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Palaeogeographic Variability and Depositional Environments of the Upper Jurassic Carbonate Rocks of Velika Kapela Mt. (Gorski Kotar Area, Adriatic Carbonate Platform, Croatia)

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Key words: Palaeogeography, Synsedimentary tectonics, Facies variability, Platform carbonates, Intraplatform trough, Limestones with chert, Hydrozoan–coral reefs and peri-reefal area, Kimmeridgian, Velika Kapela Mt., Croatia.

Abstract

Synsedimentary tectonics caused significant differentiation of sedimentary environments of the Adriatic Carbonate Platform during the Kimmeridgian. The most important changes have been recorded in W and central Croatia: along the NW part in present day W Istria there was an emergence with bauxite deposits, while along the NE margin of the platform, in the Karlovac area, a former emerged area was submerged.

Penecontemporaneously between these areas, in the wider area of Velika Kapela Mt., a shallow intraplatform trough was formed, characterised by deposition of dark mudstones with nodules and thin layers of cherts and thin interbeds of tuffs in the upper part of the succession. Occurrences of planktonic foraminifera, radiolarians, calcisphaeres and rare ammonites indicate the sporadic influence of the open sea. Along the margins of the trough, peri-reefal environments were established, with flourishing developments of different reef-building organisms – hydrozoans, stromatoporoids, corals and bryozoans. Reefs were continuously destroyed, and in this way derived material was reworked and transported towards the trough slopes. An enormous quantity of this material caused progradation towards the deeper central part of the area, which was gradually infilled and narrowed. In the final phase, the trough was completely infilled, and peri-reefal environments gradually disappeared, since they were covered by ooid bars, culminating in the establishment of shallow environments over the entire area.

A similar situation was recorded in another contemporaneous, also tectonically formed environment – the Lemeš trough, stretching from the vicinity of Bihać in NW Bosnia towards the south into Croatia, into E Lika and N Dalmatia. This trough had direct communication with the open Tethys realm, and thin-bedded and platy limestones with chert and pelagic organisms, including common ammonites, were deposited within it. The Lemeš trough was also surrounded by coral–hydrozoan reefs, and it was infilled by the same depositional processes as the neighbouring trough in the area of Velika Kapela Mt., and finally covered by shallow-water deposits.

Although both troughs were probably formed by the same tectonic act, and had approximately the same duration – during the Kimmeridgian and Early Tithonian – they differ according to their palaeogeographic and facies characteristics. The trough investigated in the Velika Kapela Mt. was isolated, surrounded by shallow-marine platform environments, and had only temporary, indirect contact with the open sea. The Lemeš trough had a continuous connection with the open sea, as indicated by the relatively rich assemblages of pelagic organisms, especially ammonites, and is characterised by abundant cherts. However, both troughs are characterised by similar depositional sequences: both are underlain and overlain by shallow-water carbonate deposits, and they represent a consequence of a specific depositional event caused by tectonic deformation (formation of pull-apart basins) within the inner part of the Adriatic Carbonate Platform.

1. INTRODUCTION

During the lengthy existence of the Adriatic Carbonate Platform (from Late Lias to the Late Cretaceous – see discussion in VLAHOVIĆ et al., 2002) some periods were characterised by the significant variability of depositional environments, i.e. apparent facies differentiation as reflected in the specific rock record. These episodes are very important for the analysis of extrinsic and intrinsic influences on platform evolution, but also for the interpretation of its physiography. One of the most significant such events took place during the Late Jurassic.

This stratigraphic level, characterised by the occurrence of so-called "Lemeš deposits" (FURLANI, 1910) and similar *limestones with cherts and ammonites*, was claimed as one of the most important evidences of the existence of supposed two Mesozoic platforms which are today incorporated into the Dinarides (HERAK, 1986, 1989), and therefore should be carefully examined. It is important to emphasize that since the isolation of the Adriatic Carbonate Platform, i.e. its establishment, which occurred in the Middle to Late Lias (see discussion in VLAHOVIĆ et al., 2002), the studied period is the first regionally recognised major palaeogeographic event. Dynamic changes in the wider surroundings caused increased tectonic activity within

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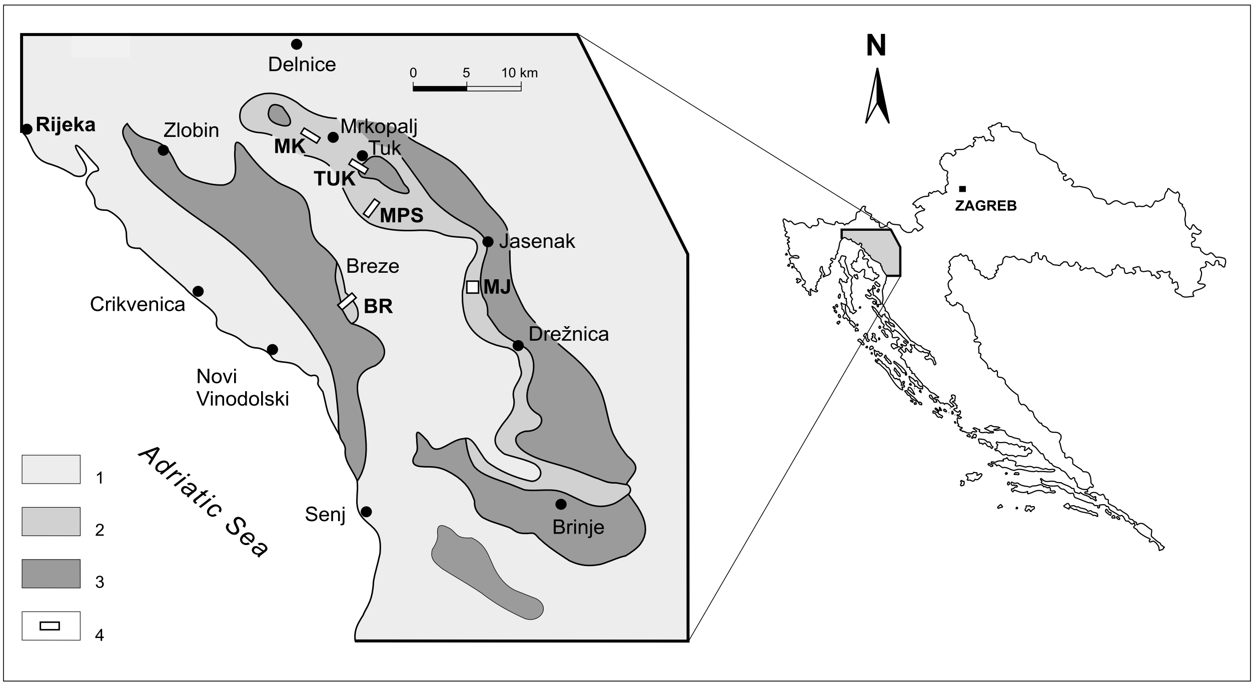

Fig. 1 Location map of the study area with the distribution of Upper Jurassic deposits of different palaeoenvironments. Legend: 1 – shallow-water Oxfordian (lithofacies A in this paper) and Tithonian limestones; 2 – *limestones with cherts* (lithofacies B_1 and B_2 in this paper); 3 – reefal–perireefal deposits (lithofacies C in this paper); 4 – position of the studied geological columns: MK – Mrkopalj; TUK – Tuk; MPS – Matić Poljana–Sunger; BR – Breze; MJ – Mala Javornica.

the platform area. However, younger tectonics obscured its consequences, and therefore made interpretation of its origin and importance very difficult (TIŠLJAR et al., 1994; VELIĆ et al., 1994, 2002; BUCKOVIĆ, 1995; MATIČEC et al., 2001; VLAHOVIĆ et al., 2001).

2. SUCCESSION OF THE KIMMERIDGIAN DEPOSITS IN E GORSKI KOTAR (WIDER AREA OF THE VELIKA KAPELA MT.)

The area of Gorski Kotar is especially interesting for the interpretation of general palaeogeographic events in the area of the Adriatic Carbonate Platform during the Late Jurassic, since during this period it was characterised by significant facies variability. Different facies were investigated in several detailed geological columns and by geological mapping of the wider area of Velika Kapela Mt. (Fig. 1).

The study area is very disturbed by younger, especially Tertiary and Quaternary tectonics, and it is not easy to find undisturbed successions of Malm carbonate deposits. Considering the main goal of the study, i.e. investigation of Kimmeridgian deposits (so-called *limestones with cherts*) and facies underlying and overlying them, the study area encompassed the region from the vicinity of Mrkopalj SE, towards Brinje. Among several columns and profiles the most complete was determined in the area of Breze (Fig. 2), but relationships in the Mrkopalj (Fig. 3), Tuk (Fig. 4), Matić Poljana–Sunger (Fig. 5) and Mala Javornica (Fig. 6) columns will also be discussed.

2.1. Lithofacies A – lagoonal limestones

Limestones with cherts are underlain in the study area by an approximately 35 m thick succession of dark grey, in some places black, thick-bedded to massive (50–80, commonly 150–200 cm thick beds) micritic limestones with oncoid and nubecularians (Fig. 2, lithofacies A). These are composed of homogenous mudstones, bioclastic wackestones with benthic foraminifera and molluscan bioclasts, peloid wackestones and bioclastic–peloid wackestone/packstones, oncoid–skeletal–peloid wackestones to grainstones and nubecularian wackestones with echinoid bioclasts and calcisphaerids.

The following fossil assemblage of shallow marine benthos has been determined by micropalaeontological analysis (in their order of occurrence): *Praekurnubia crusei* REDMOND, *Salpingoporella sellii* (CRESCENTI), *Nautiloculina oolithica* (MOHLER), *Pseudocyclammina* sp., *Cladocoropsis mirabilis* FELIX, *Everticyclammina* sp., *Kurnubia palastiniensis* HENSON, *Trocholina* sp., *Redmondoides lugeoni* (SEPTFONTAINE), *Pfenderella arabica* REDMOND, *Pseudocyclammina lituus* (YOKOYAMA), *Salpingoporella grudii* (RADOIČIĆ), *Griphoporella minima* NIKLER & SOKAČ, accompanied by indeterminable lituolids and valvulinids, molluscan, hydrozoan and echinoderm debris, ostracods, nubecularids and thaumatoporellas. Occurrences of *Saccocoma* sp. indicate sporadic pelagic influences. The aforementioned assemblage indicates a latest Oxfordian to earliest Kimmeridgian age, i.e. these deposits correspond to the Oxfordian–Kimmeridgian transition level. Biostratigraphically they belong to the *Salpingoporella*

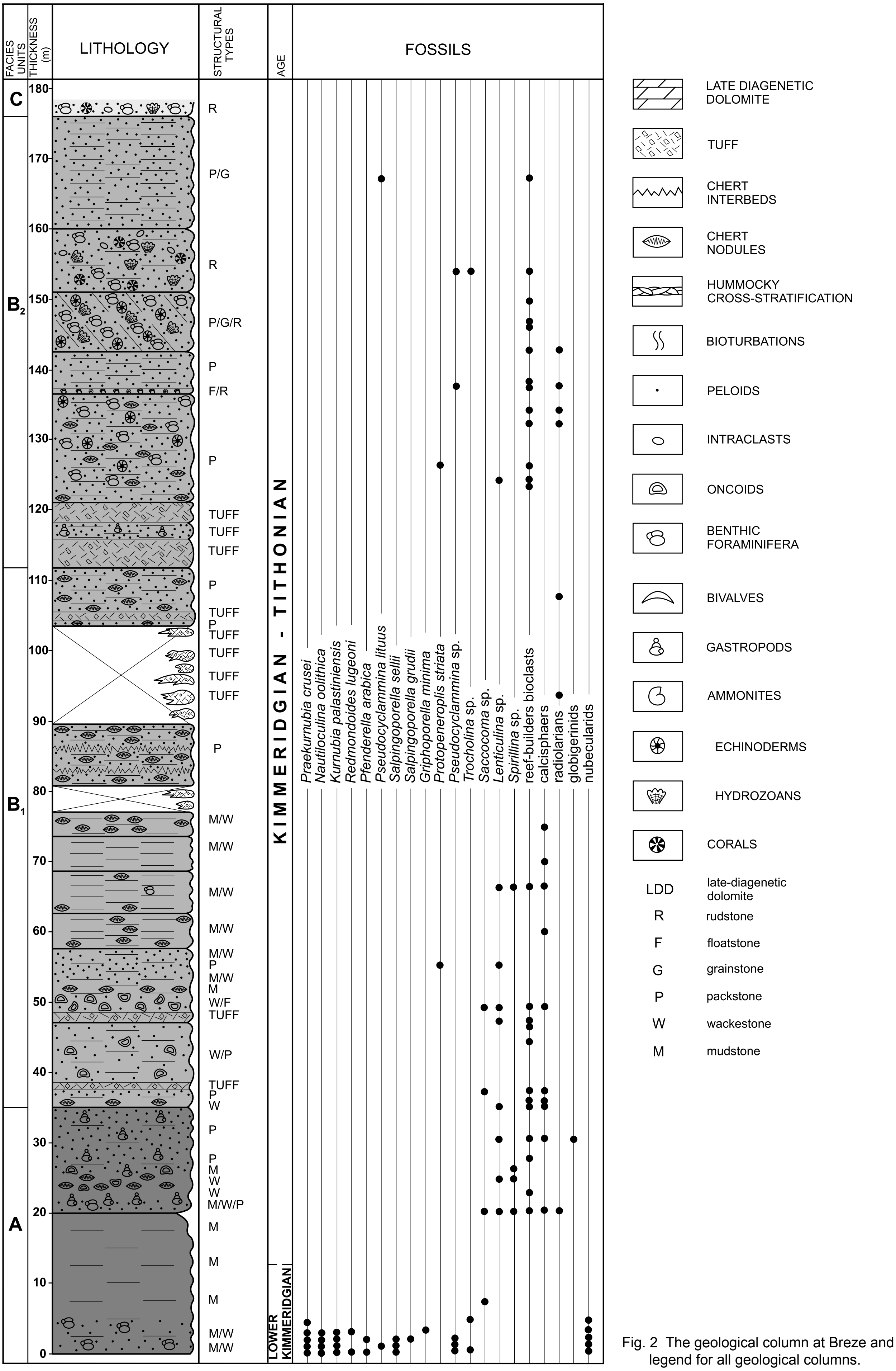

Fig. 2 The geological column at Breze and legend for all geological columns.

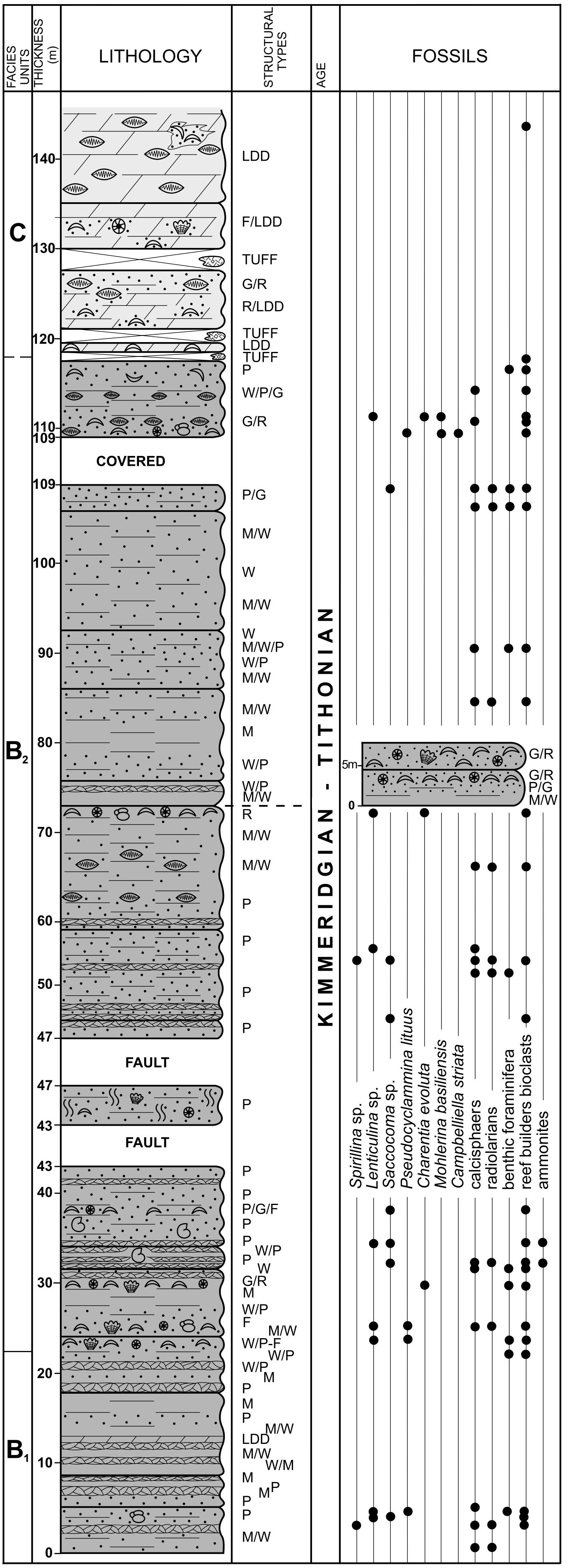

Fig. 3 The geological column at Mrkopalj.

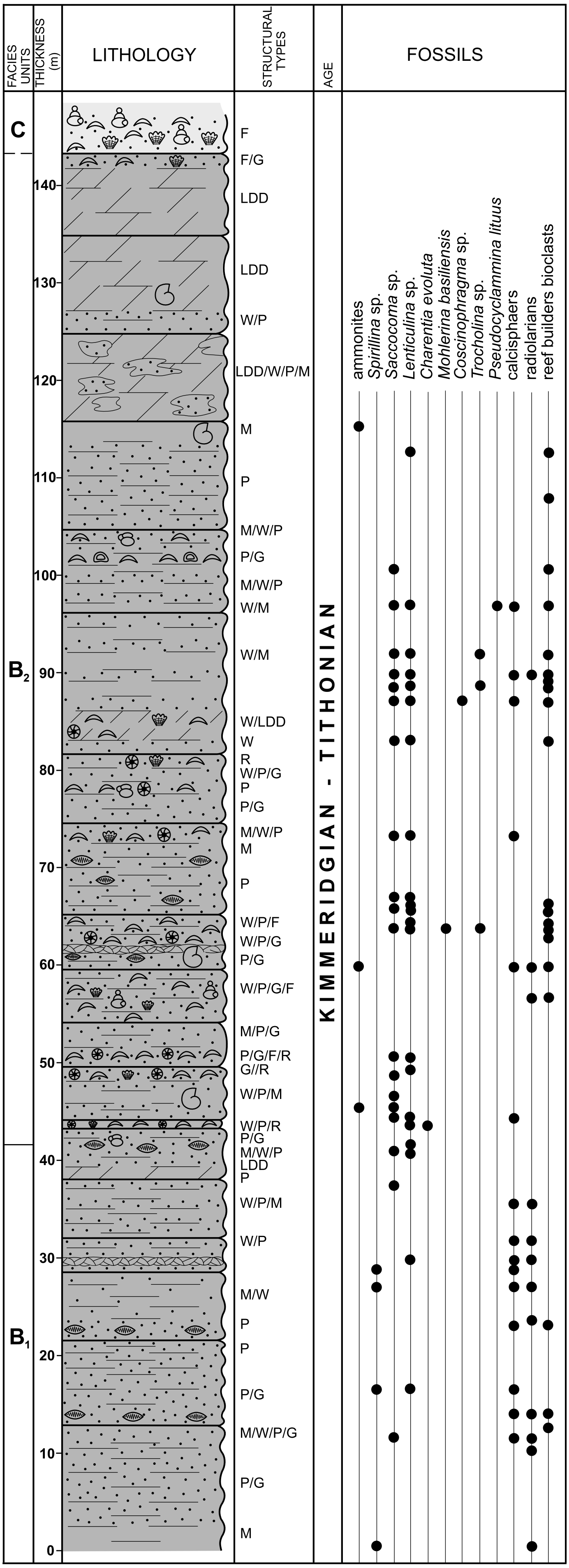

Fig. 4 The geological column at Tuk.

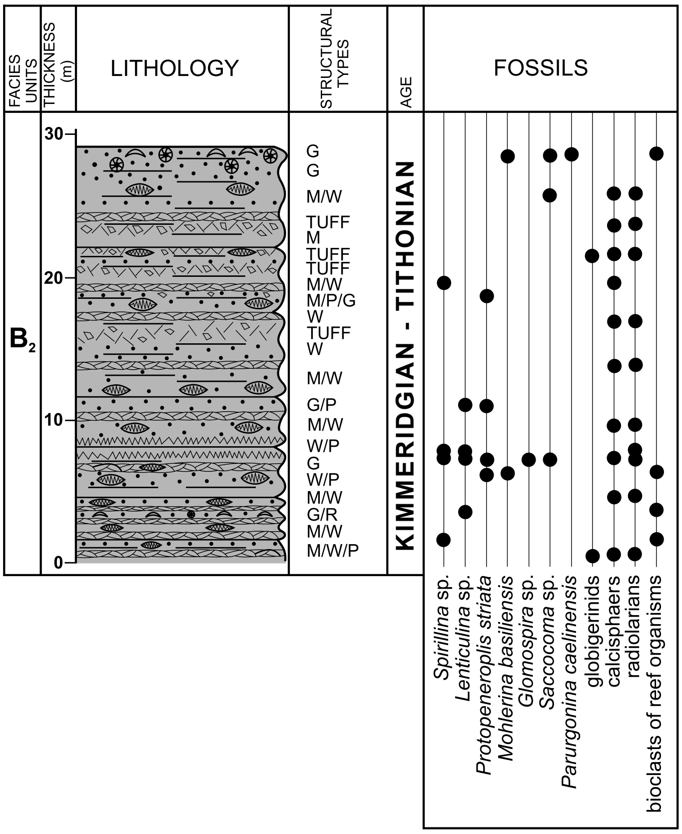

Fig. 5 The geological column at Matić Poljana–Sunger.

sellii Assemblage Zone defined by VELIĆ & SOKAČ (1974, 1978) and VELIĆ (1977).

These limestones were deposited in low energy subtidal areas of the lagoon, and its flanks probably formed gently inclined inner platform carbonate ramps. Carbonate mud, peloids, algal oncoids, ostracods, nubecularids, dasycladaceans and benthic foraminifera represent the autochthonous material, while echinoid and mollusc debris were probably introduced from neighbouring shallows.

2.2. Lithofacies B – *limestones with cherts*

Limestones with cherts (lithofacies B in Figs. 2–6) occurs in all the studied columns, but with variable thickness. The complete succession was investigated in the Breze column, while in the Mrkopalj and Tuk columns the lower part is tectonically reduced. In the Matić Poljana (Sunger) and Mala Javornica columns the lower part of this unit is also tectonically reduced, and the upper part is eroded.

Within the *limestones with cherts*, two units can be separated (B_1 and B_2), both characterised by well-bedded micritic limestones with chert nodules, but the upper (younger) unit also comprises clinoforms composed of peri-reefal debris.

Well-bedded micritic limestones with chert nodules (lithofacies B_1) are, in the central part of the Breze column, 78 m thick (Fig. 2), 23 m in the Mrkopalj column without a lower contact (Fig. 3), 43 m in the Tuk column without lower contact (Fig. 4), and 64 m thick in the Mala Javornica column without lower and upper contacts (Fig. 6). They are composed of the alternation of frequently recrystallized and silicified oncoid–peloid–skeletal wackestones (rarely skeletal–peloid packstone to grainstones), and mudstones to wackestones with pelagic fauna (Fig. 7), interlayered with cryptocrystalline cherts with radiolarians (Fig. 8), macrocrystalline late-diagenetic dolomites and intensely weathered and altered crystalo-vitroclastic tuffs to tuffitic mudstones. Besides well-bedded deposits (Fig. 9) in some places, thin-bedded varieties have been found (e.g. in the Mala Javornica profile – Fig. 10), including rare ammonites (Fig. 11).

Within peloid–skeletal wackestones, and especially within mudstones, laminae, grains and globules of organic matter (OM) occur. According to the *in situ*[3] appearance, the OM of lithofacies B_1 may be characterised as bituminite, partly as lamalginite, especially within laminated mudstones. However, they exhibit weak fluorescence intensity, and in some segments they do not fluoresce at all. This may be explained, at least partly, as a consequence of secondary oxidation of OM due to tectonically fissured deposits and their exposure to weathering. This is well documented by the

3 Analysis of the polished surface of samples in incident blue light as well as thin sections in white transmitted light and incident blue light.

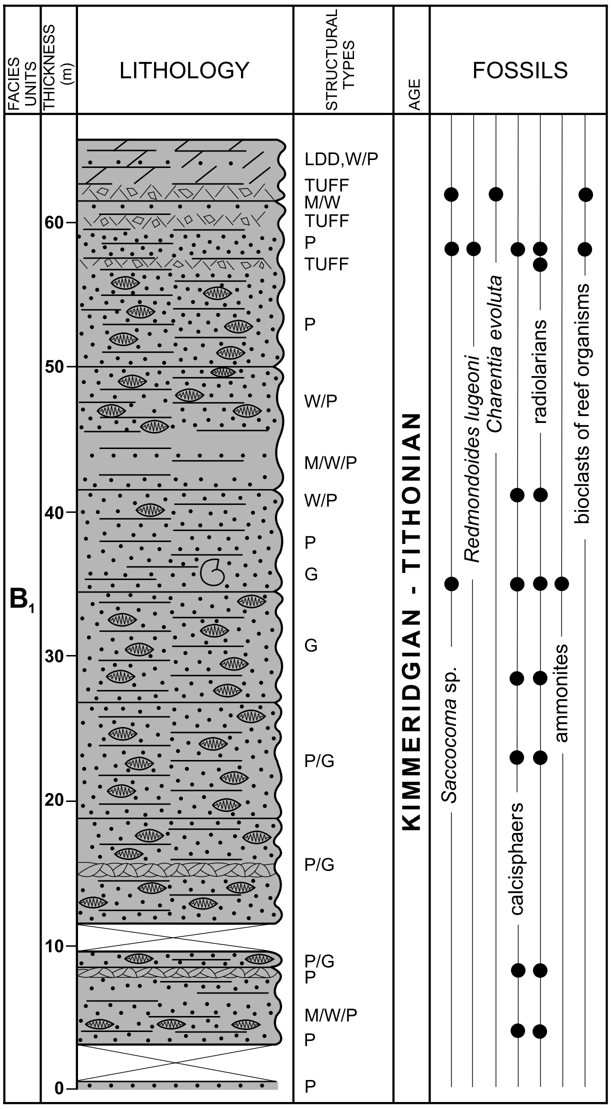

Fig. 6 The geological column at Mala Javornica.

recrystallized nature of the limestones, which increases their permeability, and by the often numerous narrow cracks infilled with secondary calcite. Even within the laminated parts of the limestones, thin secondary calcite veins have been observed showing selective oxidation of OM while penetrating into the interlaminar space.

The palynological composition of OM[4] of lithofacies B_1 shows varying amounts of marine (85–95%) and land (5–15%) derived palynodebris. The mean value of the ratio marine/terrestrial OM is estimated at 9/1.

Marine derived palynodebris consists of heterogenous, spongy, clotted and granular (Pl. 1, Figs. 2, 3, 6) as well as homogenous (Pl. 1, Figs. 1, 3) varieties of amorphous organic matter (AOM). Rare framboidal pyrite inclusions have been observed within the heterogenous type of AOM. According to the fluorescence and morphological features, four types of AOM can be differentiated: (1) heterogenous, non-fluorescent, (2) heterogenous, dull orange fluorescence, and (3) relatively homogenous, non-fluorescent, (4) relatively homogenous, dull yellow-orange fluorescence. The first two types are plankton/bacterial derived, whereas the third and the fourth types are microbial mat derived. The quantity of these four types of AOM varies from sample to sample; on average, the second type predominates. The third and the fourth types form up to 1/5 of the total AOM most common within the finely laminated parts of mudstones. As already mentioned, secondary oxidation has left an obvious signature on the preservation state of the AOM. This represents a limiting factor when estimating the true proportion of AOM which might have been partially oxidised before and during final deposition, because non-fluorescent and weakly fluorescent AOM may also be produced by biodegradation of planktonic or microbial mat OM (TYSON, 1995). It is also possible that the deposited AOM was synsedimentary affected by flushing and erosion (resuspension). Nevertheless, secondary oxidation of AOM has to be taken into account, meaning that the unoxidised equivalents would reveal a higher fluorescence intensity, thus indicating at least a moderate degree of AOM preservation. Marine palynomorphs are regularly represented by varying, but low concentrations of moderately preserved prasinophycean phycomata (*Leiosphaeridia* – Pl. 1, Fig. 2, *Tasmanites* – Pl. 1, Fig. 3), always less than 1% of the overall palynodebris composition. Moderately preserved proximate dinosporin cysts (*Escharisphaeridia* – Pl. 1, Fig. 4) occur in very low concentrations. Other types of dinosporin cysts, or parts thereof, have not been observed. The mean value of the ratio of prasinophyte phycomata/dinosporin cysts is estimated at 5/1. Prasinophyte phycomata and dinosporin cysts exhibit moderate yellow fluorescence.

Land derived palynomorphs occur in very low concentrations, represented by degraded bissacate pollen and Circumpolles pollen (*Corollina*/*Classopollis* – Pl. 1, Fig. 5). The spores are strongly degraded and they occur extremely rarely in only a few samples.

Land derived palynodebris consists mostly of brown to dark brown, weakly to moderately structured clasts of transculent phytoclasts of woody tissue (80–90%; Pl. 1, Fig. 6) and opâque phytoclasts (10–20%; Pl. 1, Fig. 2) of land plant origin. The mean value of the ratio of transculent phytoclasts/opâque phytoclasts is estimated at 6/1. Both fractions occur as lath-shaped and angular to semiangular equidimensional clasts variable in size. Their sorting and rounding is mostly weak, and in some samples weak to moderate.

[4] For palynological processing only HCl (10%) was used to dissolve the carbonates. No further treatment (dissolving of silicates in HF, heavy liquid separation, sieving, oxidation) has been attempted in order to analyze the organic matter as a whole and to avoid damaging and alteration of the preservation state of organic matter due to processing. Analysis of OM was performed both in transmitted white light and incident blue light.

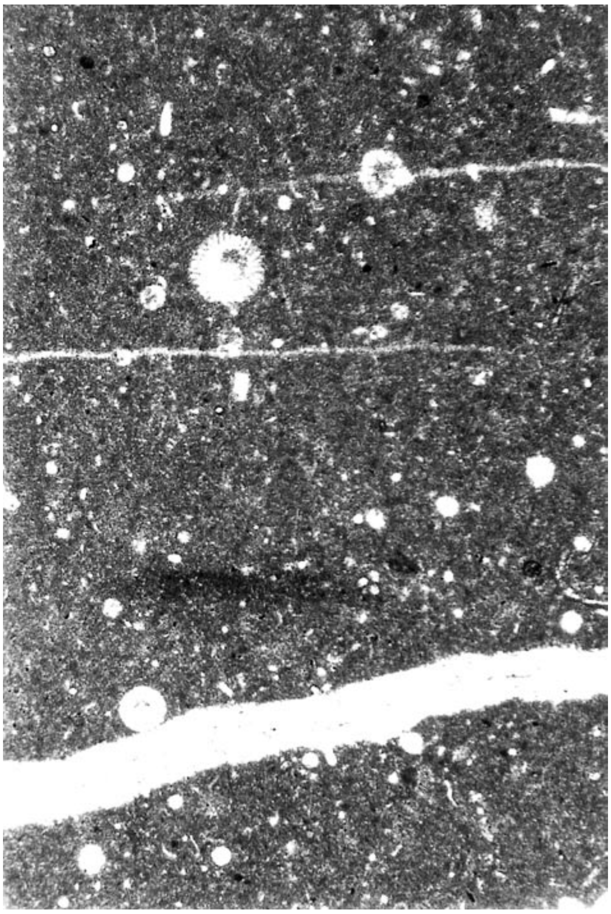

Fig. 7 A photomicrograph of fine-grained peloidal–skeletal wackestone with rare radiolarians; lithofacies B_1, Tuk column, 31x.

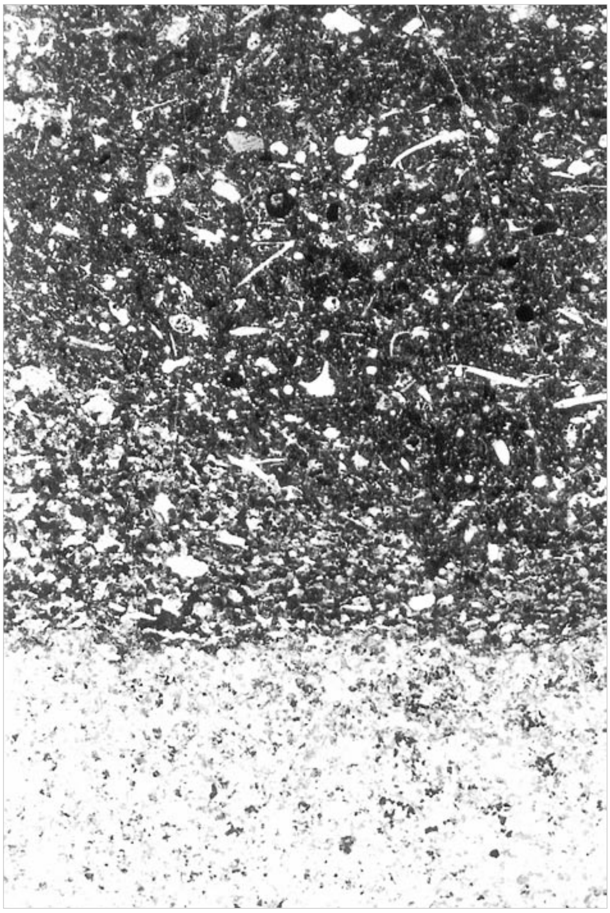

Fig. 8 A photomicrograph of the irregular contact of a diagenetic chert nodule (light grey) and peloidal–bioclastic wackestone/packstone; lithofacies B_1, Mala Javornica column, 6.5x.

An alternation of well-bedded micritic limestones with chert nodules and clinoforms composed of reefal–perireefal detritus (lithofacies B_2) has been found in the upper parts of the Breze (thickness 65 m – Fig. 2), Mrkopalj (approximately 95 m thick – Fig. 3) and Tuk columns (approximately 100 m – Fig. 4). Micritic limestones with chert nodules, as autochthonous deposits of the intraplatform trough, correspond to the previously described deposits of lithofacies B_1. These deposits alternate with thinner or thicker, in some places clinoform interbeds of bioclastic–intraclastic limestones (Fig. 12), which are mostly grainstones in their lower part, gradually passing upwards into bioclastic rudstones with a grainstone matrix. However, in some localities (e.g. Mrkopalj, Tuk, Matić Poljana–Sunger columns) mud-supported lithotypes – packstones and floatstones, are predominant.

Interbeds of dark grey to black mudstones and wackestones also contain irregular concentrations of OM, both as granules in the matrix and impregnations within micrite and along stylolytic sutures. Both the *in situ* appearance and palynological composition of the OM of lithofacies B_2 corresponds to lithofacies B_1, differing in a lower mean value of the marine/terrestrial OM ratio (4/1) as well as in the lower mean value of the transculent phytoclasts/opâque phytoclasts ratio (3/1) and their moderate sorting and rounding.

The fossil assemblage found within the *limestones with cherts*, although relatively moderate in respect to the underlying and overlying deposits, is quite interesting for facies interpretation. Two groups of fossils can be separated: autochthonous (pelagic and slope organisms) and allochthonous (peri-reefal and platform benthos). The pelagic assemblage is composed mostly of microfossils, e.g. *Globochaete alpina* LOMBARD, *Saccocoma* sp. (Fig. 13), *Spirillina* sp., calcisphaers, calcitized radiolarians, sponge spicules, pelagic bivalves and echinoderms. Among the macrofossils only rare ammonites have been found, which were indeterminable at species level; however, NIKLER (1965) has determined the genus *Perisphinctes* and species *P.* (*Virgatosphinctes*) *denseplicatus* (WAAGEN) in the area of Breze and Tuk. Within the microfossil assemblage characteristic for slope environments *Protopeneroplis striata* WEYNSCHENK, *Mohlerina basiliensis* (MOHLER) and *Lenticulina* sp. have been found.

Within successions situated in the proximal parts of the intraplatform trough, i.e. the Matić Poljana–Sunger and Mala Javornica columns (Figs. 5 and 6), besides the autochthonous deposits, numerous redeposited platform

Fig. 9 Outcrops of typical well-bedded lithofacies B_1 deposits in the Mrkopalj column (hammer for scale).

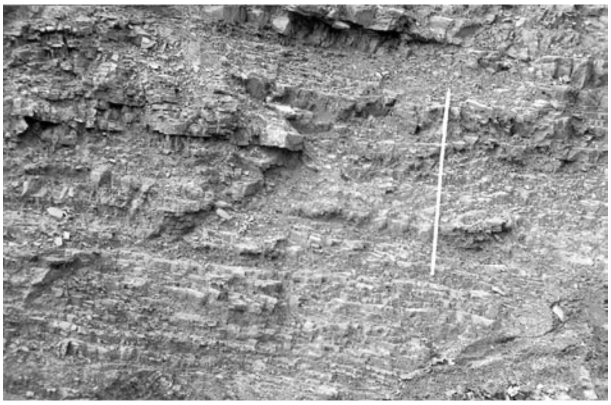

Fig. 10 Thin-bedded variety of the lithofacies B_1 deposits in the Mala Javornica column (scale is 2 m long).

benthic forms have been found, e.g. *Parurgonina caelinensis* CUVILLIER, FOURY & PIGNATTI-MORANO, *Pseudocyclammina lituus* (YOKOYAMA), *Charentia evoluta* (GORBATCHIK) and *Redmondoides lugeoni* (SEPTFONTAINE).

Clinoforms occurring within the upper part of the *limestones with cherts* comprise debris of reef-building organisms and *Pseudocyclammina lituus* (YOKOYAMA), *Campbelliella striata* (CAROZZI), *Charentia evoluta* (GORBATCHIK), *Everticyclammina* sp., *Coscinophragma* sp., valvulinids and lituolids.

According to the primary facies distribution, palynomorphs and palynodebris of *limestones with cherts* can be differentiated into autochthonous (marine derived) and allochthonous (land derived) material.

Phycomata of planktonic prasinophyte algae show a more pelagic distribution pattern, and their abundance is environmentally controlled (TYSON, 1995). They are most common in marine, organic-rich, finely laminated deposits that accumulate under conditions of lowered oxygenation (TYSON, 1995; BATTEN, 1996). Phycomata are seldom volumetrically significant in such deposits compared to the total organic matter (TYSON, 1995). Their dominance (as a percentage) is more specifically related to other phytoplankoton. TAPPAN (1980) has attributed prasinophycean algae as a “disaster species”, i.e. their abundance especially increases where the ecological conditions for the development of other phytoplankton communities are not suitable. According to TYSON (1995), the abundance of phycomata in many organic-rich deposits is at least partly a consequence of reduced dinocyst or acritarch production in permanently stratified basins which does not reflect the original phytoplankton assemblage, i.e. the real phytoplankton community dynamics. Therefore, the ratio of phycomata/dinocysts is an indicator of hydrographic stability and its value increases in the more pelagic facies of stratified basins. Distal facies with low siliciclastic sediment accumulation are characterised by condensed sections and pelagic facies with the most organic-rich sediments which reveal thin and localized occurrences

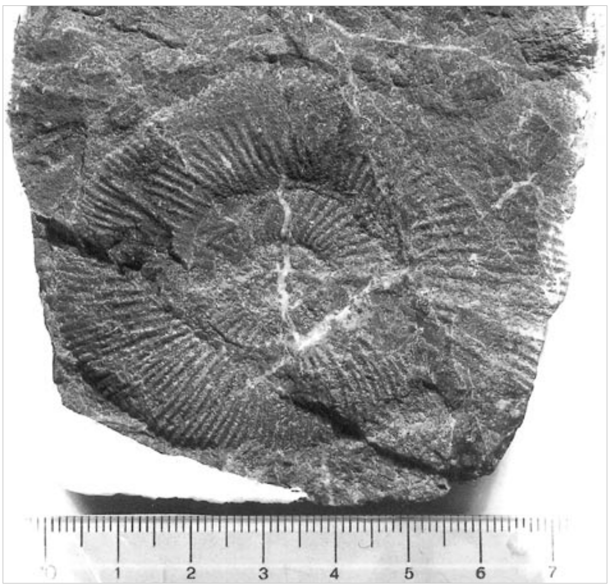

Fig. 11 Scarce ammonite (*Perisphinctes* sp.) from the lithofacies B_1 deposits in the Mala Javornica column.

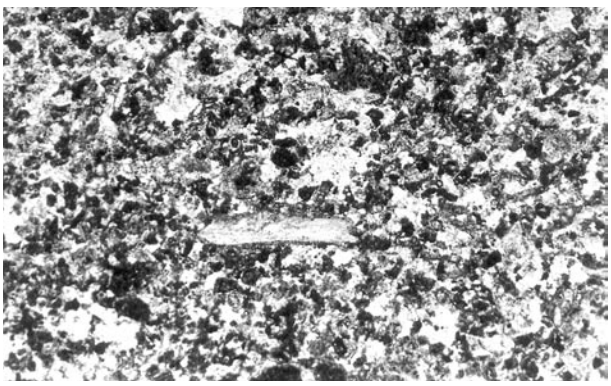

Fig. 12 A photomicrograph of fine-grained, relatively well-sorted bioclastic–intraclastic–peloidal packstone/grainstone; lithofacies B_2, Breze column, 10.5x.

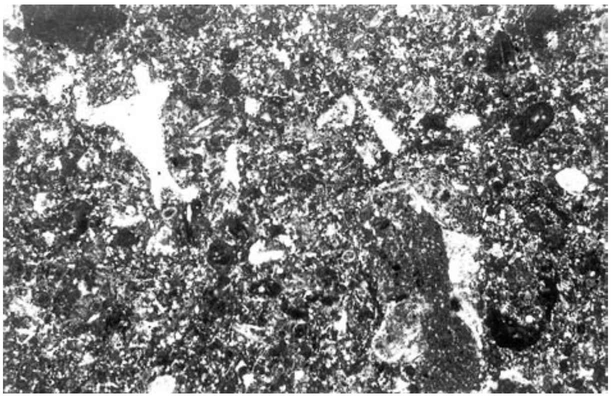

Fig. 13 A photomicrograph of bioclastic–intraclastic–peloidal packstone with coarse bioclasts of molluscs and pelagic forms including *Saccocoma* sp.; lithofacies B_2, Tuk column, 8.5x.

of unusually high phycomata abundance (TYSON, 1995). Prasinophyte phycomata are also common in the lower parts of transgressive sequences and shallow water facies related to the maximum flooding surface (TYSON, 1995). The dominance of prasinophyte algae has also been recorded from restricted (partly hypersaline, partly anoxic) lagoons and shallow water carbonate depositional sets. These occurrences probably also reflect the inhibition of dinosporin cyst production and a corresponding relative increase in prasynophytes (TYSON, 1995). Organic-rich, laminated deposits with relatively abundant prasinophycean phycomata have also been recorded from a shallow, restricted-marine, anoxic environment with increased salinity of the Adriatic Carbonate Platform (JERINIĆ et al., 1994).

The palynofacies of marine organic-rich, laminated sediments is dominated by AOM, most of it being derived from phytoplankton and bacteria (RAYNAUD et al., 1989; TYSON, 1995; BATTEN, 1996). This type of AOM is often associated with pyrite inclusions in depositional sets where iron is available. Otherwise, the sulphur is incorporated into organic compounds (TISSOT & WELTE, 1984).

The deposition of land derived palynodebris is hydrodynamically controlled according to their buoyancy features and depositional energy. According to GORIN & STEFFEN (1991) the size, sorting, rounding and preservation degree of phytoclasts as well as the ratio of marine/terrestrial organic matter are good indicators of proximal/distal relationships. In the distal direction on a carbonate shelf, the size of equidimensional opâque phytoclasts decreases, while sorting and rounding increases, the proportion of lath-shaped opâque phytoclasts increases, the preservation of phytoclasts increases, and the ratio of marine/terrestrial OM increases.

On the basis of these considerations, the palynofacies of the *limestones with cherts* indicates that they were deposited in an oxygen-depleted, relatively shallow, restricted depositional setting (lagoon). These conditions enabled formation of a palynofacies dominated by algal/microbial derived AOM with rare pyrite inclusions. This limited formation of pyrite was due to the low amount of iron which is consistent with the depositional sets of carbonate platforms. The composition of land derived organic clasts as well as their size, sorting and rounding suggests relatively short transport before final deposition and the relative proximity of the emerged part of the carbonate platform where the probably scanty and undiversified vegetation was established. Variations in the ratio of marine/terrestrial OM indicates sea-level fluctuation and/or synsedimentary tectonics with an upward regressive trend in the studied columns.

Most of the aforementioned fossils are characterised by wide stratigraphic spans, mostly from the Dogger to the Berriasian; exceptions include the species *Parurgonina caelinensis* CUVILLIER, FOURY & PIGNATTI-MORANO and *Campbelliella striata* (CAROZZI). Their occurrence within clinoforms of lithofacies B_2 are very important, since their stratigraphic ranges accompanied by the defined age of the underlying deposits can help determine the age of the *limestones with cherts*. The stratigraphic range of *P. caelinensis* in the Mediterranean region, as well as in the area of Velika Kapela Mt. (VELIĆ & SOKAČ, 1974, 1978, VELIĆ, 1977) is Kimmeridgian–Tithonian, while *C. striata* indicates a latest Lower Tithonian to Upper Tithonian age. Considering the fact that the *limestones with cherts* are overlain by a thick sequence of Tithonian peri-reefal limestones, their stratigraphic range should therefore be approximated to extend through most of the Kimmeridgian and Lower Tithonian, i.e. to the end of the Lower Tithonian.

Limestones with cherts were deposited under oxygen-depleted conditions within the intraplatform trough. Deposition of autochthonous, relatively organic-rich (mainly AOM) mudstones and wackestones, was gradually more and more interrupted by inputs of both carbonate allochtonous material (fine- and coarse-grained detritus) from reefs and ooid shoals surrounding the intraplatform trough, and a small amount of organic allochthonous material (mainly palynodebris of woody tissue) derived from the vegetation established on the emerged part of the carbonate platform. This was the consequence of progradation of peri-reefal and ooid deposits towards the inner part of the trough. Differences recorded in the investigated columns concern the variable amounts of both inorganic and organic autochthonous and allochthonous material resulting from their different positions within the intraplatform trough, characterised by the complex morphology and bathymetry as well as uneven primary bioproduction and progradation of reefal detritus and ooids.

2.3. Lihofacies C – Reefal–perireefal limestones and late-diagenetic dolomites

Massive limestones composed predominantly of reefal detritus overlie the *limestones with cherts*. They were

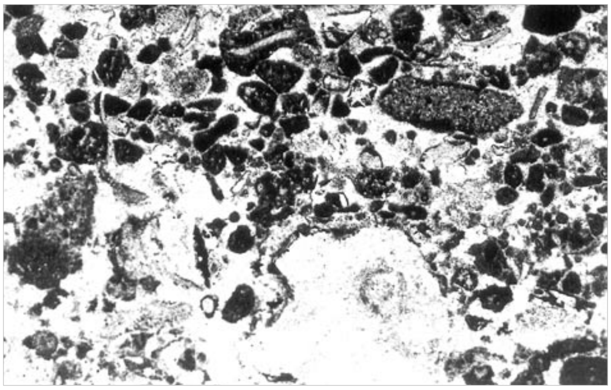

Fig. 14 A photomicrograph of bioclastic–intraclastic–peloidal grainstone with coarse bioclasts; lithofacies C, Breze column, 13x.

distinguished in the upper part of the Breze, Mrkopalj and Tuk columns (Figs. 2, 3 and 4, lithofacies C). Their thickness could not be precisely determined because of their significant tectonic disturbance, i.e. possible duplication by faulting, very significant lateral variability caused by palaeomorphology, intense late-diagenetic dolomitization and dense vegetation. However, in the area of Breze their thickness was estimated at 1000 m (ŠUŠNJAR et al., 1970).

Limestones of this unit are composed of thick-bedded to massive medium- to coarse-grained bioclastic–lithoclastic grainstone–packstones and rudstone–floatstones with lenses, nodules and interbeds of cherts, and, especially along the fault zones, late-diagenetic dolomites. Limestones are generally characterised by erosional lower bedding surfaces and either coarsening- or fining-upward trends.

Grainstones are composed of well-sorted and well-rounded bioclasts of hydrozoans, stromatoporoids, echinoderms and molluscs, micritic, biomicritic, pelmicritic and pelsparitic intraclasts, and relatively high amounts of macrocrystalline and syntaxial calcite cements (Fig. 14). Algal oncoids, micritized benthic foraminiferal tests and ooids with radial structures are less frequent. Grainstones commonly gradually change into packstones with different amounts of matrix composed either of micrite or finely crushed fossil detritus, which is in some places recrystallized into microsparite.

Rudstones differ from grainstones not only in their, by definition, larger amount of coarser grains – but also with their concurrent increase of stromatoporoid, coral and mollusc bioclasts and pelsparitic and intrasparitic intraclasts with respect to echinoderms which has been recorded. Additionally, lithotypes with coarse allochems are characterised by lesser amounts of well-rounded grains. Floatstones are characterised by the same coarse allochems, but instead of calcite cements intergranular spaces are filled by variable amounts of biopelmicritic matrix.

Chert lenses, nodules and interbeds are composed of cryptocrystalline to microcrystalline quartz aggregates with xenotypic crystal contacts and variable preservation, depending on the type of the substituted original allochem. Silicification was selective, i.e. its intensity was variable on different grains. For example, the original shape of bivalve and gastropod bioclasts and ooids are commonly preserved, even after their complete silicification. Some bioclasts (especially echinoderms), intraclasts and oncoids left as unsilicified relics within a microcrystalline or cryptocrystalline quartz mass, which is commonly contaminated by clay minerals and fine aggregates of sericite (or illite?), probably resulted from the alteration of volcanoclastic material.

Late-diagenetic dolomites are quite common, in some places even predominant, and they usually contain relics of undolomitised bioclastic limestones. They are characterised by micro- and macrocrystalline mosaic structure composed of hypidiotopic to idiotopic, rarely xenotopic dolomite crystals. Intercrystal pores, dissolution cavities and tectonic fissures usually contain calcitic cement, and their superficial parts are commonly dedolomitized.

The fossil assemblage found within the reefal–perireefal carbonates is very rich (Fig. 15). Former investigations of the wider area of Velika Kapela Mt. resulted in the description of numerous reef-building organisms – corals, hydrozoans, stromatoporoids, bryozoans, gastropods, bivalves, echinoderms, brachiopods, etc. (e.g. POLJAK, 1936a, b, 1944; MILAN, 1969; NIKLER, 1969; TURNŠEK, 1975; VELIĆ, 1977). Those most frequently mentioned are some taxa from the Sphaeractinidae family, e.g. *Ellipsactinia ellipsoidea* STEINMANN, *E. caprense* CANAVARI, *E. polypora* CANAVARI, *E. ramosa* CANAVARI, *E. tyrhenica* CANAVARI, *Sphaeractinia steinmanni* CANAVARI, *S. diceratina* STEINMANN, gastropods of genus *Nerinea*, e.g. *N. defrancei posthuma* ZITTEL, *N. zeuschneri* PETERS, then *Ptygmatis bruntrutana* (THURMANN), *Cryptoplocus consobrinus* ZITTEL, etc. Among the microfossils, typical latest Upper Jurassic forms of calcareous algae and benthic foraminifera have been determined, e.g. *Clypeina jurassica* FAVRE, *Campbelliella striata* (CAROZZI), *Kurnubia palastiniensis* HENSON, *Parurgonina caelinensis* CUVILLIER, FOURY & PIGNATTI-MORANO, etc. On the basis of the aforementioned fossil assemblage, results of previous investigations and relationships in the investigated area, it may be concluded that reefal–perireefal deposits were deposited within a stratigraphic range from the middle Kimmeridgian to the end of the Tithonian.

There is no common opinion regarding the age and stratigraphic position of the reefal–perireefal deposits within the Upper Jurassic succession of the wider area. In Slovenia, i.e. areas of Trnovski gozd, Notranjska and Suha Krajina, perireefal limestones are overlain by oolitic and Clypeina limestones according to BUSER (1989), TURNŠEK et al. (1981) and TURNŠEK (1997), and therefore their stratigraphic range is estimated as Oxfordian–Kimmeridgian. How-

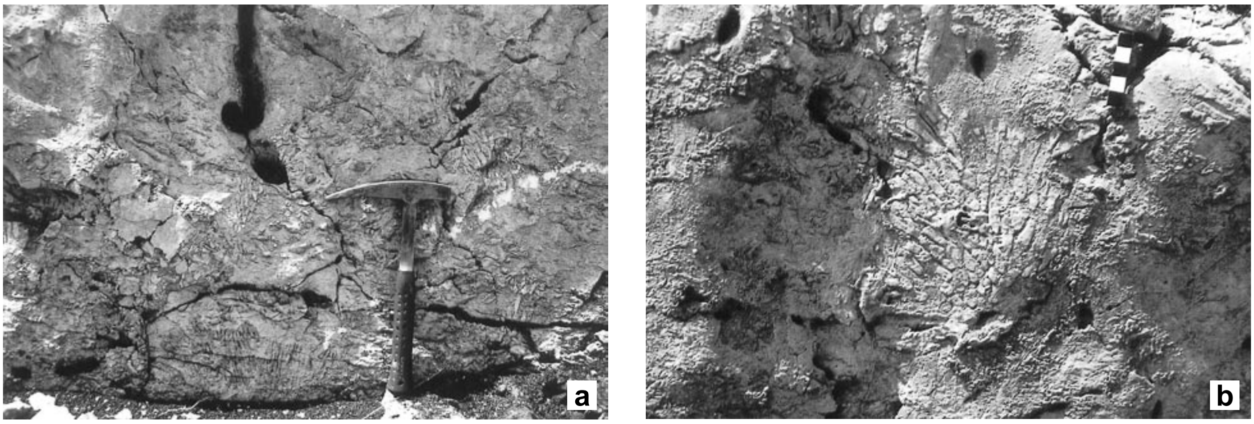

Fig. 15 (a) Massive reef–perireefal rudstones with abundant reef-building organisms (hammer for scale); (b) coral head in living position (scale bar = 5 cm). Lithofacies C, Breze column.

ever, NIKLER (1978) determined a Tihonian age for the perireefal limestones of Trnovski gozd Mt., since at the Velika Ojstrovca locality he studied a complete succession from the Middle Lias to the Tithonian: limestones with orbitopsellas are overlain by "spotty limestones" of the Upper Lias, then there was a lengthy hiatus until the transgressive Kimmeridgian *limestones with cherts*, which are overlain by perireefal facies. This described succession completely corresponds to the penecontemporaneous deposits near the northern margin of the Adriatic Carbonate Platform, studied by BUKOVAC et al. (1974, 1984) in the vicinity of Karlovac. "Reefal deposits" (although they are usually referred to as "reefal limestones", especially in the older literature, comprise a relatively small part of *in situ* reefs – most of the material is reworked) of the wider area of Velika Kapela Mt. and vicinity of Karlovac are of Upper Kimmeridgian to Tithonian age, as determined by MILAN (1965, 1969), NIKLER (1965, 1969, 1978), BUKOVAC et al. (1974, 1984), VELIĆ (1977), TIŠLJAR & VELIĆ (1991), VELIĆ et al. (1994), etc. In the areas with the most abundant Jurassic coral–hydrozoan reefs and peri-reefal areas, i.e. the E–SE part of the platform from central Bosnia to southern Montenegro, their stratigraphic position is determined only as Upper Jurassic in general (e.g. PAPEŠ, 1972, 1985; VUJNOVIĆ, 1980; MIRKOVIĆ et al., 1977, 1979; MIRKOVIĆ & VUJISIĆ, 1989).

Reefal–perireefal deposits originated in the shallow, high-energy part of the intraplatform trough, mostly as a result of the intense input and migration of bioclastic and inorganic detritus from reefs, and to a lesser extent, ooid shoals. Shallowing of the depositional area was gradual, as a consequence of the progradation of bioclastic material (generally characterised by a coarsening-upward trend), of the forereef–reef facies belt and ooid shoals over autochthonous deposits of the intraplatform trough (VELIĆ et al., 1994; TIŠLJAR et al. 1994). This trend is recorded by a gradual vertical transition from lithofacies B_1 to lithofacies B_2 and finally to lithofacies C.

Described succession is typical for the area of the eastern Gorski Kotar (Fig. 1). In the neighbouring areas of NW Gorski Kotar, NW Lika and Velebit, as well as in the Velika Kapela Mt. and area NE of it, Upper Jurassic deposits are characterised by different, but exclusively shallow-marine facies, deposited within shallow lagoons, low-energy shallow subtidal to peritidal environments. These deposits are described in detail in other papers (VELIĆ & SOKAČ, 1974, 1978; VELIĆ, 1977; TIŠLJAR & VELIĆ, 1993; TIŠLJAR et al., 1994), enabling reliable biostratigraphic correlation of these facially different successions of Upper Jurassic rocks.

3. GEOLOGICAL EVENTS DURING THE KIMMERIDGIAN ON THE ADRIATIC CARBONATE PLATFORM

During the Oxfordian, the area of the Adriatic Carbonate Platform was characterised by relatively uniform sedimentation. The southern and SW part of the platform, which is today mostly covered by the Adriatic Sea, was characterised by high-energy environments, resulting in deposition of carbonate sand bars mostly composed of ooids. The remainder of the platform, except for the NE margin which had been emergent since the Late Lias, was characterised by lagoonal environments.

The beginning of the Malmian was characterised by the gradual differentiation of environments, with the maximum in the Kimmeridgian. The SW part of the platform emerged during the Kimmeridgian, resulting in significant palaeokarstification (e.g. Biokovo – TIŠLJAR et al., 1989) and establishment of conditions suitable for the formation of bauxite deposits (in W Istria – POLŠAK, 1965; TIŠLJAR & VELIĆ, 1987; VELIĆ & TIŠLJAR, 1988; TIŠLJAR et al., 2002). A similar situation was described in the N, NE part and along the platform margin in central and SE Slovenia (DOZET & MIŠIČ, 1997), NW Bosnia (VRHOVČIĆ et al., 1983), E Herzegovina (NATEVIĆ & PETROVIĆ, 1967) and W and N Montenegro (VUJISIĆ, 1972; MIRKOVIĆ & MIRKOVIĆ, 1987).

At the same time, the NE part of the platform in the Karlovac area in Croatia was influenced by totally opposite tendencies – after lengthy emergence, a large part of this area was submerged. Formerly emergent areas, which existed from the Middle Lias to the Kimmeridgian (BUKOVAC et al., 1974, 1984; ŠPARICA, 1981; DRAGIČEVIĆ & VELIĆ, 1994, 2002), became a platform margin characterised by barrier coral–hydrozoan reefs. These Kimmeridgian–Tithonian biolithites along the N and NE margin of the Adriatic Carbonate Platform are mostly preserved in a more or less continuous belt from W Slovenia to SE Montenegro (DRAGIČEVIĆ & VELIĆ, 2002). In Croatia they are documented in the vicinity of Ozalj and Karlovac (BUKOVAC et al., 1974, 1984; DRAGIČEVIĆ & VELIĆ, 1994). Reefal and peri-reefal environments gradually prograded toward the open Tethyan realm, enabling the gradual migration of the platform margin towards the N and NE.

In the central part of the Adriatic Carbonate Platform, deeper areas were formed penecontemporaneously, in the form of two intraplatform troughs (probable pull-apart basins): one in the described eastern part of Gorski Kotar, and the other one stretching from the Karlovac area towards the south, known as the "Lemeš" trough (VELIĆ et al., 2002) which was, due to its connection with the open Tethys and greater depth, characterised by a more significant pelagic influence.

Although outcrops of the Gorski Kotar trough are not very well preserved, it may be supposed that today it is oriented approximately NW–SE, and that its western margin was completely surrounded by shallow-marine environments, while there is a possibility of at least a temporary connection with the Lemeš trough towards the SE. As previously described, Oxfordian inner platform deposits were gradually replaced by thick bedded dark grey *limestones with cherts* comprising rare ammonites and radiolarians (and including relics of tuffitic material). Towards the upper part of this sequence there is a gradual, but continuous increase of fine-grained interbeds composed of shallow-marine allochems (TIŠLJAR & VELIĆ, 1993; VELIĆ et al., 1994; TIŠLJAR et al., 1994; BUCKOVIĆ, 1995), especially the biodetritus of reef-builders and ooids derived from hydrozoan–coral–gastropod–bryozoan reefs and surrounding ooid shoals. Progradation of shallow material gradually completely infilled the former deep areas of intraplatform troughs which became overlain by typical shallow-water Clypeina limestones. Although there are similarities with penecontemporaneous "Lemeš deposits", some differences are remarkable: deposits in the area of Gorski Kotar show more characteristics typical for shallower environments (including hummocky cross stratification), beds are much thicker, cherts are less frequent and ammonites are very rare, since they were brought into this depositional area during temporary episodes of opening of the communication with the open sea. Therefore, for these deposits VELIĆ et al. (1998[5]) have proposed the name "Tuk limestones" (named after the type locality in Velika Kapela Mt.) to distinguish them from the "Lemeš deposits".

Sediments of the second, Lemeš trough, today oriented approximately N–S, were deposited in a deeper bay of Tethys, represented by thin-bedded to platy limestones interbedded with cherts, in some places with rich ammonite assemblages. These deposits are known by the name "Lemeš deposits" (FURLANI, 1910; CHOROWICZ & GEYSSANT, 1972). Although their underlying and overlying deposits are, due to younger tectonics and intense late-diagenetic dolomitization, frequently inadequately preserved, according to the field observations and literature data it is clear that in this case deeper-marine deposits also represent a sequence of variable thickness incorporated within shallow-marine deposits (e.g. at Plješevica Mt. near Bihać and N of Udbina, in vicinity of Donji Lapac, at Poštak Mt., Knin area, Svilaja Mt. and Cetina valley). The Lemeš trough was also surrounded by reefs producing an enormous quantity of bioclastic material, progradation of which caused the final infilling of the basin and re-establishment of shallow environments.

The inner part of the platform, i.e. the spacious area between emerged parts of the platform and the reef belt surrounding intraplatform troughs and platform margins, was characterised by continuous deposition of shallow-marine fossiliferous limestones, the so-called "Cladocoropsis" and "Clypeina–Campbelliella" deposits. In the Late Tithonian, after the final infilling of the former intraplatform troughs and submergence of formerly emerged areas, these environments predominated over the entire platform.

4. DISCUSSION AND CONCLUSION

From the aforementioned review of the geological events on the Adriatic Carbonate Platform during the Late Jurassic two main conclusions may be drawn:

(1) During the Kimmeridgian, completely different environments were established over formerly more or less unified shallow-water environments, indicating synsedimentary tectonic control. Near the SW margin some areas were emerged, in central parts intraplatform troughs had been formed, while contemporaneously along the NE margin formerly emerged areas (since Middle Lias) became

[5] VELIĆ, I., TIŠLJAR, J., VLAHOVIĆ, I., VELIĆ, J. & KOCH, G. (1998): Naslage gornje jure Gorskoga kotara, Like i Primorja s osobitim obzirom na vapnence s rožnjacima [*Upper Jurassic deposits of the Gorski Kotar, Lika and Primorje, including limestones with cherts* – in Croatian].– Unpubl. report, Archive of the Institute of Geology Zagreb, 113/98, 101+242 p.

submerged. Structural elements are masked by younger tectonics, hindering determination of the structural pattern. However, it is obvious that changes were gradual, probably as the consequence of a new tectonic regime, representing the beginning of the period characterised by inverse tectonics. Existing lineaments in the platform basement began to reactivate under the new conditions of compression, i.e. transpressional stress regime, transforming former normal faults into faults with horizontal to subhorizontal movements. This resulted in formation of small pull-apart basins (i.e. intraplatform troughs), local emersions and facies differentiation. Eustatic influences were subordinate during this period. Subsequent infilling of the differentiated palaeorelief of the platform was enabled by very high organic production of reef belts surrounding the intraplatform troughs' margins.

(2) The studied succession of Malmian deposits in the area of Velika Kapela Mt. (Gorski Kotar) includes Kimmeridgian deposits with pelagic influences – *limestones with cherts*. However, if these deposits represent part of the supposed long-lasting deeper marine labile belt (Epiadriaticum – HERAK, 1986, 1989), existing from the Late Triassic to the Eocene, they should be underlain and overlain by a deeper marine succession. Detailed analysis of the stratigraphic succession of Malmian deposits in SE Gorski Kotar (the wider area of Velika Kapela Mt.) undoubtedly confirmed the shallow-water origin of underlying and overlying deposits in all areas where continuous depositional successions are preserved. On the basis of the former investigations in the area of the Lemeš trough (GRIMANI et al., 1972; ŠUŠNJAR et al., 1973; POLŠAK et al., 1977; IVANOVIĆ et al., 1977) a similar conclusion can be drawn, although it had more open connection with the open Tethys realm. The desribed succession indicates the formation of temporary intraplatform troughs within a single carbonate platform.

Although, unfortunately, Malmian deposits only crop out over a relatively small area (due to the complex structural pattern of the Dinarides), on the basis of our investigation supported by available literature we can conclude that during the Late Jurassic (especially the Kimmeridgian) the area of the Adriatic Carbonate Platform was morphologically highly diversified. Consequently, different environments, from emerged areas, shallow-marine to peri-reefal and deeper-marine, existed contemporaneously over a relatively small area, and only their careful detailed investigation enabled the correct interpretation of palaeogeographical relationships.

Palaeogeographic dynamics similar to those described in this paper have characterised the geological history of only some periods on the Adriatic Carbonate Platform. This was especially true during the Late Cretaceous, when the area of the platform, as part of the Apulian or Adria Microplate, gradually approached the Laurasian continent, and the final disintegration of the platform took place.

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PLATE 1

Palynofacies of Kimmeridgian deposits of Velika Kapela Mt.

1 A fragment of a microbial mat lamina. Magnification 200x.

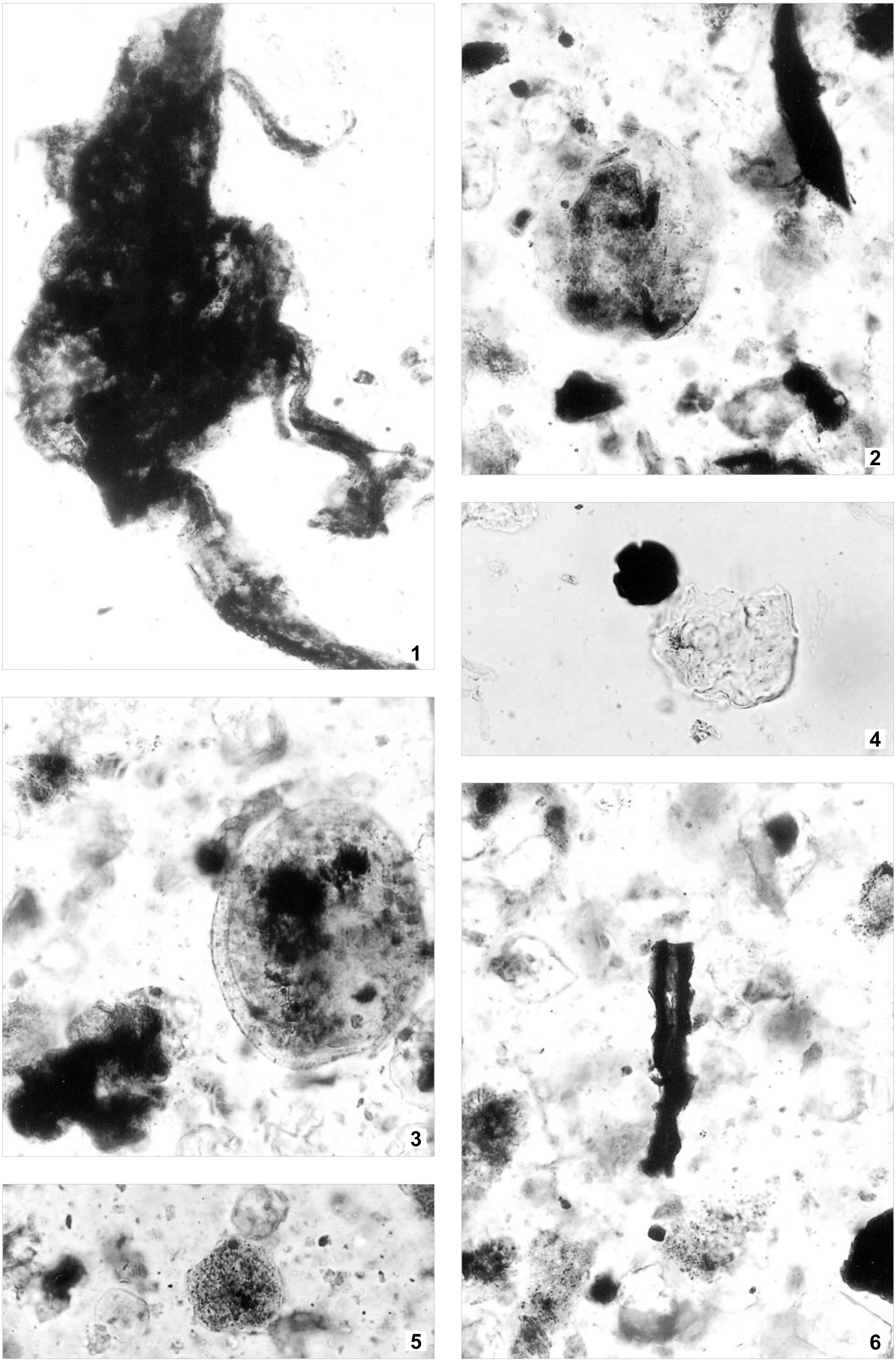
2 *Leiosphaeridia* sp., AOM, lath-shaped black particle, semiangular woody tissue. Magnification 800x.

3 *Tasmanites* sp., AOM. Magnification 800x.

4 *Escharisphaeridia* sp. Magnification 800x.

5 *Corollina* (*Classopollis*) sp. Magnification 400x.

6 Moderately structured lath-shaped woody tissue, AOM. Magnification 400x.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