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OXFORDIAN TO VALANGINIAN PALAEOENVIRONMENTAL EVOLUTION ON THE WESTERN MOESIAN CARBONATE PLATFORM: A CASE STUDY FROM SW BULGARIA

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Abstract: Three sections (Rebro, Lyalintsi and Velinovo) of the Upper Jurassic–Lower Cretaceous carbonate sequences from the Lyubash unit (Srednogorie, Balkanides, SW Bulgaria) have been studied for elucidation of biostratigraphy and palaeoenvironmental evolution. Palaeontological studies of foraminifera, supplemented by studies of calcareous dinoflagellate cysts and corals, enabled the determination of the Oxfordian–Valanginian age of the analysed sequences. They were deposited on the Dragoman Block (western part of the Moesian Platform), and during Mid–Late Cretaceous included to the Srednogorie. A possible Middle to Late Callovian age of the lowermost part (overlying the Bajocian–Lower Bathonian Polaten Formation) of the studied sections assumed till now has not been confirmed by the present studies.

Eleven facies have been distinguished and attributed to depositional environments. Marine sedimentation on a homoclinal ramp started in the Oxfordian and till the Early Kimmeridgian – in all three sections – was dominated by fine-grained peloidal-bioclastic wackestones to grainstones. Since the Late Kimmeridgian, when a rimmed platform established, facies pattern underwent differentiation into (i) the inner platform (lagoon and tidal flat facies) – only in Velinovo, (ii) reef and peri-reef facies/bioclastic shoals – mainly in Lyalintsi, and (iii) platform slope – mainly in Rebro. Sedimentation generally displays a shallowing-upward trend. Two stages in evolution of the rimmed platform are postulated. The mobile stage lasting till the Tithonian/Berriasian boundary was followed by a more stable stage in the Berriasian to Valanginian time.

Reefs are developed mainly as coral-microbial biostromes, lower coral bioherms or coral thickets, in the environment of moderate energy and sedimentation. They contain highly diversified corals (72 species). Microbialites contributed to the reef framework, but they never dominated. Locally, microencrusters and cement crusts formed important part of reefal framework. During the mobile stage of the platform evolution a relative sea-level rise interrupted reef development, as evidenced by intercalations of limestones with *Saccocoma*. During the second stage high carbonate production and/or regressive eustatic events, not balanced by subsidence, decreased accommodation space, limiting reef growth and enhancing carbonate export to distal parts of the platform.

Key words: Oxfordian–Valanginian, biostratigraphy, carbonate sedimentology, reefs, Moesian Platform, Lyubash unit, Bulgaria.

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INTRODUCTION

The Late Jurassic to Lower Cretaceous deposits of nor-thern and southwestern Bulgaria were accumulated in a bathymetrically differentiated basins, developed in the northern part of the Tethyan Ocean. The thick and continuous carbonate sequences of these ages are well exposed, providing an excellent material for biostratigraphic studies and elaboration of palaeoenvironmental development of the western part of the Moesian Platform. The shallow-water carbonate sedimentation was associated with the gradual uplift of the southern landmass and the formation of the Central Moesian Basin.

The present paper deals with carbonate successions deposited on the western part of the Moesian Platform, the main part of which is situated on the territory of Serbia and

Fig. 1. **A** – general location of the studied area, **B** – location of measured sections. Map shows distribution of the Slivnitsa Formation formed on the Dragoman Block (after Lakova *et al.*, 1999)

Romania (Patrulius *et al.*, 1976; Lefeld *et al.*, 1986). The studied part of the platform is called the positive Dragoman Block (Sapunov *et al.*, 1985). The paper presents the results of studies of the Oxfordian to Valanginian carbonate deposits from three sections: Rebro, Lyalintsi and Velinovo. As the result of the Mid–Late Cretaceous tectonics they were included in the Lyubash unit, a part of Srednogorie zone of the Balkan orogenic system (Figs 1–2; Dabovski *et al.*, 2002). The studied area is traditionally in the Bulgarian geological literature ranked as the SW Bulgaria.

The analysed sections represent different parts of the carbonate platform. Our studies are particularly focused on the section Lyalintsi. Here since the Late Kimmeridgian, and particularly during the Valanginian, coral-microbial reefs, mainly biostromes, have been formed. The Valanginian coral fauna from Lyalintsi represents the richest coral assemblages of this stage which is characterized by worldwide reduction of reef development. This long, continuous section offers a unique opportunity to study coral assemblages at the Jurassic/Cretaceous transition.

This study aims are to (1) describe the microfacies and facies and attribute them to sedimentary environments; (2) provide new biostratigraphical data; (3) interpret the depositional environments, particularly in terms of the palaeoenvironmental parameters controlling reef development.

GEOLOGICAL SETTING

The Upper Jurassic and Lower Cretaceous sediments are well represented in the North- and Southwest Bulgaria, and their stratigraphy, palaeogeography as well as palaeogeodynamics have been intensively studied and discussed in many publications.

Nachev (1969, 1970, 1973, 1976) discussed the sedimentary successions and palaeogeography in the SW Bulgaria, and outlined very idealized picture of a single marine basin with several sedimentation gaps. The Jurassic stratigraphy and tectonic structure of the SW Bulgaria has been thoroughly studied, among others, by Sapunov *et al.* (1983, 1985), Dodekova *et al.* (1985), Tchoumatchenco *et al.* (1989), Tchoumatchenco and Sapunov (1994), and Ivanova and Koleva-Rekalova (2004). They supported the idea that the Upper Jurassic–lowermost Cretaceous sediments were deposited in a bathymetrically differentiated basin, associated with the gradual emergence of the southern landmass and the formation of the Central Moesian Basin. The present study deals with the Upper Jurassic–Lower Cretaceous carbonate sedimentary successions of the Dragoman Block belonging to the Western Moesian Carbonate Platform (Patrulius *et al.*, 1976; Sapunov *et al.*, 1985). The geological structure of the SW Bulgaria was formed mostly in Mid–Cretaceous and Late Cretaceous (Dabovski *et al.*, 2002; Zagorchev, 1986, 1995, 2001; Zagorchev *et al.*, 2000). In that time the analysed in this paper area was included in the Lyubash monocline (Lyubash unit) belonging to the West Srednogorie unit of the Balkan orogenic system. The Lyubash monocline dips 20–30 degrees in the northeast direction.

Recently, Tchoumatchenco (2002) and Tchoumatchenco *et al.* (2006) have presented an alternative interpretation, in which the Jurassic Dragoman Block represents the southern continuation of the Getic unit. This interpretation is not considered in the present paper.

Since the Tithonian the sedimentary basin induced by rifting was characterized by an asymmetrical extensional framework, E–W to NW–SE. Between the northern margin (Moesian Platform) and the mobile southern margin (“Thracian Island”) the Nish–Trojan Trough with mixed carbonate-siliciclastic sedimentation has been existed. Shallow-water carbonates (Slivnitsa and Brestnica Formations) were deposited on shoals, possibly forming small islands, separated by deeper water depressions (see review by Minkovska *et al.*, 2002).

The main part of the platform studied is represented by shallow-water limestones of the Slivnitsa Formation, introduced and designated as the "Slivnitsa Limestone" (Zlatarski, 1885), later classified as "Formation" (Nikolov & Sapunov, 1970). The official definition of Slivnitsa Formation is: "the Formation is built up by thick-bedded to massive light grey to whitish organogenic and less common micritic limestones containing a large number of benthic foraminifers and massive algae, colonial corals, rudists, brachiopods, crinoids, gastropods and other benthic forms" (Nikolov & Sapunov, 1970, p. 1398). According to the earlier opinions (see Sapunov *et al.*, 1985), the age of sediments in the studied area ranges from Middle Callovian to ?Valanginian.

In the present paper we distinguished the Yavorets Formation, the Slivnitsa Formation and the Gintsi Formation (Nikolov & Sapunov, 1977). We do not accept the use of the informal lithostratigraphic unit – the Belediehan formation (see Nikolov & Sapunov, 1977) – instead of the Yavorets and Gintsi Formations, and instead of the lower part of the Slivnitsa Formation (Tchoumatchenco, 2006). According to Sapunov *et al.* (1985) this formation cannot be followed out from the type section to the neighbouring sections, which makes the name unusable.

MATERIAL AND METHODS

The studied sections: Rebro, Lyalintsi and Velinovo are located in the vicinity of Breznik and Tran, about 70 km west of Sofia (Fig. 1). The 557 m long Lyalintsi section was studied in 1981 by E. Roniewicz and V. Zlatarski (with focus on coral studies), during 1999–2000 (by DI, EK-R and P. Tchoumatchenco), and in 2004 (supplementary studies by DI, EK-R, BK). The last two samplings were done on the old road along the gorge, cutting the Lyubash Mountain around 1 km to WSW from the village of Lyalintsi. The section studied during corals sampling was located above this section along the old road on the slope of the Lyubash Mt. All these sections are approximately correlated in this paper. The sampling from 1981 provided 264 coral samples (396 thin sections, abbreviation NMNHS F). This sampling was performed along the section studied earlier by Dodekova *et al.* (1985), and it provided with samples from, practically, each coral bed observed in the sequence. Sampling from 1999–2000 provided 65 thin sections (abbreviation Li). Supplementary sampling, on both sides of a gorge, in 2004 provided 60 thin sections (abbreviation Lia). The Rebro section is 320 m long and located close to the village Rebro. The 381 m long section in Velinovo is located at the end of this village. The sampling in Rebro (62 thin sections; abbreviation Re) and Velinovo (56 thin sections; abbreviation Ve) was preformed in 1999–2000 by DI and EK-R and P. Tchoumatchenco.

The studied corals are housed in the National Natural History Museum, Bulgarian Academy of Sciences (BAS, collection NMNHS F), the thin sections from Lyalintsi abbreviated as Lia are housed at the Institute of Geological Sciences, Jagiellonian University, and other samples and thin sections in the Laboratory for Geocollections, Geological Institute, BAS, Sofia.

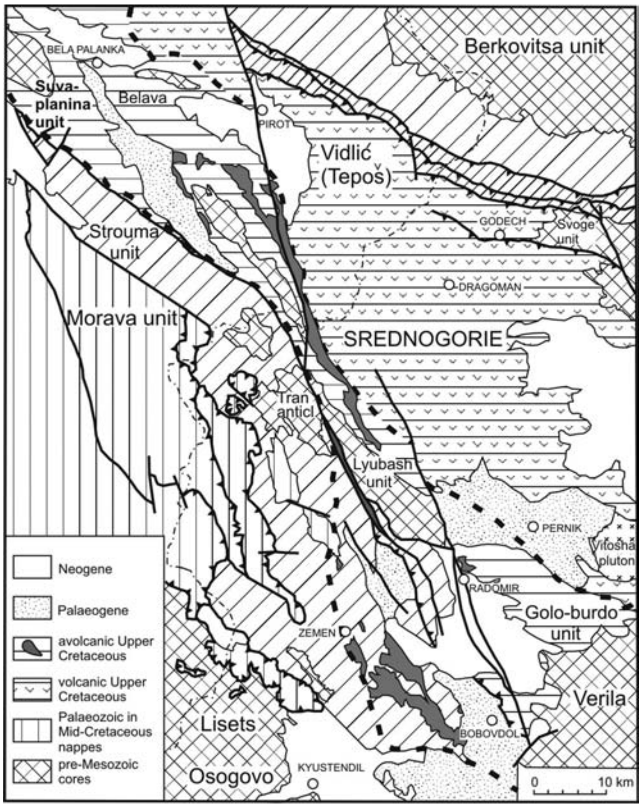


Fig. 2. Generalized geological map of SW Bulgaria with major tectonic lines (after Zagorchev *et al.*, 2006)

GENERAL DESCRIPTION OF SEDIMENTS AND FORMATIONS

Figure 3 presents vertical distribution of facies in all three sections. Facies are attributed to main stages of the evolution of ramp and platform, which is considered in the chapter *Discussion* and summarized in Fig. 16. Main coral intervals in the section Lyalintsi are marked in the Fig. 4.

According to a local lithostratigraphy, modified in this paper, the studied sediments represent three formations: Yavorets Formation, Gintsi Formation and Slivnitsa Formation. Erosional unconformity indicates boundary with the underlying Polaten Formation. In all studied sections the upper part of the sections is eroded and overlain by Turonian deposits.

The Yavorets Formation is composed of grey, thin, middle to thick-bedded peloidal and peloidal-bioclastic wackestones to grainstones with *Globuligerina* (F 1), peloidal-bioclastic packstones to grainstones with chert nodules (F 2), and rarely peloidal-bioclastic packstones to fine grained rudstones with *"Tubiphytes"* (F 3). Facies F 3 occur only in more shallow-water settings (Lyalintsi, and mainly, Velinovo). The succession of these microfacies shows a general coarsening upward trend. Because the sediments of

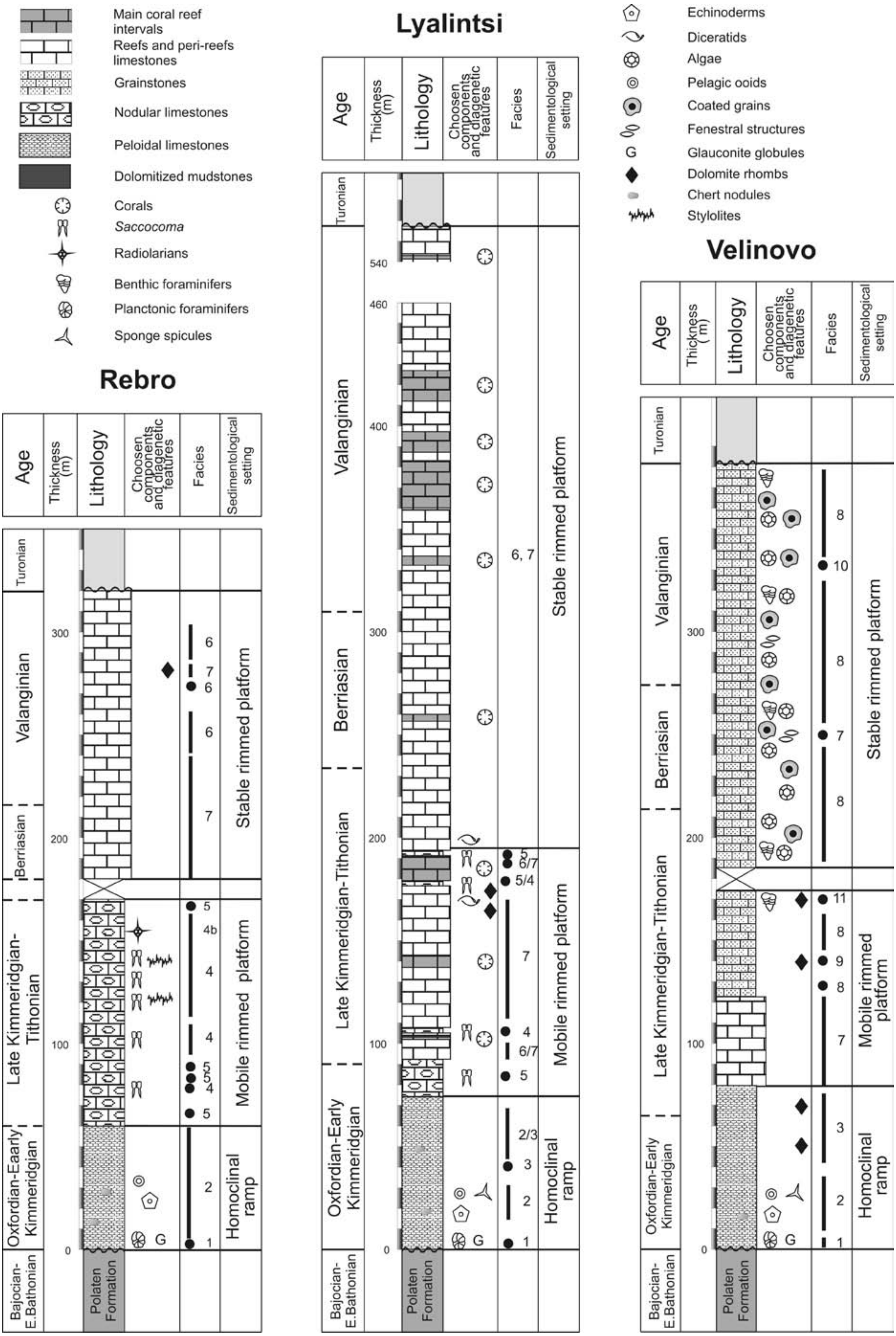


Fig. 3. Stratigraphic logs of three measured sections: Rebro, Lyalintsi and Velinovo, with distribution of facies (F) ascribed to main stages of ramp–platform evolution. Only the main, most characteristic biota, allochems and diagenetic features are marked

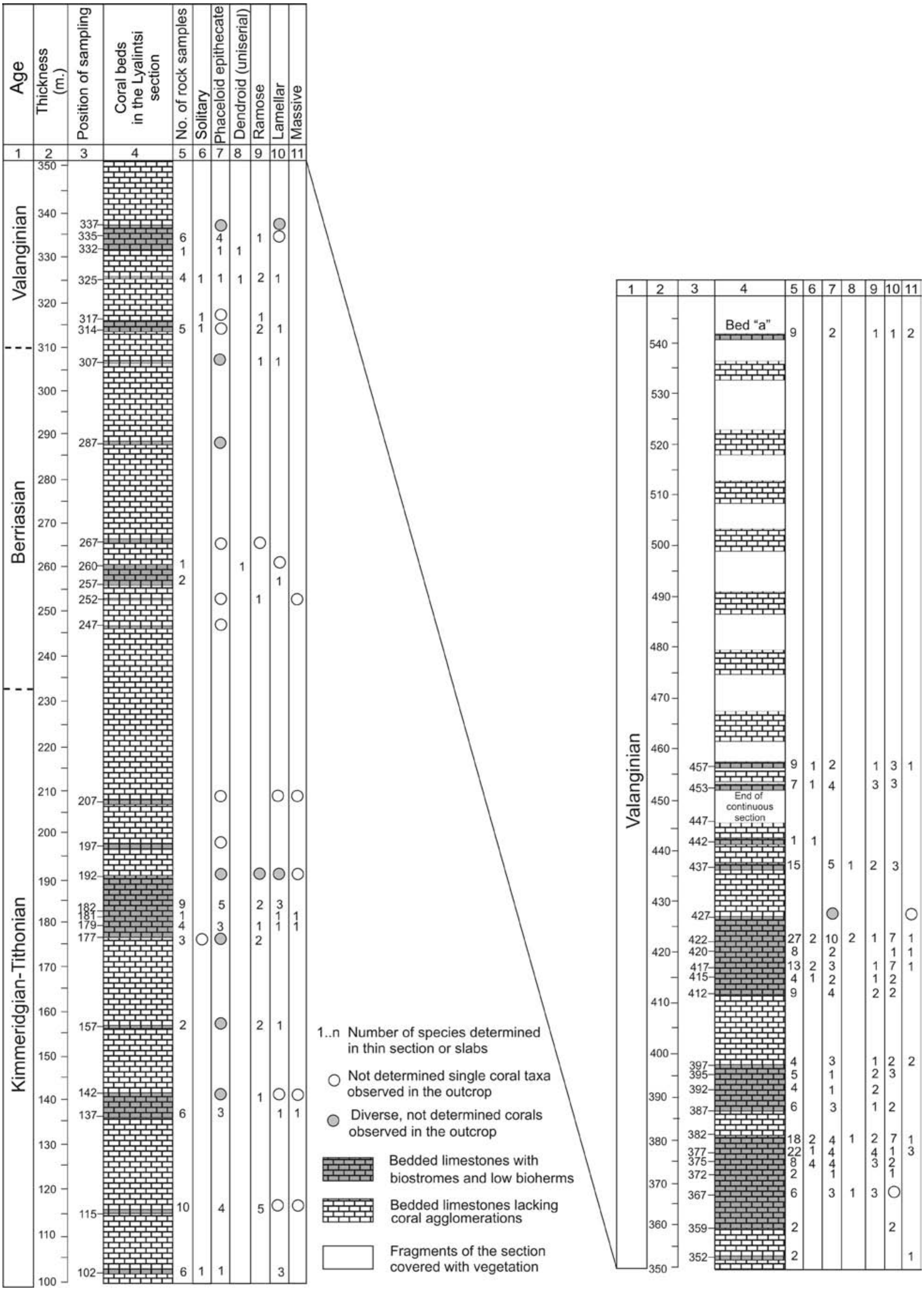


Fig. 4. Distribution of coral biostromes and low bioherms in the section Lyalintsi. The number of coral species in respective growth form categories and sample numbers are given in the columns 5–11, as well as distribution of corals non-determined taxonomically observed in the field (for details see the legend)

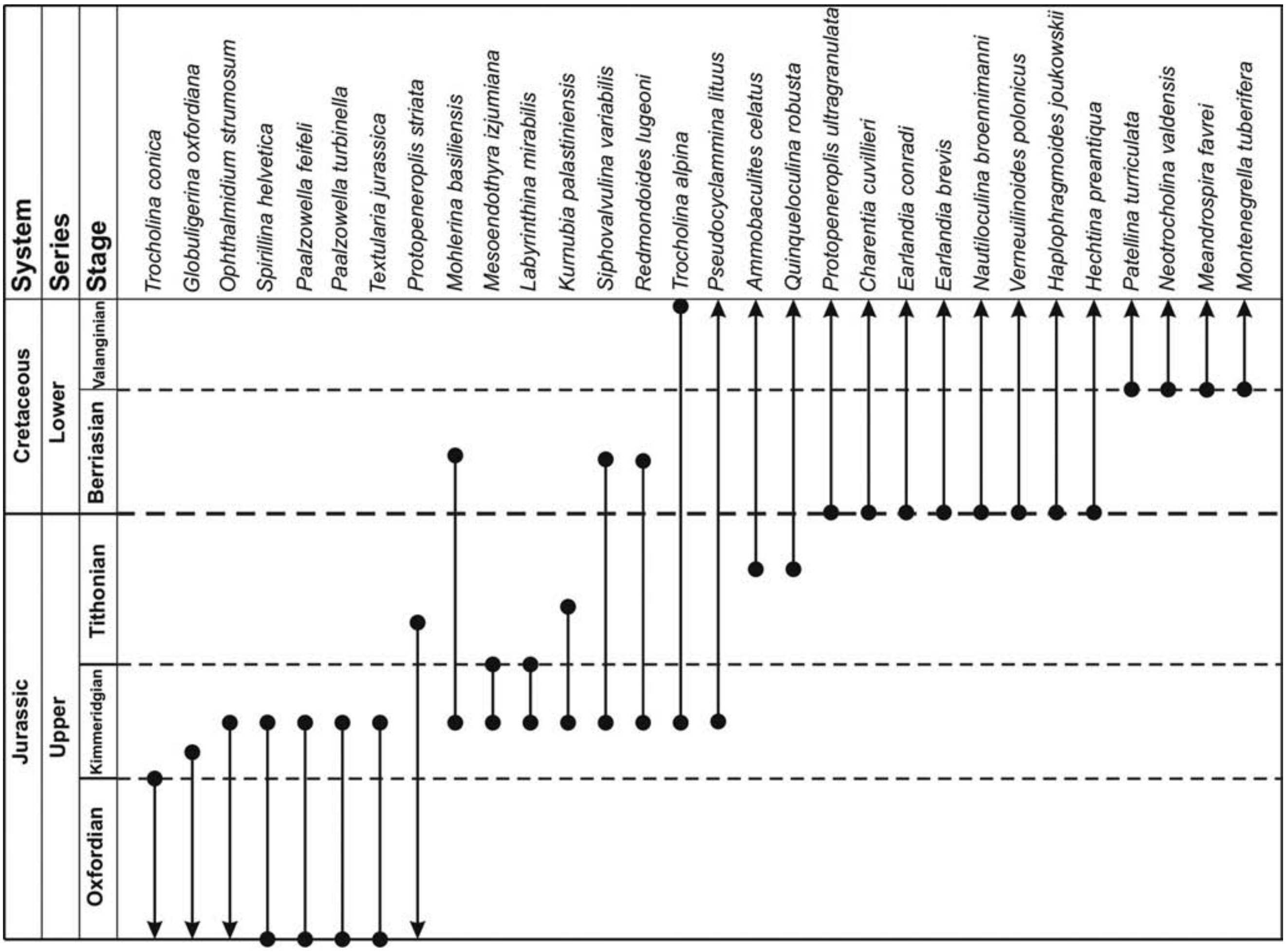


Fig. 5. Stratigraphic distribution of the most important foraminifera species from the studied sections Rebro, Lyalintsi and Velinovo

the lowermost part in all three sections are lithologically identical or very similar to each other, and differ from the overlying sediments of the Gintsi and Slivnitsa Formations, we attributed them to the Yavorets Formation. This formation has not previously been distinguished in the Lyalintsi and Velinovo sections (Sapunov *et al.*, 1985).

The Gintsi Formation (*Ammonitico Rosso*-like facies) is built up mainly of thin to medium-bedded limestones of grey to pink, fine grained peloidal-*Saccocoma* wackestones and packestones (F 4) with intercalations of bio-lithoclastic grainstones to rudstones with *Saccocoma* (F 5), and in one recognized bed with peloidal wackestones with radiolaria (F 4a). Limestones show indistinct nodular structure. The Gintsi Formation forms a continuous succession in the Rebro section. In Lyalintsi it occurs as wedges within the Slivnitsa Formation. This formation does not occur in Velinovo.

The Slivnitsa Formation shows the highest facies and microfacies differentiation. It is composed by reefal and peri-reefal facies (or bioclastic shoals facies) (F 6, F 7; mainly in Lyalintsi and Rebro), as well as limestones of the inner platform (lagoon and tidal flat, F 8–F 11, only in Velinovo). They are developed as thin, medium and thick-bedded limestones of various colour (light grey, beige and grey-pink).

BIOSTRATIGRAPHICAL RESULTS

This study presents results of biostratigraphic studies of foraminifers and calcareous dinocysts (cadosinids and stomiosphaerids). As a result the Oxfordian–Valanginian age of the limestones was determined (Figs 5–7).

The stratigraphic distribution of the foraminiferal taxa has been presented after Dragastan (1975, 1978), Velić and Sokač (1978, 1983), Darsac (1983), Salvini-Bonnard *et al.* (1984), Arnaud-Vanneau *et al.* (1987, 1991), Altiner (1991), Bucur *et al.* (1993, 1995, 1996, 2004), Darga and Schlagintweit (1991), Septfontaine *et al.* (1991), Chiocchini *et al.* (1994), Schlagintweit and Ebli (1999), Schlagintweit *et al.* (2003, 2005), and papers cited therein.

The question of the Callovian in the studied sections

The previously assumed Middle–Late Callovian age of the lowermost part of the sections (Sapunov *et al.*, 1985) was not confirmed. Ivanova (in Ivanova & Koleva-Rekalova, 2004) determined the lowermost part from the sections Berende Izvor and Velinovo as the Middle Callovian–Oxfordian, on the basis of the range of *Globuligerina oxfordiana* (Grigelis), as well as on data from Sapunov *et al.* (1985). According to new detailed micropalaeontological studies

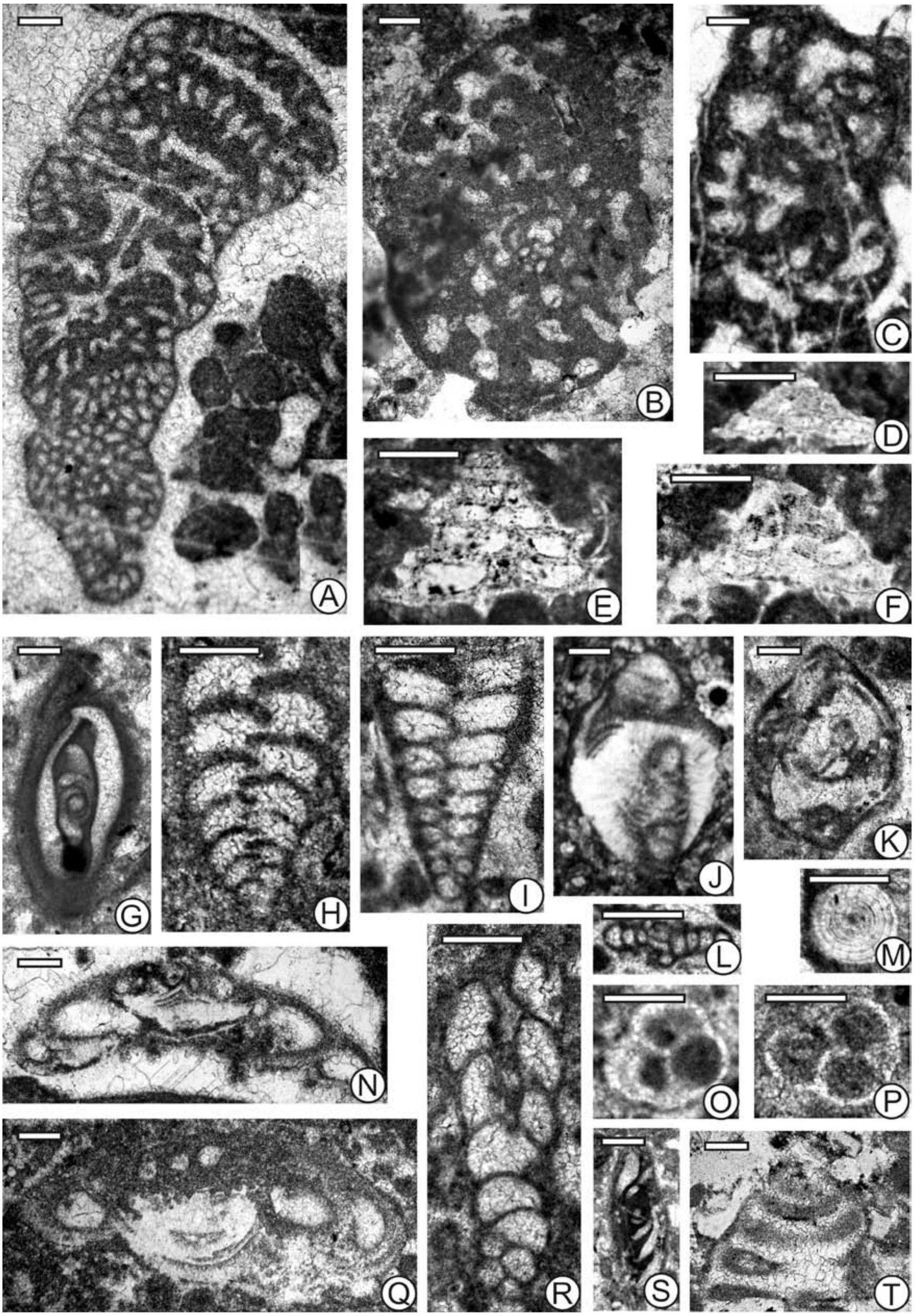


Fig. 6. The most important Oxfordian to Tithonian foraminifera from the sections studied: **A** – *Kurnubia palastiniensis* Henson (Ve 38), **B**, **C** – *Labyrinthina mirabilis* Weynschenk (**B** – Ve 22, **C** – Ve 26), **D** – *Paalzowella turbinella* Gümbel (Lia 5.2), **E, F** – *Paalzowella feifeli* Paalzow (**E** – Lia 5.2, **F** – Re 5), **G, S** – *Ophthalmidium strumosum* Gümbel (**G** – Lia 1.1, **S** – Lia 4.2), **H** – *Redmondoides lugeoni* (Septfontaine) (Lia 65.2a), **I** – *Textularia jurassica* Gümbel (Li 10), **J, K** – *Protopeneroplis striata* Weynschenk (**J** – Ve 3, **K** – Lia 13.2), **L** – *Glomospirella* sp. (Li 8), **M** – *Spirillina helvetica* Kübler et Zwingli (Li 13), **N, Q** – *Mohlerina basiliensis* (Mohler) (Lia 60.2b), **O, P** – *Globuligerina oxfordiana* (Grigelis) (**O** – Li 10, **P** – Lia 1.2), **R** – *Siphovalvulina variabilis* Septfontaine (Ve 45), **T** – *Trocholina conica* (Schlumberger) (Lia 1.1). All scale bars 100 μm

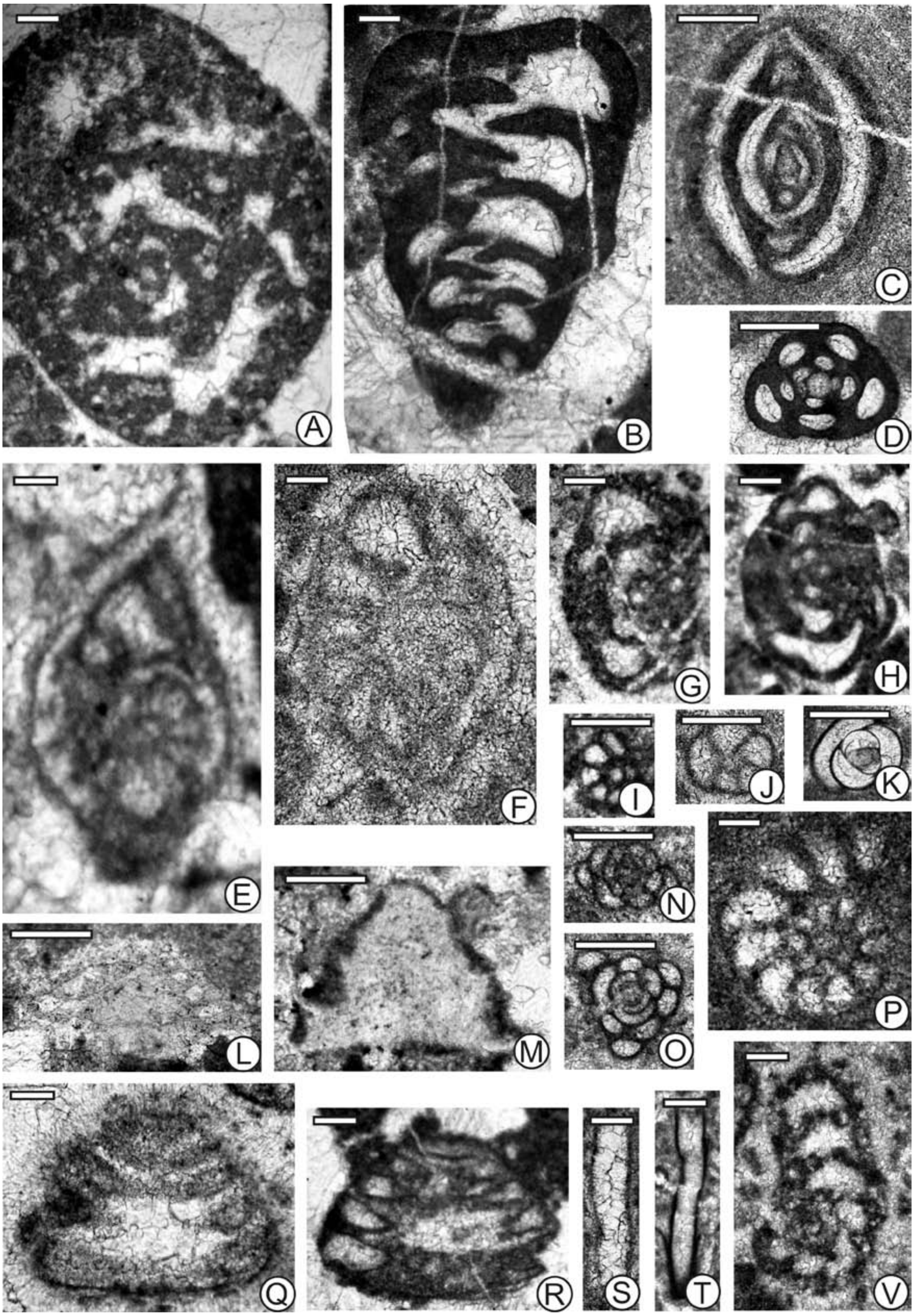


Fig. 7. The most important Berriasian to Valanginian foraminifera from the sections studied: **A** – *Pseudocyclammina lituus* (Yokoyama) (Lia 60.2b), **B** – *Verneuilinoides polonicus* (Cushman et Glazewski) (Ve 41), **C**, **D** – *Quinqueloculina robusta* Neagu (**C** – Ve 40, **D** – Ve 44), **E, F** – *Protopeneroplis ultragranulata* (Gorbachik) (**E** –Li 33A, **F** – Ve 46), **G**, **H** – *Charentia cuvillieri* Neumann (**G** – Ve 40, **H** – Li 33A), **I** – *Haplophragmoides joukowskyi* Charollais, Broennimann et Zaninetti (Li 40), **J** – *Dobrogelina* sp. (Lia 56.2b), **K** – *Istriloculina emiliae* Neagu (Ve 46), **L** – *Neotrocholina valdensis* Reichel (Re 41A), **M** – *Patellina turriculata* Dieni et Massari (Re 41A), **N, O** – *Meandrospira favrei* (Charollais, Brönnimann et Zaninetti) (**N** – Li 53, **O** – Re 46), **P** – *Mayncina* cf. *bulgarica* Laug, Peybernès & Rey (Ve 49), **Q, R.** *Trocholina alpina* (Leupold) (**Q** – Ve 35, **R** – Ve 26), **S**, **T** – *Earlandia conradi* Arnaud-Vanneau (**S** – Li 22, **T** – Lia 34.1a), **V** – *Ammobaculites celatus* Arnaud-Vanneau (Li 50). All scale bars 100 µm

the presence of the Middle and Upper Callovian Substages for the sections studied cannot be proved. The stratigraphic range of the species *G. oxfordiana* according to extended studies is from the Bajocian to lowermost Kimmeridgian (Farinacci *et al.*, 2000 – *vide* Schlagintweit *et al.*, 2003) and the new information calls for a new biostratigraphical interpretation. Moreover in the first sample from the Rebro section, only 0.2 m above the Polaten–Slivnitsa Formation boundary the calcareous dinoflagellate species *Colomisphaera fibrata* (Nagy) with the range Oxfordian has been found.

Oxfordian Stage–Lower Kimmeridgian Substage

Several foraminiferal species have been recorded from this interval: *Trocholina conica* (Schlumberger) (sensu Mancinelli & Coccia, 1999), *Globuligerina oxfordiana* (Grigelis), *Ophthalmidium strumosum* Gümbel, *Spirillina helvetica* Kübler et Zwingli, *Paalzowella feifeli* Paalzow, *Paalzowella turbinella* Gümbel, *Ammobaculites irregularis* Gümbel, *Textularia jurassica* Gümbel, *Protopeneroplis striata* Weynschenk, *Dentalina* sp., *Lenticulina* sp. The first eight species do not reach the Late Kimmeridgian.

Upper Kimmeridgian Substage–Tithonian Stage

In sections of Rebro and Lyalintsi, the Upper Kimmeridgian substage and Tithonian stage have been determined on the basis of the presence of rare calcareous dinocysts. In both sections *Stomiosphaera moluccana* Wanner and *Colomisphaera nagyi* Borza, which are index species for the Upper Kimmeridgian Substage, have been found, as well as rare *Carpistomiosphaera tithonica* Nowak. The first occurrence of the last one is at the base of the Tithonian Stage and the species is known from the lowermost Lower Tithonian. In the studied sections numerous fragments of the pelagic crinoid genus *Saccocoma* Agassiz have been found. "*Saccocoma*-Coeno-Zone" reaches from the Kimmeridgian to the lowermost Early Tithonian (Diersche, 1980 – *fide* Gawlick & Schlagintweit, 2006). Our biostratigraphical data indicate that in the analysed sections, the *Saccocoma* bearing limestones (F 4–5) were formed from the Kimmeridgian to the Late Tithonian.

In the section Lyalintsi typical of this interval is the appearance of the foraminifers' species *Mohlerina basiliensis* (Mohler). In the section Velinovo the foraminiferal association contains more numerous and more diversified foraminiferal species: *Labyrinthina mirabilis* Weynschenk, *Kurnubia palastiniensis* Henson, *Mesoendothyra izjumiana* Dayn, *Trocholina alpina* (Leupold), *Protopeneroplis striata* Weynschenk, *Siphovalvulina variabilis* Septfontaine, *Redmondoides lugeoni* (Septfontaine), and *Pseudocyclammina lituus* (Yokoyama). The species *Protopeneroplis striata* Weynschenk disappears in this interval, whereas *Siphovalvulina variabilis* Septfontaine, *Redmondoides lugeoni* (Septfontaine), and *Pseudocyclammina lituus* (Yokoyama) reach to the Early Cretaceous.

Berriasian Stage

Some species with range from the Upper Tithonian as *Protopeneroplis ultragranulata* (Gorbachik), *Nautiloculina bronnimanni* Arnaud-Vanneau et Peybernès, *Charentia cuvillieri* Neumann are found together with typical for the Berriasian stage species as: *Haplophragmoides joukowskyi* Charollais, Broennimann et Zaninetti, *Dobrogelina ovidi* Neagu, *Hechtina praeantiqua* Bartenstein et Brand, *Moesiloculina danubiana* Neagu, *Istriloculina emiliae* Neagu, as well as rich association of representatives of the genus *Trocholina*, including species characteristic for Berriasian. In this interval also *Earlandia conradi* Arnaud-Vanneau and *Earlandia brevis* Arnaud-Vanneau appear, which reach the Aptian.

Valanginian Stage

The Valanginian age of sediments in the sections studied has been defined on the basis of the first appearance of the species: *Meandrospira favrei* Charollais, Brönnimann et Zaninetti as well as the presence of the association: *Meandrospira favrei* Charollais, Brönnimann et Zaninetti, *Patellina turriculata* Dieni et Massari, and *Neotrocholina valdensis* Reichel.

Valanginian age in the section Lyalintsi at levels 420 m and between 421–427 m is also suggested by the presence of dasycladale species *Montenegrella* cf. *tuberifera* (Sokač et Velić) (determination by I. Bucur). *Montenegrella tuberifera* is known from Valanginian to Aptian.

Stratigraphic boundaries in the studied sections

Micropalaeontological analysis indicates that the stratigraphical boundaries between stages and substages are within following intervals:

Lower Kimmeridgian/Upper Kimmeridgian
Rebro ca. 60–67 m
Lyalintsi ca. 87–92 m
Velinovo ca. 66–71 m
Tithonian/Berriasian
Rebro ca. 169–180 m
Lyalintsi ca. 220–247 m
Velinovo ca. 214–223 m
Berriasian/Valanginian
Rebroabove ca. 216 m
Lyalintsiabove ca. 307–314 m
Velinovoabove ca. 275 m

Change in taxonomical composition of coral fauna in the Kimmeridgian–Valanginian interval

In the Lyalintsi section, first coral assemblages can be placed in the Upper Kimmeridgian (Sapunov *et al.*, 1985, and new biostratigraphic data herein). Based on the biostratigraphy of the sequence in Lyalintsi, 25 species (22 genera) are observed in the Upper Kimmeridgian–Tithonian (between 102 m – first coral level – and ca. 220–247 m), 20 species (20 genera) were identified in the Berriasian (between 220–247 and 307–314 m), and 62 species (45 genera)

Fig. 8. Field photograph from Lyalintsi showing limestones of F 1–F 3 in the lower, left side of photograph, and massive reefal (?) limestones in the upper part

in the Valanginian (between 307–314 and 557 m) (Fig. 4; Roniewicz, 2008).

In the Lyalintsi section, coral fauna in the Kimmeridgian–Valanginian interval is dominated by the Late Jurassic genera. However, as in other Cretaceous assemblages "typical Cretaceous" coral fauna appears in the Hauterivian (Roniewicz & Morycowa, 1993). Up to the boundary zone between the Tithonian and Berriasian, these are exclusively Late Jurassic genera; however, such typically Jurassic ones as *Isastrea*, *Thamnasteria* and *Stylina* are lacking. The first Cretaceous taxon, *Felixigyra* cf. *duncani* Prever, appears at 182 m (latest Tithonian). *Felixigyra* is known only from the Lower Cretaceous; to date known only from Barremian–Albian (Morycowa & Decrouez, 2006). This genus was also reported from the Tithonian (Turnšek & Mihajlović, 1973), but according to new biostratigraphic data these sediments belong to the Lower Cretaceous (Dr. D. Turnšek, personal information, 1991).

In the Valanginian part of the section, apart from Jurassic taxa, typically Cretaceous corals were found. The new genus and species (Roniewicz, 2008), identified at the 339 m level, represents the Cretaceous family Aulastreoporidae. Another species, *Cladophyllia clemencia* de Fromentel (frequent in the interval of 359–377 m) has been known to date only from the Hauterivian (Löser *et al.*, 2002).

Analyses of the worldwide stratigraphic distribution of Cretaceous corals show that 23 scleractinian genera are known from the Berriasian and 106 from the Valanginian (Löser, 1998). Valanginian corals from Lyalintsi represent the most diversified coral fauna of that age in the world, observed in one succession. However, it should be stressed that one of the richest Mesozoic coral faunas from the Štramberk Limestone in Moravia (Czech Republic) is of the Tithonian–Lower Berriasian age, and, at least in the case of Štramberk-type limestones from the Polish Flysch Carpathians, these coral-bearing limestones can partly represent even the Valanginian (Kołodziej, 2003; Ivanova & Kolodziej, 2004). Although in terms of age and taxonomical diversity corals from Lyalintsi could be comparable with corals from "Štramberk facies" there is an important difference. Štramberk Limestone from Moravia and Štramberk-type limestones from Poland contain highly diversified corals from the suborder Pachythecaliina (17 genera, 35 species, and 14 genera, 22 species respectively; e.g., Ogilvie, 1897; Eliášová, 1975, 1978; Kołodziej, 2003). In Lyalintsi this coral group is represented only by 4 genera and 5 species. The unique morphological features of these corals suggest that the Pachythecaliina should be classified to the order Hexanthiniaria, and not to Scleractinia (Eliášová, 1978; Roniewicz, 2008).

FACIES DESCRIPTION

Sedimentological and palaeontological analyses allow to recognize eleven facies (F) representing (i) homoclinal ramp, (ii) the inner platform (lagoon, tidal flat), (iii) reefs and peri-reefal/bioclastic shoal environments, and (iv) platform slope. Lagoonal and intertidal environments can show high microfacies variability within small area (see Flügel, 2004). Therefore, facies F 9, F 10 and F 11, distinguished in the Velinovo section, may possibly be regarded as microfacies rather than facies.

Descriptions of the facies are presented in order which generally reflects changes in a geometry of the investigated platform: from an initial, homoclinal ramp to a rimmed platform. An interpretation of the palaeonvironmental evolution is presented in the next chapters.

Homoclinal ramp (F 1–F 3)

F 1. Peloidal and peloidal-bioclastic wackestones to grainstones with Globuligerina *(Figs 8, 9 A)*

This facies occupies the lowermost parts of all the sections. Besides various types of peloids, the allochems include rare bioclasts (echinoderms, bivalves, calcified spicules of siliceous sponges), as well as rare *Globuligerina* tests, glauconite and quartz grains in the lowermost part of the sections. Some bioclasts are glauconized and ferruginized.

F 2. Peloidal-bioclastic packstones to grainstones with chert nodules (Figs 8, 9 B–D)

This facies is also represented in all three sections. The main components are peloids. Other allochems include bioclasts: fragments of echinoderms, bivalves, calcified sponge spicules, very rare *Saccocoma* ossicles, "*Tubiphytes" morronensis* Crescenti, and rare, macroscopically visible belemnites, micritized grains, small micritic intraclasts (strongly micritized bioclasts?), small oncoids and "pelagic" ooids.

F 3. Peloidal-bioclastic packstones to fine grained rudstones with "Tubiphytes" (Figs 8, 9 E–F)

This facies occurs only in thin intervals. Apart of peloids, relatively numerous are echinoid fragments and "*Tubiphytes" morronensis*. In Rebro (Re 19) also a fragment of coral was found, which is the earliest occurrence of coral fragment in all the studied sections. In Velinovo some beds are slightly or strongly dolomitized.

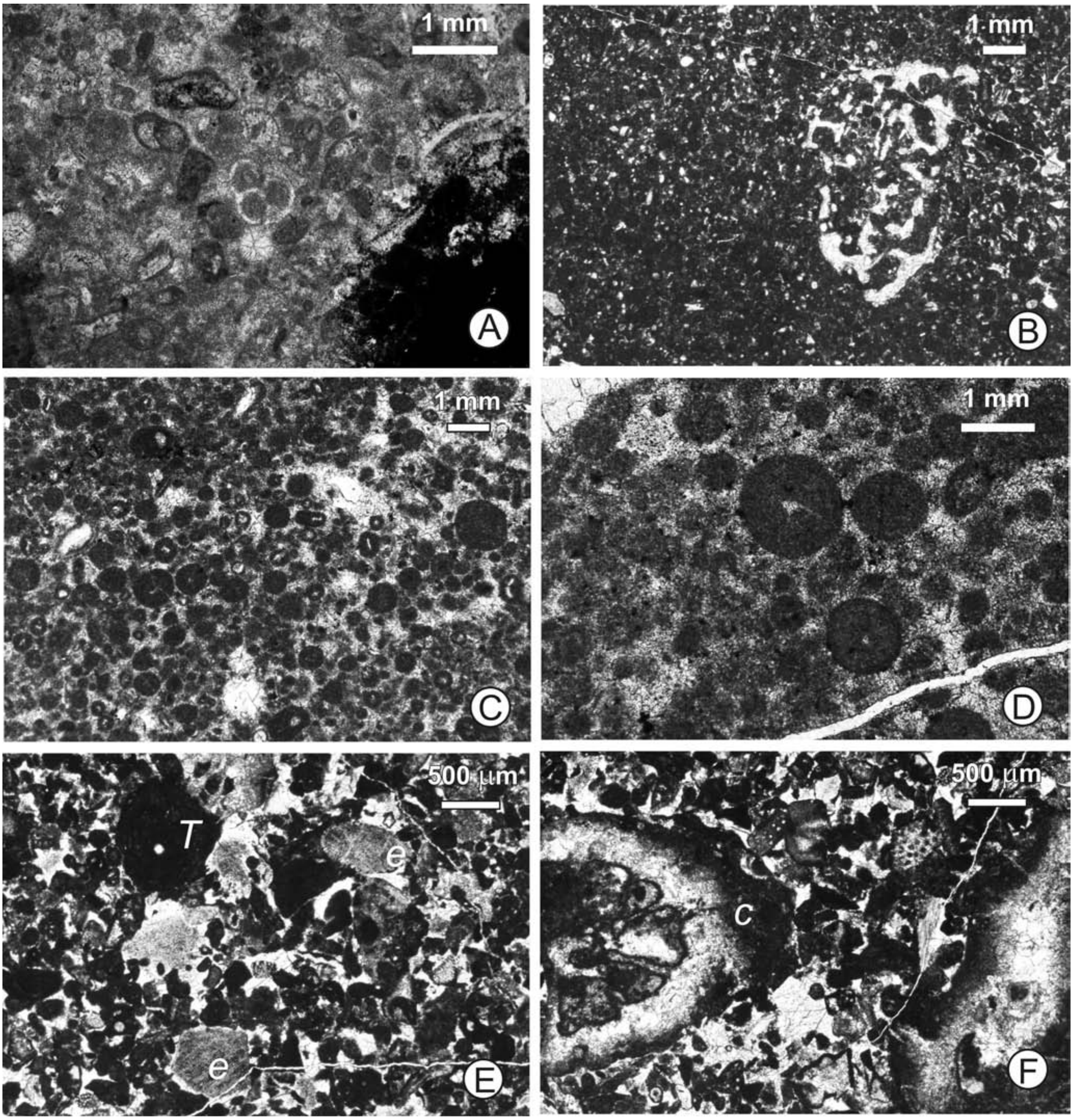


Fig. 9. Microphotographs of microfacies F 1–F 3: **A** – recrystalized peloidal and peloidal-bioclastic wackestones to grainstones with *Globuligerina* (F 1; Lia 2.1), **B** – peloidal-bioclastic packstones with calcified sponge (F 2; Re 12), **C**, **D** – peloidal-bioclastic grainstone with micritized "pelagic" ooids (F 2; Re 3), **E**, **F** – peloidal-bioclastic grainstone/fine grained rudstone with *"Tubiphytes"* (*T*), echinoid (*e*) and coral (*c*) fragments (F 3; Re 19)

Rimmed platform: platform slope (F 4 and F 5)

F 4. Peloidal-*Saccocoma *wackestones and packstones with chert nodules (Fig. 11 A–C) and F 4a. Peloidal wackestones with radiolarians (Fig. 11 D)

These facies are mainly represented at the Rebro section, and rarely at the Lyalintsi section. They are characterized by an abundant accumulation of antler-like brachial plates and other elements attributed to non-stalked crinoids *Saccocoma* exhibiting syntaxial overgrowths. *Saccocoma* are accompanied by peloids, rare foraminifers, calcified sponge spicules and sparse radiolarians. In one bed (Re 38) radiolarians dominate (F 4a). Some beds (mainly wackestones) from the sections Rebro and Lyalintsi are reddish. The limestones reveal indistinct nodular appearance. There are numerous stylolites filled with insoluble material stained by red Fe-oxides, and locally filled by dolomite rhombs.

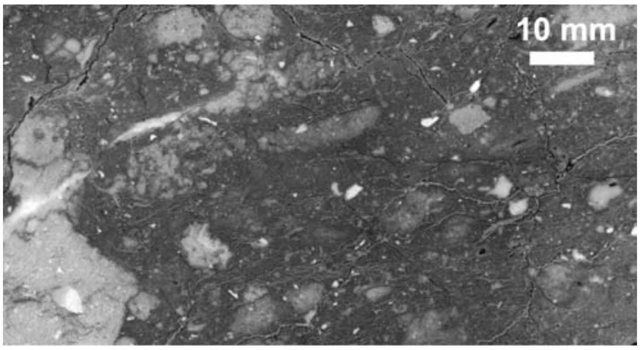


Fig. 10. Polished slab of bio-lithoclastic rudstones with *Saccocoma* (F 5). Note light lithoclasts of shallow-water limestones

F 5. Bio-lithoclastic grainstones to rudstones with Saccocoma (Figs 10, 11 E–F)

The main allochems are bioclasts which represent small fragments of corals (up to 5.0 mm in size), echinoderms (*Saccocoma* occur less frequently than in F 4), and rarely foraminifers, "*Tubiphytes*" *morronensis*, fragments of unidentified shells and calcified sponge spicules. Some bioclasts are partially silicified. Other grains include peloids and intraclasts; they are usually small, but some of them attain several centimeters.

Rimmed platform: reef (F 6, 6a) and peri-reef/bioclastic shoal facies (F 7)

F 6. Coral-microbial boundstones (Figs 8, 12, 13 A–G)

Coral-microbial boundstones seem to be developed mainly as biostromes or low bioherms. The presence of small bioconstructions or coral thickets between main coral-bearing intervals can not be excluded. Only in one place do boundstones show massive appearance (Fig. 8). Corals are rare, and possibly microencruster–early cement crusts dominate, but more detailed studies are necessary.

Corals are numerous, diversified and often preserved in life position. Phaceloid (pseudocolonial), and thin lamellar (platy) corals dominate (for more details see the next chapter). Microbial crusts and microencrusters are often present and locally abundant. They are represented by *Lithocodium aggregatum* Elliott, *Bacinella irregularis* Radoičić (much rarer than *Lithocodium*), *"Tubiphytes" morronensis* Crescenti, *Koskinobullina socialis* Cherchi et Schroeder, *Radiomura cautica* Senowbari-Daryan et Schäfer – mostly of problematic origin (see Leinfelder *et al.*, 1993; Schmid, 1996). Algae are represented by green algae: *Thaumatoporella parvovesiculifera* (Raineri), fragments of dasycladales, and rivulariaceans cyanobacteria. As in other reefs in the Tethyan domain algae are much rarer than in lagoons (e.g., Bucur *et al.*, 2005). Apart from corals other macrofaunas are rare. Growth cavities filled with early cement and fine peloidal-bioclastic sediments occur commonly. Locally microencrusters and cement crusts dominate the framework. In such boundstones microencrusters are dominated by *"Tubiphytes" morronensis*, *Radiomura cautica* and small sclerosponges (*Murania reitneri*? Schlagintweit, ?*Calcistella jachenhausensis* Reitner, ?*Cylicopsis* sp.). Corals are bored by bivalves and foraminifer *Troglotella incrustans* Wernli et Fookes associated with *Lithocodium aggregatum* encrustations (cf. Schmid & Leinfelder, 1996; Kołodziej, 1997). The rate of macroborings is low to moderate. Apart from microencrusters corals are encrusted by stromatolitic or thrombolitic microbial crusts showing dense or micropeloidal microfabric. In some samples dolomitization was recognized.

*F 6a. Diceratid-*Bacinella *boundstones (Fig. 14)*

Boundstones are locally formed by diceratid rudists associated with *Bacinella irregularis* co-occurring with *Thaumatoporella parvovesiculifera*. They occur in Lyalintsi within the interval 210–270 m but mainly as isolated blocks, so their position can not be exactly established.

F 7. Bio-lithoclastic grainstones to rudstones (Fig. 13 H)

Bioclasts are represented by corals encrusted mainly by *Lithocodium aggregatum* and microbialites, echinoderms (excluding *Saccocoma*), sclerosponges, bryozoans, fragments of thick-wall bivalves, serpulids, foraminifers, "*Tubiphytes*", and algae. Lithoclasts represent reef debris (including debris of microbialites), up to 20 mm in diameter. Some beds are partly dolomitized.

Rimmed platform: lagoon and tidal flat (F 8–F 11)

The microfacies group assigned to lagoon and tidal flat environments has been recognized only in the middle and upper part of the Velinovo section.

F 8. Foraminiferal-algal-peloidal grainstones, rarely packstones to wackestones (Fig. 15 A–E)

This is the most common facies of the studied lagoonal sediments. It is characterized by numerous benthic foraminiferal tests, rivulariacean-like cyanobacteria, and rarely fragments of dasycladalean algae. Other grains include: peloids, irregular lumps, oncoids, and pisoids with thick nuclei and densely-spaced fibrous laminae. Larger bioclasts are represented by micritized small gastropods and bivalve fragments. Grains are often linked by micritic-peloidal bridges. In some samples fenestral structures occur, and voids are filled by blocky cement and also by crystal silt. Irregularly distributed dolomite (or dedolomite) rhombs were observed in some thin sections.

F 9. Mudstones with dedolomite rhombs (Fig. 15 G)

The matrix is composed of micrite with dispersed calcite pseudomorphs after dolomite.

F 10. Intraclastic breccia (Fig. 15 F)

Irregular, small micritic intraclasts occur within the micritic matrix. Fenestral pores occur in some intraclasts. Rare foraminiferal tests have been detected, however it is possible that some micritic grains are micritized foraminifera.

F 11. Dolomites (Fig. 15 H)

These dolomites are interpreted as synsedimentary/early diagenetic dolomites attributed to tidal flat environment.

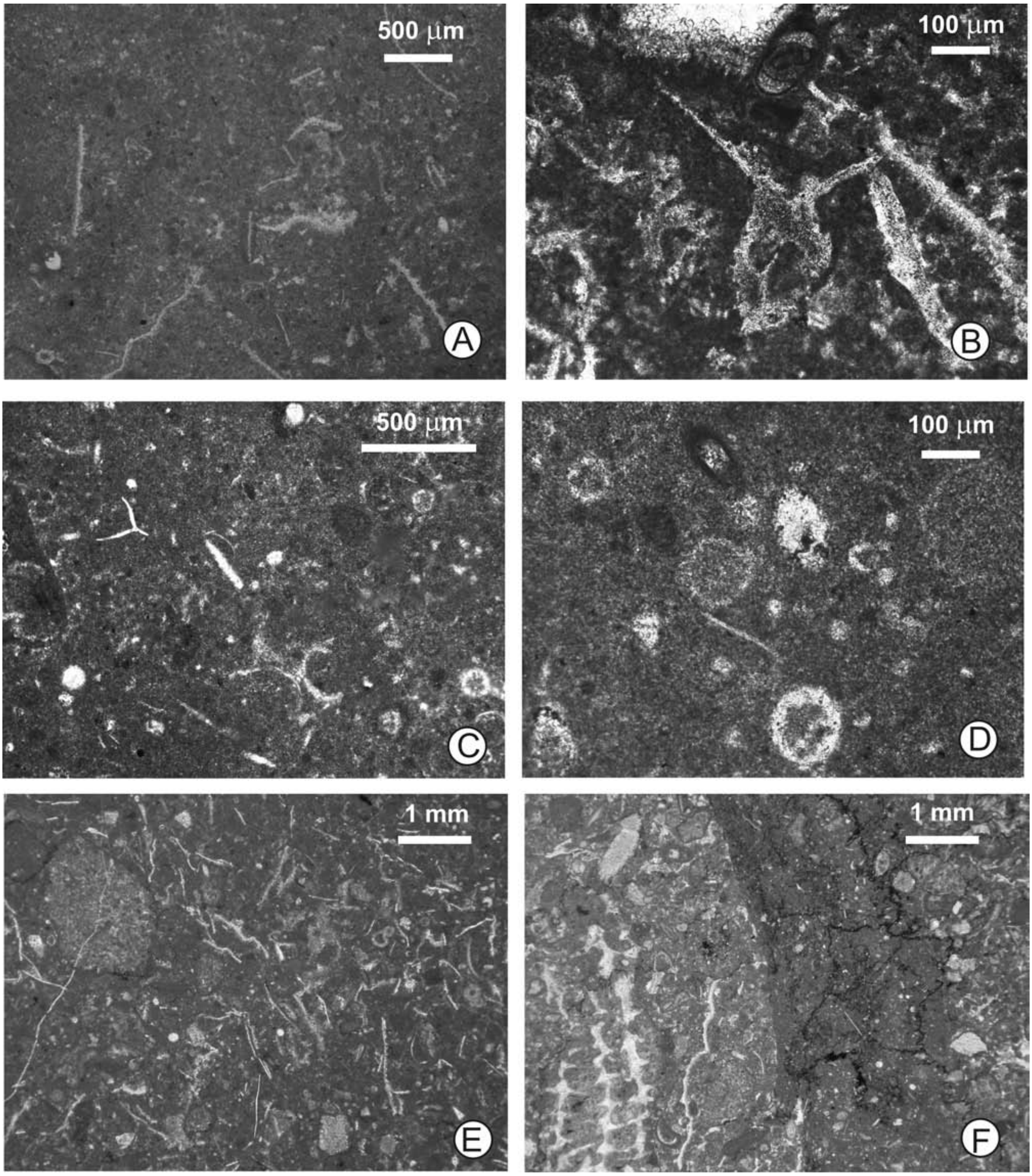


Fig. 11. **A**–**B.** Microphotographs of peloidal-*Saccocoma* wacke- to packstones (F 4): **A** – Re 34, **B** – Re 28), **C**–**D** – peloidal wackestone with calcified radiolarians and rare *Saccocoma* (F 4a; Re 38), **E**–**F** – bio-lithoclastic fine-grained rudstone with *Saccocoma* (F 5), **F** – note intraclast with coral and stylolites within matrix (**E** – Lia 72.2, **F** – Lia 54.2)

PALAEONVIRONMENT OF CORAL–MICROBIAL BUILDUPS

Coral reef intervals and coral-bearing limestones in the Lyalintsi section occur within the interval between 102 and 557 m (total thickness of coral boundstones attains at least 100 m) within the continuous succession fragmentarily exposed. It offers a unique opportunity to study coral assemblages and their palaeoenvironment during the Late Kimmeridgian–Valanginian time span. The interpretation presented here is based on analyses of the taxonomy of scleractinians and their growth forms, associated biota (particu-

Fig. 12. Fragment of coral biostrome formed by branching coral, Lyalintsi

larly microencrusters), microbialites, sedimentary matrix, as well as spatial relationships with lithological successions in the Rebro and Velinovo sections.

Abundant corals, participation of microbialites, microencrusters and early cement crusts in the reef framework justify using the term *reef* for the analysed coral-microbialite buildups, mainly biostromes. A broad meaning of this term is now commonly accepted (see Insalaco *et al.*, 1997; Wood, 1999; Riding, 2002; Flügel, 2004). Coral assemblages do not form reefs, when their skeletons are spaced more than twice the diameter of the skeletons apart, and thus do not significantly influence physical sedimentation processes. Those lithosomes should be regarded as level bottom communities (Riding, 2002; see also Sanders & Baron-Szabo, 2005), and such coral assemblages certainly occur in Lyalintsi and Rebro within facies called here as peri-reef facies.

Composition of coral fauna in the section Lyalintsi

Taxonomical diversification of coral fauna resulted in variety of growth forms, the spectrum of which corresponds to basic forms typified by Coates and Jackson (1985) in the recent fauna: *solitary*, *phaceloid* (= pseudocolonial), *colonial multiserial* (in different shapes: *ramose*, *lamellar* evolving into *submassive* with flat calicular surface, and *massive* having convex calicular surface), and *colonial uniserial* (dendroid with zigzag terminal budding). The above list is here completed by a distinction between phaceloid epithecate and non-epithecate corals, the former being typical of Mesozoic corals, while the latter of recent shallow-water corals.

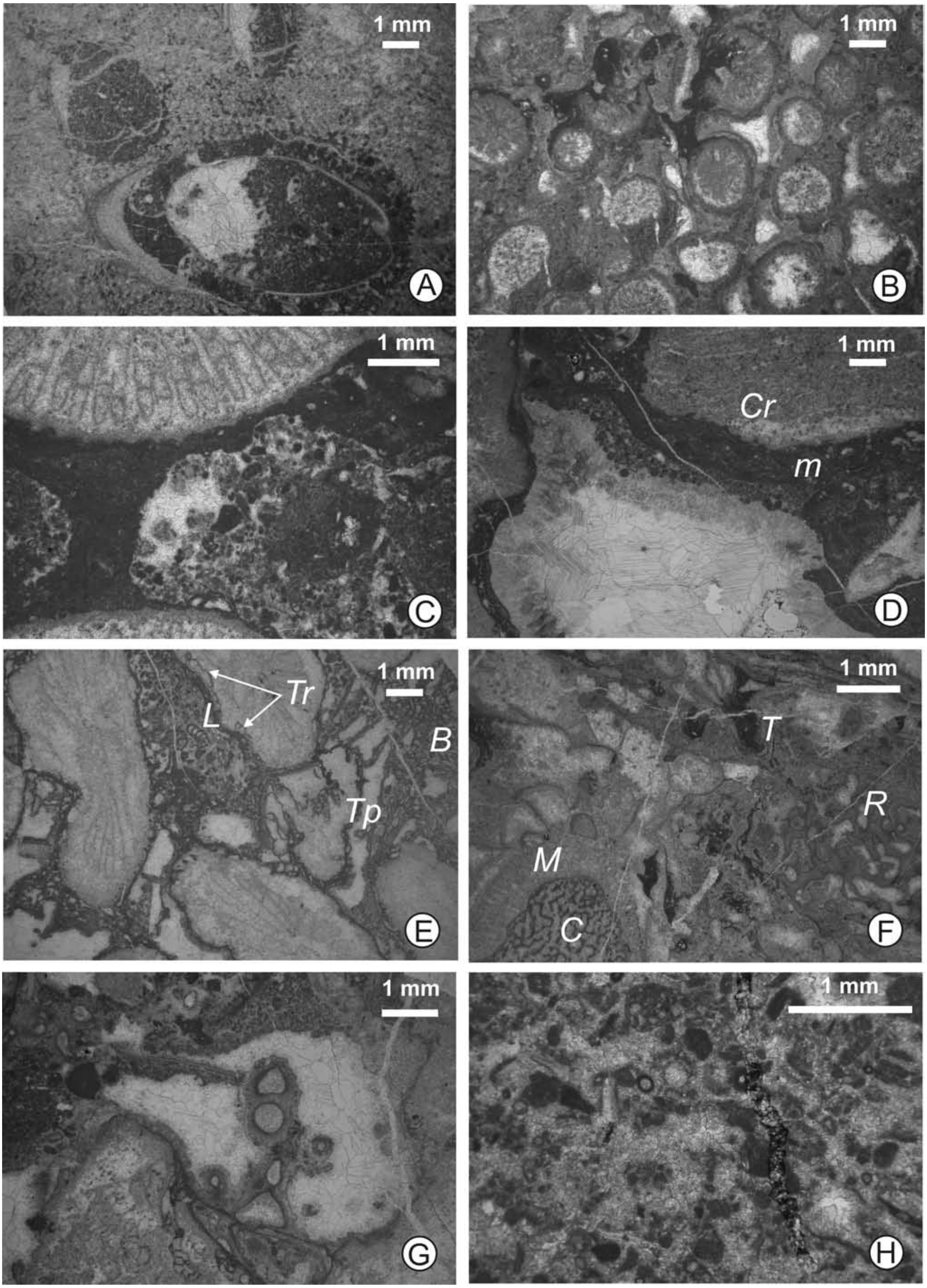
Although coral shapes seem to be analogical to those observed in the recent, abundance of phaceloid and lamellar corals in combination with particular skeleton structures in Mesozoic corals causes that interpretation of their environments is not simple. The following structures have no equivalents in recent reef corals: (1) common epithecal wall in solitary and phaceloid genera (Roniewicz & Stolarski, 1999), (2) common balcony- or flange-like structures on the septal flanks, that is pennules coalescing into menianes (Gill, 1967; Morycowa & Roniewicz, 1995), and (3) regular structural porosity of septa. Growth forms, functional morphology and their palaeoenvironmental significance are further discussed in more detail.

In the Lyalintsi section, the taxonomical coral spectrum comprises 72 species (including 6 new, 24 determined to the generic level, and 1 to the family level) of 50 genera (three new) assigned into 23 families (one new) (Roniewicz, 2008), showing the highest taxonomical diversity in the Valanginian part of the section. The majority of these corals belongs to the order Scleractinia, and 5 species from 4 genera of the suborder Pachythecaliina represent the order Hexantiniaria (compare the systematic paper on the corals from Lyalintsi by Roniewicz, 2008). The Tables 1–3 show differentiation of growth forms, colony shapes and skeletal peculiarities of this fauna. Their palaeoenvironmental significance is further considered.

Among above mentioned growth forms the pseudocolonial phaceloid (Table 1) and lamellar corals (Table 2) are the most characteristic of the Jurassic/Early Cretaceous, and these are the most diversified and common in the Lyalintsi succession. Pseudocolonial, phaceloid corals are represented by approximately 35% species and 28% genera and nearly all of them show a permanent epithecal wall. These corals are associated with colonial corals of various types: meandroid, plocoid, thamnasterioid, and only one cerioid unidentified actinastraeid coral (Table 2). Ramose colonies are over 30 cm high and their branches have diameter from below 10 mm to approximatelly 30 mm.

Corals of lamellar colony form are a group significant for palaeoecological considerations. In Lyalintsi this group is represented by 33% species and 37% of genera, usually thin-lamellar or frondose corals (Table 2). The colonies extend subhorizontally on the substrate in the form of thin lamellae, sometimes set in tiers, or form thick lamellae (ca. 3–5 cm), or submassive bodies up to 20 cm in thickness with a flat upper surface (especially in the Valanginian rhipidogyrinans and rarely in single beds in the Tithonian, or in the Berriasian.

Fig. 13. Microphotographs of reefal (F 6; A–G) and peri-reefal facies (F 7; H); Lyalintsi: **A** – *Microsolena agaricformis* bored by lithophagid bivalves (Lia 75a/19), **B** – *"Tubiphytes" morronensis* and cement crusts between coral branches of *Stylosmilia octonaria* (Lia 73/17), **C** –Microbial "bridge" connecting coral branches (30257c), **D** – Growth cavitiy filled by cement, *Cr*– coral, *m* – microbial crust (NMNHS F 30257c), **E** – Branching coral encrusted by *Thaumatoporella parvovesiculifera* (*Tp*), *Bacinella irregularis* (*B*) and *Lithocodium aggregatum* (*L*) associated with boring foraminifer *Troglotella incrustans* (*Tr*) (NMNHS F 30202a), **F** – Microencruster-cement crusts framework; *R – Radiomura cautica*, *T – "Tubiphytes" morronensis*, *C–?Cylicopsis* sp., *M – Murania reitneri*? (Lia 49.2), **G** – *Radiomura cautica* encrusting coral skeleton (NMNHS F 30254a), **H** – bioclastic grainstone (F 7) with stylolite stained by Fe-oxides, and filled by dolomite rombs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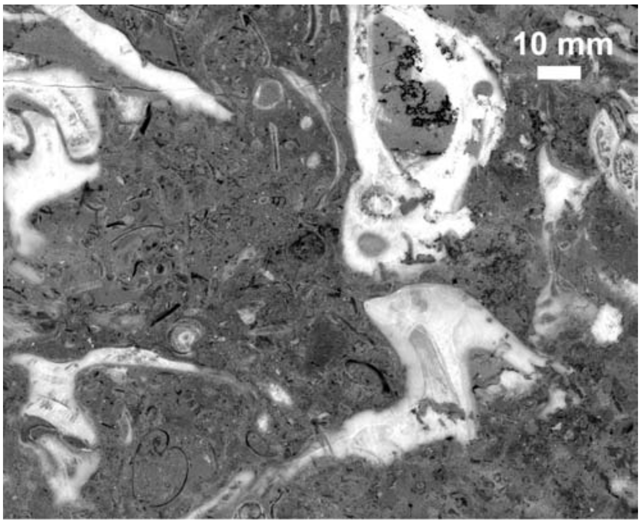


Fig. 14. Polished slab of diceratid-*Bacinella* boundstone (F 6a), Lyalintsi

Table 1

Differentiation of coral growth forms in the Lyalintsi sequence (the most frequent in bold)

Growth form	Number of species/genera	Common taxa
solitary	> 6/5	*Haplaraea*, *Montlivaltia*, *Pleurosmilia*, ***Rhipidogyra***, *Trocharaea*
phaceloid epithecate, common corals corallite diameters 1.5-25 mm	25/14	***Calamophylliopsis***, ***Cladophyllia***, ***Latomeandra***, *Misistella*, *Stylosmilia*, ***Thecosmilia***
colonial: plocoid, thamnasterioid meandroid, cerioid	10/8	*Actinaraea*, ***Microphyllia***, ***Microsolena***, *Pseudocoenia*, ***Solenocoenia***, *"Thamnarea"*
colonial uniserial	2/2	*Enallhelia*, *Tiaradendron*

A significant number of species, all from the families Microsolenidae and Latomeandridae (Table 3) are characterized by septa covered with pennules that may indicate adaptations to filtering mode of feeding (see below). Moreover, corals with a regular, structural porosity of septa of the microsolenid genera enumerated above, and haplareid genera (Table 2) are common, although not especially diversified taxonomically (Table 3). In both groups, the most frequent are colonial corals with lamellar shapes.

Massive corals (convex colony surface) and solitary forms constitute together 18% of all genera, but are not common in comparison with other types.

Table 2

Differentiation of colony shape in the coral fauna from the Lyalintsi sequence (the most frequent in bold)

Colony shape	Number of species/genera	Common taxa
ramose diameter of branches from <10 mm to 25 mm	7/7	*Actinaraea*, ***Microphyllia***, *Microsolena*, *Pseudocoenia*, ***Solenocoenia***, ***"Thamnarea"***
lamellar common corals (thickness up to 5 cm)	24/19	*Actinaraea*, ***Dimorphastrea***, ***Microsolena***, *Protoseris*, ***Synastrea***
thick-lamellar to submassive (thickness to 20 cm)		*Comoseris*, *Complexastrea*, *Microsolena*, ***Ogilvinella***, ***Placogyra***, *Pruvostastraea*
massive	6/4	*Bilaterocoenia*, *Comoseris*, ***Cyathophora***, ***Pseudocoenia***

Table 3

Pennular septa and septal structural porosity in the coral fauna from the Lyalintsi sequence
(the most frequent in bold)

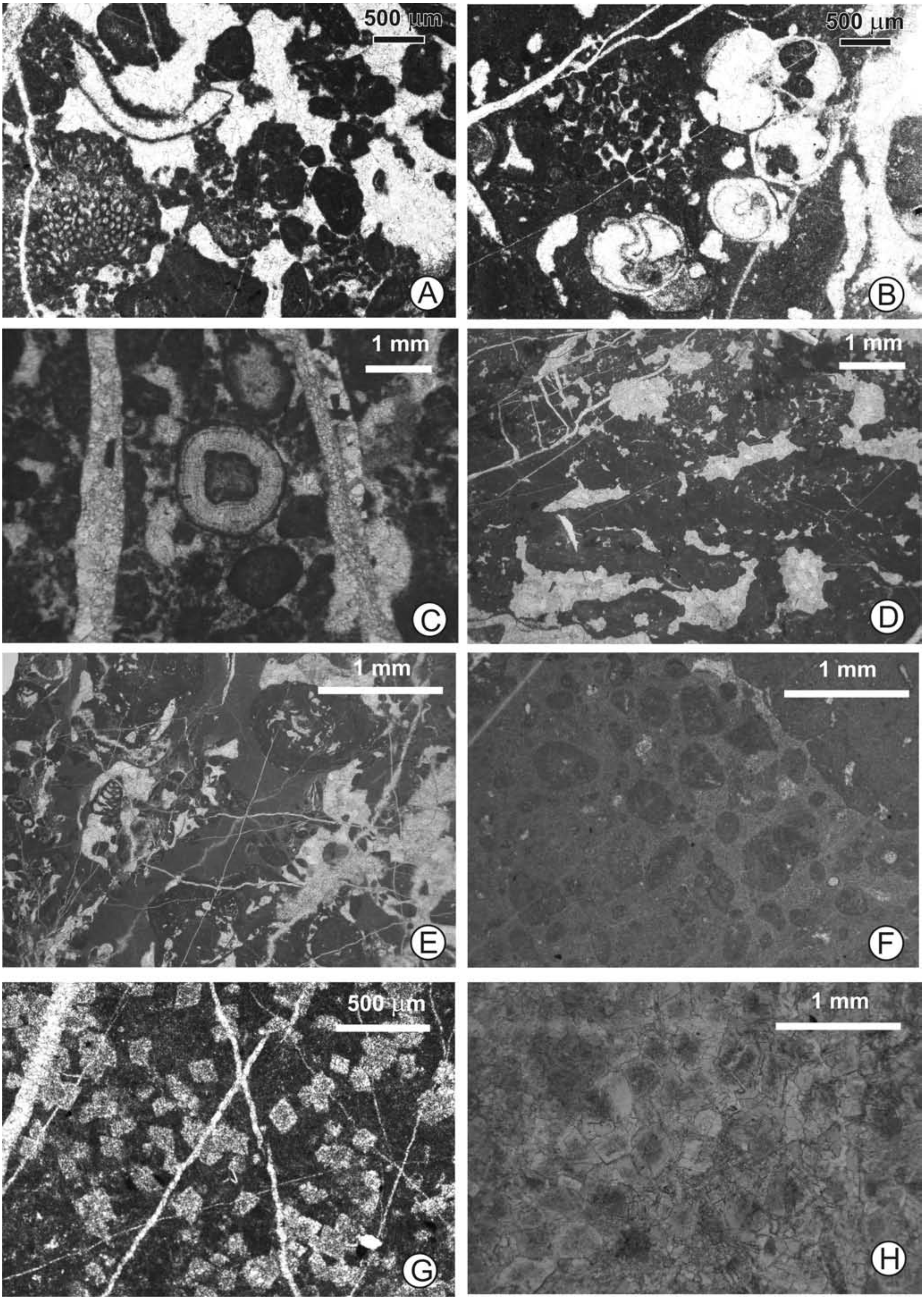
Septal structure	Percent of species	Taxa
septa pennular	15%	*Comophyllia*, *Comoseris*, *Dermoseris*, ***Dimorphastrea***, ***Latomeandra***, ***Microphyllia***, ***Microsolena***, *Ovalastrea*, *Periseris*, *Protoseris*, ***Synastrea***, ***"Thamnarea"***, *Trocharea*
septa regularly porous	6.5%	*Actinaraea*, *Comoseris*, *Dermoseris*, *Haplaraea*, ***Microsolena***, ***Synastrea***, *Trocharea*

Reef type

In general character of coral assemblages and associated biota, the analysed material has more in common with Jurassic coral–microbial reefs, than with Early Cretaceous (Urgonian) reefs. It is in agreement with a general observation that Berriasian and Valanginian corals are similar to Late Jurassic ones; a new type of coral fauna appeared in the next stage of coral evolution in the Hauterivian (Roniewicz & Morycowa, 1993).

This similarity justifies using the Jurassic case studies in the interpretation of the studied reefs also of Berriasian–Valanginian age. In the Late Jurassic, particularly in the Oxfordian, corals, sponges and microbialites commonly

Fig. 15. Microphotographs of microfacies of lagoon and tidal flat environments (F 8–F 11) from Velinovo: **A**, **D** – Algal-foraminiferal-peloidal grainstone (F 8), **A** – note micritic-peloidal "bridges" between bioclasts and micritized grains (Ve 40), **B** – F 8 with locally numerous gastropods (Ve 43), **C** – peloidal-bioclastic wackestone with pisoids (Ve 45), **D** – peloidal-bioclastic wackestone with fenestral voids (Ve 47), **E** – foraminiferal-algal grainstones with vadose silt (Ve 41), **F** – intraclastic breccia (F 9; Ve 51), **G** – mudstone with dedolomite rhombs (F 8), **H** – dolomite (F 11)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formed a variety of reef types in different environmental settings (e.g., Leinfelder, 1993; Leinfelder *et al.*, 1994, 1996, 2002; Insalaco *et al.*, 1997). In some Middle Jurassic (Bajocian: Geister & Lathuilière, 1991; Olivier *et al.*, 2006), Late Jurassic (Oxfordian: e.g., Dupraz & Strasser, 2002; Olivier *et al.*, 2004; Lathuilière *et al.*, 2005), and Early Cretaceous (e.g., Hauterivian: Götz *et al.*, 2005) coral reefs, faunal and lithological changes are well recorded. They were controlled by environmental changes in such factors as water depth or nutrient content.

Surprisingly, although the reefs alternately withdrew and reappeared within the Lyalintsi section, when the coral-microbial biostromes renewed they did not show (with rare exceptions) significant differences from those earlier deposited.

When compared with Oxfordian coral reefs (Insalaco *et al.*, 1997: eight types of reefs) the buildups from the Lyalintsi section, mainly biostromes, seem to represent transitional reef type between biostromal units dominated by platy microsolenids within limestone facies (Oxfordian type I), and coral-microbial reefs dominated by massive, branching ramose and phaceloid facies (Oxfordian type IV). However, in Lyalintsi lamellar forms rarely dominate (102, 257 and 359 m levels), and in the remaining assemblages ramose colonies and phaceloid corals dominate, with the addition of submassive colonies, massive colonies being rare.

In the Bulgarian reefs, abundant corals co-occur with microencrusters and cement crusts. Microencruster-cement crust framework appears to be characteristic especially to the Late Jurassic–earliest Cretaceous in the Neotethyan realm and was described in details from the Northern Calcareous Alps (Schlagintweit & Gawlick, 2008). Boundstones of this type occur also in Štramberk-type limestones (Tithonian–earliest Cretaceous) in Romania and in the Polish Flysch Carpathians (Sasaran, 2006, figs 3.7, 3.14; Hoffmann *et al.*, in press). Microencruster framework contains mainly *"Tubiphytes" morronensis*, *Radiomura cautica* and thin sclerosponge crusts (in Bulgarian reefs *Murania reitneri*? is common).

Palaeoenvironmental interpretation

The lithology of sediments from the analysed sections as well as character of coral assemblages in Lyalintsi suggest reef development in an environment of an outer platform, separated from an inner platform by bioclastic shoals. Coral structures, associated organisms and sediment features in Lyalintsi sequence contribute to the interpretation of the nutrient availability, depth and hydrodynamics of the reef environment considered.

Trophy. In Lyalintsi, microbialites, microencrusters and cement crusts significantly contributed to the buildups growth fabric. Detailed quantitative analyses of microencrusters were not performed, but microfacies analysis revealed that in about 40% of observed thin sections encrustations of *Lithocodium aggregatum* are present on coral skeletons. This light-dependent microorganism, is interpreted as an indicator of oligotrophic and well-illuminated waters (Leinfelder *et al.*, 1993; Dupraz & Strasser, 2002; Olivier *et al.*, 2004).

Microbial overgrowth, usually showing peloidal microfabric, occurs as the second layer of encrustation or directly covers coral skeletons. Early lithification of intra-reef biopelmicrite is evidenced by numerous growth cavities filled with biopelmicrite/biopelsparite or with sparitic cement. The microbialites, generally interpreted as reflecting nutrient-richer conditions, can develop together with phototrophic organisms inside the reefs, where metabolic products of heterotrophic bacteria were fuelled with organic matter produced by phototrophs (Dupraz & Strasser, 2002).

In the case of analysed reefs, the microbial development was controlled mainly by authigenic factors. No microbialite dominated intervals have been identified within the Lyalintsi section, suggesting lack of significant changes in nutrient levels; neither in Lyalintsi, nor in the Rebro and Velinovo sections (allogenic factors discussed by Sanders and Baron-Szabo, 2005). Oligotrophic or mildly mesotrophic environment of analysed reefs is also suggested by relatively rare macroborings, *Terebella lapilloides* Münster and rare concentrations of macrofauna (diceratid bivalves). However small heterotrophic microorganisms: serpulids, bryozoans, encrusting sclerosponges, as well fragments of echinoderms and bivalves are visible in thin sections.

A particular coral skeletal structure, that is a regular septal porosity of the microsolenid and haplareid corals (Table 3) is supposed to be the result of reduced carbonate deposition involved by light deficiency, or somewhat raised trophy (Insalaco, 1996; Rosen *et al.*, 2002, and literature therein). An augmented nutrient level, accompanied by lower background sedimentation can be also inferred from the more frequent bivalve borings within those lamellar corals than in others.

Typical microsolenid biostromes built of lamellate colonies characteristic of the Late Jurassic and Early Cretaceous (Insalaco, 1996; Rosen *et al.*, 2002) are lacking in the section. Nevertheless, corals from the order Microsolenina (Table 3: microsolenids and latomeandrids) occur as a permanent element in heterogeneous assemblages throughout the whole succession. This suborder is characterized by septal faces provided with pennules and menianes (Gill, 1967; Morycowa & Roniewicz, 1995). In these features microsoleninan corals resemble recent agariciids, particularly *Leptoseris fragilis* Milne Edwards et Haime, the corals living on deep slopes (below 100 m) of the recent reefs or on the sea floor (Chevalier, 1987; Schlichter, 1992, and references therein). *Per analogiam*, microsoleninan corals, lamellar and provided with menianes (skeletal structures optimizing heterotrophic nutrition), are considered to be indicative of light deficient conditions caused by depth or turbidity (Morycowa & Roniewicz, 1995; Geister & Lathuilière, 1991; Gill *et al.*, 2004; "euphotic floor model": Rosen *et al.*, 2002; compare also Sanders & Baron-Szabo, 2005). Although the studied corals from the suborder Microsolenina do not form distinct reefal units, they could show extended growth during short episodes.

Depth and water dynamics. We suppose that growth and demise of reefs within the analysed section were mainly controlled by sea-level fluctuations and associated changes in illumination, depositional energy, rate of background sedimentation, and accommodation space. Sea-level rise evidently disturbed reef growth during the mobile stage of the platform evolution in the Late Kimmeridgian–Tithonian as evidenced by intervals of deeper water limestones with *Saccocoma* (F 4, F 5) or radiolarians (F 4a) in the Lyalintsi succession. These limestones (Gintsi Formation) form a thick interval in the Rebro section.

In the Valanginian, a prevailing number of coral beds with colonial ramose and phaceloid epithecate coral associations in life position suggests a persistency of moderate hydrodynamic conditions during a considerable span of time, however other environmental factors could influence their taphonomy.

Similar assemblages dominated by ramose and phaceloid corals are known in the Middle Jurassic reefs (France: Olivier *et al.*, 2006), in the Late Jurassic European reefs, mainly the Oxfordian (England, France, Swiss: types III and VIII of Insalaco *et al.*, 1997), and the Early Kimmeridgian (Central Poland: Roniewicz & Roniewicz, 1971). In contrast to the recent reefs dominated by ramose colonial corals, the Mesozoic reefs built of phaceloid corals were developed mainly in protected platform-interior settings. Such corals can be preserved *in situ* if they continuously baffled sediment during their growth Some authors even suggest that branching corals were adapted to enhanced sedimentation because with their high growth rate they were able to keep pace with sediment accumulation (e.g., Leinfelder *et al.*, 1994, 1996; Helm & Schülke, 1998, 2006; Lathuilière *et al.*, 2005).

The presence of bioclastic matrix (grainstones–packstones) and the absence of microbialites between branches of some corals from Lyalintsi, evidence episodes of higher energy and higher background sedimentation. Constratal growth fabric of scleractinians occurs when vertical coral accretion occurred at similar rate to background sedimentation. As a result, constratal fabric would be more sensitive to extrinsic sedimentological factors and more likely to be buried (Insalaco, 1998). Additionally, microbialites which contributed to reef formation strengthened the growth fabric (e.g., Bajocian coral-microbial biostromes; Olivier *et al.*, 2006).

In the Lyalintsi section distinct horizons with coral biostromes could be observed, but unfortunately, lateral changes are hardly recognizable in the field. The samples collected between main coral-bearing beds contain fragments of corals. Such deposits can represent peri-reef deposits. On the other hand, thick coral-barren intervals suggest withdrawal of reefs or their poorer development during long span of time. High energy and high accumulation rate could significantly reduce development of corals and microbialites. However, even in such stressful environment reefs could develop. Reef type VIII in the classification of Insalaco *et al.* (1997) is represented by reefal thickets which could occur among more stable sediments within hydrodynamic quiet areas protected by sand shoals, and over the shoals themselves. The presence of bioclastic grainstones with coral fragments as well coral colonies in the sections Velinovo (Sapunov *et al.*, 1985) and Rebro indicates that sea-level fluctuations resulted in the migration of reefal facies.

DISCUSSION

The Early Oxfordian is characterized by gaps, condensed sequences, and lack of larger reefs. Change in accumulation rates occurred in the Middle Oxfordian (Norris & Hallam, 1995; Rais *et al.*, 2007, and references therein). On the studied part of the Moesian Platform the Oxfordian marine carbonates overlie the erosional surface of the oncoid-bearing limestones of the Bajocian–Early Bathonian Polaten Formation. Above Bathonian, Oxfordian has been recognized, while Callovian is lacking, contrary to earlier literature (Sapunov *et al.,* 1985). In all the studied sections, deposits show uniform character (Fig. 16 – phase 1). Peloidal wacke-packstones with rare *Globuligerina,* and admixture of quartz in the lowermost part (F 1) were deposited on a homoclinal ramp. Small thickness (from 0.2 to 6 m) and synsedimentary mineralization within F 1 indicate a lower deposition rate of the lowermost Oxfordian sediments. The presence of *Globuligerina* suggests a deeper setting of deposition.

In the Early Kimmeridgian sedimentation shows still uniform character (F 2 – peloidal-bioclastic packstones to grainstones with chert nodules). The limestones were, most probably, formed at the upper part of the homoclinal ramp under influence of open-marine conditions (rare *Saccocoma*), where autochthonous and allochthonous components were mixed (Fig. 16 – phase 2).

Later, but still in the Early Kimmeridgian, relatively uniform sedimentation continued, although the gradual differentiation of environments was recognized at this time (Fig. 16 – phase 2). Peloidal-bioclastic packstones and grainstones with cherts (F 2) occur in all of the studied sections, whereas peloidal packstones to rudstones with *"Tubiphytes" morronensis* (F 3) occur in more shallow-water settings in the Lyalintsi and Velinovo successions. All these microfacies are characteristic of the Yavorets Formation, which were principally deposited in the deeper settings (Sapunov *et al.*, 1985). Despite these lithological similarities only sediments from Rebro were traditionally attributed to the Yavorets Formation, whereas these ones from Lyalintsi and Velinovo were previously assigned to the Slivnitsa Formation (Sapunov *et al.*, 1985).

Siliceous sponges, preserved mainly as isolated calcified spicules, were possible silica source for chert formation. Although sponge spicules and chert nodules occur in the Rebro, Lyalintsi and Velinovo sections, no sponge reefal units occur. Siliceous sponge biostromes and sponge-microbialite mud-mounds were extensively developed at the northern margin of the Tethys during the Middle and Late Oxfordian. The Late Jurassic sponge reefs are very rare or absent in the eastern part of the northern Tethys, the southern hemisphere and the Pacific realm, which is explained as a result of the lack of deeper epeiric seas and wide flooded shelves. During the Kimmeridgian, except for the area of the southern Germany, the northern Tethys underwent a significant change from siliceous sponge facies to coral facies. In the Tithonian only scattered sponge reefs occur (Leinfelder *et al.*, 2002). The lack of broad carbonate shelves/ramps should be also taken into consideration when interpreting the absence of sponge facies in the studied area.

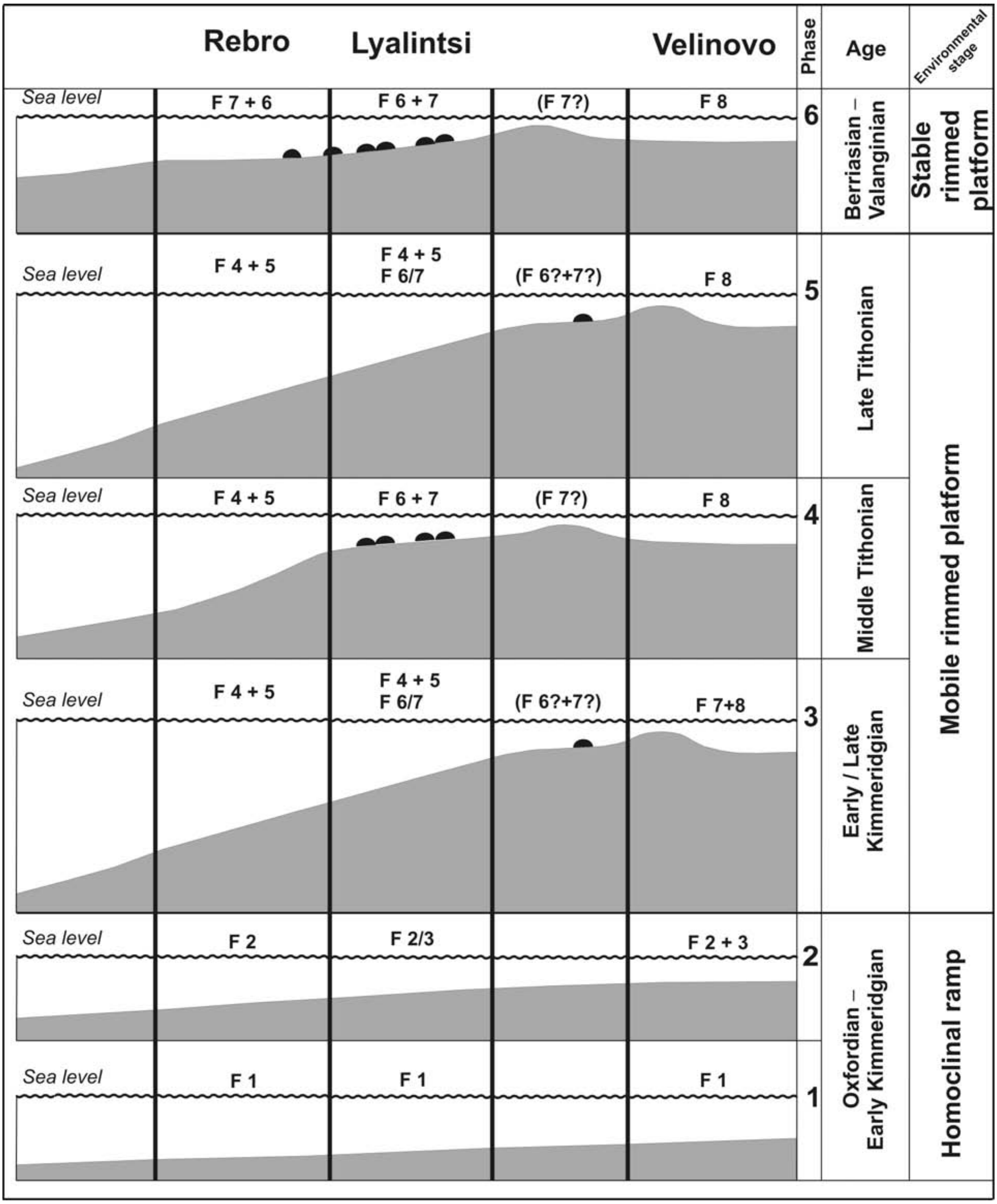

Fig. 16. Main phases of the ramp–platform evolution from Oxfordian to Valanginan. Location of the analysed sections and distribution of described main facies are shown

After the relatively unified sedimentation on the homoclinal ramp, a rimmed platform originated around the Late Kimmeridgian, when first coral limestones appeared. Coral growth influenced the carbonate platform morphology and resulted in environmental lateral facies differentiation over a relatively small area (recent distance between Rebro and Velinovo is about 13 km). Two stages of the rimmed carbonate platform evolution have been recognized: a mobile stage (Fig. 16 – phases 3, 4, 5), and a stable one (Fig. 16 – phase 6; Ivanova *et al.*, 2006). The sea-level oscilations during the mobile stage was possibly controlled mainly by tectonics as sudden change of facies (F 4 – F 6 –

F 4) suggests. The transition between both stages occurred around the Jurassic/Cretaceous boundary.

Facies differentiation is well recognizable during a mobile stage. The section in Rebro is characterized by deeper water sediments: peloidal-*Saccocoma* wackestones and packstones with chert nodules (F 4), and sporadically by peloidal wackestones with radiolaria (F 4a). Sapunov *et al.* (1985) have taken into account the reddish colour and indistinct nodular appearance of these limestones and referred them to the Gintsi Formation (the *Ammonitico Rosso* lithofacies). Principally, the *Ammonitico Rosso* is composed of pelagic and condensed limestones deposited on submerged elevations or current-swept structural highs (e.g., Rehakova, 1995; Clari & Martire, 1996). In the studied case the limestones acumulated on a platform slope setting, where they are interbeded with carbonate gravity mass flows (F 5 – bio-lithoclastic grainstones to rudstones with *Saccocoma*) containing clasts of limestones imported from the shallow-water part of the platform (Lyalintsi).

The intervals of limestones with *Saccocoma* (Gintsi Formation) recognized in the Lyalintsi section interbedded with shallow-water limestones of the Slivnitsa Formation evidence recurrent sea level rises during the mobile stage of the platform evolution in the Tithonian. This resulted in interruption of reef development (Fig. 16 – phases 3 and 5). In the section Velinovo relative sea-level rise is reflected by the occurrence of intervals with sediments characteristic for bioclastic shoals or peri-reef facies (F 7) deposited in the vicinity of reefs (or coral thickets).

The second stage of the platform evolution – from Berriasian to Valanginian – was more tectonically stable, without considerable vertical facies changes, but still showing lateral variations (Fig. 16 – phase 6). Reefal, peri-reefal or bioclastic shoals sediments dominate in the Lyalintsi section, whereas the Rebro section is dominated by bioclastic carbonates, however possibly deposited in the more distal part of the platform. The presence of coral colonies *in situ* were also observed in the Velinovo (Sapunov *et al.*, 1985) and Rebro sections.

Facies differentiation between the outer platform, reefal zone and the inner platform evidences the existence of a barrier between Lyalintsi and Velinovo, possibly developed as bioclastic shoals (oolites were not identified), which obviously formed an effective morphological barrier isolating the inner platform from the outer platform with reefs.

The stratigraphic distribution of the studied reefal limestones is in contrast to the global restriction of coral reefs development, especially in the Valanginian (with some exceptions, e.g., the Štramberk Limestone of mostly Tithonian age). A worldwide transgression continued through the Kimmeridgian and the Early Tithonian. Reefs formed during that time are much rarer than in the Oxfordian. The middle Tithonian withdrawal of reefs in most areas is correlated with global sea-level fall. Further shallowing trend caused a decline of the “Reef Age” during the latest Tithonian–Berriasian time. Reefs grew whenever third-order sea-level rise opened “the reef window” (Leinfelder *et al.*, 2002). However, sea level-curves proposed by various authors differ (see Hallam, 2001). Sea-level curve presented by Haq *et al.* (1987) shows several rapid sea-level oscillations during the Tithonian, but these authors, as well as Hallam (1988), agree that the Tithonian sea-level peak was followed by a fall in the earliest Cretaceous.

In the studied reefs, corals show the highest taxonomical diversity in the Valanginian. Reefal coral-microbial biostromes, low bioherms or coral thickets were formed in an environment of moderate energy, and moderate or episodically a high rate of sedimentation, as suggested by numerous phaceloidal corals in growth position. Locally, microencrusters and cement crusts were important part of reef framework. In contrast to the reef described by Schlagintweit and Gawlick (2008) the microencruster-cement framework is in Bulgarian reefs often associated with corals.

The environment was rather oligotrophic or mildly mesotrophic as indicated by the absence of pure microbialite reefs, a lack of siliciclastic intercalations, poor developement of heterotrophic macrofauna, and low to moderate borings intensity. All that suggest that the nutrient level was rather low and nutrient fluctuations were not significant controls in reef development.

Autocyclicity is assumed to be fundamental for reef development during the second stage. High carbonate production and/or regressive eustatic events not compensated by substrate subsidence reduced accommodation space. High energy enhanced accumulation rate, reduced or eliminated corals and microbialite growth (cf. Leinfelder *et al.*, 1996, 2005). Bioclastic material in Rebro appears to have derived mainly from Lyalintsi reefal zone. Within such shoals short-time patch reefs could exist during shoal stability and within protected areas (reef type VIII according to the classification of Insalaco *et al.*, 1997).

Microfacies recognized in the Velinovo section – developed during the stable stage of the platform – represent lagoon and intertidal environments (F 8–F 11). Sporadic input of carbonate material from bioclastic shoals or their landward migration is evidenced by local occurrence of F 7, however much rarer than in the previous mobile stage. Foraminiferal-algal grainstones are characteristic of high-energy open lagoon (e.g., Bucur *et al.*, 2005). Rare dasycladaleans and rare fragments of other macrofauna (only gastropods are locally numerous) suggest more restrictive lagoonal environment. The presence of crystal silt in some samples indicates meteoric-vadose diagenesis, possibly due to short subaerial exposure in a supratidal zone. Microfacies F 8–10 can be interpreted as deposits of a tidal flat (cf. Schlagintweit *et al.*, 2003). In contrast to dolomitization occurring locally within sediments of the outer platform, dolomites from this zone are possibly a result of the synsedimentary/early diagenetic dolomitization of lagoonal and tidal flat limestones.

At the top of the Valanginian limestones, a karstified surface is developed and represents a boundary with the Turonian (Late Cretaceous) deposits. During the Hauterivian most part of the Moesian carbonate platform was drowned. However, the Hauterivian shallow-water sedimentation still occurred on small shoals of the Western Fore-Balkan and the Eastern Moesian Platform (Nikolov *et al.*, 1998; Minkovska *et al.*, 2002). Platform drowning was initiated locally in the Late Valanginian as indicate our new observations of the section in Berende Izvor. Sedimentary succession from this locality was also deposited on the Dragoman Platform, but during Mid–Late Cretaceous was not included in the Lyubash monocline. New data based on microfacies analysis of the uppermost part of the section overling lagoonal sediments (Ivanova & Koleva-Rekalova, 2004) revealed outer platform deposits evidencing an deepening event. This event is recorded, because in contrast to Velinovo, Late Valanginian age was recognized in the uppermost part of the Berende Izvor section (Ivanova & Koleva-Rekalova, 2004, and unpublished data of D. Ivanova). If this event is not related to a local tectonics it could be correlated with sea level rise in the early Late Valanginian (van de Schootbrugge *et al.*, 2000).

Recently, Tchoumatchenco (2002, 2006) has proposed a sequence stratigraphic subdivision of the Jurassic–lowermost Cretaceous deposits of the western Bulgaria, including the Lyubash Mt, though without detailed discussion. A sequence stratigraphic analysis was beyond of scope of this paper. More extensive studies are needed to reveal both vertical and lateral changes within the studied sections, as well as comparative studies in adjacent areas. These will allow a more reliable reconstruction in terms of sequence stratigraphy.

CONCLUSIONS

1. Three sections studied: Rebro, Lyalintsi and Velinovo (SW Bulgaria) represent the Dragoman Block, a western part of the Moesian Carbonate Platform, since Mid–Late Cretaceous forming the Lyubash unit, a part of the Srednogorie, Balkanides. Micropalaeontological studies of foraminifera and calcareous dinoflagellate cysts indicate the Oxfordian–Valanginian age of the analysed sequences. Middle to Late Callovian age of the lowermost part of the studied sections, assumed in the older literature, has not been confirmed.

2. Eleven facies have been distinguished and attributed to depositional environments. Marine sedimentation started on a carbonate homoclinal ramp in the Oxfordian and till Early Kimmeridgian carbonate sedimentation was dominated by fine-grained peloidal-bioclastic wackestones to grainstones. The lowermost part of Oxfordian deposits exhibits features of sedimentation at lower rates. Since the Late Kimmeridgian when the rimmed platform was established, facies pattern underwent differentiation into (i) the inner platform (lagoon and tidal flat facies), (ii) reef and peri-reef/bioclastic shoal environments, and (iii) the platform slope.

3. Sedimentatary successions display generally a shallowing-upward trend. Two stages in the evolution of the rimmed platform are postulated. During the first mobile stage (Late Kimmeridgian to Tithonian/Berriasian boundary) relative sea-level fluctuations, possibly controlled mainly by local tectonics, have been the primary cause of vertical facies changes. Sea-level rise interrupting reef development is evidenced by intercalations of limestones with *Saccocoma*. In the second, a more stabile stage (Berriasian to Valanginian) high carbonate production (not balanced by subsidence) and/or eustatic regressive events decreased accommodation space, limiting reef development and enhancing carbonate export to distal parts of the platform. The Rebro section during development of the carbonate platform was dominated by slope deposits (during the first stage) and peri-reef, rarely reefal facies (second stage); the Lyalintsi section was dominated by reef and peri-reef facies; and the Velinovo section is characterized mainly by deposits of the inner platform (lagoon and tidal flat).

4. Reefs are developed mainly as coral-microbial biostromes and represent environment of moderate energy and sedimentation. They contain highly diversified scleractinian corals dominated by phaceloid and lamellar forms, preserved often in life position. Microbialites, microencrusters and cement crusts contributed to the reef framework. No boundstones dominated by microbialites were recognized, which together with relatively rare macroborings, rare concentrations of heterotrophic macrofauna, indicate oligotrophic or mildly mesotrophic environment. The highest development of reefs in Lyalintsi is observed in Valanginian part of the sequence studied which is in contrast to general worldwide reefs decline at that time.

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