The coralline flora of a Miocene *maërl:* the Croatian “Litavac”

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ABSTRACT

The fossil coralline flora of the Badenian bioclastic limestone outcropping in Northern Croatia is known by the name “Litavac”, shortened from “Lithothamnium Limestone”. The name was given to indicate that unidentified coralline algae are the major component. In this first contribution to the knowledge of the coralline flora of the Litavac, Lithothamnion valens *seems to be the most common species, with an unattached, branched growth-form. Small rhodoliths composed of* Phymatolithon calcareum *and* Mesophyllum roveretoi *also occur. The Badenian benthic association is dominated by melobesioid corallines, thus it can be compared with the modern maërl facies of the Atlantic Ocean and Mediterranean Sea. Since* L. valens *still survives in the present-day Mediterranean, an analogy between the Badenian Litavac and the living* L. valens *facies of the Mediterranean is suggested.*

Keywords: calcareous Rhodophyta, Corallinales, rhodoliths, maërl, Badenian, Croatia

1. INTRODUCTION

Since Roman times, a building stone named “Litavac” has been quarried at many Croatian localities, particularly on the SW slopes of the Medvednica Mts. (Fig. 1). The name derives from the shortening of the Croatian words ***lit**otamnijski **vap**nenac* meaning “Lithothamnium Limestone”.

The Litavac corresponds to a facies of biolithites and bioclastic limestones (e.g. biocalcirudites, biocalcarenites and biocalclutites) belonging to the Upper Badenian succession (Lower Serravallian of the standard chronostratigraphy; details in PILLER et al., 2007) which are characterized by fully marine environments in Northern Croatia (KOCHANSKI, 1944; ŠIKIĆ, 1967, 1968; AVANIĆ et al., 1993; VRSALJKO et al., 2005, 2006). The Upper Badenian deposits unconformably overlie older rocks, and in the area of Mt. Medvednica over Upper Triassic dolomites. The Litavac facies is interposed between a facies of coarse-grained clastics (with clasts from underlying dolomites and limestones), at the base and an overlying facies of fine-graded clastics: fine-graded sands, marls, clayey limestones and calcsiltites (VRSALJKO et al., 2006, 2007a). Litavac is almost structureless, but cross-bedding or even flat-bedding can occasionally be observed.

A description of the stratigraphy and palaeogeography of Miocene deposits from the investigated area (SW Medvednica) and neighbouring Samoborsko gorje – Žumberak Mts. is provided by VRSALJKO et al. (2005). The sedimentology and palaeoenvironmental evolution of Upper Badenian and Sarmatian deposits of Mt. Medvednica is discussed by VRSALJKO et al. (2006).

The Litavac is composed predominantly of corallines with fragments of bivalves including *Lucinoma boreale* (L.), *Nucula* sp., Pectinidae, *Ostrea* sp., Arcidae, Glycymerididae, Cardiidae, *Glossus humanus* (L.), *Corbula gibba* (OLIVI), gastropods (*Conus* sp. *Ficus* sp.), echinoderms (*Clypeaster* sp.), marine benthic foraminifers (Textulariidae, *Planostegina* sp., *Amphistegina* sp., *Brizalina dilatata* (REUSS), *Heterolepa dutemplei* (D’ORBIGNY) with common *Lobatula lobatula*

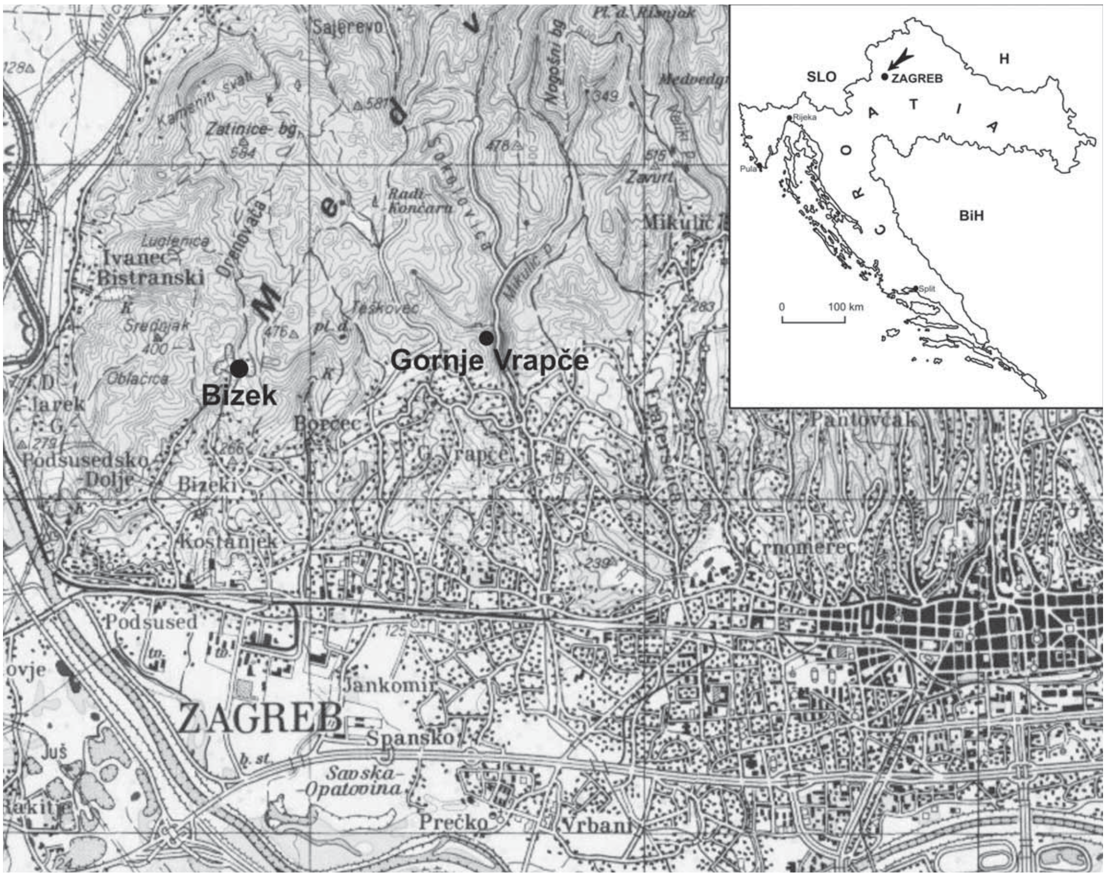


Figure 1: Map of the investigated Litavac quarries in the Zagreb area, Croatia.

(WALKER & JACOB), *Elphidium fichtelianum* (D'ORBIGNY) and rare planktonic forams), ostracods (*i.e. Cytheretta tenuipunctata dentata* BRESTENSKA), bryozoans, hydrozoans and corals (*Flabellum* sp.), denoting a shelf palaeoenvironment within the infralittoral to shallow circalittoral zones (VRSALJKO et al., 2007a, c,d). The skeletal fragments are cemented with calcite.

The name "Lithothamnium limestones" refers to the dominance of coralline nodules and remains but has simply a lithogenetic sense, since several genera of non-geniculate coralline algae other than *Lithothamnion* can be identified. The same is true for the Tortonian "*Calcari a Briozoi e Litotamni*" of the central-southern Apennines in Italy, (= Bryozoan and Lithothamnium limestones; SIMONE & CARANNANTE, 1985; BRANDANO, 2002), for the Badenian Leitha Limestone of the Vienna basin (=*Nullipora, Lithothamnium* or *Lithothamnion* limestone; RIEGL & PILLER & 2000), for the Badenian Leithakalk units of Hungary (RANDAZZO et al., 1999) and for the Early Badenian Pinczow Limestones in Poland (STUDENCKI, 1988).

Despite the historical use of Litavac as a building stone (more than 2250 m^3 were used to build the present Zagreb Cathedral; VRSALJKO & al., 2007a,b), and its importance as a reservoir rock for water and oil and gas (LUČIĆ et al., 2001), the taxonomy of the coralline algae composing the limestone has never been investigated in detail. The aim of this paper is to provide a first account of the fossil coralline flora of the northern Croatian Litavac, and its possible palaeoenvironmental interpretation.

2. MATERIAL AND METHODS

Sampling has been performed at the quarries of Gornje Vrapče and Bizek (NW of Zagreb, Medvednica Mt.; Fig. 1), in the bioclastic limestones facies of Upper Badenian age. Figured specimens are from the Bizek quarry where the Litavac crops out and is about 30 m thick (see VRSALJKO et al., 2007d). Observations of coralline anatomy and biometry have been made on thin sections. Thallus nomenclature follows BASSO et al., (1997). In particular, the terms cortex and medulla, in the description of protuberances, are used with a merely topographic sense, to distinguish the central cell filaments running parallel to the main axis of the protuberance (= the medulla) from the derivatives diverging and bending toward the surface of a protuberance (= the cortex). The terms *unattached branches* and *prâline* are used according to BASSO (1998). Growth-form nomenclature follows WOELKERLING et al., (1993). Percentage quantification of total coralline algal thalli is based on visual estimate.

3. RESULTS

The Litavac from the studied localities is a calcareous rudstone, mainly composed of fragments of fruticose corallines (VRSALJKO et al., 2007d, fig. 2). The Litavac corallines are free-living, unattached branches or small rhodoliths with various degrees of protuberance development. The Litavac underwent dolomitization and dissolution, preventing identification of a large part of the algal remains. However, despite fossil diagenesis, numerous algal fragments still have their microscopical anatomy preserved, therefore allowing identification.

3.1. The coralline flora

Division Rhodophyta WETTSTEIN, 1901
Order Corallinales SILVA & JOHANSEN, 1968
Family Hapalidiaceae GRAY, 1864 emend. HARVEY, BROADWATER, WOELKERLING & MITROVSKI, 2003
Subfamily Melobesioideae BIZZOZERO, 1885
Genus *Phymatolithon* FOSLIE, 1898
***Phymatolithon calcareum* (PALLAS) ADEY & MCKIBBIN, 1970**
(Pl. 1, Fig. 1)

Neotype: BM Box Collection No. 1626 (WOELKERLING & IRVINE, 1986).
Basionym: *Millepora calcarea* PALLAS 1766, p.265.
1943 *Pomatophyllum operculatum* CONTI, p. 52–54, fig. 3, pl. VI/4, pl. VIII/5
1950 *Lithothamnion operculatum* CONTI, p. 117
1997 *Phymatolithon calcareum* – BASSO et al., p. 168–170, pl. 36

The lumpy growth-form of this species has been identified in a single rhodolith, about 6 mm in diameter, among dominant branches of *L. valens*. The thallus shows a thin hypothallium, with cells L 6–11 x D 6–7 μm, a perithallium with cells L 8–11 x D 7–8 μm and rounded multiporate conceptacles with diam. 125–150 x 75–90 μm in height. Although the epithallial cells are not preserved, the specimen is attributed to *Phymatolithon calcareum* on the basis of the correspondence of all the other known anatomical features (BASSO et al., 1997).

P. calcareum is distributed from the Oligocene to Recent (BASSO et al., 1997).

Genus *Mesophyllum* LEMOINE, 1928
***Mesophyllum roveretoi* CONTI, 1943**
(Pl. 1, Figs. 2–3)

Protologue: CONTI, 1943, p.55, pl. VII, fig. 1a–c; pl. 8, fig. 6.

Rhodolith-forming plant with a lumpy growth-form shows stout protuberances reaching about 2 mm in length. Each thallus barely exceeds 450 μm in thickness, but several thalli are superimposed to give the total thickness. In thin sections, the protuberances appear to have originated from the superposition of fertile and sterile layers of the thallus, which thicken up in correspondence with the conceptacle chambers. Hypothallium coaxial is 100–200 μm thick, with cells L 22–25 x D 12–14 μm. Perithallial cells are L 9–16 x D 8–9 μm. Multiporate conceptacles abundant has D 275–425 x H 155–205 μm with roof thickness of 50–75 μm. Several conceptacle chambers show a partial infill of irregularly-shaped, large "cells".

The stratigraphic distribution of *M. roveretoi* ranges from the Upper Eocene to the Miocene of the Tertiary Piedmont Basin (FRAVEGA et al., 1987) and in the Badenian of the Leitha Limestone (Vienna Basin; CONTI, 1946b).

Genus *Lithothamnion* HEIDRICH, 1897
***Lithothamnion valens* FOSLIE, 1909**
(Pl. 1, Figs. 4–6)

Holotype: TRH, unnumbered; includes slides 1731–1733. Figured by BASSO et al. (1997, pl. 37, figs. 1–8; pl. 38, figs. 3, 5, 6).
1946a *Lithothamnium ramosissimum* (GÜMBEL non REUSS) CONTI, p.18–22, pl. I/1 a–f; pl. VII/1–3
1997 *Lithothamnion valens* – BASSO et al. (1997), p. 170–176

The species is common as branches and their fragments, with diameters ranging from 2 to 4–5 mm. Also some prâlines with fruticose growth-forms have been identified. Single protuberances (branches) can regularly exceed 2 cm in length. Fragments of branches containing the hypothallium have not been observed. The perithallium shows a sharp zonation, with large rectangular cells (L 17–24 x 9–12 μm) at the base of each growth zone, gradually decreasing in size toward the more square shaped cells at the top of the same zone (L 10–12 x 9–12 μm). This superimposed growth zone begins sharply with the large cells, without any transition. Multiporate conceptacle chambers D 260–380 x H 105–120 μm show roof thickness ranging from 32 to 45 μm. The stratigraphic distribution of *L. valens* ranges from the Priabonian to the Recent (BASSO et al., 1997).

3.2. The facies

On the basis of the lithology and fossil components (relative abundance of prâlines, more or less fragmented coralline unattached branches, small and large benthic/planktic foraminifera and molluscan remains) at least three different facies can be distinguished within the Bizek limestone.

Branches dominate in facies A, small rhodoliths dominate in facies B, corallines are fragmented and probably were not autochthonous in facies C. Facies A and B were also recognized at Gornje Vrapče (Fig. 1), though their geometry and palaeoenvironmental / stratigraphic relationships need further investigation.

Facies A (Pl. 1, Fig. 7) has been sampled at about 50 cm above the Triassic base. It represents a micro-breccia with angular and sub-rounded clasts of dolomite mixed with bioclasts. Coralline branches and their fragments are dominant in the limestone. Other components include centimetre to millimetre-sized fragments of bryozoan colonies and small benthic foraminifera (*Lobatula lobatula,* Textularidae, Elphidiidae, Miliolidae). External moulds of large Arcidae and *Glycymeris* sp. randomly occur. Dolomitization of bioclasts is extensive, and was followed by dissolution, both of bioclasts and lithoclasts. The resulting mouldic porosity involves about 20–30% of the rock.

The well preserved algal fragments (about 20–40% of the total algal fragments) are irregularly cylindrical, 1–5 mm in diameter and up to about 1 cm in length. Corallines with lumpy to fruticose growth-forms compose sparse, small prâlines (sensu BASSO, 1998), 1–3 cm in diameter. Most algal remains belong to *L. valens*, with the contribution of *P. calcareum* and *M. roveretoi*.

PLATE 1

1 *Phymatolithon calcareum* (PALLAS) ADEY & MCKIBBIN, 1970. Two conceptacles with the characteristic roof. Note thallus zonation and abraded thallus surface. Thin section BIZ1, Bizek quarry, OM photograph.

2 *Mesophyllum roveretoi* CONTI, 1943. Several superimposed fertile thalli which compose a protuberance. The coaxial hypothallium is visible. Thin section CRO4/1C, Bizek quarry, OM photograph.

3 *Mesophyllum roveretoi* CONTI, 1943. Detail of the multiporate conceptacles. The improper thallus orientation hides the coaxial organization of the hypothallium. Thin section CRO4/1C, Bizek quarry, OM photograph.

4 *Lithothamnion valens* FOSLIE, 1909. An oblique section of a protuberance showing the typical thallus zonation and multiporate conceptacles. Note diagenetic fractures deforming the original conceptacle shape. Thin section CRO4/1A, Bizek quarry, OM photograph.

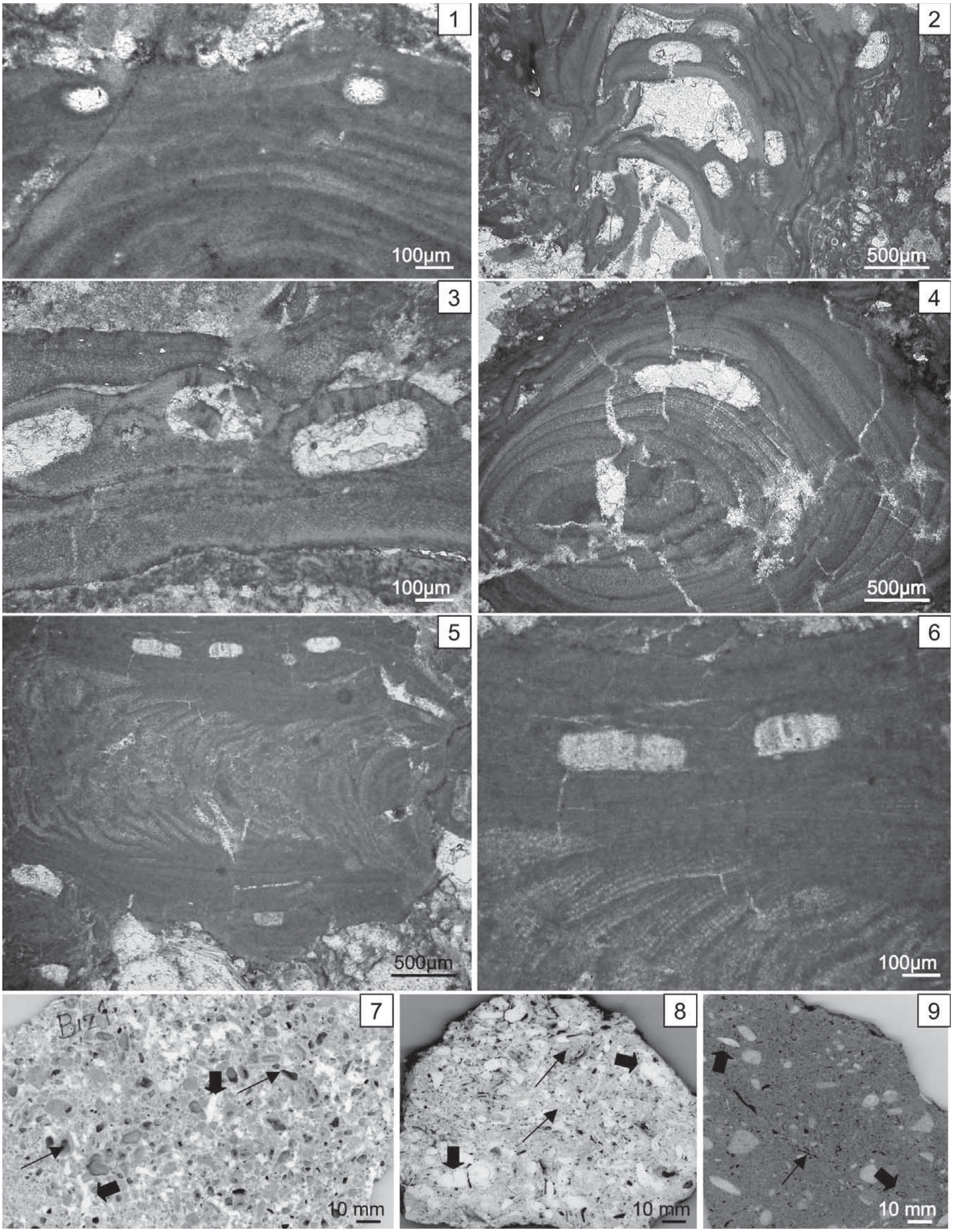
5 *Lithothamnion valens* FOSLIE, 1909. A longitudinal section of a protuberance showing the sharp zonation in the medulla and the multiporate conceptacles developing in the. cortex. Thin section BIZ6, Bizek quarry, OM photograph.

6 *Lithothamnion valens* FOSLIE, 1909. Detail of the multiporate conceptacles of Fig. 5. Note the preservation of some (?sporangial) remains hanging from the roof of the conceptacle. Thin section BIZ1, Bizek quarry, OM photograph.

7 Litavac facies A (Bizek quarry, sample BIZ 1). Note the preserved fossil algal thalli appearing as white, irregular cylindrical clasts in the limestone (thick arrows on branching growth-forms). Mouldic porosity due to dissolution of dolomitic clasts is indicated by thin arrows.

8 Litavac facies B (Bizek quarry, sample BIZ 6). Note the common occurrence of small rhodoliths (thick arrows), together with branching growth-forms and the abundant larger foraminifera (arrows).

9 Litavac facies C (Bizek quarry, sample BIZ 8). Most coralline algae that occur as micro-fragments are detectable only under O.M. Benthic and planktic foraminifera are the major components. Note also common *Ditrupa* (thick arrows) and molluscan (arrow) shell fragments.


1
100µm
2
500µm
3
100µm
4
500µm
5
500µm
6
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7
10 mm
8
10 mm
9
10 mm

Two other facies B and C (Pl. 1, Figs. 8, 9) appear as lateral variations at the same stratigraphic level, at about 15 m height within the Upper Badenian strata. In the algal biocalcarenite of facies B (Pl. 1, Fig. 8), which represents the most typical Litavac, the fragments of coralline branches become less abundant and smaller, while small rhodoliths become common. The coralline flora is composed of *Lithothamnion* spp. and *Mesophyllum* spp. Large benthic foraminifera (*Amphistegina* and *Planostegina*) are the co-dominant components.

In facies C (Pl. 1, Fig. 9), an evident orientation of the grains is observed. It represents a mud supported micro-conglomerate with small sub-rounded dolomitic clasts in a matrix of fine grained crushed bioclasts. The dominant components are the large benthic foraminifera, mostly as fragments, together with small benthic and common planktic foraminifera. Other components are small gastropods and fragments of bivalves together with annelid tubes. Millimetre-sized fragments of uncommon corallines also occur.

4. DISCUSSION AND CONCLUSIONS

The accumulation of prevalently loose-lying non-geniculate, branched corallines corresponds to the modern concept of *maërl*. Maërl is a Breton word defining a benthic association dominated by free-living, branching algal thalli. Along the north-western coast of France, at many localities in Ireland, and in Galicia, maërl covers large areas of the infralittoral sea-floor at < 20 m of water depth in a macrotidal environment, thus exposed to oscillating tidal currents (CABIOCH, 1969; BIOMAERL team, 2003). In the Mediterranean, maërl occurs infrequently at about 40 m of water depth, in current-swept, coastal bio-detritic, benthic environments of the upper circalittoral zone (BASSO & BRUSONI, 2004).

The available literature reports analogues of fossil algal facies in the Miocene of Europe. The "branching algae facies" reported by STUDENCKI (1988) occurs in the basal layer of the Pinczow Limestone outcropping west of Pinczow (NE of Cracow, Poland). It is composed of an accumulation of branching thalli of *Sporolithon* sp. and *Lithothamnion valens* (reported as *Archaeolithothamnium* sp. and *Lithothamnium ramosissimum* (GÜMBEL) respectively in STUDENCKI, 1988) and subordinate encrusting growth-forms of *Mesophyllum ingestum* CONTI, 1946b and *Neogoniolithon contii* (MASTRORILLI) QUARANTA, VANNUCCI & BASSO, 2007 (reported as *Mesophyllum rigidum* MASTRORILLI in STUDENCKI, 1988). This facies has been interpreted as the first step of an ecological succession leading to a rhodolith pavement along a shallowing trend (STUDENCKI, 1988).

Maërl occurs as a facies of the Leitha Limestone in the Vienna Basin (DULLO, 1983; RIEGL & PILLER, 2000). Several species of non geniculate corallines have been identified in the Austrian Leitha Limestone, among which the most common are *Lithothamnion valens*, *Lithothamnion ramosissimum* (REUSS) PILLER, 1994, *Phymatolithon calcareum*, *Mesophyllum roveretoi*, *Spongites albanensis* (LEMOINE) BRAGA, BOSENCE & STENECK, 1993 (for reference: CONTI, 1946b; PILLER, 1994; BASSO et al., 1997). Among these species, *L. valens* and *L. ramosissimum* commonly show a free-living, branching growth-form, while the others have been identified as encrusting thalli or rhodolith builders.

A cool-water, algal rudstone/floatstone microfacies composed of whole and fragmented red algae has been described for the Hungarian Leithakalk (RANDAZZO et al., 1999). Corallines appear in numerous growth-forms, can be referred to maerl or prâlines and are associated with benthic foraminifera (*Amphistegina* and *Heterostegina*) and worm tubes. They are reported to belong to several coralline genera, including *Lithothamnion, Sporolithon* (quoted as *Archaeolithothamnion*), *Mesophyllum* and *Lithophyllum*. Unluckily, the absence of palaeontological descriptions and insufficient illustration prevent confirmation and more detailed identification of the reported taxa (RANDAZZO et al., 1999).

Branch fragments of corallines in a marly matrix, possibly comparable with a maërl, occur in the Badenian algal limestones of the Transylvania Basin (Romania; BUCUR & FILIPESCU, 1994). The diversified coralline flora of the Badenian algal limestones includes several species of the genera *Sporolithon*, *Lithothamnion* (among which *L. ramosissimum,* quoted as *P. archaeotypum* CONTI), *Mesophyllum* (among which *M. roveretoi*), *Lithophyllum* and *Spongites albanensis* (quoted as *Lithophyllum?albanense* LEMOINE), mostly composing rhodoliths (BUCUR & FILIPESCU, 1994).

These observations support the conclusion that in Paratethys, a Badenian maërl was predominantly composed of *Lithothamnion* (free-living branches) and *Mesophyllum*, with locally subordinate *Sporolithon, Spongites* and *Phymatolithon* (in rhodoliths).

We can attempt a comparison of this Badenian fossil association with the present-day maërl. The coralline association of the Atlantic maërl (NW France, Ireland and Galicia) is dominated by *Lithothamnion corallioides* (P.L. & H.M. CROUAN) P.L. & H.M. CROUAN, 1867 and *Phymatolithon calcareum.* Other species contributing to the Atlantic maërl are *Lithothamnion glaciale* KJELLMAN*, Lithothamnion tophiforme* (ESPER) UNGER, 1858*, Lithophyllum dentatum* (KÜTZING) FOSLIE, 1900*, Lithophyllum fasciculatum* (LAMARCK) FOSLIE, 1900 and, more occasionally, *Mesophyllum*.

The Mediterranean maërl has a diversified algal flora, with the occurrence of several species of *Lithothamnion*, *Phymatolithon*, *Lithophyllum* and Mastophoroideae. Presently, *L. valens* is a Mediterranean endemic, infrequently occurring at considerable depth (50–70 m), mainly in the Western Mediterranean (BASSO, 1996; BABBINI & BRESSAN, 1997). In the tropics, an analogous maërl (based on the algal growth-form) is represented by the accumulation of unattached branches of *Neogoniolithon* in seagrass meadows (BASSO et al., in press). The Badenian maërl has no obvious analogies with the tropical *Neogoniolithon* facies. The Atlantic and the Mediterranean maërl and their Badenian fossil counterparts are dominated by melobesioid corallines. However, one of the most characteristic and abundant species in the Badenian maërl, *Lithothamnion valens*, does not occur in the present-day maërl association living in the Atlantic. Since *L. valens* still occurs in relatively deep Mediterranean waters, we conclude that the temperate-water, modern Mediterranean maërl is floristically the most similar analogue of the Badenian Litavac. However, direct palaeodepth interpretations based on the Mediterranean occurrence of *L. valens* would be speculative, until further palaeoecological investigations based on the whole benthic association and sedimentary environment of the Litavac have hopefully clarified the matter.

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