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Upper Jurassic Carbonate Facies Succession at Breze (Velika Kapela, Croatia)

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Key words: Upper Jurassic, Shallow-water platform carbonates, Platform facies retrogradation, Platform facies progradation, Deeper-water pelagic influenced platform carbonates, Intraplatform trough, Adriatic carbonate platform, Velika Kapela, Croatia.

Abstract

Environmental differentiation at the end of the Lower Malm, as observed at Breze, was caused by gradual synsedimentary tectonics when the hitherto uniform Adriatic carbonate platform was partly differentiated into two different sedimentary environments. Thus the sunken intraplatform trough of unknown dimensions, which was possibly connected with the open basin (similar to the modern "Tongue of the ocean"?), formed the depositional site of deeper-water pelagic influenced platform carbonates. This gradual change in sedimentary environment can be defined as shallow-water platform facies retrogradation.

Periodic shedding of carbonate material, during the Upper Malm, from the perireefal/reefal margin of the intraplatform trough by mechanisms of gravity flows, caused the deeper-water inclined marginal part of the trough to be filled up resulting in the re-establishment of shallow-water sedimentary conditions. This process can be defined as shallow-water platform facies progradation whereby shallowing-upward sequence is formed.

1. INTRODUCTION AND REVIEW OF PREVIOUS RESEARCH

In studies of the Upper Jurassic sediments of Mt. Velika Kapela, particular attention has been paid to the carbonate sucession at Breze. Recently, these carbonate deposits were the subject of several, mostly biostratigraphic and mineralogical studies, which have defined detailed biofacies and the main lithofacies characteristics of these sediments.

NIKLER (1965, 1978) established, within the Upper Jurassic succession, the central position of limestones with intercalations and nodules of chert. These limestones occur between underlying micritic limestones and overlying biostromal limestones with remains of former bioherms. NIKLER (1965, 1978) also recorded a very rich Oxfordian - Lower Kimmeridgian microfossil association in the micritic limestones and an equally rich Tithonian microfossil association in the biostromal limestones.

Most of this Lower and Upper Malmian biota, in this part of Velika Kapela, were also determined by GUŠIĆ (1969) and MILAN (1969) who in the broader area of Velika Kapela additionally distinguished two different Lower and Upper Malmian facies; one with predominant pseudooolitic limestones and another with predominant reefal limestones.

Also, at Breze ŠĆAVNIČAR & NIKLER (1976) described a layer of slaty green sediment (2-3 m in thickness) and established its pyroclastic origin.

As most of the previous investigations at Breze were predominantly biostratigraphically oriented, the main purpose of this paper is to reinvestigate the superpositional carbonate succession composed of four lithofacies and biofacies types with regard to the sedimentary mechanisms and conditions that controlled Upper Jurassic sedimentation on this part of the Adriatic carbonate platform. This paper is therefore both supplimentary and complementary to the recent investigations by VELIĆ et al. (1994) on the broader area of Velika Kapela.

2. GEOGRAPHICAL SETTING AND LITHOLOGICAL DESCRIPTION OF THE FACIES UNITS

A continuous succession of Upper Jurassic carbonates is well exposed along the road between Novi Vinodolski - Jasenak, approximately 15 km northwest of Novi Vinodolski near Breze village (Fig. 1).

The total thickness of the investigated deposits is approximately 300 m. Four distinct facies units which originated under different conditions and in different environments have been distinguished. These are: 1) Facies A - pelletal wackestone/packstones, 2) Facies B - pelletal-bioclastic wackestones with intercalations and nodules of chert (in irregular alternation with siliceous beds), 3) Facies C - normally graded bioclastic packstone/floatstones and 4) Facies D - bioclastic-peloidal wackestone/packstones with rare floatstones and sporadic grainstones.

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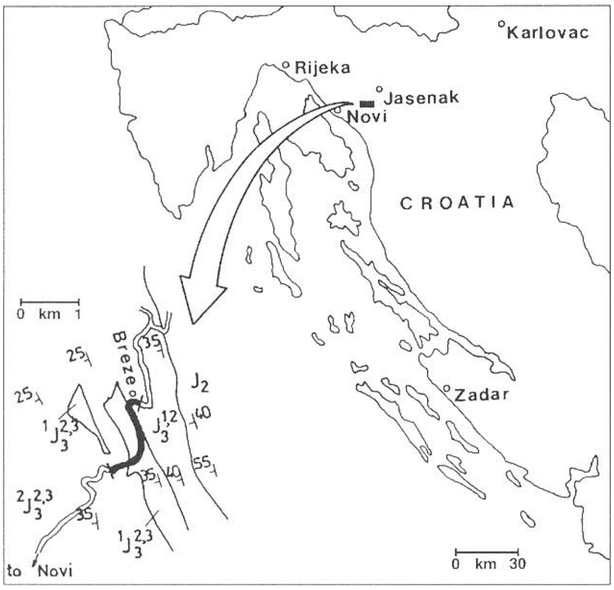

Fig. 1 Geographic location of the studied facies succession. The studied profile is exposed along the shaded part of the road. Geological sketch according to Basic Geological Map 1:100 000, sheet Crikvenica, (ŠUŠNJAR et al., 1970). Legend: J_2 - Dogger; $J_3^{1,2}$ - Lower Malm (Oxfordian-Lower Kimmeridgian); $^1J_3^{2,3}$ - Upper Malm (Kimmeridgian-Tithonian; limestones with chert); $^2J_3^{2,3}$ - Upper Malm (Kimmeridgian-Tithonian; reef and perireef limestones).

Grey-coloured, well bedded (30-60 cm thick) limestones of facies A belong to the lowest level of the investigated succession (Fig. 2). These are pelletal wackestone/packstones frequently in irregular alternation with mudstone/pelletal wackestones and sporadically floatstones. The dominant component of these mud-supported limestones are tiny oval to suboval pellets between 0.02-0.1 mm in size and more rare oval peloids up to 2 mm in size (Fig. 3). Beside these non-skeletal allochems this structural type always contains numerous benthic foraminiferal species: *Kurnubia palastiniensis* HENSON, *Praekurnubia crusei* REDMOND, *Pseudocyclammina lituus* (YOKOYAMA), and *Valvulina lugeoni* SEPTFONTAINE, as well as debris of *Thaumatoporella*. Small echinoderm and larger gastropod bioclasts are also often found. Occasionally these skeletal fragments are micritized and more rarely coated. *Macroporella sellii* CRESCENTI (Fig. 4), characteristic of the Lower Malm (SARTONI & CRESCENTI, 1962; NIKLER & SOKAČ, 1968; GUŠIĆ, 1969; VELIĆ & SOKAČ, 1974; VELIĆ, 1977) is very common throughout this facies. Rarely large-sized *Cladocoropsis mirabilis* FELIX can be found in growth position (Fig. 5).

The deposits of the facies B continuously overly facies A (Fig. 2). The boundary between these two conformable facies units can be observed in a transition zone (approximately 15 m thick) with a gradual decrease of facies A allochems content and a gradual increase of facies B allochems content.

The total thickness of facies B is 72 m and two members of this facies can be distinguished: a lower, thicker unit (38 m) is represented by pelletal-bioclastic wackestones with rare intercalations and nodules of chert and an upper, thinner unit (34 m) where pelletal-bioclastic wackestones and siliceous beds occur in irregular alternation. In this upper unit of facies B the intercalations and nodules of chert are very frequent.

The pelletal-bioclastic wackestones are medium bedded (25-50 cm) and contain dominantly oval to suboval pellets up to 0.06 mm in diameter, echinoderm fragments between 0.02-1 mm and rarer calcitised radiolarian tests as well as sponge spicules suspended in the carbonate mud (Fig. 6). Frequently tiny echinoderm fragments (0.02-0.06 mm) are the dominant component of this facies and, more rarely, small-sized hydrozoan and gastropod debris can be found. However, no regular pattern can be observed in this allochem content. In the upper 34 m these limestones irregulary alternate with greyish-green siliceous beds. Contacts between these two lithological types are always sharp.

The slaty textured to sporadically thin-bedded (5-15 cm) siliceous intervals within facies B vary in thickness from 0.4-3 m (Fig. 7). Easy cleavage and poor consolidation are the main characteristics of the slaty textured siliceous sediments, whereas the thin bedded variety show greater consolidation and irregular fractures.

These siliceous beds belong to very fine-grained vitric pyroclastics that have been devitrified and secondarily altered in varied proportions ranging from chert to clayey alteration products (ŠĆAVNIČAR & NIKLER, 1976). These altered pyroclastics usually contain a large amount of the quartz-skeletal biota such as radiolarians and spicules of siliceous sponges (ŠĆAVNIČAR & NIKLER, 1976). Also, in chert intercalations (Fig. 8) and nodules within the interbedded limestones, ŠĆAVNIČAR & NIKLER (1976) observed the relics of calcitic allochems (pellets, bioclasts, calcitised radiolarians and sponge spicules), indicating partial alteration of these limestones by chalcedony and quartz.

ŠĆAVNIČAR & NIKLER (1976) labelled the above described succession (here called facies B) as the "Lemeš" beds according to lithologically equivalent deposits on Mt. Svilaja (central Dalmatia) where the stratigraphic range was determined as Upper Kimmeridgian-Lower Tithonian (FURLANI, 1910; SALOPEK, 1910; ZIEGLER, 1963; NIKLER, 1965; CHOROWICZ & GEYSSANT, 1972). Recently, VELIĆ et al. (1995) have attempted to lithologically differentiate typical "Lemeš" limestones from the limestones with intercalations and nodules of chert of Velika Kapela. However, detailed analysis and elaboration of these two facies is currently unavailable.

Within facies B one thin-bedded interval (10 cm thick) of bioclastic limestone (typical of facies C) can be observed (Fig. 9). After this first appearance, in the next 11 m of the succession, bioclastic limestones of facies C appear again within facies B as 8-25 cm thick intervals. The main textural characteristic of these bioclastic intervals is a more or less clearly expressed normal grading of bioclasts and their frequent orientation

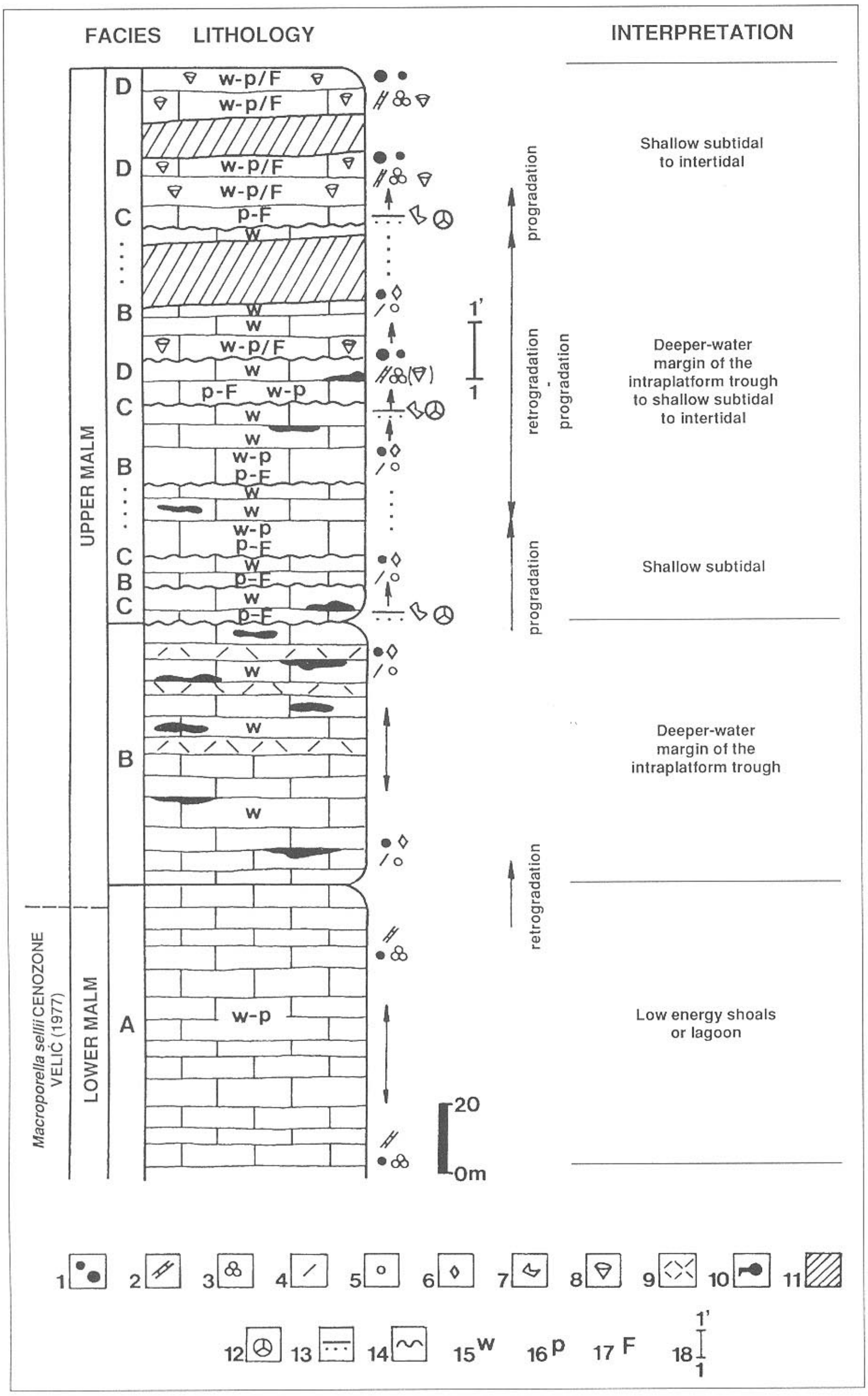

Fig. 2 Schematic stratigraphic column of the studied facies succession. Legend: 1) pellets and peloids; 2) green algae; 3) benthic forams; 4) spicules of the sponges; 5) radiolarians; 6) small fragments of echinoderms; 7) coarser fragments of echinoderms; 8) molluscs; 9) pyroclastic beds; 10) chert; 11) late-diagenetic dolomites; 12) hydrozoans; 13) normal gradation; 14) erosion surface; 15) wackestone; 16) packstone; 17) floatstone; 18) position of the detailed interval.

parallel to bedding.

These bioclastic-pelletal packstone/floatstones, in the lower part of each thin bedded interval, are always separated from the underlying facies B by an erosional surface. They are composed of poorly sorted, abraded and broken echinoderm and hydrozoan fragments predominantly 2-3 mm in diameter as well as variously sized angular micritic intraclasts (Fig. 10). Smaller bioclasts of indeterminable bivalves, gastropods, green and red algae are rarely present. Intergranular pores are filled with carbonate mud often enriched with oval pellets, but locally irregular drusy calcite has been developed as a result of partial recrystallisation.

Passing upwards in each interval the skeletal debris decreases in grain-size and in their uppermost parts these bioclastic intervals are terminated by a sharp contact (but not erosional) with the overlying facies B.

In the remaining part of the facies succession, bioclastic intervals become much thicker (1.5-11 m) where they irregularly alternate with deposits of facies B. In these medium-thick bioclastic units normal grading of the bioclasts is sometimes observed most frequently at the base of units.

Within uppermost 1-5 m of each thicker bioclastic unit, a gradual change in allochem content can be observed. In these bioclastic-peloidal wackestone/pack-

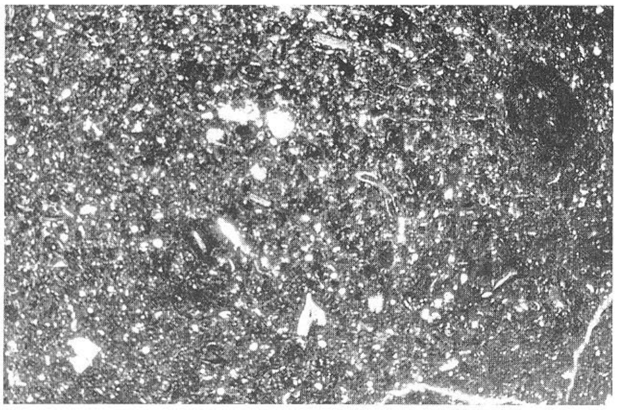

Fig. 3 Microfacies of the shallow-water facies A limestones composed of pellets and rare peloids (25x).

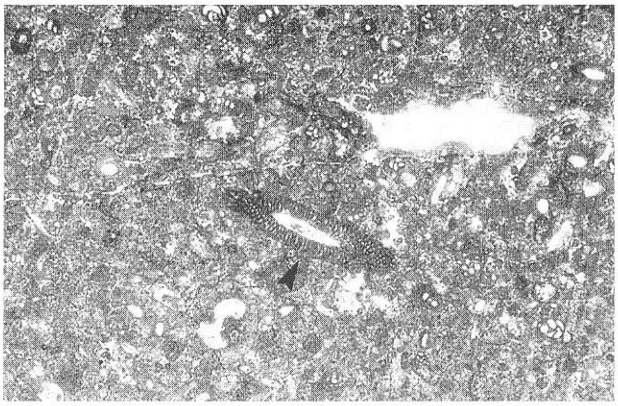

Fig. 4 Arrow points at *Macroporella sellii* CRESCENTI from facies A - index species of the Lower Malm (50x).

stones with rare floatstones and grainstones of facies D, oval peloids (1-2 mm in diameter), echinoderm cortoids, micritic intraclasts and rare benthic foraminifera (e.g. *Pseudocyclammina lituus* (YOKOYAMA) - Fig. 11) are the predominant components. Also, irregular fenestrae and/or dissolution vugs filled by drusy calcite cement are present (Fig. 11). Also, large Diceratid shells (Fig. 12) can occasionally be found in bioclastic-peloidal floatstones. Carbonate mud and drusy calcite fill the intergranular pores while rare thin rims of early diagenetic submarine calcite cement can be observed on the surfaces of the single allochems.

The facies succession ends with a thick (33 m) package of facies D (Fig. 2) rich with various bivalve and gastropod fragments. NIKLER (1965, 1978) determined 13 Tithonian gastropod species of the genera *Nerinea, Cryptoplocus, Ptygmatis, Iteria*, various Tithonian hydrozoan species and a very rich microfosil assemblage with *Clypeina jurassica* FAVRE, *Salpingoporella anullata* CAROZZI, *Pseudocyclammina lituus* (YOKOYAMA) etc. from this part of the succession.

This uppermost part of the facies succession was subject to late diagenetic dolomitization (Fig. 2). Within the 5-13 m thick units of xenotopic dolomite, relics of allochems typical for this facies can usually be found.

3. DEPOSITIONAL ENVIRONMENTS

The characteristics of the facies A limestone unit indicate deposition in low-energy platform shoals and/or lagoons, probably mostly below the fair-weather wave-base, with calm water and a low, constant rate of sediment accumulation. Under such environmental conditions a large amount of carbonate mud has been deposited. Frequently observed pellets could be the result of organic agglutination, inorganic extraction from the water, micritization of microdebris or a combination of all of these proceses (BEALS, 1965). Certainly, a faecal origin cannot be discounted but the real mechanism(s) is/are questionable. The uniformity of shape and dimension of the pellets probably indicates a common origin or, alternatively, various processes of origin which were quite similar.

A sporadically observed gradual transition from pellets into pure carbonate mud indicates their probable destruction, most likely, during periods of increased water energy as suggested by occasional finds of tiny echinoderm fragments, larger peloids and hydrozoan (*Cladocoropsis*) bioclasts indicating some higher wave and current action.

Rather frequent finds of radiolarian tests in the overlying deposits of facies B indicate a pelagic influence.

Fig. 5 *Cladocoropsis mirabilis* FELIX in the growth position within the facies A.

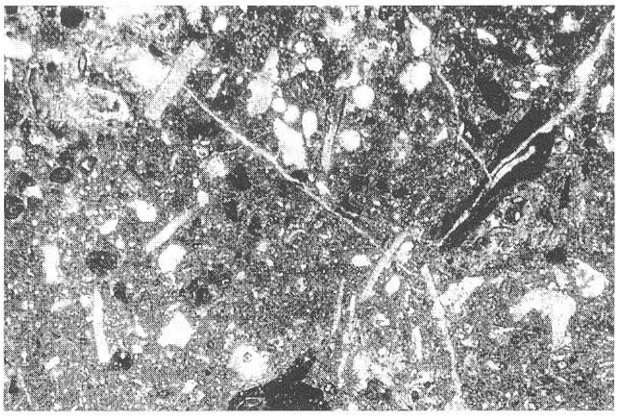

Fig. 6 Microfacies of the pelagic influenced facies B limestones composed of small echinoderm fragments, pellets, and rare calcitised radiolarian tests and sponge spicules (25x).

Fig. 7 Slaty textured to thin bedded siliceous bed interval within the pelagic influenced facies B limestones.

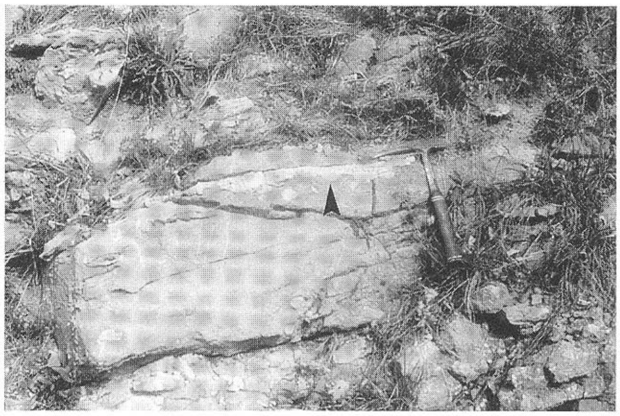

Fig. 8 Chert intercalation inside the pelagic influenced facies B limestones.

Additionally, the complete absence of benthic biota with only tiny echinoderm fragments, sponge spicules and pellets within the carbonate mud indicates a quiet, low-energy depositional environment influenced by the open sea. Furthermore, TIŠLJAR & VELIĆ (1993) and VELIĆ et al. (1994) presumed that such "Lemeš" limestones of Velika Kapela with chert intercalations and nodules were deposited in the deeper-water (lagoonal ?) environment below the fair-weather wave-base.

The very low rate of carbonate accumulation in such an environment enabled the preservation of the pellets that were slowly lithified. Also, the low rate of sedimentation enabled considerable accumulation of vitroclasts derived from distant vulcanic eruptions and transported by the wind. Here, this pyroclastic material was devitrified and altered ranging from chert to clayey alteration products, thus, enriching the water with SiO_2 (ŠĆAVNIČAR & NIKLER, 1976). Therefore, intercalations and nodules of chert within B facies limestones resulting mostly from the dissolution of volcanogenic silica, although, the presence of calcitised radiolarians and sponge spicules indicates considerable biogenic source of silica.

A much higher rate of carbonate accumulation in the surrounding shallow platform environments (VELIĆ & SOKAČ, 1974; VELIĆ, 1977), relative to the slow and almost insignificant contribution of the aeolian pyroclasts, is the main cause of their non-appearance in contemporaneous, adjacent shallow-water carbonates. However, they are probably present but difficult to observe.

Sedimentary characteristics of the intercalated bioclastic deposits of facies C indicate allochthonous sediments representing gravity displaced coarser carbonate material deposited along an inclined slope. Since the majority of this material consists of angular echinoderm and hydrozoan bioclasts, a contemporaneous perireefal/reefal hydrozoan environment must have existed locally and somewhat deeper down the slope an environment with echinoderm (crinoid?) "meadows". Processes of bioerosion, supported by wave and current activity, enhanced the accumulation of carbonate debris in the perireefal/reefal area. When the equilibrium between these two proceses was disturbed by periodic storms, smaller earthquakes, etc. carbonate material was displaced down the slope sweeping up the deeper living echinoderms to be deposited with definite textural characteristics as bioclastic intercalations within facies B. Based on these textural characteristis, these bioclastic deposits of facies C can be interpreted as turbiditic sheets with T-a Bouma sequences.

Fig. 9 Normally graded bioclastic interval of facies C limestones within the pelagic influenced facies B limestones.

Fig. 10 Microfacies of the normally graded bioclastic intervals of facies C composed mostly of coarser echinoderm fragments and hydrozoans (25x).

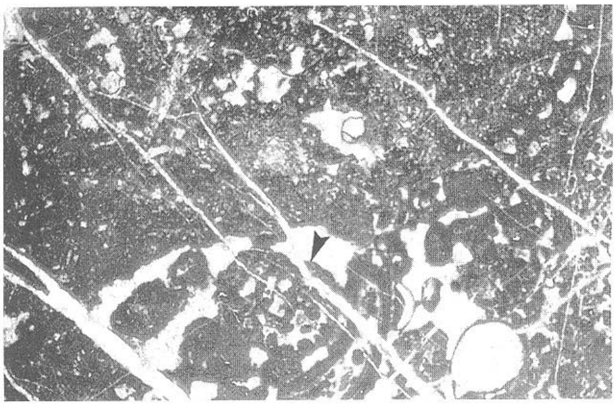

Fig. 11 Microfacies of the shallow-water D facies limestones with rare irregular fenestrae and/or dissolution vugs. Arrow points at *Pseudocyclammina lituus* (YOKOYAMA) (25x).

Fig. 12 Diceratid shells inside the shallow-water limestones of facies D.

Successive infilling of this inclined deeper-water sedimentary environment with bioclastic material resulted in progressive shallowing of the depositional environment, particularly when the displacement of bioclasts down the slope became more pronounced (thicker units of the facies C). This led to a gradual decrease in water depth and a transition into a higher energy shallow subtidal environment, above the fair-weather wave-base, that facilitated the renewed development of the large benthic foraminifera, calcareous green algae and other platform biota as well as shallow-water allochems (peloids, cortoids) of facies D. A high rate of carbonate accumulation in such a shallow-water environment was very favourable for local formation of the rudistid (*Diceras* sp.) buildups observed in the uppermost part of the facies succession and identified as biostromes by NIKLER (1978). The presence of occasional irregular fenestrae and/or dissolution vugs within this facies indicate variable, periodic environmental conditions close to the low tide (even to intertidal) when deposits were subject to vadose diagenetic processes.

4. DISCUSSION AND CONCLUSION

Upper Jurassic environmental differentiation observed at Breze was triggered by tectono-eustatic causes. Synsedimentary tectonics at the end of the Lower Malm, appears to be the most likely event responsible for the deepening of the sedimentary environment that enabled the deposition of the pelagic influenced carbonates of facies B. Such a conclusion is based on the following facts.

Malmian shallow-water carbonate successions in the NE part of Velika Kapela (VELIĆ & SOKAČ, 1974; VELIĆ, 1977), western Gorski kotar (TIŠLJAR & VELIĆ, 1993), western Istria (VELIĆ & TIŠLJAR, 1988) and southern Dalmatia (TIŠLJAR, 1979, 1985) indicate stable platform sedimentary conditions with no "traces" of some considerable sea level rise (i.e. platform drowning). Thus, in these areas in the uppermost part of the Lower Malm and Upper Malm a clear succession of shallowing-upward sequences and even one marked regression (Upper Kimmeridgian-Lower Tithonian, western Istria) can be distinguished.

From these data it can be concluded that the deepening at Breze, which began at the end of the Lower Malm, has to be a consequence of tectono-eustatic dynamics that only affected some parts of the Adriatic carbonate platform. Regarding the lateral extension of these subsidential dynamics, pelagic influences within facies B indicate a connection with an open marine environment. Thus, the Breze locality is only one remnant of this wider Malmian environmental differentiation on the Adriatic carbonate platform, as similar sedimentary characteristics (deeper-water pelagic influenced carbonates) can also be observed in adjacent or more distant platform areas (FURLANI, 1910; SALOPEK, 1910; ZIEGLER, 1963; NIKLER, 1965; CHOROWICZ & GEYSSANT, 1972; VELIĆ & SOKAČ, 1974; VELIĆ, 1977; NIKLER, 1978).

If we take into consideration the simultaneous uninterrupted shallow-water platform sedimentation in the previously mentioned Adriatic platform areas, we can assume some similarity of this platform interior-open basin environment connection with the recent "Tongue of the ocean" of the Bahamas (TUCKER & WRIGHT, 1990). The same comparison was made by BOSELLINI et al. (1981) for Belluno Trough (Venetian Alps-Italy), while RADOIČIĆ (1982) called such a connection an "intraplatform furrow". Contrary to that, HERAK (1986, 1989, 1991, 1993) explains the presence of the pelagic influences inside the carbonate platform shallow-water area by the existence of a continuous interplatform pelagic belt (the Epiadriaticum) that separated two carbonate platforms, Adriaticum and Dinaricum, throughout the Mezozoic.

However, the succession at Breze suggests that after deposition of the Lower Malmian deposits of facies A (cenozone Macroporella sellii - VELIĆ, 1977), synsedimentary tectonics caused the formation of a regional sedimentary trough connected with the open basin. On the margin of such a deeper-water sedimentary environ-

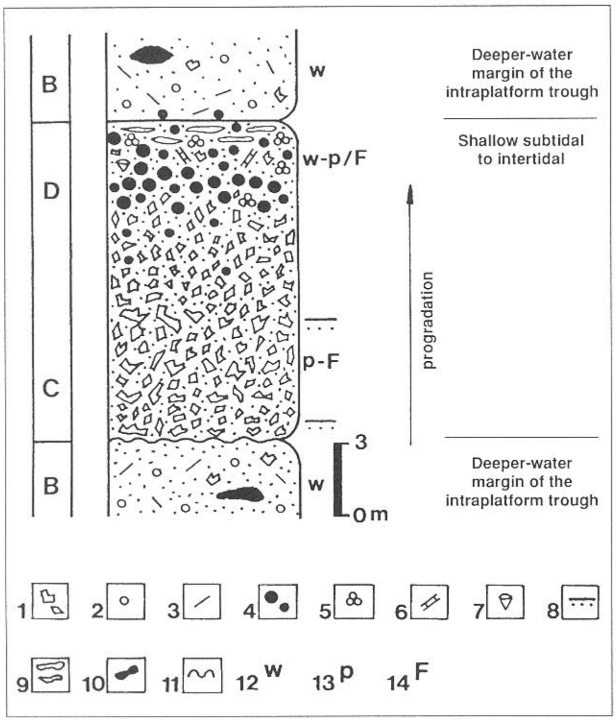

Fig. 13 Detailed interval showing progradation of the shallow-water platform facies over gently inclined deeper-water margin of the intraplatform trough environment. Legend: 1) small and coarser fragments of echinoderms and hydrozoans; 2) radiolarians; 3) spicules of the sponges; 4) pellets and peloids; 5) benthic forams; 6) green algae; 7) molluscs; 8) normal gradation; 9) fenestrae and/or dissolution vugs; 10) chert; 11) erosion surface; 12) wackestone; 13) packstone; 14) floatstone.

ment below the fair-weather wave-base, deposits of facies B slowly accumulated simultaneously influenced by pelagic material brought from the open sea area. This process can be envisaged as tectonically caused retrogradation of the shallow-water platform facies, whereby the part of the facies succession ranging from shallow-water to deeper-water pelagic influenced platform carbonates was formed.

By periodic shedding of the shallow-water carbonate material from the reefal/perireefal margin of the intraplatform trough by mechanisms of the gravity flows, triggered by periodical storms and/or, more likely, smaller earthquakes, the deeper-water marginal part of the trough was progressively filled up when normally graded bioclastic intervals of facies C were deposited. When this shallowing reached the shallow subtidal, the shallow-water allochems and biota of facies D was developed.

This slope depositional environment was only gently inclined (i.e. a carbonate ramp - TIŠLJAR & VELIĆ, 1993; VELIĆ et al., 1994) and the bioclastic material was not displaced very far. Otherwise, the observed thicknesses (11 m maximum) of the bioclastic units (facies C) would not have sufficed to infill steeper and deeper areas to raise them above the fair-weather wave-base.

Contrary to this Upper Malmian infilling process of the trough margin at Breze, sedimentary conditions on most platform margins were rather different during Mid-Jurassic times; for example the Belluno Trough (Venetian Alps-Italy) was infilled with gravity displaced oolitic sand with minor amounts of skeletal debris that reached thicknesses of several hundred metres (BOSELLINI et al., 1981). Furthermore, such oolitic shedding has also been documented from the margins of many other Tethyan carbonate platforms, which indicates that during the Mid-Jurassic prolific oolite formation was globally expressed (BOSELLINI, 1989).

At Breze, once the shallow subtidal environment was restablished, the rate of carbonate accumulation was rather high capping the thick bioclastic units, resulting in further shallowing which reached the low tide and even intertidal levels with sporadic subaerial exposure. This process can be explained as the progradation of the shallow-water platform facies (progradation of reefal-perireefal clinoforms - TIŠLJAR & VELIĆ, 1993) over the gently inclined "ramp", when the shallowing-upward sequence, ranging from the deeper-water pelagic influenced to shallow-water platform carbonates, was formed (Fig. 13).

Several times continuously observed successive shallowing-upward sequences consisted of the B, C+D facies units (Fig. 2) indicating repeated retrogradation (constant or periodic subsidence?) and progradation of the shallow-water platform environments. Such periodic variation of sedimentary dynamics on the margin of the intraplatform trough, during the Upper Malm, indicates here a rather expressive tectonic activity (small earthquakes?) that appear to be a possible cause for the initiation of periodical gravity flows.

Acknowledgments

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