudists are rounded and mixed with corals on top of a several tens of metres thick calcarenite package, interpreted as a basin-wide shelf (ARDÈVOL et al. 2000). The rudists are interpreted as resedimented.

In the central sector, the horizon is well developed with 6.7 km of lateral extension from Moror to the west (fig. 3). At Moror, it is more than 2m thick and gradually thining out westward. The rudists are mostly found in life position within a muddy matrix, and a small coral branch has also been identified.

The rudist species and their occurrence

The specimens described below are housed in the Palaeontology Collections of the Universitat Autònoma de Barcelona, Spain (PUAB).

Hippuritella castroi (VIDAL)

The collected specimens show small pillars, commonly quadrangular or rectangular in the transverse section of the right valve, and the ligamentary crest is absent or represented by a slight inflection of the external layer (fig. 5.1).

This rudist species is very abundant in both *Hippuritella castroi* horizons of the eastern sector, where VIDAL (1874) and PONS (1977) described the species. They are scarce in the northern and central sectors.

Hippuritella aff. *castroi* (VIDAL)

This specie is probably the ancestor of *Hippuritella castroi* (VIDAL) because they differ only in their ligamentary crest. The crest of *H.* aff. *castroi* (VIDAL), represented by an inflection of the external layer, is generally more pronounced than the one of *H. Castroi* (VIDAL) (fig. 5.3). However, some specimens may be difficult to differentiate due to the intraspecific variability of the crest of both species. This rudist species is present in the *Radiolitella pulchella* horizon of the eastern and central sectors, between the Barcedana river and Comiols area (fig. 1), as well as in the *Hippurites radiosus* horizon of the most eastern sector.

Hippuritella lapeirousei (GOLDFUSS)

This species is easily identifiable because of its reduced diameter, lack of ligamentary crest, and small triangular

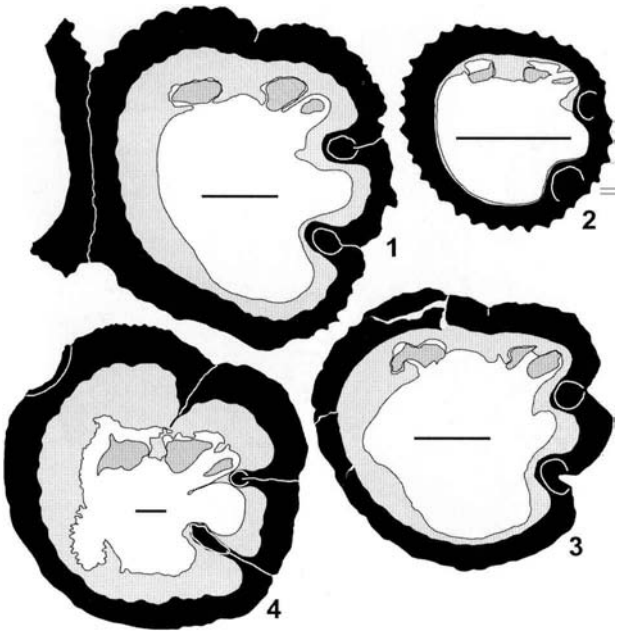

Fig. 5: Tranverse sections of the right valve. **1.** *Hippuritella castroi* (VIDAL), n° PUAB 60057. **2.** *Hippuritella lapeirousei* (GOLDFUSS), n° PUAB 63242. **3.** *Hippuritella* aff. *castroi* (VIDAL), n° PUAB 63235. **4.** *Hippurites radiosus* DES MOULINS, n° PUAB 63231. The specimen in **Fig.** 5.1 comes from the *Hippuritella castroi s.s.* horizon of the eastern sector (Isona); the specimens in figs. 5.2-4 come from the *Hippurites radiosus* horizon of the easternmost sector. Scale bar is 10 mm.

pillars, wider than long (fig. 5.2). The pillars differentiate this species from *Hippuritella castroi* (VIDAL). The specimens have been found in the *Radiolitella pulchella* horizon of the central sector (Terradets), and the *Hippurites radiosus* horizon of the southern and the most eastern sectors.

Hippurites lamarcki DOUVILLÉ

Several exemplars from the northern sector and three specimens from the central sector have been studied. They show the characteristic features of the species. The specimens from the northen sector, present in the Puimanyons member, have been described as *Hippurites serratus* DOUVILLÉ by PONS (1977).

Hippurites radiosus DES MOULINS

More than twenty five specimens have been studied from the *Hippurites radiosus* horizon, which areparticularly well preserved in the most eastern) sector. The rudists show the typical features of the species (fig. 5.4).

Biradiolites ara PONS

PONS (1977) described this species from the *Hippuritella castroi* s.s. horizon of the central sector. We have also studied more than twenty specimens from the *Biradiolites chaperi* horizon in this sector. The rudist specimens from both horizons are similar, as observed in the transverse section of the right valve (figs. 6.1-3), but the specimens from the *Hippuritella castroi s.s.* horizon are larger.

Biradiolites chaperi TOUCAS

This species has been found in the *Hippurites radiosus* horizon of the southern sector, in the *Radiolitella pulchella* horizon of the eastern and central sectors, and in the *Hippuritella castroi* lower horizon and *Biradiolites chaperi* horizon of the central sector. This rudist species has been described by PONS & VICENS (1986).

Biradiolites royanus (D'ORBIGNY)

We have assigned to this species an isolated and badly preserved rudist found in the *Hippurites radiosus* horizon of the central sector (Moror). The specimen has a thin external layer commonly with compact structure. The transverse section of the right valve shows a smooth shell with two long and narrow folds, which are located on the posterior side and between little pronounced radial bands.

Biradiolites lameracensis TOUCAS

The shell of this species shows folds commonly less developed on the anterior and dorsal sides but present between separated radial bands. The posterior band is narrower than the ventral band, which is invaginated and partially covered by the surrounding folds (fig. 6.4). The specimens have been found in the *Radiolitella pulchella* horizon of the central sector.

Biradiolites moroi (VIDAL)

This species has provided more than fifty specimens with an elongate, conical or cylindrical, right valve. This valve has ribs but they may be so thin that the shell looks smooth. The radial bands are pronounced, flat, separated by a groove, and slightly depressed (fig. 7.1).

The specimens are uniform due to few growth interruptions. The transverse section of the right valve lacks a ligamentary crest (fig. 6.5). The structure is mostly cellular and well developed on the anterior and dorsal sides and compact on the radial bands (fig. 8.1).

The left valve is mostly concave or flat. Some specimens with marked ribs and growth interruptions are similar to *Biradiolites sellesi* (BAUDELOT), as described later.

B. moroi (VIDAL) is the only species found in the *Biradiolites moroi* horizon of the central sector (between

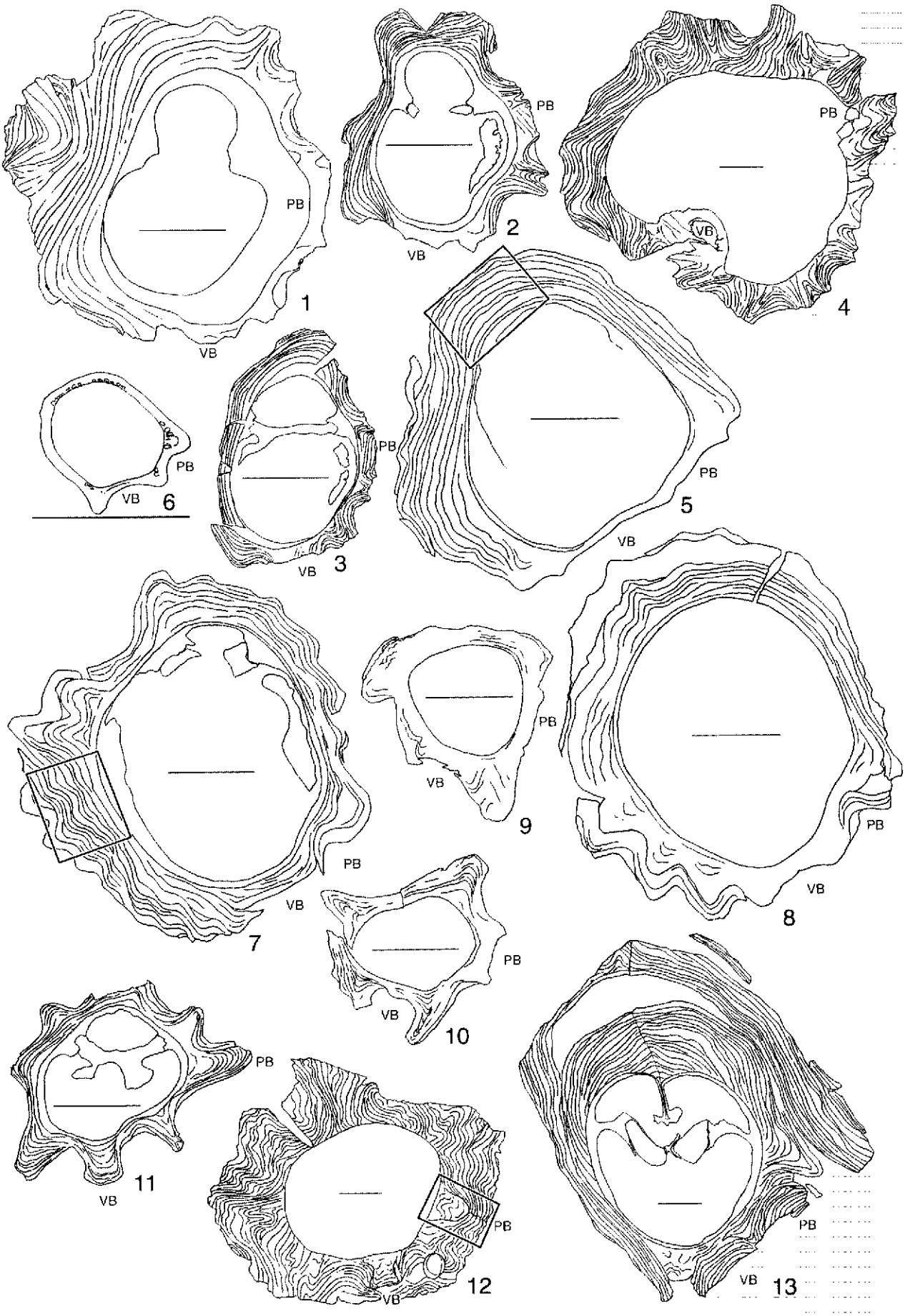
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Fig. 7: Ventral view of two specimens showing the radial bands. PB, posterior band; VB, ventral band. **1.** *Biradiolites moroi* (VIDAL), *Biradiolites moroi* horizon of the central sector (Moror), n° PUAB 63209. **2.** *Biradiolites sellesi* (BAUDELOT), *Hippuritella castroi s.s.* horizon of the central sector (Moror), n° PUAB 63353. Scale bar is 10 mm.

Fig. 6: Transverse sections of the right valve. **1.** Holotype of *Biradiolites ara* PONS, *Biradiolites castroi s.s.* horizon (Terradets), n° PUAB 3176. **2.** *Biradiolites ara* PONS, *Biradiolites chaperi* horizon (Moror), n° PUAB 63428. **3.** *Biradiolites ara* PONS, *Biradiolites chaperi* horizon (Moror), n° PUAB 63428. **4.** *Biradiolites lameracensis* TOUCAS, *Radiolitella pulchella* horizon (Toló), n° PUAB 63488. Note the deformation on the posterior band. **5.** *Biradiolites moroi* (VIDAL). *Biradiolites moroi* horizon (Moror), n° PUAB 63197. The box shows the location of the **Fig.** 8.1. **6.** *Biradiolites osensis* (VIDAL), *Radiolitella pulchella* horizon (Alzina streamlet), n° PUAB 63579. **7.** *Biradiolites sellesi* (BAUDELOT), *Hippuritella castroi s.s.* horizon (Moror), n° PUAB 63359. The box shows the location of the **Fig.** 8.2. **8.** *Biradiolites sellesi* (BAUDELOT), Hippuritella castroi *s.s.* (Moror) n° PUAB 63360. **9.** *Biradiolites* nov. sp., *Radiolitella pulchella* horizon (Hostal Roig), n° PUAB 63593. **10.** *Biradiolites* nov. sp., *Radiolitella pulchella* horizon (Hostal Roig), n° 63590. **11.** *Bournonia* sp., *Radiolitella pulchella* horizon (Estanyó), n° PUAB 63473. **12.** *Lapeirousia* sp., *Radiolitella pulchella* horizon (Estanyó), n° PUAB 63463. The box shows the location of the **Fig.** 8.3. **13.** *Praeradiolites boucheroni* TOUCAS, *Hippuritella castroi s.s.* horizon of the northern sector (Orcau), n° PUAB 63623. The specimens in figs. 6.1-12 come from the central sector. PB, posterior band; VB, ventral band. Scale bar is 10 mm.

Cellers and Moror). The *Hippuritella castroi s.s.* horizon of the northern sector has provided some rounded specimens (Suterranya).

Biradiolites osensis (VIDAL)

The collected specimens are small, with less than 15 mm in greater diameter. The right valve is elongate, smooth; and has three folds on the postero-ventral side. The radial bands are located between these folds, and the ventral band is wider than the posterior band (fig. 6.6). The external layer of the right valve is thin with compact structure. The left valve has not been found. The rudists come from the *Hippuritella castroi* lower horizon and *Radiolitella pulchella* horizon of the central sector (Barcedana river and l'Alzina, respectively).

Biradiolites aff. *osensis* (VIDAL)

Six specimens of this species have been found in the *Biradiolites chaperi* horizon of the central sector (Moror). They look like *Biradiolites osensis* (VIDAL) because the general morphology of the right valve is similar. However, *B.* aff. *osensis* (VIDAL) has a single fold instead of three. This fold is located on the dorsal side of the posterior band. In addition, the ventral radial band projects slightly outward.

Biradiolites sellesi (BAUDELOT)

Forty seven specimens of this species have been found in the *Hippuritella castroi s.s.* horizon of the northern and central sectors (Orcau, Cellers). The right valve is conically elongate and has common growth interruptions and marked ribs. The radial bands are flat and separated by a groove (fig. 7.2). The transverse section of the right valve shows the lack of a ligamentary crest and mostly compact structure (figs. 6.7,8,8.2). The left valve is flat or slightly convex.

Biradiolites sellesi (BAUDELOT) has morphologic features similar to *B. moroi* (VIDAL) with variations in the development of the growth lines. Further research may conclude that both species are the same.

Biradiolites nov. sp.

The right valve of this species is elongate and nearly cylindrical. Its transverse section is triangular due to the disposition of long and, commonly narrow, ribs; one rib is located on the dorsal side, one between the radial bands, and two on the anterior and antero-dorsal sides (figs. 6.9,10). The radial bands are not well defined, with the posterior band a little more projected outward. The left valve, with a greater diameter of 3.5 mm, is very concave and located inside the right valve. The specimens have been found in the *Radiolitella pulchella* horizon of the central sector (area of the Barcedana river).

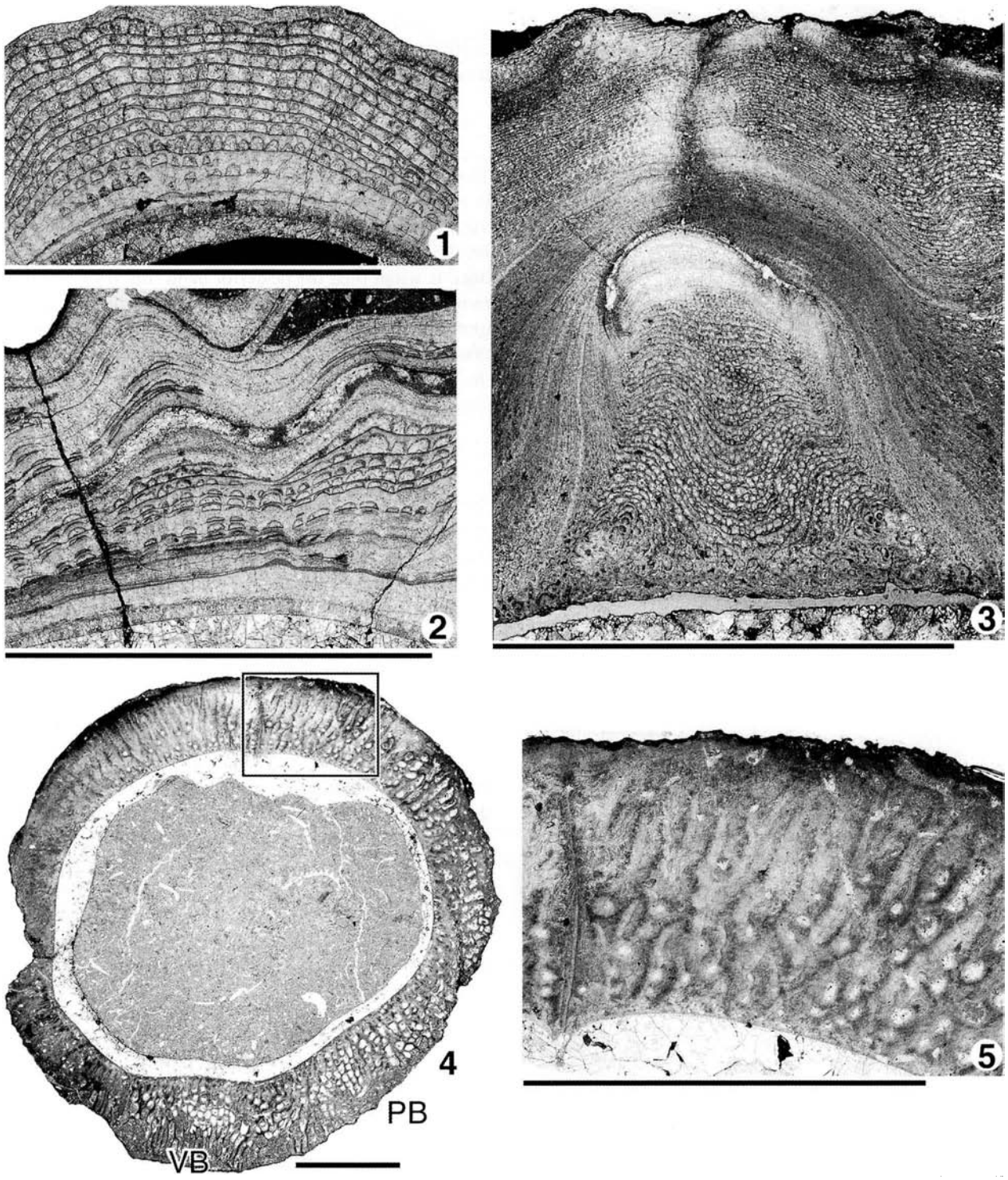

Fig. 8: 1. *Biradiolites moroi* (VIDAL). Close up of the specimen in **Fig.** 6.5. **2.** *Biradiolites sellesi* (BAUDELOT). Close up of the specimen in **Fig.** 6.7. **3.** *Lapeirousia* sp. Close up of the posterior band of the specimen in **Fig.** 6.12. **4.** *Radiolitella pulchella* (VIDAL), *Radiolitella pulchella* horizon of the central sector (Estanyó), nº PUAB 63454. Transverse section of the right valve. PB, posterior band; VB, ventral band. The box shows the location of the **Fig.** 8.5. **5.** *Radiolitella pulchella* (VIDAL). Close up of the dorsal side of the specimen in **Fig.** 8.4. Scale bar is 10 mm.

Bournonia sp.

An isolated poorly preserved specimen has been found in the *Radiolitella pulchella* horizon of the central sector (Barcedana river). The specimen has the left valve slightly convex. The transverse section of the right valve shows the radial bands represented by two big folds projected outward (fig. 6.11). The posterior band is slightly narrower than the ventral band. There is a fold between the radial bands and a maximum of six little developed wide folds on the anterior and dorsal sides.

Lapeirousia sp.

Ten well preserved specimens have been found in the *Radiolitella pulchella* horizon of the eastern and central sectors, but the species has not been determined. The external layer of the right valve is very thick with undulated laminae. The radial bands are not seen because they are covered by the laminae, but they are well differentiated in the transverse section, that also shows weakly developed pseudopillars (figs. 6.12, 8.3).

Praeradiolites boucheroni Toucas

The studied specimens are more than 10 cm in diameter and 15 cm in length. The shape is conical or cylindrical and the transverse section of the right valve is triangular or rectangular, due to the presence of very closed radial bands on a flat side (fig. 6.13). The great intraspecific variability of the species makes its determination difficult, so that diverse specimens have been attributed to *Praeradiolies echennensis* Astre var. *montsecanus* Baudelot, *P.* cf. *maximus* Astre, and *P.* cf. *fuxeensis* Astre (Baudelot & Souquet 1962), or to *P. leymeriei* (Bayle) and *P. echennensis* Astre (Pons 1977).

Sixty nine specimens have been collected from several horizons. The *Hippurites radiosus* horizon contains these rudists in the most eastern and central sectors (Sallent, Terradets); *the Radiolitella pulchella* horizon in the central sector (Barcedana river); the *Hippuritella castroi* horizon in the northern, eastern, and central sectors (Suterranya, Isona, Barcedana river); in the *Hippuritella castroi s.s.* horizon in the northern and central sectors, where they are extremely abundant (Orcau, Moror, Barcedana river), and the *Biradiolites chaperi* horizon in the northern and central sectors.

Praeradiolites leymeriei (Bayle)

The specimens are less than 5 cm in greater diameter with a right valve commonly short. The laminae are inclined toward the lower part of the valve and the radial bands are formed by two well marked sinuses, the ventral one somewhat wider than the posterior one. The left valve is commonly smooth and very convex. Some poorly preserved specimens have been found in both *Hippuritella castroi* horizons of the eastern sector.

Radiolitella pulchella (Vidal)

The right valve of this species is conical and bent toward the posterior side. The anterior and dorsal sides are smooth, while the posterior and ventral sides have more or less pronounced ribs. The poorly defined radial bands are located between these ribs. The transverse section of the right valve shows a small ligamentary crest and an inflection at the boundary between the external and internal layers on the side of the bands. The left valve is flat or slightly convex with the vertex displaced to the anterior part, and shows the same ornamentation as the right valve but more diminished. Characteristically, the external layer shows canals in both valves from the vertex to the commissure but the structure may be compact on the anterior and dorsal sides (fig. 8.4,5).

The collected specimens are bigger than the ones described by Vidal (1878) from the eastern Pyrenees, but we have assigned them to the same species following Pons (1977). This rudist species is found in the *Radiolitella pulchella* horizon of the eastern and southern sectors. The *Hippurites radiosus* horizon of the southern sector has provided poorly preserved small specimens.

Rosellia sp.

Fifteen poorly preserved specimens have been found in both *Hippuritella castroi* horizons of the eastern sector. The rudists show a ligamentary crest and a characteristic structure of the external layer of the right valve, because the cells are big, rounded, a little irregular, and with thick septa. The rudists are similar to *Rosellia xavieri* Pons (Pons 1977).

Mitrocaprina sp.

Five poorly preserved left valves of this genus have been collected in the central sector from the *Hippurites radiosus* and *Radiolitella pulchella* horizons (Terradets).

Monopleura cf. *falgasi* Vidal

Six poorly preserved specimens show the external features of the species as described by Vidal (1878). The specimens come from the *Hippuritella castroi* lower horizon of the eastern sector (la Posa church), and the *Hippuritella castroi s.s.* and *Biradiolites chaperi* horizons of the central sector (Terradets and l'Alzina, respectively).

Monopleura cf. *figolina* Vidal

The found specimens have a smooth, conical right valve, that shows marked growth lines or thin ribs, which are features that were described for this species by Vidal (1878). Eight specimens have been collected from the *Biradiolites chaperi* horizon of the central sector (Moror).

Fig. 9: *Monopleura moroi* (VIDAL), *Hippuritella castroi s.s.* horizon of the central sector (Moror). Group of five individuals in life position, n° PUAB 63275. Scale bar is 10 mm.

Monopleura moroi (VIDAL)

This species has the right valve conically elongate, and elliptical in section, commonly smooth or showing thin ribs. The left valve is small with the apex in a marginal position. Fig. 9 shows a group of five individuals in life position.

About one hundred specimens have been collected from the *Hippuritella castroi s.s.* horizon of the central sector (mostly at Moror). Five specimens come from the *Biradiolites moroi* horizon of the northern and central sectors (Suterranya, Moror).

Monopleura aff. *moroi* (VIDAL)

Eighteen specimens of this species have been found associated with *Monopleura moroi* (VIDAL). *M.* aff. *moroi* (VIDAL) is bigger, with a greater diameter of more than 30 mm. The right valve is very short and nearly circular in transverse section, and the left valve is commonly more flat. Both types of rudists are considered two different species because they are well differentiated and no intermediate specimens have been found; however, more extensive studies are needed to confirm this assumption.

Apricardia sp.

Eleven poorly preserved specimens have been collected and tentatively assigned to *Apricardia sicoris* ASTRE as described by ASTRE (1932) from the eastern Pyrenees. The rudists come from the *Radiolitella pulchella* horizon and *Hippuritella castroi* lower horizon of the eastern sector, and the *Radiolitella pulchella* horizon of the central sector.

Discussion

The recognition of the rudist-bearing horizons, totally or partially present in the different sectors of the Upper Cretaceous Central Pyrenees foredeep, has proven to be an excellent tool for high-resolution stratigraphic correlations among the sectors (fig. 10). Detailed correlation schemes with the elaboration of high-resolution 3D cross sections are in progress.

In the northern sector, the rudist-bearing calcarenite packages are interpreted as highstand systems tracts in the sequence-stratigraphic framework introduced by ARDÈVOL et al. (2000). These authors define four depositional sequences in the interval mid Campanian-Maastrichtian (Aren 1-4), separated by sequence boundaries SB 1-5 (fig. 10). According to our interpretation, the Aren 1 sequence can be divided in two sequences (1A, 1B) separated by the SB 1B sequence boundary. Four horizons from the northern sector, namely *Hippurites lamarcki*, rudist free, *Hippurites radiosus*, and *Biradiolites chaperi* horizons, are related with third-order highstand systems tracts of four sequences (a previous sequence, Aren 1A, Aren 1B, and Aren 2, respectively; fig. 10). The other horizons are related with fourth-order highstand systems tracts present within the Aren 2 sequence.

These depositional sequences have been traced basinward and correlated with basinal deposits with planktonic foraminifera (ARDÈVOL et al. 2000). These correlations allowed the precise dating of the sequences and, consequently, the rudist-bearing horizons (fig. 10). According to these datings, the horizons are distributed within the mid-late Campanian in the time scale of GRADSTEIN et al. (1995), and can be used as a local biostratigraphic scale. These determinations are in agreement with magnetostratigraphic rock datations from the southern sector (GALBRUN et al. 1993, LÓPEZ-MARTÍNEZ et al. 1998). The two horizons identified in this sector, namely *Hippurites radiosus* and *Radiolitella pulchella*, are exposed several tens of metres below the chron 32 that characterizes the latest Campanian, age that may be assigned to the corresponding horizons identified in the eastern Pyrenees (VICENS, 1992) and Aquitaine basin (PLATEL 1996). Studies in progress based on 87Sr/86Sr isotope analysis may contribute to refine the rudist biostratigraphic scale.

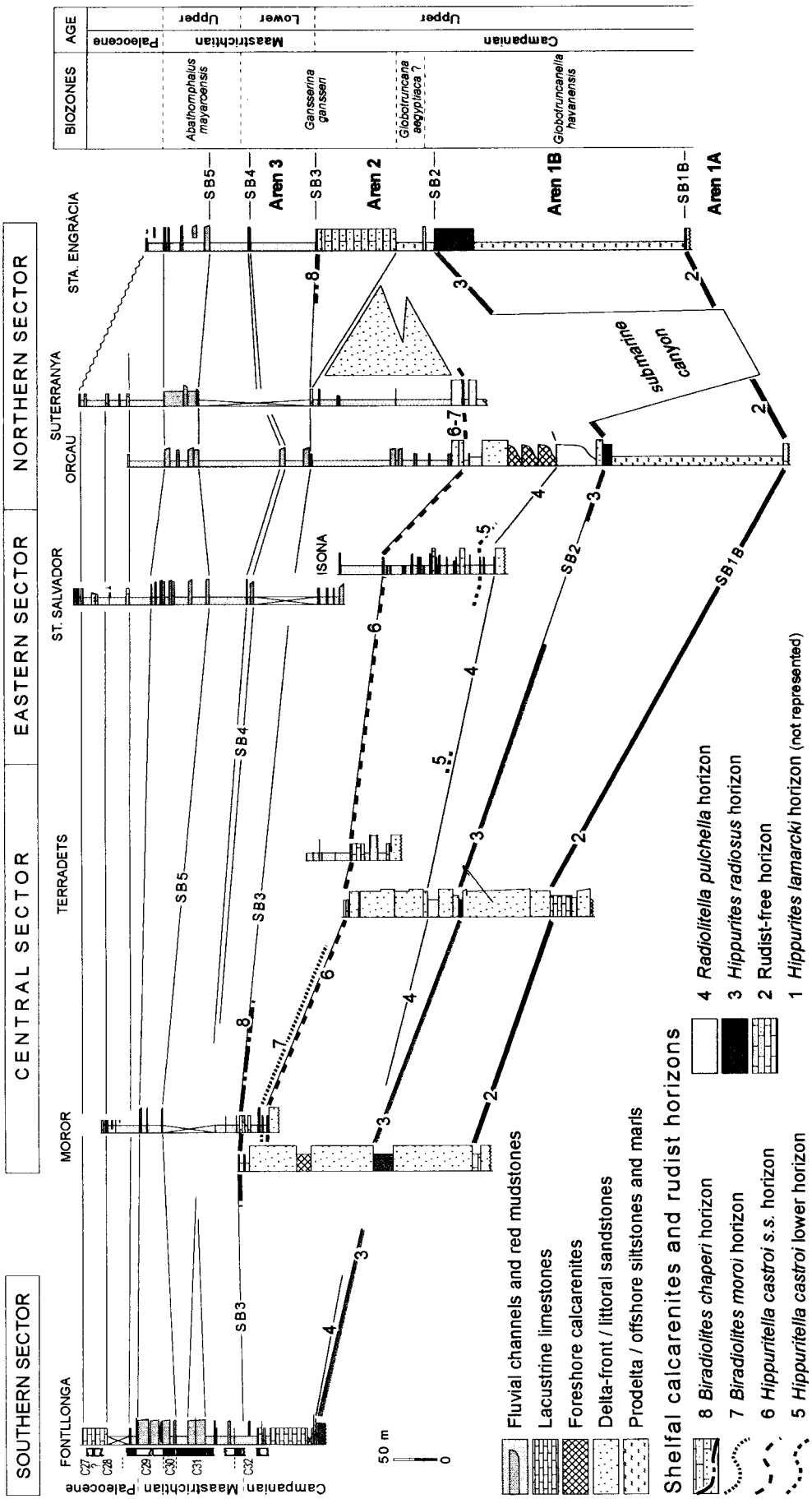

Fig. 10: Schematic cross section showing the correlation of the rudist-bearing horizons along the geographic sectors defined in the basin, and their calibration by means of paleomagnetic and plancktonic formainifera scales.

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