GEOLOGICA CARPATHICA, 55, 1, BRATISLAVA, FEBRUARY 2004
3–18

LATE JURASSIC PALEOENVIRONMENTAL EVOLUTION OF THE WESTERN DINARIDES (CROATIA)

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(Manuscript received October 28, 2002; accepted in revised form June 23, 2003)

Abstract: Upper Jurassic limestones exposed in four selected successions of the Western Dinarides show contemporaneous but different facies development within the Western Dinaric region, which belongs to the marginal and northwestern part of the large Upper Triassic-to-Upper Cretaceous Adriatic-Dinaric carbonate platform. In the framework of global tectonic movements in the Tethyan Realm during the Late Jurassic, block-faulting on the northeastern margin of the Adriatic-Dinaric carbonate platform significantly affected platform interior, through differential synsedimentary tectonic movements: uplifts and tiltings culminating in sporadical emersions, and simultaneous increased subsidences, with the formation of intraplatform troughs connected to the open sea. Thus, block-faulting initiated changes in accommodation space within the inner platform realm and acted as an indirect impulse for autocyclic processes to take place both in the shallow-water and/or deeper-water platform environments.

Key words: Late Jurassic, Croatia, Western Dinarides, Adriatic-Dinaric carbonate platform, paleoenvironments, synsedimentary tectonics.

Introduction

The documentation of lateral variations in sedimentary successions is critical for paleoenvironmental reconstructions. Sedimentological and petrographic features of many Upper Jurassic sedimentary successions from the Western Dinarides, as well as their biostratigraphy, are described by numerous authors (e.g. Radoičić 1966; Gušić 1969; Milan 1969; Gušić & Babić 1970; Babić 1973; Savić 1973; Pleničar et al. 1976; Nikler 1978; Ćosović 1987; Velić & Tišljar 1988; Tišljar & Velić 1991, 1993; Tišljar et al. 1994; Velić et al. 1994, 1995; Bucković 1994, 1995, 1998). They show that sedimentary environments were strongly differentiated. For this study, we have chosen four distinct successions, each characterized by its own unique sedimentary signature. They represent the four typical Upper Jurassic environments in the Western Dinarides. These are (1) Sošice, a deep-water succession with open basin characteristics; (2) Breze, a predominantly shallow-water platform succession, partly with deeper-water characteristics; (3) Jazvina, a shallow-water platform succession; and (4) Rovinj, a shallow-water platform succession, punctuated by an emersion.

Biostratigraphic correlation plays a key role in lateral tracing of these successions, which are several tens of kilometres apart. The investigated successions have been subdivided into informal lithostratigraphic units, which do not coincide with the chronostratigraphic units. Therefore, the ages of these units are only approximately defined. Sartoni & Crescenti (1962) were the first within the Mediterranean Realm to subdivide an entirely carbonate Mesozoic succession into biostratigraphic units and correlate them with the chronostratigraphic scale. They were later followed by numerous authors (e.g. De Castro 1962; Farinacci & Radoičić 1964; Nikler & Sokač 1968; Gušić 1969; Gušić et al. 1971; Babić 1973; Ćosović 1987; Velić 1977; Tišljar & Velić 1993). According to Velić (1977), the Oxfordian and the lowermost Kimmeridgian correspond to the *Macroporella sellii* Cenozone, while the Middle–Upper Kimmeridgian and the Tithonian correspond to the *Clypeina jurassica* Cenozone. The latter has two subzones: the *Clypeina jurassica* s.str. Subzone (Upper Kimmeridgian–Lower Tithonian), and the *Clypeina jurassica* and *Campbelliella striata* Subzone (Upper Tithonian). The interval between these two cenozones is occupied by the *Cylindroporella anici* Cenozone. However, as we did not found *Cylindroporella anici* Nikler et Sokač, we could not trace the range of this cenozone across our successions.

In this paper, we document facies changes within the selected carbonate successions of the Western Dinarides in order to reconstruct and analyse the paleoenvironmental evolution of the northwestern part of the Adriatic-Dinaric carbonate platform during the Late Jurassic. To do this, we use our own results from current and some earlier field investigations as well as the published results of other researchers.

Geological setting

The study area (Fig. 1) represents part of a huge and long-lasting carbonate platform, named "the carbonate platform of the External Dinarides" by Polšak et al. (1982) and/or "the Adriatic-Dinaridic carbonate platform" by Gušić & Jelaska (1993), Jelaska et al. (1994, 2000), Pamić et al. (1998), Trubelja et al. (2001). Some Croatian geologists have also named it the Adriatic Carbonate Platform (e.g. Gušić & Jelaska 1990; Barić & Velić 2001; Ćosović & Moro 2001; Kapelj et al. 2001; Matičec et al. 2001; Velić 2001; Velić et al. 2001; Vlahović et al. 2001).

Herak (1986), however, distinguished an Adriatic from a separate Dinaric platform. Among the commonly used various names for the fossil carbonate platform(s) of the karst Dinar-

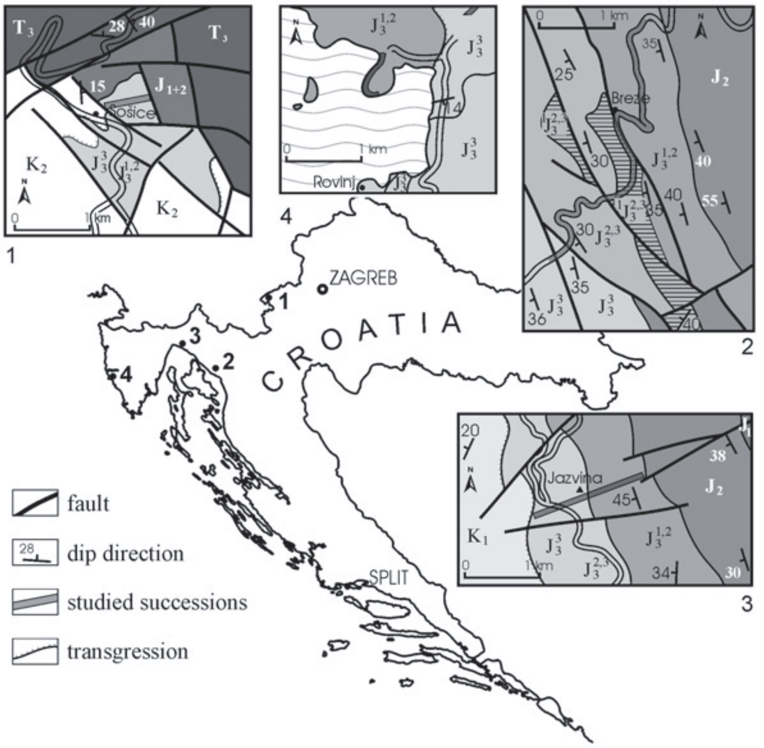


Fig. 1. Geographical locations of the studied successions: **1** — Sošice; **2** — Breze; **3** — Jazvina; **4** — Rovinj. Geological sketches 1–4 according to Basic Geological Map 1:100,000, sheets: Novo Mesto (Pleničar et al. 1976) (1); Crikvenica (Šušnjar et al. 1970) (2); Delnice (Savić D. & Dozet 1984) (3); and Rovinj (Polšak & Šikić 1969) (4) (all modified). *Legend:* $\mathbf{T_3}$ — Upper Triassic; $\mathbf{J_{1+2}}$ — Liassic and Dogger; $\mathbf{J_2}$ — Dogger; $\mathbf{J_3^{1,2}}$ — Oxfordian-Lower Kimmeridgian; $\mathbf{{}^1J_3^{2,3}}$ — Middle Kimmeridgian–Lower Tithonian (beds with layers and nodules of chert) and, $\mathbf{J_3^{2,3}}$ — Middle Kimmeridgian-Lower Tithonian; $\mathbf{J_3^3}$ — Upper Tithonian; $\mathbf{K_1}$ — Lower Cretaceous; $\mathbf{K_2}$ — Upper Cretaceous.

ides in Croatia, we prefer to use the name "Adriatic-Dinaric carbonate platform (ADCP)" following the usage adopted by the majority of Croatian geologists. A more elaborated explanation of this choice is beyond of scope of this paper.

According to Jelaska et al. (1994, 2000), the ADCP starts with Norian-Rhaetian peritidal stromatolitic dolomite ("Hauptdolomit"). Interrupted by several pelagic incursions and short emersions, the carbonate sedimentation regime lasted until the Lutetian transgression, when platform conditions were partly restored for the last time. Today, sediments of the ADCP crop out in a vast area extending from northeastern Italy along the eastern Adriatic coast to northwestern Greece and cover an area of about 1400 by 350 km (Jenkyns 1991; Grötsch et al. 1993).

Description of the studied successions

Within the Upper Jurassic sediments of the studied successions, various lithostratigraphic units can be distinguished, formed in particular environments and under identifiable sedimentary conditions.

The Sošice succession

Description. Within the Sošice succession (Mt Žumberak), two units can be distinguished (Fig. 2a): (1) the Sošice-1 Unit (So-1), consisting of pelletal-bioclastic wackestones, sporadically interbedded with coarse-grained layers which include bioclastic-intraclastic grainstone/rudstones in the lower part and bioclastic-peloidal grainstones in the upper part of a single interbedded layer; and (2) the Sošice-2 Unit (So-2), composed of skeletal wackestones. Between these two units, there is a portion of the section covered by vegetation.

The pelletal-bioclastic wackestones of the So-1 Unit form 20–70 cm thick beds dominated by cryptocrystalline spheroidal-ellipsoidal pellets and filaments embedded in calcareous mud (Fig. 3.1). In the Middle and Upper Jurassic carbonate deposits of the Mediterranean and Atlantic areas, filaments are usually interpreted as skeletal fragments of pelagic bivalves or their prodissoconchs (e.g. Colom 1955; Peyre 1959; Bernoulli 1967). Beside the pellets and filaments, there are calcitized radiolarians, sponge spicules, and ostracode fragments, which are locally more abundant. Coarse-grained interbedded layers, 5–20 cm thick, are separated from the wackestones at their lower bedding planes by sharp and uneven erosional contacts. In the lower part, these grainstone/rudstones contain poorly sorted angular to subrounded echinoderm fragments, commonly with micritic envelopes and/or abraded surfaces (Fig. 3.2). Subrounded intraclasts, peloids (micritized bioclasts and/or rounded intraclasts?) and molluscan fragments are less common. Going upwards within a single coarse-grained layer, the size of particles gradually decreases, grading into grainstones with prevailing spheroidal peloids, intraclasts, foraminifers, and molluscan fragments (Fig. 3.3). Among the foraminifers, *Nautiloculina oolithica* Mohler, *Protopeneroplis striata* Weynschenk, *Trocholina elongata* (Leupold), and *Pseudocyclammina lituus* (Yokoyama) have been determined, indicating an early Late Jurassic age (Velić 1977).

The skeletal wackestones of the So-2 Unit differ from the underlying pelletal-bioclastic wackestones by containing abundant calpionellids, embedded in the calcareous mud (Fig. 3.4). In these 2–10 cm thick beds, *Calpionella alpina* Lorenz and *Calpionella elliptica* Cadisch have been determined, evidencing the *Calpionella* Cenozone (Late Tithonian/Early Berriasian; Remane 1964; Babić 1973). Sponge spicules, echinoderm fragments, and calcitized radiolarian tests are much rarer. Bioturbation occurs only locally. Wackestones of this Unit are thinly bedded, sporadically more marly, and without any sedimentary structures.

Interpretation. The facies of the So-1 Unit is quite similar to that of toe-of-slope sedimentary environments, as it has been described by many authors (e.g. Masetti et al. 1991; Reijmer & Everaars 1991; Reijmer et al. 1991; Herbig & Bender 1992; Harris 1994; Herbig & Mamet 1994). The sedimentary textures and the occurrence of benthic foraminifers in the coarse-grained, interbedded layers clearly indicate gravity redeposition from a shallow-water platform into the adjacent deep-water environment at the bottom of the slope. Due to variations in the turbidit-

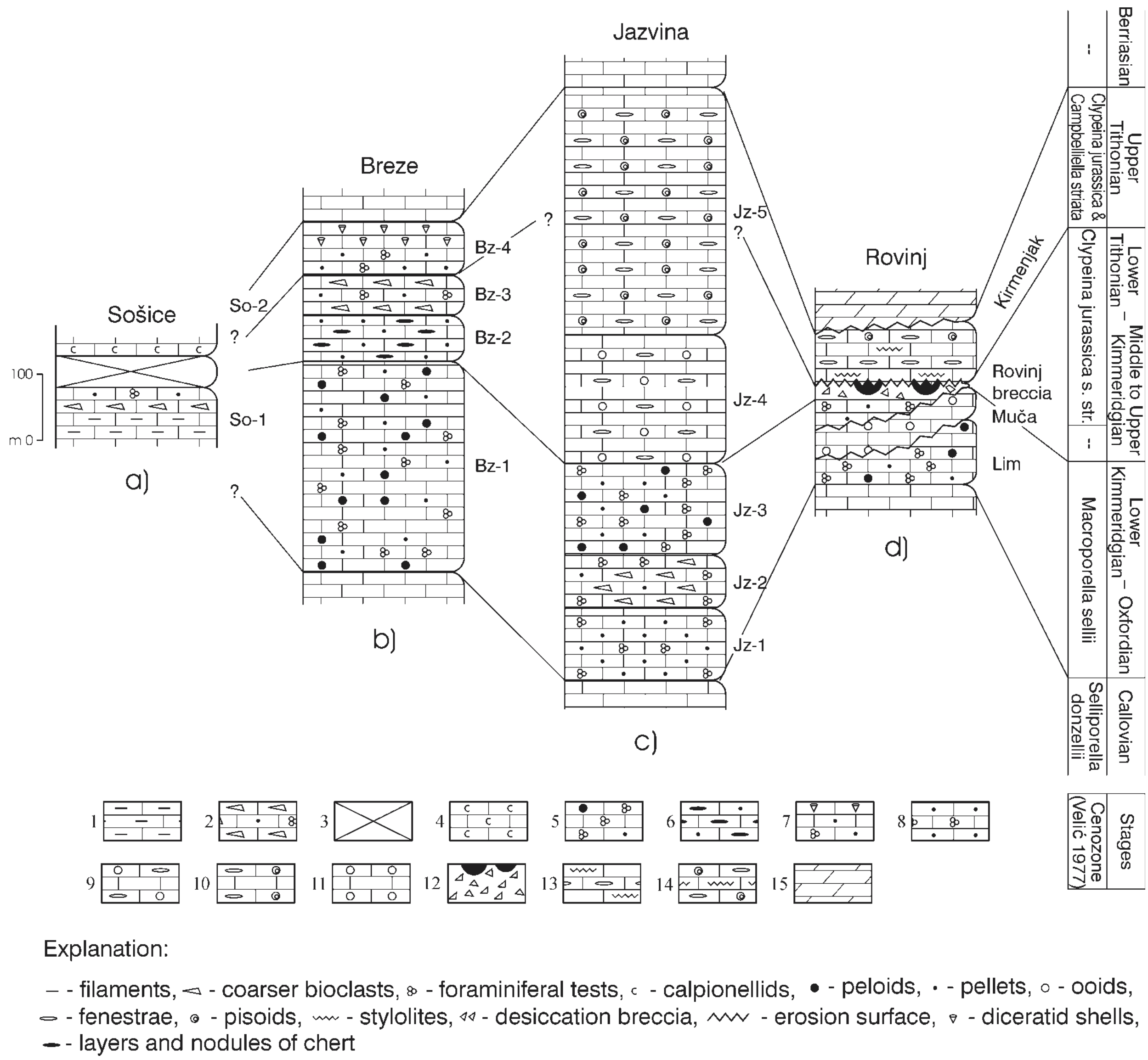


Fig. 2. Correlation of studied Upper Jurassic successions: **a)** Sošice (Bucković 1998, modified); **b)** Breze (Velić et al. 1994; Bucković 1994, 1995; modified); **c)** Jazvina (Tišljar & Velić 1993; Tišljar et al. 1994; Bucković 1994; modified); **d)** Rovinj (Tišljar & Velić 1987; Velić & Tišljar 1988; Tišljar et al. 1994, 1995; Velić et al. 1995; modified). **1** — pelletal-bioclastic wackestones; **2** — layers of bioclastic grainstones, grainstone/rudstones (in So-1 Unit) and wackestone/floatstones, grainstone/floatstones (in Jz-2 Unit); **3** — covered portion of section; **4** — skeletal wackestones; **5** — pelletal and peloidal wackestones; **6** — pelletal-bioclastic wackestones with layers and nodules of chert (in irregular alternation with siliceous beds); **7** — pelletal-bioclastic wackestones; **8** — mudstones and pelletal wackestones; **9** — shallowing- and coarsening-upward sequences (see Fig. 5a for details); **10** — shallowing- and coarsening-upward sequences (see Fig. 5b for details); **11** — coarsening-upward sequences (see Fig. 7a for details); **12** — Rovinj breccia; **13** — shallowing-upward sequences (see Fig. 7b for details); **14** — shallowing- and coarsening-upward sequences (see Fig. 7c for details); **15** — dolomites.

ic flow and in the amount of transported sediment, the coarse-grained layers are of variable thickness and grain size.

The thin beds of the So-2 Unit represent autochthonous carbonate mud deposition ("pelagic rain") with open marine fauna. More marly intervals correspond to increased influx of fine-grained siliciclastic detritus, derived from the north, that is from the Hercynian massifs (Pamić et al. 1998).

The Breze succession

Description. Within the Breze succession, along the main road, starting from the Dogger-Malm boundary, four units have been distinguished (Bucković 1994, 1995) (Fig. 2b): (1) the Breze-1 Unit (Bz-1), consisting of pelletal-skeletal wackestones; (2) the Breze-2 Unit (Bz-2), composed of pelletal-bioclastic wackestones with chert layers and nodules (in irregular alternation with siliceous beds); (3) the Breze-3 Unit (Bz-3), consisting of pelletal-bioclastic wackestones frequently interbedded with bioclastic packstone/floatstones; and (4) the Breze-4 Unit (Bz-4), composed of bioclastic-peloidal wackestone/packstones with rare floatstones and sporadic grainstones.

Velić et al. (1994) and Bucković (1994, 1995) contemporaneously and separately investigated this profile, and therefore

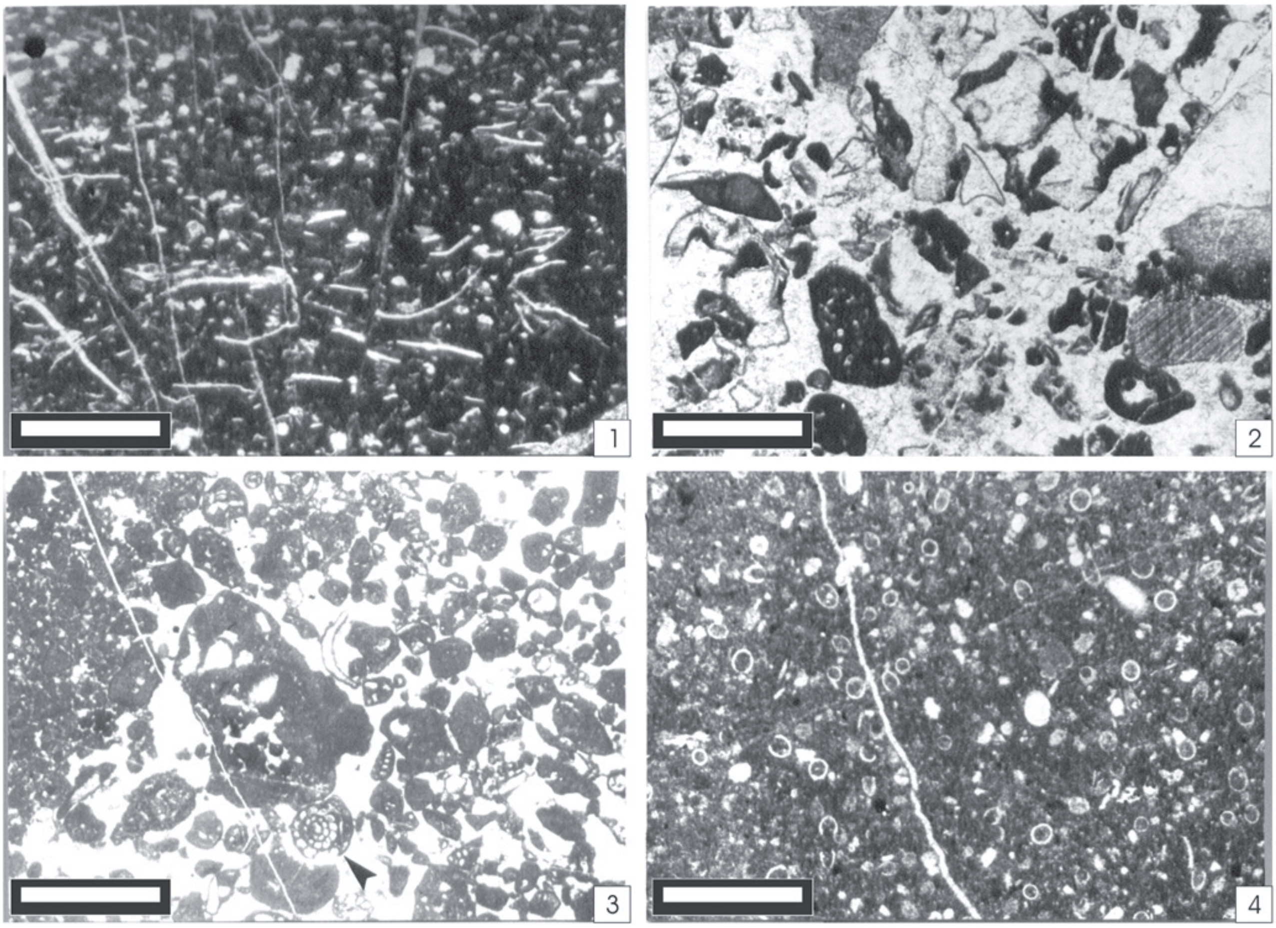


Fig. 3. Typical microfacies of units from the Sošice succession. **1** — Pelletal-bioclastic wackestone with filaments. Toe-of-slope environment. So-1 Unit. Sošice. Scale bar 0.8 mm. **2** — Bioclastic-intraclastic grainstone/rudstone with predominant coarser echinoderm and molluscan fragments. Lower part of a single interbedded coarse-grained layer. Toe-of-slope environment. So-1 Unit. Sošice. Scale bar 1.6 mm. **3** — Bioclastic-peloidal grainstone with *Nautiloculina oolithica* Mohler (arrow). Upper part of a single interbedded coarse-grained layer. Toe-of-slope environment. So-1 Unit. Sošice. Scale bar 1.6 mm. **4** — Skeletal wackestone with calpionellids. Basin environment. So-2 Unit. Sošice. Scale bar 0.4 mm.

the description of its facies characteristics mainly correspond to each other.

The predominant component of the pelletal-skeletal wackestone beds of the Bz-1 Unit (each 20–90 cm thick) are oval to suboval tiny faecal pellets and rarer coarser peloids (micritized bioclasts and/or rounded intraclasts?) which in places prevail forming peloidal-skeletal wackestones (Fig. 4.1). They contain a rich benthic biota: *Praekurnubia crusei* Redmond, *Kurnubia palastiniensis* Henson, *Salpingoporella sellii* (Crescenti), *Pseudocyclammina lituus* (Yokoyama) and *Redmondoides lugeoni* (Septfontaine), as well as debris of *Thaumatoporella*. This assemblage belongs to the *Macroporella sellii* Cenozone (Velić 1977). Echinoderm and molluscan fragments of variable sizes are sporadically present. Very rarely, large fragments of *Cladocoropsis mirabilis* Felix can be found.

Separated by a minor fault, deposits of the Bz-2 Unit overlie the Bz-1 Unit. Its lower portion (the first 38 m) is characterized by pelletal-bioclastic wackestones with rare intercalations and nodules of chert, whereas the upper part (the next 34 m) consists of an irregular alternation of pelletal-bioclastic wackestones and greyish-green siliceous beds. The lower portion of this unit is characterized by thicker bedding in comparison with its upper part (10–50 cm compared to 3–15 cm). Additionally, layers and nodules of chert inside the upper part of this unit are very frequent. Besides the pellets, the wackestones contain tiny echinoderm fragments and rare calcitized radiolarians, sponge spicules, as well as hydrozoan and gastropod debris (Fig. 4.2). Such limestones alternate with easily cleavaged and poorly consolidated siliceous beds in the upper portion of this unit. The contacts between wackestones and siliceous beds are always sharp. The siliceous beds are clayey-tuffitic layers formed by the alteration of volcanic ash and fine-grained vitric tuffs, containing radiolarians and spicules of siliceous sponges (Šćavničar & Nikler 1976).

The first appearance of the bioclastic packstone/floatstone layer inside the pelletal-bioclastic wackestones marks the beginning of the Bz-3 Unit. The bioclastic packstone/floatstones are 2–10 cm thick layers characterized by more or less clearly expressed grading and orientation of elongated bioclasts parallel to bedding. They are composed of poorly sorted, abraded and broken echinoderm, hydrozoan, and molluscan fragments, as well as micritic intraclasts (Fig. 4.3). Peloids, ooids, and algal bioclasts are rarely present. These coarse-grained

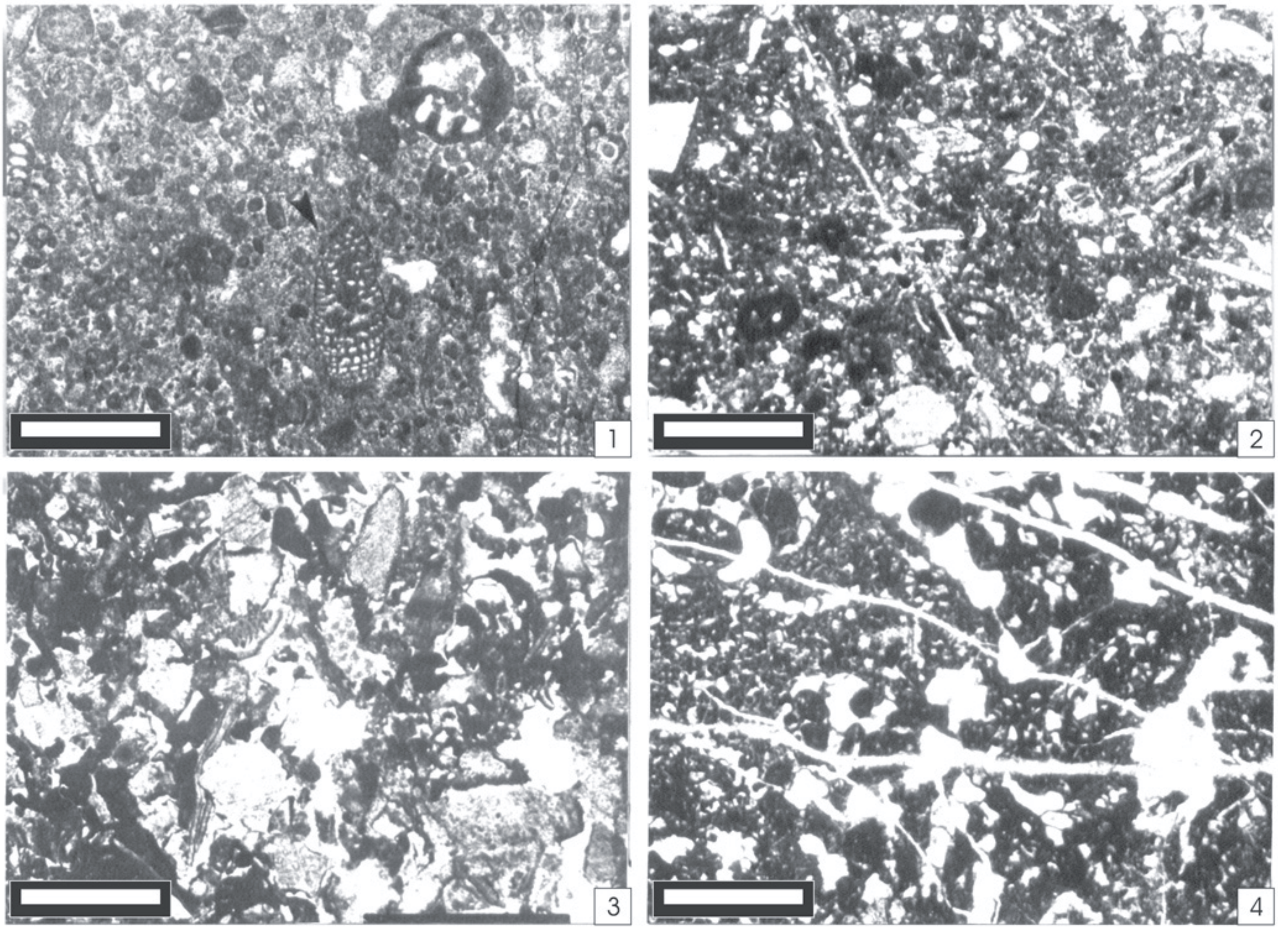


Fig. 4. Typical microfacies of units from the Breze succession. **1**— Peloidal-skeletal wackestone. Arrow points at *Kurnubia palastiniensis* Henson. Platform lagoon environment. Bz-1 Unit. Breze. Scale bar 0.8 mm. **2** — Pelletal-bioclastic wackestone with small echinoderm fragments, sponge spicules, and rare calcitized radiolarians. Intraplatform trough environment. Bz-2 Unit. Breze. Scale bar 0.8 mm. **3** — Bioclastic packstone/floatstone with coarser echinoderm and hydrozoan fragments. Intraplatform trough environment. Bz-3 Unit. Breze. Scale bar 1.6 mm. **4** — Pelletal-bioclastic wackestone with irregular fenestrae and/or dissolution vugs. Platform intertidal to supratidal environment. Bz-4 Unit. Breze. Scale bar 0.8 mm.

layers are always separated from both the underlying and overlying wackestones by sharp contacts, of which the lower one is erosional. Upwards in this section, the coarse-grained interbedded layers become more frequent and thicker.

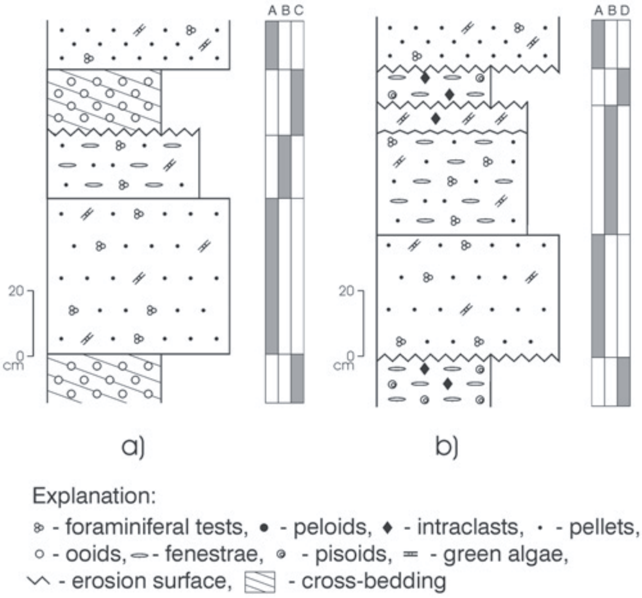
At the top of the last coarse-grained layer, a change in particle content occurs and marks the beginning of the Bz-4 Unit. In 15–80 cm thick beds of pelletal-bioclastic wackestones, more rarely peloidal and/or ooidal grainstones, pellets, micritic intraclasts, and molluscan fragments are the predominant components. Foraminifers occur more rarely. Irregular fenestrae and/or dissolution vugs filled by drusy calcite frequently occur (Fig. 4.4). Large diceratid shells, as well as *Clypeina jurassica* Favre, *Campbelliella striata* (Carozzi), and *Pseudocyclammina lituus* (Yokoyama) can occasionally be found, defining the *Clypeina jurassica* and *Campbelliella striata* Subzone (Velić 1977).

Interpretation. The presence of large amounts of pelllets and benthic foraminifers implies that the Bz-1 Unit has been deposited in low-energy platform shoals and/or lagoons with slow and constant rate of sediment accumulation ("open platform" — Wilson 1975; low-energy shallow lagoon — Velić et al. 1994). Echinoderm, molluscan, and *Cladocoropsis* fragments indicate sporadic higher energy conditions, when carbonate material was derived from neighbouring reef-mounds or patch reefs whose relicts composed of coral, hydrozoan, spongiomorph and diceratid skeletons can be found locally (Velić et al. 1994).

In the Bz-2 Unit, the absence of benthic biota and the rather common presence of radiolarian tests indicates greater depth and a stronger influence of the open sea. This depositional environment was a rather spacious, elongated lagoon, bounded by inner carbonate ramps, which was only sporadically connected with the open sea (Velić et al. 1994). In this deeper-water environment, the vitroclasts, carried by the wind from distant volcanic eruptions, were devitrified and altered, resulting in chert or clayey-tuffitic layers (Šćavničar & Nikler 1976).

The first coarse-grained bioclastic packstone/floatstone layer of the Bz-3 Unit represents gravity displaced carbonate material, deposited in a deeper-water environment. Velić et al. (1994) referred to it as an elongated intraplatform lagoon, but Bucković (1994, 1995) identified it as an intraplatform trough. Both Velić et al. (1994) and Bucković (1994, 1995) regard this gravity displaced carbonate material as massive peri-reefal deposits. Processes of redeposition were very similar to those in which the allochthonous layers of So-1 Unit were formed. However, here the episodic accumulation of the redeposited bioclastic coarse-grained material in the deeper-water environment produced successive infilling and progressive shallowing of the original deeper-water environment and, thus, the gradual progradation of the shallow-water platform environment (Bucković 1994, 1995). However, as distinct from Sošice, here this infilling and progressive shallowing of the original deeper-water environment was possible because both the depth and spaciousness of this elongated intraplatform trough were probably much smaller than the Sošice deep-water environment.

Later in the sedimentary succession, gravity displaced carbonate material, that is peri-reefal deposits, was overlain by prograding ooid-bioclastic and ooid carbonate shoals (Velić et al. 1994). Once the shallow-water environment was re-established, carbonate accumulation of the Bz-4 Unit became rather high, resulting in further shallowing, which periodically reached up to intertidal-supratidal levels, producing shallowing-upward sequences with sporadic subaerial exposure (Velić et al. 1994; Bucković 1994, 1995).



Figs. 5a–b. Detail of sequences in: **a)** Jz-4 Unit (Bucković 1994; modified); **b)** Jz-5 Unit (Tišljar & Velić 1993; Tišljar et al. 1994; Bucković 1994; modified). **A** — shallow subtidal, **B** — intertidal-supratidal, **C** — oolite shoal (tidal bar, in: Tišljar & Velić 1993; Tišljar et al. 1994), **D** — vadose zone.

The Jazvina succession

Description. At the Jazvina locality, five units have been recognized (Tišljar & Velić 1993; Bucković 1994). In this paper we name them as follows (Fig. 2c): (1) the Jazvina-1 Unit (Jz-1), with mudstones and pelletal wackestones; (2) the Jazvina-2 Unit (Jz-2), with bioclastic wackestone/floatstones and grainstone/rudstones; (3) the Jazvina-3 Unit (Jz-3), with peloidal-skeletal wackestones and packstones; (4) the Jazvina-4 Unit (Jz-4), composed of shallowing and coarsening-upward sequences with mudstones or pelletal wackestones as the lower sequence facies types, fenestral mudstones or pelletal wackestones as the middle sequence facies types, and ooid grainstones as the upper sequence facies types (Fig. 5a); and (5) the Jazvina-5 Unit (Jz-5), composed of shallowing- and coarsening-upward sequences, which differ from the underlying Jz-4 sequences by the presence of the pisoid-intraclastic grainstone/rudstones as the upper sequence facies types (Fig. 5b).

Tišljar & Velić (1993) and Bucković (1994) contemporaneously and separately investigated this profile, and therefore the description of its facies characteristics mainly correspond to each other.

Mudstone and pelletal wackestone beds of the Jz-1 Unit are 20–90 cm thick and mostly contain variable amounts of foraminifers and peloids in carbonate mud. Among the foraminifers, *Pseudocyclammina lituus* (Yokoyama), *Redmondoides lugeoni* (Septfontaine), *Praekurnubia crusei* Redmond, *Kurnubia palastiniensis* Henson and *Trocholina elongata* (Leupold) have been determined. Sporadically, tiny molluscan fragments, algal oncoids, and cyanophyte filaments with thick micritic envelopes can also be found. Bioturbation occurs locally. Coarse-grained, coated *Cladocoropsis*, echinoderm, and molluscan fragments occur more frequently in the upper part of this unit. This indicates a gradual transition into the overlying Jz-2 Unit.

Rhythmical alternations of the bioclastic wackestone/floatstones with bioclastic grainstone/rudstones is the main characteristic of the Jz-2 Unit. Both facies types are 20–60 cm thick and contain various coarse-grained molluscan and hydrozoan skeletal debris (Fig. 6.1). Sporadically, hummocky cross stratification (HCS) is observed within the grainstone/rudstones. Besides the above mentioned allochems, peloids, subspheroidal micritic intraclasts, and algal oncoids occur very rarely. Foraminifers keep occurring; in addition to those from the underlying unit, *Nautiloculina oolithica* Mohler, *Labyrinthina mirabilis* Weynschenk, *Chablaisia chablaisensis* Septfontaine, and *Mohlerina basiliensis* (Mohler) appear, indicating the *Macroporella sellii* Cenozone (Velić 1977).

Poorly sorted and locally bioturbated, mud-rich limestones of the Jz-3 Unit predominantly contain typical shallow-water allochems; pellets, peloids, and benthic foraminifers (Fig. 6.2). Whereas peloidal-skeletal wackestone beds dominate, packstones are rarer. Packstones commonly contain numerous foraminifers, well-known from the underlying units. However, contrary to the underlying units, this whole unit is additionally characterized by the presence of the algal species *Salpingoporella sellii* (Crescenti). Algal oncoids, tiny molluscan fragments, and angular to rounded micritic intraclasts also occur in variable proportions. Algal oncoids and coarser micritic and/or pelmicritic intraclasts may be the dominant component in a few places inside this unit, thus forming individual beds of oncoid-intraclastic wackestone/floatstones or grainstone/rudstones. This unit is characterized by 15–80 cm thick beds.

Shallowing- and coarsening-upward sequences of the Jz-4 Unit consist of three texturally and compositionally various facies types. The thickness of the lower sequence facies types ranges from 40–120 cm, whereas the thicknesses of the middle and upper sequence facies types are frequently equal, amounting to 15–20 cm.

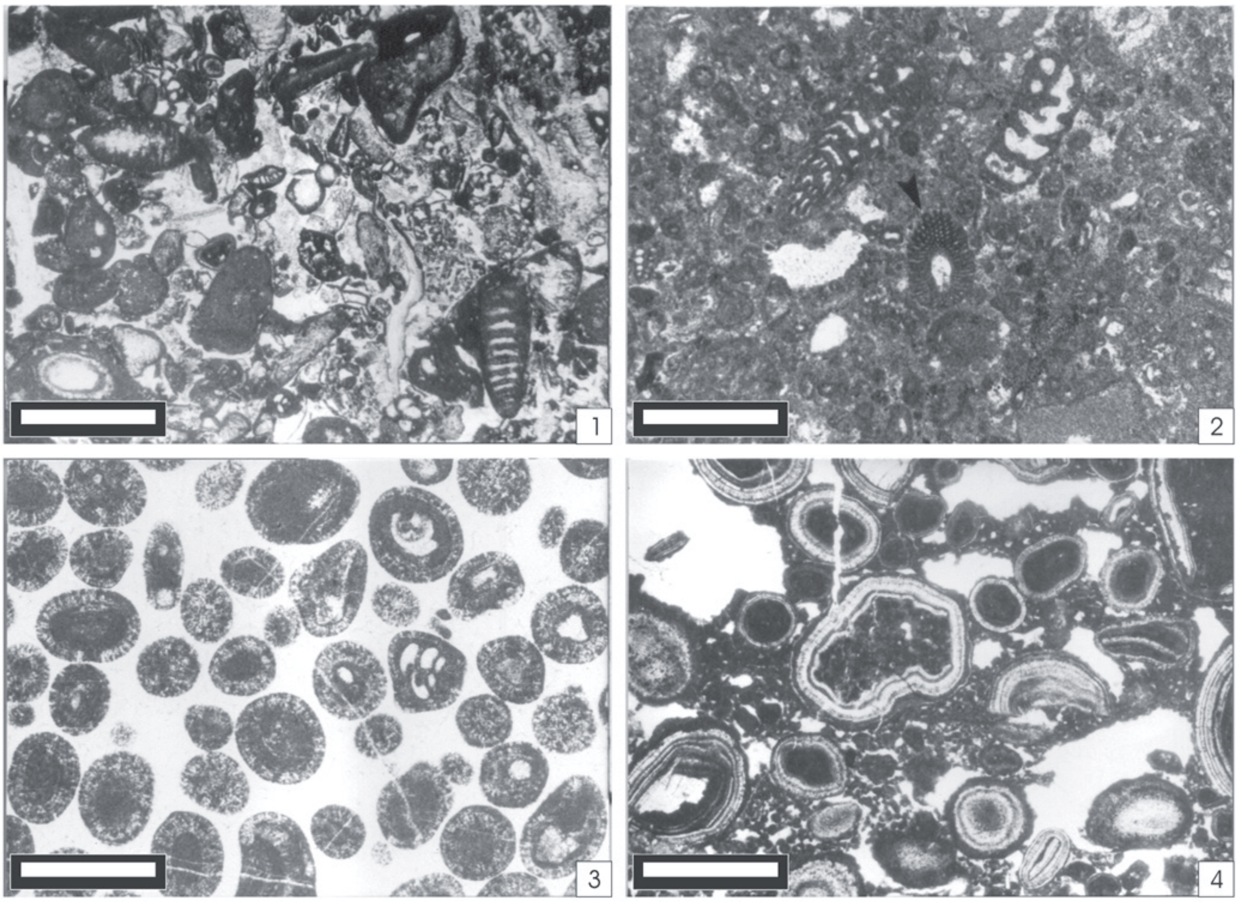


Fig. 6. Typical microfacies of units from the Jazvina succession. **1** — Bioclastic grainstone/rudstone with predominant coarser molluscan fragments. Platform lagoon environment. Jz-2 Unit. Jazvina. Scale bar 1.6 mm. **2** — Peloidal-skeletal wackestone with *Salpingoporella sellii* (Crescenti) (arrow) and *Praekurnubia crusei* Redmond. Platform subtidal environment. Jz-3 Unit. Jazvina. Scale bar 0.8 mm. **3** — Ooid grainstone composed of ooids with well preserved radial-fibrous fabric. Platform oolite shoal environment. Jz-4 Unit. Jazvina. Scale bar 1.6 mm. **4** — Pisoid-intraclastic grainstone/rudstone with micritic and/or micritic-pelletal intraclasts surrounded with pisoid envelopes. Platform vadose environment. Jz-5 Unit. Jazvina. Scale bar 1.6 mm.

Mudstone or pelletal wackestone beds are usually 20–60 cm thick and contain pellets, rare peloids, and foraminifers. In these members, rare algal oncoids and fragments of *Clypeina jurassica* Favre and/or *Salpingoporella annulata* Carozzi are also present. Less common allochems are mainly tiny molluscan and echinoderm fragments. This allochem content continues into the middle member with the distinct difference that the latter contains irregular fenestrae, molds of bioclasts, and/or dissolution vugs filled by drusy calcite. Only locally, fenestrae, molds, and vugs are roofed by microstalactitic cement, while some larger molds and dissolution vugs are lined at their bottom with crystal silt showing geopetal fabric.

Ooid grainstones are composed of well sorted ooids with peloidal and, much more rarely, bioclastic nuclei, surrounded by a microcrystalline envelope. Within the individual ooids primary radial-fibrous fabric is clearly visible (Fig. 6.3). Numerous ooid grainstone members contain only crushed and/or regenerated ooids with a considerable amount of crystal and pelletal silt in the pore spaces, thus showing geopetal fabric, while microstalactitic and meniscus cement occur rarely. Locally, ooid grainstone members show distinct cross lamination.

Because this unit originated under different conditions than the underlying one, some fossils are lacking (Tišljar & Velić 1993). Thus, *Kurnubia palastiniensis* Henson and *Trocholina alpina* (Leupold) become the predominant foraminifers. *Clypeina jurassica* Favre, which appears after the first ca. 60 metres of this unit, defines the vertical range of the *Clypeina jurassica* s.str. Subzone (Velić 1977).

A distinct cyclic pattern of three facies types can also be observed in the Jz-5 Unit.

The first two members of these shallowing- and coarsening-upward sequences are characterized by the same compositional and textural features as the first two members from the underlying Jz-4 Unit. However, the middle, fenestral, member is frequently capped with skeletal-intraclastic grainstones containing abundant *Clypeina jurassica* Favre and/or *Campbelliella striata* (Carozzi), fragments and micritic intraclasts. In a few places, these grainstones contain variable amounts of molluscan and echinoderm fragments, cortoids, and foraminiferal tests. The thicknesses of these first two members are frequently equal, amounting to 35–50 cm.

The third facies types are always 10–15 cm thick pisoid-intraclastic grainstone/rudstones. They contain angular to rounded micritic-pelletal intraclasts (sometimes with fenestral fabric), with or without pisoid envelopes (Fig. 6.4). Intergranular pores commonly contain variable amounts of crystal and pelletal silt; this internal sediment frequently shows grading and geopetal fabric. Meniscus and microstalactitic cements occur only sporadically.

Beside sporadic findings of the foraminifers *Redmondoides lugeoni* (Septfontaine) and *Pseudocyclammina lituus* (Yokoyama), this unit contains abundant fragments of the dasyclad species *Clypeina jurassica* Favre and *Campbelliella striata* (Carozzi). *Campbelliella striata* occurs throughout this unit, while *Clypeina jurassica* disappears after about the middle. This unit belongs in its entire range to the *Clypeina jurassica* and *Campbelliella striata* Subzone (Velić 1977).

Interpretation. The depositional environment for the Jz-1 Unit is interpreted as a shallow, low-energy lagoon below the fair-weather wave-base, situated in the inner platform region. Tišljar & Velić (1993) consider this unit to be deposited in low energy shoals in the outer part of the carbonate ramp (outer-ramp?), probably mostly below the fair weather wave-base, with constant and steady accumulation of sediment in a quiet water environment. However, the increasing amount of coarse-grained fragments in the upper part of this unit suggests stronger influence of adjacent environments, inhabitated by molluscs, echinoderms, and hydrozoans. These could be reef mounds or patch-reefs build-up of various coarser skeletal organisms. These organic structures could be formed on lagoonal floor irregularities providing hard substrate, where bottom currents provide oxygen and nutrients. Their growth was due to local accumulation of skeletal material and to the baffling and trapping of finer sediment by lagoonal organisms (e.g. fleshy algae). As a result of destruction of these structures by currents and waves during major storms, coarse-grained skeletal fragments were spread throughout the lagoon, sporadically initiating formation of additional lagoonal floor irregularities which became nucleui for new organic structures. When reef mounds or patch-reefs, in such a way, spread (prograded) and occupied more space, the Jz-2 Unit, composed solely of coarse-grained skeletal fragments, began to be deposited during major storms. These limestones are typical examples of bioclastic carbonate sediments deposited on a carbonate platform in high energy shoals, in which large quantities of fossil debris, transported by waves and tidal currents, have been accumulated (Tišljar & Velić 1993). Bioclast abundance, good sorting, and partial hummocky cross stratification in this unit clearly indicate high-energy, stormy conditions, in which the waves and currents reworked and transported skeletal fragments. Rhythmical alternation of wackestone/floatstones and grainstone/rudstones indicate oscillations in water energy; wackestone/floatstones were deposited when storms began to calm down.

High carbonate mud content within the Jz-3 Unit suggests a subtidal depositional environment (shoreface above fair-weather wave-base and/or lagoon — Tišljar & Velić 1993). Contrary to the depositional environment of the Jz-1 Unit, rich foraminiferal content (particularly in the packstones) indicates better water circulation above the fair-weather wave-base and thus more favourable ecological conditions than those in the Jz-1 Unit. Packstone beds suggest sporadic higher-energy environments, triggered by periodical storms which winnowed the muddy foraminiferal material. During sporadic major storms, carbonate mud was washed out and neighbouring reef mounds or patch-reefs were eroded, giving rise to bioclastic-intraclastic grainstone/rudstone beds.

Within the Jz-4 Unit, three sedimentary environments with different depositional styles can be recognized. Periodically changing conditions, ranging from shallow subtidal to oolite shoals, have produced a series of shallowing- and coarsening-upward sequences. Gradual transition of the mudstones and pelletal wackestones to those with fenestral fabric, as well as molds of bioclasts and/or dissolution vugs, clearly indicate shallowing-upward evolution, with sporadic subaerial exposure as a consequence of tidal-flat progradation or aggradation in the subtidal zone of maximum carbonate productivity (Tišljar & Velić 1993). Oolite shoals from adjacent areas, which constantly changed their position during periodic storms and/or higher tidal currents, capped the underlying intertidal-supratidal fenestral deposits, thus forming the third, ooid grainstone member of the shallowing- and coarsening-upward sequences. During stormy periods, ooids were thrown by waves onto the vadose zone, and thus subjected to desiccation and vadose diagenesis, producing vadose features (microstalactitic and meniscus cement, crystal and pelletal silt). Triggered by periodical storms and/or high tides, several episodes of re-deposition took place, when ooidal deposits were transported from the vadose to the subtidal zone and back, which caused their partial cracking and multiphase regeneration. Tišljar & Velić (1993) consider this unit to be deposited in specific circumstances ranging from beach bar to lagoon and intertidal environments as a result of ooid bar and tidal flat progradation, so their interpretation of this unit is rather different. They interpreted these shallowing-upward sequences as beginning with the ooid grainstones, and passing up into the lagoonal mudstones/wackestones (for such a model see also Straser 1994; Straser et al. 1999). They are capped by the fenestral tidal flat wackestones with the evidence of subaerial exposure.

The first two facies types of the Jz-5 Unit originated under similar conditions as the first two facies types of the underlying Jz-4 Unit. However, after the final emergence of the second member, carbonate detritus (mainly intraclasts), thrown onto the emergent surface from the adjacent subtidal environments by action of storm waves and high tides, was exposed to vadose diagenesis. During these periods, some intraclasts developed pisoid envelopes, and internal sediment was produced (for a more complex and different interpretation of this unit, see Tišljar & Velić 1993).

The Rovinj succession

Description. Inside the Upper Jurassic succession in the vicinity of Rovinj, earlier authors have distinguished four units (see Tišljar & Velić 1987; Velić & Tišljar 1988; Tišljar et al. 1994, 1995; Velić et al. 1995) (Fig. 2d): (1) the Lim Unit, consisting of peloidal-skeletal wackestones, less commonly peloid grainstones or packstones; (2) the Muča Unit, composed of coarsening-upward sequences with peloidal-skeletal wackestones as the lower sequence facies types, ooid grainstones as the middle sequence facies types and the bioclastic-ooidal grainstones, more rarely rudstones, as the upper sequence facies types (Fig. 7a); (3) the Rovinj Breccia Unit; and

(4) the Kirmenjak Unit, consisting in its lower part of shallowing-upward sequences with black-pebble breccia as the lower sequence facies types, mudstones as the middle sequence facies types, fenestral mudstones as the upper sequence facies types. In the upper part of the Kirmenjak Unit black-pebble breccia does not appear and there are shallowing- and coarsening-upward sequences starting with mudstones as the lower sequence facies types, fenestral mudstones as the middle sequence facies types, and ending with the pisoid-intraclastic grainstone/rudstones as the upper sequence facies types (Figs. 7b–c).

All these units follow each other in normal superposition, with the exception of the Lim and Muča Units, which pass laterally into each other, so that the Muča Unit represents one giant lens-like sediment body inside the Lim Unit (Tišljar & Velić 1987; Velić & Tišljar 1988; Tišljar et al. 1994, 1995; Velić et al. 1995). Here we give a short (summarized) description and interpretation of these units according to these authors.

Peloidal-skeletal wackestones of the Lim Unit are 30–90 cm thick beds composed of micrite, sphaeroidal peloids and diverse platform allochems: foraminifers, molluscan and echinoderm fragments, less frequently green algae and algal oncoids (Fig. 8.1). Rarely, fragmented, coarse-grained *Cladocoropsis* fragments are found, usually covered with thin micritic envelopes and/or coated with few oncoid envelopes. Rounded intraclasts are in places more abundant. Among the foraminifers, *Redmondoides lugeoni* (Septfontaine), *Kurnubia palastiniensis* Henson, *Praekurnubia crusei* Redmond, *Trocholina elongata* (Leupold), *Trocholina alpina* (Leupold), *Nautiloculina oolithica* Mohler, *Pseudocyclammina lituus* (Yokoyama), and *Chablaisia chablaisensis* (Septfontaine), as well as the dasyclad *Salpingoporella sellii* Crescenti, are the most common constituents, indicating the *Macroporella selli* Cenozone (Velić 1977).

Huge, being several kilometers long and several tens of metres thick, the lense of the Muča Unit distinctly differs from the Lim Unit by its composition. It consists of a successive series of coarsening-upward sequences, each composed of three texturally and compositionally different facies types. The thickness of the lower sequence facies types ranges from 20–40 cm, whereas the thickness of the middle and upper sequence facies types are commonly equal, amounting to 40–70 cm.

The peloidal-skeletal wackestones have the same allochem content as the underlying wackestones of the Lim Unit. Small-scale cross-bedded ooid grainstones are composed of well-sorted ooids with peloidal and/or bioclastic nuclei and radial-fibrous microstructure (Fig. 8.2). Intraclasts, foraminifers, and tiny molluscan fragments are much rarer. Bioclastic-ooidal grainstones, more rarely rudstones, differ from the underlying ooid grainstones by the presence of large amounts of various foraminifers, as well as by coarse-grained, frequently abraded coral, molluscan, and hydrozoan fragments (Fig. 8.3). In a few places, entire coral heads are present. The surfaces of many of these bioclasts are coated and/or micritized. Distinct, large-scale cross-bedding is clearly visible. The foraminiferal association of this unit corresponds fully to that of the Lim Unit.

The Rovinj Breccia Unit consists of 1–8 cm sized, rounded to angular limestone fragments that belong, compositionally and texturally, to the underlying Lim Unit. Only sporadically these fragments were derived from the Muča Unit. The breccia cement is microcrystalline calcite, pigmented in places by

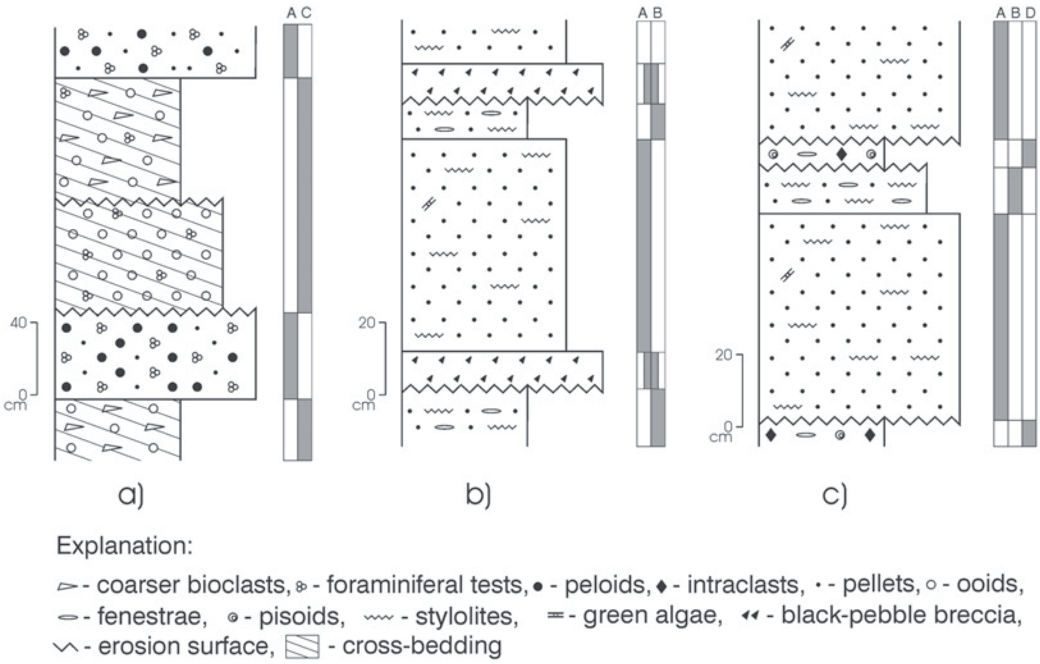


Fig. 7a–c. Detail of sequences in: **a)** Muča Unit; **b)** and **c)** Kirmenjak Unit (Tišljar & Velić 1987; Velić & Tišljar 1988; Tišljar et al. 1994; Velić et al. 1995; Tišljar et al. 1995; modified). **A** — shallow subtidal (tidal bar, in: Tišljar & Velić 1987; Velić & Tišljar 1988; Tišljar et al. 1994; Tišljar et al. 1995), **B** — intertidal-supratidal, **C** — oolite shoal, **D** — vadose zone.

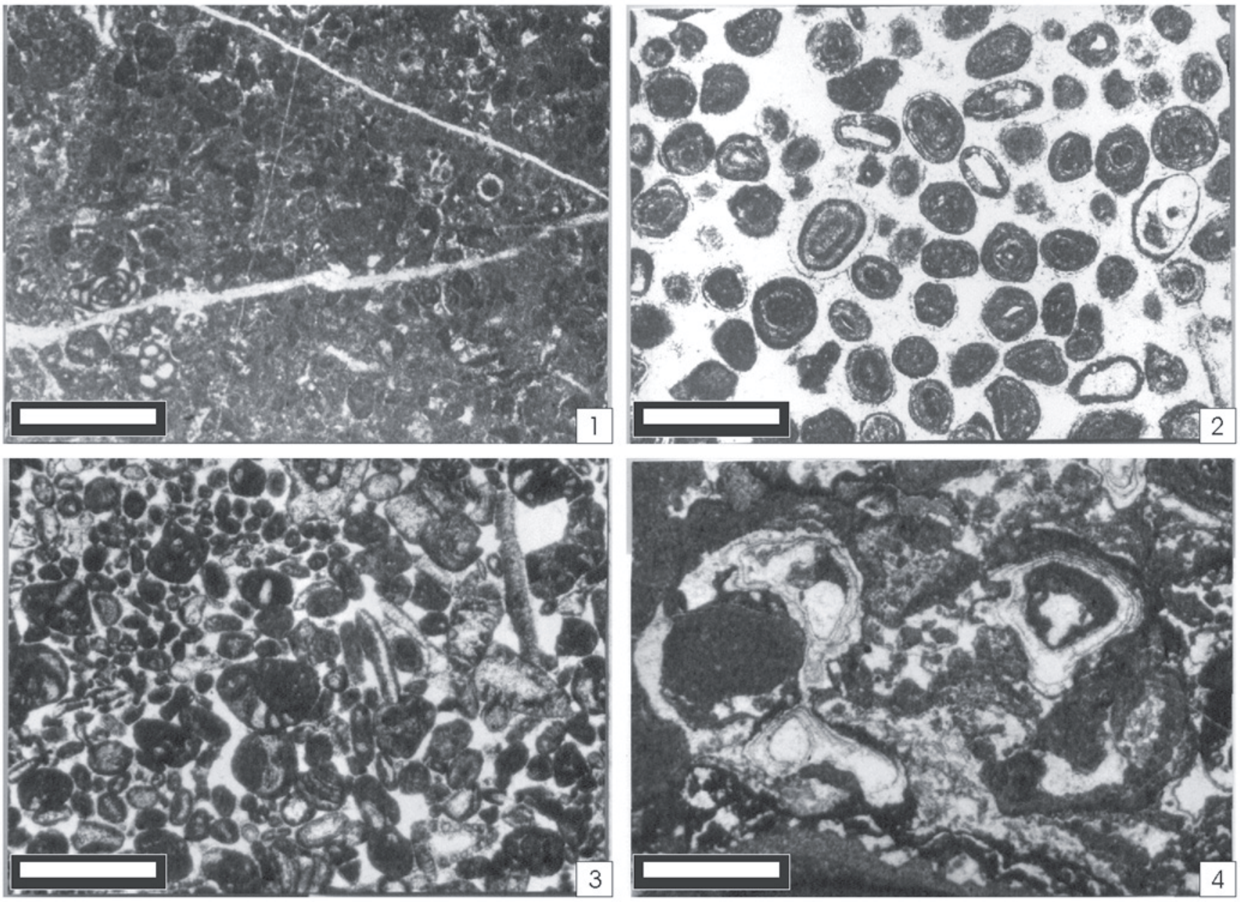


Fig. 8. Typical microfacies of units from the Rovinj succession. **1** — Peloidal-skeletal wackestone. Platform subtidal environment. Lim Unit. Rovinj. Scale bar 0.8 mm. **2** — Ooid grainstone composed of ooids with rarely preserved radial-fibrous fabric. Platform oolite shoal environment. Muča Unit. Rovinj. Scale bar 1.6 mm. **3** — Bioclastic-ooidal grainstone with predominant molluscan fragments, foraminifers and oomoldic ooids. Platform oolite shoal environment. Muča Unit. Rovinj. Scale bar 1.6 mm. **4** — Pisoid-intraclastic grainstone/rudstone with micritic and/or micritic-pelletal intraclasts surrounded with pisoid envelopes. Platform vadose environment. Kirmenjak Unit. Rovinj. Scale bar 1.6 mm.

Fe-minerals. The thickness of the breccia varies from a few decimetres to 8 metres; it has a lens-like form and is commonly separated from the Lim Unit by a sharp and uneven contact. In a few places, the breccia is overlain by bauxites composed, according Šinkovec (1974), of boehmite, kaolinite, and hematite.

Overlying the breccia and bauxite, there is the Kirmenjak Unit, composed of successive series of shallowing-upward sequences and then shallowing- and coarsening-upward sequences. The thicknesses of sequence facies types are variable. The black-pebble breccia, as the lower facies type of the shallowing-upward sequences, consists of subrounded black and/or brown mudstone and/or fenestral mudstone fragments, inserted in a carbonate, clayey, or marly matrix. Its thickness ranges from 5–25 cm. Mudstones with very rare pellets, foraminifers, ostracodes, and dasyclads are 40–120 cm thick. The foraminifer *Kurnubia palastiniensis* Henson, as well as the dasyclads *Salpingoporella annulata* Carozzi, *Clypeina jurassica* Favre, and *Campbelliela striata* (Carozzi), can be recognized in only a few places inside the mudstones, defining the *Clypeina jurassica* and *Campbelliela striata* Subzone (Velić 1977). Bioturbation occurs frequently. Fenestral mudstones from both types of sequence and pisoid-intraclastic grainstone/rudstones (Fig. 8.4) from the shallowing- and coarsening-upward sequences within the upper Kirmenjak levels, are characterized by similar features as the texturally identical member inside the Jz-5 Unit. However, their thickness is smaller here, ranging from 10–15 cm for fenestral mudstones and from 5–10 cm for pisoid intraclastic grainstone/rudstones.

Interpretation. The sedimentary signature of the Lim Unit indicates deposition in an agitated, shallow subtidal environment, above the fair-weather wave-base. This environment was very similar to that of the Jz-3 Unit.

The abundance of ooids and the mud-free, sorted, and cross-bedded nature of the Muča middle sequence facies types indicate a high-energy oolite shoal environment, which migrated laterally by the action of waves and currents, thus capping the adjacent shallow subtidal deposits as the middle facies type of one coarsening-upward sequence. When the weather became more stormy, waves and currents eroded the existing lagoonal patch reefs, mainly composed of robust coral colonies, and coarse-grained skeletal fragments were transported by currents and waves onto the migrating oolite shoal, thus producing the upper facies type of a single coarsening-upward sequence and with distinctive large-scale textural features. In this way, as the stormy conditions periodically affected this area, successive coarsening-upward sequences were produced.

During the initial stage of regression that occurred in this area after the deposition of the Lim and Muča Units, their deposits were subjected to multi-phased alternation of subaerial exposure and action of tidal and/or storm waves, in which they were partly cracked, fragmented, and transported over short distances, forming the Rovinj breccia. After the sea retreated completely, karst topography was formed, with wide local depressions into which pelitic clayey material was brought (by fresh water flows?) and altered into bauxite.

The Kirmenjak Unit has been deposited in environmental conditions ranging from shallow subtidal to supratidal and vadose zone, as a result of tidal-flat progradation or aggradation in the subtidal zone, that is this unit originated under similar circumstances as the Jz-5 Unit. Velić & Tišljar (1988) interpreted the black-pebble breccia as indicators of the the existence of local swamps. However, blackening may occur not only within the swamps but also within the subtidal, intertidal, and supratidal zones, that is whenever dark organic substance is available and the geochemical and mineralogical conditions for its preservation and fixation are right (Strasser 1984). After these swamps were dried up, swampy black and/or brown deposits, rich in organic matter, was fragmented by the action of tidal and/or storm waves, and then partly transported back to the adjacent subtidal (intertidal?) environment. After the swampy deposits were fully flooded or completely eroded, thus formed black-pebble fragments were gradually buried under subtidal mudstone, that is under middle sequence facies type.

Discussion

Within the lithostratigraphic framework established for each succession, important differences in the nature of paleoenvironmental conditions have been noticed. These differences can be interpreted as being the consequence of different sedimentary histories, which took place at paleogeographically distant ADCP areas. On the basis of our own research and the published results of earlier researchers (e.g. Tišljar & Velić 1987, 1991, 1993; Velić & Tišljar 1988; Tišljar et al. 1989, 1994, 1995; Velić et al. 1994, 1995, 1995, 2002; Vlahović et al. 2001; etc.) the following reconstruction of the geological evolution of the area can be envisaged.

Starting from the beginning of the Oxfordian, sedimentation within the investigated ADCP realm took place in a lagoonal or shallow subtidal platform environment below and/or above the fair-weather wave-base, with predominant accumulation of carbonate mud and micritic allochems (pellets and peloids), into which, from time to time, fine-grained skeletal debris was derived from adjacent reef mounds and/or patch-reefs. This is clearly recorded inside the whole Jz-1, Bz-1 and Lim Units. During the Middle Oxfordian, sedimentary environments began to diversify and each investigated area assumed its own evolution up to the end of the Late Jurassic.

At Jazvina, the reef mounds and/or patch-reefs spread and occupied broader lagoonal area, so that the coarse-grained skeletal detritus was predominantly deposited (Jz-2 Unit). By gradual shallowing of this lagoonal environment, subtidal areas above the fair-weather wave-base existed in the Late Oxfordian. This shallowing event had a negative effect on the growth of sediment trappers and, consequently, the growth of reef mounds and/or patch-reefs was markedly reduced. On the other hand, however, these environments were very favourable for foraminifers and dasyclads, as well as the development of various coated grains (oncoids, peloids) (Jz-3 Unit). In the Early Kimmeridgian, the gradual shallowing progressed and oolite shoals, surrounded by lagoons and tidal flats, came into existence (Jz-4 Unit). This sedimentary system gradually prograded seaward and in the Tithonian was replaced by a peritidal sedimentary system (Jz-5 Unit), indicating continuous regression. Both sedimentary systems gave rise to high-frequency relative sea-level fluctuations. However, besides certainly active the autocyclic processes of progradation of the oolite shoals or tidal flat or aggradation in the subtidal zone of maximum carbonate productivity, allocyclic influence on these relative sea-level fluctuations cannot be excluded. Orbitally controlled (Milankovitch), high-frequency sea-level fluctuations may also lead to metre-scale shallowing- and coarsening upward sequences (e.g. Strasser 1991; Goldhammer et al. 1993; Strasser et al. 1999). Milankovitch high-frequency sea-level fluctuations are commonly related to fluctuations of climate linked to varying amount of insolation, whereby the waxing and waning of ice caps, especially during glaciation periods (such as nowadays), act as amplifier of the inherently weak insolation signal. During the Late Jurassic, ice in high latitudes was probably present, but ice-volumes were not sufficient to induce important glacio-eustatic fluctuations (Frakes et al. 1992; Eyles 1993; Valdes et al. 1995), although volume changes of alpine glaciers could make a small contribution (Fairbridge 1976; Valdes et al. 1995). Frakes et al. (1992) also speak of a “cool mode” in paleoclimate from the Middle Jurassic to Early Cretaceous, with a pronounced seasonality. Thus, Late Jurassic high-frequency sea-level fluctuations were probably also influenced by variations of insolation, which themselves were linked to the orbital parameters of the Earth (Berger et al. 1989). Thus, periodical shallowing-upward and shallowing- and coarsening-upward sequences within the Upper Jurassic ADCP successions had to be at least partly originated by allocyclic processes, that is their origin was certainly partly controlled by orbital cycles in the Milankovitch frequency band. It is possible, that the two sets of processes (autocyclic and allocyclic, respectively) jointly produced a synergistic effect, though, for the time being, their share in the total process cannot be reliably determined because we cannot, as yet, measure the duration of our sequences. A similar environmental evolution, with a dominant regressive trend, is also recorded within the Rovinj succession. Starting from the Middle Oxfordian and following the subtidal sedimentary environment above the fair-weather wave-base where the Lim Unit was deposited, the environment became diversified and partly shallowed, with sedimentary characteristics close to the typical beach-barrier island-lagoonal system, where successive series of distinctive coarsening-upward sequences were produced (Muča Unit). Thus, in what is today the Rovinj area, sedimentary conditions from the beginning of the Oxfordian and during the Early Kimmeridgian also show a general shallowing-upward trend. Contrary to the situation at Jazvina, however, it ends with an emersion as a final regressive event. After the emersion phase lasting from the Middle Kimmeridgian to Early Tithonian, that is until the beginning of the Late Tithonian, a gradual transgression took place (Kirmenjak Unit).

Thus, viewing the Rovinj succession as a whole, two major depositional periods can be distinguished: (1) a regressive evolution from the very Late Oxfordian to the Early Kimmeridgian, and (2) a transgressive evolution in the Late Tithonian. The sequence boundary between the regressive and the transgressive phase is marked by the occurrence of the Rovinj breccia, which was formed during the gradual retreat of the sea and is capped by an important emersion horizon, locally with bauxites.

Distinctive emersion horizon, clearly recorded at Rovinj area, was only a partial consequence of the significant geodynamic changes that, in the Kimmeridgian, took place across the whole ADCP. Thus, the transitional, northeastern marginal ADCP-basin realm with a series of small islands (Bukovac et al. 1974, 1984; Dozet 1994) was partly drowned. As these environmental changes were of opposite character to those in the Rovinj area, we assume that this event is clear evidence of synsedimentary tectonics within the marginal ADCP-basin realm.

In the Kimmeridgian, intensive synsedimentary tectonics markedly affected also some other parts of the ADCP. In many places, there are deeper-water, locally ammonite-bearing, carbonates and cherts intercalated inside the Malm shallow-water carbonate successions (Furlani 1910; Salopek 1910; Ziegler 1963; Nikler 1965, 1978; Chorowicz & Geyssant 1972; Velić & Sokač 1974; Velić 1977). One of those pelagic-influenced successions is recorded at Breze. When correlated with biostratigraphical units, these pelagic-influenced carbonates correspond to the *Cylindroporella anici* Cenozone and, probably, to the lower part of *Clypeina jurassica* Cenozone (Velić 1977). Therefore, it is possible to conclude that in the Middle Kimmeridgian some internal parts of the ADCP subsided and became connected with the open basin, thus forming an intraplatform trough with pelagic deposition (Bz-2 Unit). Comparing the composition of these pelagic sequences from the various ADCP localities, the existence of two main intraplatform troughs has been supposed (Vlahović et al. 2001). One can be traced from western Croatia (Karlovac region) towards the south and southeast, with typical outcrops between Mt Svilaja and Mt Kozjak (the Lemeš beds), while the other occupies the central part of the Mt Velika Kapela area. They differ from each other by the more pronounced pelagic influences in the Lemeš Trough. The typical Lemeš beds are composed of light-coloured, platy limestones with ammonites, radiolarians, and sponge spicules, alternating with chert beds. Contrary to that, in the Mt Velika Kapela area, there occur medium- to thick-bedded dark limestones with sporadic chert intercalations and nodules and much rarer pelagic fauna. It can be assumed that the Lemeš depositional area was very similar to the recent Bahamas "Tongue of the Ocean", as it has been envisaged by Bosellini et al. (1981) for the Belluno Trough in the Venetian Alps (Italy). Since the majority of allochthonous bioclastic layers within the Bz-3 Unit consist of hydrozoan, molluscan, and echinoderm bioclasts, a contemporaneous peri-reefal environment must have existed at the margin of the Mt Kapela Trough. Disturbed by periodic storms, peri-reefal debris was displaced down the slope, sweeping up the deeper living echinoderms (crinoids), to be deposited in the elongated lagoon or intraplatform trough. Successively repeated, this process progressively filled up the lagoon and, consequently, in the Late Tithonian, peri-reefal and shallow subtidal to peritidal environment capped the former deeper-water lagoon area (Bz-4 Unit).

Contrary to the "intraplatform" origin of the Upper Jurassic pelagic-influenced deposits, Herak (1986, 1989) has supposed the existence, throughout the Mesozoic, of a temporally and spatially continuous labile interplatform pelagic belt (the Epiadriaticum), connecting the Budva Zone (Montenegro) with the Tolmin Zone (Slovenia) and separating two independent carbonate platforms; the Adriaticum and the Dinaricum. However, the origin of the Upper Jurassic pelagic-influenced deposits is still controversial and a common topic of heated debate (see Dragičević & Velić 2001).

Upper Jurassic synsedimentary tectonics also played a major role in the evolution of the northeastern margin of the ADCP. Thus, the Sošice succession is only the last episode of the extensive platform subsidence (controlled by normal faults?) and drowning. In the Mt Žumberak area, where the Sošice locality is situated, during the Liassic–Valanginian, the ADCP-basin margin was gradually shifting towards the southwest, as a consequence of regional, large-scale tectonic movements. During the Jurassic, the basinal area increased and spread over the drowned part of the ADCP (Babić 1976). These events mark the disintegration phase of the platform, starting from the Early Jurassic, as was already assumed by some earlier researchers (e.g. Gušić 1969; Gušić & Babić 1970; Jelaska 1973; Babić 1976). The platform disintegration occurred as a consequence of larger and complex global geotectonical movements (break-up of Pangea), which had commenced both along the northeastern margin of the large Dinaric-Apulian platform and inside its interior, culminating in crustal separation and the opening of the Dinaric branch of the Tethys and the Mid Adriatic-Ionian intraplatform basin. These spreading processes took place in the latest Late Triassic and more pronouncealy at the beginning of the Early Jurassic. With this, the ADCP formed a part of an extensive carbonate platform system, which fringed the gradually opening Dinaric branch of the Tethys at its northeastern side, and also the gradually opening Mid Adriatic-Ionian intraplatform basin at

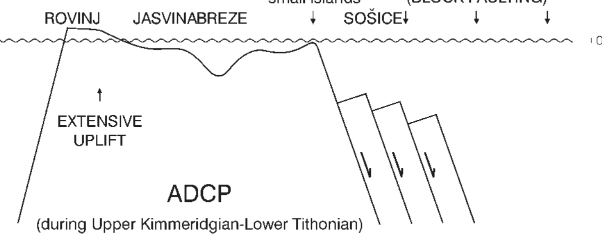


Fig. 9. Schematic sketch showing tectonic control on platform uplift caused by interplatform extensional tectonic movements (not to scale) (Chen et al. 2001, modified).

its southwestern side, separating Apulia platform from ADCP (Marcoux et al. 1993; Zappaterra 1994; Pamić et al. 1998; Grandić et al. 1999). As the Sošice locality was positioned in the vicinity of the northeastern platform margin affected by the spreading processes, it was subjected to block-faulting, which resulted in changing of the sedimentary environments during the Jurassic. Thus, in the Early Liassic the Sošice locality experienced the platform subtidal environment, in the Middle Liassic, platform margin environment, during the Late Liassic-Late Dogger, platform slope environment, in the Early Malm, bottom of the platform slope environment (toe-of-slope), and, finally, in the Late Malm, the basin environment (Bucković 1998).

Chen et al. (2001) showed how such "rapid" subsidence of platform margin, controlled by faults, can be accompanied by the relative uplift of the platform interior, resulting in an increase of the accommodation space in the platform margin, but a decrease of accommodation space on the platform interior. The exposure zones on the platform may therefore temporally correspond to deepening in the platform margin. This situation, with contrasting between the platforms and their margins is the result of interplatform extensional tectonic movements. Thus, if we take into account the subsidence and drowning of the northeastern ADCP margin, we assume that an extensive contemporaneous tectonic uplift took place in the southern ADCP area (Fig. 9).

Presumably, as the ADCP-basin margin, that is barrier reef complex and series of small islands, gradually shifted its position towards the southwest as a consequence of extensional block-faulting (Fig. 10a–c), the investigated ADCP interior realm became more and more strongly affected by these movements, resulting in very slight gradual uplift and, consequently, a continuous regression trend at Jazvina (clearly observed from Jz-1 to Jz-5 Unit) and, especially, in the wider Rovinj area, where it culminated with the Middle Kimmeridgian emersion (Fig. 10a–b).

We also suppose that the partial ADCP interior uplifts were contemporaneous to the Middle Kimmeridgian subsidence in the Mt Velika Kapela, Mt Svilaja, and Mt Kozjak, where the large intra-ADCP troughs with pelagic-influenced carbonate deposition were formed (Bz-2 Unit and the Lemeš beds). Therefore, during the Late Kimmeridgian, when a global eustatic sea-level fall is documented (Haq et al. 1988), the deeper-water pelagic-influenced carbonates were deposited in some ADCP areas, indicating that platform margin synsedimentary tectonics also affected the ADCP interior. The Late Tithonian shallow-water deposits (Bz-4 Unit) overlying the deeper-water carbonates (Bz-2, -3 Units) and the emersion horizon in the Rovinj area (Kirmenjak Unit) are evidence that the formerly differentiated morphology of the platform was levelled (Fig. 10c). As the opening of the Dinaric branch of the Tethys Ocean stopped during the Late Jurassic–Early Cretaceous and when its closure be-

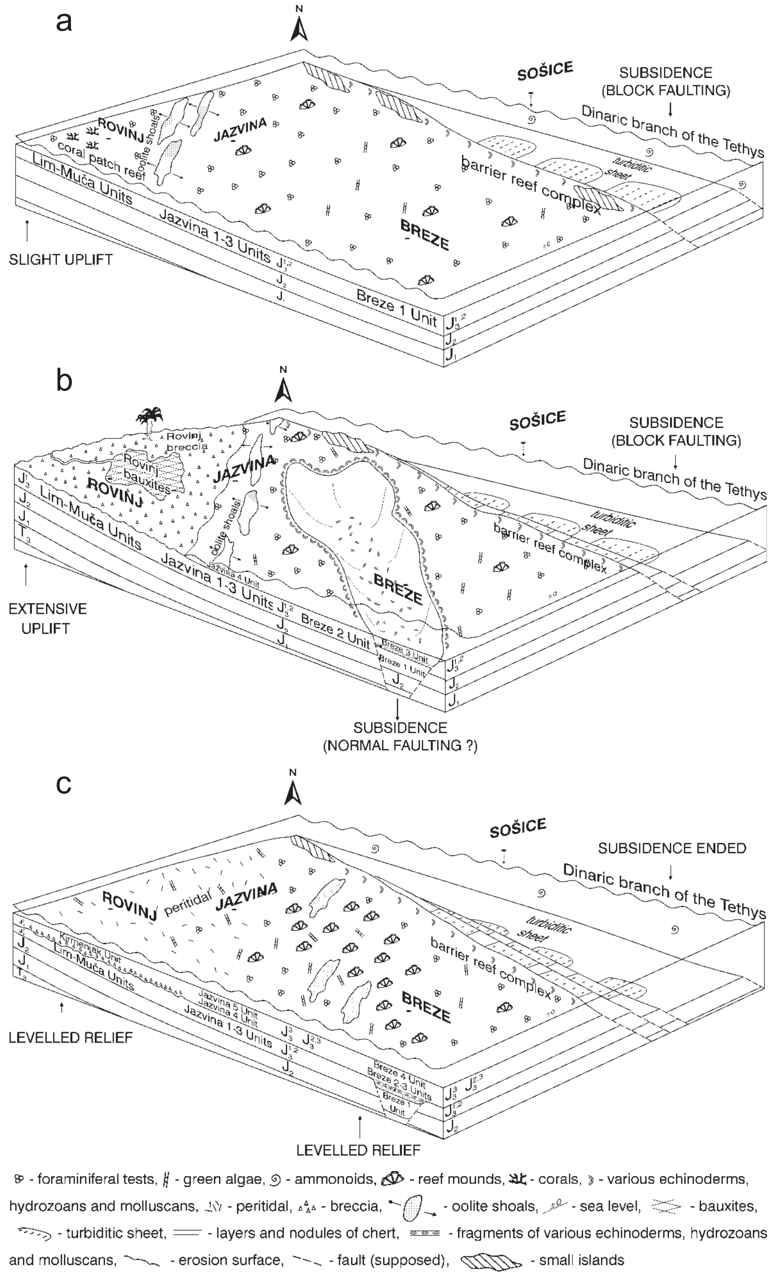


Fig. 10. Schematic reconstructions of the investigated area (not to scale). $\mathbf{J_1}$ — Liassic; $\mathbf{J_2}$ — Dogger; $\mathbf{J_3^{1,2}}$ — Oxfordian–Lower Kimmeridgian; $\mathbf{J_3^{2,3}}$ — Middle Kimmeridgian-Lower Tithonian; $\mathbf{J_3^3}$ — Upper Tithonian. **a)** Beginning of the Kimmeridgian: block-faulting processes operate still rather far from the broader Rovinj and Jazvina area, thus causing there only slight tilting which produced gradual regression (Lim and Muča Units, Jz-1, -3 Units). **b)** Late Kimmeridgian: block-faulting processes advanced towards the southwest, thus simultaneously causing extensive uplift and emersion in the broader Rovinj area (Rovinj Breccia Unit), but also, subsidence and deeper-water sedimentation in the broader Breze area (Bz-2, -3 Units). At Jazvina, regression continued (Jz-4 Unit). **c)** End of the Tithonian: block-faulting processes came to an end and weakened uplift in the broader Rovinj area. Autocyclic and allocyclic processes prevailed, causing gradual levelling of the platform relief. Thus, shallow-water platform sedimentation was re-established in the Rovinj (Kirmenjak Unit) and Breze (Bz-4 Unit) areas.

gan (Fourcade et al. 1993; Pamić et al. 1998), we suppose that this event also stopped further subsidence and drowning at the northeastern ADCP margin and uplift in the Jazvina and Rovinj area. Thus, autocyclic and allocyclic processes began to prevail. Due to the slight subsidence rate combined with global eustatic sea-level rise (Haq et al. 1988) and/or synsedimentary tectonics (tangential folding and faulting and normal block faulting were widespread processes in the Late Jurassic Tethyan Realm — Dercourt et al. 1993), the Rovinj area was drowned at the beginning of the Late Tithonian, whereas the Lemeš and Velika Kapela Trough were fully covered by the progradation of the marginal peri-reefal environments. Thus, the shallow water platform sedimentation was re-established over the whole western Dinaric part of the ADCP (Fig. 10c). Afterwards, more or less uniform shallow-water conditions, without any further major synsedimentary tectonic disturbances, continued into the Berriasian over the whole ADCP area.

Conclusions

Upper Jurassic synsedimentary tectonic movements clearly recognized on the ADCP by many earlier researchers were probably reflexions of the Late Jurassic phase of the Alpine tectonic cycle, although inside the ADCP no orogenic movements occurred during that time. There are no traces of thrusting or nappe movements, extensive volcanism or metamorphism. Furthermore, there are no angular unconformities to be found; the continuity of sedimentation being disturbed only by periodical emersions. However, synsedimentary tectonics created the paleogeography of the Upper Jurassic ADCP, producing the environmental differentiation and thus considerably influencing the sedimentation.

The opening of the Dinaric branch of the Tethys and the thus induced block-faulting at the northeastern ADCP margin probably caused uplift and subsidence within the investigated Late Jurassic inner ADCP realm, which led to more or less drastic changes of sedimentary conditions. These synsedimentary tectonic movements produced changes in accommodation space, triggering indirectly the autocyclic processes which, partly in interaction with Milankovitch high-frequency sea-level fluctuations, produced various types of sedimentary environments and signatures within the investigated ADCP realm.

In the Jazvina and Rovinj areas, during the Oxfordian through the Early Kimmeridgian, regressive sedimentary events took place; in the Jazvina area from low-energy lagoon to shallow subtidal and at Rovinj area from shallow subtidal to oolite shoals. Contrary to these areas, during the same time in the Breze area, sedimentary events were of the opposite character and sedimentary environments shifted from low-energy lagoon to deeper-water intraplatform lagoon (trough).

In the Rovinj area, regressive trend culminated with an emersion lasting through the Middle-Late Kimmeridgian and Early Tithonian, while in the Jazvina area, shallow-water environments persisted and periodically changed from shallow subtidal to intertidal-supratidal and oolite shoals. In the Breze area, at the same time, sedimentation in an intraplatform trough continued.

In the Late Tithonian, the transgression drowned the Rovinj area; hence shallow-water sedimentation was re-established and took place in environments ranging from shallow subtidal to supratidal and vadose zone. The same sedimentary events also characterized the Jazvina area at that time. In the Breze area, during the Early Tithonian, peri-reefal deposits infilled and capped the earlier intraplatform lagoon, so at the beginning of the Late Tithonian shallow-water sedimentation was re-established in the Breze area.

The block-faulting on the northeastern ADCP margin played a major role in the development of the Sošice early Upper Jurassic toe-of-slope environment, afterwards progressing into a late Upper Jurassic basinal depositional environment.

Due to the complex neotectonic overprint, these larger-scale movements on the northeastern ADCP margin, as well as their intraplatform synsedimentary reflexions, are hard to document with direct field evidence.

Acknowledgement: This paper is a contribution to the Project No. 119306 supported by the Ministry of Science of the Republic of Croatia. We thank two anonymous referees and Professor André Strasser for reviewing the manuscript and giving justified criticism and constructive and valuble suggestions which essentially improved the paper. Prof. Jakob Pamić is thanked for his comments.

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