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Lower Aptian Rudist Faunas (Bivalvia, Hippuritoidea) from Croatia

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Key words: Rudist faunas, Lower Aptian, Lower Cretaceous, Adriatic Carbonate Platform, Croatia.

Abstract

Lower Aptian rudist faunas from Croatia consist of *Requienia*? *zlatarskii* PAQUIER, *Toucasia* sp., *Agriopleura* sp., *Glossomyophorus costatus* MASSE, SKELTON & SLIŠKOVIĆ, *Himeraelites* sp. and *Offneria* sp. This assemblage has a clear Southern Tethyan (Arabo–African) significance and typifies the Early Aptian. Faunas from the interior of the Adriatic Carbonate Platform in Istria are dominated by Requieniidae while those from the northeastern area in the vicinity of Tounj–Ogulin, close to the platform margin, exhibit a higher diversity and include, beside requieniids, Caprinidae, Caprotinidae and Monopleuridae, in conjunction with evidence of open marine conditions.

1. INTRODUCTION

In the Lower Cretaceous of Croatia, notwithstanding the remarkable stratigraphic development of shallow water carbonate platforms, rudist bearing sediments are rare and/or poorly documented. Rudist faunas have been hitherto mentioned from the following localities:

- in Istria, in the Kanfanar–Dvigrad area, where *Toucasia* rich beds from the Kanfanar Formation, of early Aptian age, were acknowledged (TIŠLJAR, 1978; VLAHOVIĆ et al., 2002, among others). The Veli Brijun Island also exposes a remarkable requieniid rich locality of Aptian–Albian age (VELIĆ & TIŠLJAR, 1987),
- in the Lika region, near Korenica, "*Offneria rhodanica*" PAQUIER was collected by POLŠAK (1970) in Aptian limestones,
- Tounj, near Ogulin where the presence of requieniids was indicated by VELIĆ & SOKAČ (1978, 1979) in Aptian limestones,
- from Svilaja Mt., in the hinterland of Split, caprinid facies including a few *Offneria* sp. and *Glossomyophorus costatus* MASSE, SKELTON & SLIŠKOVIĆ of Early Aptian age was reported by CVETKO-TEŠOVIĆ et al. (2003).

The foregoing shows that the Aptian is a key stage for Lower Cretaceous rudist studies in Croatia, as well as in adjacent regions: in Slovenia, where Aptian caprinids have been described by PLENIČAR & BUSER (1967) and TURNŠEK et al. (1992), and in Bosnia, where caprinids and caprotinids have been studied by MASSE et al. (1984).

The objective of the present paper is to specify the taxonomic position of Lower Aptian rudists found in the Kanfanar area of Istria, and the Tounj area of central Croatia (Fig. 1). This study is based on material collected from these two areas and includes the taxonomic reappraisal of caprinids figured from the Lika region, Slovenia and Bosnia. The present contribution includes a description of the regional stratigraphy followed by a systematic palaeontological study of the rudist material. The faunal assemblages are subsequently discussed in terms of biostratigraphy, palaeoecology, palaeogeography and palaeobiogeography.

2. STRATIGRAPHIC SETTING

Lower Aptian shallow water carbonates are widely distributed along the Croatian part of the Karst Dinarides, i.e. within deposits of an ancient Adriatic Carbonate Platform (AdCP). The carbonates were deposited within different platform environments, most frequently within extensive lagoons and protected shallow peritidal settings, rarely within bioconstructed bodies. Orbitolinid-bearing limestones are widespread. Rudists appear as the coarsest bioclasts within floatstones intercalated in orbitolinid-bearing limestones or within skeletal carbonate bodies. There are two well investigated areas in Croatia that are characterized by relatively rudist-rich limestones – western Istria and an area surrounding the town of Ogulin in central Croatia (Fig. 1).

2.1. Kanfanar area in western Istria – – western Croatia

The stratigraphic succession of Jurassic and Cretaceous platform carbonates in western Istria is divided into

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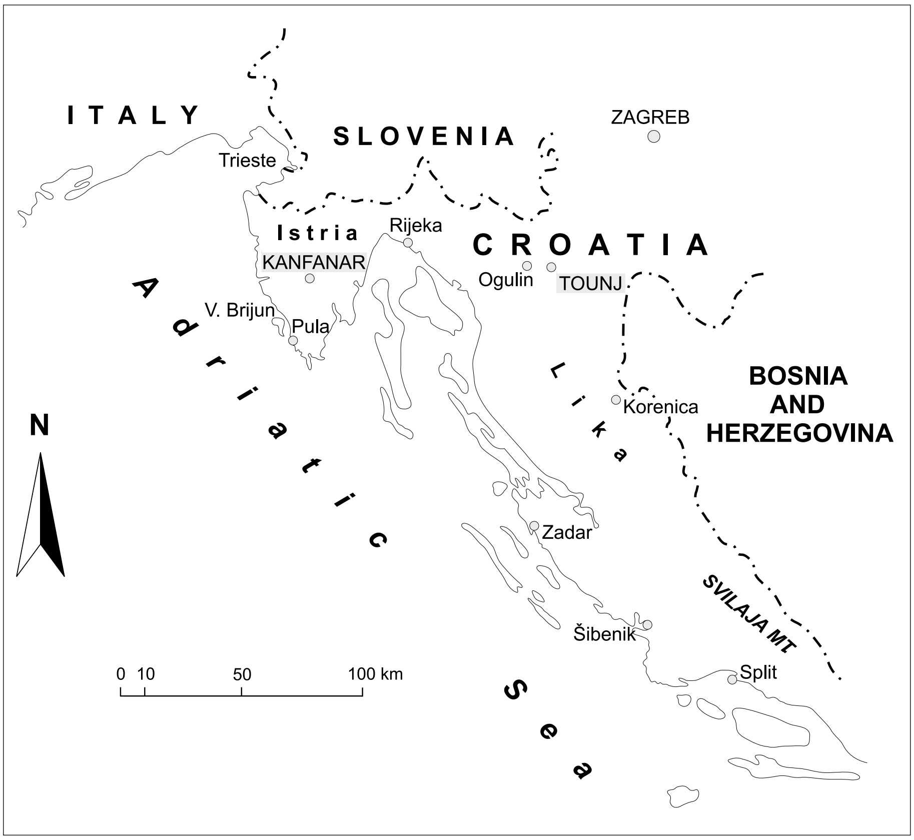

Fig. 1 Location map.

three megasequences (VELIĆ et al., 1995) bounded by major discontinuities – emersion surfaces representing time periods of subaerial exposure characterized by scattered accumulation of bauxite laterites. The megasequences are of the following chronostratigraphical ranges (VELIĆ et al., 2002): Bathonian–Lower Kimmeridgian (I), Upper Tithonian–Upper Aptian (II) and Upper Albian–Upper Santonian (III).

The best outcrops of Aptian carbonates of western Istria are exposed in the Kanfanar area (Fig. 2). They represent the uppermost part of the second megasequence. Relatively uniform lithologies imply that the carbonates were deposited within a generally stable lagoonal environment. As a result of Late Aptian–Early Albian subaerial exposure and subsequent erosion, the thickness of Lower Aptian carbonates is highly variable, i.e. they are locally absent (see fig. 1 in VELIĆ et al., 1989).

Owing to its commercial value, Lower Aptian limestones with rudists in Istria are relatively well investigated from a stratigraphic and palaeoenvironmental point of view. The commercial name of the deposits is "Istrian Yellow" (VELIĆ & HVALA, 2002). The limestones have been studied in detail along sections in the Lim valley and Kanfanar quarry (Fig. 3; VELIĆ et al., 1995; TIŠLJAR et al., 1995; VLAHOVIĆ, 1999;

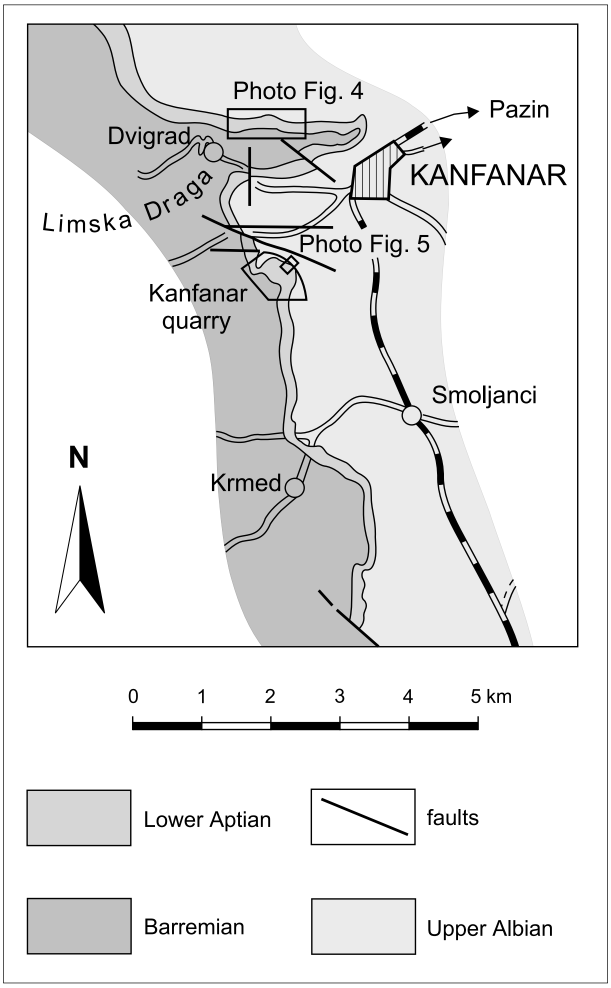

Fig. 2 Geological sketch-map of the Kanfanar area.

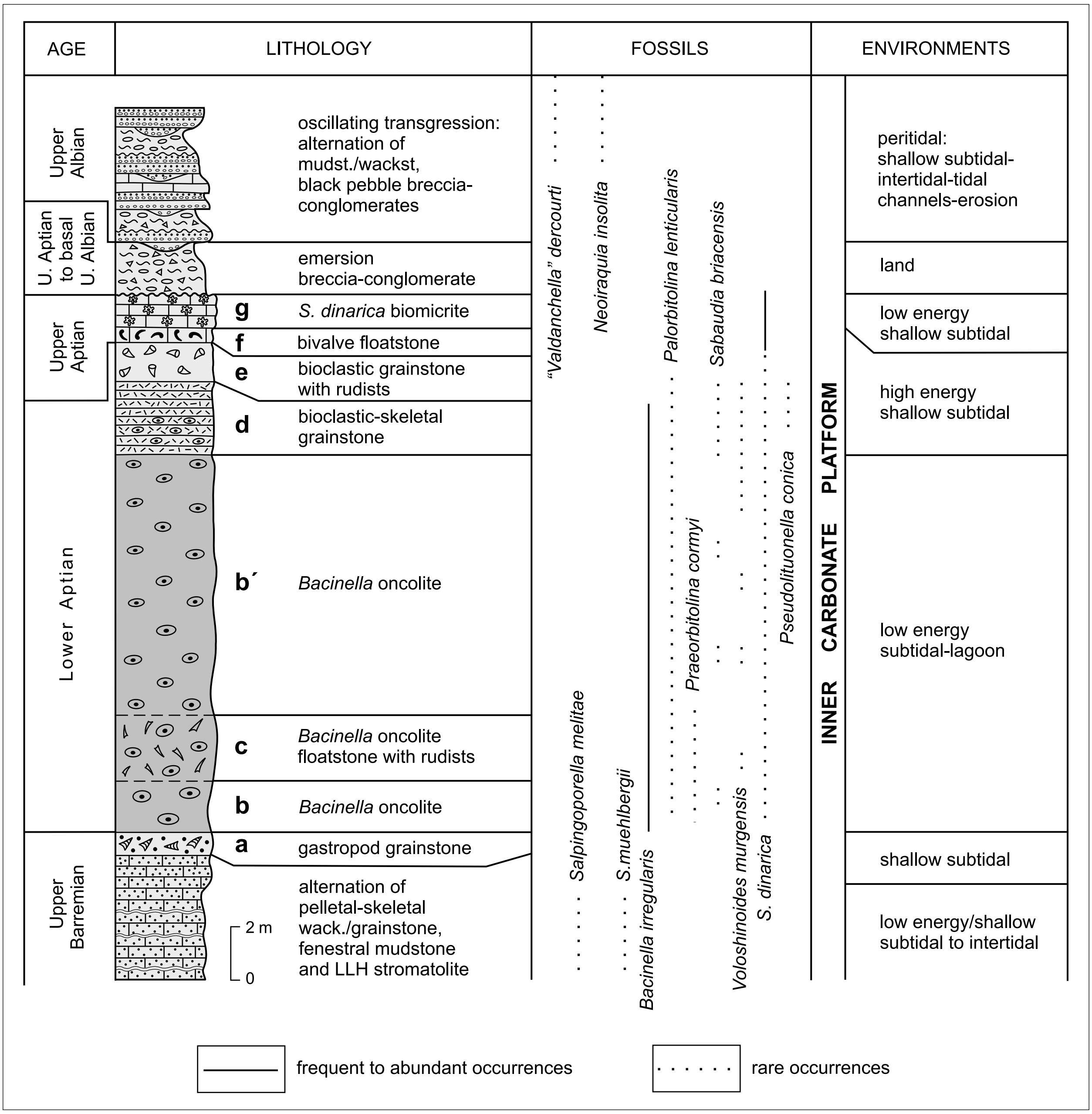

Fig. 3 Stratigraphic column of Aptian carbonates in the Kanfanar area (modified after VELIĆ et al., 1995).

VLAHOVIĆ, et al., 2002). *Bacinella*-rich beds are the dominant facies, and these include scattered rudists (Fig. 3).

The succession of Aptian carbonates around Kanfanar has been described in detail by VELIĆ et al. (1995) and VLAHOVIĆ (1999). Underlying Barremian gastropod grainstones (bed *a* in Fig. 3), are overlain by a massive and compact 19.5 m thick interval of oncoid-bearing Lower Aptian limestones (Figs. 4 and 5).

VLAHOVIĆ (1999) assigned these Aptian carbonates to a unique informal *Kanfanar Fm.* consisting of a lower *Sv. Petar Mb.* (Lower Aptian massive oncoid-bearing limestones), and an upper *Begovac Mb.* (topmost Lower Aptian and Upper Aptian limestones).

The *Sv. Petar Mb.* shows a basal interval (2 m thick) composed of rhythmic alternations of *Bacinella*-oncoid floatstones and mudstones (interval *b* in Fig. 3). The interval is overlain by an approximately 2.50 m thick *Bacinella*-oncoid floatstone containing rudists (beds *c* in Fig. 3) described in Section 3. Overlying the main rudist bed, the main mass of *Bacinella*-oncoid floatstones containing rare requieniid shells is approximately 15 m thick (interval *b'* in Fig. 3).

Besides *Bacinella irregularis* RADOIČIĆ, the limestones are characterized by a typical Lower Aptian microfossil association, including: *Salpingoporella dinarica* RADOIČIĆ, *Palorbitolina lenticularis* (BLUMENBACH), *Sabaudia briacensis* ARNAUD-VANNEAU,

Fig 4 Panoramic view of the northern slope of Lim valley (north of Kanfanar) showing the undisturbed Lower Cretaceous well-bedded carbonate succession. The massive bed of Lower Aptian *Bacinella* oncolite (upper third of the succession) is 19.5 m thick.

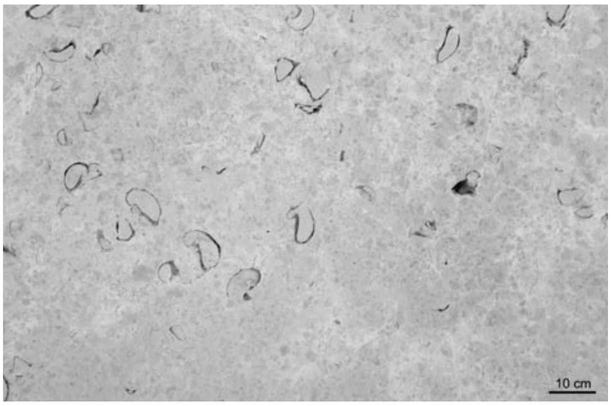

Fig. 5 Polished slab of massive Lower Aptian *Bacinella* oncolite from Kanfanar quarry containing requieniid shells. These limestones are the well-known architectural-building stone named "Istrian Yellow".

S. minuta (HOFKER), *Vercorsella scarsellai* (DE CASTRO), *V. laurentii* (SARTONI & CRESCENTI), *Novalesia distorta* ARNAUD-VANNEAU, *Praechrysalidina infracretacea* LUPERTO-SINNI, *Debarina hahounerensis* FOURCADE et al., *Mayncina bulgarica* LAUG et al., *Voloshinoides murgensis* LUPERTO-SINNI & MASSE, *Archaealveolina* sp. and very rare, but biostratigraphically very important, *Praeorbitolina cormyi* SCHROEDER.

Above the *Bacinella*-oncoid floatstones an approximately 2.7 m thick interval of bioclastic–skeletal grainstones occurs (interval *d* in Fig. 3) containing *Palorbitolina lenticularis* and other orbitolinids (mostly broken), primitive alveolinids, *Pseudonummoloculina aurigerica* CALVEZ and rare *Pseudolituonella conica* LUPERTO-SINNI & MASSE.

The interval previously described as *Bacinella*-oncoid beds is biostratigraphically assigned to the *Palorbitolina lenticularis taxon-range zone* (VELIĆ et al., 1995). The aforementioned deposits are followed by a 1.5 m thick interval of bioclastic grainstones containing rudist bioclasts (bed *e* in Fig. 3) that represent a transitional interval between Lower and Upper Aptian deposits in Istria. It is continuously overlain by a thin Upper Aptian sequence consisting of a 0.5 to 1.5 m thick bivalve coquina containing *Salpingoporella dinarica* and *Praechrysalidina infracretacea* (bed *f* in Fig. 3), and by 0.7 to 2.5 m thick biomicrite with abundant *S. dinarica*, frequent *P. infracretacea* and miliolids (interval *g* in Fig. 3). These Upper Aptian deposits were assigned by VELIĆ et al. (1995) to the *Salpingoporella dinarica abundance zone.*

The overlying emersion breccia and conglomerates, 1.0 to 2.5 m thick, were deposited during the emersion phase from the early Late Aptian to the early Late Albian. They are followed by wackestones to packstone/grainstones containing the following Late Albian orbitolinid and other foraminiferal association: "*Valdanchella*" *dercourti* DECROUEZ & MOULLADE, *Neoiraquia insolita* (DECROUEZ & MOULLADE), *Paracoskinolina fleuryi* DECROUEZ & MOULLADE, *Pseudonummoloculina aurigerica* CALVEZ, *P. heimi* (BONET), *Cuneolina pavonia* (D'ORBIGNY), *C. parva* HENSON, *Sabaudia auruncensis* (CHIOCCHINI & DI NAPOLI), *S. minuta* (HOFKER), *Vercorsella scarsellai* (DE CASTRO), *V. laurentii* (SARTONI & CRESCENTI), *Mayncina bulgarica* LAUG, etc.

Finally, it could be concluded that frequent rudist occurrences are limited to the Lower Aptian *Bacinella*-oncoid floatstones – within interval *c* in Fig. 3, and the bioclastic grainstones representing the transition from the Lower to the Upper Aptian – bed *e* in Fig. 3. Rudists occur sporadically within the *Bacinella*-oncoid intervals *b* and *b'* in Fig. 3.

2.2. Tounj and Ogulin area – central Croatia

Lower Aptian platform carbonates in the vicinity of Ogulin (Fig. 6) are characterized by *Palorbitolina*-limestones ("Lower orbitolinid limestones" sensu VELIĆ & SOKAČ, 1978) comprising intercalations of kilometre-long bioclastic–skeletal bodies containing rudists.

In contrast to sections in Istria, it is impossible to measure and to describe in detail the Lower Aptian deposits in the area of Ogulin–Tounj due to tectonic disturbance and widespread Neogene and Quaternary cover (Figs. 6 and 8). Therefore, the overall facies characteristics of the deposits will be described in a general manner.

According to facies characteristics, the Lower Aptian carbonate platform succession of the Tounj area can be subdivided into two parts (Fig. 7). The lower part is represented by orbitolinid-rich (*Palorbitolina* and *Praeorbitolina*) wackestones characterized by the presence of calcisphaeres and scattered pelagic microfossils – *Hedbergella* sp., *Saccocoma* sp. and some lageniids, suggesting an influence from the open sea (VELIĆ & SOKAČ, 1978).

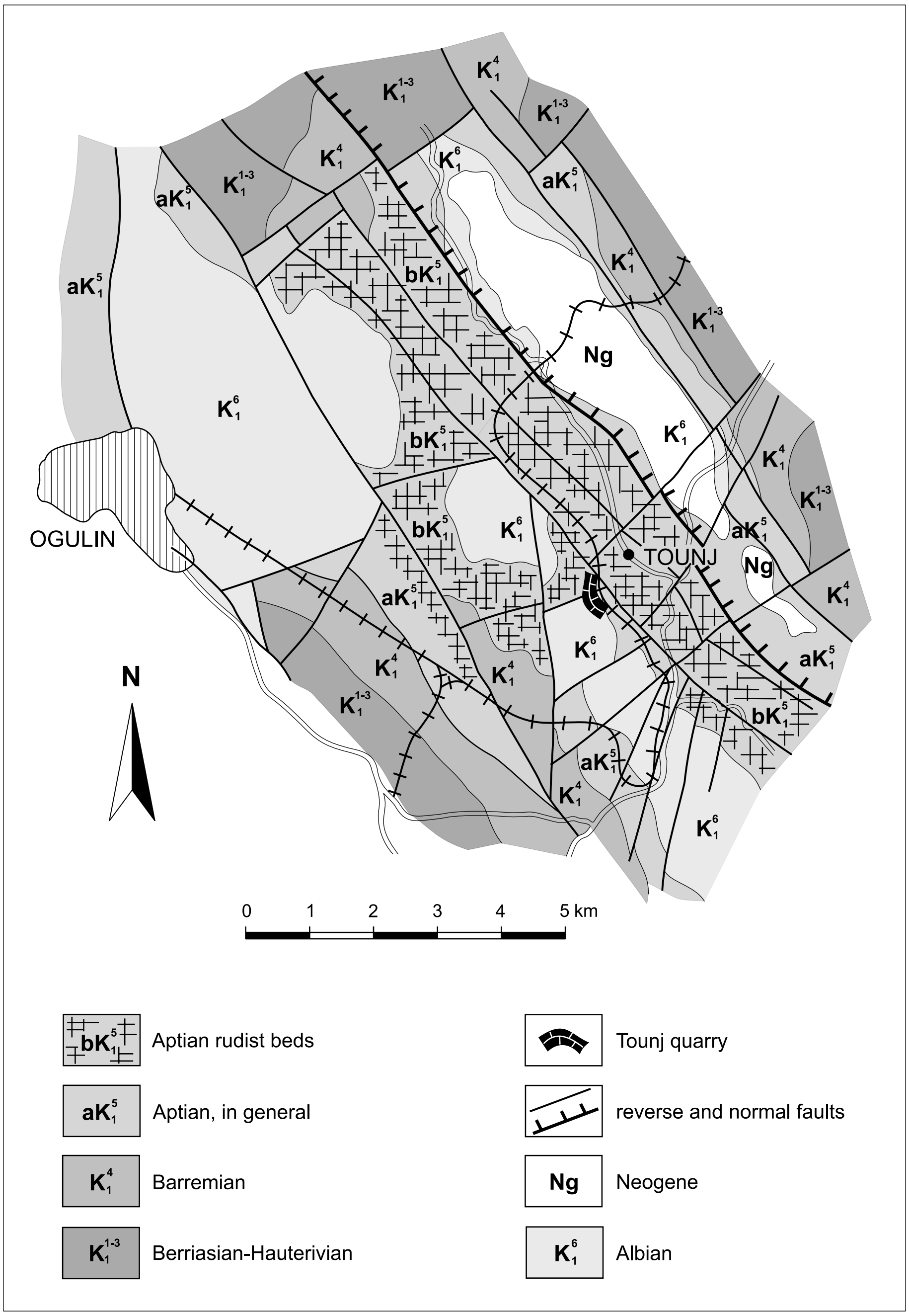

Fig. 6 Geological sketch map of the Ogulin–Tounj area (after VELIĆ & SOKAČ, 1981).

In the upper part of the Lower Aptian deposits, upwardly and laterally to the aforementioned orbitolinid limestones, there are massive, coarse-grained bioclastic–skeletal floatstones to rudstones and skeletal bodies that also contain benthic foraminifera, mainly orbitolinids. Rudists (see Section 3) are associated with corals and gastropods, and fragments of bryozoans, stromatoporoids and other encrusting organisms.

Terminal beds of the Lower Aptian, deposited in subtidal–lagoon environments, also belong to the orbitolinid limestones and open marine influences are recorded. Upper Aptian deposits are in normal, continuous succession and are characterized by an alternation of algal (*Salpingoporella dinarica*) wackestones and orbitolinid-rich (*Mesorbitolina parva–texana* group) packstones/grainstones. They were deposited in shallow, low current-energy subtidal to higher current-energy peritidal environments during shallowing upward cycles.

The overall thickness of the Lower Aptian deposits in the Tounj area can be estimated as more than 300 m (Fig. 7), three times the average thickness in the surrounding terrain of central Croatia where it is less than 100 m. This is due to high bioclastic–skeletal production in coral/rudist environments coupled with the provision of a lot of accommodation space.

Biostratigraphically, Aptian deposits are characterized by development of *Palorbitolina*-limestones during the Early Aptian ("Lower orbitolinid limestones" sensu VELIĆ & SOKAČ, 1978, and VELIĆ, 1988), and

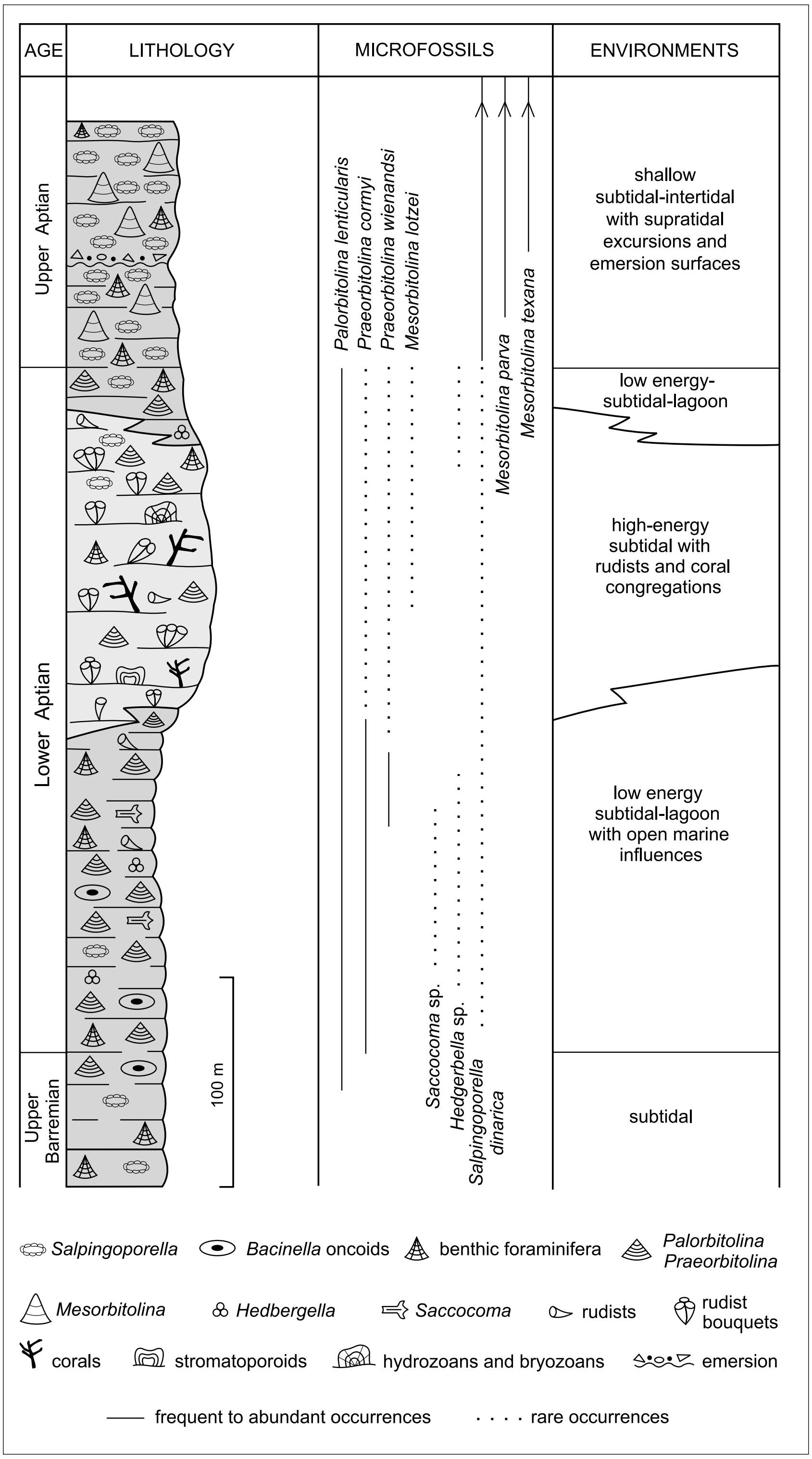

Fig. 7 Stratigraphic column of the Upper Baremian–Lower Aptian in the Ogulin–Tounj area.

both maximal development of the alga *Salpingoporella dinarica* RADOIČIĆ and the first appearance of large *Mesorbitolina* during the Late Aptian.

The complete succession of the "Lower orbitolinid limestones" corresponds to the stratigraphic range of *Palorbitolina lenticularis* (BLUMENBACH). They contain other Early Aptian index-fossils including *Praeorbitolina cormyi* SCHROEDER, *P. wienandsi* SCHROEDER, *Orbitolina* (*Mesorbitolina*) *lotzei* SCHROEDER, *Sabaudia briacensis* ARNAUD-VANNEAU, *Neotrocholina friburgensis* GUILLAUME & REICHEL, *N. aptiensis* JOVČEVA, *Derventina filipescui* NEAGU associated with foraminifera of wider stratigraphic range as well as with rare occurrences of *Salpingoporella dinarica* RADOIČIĆ. Biostratigraphically, these deposits could be assigned to the *Palorbitolina lenticularis taxon-range zone*.

Fig. 8 Tounj quarry. Fault contact (in the centre of the photograph) of well-bedded Albian limestones (K_1^6, on the left) and thick-bedded to massive Lower Aptian rudist limestones (bK_1^5, on the right). Elevation from the bottom to the top of the quarry is approx. 80 m, comprising an approximately equally thick part of the Lower Aptian succession.

The stratigraphic position of the rudist-containing bodies in the wider area of Tounj, i.e. in central Croatia, is within the upper part of the Bedoulian. It corresponds to the range of *P. wienandsi* and *O.* (*M.*) *lotzei*, in association with other aforementioned benthic foraminifera.

Limestones characterized by the mass appearance of the alga *Salpingoporella dinarica* (*S. dinarica abundance zone*) overlie the described Lower Aptian deposits in the area of Tounj, similar to the precisely described Aptian facies development in Istria (see Section 2.1.). Upwardly, the first appearance of the large *Mesorbitolina* indicates the presence of Gargasian deposits.

3. SYSTEMATIC PALAEONTOLOGY

The repository of rudist specimens described in the present paper is at the Centre de Sédimentologie–Paléontologie, Université de Provence, Marseille. Nevertheless, owing to the fact that most of the studied material was observed on natural outcrops of more or less compact and massive limestones, the corresponding specimens are expected to be still "*in situ*". The symbols used for descriptions are as follows: UV – upper valve; LV – lower valve; D – dorsal side; V – ventral side; A – anterior side; P – posterior side; pmp – posterior myophoral plate; pmc – posterior myophoral cavity; pm – posterior myophore; am – anterior myophore; at – anterior tooth; as – anterior socket; ct – central tooth; pt – posterior tooth; ps – posterior socket; bc – body cavity; cp – cardinal platform; L – ligament crest/dorso-ventral axis; com – commissure; ab – anterior band; pb – posterior band; ib – interband; cl – outer calcitic shell layer; hcp – horizontal concave partitions; tab – body cavity tabulae.

Order Hippuritoida NEWELL, 1965
Superfamily Hippuritoidea GRAY, 1848
Family Requieniidae DOUVILLE, 1915
Genus *Requienia* MATHERON, 1842
Requienia? *zlatarskii* PAQUIER, 1903

Pl. I, Figs. 1–7

At Kanfanar quarry, besides *Toucasia* as formerly mentioned by various authors (see in VLAHOVIĆ et al., 2002), requieniids are represented by numerous sections showing:

- a lower valve with a lamellar anterior side, a smooth posterior side, a pronounced, acute, ventral carina, and lacking a myophoral plate (PI. I, Figs. 1, 3, 4, 7),
- a moderately convex upper valve with a well-defined body cavity (PI. I, Figs. 1, 2, 4, 5),
- on both valves, a cardinal platform extending over nearly 1/3 of the dorso-ventral axis (PI. I, Figs. 4, 5).

The apparent absence of myophoral processes in both valves and the relatively wide development of the cardinal platform suggest muscle attachment onto this platform. Assuming that this interpretation is correct, this leads us to exclude the present material from *Requienia*, because the genus is characterized by a posterior myophoral plate in the upper valve (DOUVILLE, 1915). Similarly *Matheronia* seems inadequate because in the representatives of this genus (especially *Matheronia virginiae* GRAS, the type species) the cardinal

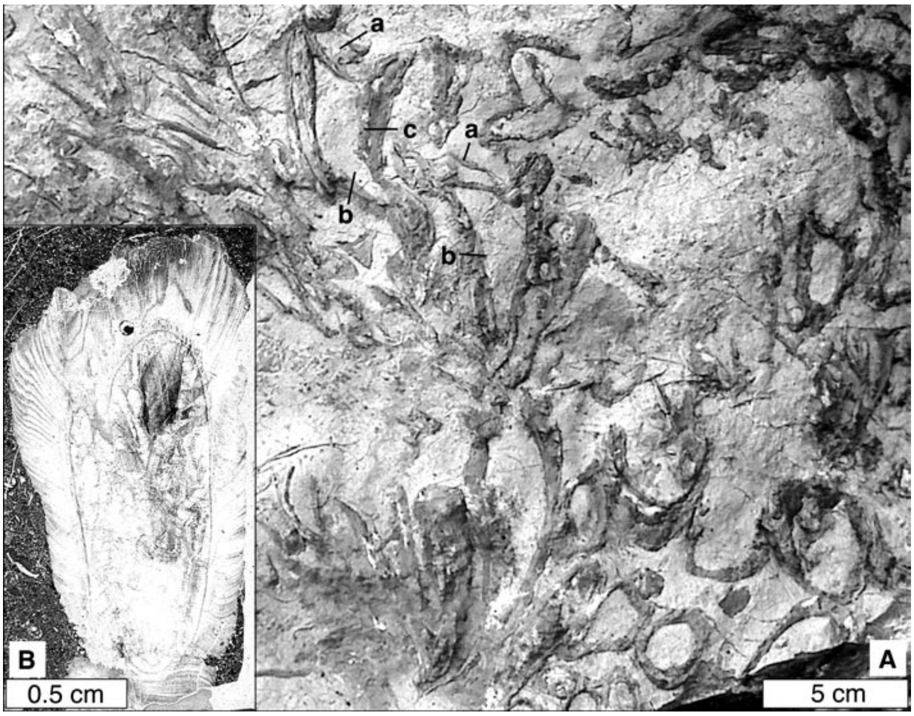

Fig. 9 *Agriopleura* sp., Tounj. (A) field photograph showing a bouquet-like aggregation of mainly upward oriented (life position) shells. The typical attributes of the genus are: a) concave upper valve, b) sub-triangular outline of the lower valve, c) elongated teeth. (B) Longitudinal oblique thin section showing a compact shell structure with growth banding.

platform is poorly developed and muscle attachment is on the walls of both valves (PAQUIER, 1903; DOUVILLE, 1915). *Lovetchenia* possesses a wide cardinal platform on both valves but muscles are attached on the widened and thickened commissural edges (MASSE, 1993).

Notwithstanding the foregoing difficulties to find a genus for housing our material we tentatively place it close to *Requienia zlatarskii* PAQUIER (PAQUIER, 1903). This form and *Requienia petersi* TOULA as well (TOULA, 1902) posses a lower valve with a lamellar anterior side, a smooth posterior side, an acute ventral carina, while the upper valve is slightly convex. Whereas *R. zlatarskii* displays a small myophoral plate on the posterior side of the upper valve the internal characters of *Requienia petersi* are nearly unknown. Because the later was poorly described *R. zlatarskii* appears more appropriate for our material.

Genus *Toucasia* MUNIER CHALMAS, 1873
Toucasia sp.

PI. II, Figs. 1–6

In the Kanfanar area this genus is represented by numerous randomly oriented sections of isolated lower valves or bivalve specimens, with several whorls (PI. II, Figs. 2, 3). The lower valve shows a rounded posterior side and a nearly flat anterior side. The dorso–ventral axis (DV) ranges from 5 to 8 cm, while the antero–posterior one (AP) fluctuates from 4 to 6 cm. The corresponding ratio (AP/DV) is therefore 0.8 to 0.75, a value close to those of *Toucasia carinata* MATHERON (MASSE et al., 1998a). On juvenile specimens and/or sections of the juvenile part of the shell the junction between the posterior and the anterior site is characterized by an acute ventral carina (PI. II, Fig. 4) which tends to disappear in adults (PI. II, Figs. 2, 3, 5, 6). The posterior myophoral plate of the lower valve, a diagnostic attribute of the genus, corresponds externally to a dark line and/or a small groove. The transverse section of the myophoral plate has a low triangular shape on both valves (PI. II, Figs. 2, 3, 5, 6). At Tounj *Toucasia* is also present. In both localities the absence of complete, isolated specimens, precludes a precise identification of the species.

Family Monopleuridae MUNIER CHALMAS, 1873
Genus *Agriopleura* KÜHN, 1932

Fig. 9 (A–B)

At Tounj, longitudinal sections ascribed to this genus are characterised by a triangular shaped lower valve indicating a conical morphology and a depressed, concave upward, upper valve (Fig. 9). The lower valve has a smooth outer surface. Sections with elongated slender teeth and myophoral bulges connected to the inner side of the upper valve are also present. Thin sections, cut in the rock bearing *Agriopleura* specimens, show the acellular outer shell (calcitic) layer with an oblique, sometimes wavy growth banding (Fig. 9B). The absence of well preserved transverse sections preclude observation of the radial bands and the overall configuration of the myocardinal apparatus, especially the ligamental crest and surrounding cavities, all characters with strong taxonomic implications at the species level.

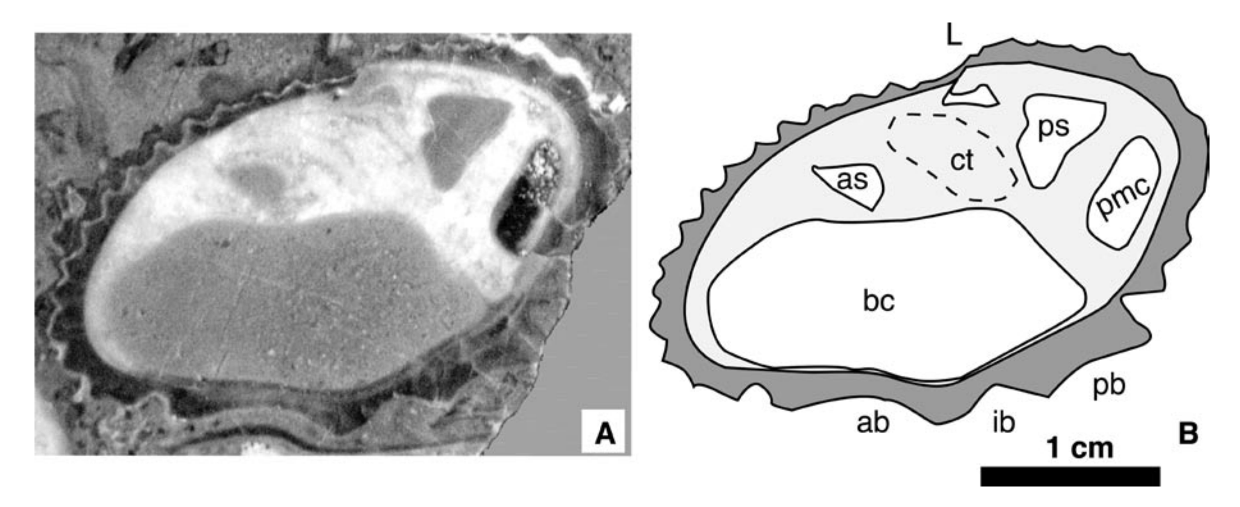

Fig. 10 *Glossomyophorus costatus,* Tounj. (A) Transverse section of a lower valve showing the main attributes of the species: ornamentation, radial bands and internal myocardinal characters. (B) Interpretation of A.

Family Caprotinidae (GRAY, 1848) SKELTON, 1978
Genus *Glossomyophorus* MASSE, SKELTON & SLIŠKOVIĆ, 1984
Glossomyophorus costatus MASSE, SKELTON & SLIŠKOVIĆ, 1984

Fig. 10 (A–B)

Our material was collected at Tounj and is mainly represented by transverse sections of the lower valve with an elliptical outline (linked to a dorso–ventral compression) and a well defined (dark coloured), strongly ribbed, outer shell layer. The ventral zone shows a relatively wide slightly elevated anterior band and a narrow, ribbed and salient, posterior band. The interband corresponds to a narrow acute groove. Notice that in sections close to the apex the shell outline is nearly circular with some antero–posterior compression and the outer shell ornamentation less vigorous especially on the dorsal side. Internal characters consist of a row of three holes: two sockets and a myophoral cavity for the teeth and the myophoral plate of the opposite valve, respectively. All these attributes conform to the definition of *Glossomyophorus costatus* MASSE, SKELTON & SLIŠKOVIĆ (1984).

Family indet.
Genus *Himeraelites* DI STEFANO, 1889
Himeraelites sp.

PI. III, Figs. 1–4

We ascribe to this genus a set of transverse sections of the lower valve found at Tounj. The outline is rounded with a slightly antero–dorsal–postero–ventral compression. The dorso–ventral axis (DV) is 3.2 to 4 cm in long, while the antero–posterior one (AP) is 2.5 to 3 cm. The corresponding ratio (AP/DV) is therefore 0.75 to 0.85. Nevertheless, it is about 1 close to the apex. The outer shell layer is very thin (about 1 mm) with fine costulation which is frequently missing (due to micritization) while the inner (originally aragonitic) shell layer is thick (1.6–1.8 cm) on the dorsal side and thinner on the ventral side (0.3–0.4 cm).

Owing to the sparitisation of the dorsal side, the cardinal elements are poorly defined, nevertheless the acute central tooth and the adjacent anterior socket are frequently detectable through the paramorphic preservation of antecedent aragonitic structures (PI. III, Figs. 2–4). The thin ligamental cavity is bent towards the anterior side and deeply penetrates into the dorsal side until the central tooth.

There is an anterior inner thickening corresponding to the anterior myophore, the posterior one is assumed to be located on the thickened posterior side.

Family Caprinidae D'ORBIGNY, 1847
Genus *Offneria* PAQUIER, 1905

Fig. 11 (A–B)

From central Croatia, POLŠAK (1970) described *Offneria rhodanica* PAQUIER represented by a portion of the upper valve showing the diagnostic attributes of the genus *Offneria.* Whether the figured specimen (POLŠAK, 1970, fig. 2, p. 147) belongs to *O. rhodanica* or *O. murgensis* MASSE (MASSE, 1992) is not clear. In contrast, figures of rudist specimens from southwestern Slovenia (Trnovski Gozd), provided by PLENIČAR & BUSER (1967), identified as *Caprina* cf. *douvillei* PAQUIER and *Offneria rhodanica* PAQUIER, clearly belong to *Offneria murgensis* MASSE. This assignment is based on the complex canal network observed on specimens from plate II, figs. 1 and 2 of PLENIČAR & BUSER (1967), whereas fig. 2 illustrates a lower valve with a well developed canal system (a feature unknown in *Caprina douvillei*), while the canal organisation of *Offneria rhodanica* is more simple, especially at the

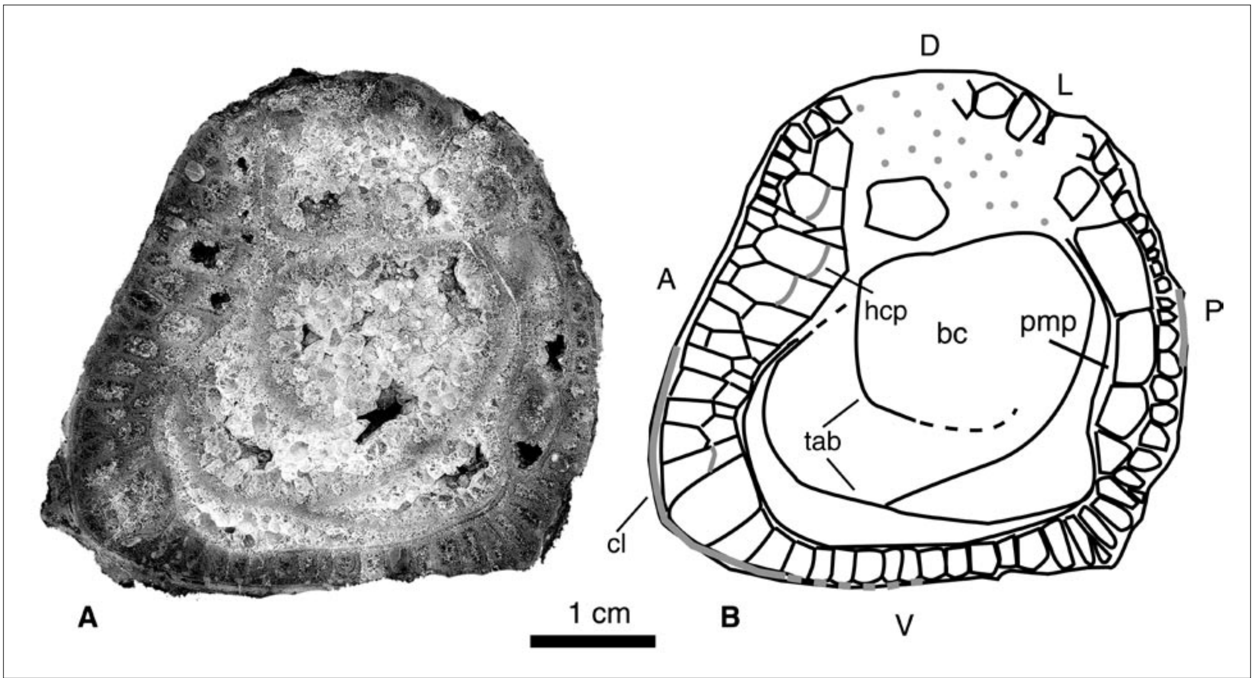

Fig. 11 *Offneria murgensis*, Kladanj, Bosnia. (A) Transverse section of the lower valve showing the canal architecture and myocardinal elements. (B) Interpretation of A.

articulation between the ventral and posterior sides of the shell. On plate V, fig. 2 in PLENIČAR & BUSER (1967) a similar configuration is shown.

Offneria rhodanica collected in the Kladanj area (Bosnia) and mentioned by MASSE et al. (1984) has not been described nor illustrated hitherto. A reappraisal of this material (lower valve housed in Masse collection) shows the following characters (Fig. 11):

- the ventral side bears a continuous row of canals and is slightly depressed; canal walls are bifurcated at the posterior/ventral junction,
- on the posterior side the inner row of wide canals flanking the myophoral plate is surrounded externally by a row of numerous small canals,
- on the anterior side there are several rows of polygonal or rounded canals, the size of which decreases outward,
- the body cavity possesses tabulae,
- horizontal concave partitions are present locally in canals having a relatively large size,
- vertical walls dividing canals are common,
- the thin calcitic outer shell layer is preserved near the articulation between the anterior and ventral sides.

This set of characters typifies *Offneria murgensis* MASSE (MASSE, 1992; CHARTROUSSE, 1998).

4. DISCUSSION

4.1. Biostratigraphy

Toucasia is documented from the Upper Hauterivian (MASSE et al., 1998d) to the Albian (DOUVILLE, 1915; MASSE, 1996). *Agriopleura* is also known to appear in the Upper Hauterivian (MASSE, 1996; MASSE et al., 1998b) and became extinct in the mid-Aptian. *Himeraelites* was originally described from the Albian–Cenomanian (DI STEFANO, 1889) and possesses a significant record in the Albian from Italy (MASSE et al., 1998c). It was also documented from the Upper Aptian of Algeria (CHIKHI AOUIMEUR, 1983), from the mid-Aptian of Saudi Arabia (HUGHES, 1998), and the Lower Aptian of southern Italy (MASSE, 1992). There is no clear taxonomic framework for pre-Albian species, the detailed biostratigraphic distribution of which is therefore unknown.

Requienia zlatarskii was found by PAQUIER (1903) in Bulgaria, in beds ascribed to the Barremian. Closely related forms were also mentioned by PAQUIER (1908) from Serbia in orbitolinid limestones considered Barremian to Lower Aptian in age. *R.* cf. *zlatarskii* was identified by one of the present authors (JPM) in the Lower Aptian of Bosnia and in southern Dobrodja (Romania), too. A closely related form was figured from the Zonguldak area (Western Pontids – Turkey, MASSE et al., in press) and from Algeria (FLIERT, 1952), but in the latter case figures are lacking.

Glossomyophorus costatus and *Offneria* are typical Lower Aptian species (MASSE et al., 1984; MASSE,

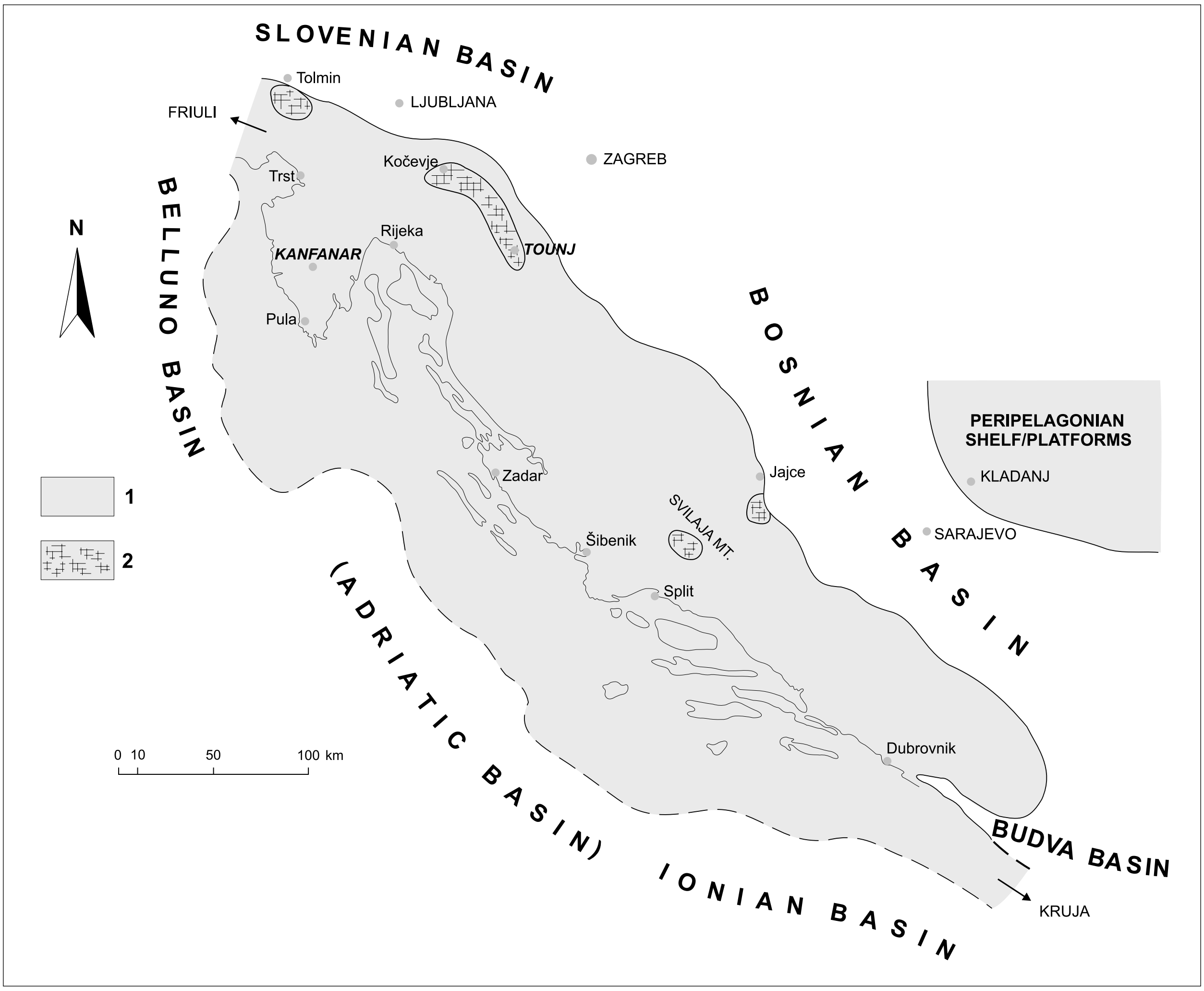

Fig. 12 Recent extent of Adriatic Carbonate Platform deposits (1) and surrounding domains, showing the position of Lower Aptian rudist-rich skeletal limestones (2).

1992; BARON-SZABO & STEUBER, 1996; MASSE et al., 1998b; SKELTON & MASSE, 2000).

In conclusion, notwithstanding taxonomic uncertainties concerning the species of *Toucasia*, *Agriopleura*, and *Himeraelites*, the presence of *Requienia*? *zlatarskii*, *Glossomyophorus costatus* and *Offneria murgensis* suggests an early Aptian age for the Croatian faunas. This is also in accord with the micropalaeontological data.

4.2. Palaeoecology and palaeogeographic setting

Early Aptian times represented a significant change in platform settings, relative to antecedent Valanginian–Barremian conditions. While pre-Aptian platforms in the region were dominated by intertidal or restricted subtidal conditions without rudists, the Aptian was marked by the onset of more open conditions with the dominance of subtidal settings where rudists have a significant record. This trend is also documented on neighbouring Periadriatic platforms where the Early Aptian appears to have been a golden age for rudist development (SARTORIO, 1986, 1987; MASSE, 1992).

Oligospecific associations of *Toucasia* and *Requienia*? *zlatarskii* found at Kanfanar in a muddy substrate document the proximal zone of the inner platform rudist bearing domain, excluding severely restricted subtidal and intertidal settings. More diverse rudist faunas including *Glossomyophorus*, and *Himeraelites*, as well as corals, stromatoporoids, hydrozoans, bryozoans, etc., with a tendency for shell aggregation, found at Tounj, tend to indicate the distal zone of the inner platform rudist-bearing domain, i.e. more open setting than those at Kanfanar. Rudists and other organisms flourished within a high energy belt where skeletal remains accumulated or were transported locally, either basinward into a relatively deeper subtidal or backward – into a restricted lagoon, behind prograding bioclastic–skeletal bodies. Similar settings may be expected for the *Offneria*-bearing sediments from central Croatia, by comparison with palaeoecological models from the Middle East (MASSE et al., 1998b; BORGOMANO et al., 2002).

The recent extent of the Adriatic carbonate platform (AdCP) deposits and position of the discussed Aptian

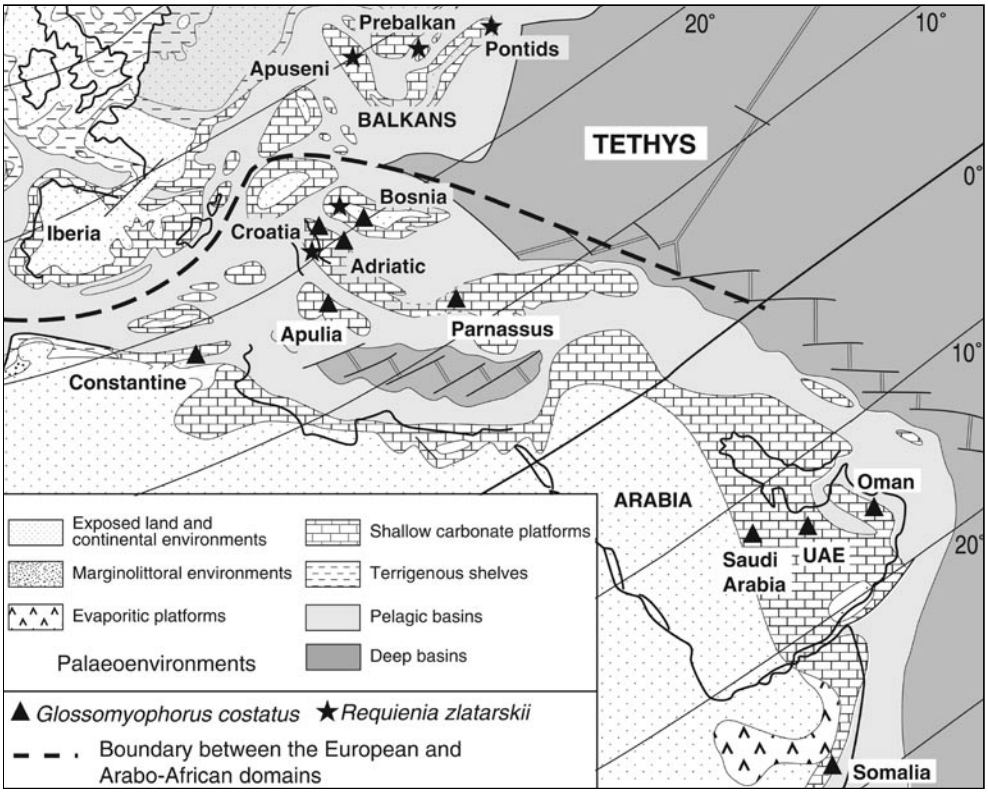

Fig. 13 Palaeogeographic reconstruction of the Mediterranean and Middle East Tethyan domain during the Early Aptian (modified, after MASSE et al., 1993) showing the distribution of *Glossomyophorus costatus* in the Arabo–African margin, and *Requienia zlatarskii* restricted to the Balkans and Black Sea region of Turkey.

deposits (Fig. 12; DRAGIČEVIĆ & VELIĆ, 2002), provide a clue for understanding the palaeoenvironmental settings. Kanfanar was located in the inner part of the platform, possibly 50 km from the platform edge, facing the Belluno basin. In contrast, Tounj was situated close to the platform edge facing the Slovenian–Bosnian basin. These locations may also explain the vertical development of rudist-rich limestones in the two areas. The Kanfanar area may be regarded as a relatively stable, i.e. low or moderately subsiding, platform interior. However, the platform edge facing the Slovenian–Bosnian basin is known as a dynamic, unstable and tectonized margin (e.g. CHARVET, 1970; COUSIN, 1973; BLANCHET, 1975; JELASKA, 1987; BUSER, 1989; PAMIĆ et al., 1998; DRAGIČEVIĆ & VELIĆ, 2002, etc.), expected to promote strongly subsiding blocks and possibly an outer platform escarpment.

4.3. Palaeobiogeography

In Aptian times *Toucasia* had a wide extent in the Mediterranean and outside the Mediterranean regions (MASSE, 1985).

Agriopleura had also a wide extent in the Mediterranean region and occurred on African and European Tethyan margins (MASSE, 1985). In France and Switzerland, *Agriopleura* species are recorded in the Upper Hauterivian–Barremian and are missing in the Lower Aptian. In contrast in the Arabo–African domain, *Agriopleura* is mainly documented from the Lower Aptian (MASSE, 1992; HUGHES, 1998; SKELTON & MASSE, 2000). This contrasting palaeobiogeographical distribution through time suggests an African affinity for the Croatian *Agriopleura*.

Requienia zlatarskii (see biostratigraphy) seems to be a Balkan element present on both European and African margins, but with a restricted palaeobiogeographical distribution, running from the Pontides to Serbia and Bosnia through Moesia. Croatia is the southernmost location of this species (Fig. 13).

Glossomyophorus costatus was firstly recognized from Saudi Arabia, Southern Italy and Bosnia (MASSE et al., 1984). It has currently been widely observed in other regions of the eastern Mediterranean and Middle East (Oman, United Arab Emirates, Somalia, Northern Italy, Greece and North Africa – SKELTON & MASSE, 2000; Fig. 13). This species is therefore a south Tethyan (Arabo–African) palaeobiogeographical marker.

Offneria murgensis, the presence of which is highly suspected in Central Croatia but well established in Slovenia and Bosnia, is also an Arabo–African form (MASSE, 1992; HUGHES, 1998; MASSE et al., 1998b).

5. CONCLUSION

Lower Aptian rudist faunas investigated at Kanfanar (Istria) and Tounj (central Croatia) consist of Requieniidae: *Requienia*? *zlatarskii*, *Toucasia* sp. (close to *T. carinata*), Monopleuridae: *Himeraelites* sp. and *Agrio-*

pleura sp., Caprotinidae: *Glossomyophorus costatus*, and Caprinidae: *Offneria* sp., probably *O. murgensis*. Besides the typical Early Aptian species (*Offneria murgensis* and *Glossomyophorus costatus*), poorly defined species of *Himeraelites* and *Agriopleura*, also have Lower Aptian affinities. The associated benthic foraminifera, mainly the *Palorbitolina–Praeorbitolina* doublet, corroborates the foregoing age assignment.

The Croatian rudist assemblage closely resembles the Italian one although some elements (*Glossomyophorus*, *Offneria*) have been reported from neighbouring areas of Slovenia and Bosnia. Notwithstanding its South Tethyan (Arabo–African) palaeobiogeographic significance this assemblage also shows Balkan forms (*Requienia*? *zlatarskii*).

Faunas from Kanfanar are dominated by low diversity (*Requienia*? *zlatarskii*, *Toucasia*) and low density assemblages associated with *Bacinella* dominated biotopes, in relatively restricted settings of the Adriatic Carbonate Platform interior. In contrast, faunas from Tounj are more diverse (*Toucasia*, *Glossomyophorus*, *Himeraelites* and *Agriopleura*) and consist of densely packed assemblages associated with corals and other encrusting organisms. The corresponding thick congregations mark the proximity to an outer margin of the Adriatic Carbonate Platform, facing the Slovenian–Bosnian basin, and open marine conditions.

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PLATE I

Requienia? *zlatarskii*, sections from Kanfanar quarry.

1–2 Anterior–posterior cross sections of bivalve specimens showing the lamellar anterior side, convex upper valve, the body cavity of which is separated from the lower part by a well defined cardinal platform.

3 *Ibidem*. Upper valve absent.

4–5 Dorso–ventral cross sections of bivalve specimens showing the body cavity of the upper valve and the cardinal platform.

6–7 Field photographs showing the strong anterior–posterior asymmetry and the ventral carina.

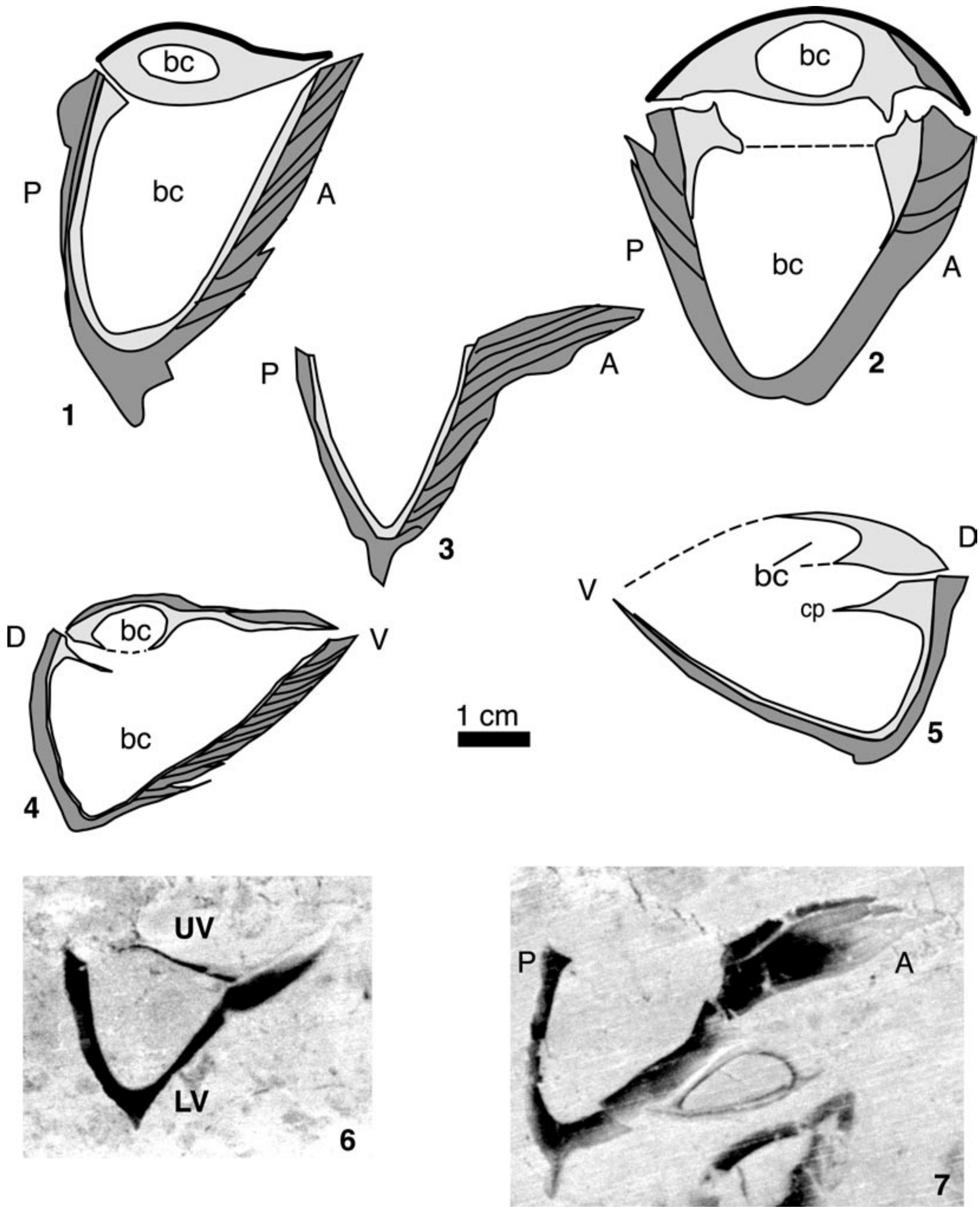
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PLATE II

Toucasia sp., sections from Kanfanar quarry.

1 Dorso–ventral cross section of a bivalve specimen showing the myocardinal characters.

2 Transverse-oblique section showing the spirogyrate organisation of the lower valve and the posterior myophoral plate.

3 Section close to Fig. 2, myophoral elements not preserved.

4 Tranverse oblique section of the lower valve showing the posterior myophoral plate.

5 Transverse section of a lower valve showing the posterior myophoral plate.

6 Transverse section of a lower valve showing the myocardinal elements.

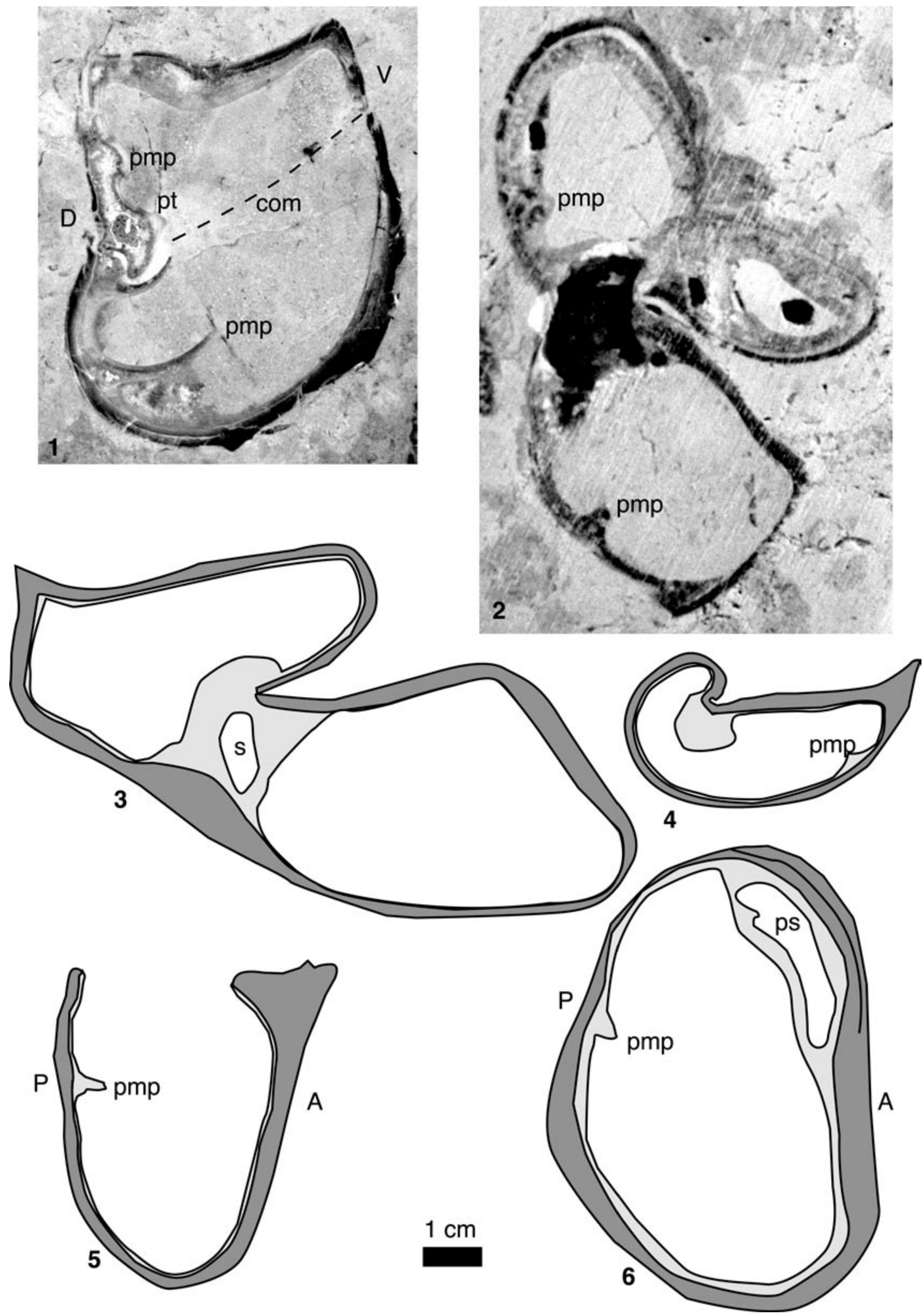
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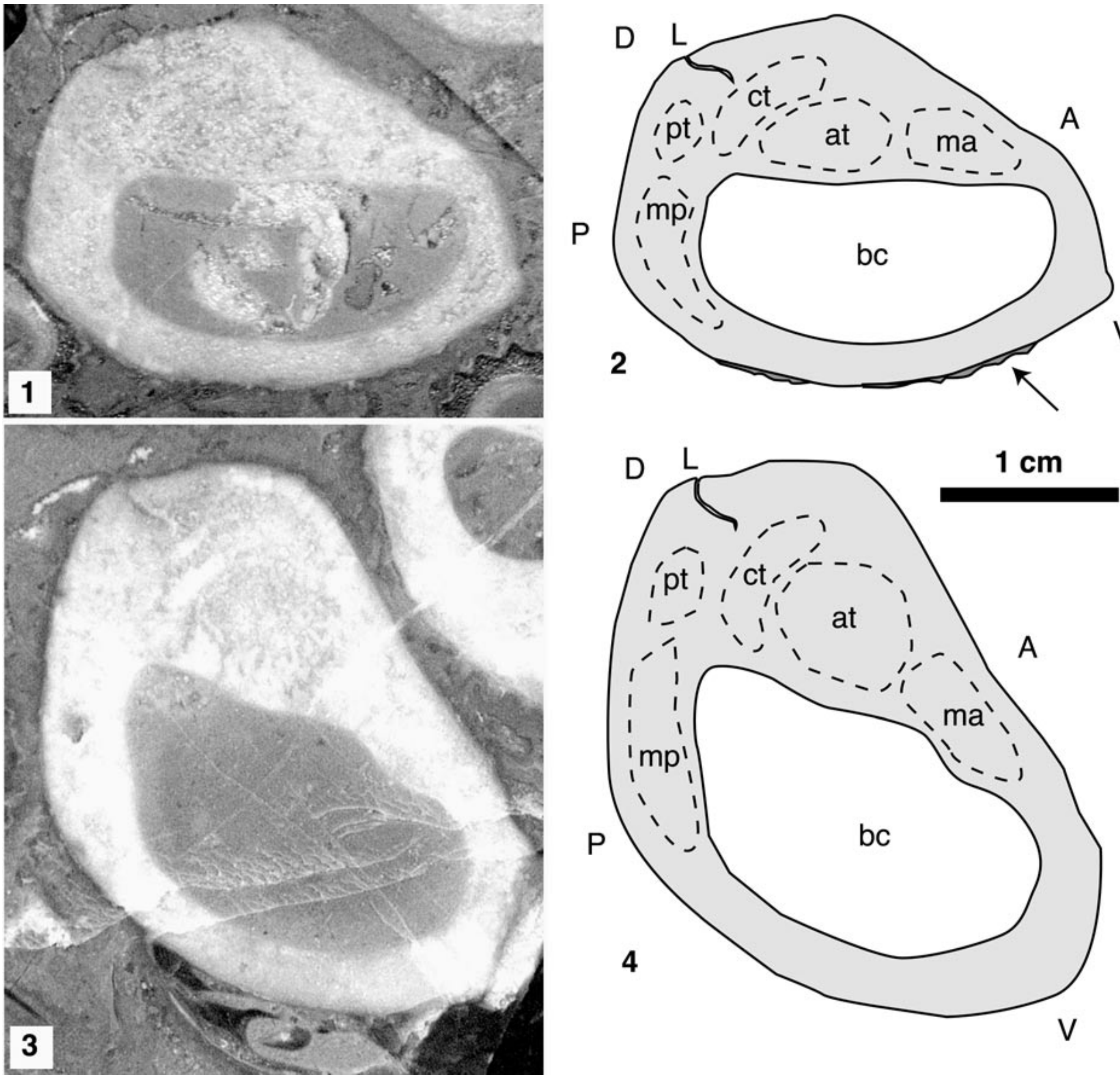
PLATE III

Himeraelites sp., Tounj.

1–2 Transverse section of the lower valve and interpretation of the myocardinal features.

3–4 *Ibidem*. Notice the development of the inner formerly aragonitic shell, the calcitic, finely ribbed outer shell is partly preserved on specimen 1–2 (arrow).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