

Carbonate Platform Megafacies of the Jurassic and Cretaceous Deposits of the Karst Dinarides

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Abstract

Platform carbonate deposits of the Karst Dinarides area have a stratigraphic range from the Middle Triassic (or even Carboniferous in some places) to the Middle Eocene, forming a belt nearly 700 km long and, (after reduction by younger tectonics) 80–210 km wide.

Besides their significant thickness (4500 to 8000 m) they are characterised by frequent lateral and vertical alternations of different facies, mostly associated with shallow marine environments. Environments ranging from peritidal through low-energy shallow subtidal–lagoons, restricted inner platform shallows, high-energy tidal bars, beach and shoreface to reefal–perireefal predominate, but there are also carbonate slope deposits and those representing temporarily drowned platform facies and intraplatform troughs.

The Jurassic to Cretaceous part of this carbonate succession has been subdivided into 19 megafacies units (9 for the Jurassic and 10 for the Cretaceous), the majority of which represent an inner part of the ancient Adriatic Carbonate Platform. Marginal parts of the platform are mostly buried, either by the recent Adriatic Sea along the SW margin, or younger deposits along the NE margin; at some localities such Jurassic and Cretaceous deposits are represented by debrites and/or carbonate turbidites. An additional short review of the overlying Uppermost Cretaceous and Palaeogene deposits (4 megafacies units) enabled a better insight into the post-platform evolution.

The very complex vertical and lateral alternation of different megafacies units, including emerged areas which were observed throughout the studied sequence in different parts of the Karst Dinarides, indicate the significant palaeogeographic dynamics of the region. This variability resulted from interaction of the global eustatic signal and local factors, including extensive organic production on the carbonate platform and synsedimentary tectonics controlled by the specific palaeogeographic position of the platform during its geological history.

1. INTRODUCTION

Platform carbonate deposits found along the NE Adriatic coast, usually referred to as the “Karst Dinarides”, represent a belt approximately 700 km long and, (after tectonic reduction), 80–210 km wide. This huge carbonate body stretches from the Julian Alps along the border between Italy and Slovenia, through the western and central parts as well as the coastal area and Adriatic islands of Croatia, through the western and southern part of Bosnia and Herzegovina to SE Montenegro and NW Albania (Fig. 1). The entire area was characterised by the long-term (Middle Triassic to Middle Eocene, or in some areas, from Carboniferous) existence of carbonate platform environments, resulting in a very thick sequence of deposits.

After POLŠAK (1965a), who suggested that “*the most appropriate term for the entire depositional area with characteristics of carbonate sill (the old term for carbonate platform – auth. comm.) stretching from NW Slovenia to Montenegro would be Adriatic Zone*”, the area of Karst Dinarides was treated by numerous authors as a united carbonate platform, although with different names. The most common terms were “*Carbonate shelf of Dinarides*” (JELASKA, 1973), “*Platform of the Outer Dinarides*” (GRANDIĆ, 1974), “*Adriatic Plate (“carbonate platform”)*” (POLŠAK, 1981), “*Carbonate Platform of the Outer Dinarides*” (TIŠLJAR, 1983), “*Mesozoic Carbonate Platform*” (TIŠLJAR et al., 1983b), “*Dinaric Carbonate Platform*” (OGORELEC, 1987; DRAGIČEVIĆ & VELIĆ, 1994; BUSER, 1989), “*Adriatic–Dinaric Carbonate Platform*” (VELIĆ et al., 1987; GUŠIĆ & JELASKA, 1993), “*Adriatic–Dinaridic Carbonate Platform*” (PAMIĆ et al., 1998) and “*Adriatic Carbonate Platform*” (GUŠIĆ & JELASKA, 1990). All these names are synonymes for a single carbonate platform without regard to the recent geotectonic situation.

Since the 2nd International Symposium on the Adriatic Carbonate Platform, which was held in 1991 in Zadar, Croatia (VLAHOVIĆ & VELIĆ (eds.), 1991), it seems that most of the authors refer to this carbonate platform as the *Adriatic Carbonate Platform*.

A second, smaller group of authors accepted the geotectonic concept of the Dinarides according to HERAK (1986), considering the existence of several

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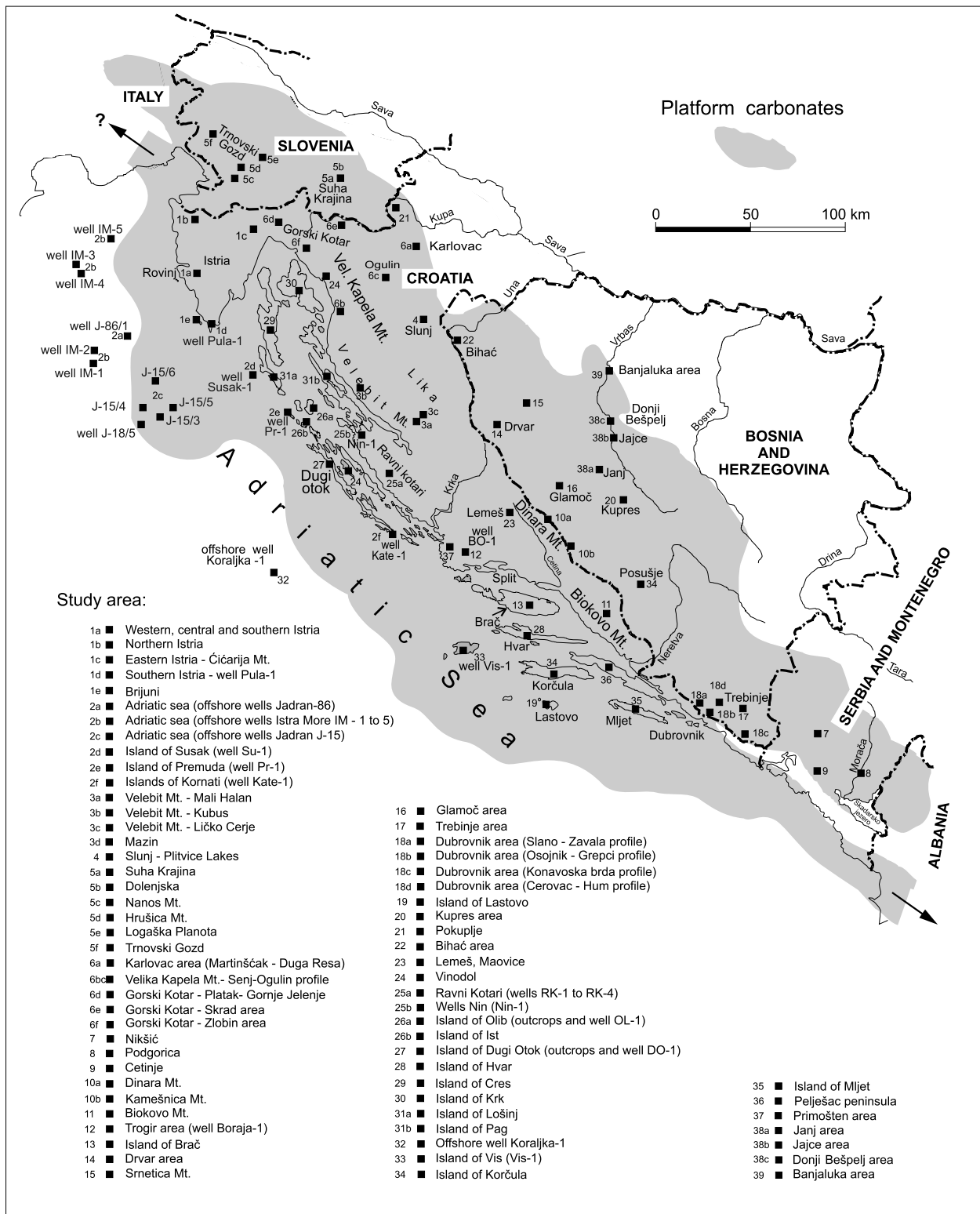


Fig. 1 Location map with schematic drawing of the Mesozoic platform carbonate deposits of the Karst Dinarides region.

palaeogeographic units in the same area during the Mesozoic. According to HERAK (1986, 1989, 1991, 1993) two carbonate platforms existed in the area of the Karst Dinarides from the Late Triassic to the Eocene – the Adriatic Carbonate Platform (Adriaticum) and the Dinaric Carbonate Platform (Dinaricum), separated by a persistent deep-water interplatform trough (Epi-adriaticum). For more information on this concept see

BLAŠKOVIĆ (2001) and VLAHOVIĆ et al. (2002c – this vol.).

However, in this paper we will not use any specific term for the carbonate platform on which most of the carbonate deposits originated – instead we will use the term Karst Dinarides. Namely, the Adriatic Carbonate Platform s.s. comprises deposits of a stratigraphic range from the Upper Lias to the end of Cretaceous

(see discussion by DRAGIČEVIĆ & VELIĆ, 2002 and VLAHOVIĆ et al., 2002c in this vol.), and we will discuss also some older and younger deposits.

Carbonate platform deposits of the Karst Dinarides are, besides their significant thickness (4500–8000 m, 6000 m in average), characterised by frequent lateral and vertical alternations of different facies, mostly associated with shallow marine environments. Environments ranging from peritidal through low-energy shallow subtidal – lagoons, restricted inner platform shallows, high-energy tidal bars, beach and shoreface to reefal–perireefal areas are the most common, but the succession also comprises deposits of carbonate slopes and temporarily drowned platform facies and intraplatform troughs.

On the basis of their main sedimentological, lithological, biofacies and lithofacies characteristics, the deposits accumulated in this area from the Early Jurassic to Eocene can be subdivided into several megafacies units characterised by their extensive occurrence, i.e. regional importance, regardless of their thickness.

For subdivision of rock sequences into megafacies, the additional works of numerous other investigators were also consulted. Unfortunately, it was commonly impossible to use data from older publications, because although information on stratigraphy, palaeontological composition and general lithology was provided elements needed for facies reinterpretation were lacking; therefore these papers were neither used nor cited. This paper deals with a several thousand metre thick sequence of deposits covering a huge area, and therefore only simplified typical geological columns are presented. For detailed sedimentological and stratigraphical interpretations and illustrations, interested readers should check the original literature cited in this paper.

The lateral and vertical pattern of different megafacies units, their locations, thickness and duration of sedimentary environments resulting in their deposition provide significant information not only about conditions in the depositional area but also about syndimentary tectonics and the palaeogeomorphological evolution of the carbonate platform.

Temporal and spatial correlation of the megafacies identified here document the main sedimentological and tectonic events in the area of the Karst Dinarides. Additionally, these data provide important arguments for interpretation of the palaeogeography of the entire area during the Jurassic and Cretaceous (and Palaeogene to a certain extent).

2. CARBONATE MEGAFACIES OF THE JURASSIC DEPOSITS

Jurassic carbonate deposits of the Karst Dinarides can be subdivided into 9 megafacies units (Figs. 2–4):

- J-1: Megafacies of peritidal micritic, fenestral and vadose limestones with interbeds of early-diagenetic dolomites and emersion breccia, emersions and occasional bauxites;
- J-2: Megafacies of lagoonal and subtidal inner platform oncoid, pelletal and skeletal mudstones/wackestones;
- J-3: Megafacies of bioturbated and late-diagenetically dolomitized “spotty limestones” – mudstones and wackestones deposited in isolated and restricted lagoon/deeper subtidal areas of the inner platform;
- J-4: Megafacies of lithotid and brachiopod lithosomes and tempestite coquinas of shallow subtidal and lagoonal regions of the inner platform;
- J-5: Megafacies of ooid grainstones deposited in environments with agitated water and ooid bars;
- J-6: Megafacies of skeletal and intraclastic grainstones/rudstones deposited in shallows with agitated water;
- J-7: Megafacies of peri-reefal bioclastic limestones (rudstones and grainstones) with hydrozoan, stromatopoid and coral patch reefs and biostromes;
- J-8: Megafacies of “limestones with cherts” (including “Lemeš deposits”), deposited within intraplatform troughs with temporary or continuous connection to the open sea, and
- J-9: Megafacies of late-diagenetic dolomites.

2.1. Megafacies of peritidal micritic, fenestral and vadose limestones with interbeds of early-diagenetic dolomites and emersion breccia, emersions and occasional bauxites (J-1)

Deposits of *megafacies J-1*, i.e. peritidal micritic, fenestral and vadose limestones with interbeds of early-diagenetic dolomites and emersion breccia, emersions and occasional bauxites, are most common in the Lower and Middle Lias, Dogger, Oxfordian, Kimmeridgian and Upper Tithonian deposits (Figs. 2–4). They are mostly composed of fenestral and/or vadose limestones (mudstones, pelletal and/or skeletal wackestones), with layers of LLH-stromatolites and skeletal/pelletal packstones and grainstones, while black-pebble and tempestite breccias and early-diagenetic dolomites are infrequent (TIŠLJAR, 1976; TIŠLJAR & VELIĆ, 1991).

At some localities, mostly within Middle Lias and Tithonian sediments, deposits of this megafacies are characterised by numerous shallowing-upward cycles on a dm- to m-scale. Cycles ending with desiccation cracks, desiccation breccia or vadose features (“desiccation cycles” – TIŠLJAR et al., 1983a; “vadose rhythms” and “vadose cycles” – TIŠLJAR, 1983; TIŠLJAR & VELIĆ, 1993) are common. A very good example of these cycles was described from Upper Tithonian deposits in western Istria (locality 1a on

Fig. 1), but similar deposits were also found in a penecontemporaneous succession in offshore wells in the northern Adriatic (locality 2c, wells J-15/3, J-15/4, J-15/6, J-18/5; VESELI, 1999).

Early-diagenetic dolomites without traces of evaporites, formed by early-diagenetic dolomitization of supratidal carbonate muds under a relatively humid climate have been found only as thin interbeds within peritidal limestones of Liassic age, e.g. in the Lika region near Ličko Cerje and Mazin (localities 3c and 3d), and within Tithonian subtidal algal “clypeina limestones” near Slunj in central Croatia (locality 4).

Emersion breccias with typical palaeokarstic features and stratigraphic hiatuses, with sequences characterised by reductions of several tens to several hundreds metre thick intervals, partly with bauxite (Figs. 2–4) have been documented from various stratigraphic levels in different regions of the Karst Dinarides. A hiatus lasting from the Middle Lias to the Kimmeridgian has been documented in Trnovski Gozd (NIKLER, 1978), the Suha Krajina in Slovenia (locality 5a – BUSER, 1969; DOZET, 1994), the Karlovac environs in Croatia (locality 6a – BUKOVAC et al., 1974; ŠPARICA, 1981; DRAGIČEVIĆ & VELIĆ, 1994), western and central Bosnia (ŠPARICA, 1981; MOJIČEVIĆ et al., 1978; MARINKOVIĆ & AHAC, 1980; VUJNOVIĆ, 1980) and in Montenegro west of Nikšić (locality 7 – RADOIČIĆ & VUJISIĆ, 1970), and north and northeast of Podgorica (locality 8 – ŽIVALJEVIĆ et al., 1971).

Upper Jurassic hiatuses or shorter gaps with karstification and/or bauxite formation were determined in different regions of the Karst Dinarides, usually in a stratigraphic range from the Oxfordian to the late Tithonian. E.g., in Slovenia important emersions occur mostly within Kimmeridgian beds (BUSER et al., 1967; DOZET & MIŠIĆ, 1997) in the Nanos Mt.

(locality 5c), near Hrušica Mt. (locality 5d), in Logaška Planota (locality 5e) and Suha Krajina (locality 5a). In Croatia emersion in western Istria (locality 1a) lasted from the latest Oxfordian/earliest Kimmeridgian to the late Tithonian (VELIĆ & TIŠLJAR, 1988), on the Biokovo Mt. (locality 11, Fig. 3) from Early Oxfordian to Early Kimmeridgian and from Late Kimmeridgian to the Middle Tithonian (TIŠLJAR et al., 1989; TIŠLJAR & VELIĆ, 1991), and on the Dinara Mt. (locality 10a) from late Tithonian to the Early Valanginian (Fig. 5). In western Bosnia emersion of similar duration to that in Istria was recorded NW of Drvar (locality 14 – ŠUŠNJAR & BUKOVAC, 1978), in Srnetica Mt. SE from Bosanski Petrovac (locality 15 – VRHOVČIĆ et al., 1983) and NW from Glamoč (locality 16 – AHAC et al., 1977), in eastern Herzegovina N and NW from Trebinje (locality 17 – NATEVIĆ & PETROVIĆ, 1967), and in Montenegro in the region of Nikšić (locality 7 – RADOIČIĆ & VUJISIĆ, 1970; VUJISIĆ, 1972) and NW of Cetinje (locality 9 – ANTONIJEVIĆ et al., 1969).

2.2. Megafacies of lagoonal and subtidal inner platform oncoid, pelletal and skeletal mudstones/wackestones (J-2)

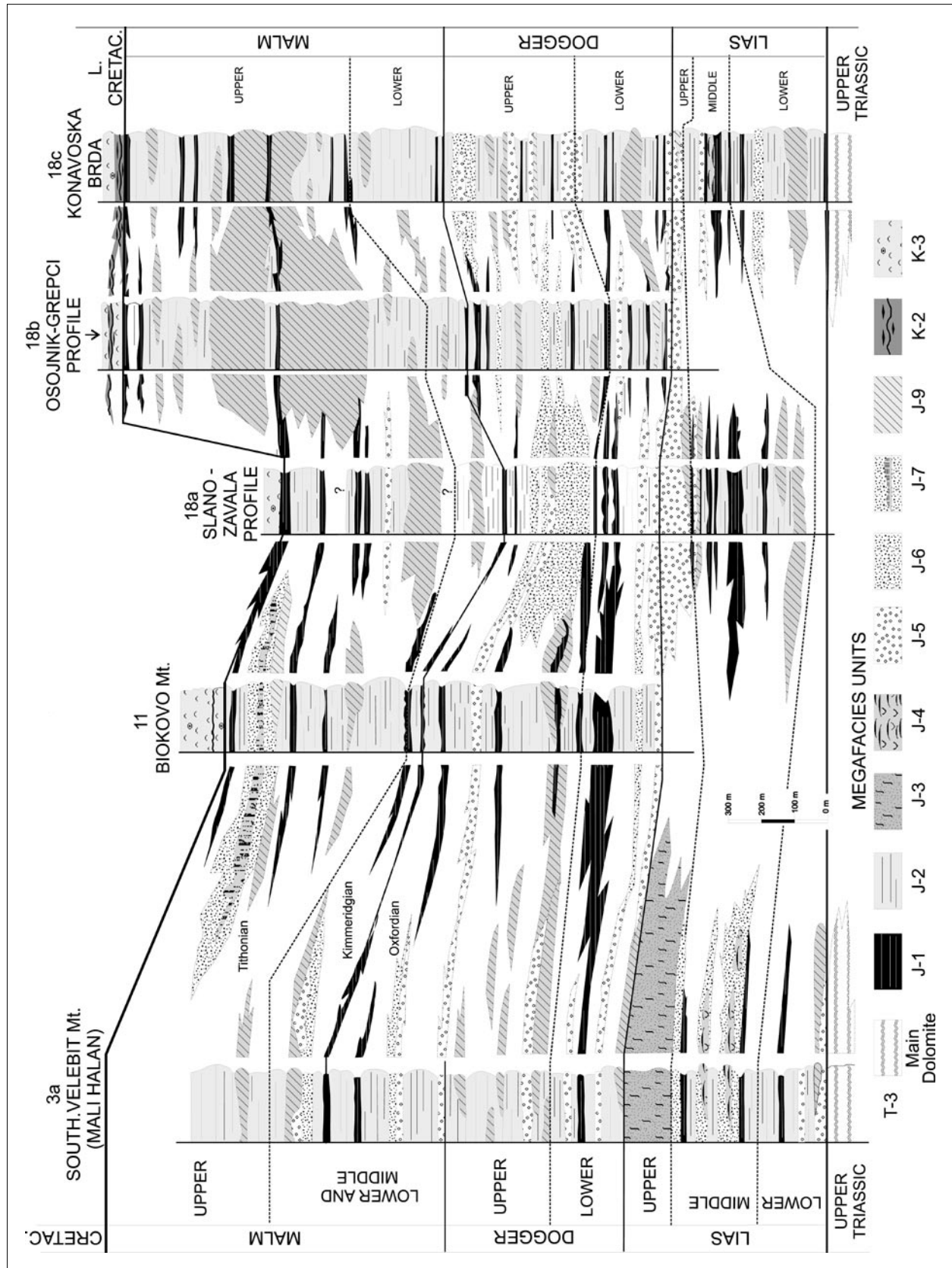
Megafacies J-2 is a dominant facies type within Jurassic deposits (Figs. 2–4). It is composed of thick-bedded to massive wackestones/packstones to floatstones with algal oncoids (“cyanoids” – RIDING, 1983), as well as pelletal and skeletal wackestones and mudstones containing faecal pellets, gastropod cortoids and centripetally micritized benthic foraminiferal tests and mollusc bioclasts.

Massive and/or thick-bedded mudstones and wackestones of *megafacies J-2* are predominant in the Middle Lias, Lower and Middle Dogger, Oxfordian and Kimmeridgian carbonates. This megafacies prevails in Velika Kapela Mt. and in the Senj–Ogulin profile (locality

Fig. 2 Correlation of Jurassic and Cretaceous platform carbonate megafacies from the Senj–Ogulin profile (modified after MATIČEĆ et al., 1997), Triassic, Jurassic, Cretaceous and Palaeogene carbonates of northern margin of the carbonate platform in the Karlovac–Duga Resa area (modified after BUKOVAC et al., 1974; DRAGIČEVIĆ & VELIĆ, 1994, 2002), and Cretaceous–Palaeogene carbonates of northern margin of the carbonate platform in the Donji Bešpelj area, Bosnia and Herzegovina (modified after DRAGIČEVIĆ, 1987; DRAGIČEVIĆ & VELIĆ, 1994). Legend: K-10: Megafacies of calcilithite–marly flysch; K-9a: Megafacies of slope carbonates: carbonate debrites and coarse-grained carbonate turbidites; K-9b: Megafacies of slope carbonates: middle- to fine grained carbonate turbidites or allodapic limestones; K-6: Megafacies of rudist coquinas/coquinites with small rudist biostromes and lithosomes; K-6a: Megafacies of coarse-grained rudist coquinas/coquinites accumulated within shallows with agitated water, “intra-shelf troughs”, and particularly on the slope toward the open sea; K-5: Megafacies of intraclastic/peloidal and skeletal foreshore and shoreface grainstones and packstones; K-4: Megafacies of inner platform lagoonal and shallow subtidal oncoid and peloidal micritic limestones; K-3: Megafacies of peritidal–tidal flat pelletal and stromatolitic limestones forming shallowing-upward cycles; K-2: Megafacies of peritidal and vadose limestones, black-pebble breccia/conglomerates, emersion breccia, clays, swamp deposits and palaeosols, long-lasting emersions and bauxites; J-9: Megafacies of late-diagenetic dolomites; J-8: Megafacies of “limestones with cherts” (including “Lemeš deposits”), deposited within intraplatform troughs with temporary or continuous connection to the open sea; J-7: Megafacies of peri-reefal bioclastic limestones (rudstones and grainstones) with hydrozoan, stromatoporoid and coral patch reefs and biostromes; J-6: Megafacies of skeletal and intraclastic grainstone/rudstones deposited in shallows with agitated water; J-5: Megafacies of ooid grainstones deposited in environments with agitated water and ooid bars; J-4: Megafacies of lithotid and brachiopod lithosomes and tempestite coquinas of shallow subtidal and lagoonal regions of the inner platform; J-3: Megafacies of bioturbated and late-diagenetically dolomitized “spotty limestones” – mudstones and wackestones deposited in isolated and restricted lagoon/deeper subtidal areas of the inner platform; J-2: Megafacies of lagoonal and subtidal inner platform oncoid, pelletal and skeletal mudstones/wackestones; J-1: Megafacies of peritidal micritic, fenestral and vadose limestones with interbeds of early-diagenetic dolomites and emersion breccia, emersions and occasional bauxites; T-3: Megafacies of peritidal and supratidal carbonates – Main Dolomite (Hauptdolomit).

6b–c on Fig. 1), in the Dogger of Velebit Mt. (localities 3a–b), and Biokovo Mt. (locality 11), as well as in the Trnovski Gozd (locality 5f) and Karlovac area (locality 6a), and Lower Malm of the Dubrovnik region (locality 18b – Osojnik–Grepci area).

Similar deposits are also known within Jurassic deposits of other areas of the Karst Dinarides, but literature data are quite scarce. E.g., deposits belonging to megafacies J–2 can also be found in the Dogger of the central part of the Karst Dinarides in western Bosnia



and Croatia, in Malm deposits of Suha Krajina in Slovenia (locality 5a; DOZET, 1995), the Oxfordian and Kimmeridgian of SE Montenegro, and Upper Kimmeridgian and Tithonian of Eastern Herzegovina (RADOIČIĆ, 1966), etc.

Upper Malm deposits are frequently composed of algal wackestones, (so-called *Clypeina* limestones), which usually represent the initial members of small-scale shallowing-upward cycles (TIŠLJAR & VELIĆ, 1991).

2.3. Megafacies of bioturbated and late-diagenetically dolomitized “spotty limestones” – mudstones and wackestones deposited in isolated and restricted lagoon/deeper subtidal areas of the inner platform (J–3)

Deposits of *megafacies J–3* are typical for the Upper Lias of the Velebit Mt. (Figs. 2 and 3; localities 3a – Mali Halan and 3b – Kubus), Velika Kapela Mt. and Senj–Ogulin profile (locality 6b–c), and Platak–Gornje Jelenje in Gorski Kotar (locality 6d). This megafacies is widely distributed in the western part of the Karst Dinarides, stretching from W Bosnia and S Croatia (northern Dalmatia) towards the NW into southern Slovenia (TIŠLJAR & VELIĆ, 1991; DOZET & ŠRIBAR, 1998a; DRAGIČEVIĆ & VELIĆ, 2002). However, it is completely missing in the ESE, from central Bosnia towards Herzegovina, Montenegro and the Croatian southern Adriatic coast (Fig. 3).

The main characteristic of these “spotty limestones” is intense bioturbation of carbonate muds in restricted areas with very reduced fossil assemblages, indicating low sedimentation rates during late Lias. The depositional area was probably an isolated, restricted lagoon in the inner part of the platform, formed by the interaction of gentle synsedimentary tectonics and eustatic sea-level change.

This spotty appearance is a consequence of bioturbation and different amounts of organic matter in a host rock (predominantly mudstones) and bioturbation infillings (mostly wackestones to packstones), although differences have been subsequently exaggerated by the variable influences of late-diagenetic dolomitization and recrystallization.

2.4. Megafacies of lithiotid and brachiopod lithosomes and tempestite coquinas of shallow subtidal and lagoonal regions of the inner platform (J–4)

Deposits separated into *megafacies J–4* are present only within the Middle Lias deposits (Figs. 2 & 3), in Velebit Mt. (localities 3a–b), near Duga Resa in the Karlovac area (locality 6a), Velika Kapela Mt. and Senj–Ogulin Profile (locality 6b–c), and Dubrovnik area (locality 18c – Konavoska Brda).

Biostromes are 0.3–0.8 m thick, and are characterized by their limited lateral extent. They are composed of very large shells of lithiotids and brachiopods lithified in living position, and occur only at some localities, for example, on the Kubus ridge of Velebit Mt. (locality 3b) and Konavoska Brda near Dubrovnik (locality 18c). However, shell coquinas and tempestite coquinas consisting of coarse debris of lithiotids and brachiopods very often occur in penecontemporaneous deposits, both in these and other aforementioned localities (e.g. JELASKA & VELIĆ, 1971; TIŠLJAR & VELIĆ, 1991; BUSER & DEBELJAK, 1996; DEBELJAK & BUSER, 1998).

Limestones with lithiotids can be found throughout the area of the former platform except for its marginal parts (Fig. 1; DRAGIČEVIĆ & VELIĆ, 2002). Depending on bathymetry and morphology of the sea bottom, the frequency of these beds varies from place to place, with maximal 4 to 12 beds in Middle Lias of the Velebit Mt. (locality 3b; SOKAČ, 1973), and minimal 1 to 3 beds in the W Gorski Kotar (Platak–Gornje Jelenje – locality 6d).

Tempestite coquinas were deposited by storm waves and storm tides in shallow subtidal to lower intertidal environments, and are associated with limestones of *megafacies J–1, J–2* and *J–6*.

2.5. Megafacies of ooid grainstones deposited in environments with agitated water and ooid bars (J–5)

Deposits of *megafacies J–5* are most common in the Middle and Upper Lias and Dogger of the Trnovski Gozd (locality 5f on Fig. 1), in the Upper Lias, Dogger and Malm succession of Velika Kapela Mt. and the Senj–Ogulin profile and Karlovac area (Fig. 2), and

Fig. 3 Correlation of the Jurassic platform carbonate megafacies units of Velebit Mt. (Mali Halan), Biokovo Mt. (area of Kozica) and the southern Adriatic (locations 18a – Osojnik and 18b – Konavoska brda). Partly modified after TIŠLJAR & VELIĆ (1991). Legend: K–3: Megafacies of peritidal–tidal flat pelletal and stromatolitic limestones forming shallowing-upward cycles; K–2: Megafacies of peritidal and vadose limestones, black-pebble breccia/conglomerates, emersion breccia, clays, swamp deposits and palaeosols, long-lasting emersions and bauxites; J–9: Megafacies of late-diagenetic dolomites; J–7: Megafacies of peri-reefal bioclastic limestones (rudstones and grainstones) with hydrozoan, stromatoporoid and coral patch reefs and biostromes; J–6: Megafacies of skeletal and intraclastic grainstone/rudstones deposited in shallows with agitated water; J–5: Megafacies of ooid grainstones deposited in environments with agitated water and ooid bars; J–4: Megafacies of lithiotid and brachiopod lithosomes and tempestite coquinas of shallow subtidal and lagoonal regions of the inner platform; J–3: Megafacies of bioturbated and late-diagenetically dolomitized “spotty limestones” – mudstones and wackestones deposited in isolated and restricted lagoon/deeper subtidal areas of the inner platform; J–2: Megafacies of lagoonal and subtidal inner platform oncoid, pelletal and skeletal mudstones/wackestones; J–1: Megafacies of peritidal micritic, fenestral and vadose limestones with interbeds of early-diagenetic dolomites and emersion breccia, emersions and occasional bauxites; T–3: Megafacies of peritidal and supratidal carbonates – Main Dolomite (Hauptdolomit).

in the Lower, Middle and Upper Dogger and Lower Malm of Velebit Mt., Upper Lias/Lower and Middle/Upper Dogger of Biokovo Mt. and Upper Lias and Lower to Middle Dogger in the Dubrovnik area (Fig. 3; DRAGIČEVIĆ & VELIĆ, 2002). Ooid grainstones and bioclastic–ooid grainstones are also common in Oxfordian strata of western Istria and western Gorski Kotar area (Fig. 4).

Deposits of this megafacies are also widely distributed in several levels of Jurassic rocks in other parts of the Karst Dinarides, most commonly in Upper Lias–Lower Dogger, Dogger and Malm in general, and Oxfordian and Tithonian. The best outcrops are described from Bosnia and Herzegovina, SE of Kupres (locality 20), Montenegro (see DRAGIČEVIĆ & VELIĆ, 2002 – this Vol.; FARINACCI & RADOIČIĆ, 1964; RADOIČIĆ, 1966; D'ARGENIO et al., 1971), and especially Slovenia (BUSER, 1978, 1979; OREHEK & OGORELEC, 1979, 1981; OGORELEC & DOZET, 2000), in different levels of stratigraphic range Middle Lias to Kimmeridgian (DOZET & ŠRIBAR, 1998a), and in some places throughout the Dogger, Oxfordian and Lower Kimmeridgian (STROHMENGER & DOZET, 1990; DOZET, 2000).

Ooid grainstones were frequently deposited in the form of ooid bars, exhibiting large-scale cross-bedding, but also ooid grainstones or ooid–bioclastic–intraclastic grainstones to rudstones are common as the first member of the shallowing-upward cycles. In this type of parasequences the second member is pelletal or oncoid wackestone or peloid–oncoid floatstone, while the third, upper member of the cycles, is pelletal or oncoid wackestone with fenestral fabric, locally with vadose features (TIŠLJAR & VELIĆ, 1991).

Ooid grainstones are composed of well-sorted, spheroidal and frequently broken ooids and mosaic and/or fibrous calcite cement. Rocks comprise different ooid types: most common are radial, tangential and micritic, although there are also oomoldic, leached and broken and regenerated ooids. Oomoldic and leached ooids are more frequent only within oolitic grainstones of Lower Dogger age in the Dubrovnik area (locality 18b – Osojnik–Grepci profile) and from the Lower Lias on Velebit Mt. (locality 3a – Mali Halan). Their abundance indicates that ooid tidal bars were occasionally exposed to the influence of fresh water, causing complete or partial leaching of their probably originally aragonitic cortex.

Ooid grainstones of *megafacies J-5* were deposited in environments of ooid shoals and bars with high water-energy.

2.6. Megafacies of skeletal and intraclastic grainstone/rudstones deposited in shallows with agitated water (J-6)

Megafacies J-6 consists of bioclastic grainstones and rudstones, and sporadically of floatstones containing

well-sorted and rounded intraclasts, bioclasts and coated bioclasts (“cortoids”), 0.5–10 mm in size. Bioclasts of hydrozoans and other stromatoporoids, intraclasts and ooids are predominant, while fragments of corals and gastropods are relatively rare. These rocks are characterised by their high content of drusy mosaic and often fibrous rim calcite cement, and they originated by the destruction of skeletons of reef and patch-reef organisms in open shoals with high water energy and normal marine salinity and by migration and deposition of bioclasts in shoals with agitated water.

Deposits of *megafacies J-6* (Fig. 4) are common only in the Malm of western and southern Slovenia in the Trnovski Gozd area (locality 5f – TURNŠEK et al., 1981; OGORELEC et al., 1996), and in Croatia in the Pokuplje (locality 21) and Karlovac area (locality 6a), in western Istria (locality 1a – “tidal bar facies” in TIŠLJAR & VELIĆ, 1987), in Oxfordian sediments of western Gorski Kotar area (locality 6d – Platak–Gornje Jelenje), in the Upper Tithonian of Velika Kapela Mt. and Senj–Ogulin profile (locality 6b–c), and in the Oxfordian of Velebit Mt. (Mali Halan – locality 3a) and Biokovo Mt. (locality 11).

A variety of *megafacies J-6* deposits, composed of well-sorted and rounded intraclasts and bioclasts of pachyodont shells and echinoderms deposited in shallows with agitated water, occur in the Lower and Middle Lias in western Slovenia, in the Middle Lias and Upper Dogger of Velebit Mt. (Mali Halan – locality 3a), while in the Lower Dogger of the Biokovo Mt. (locality 11) skeletal and intraclastic grainstones/rudstones occur (Fig. 3). Deposits of this variety of *megafacies J-6* are especially important for the Middle Dogger succession of the Dubrovnik area (localities 18a–c on Fig. 3).

2.7. Megafacies of peri-reefal bioclastic limestones (rudstones and grainstones) with hydrozoan, stromatoporoid and coral patch reefs and biostromes (J-7)

Deposits of *megafacies J-7* only occur sporadically in typical carbonate platform deposits, usually within the succession of *megafacies J-6* in Malm deposits (Figs. 2 & 3). Smaller coral and/or hydrozoan patch-reefs were well developed in the Oxfordian of the Island of Lastovo (locality 19), in the Tithonian of Velika Kapela Mt. and the Senj–Ogulin profile (locality 6b–c) and in the Gorski Kotar (Zlobin area – locality 6f).

During the Late Jurassic the northern, NE and SE margins of the platform were characterised by an almost continuous belt of coral–hydrozoan barrier reefs stretching from W Slovenia (TURNŠEK, 1966; TURNŠEK et al., 1981) to SE Montenegro and NW Albania (VELIĆ et al., 2002a). In addition, there were also coral–hydrozoan reefs within the platform interior, where they surrounded intraplatform depressions, e.g. in Gorski Kotar (VELIĆ et al., 1994, 2002b) or the “Lemeš” trough extending approximately from the vicinity of Bihać in W Bosnia (locality 22) towards

the south to Central Dalmatia, i.e. Knin, Drniš and Sinj (VELIĆ et al., 2002a). Besides this, barrier reefs, extending for tens or hundreds of kilometres, there were also isolated patch reefs, for example near Senj (locality 6b), in Gorski Kotar near Zlobin (locality 6f), in Biokovo (locality 11) in Croatia, as well as in the area of Nanos, Hrušica (localities 5c–d) and Dolenjska (locality 5b) in Slovenia (TURNŠEK, 1997). Most of these reefs were not preserved *in situ* as skeletal reefs – they occur as smaller or larger quantities of skeletal detritus in the form of peri-reefal bioclastic limestones of a rudstone/grainstone type.

Large organic reefs or reef complexes have not been recognized within Jurassic carbonates in the Croatian part of the Adriatic Carbonate Platform. Some of these ancient reefs have been completely destroyed and redeposited (TIŠLJAR & VELIĆ, 1991), e.g. there are relics of destroyed reefs in the Upper Malm of the Pokuplje and Karlovac area (localities 21 and 6a), in Gorski Kotar near Zlobin (locality 6f), in the Oxfordian of western Istria (locality 1a), in the Lower Tithonian of Velika Kapela Mt. (locality 6b) and in the Upper Malm of Biokovo Mt. (locality 11).

Opinion is divided concerning the stratigraphic position of reefal/peri-reefal deposits within Upper Jurassic deposits in Slovenia. For example: TURNŠEK et al. (1981), BUSER (1989) and TURNŠEK (1997) consider these deposits to be of Oxfordian–Kimmeridgian age, while NIKLER (1978) considered that they are of Upper Kimmeridgian–Tithonian age, similar to the age of corresponding deposits in Croatia (MILAN, 1965, 1969; NIKLER, 1965, 1969, 1978; BUKOVAC et al., 1974, 1984; VELIĆ, 1977; TIŠLJAR & VELIĆ, 1991; VELIĆ et al., 1994). Reefal/peri-reefal deposits with abundant corals and hydrozoans are very common along the NE margin of the platform in the area from central Bosnia to southern Montenegro, but their stratigraphic age is generally determined as Upper Jurassic (e.g. PAPEŠ, 1972, 1985; VUJNOVIĆ, 1980; MIRKOVIĆ & VUJISIĆ, 1989; MIRKOVIĆ et al., 1977, 1979).

2.8. Megafacies of “limestones with cherts” (including “Lemeš deposits”), deposited within intraplatform troughs with temporary or continuous connection to the open sea (J–8)

Megafacies J–8 comprises “limestones with cherts”, and it is especially well developed in the Kimmeridgian of Velika Kapela Mt., in the area of Karlovac (Fig. 2) and within the so-called “Lemeš beds” which can be found in the central part of the platform from Bihać in NW Bosnia, along the Una valley, through E Lika (Donji Lapac, Udbina) and N Dalmatia (Knin, Drniš) to central Dalmatia (Sinj) (Fig. 7 in VELIĆ et al., 2002a). Comparable deposits are completely missing in the coastal area and on the islands of the central and southern Adriatic (TIŠLJAR & VELIĆ, 1991). “Limestones with cherts” deposited within an intraplatform trough in the area of the present day Velika Kapela Mt. (locality 6b–c) had only weak, temporary

connections with the open sea. On the contrary, for deposits of the so-called “Lemeš beds” a continuous and direct connection with the open Tethys is supposed.

“Limestones with cherts” have also been found in Slovenia, where according to BUSER (1989) in the region of Trnovski Gozd (locality 5f) they were accumulated somewhat earlier, during the Oxfordian, in a deeper trench formed within the platform, which was connected towards the north with the Slovenian Basin.

In the area of Velika Kapela Mt. and the Senj–Ogulin profile (locality 6b–c, Fig. 2) thin- to well-bedded grey to dark grey mudstones/wackestones with interbeds of cherts gradually overlaid Oxfordian deposits of *megafacies J–2*. Their thickness is very variable, and their upper boundary is also gradual with redeposited bioclastic limestones of *megafacies J–5* (Fig. 2).

In their lower part “limestones with cherts” are composed of grey to dark grey pelletal–bioclastic wackestones and mudstones with nodules and rare lenses of cherts. In their upper part within the well-bedded rocks of similar lithology, but including small peloids, oncoids, pelagic crinoids, bioclasts of echinoderms, corals, hydrozoans and stromatoporoids, rare ooids and very rare ammonites, there are lot of nodules, lenses and intercalations of cherts.

Cherts comprise numerous relics of radiolarians and spicules of silica sponges. They originated by early-diagenetic silicification of carbonate muds under the influence of solutions enriched in silicic acid originating from fine volcanoclastic detritus, and some beds are direct products of the alteration of tuffs, as first mentioned by ŠČAVNIČAR & NIKLER (1976).

“Lemeš beds” were described as platy to thick-bedded limestones with interbeds and lenses of cherts and/or thin-bedded silicified limestones (IVANOVIĆ et al., 1977, 1978; KRKALO et al., 1995). Limestones are mostly pale brown fossiliferous mudstones to wackestones, but also wackestones to packstones comprising pellets, ooids, oncoids and bioclasts. They contain relatively numerous ammonites, aptichuses, fish remains, brachiopods, benthic and pelagic foraminifera, calcisphaeres and radiolarians.

According to KRKALO et al. (1995) “Lemeš beds” at a typical locality in Svilaja Mt. (Lemeš, Maovice – locality 23) within the continuous succession of Upper Jurassic deposits overlie dark grey Oxfordian limestones (probably representing deposits of *megafacies J–2*). In their basal part there is an alternation of platy and thin-bedded limestones (beds up to 20 cm thick) with chert lenses and nodules (cm- to dm-thick). Limestones predominate, but the proportion of cherts increases upwards. Interbeds and lenses of montmorillonitic clays containing volcanic glass and pyroclastic quartz have been determined. In the central part of the succession thin bedded siliceous sediments prevail – silicified carbonates (predominantly mudstones) and 5–10 cm thick cherts with relics of ammonites and bivalves, characterised by occurrences

of horizontal and oblique lamination. The upper part of the "Lemeš beds" succession begins with the alternation of limestones and cherts, characterised by the gradual reduction in the proportion of chert (they finally disappear completely) and thickening of limestone beds (up to 80 cm), containing successively more shallow water carbonate debris, especially bioclasts of bivalves and echinoderms.

For more details on the Kimmeridgian environments and deposits in the area of Velika Kapela see VELIĆ et al. (1994, 2002b – this Vol.) and BUCKOVIĆ (1995).

2.9. Megafacies of late-diagenetic dolomites (J–9)

Megafacies J–9 includes large masses, bodies and layers of microcrystalline to coarsely-crystalline dolomites with mosaic texture. They often contain relics of more or less intensively dolomitized limestones, mainly of *megafacies J–2, J–6* and *J–7*, and rarely of *megafacies J–1* (Figs. 2–4).

Their late-diagenetic origin is suggested by the following features: the relative large size of dolomite crystals (0.02–0.8 mm), selective dolomitization of limestone components, occurrence of irregular dolomite lenses and bodies within undolomitized or weakly dolomitized limestones, gradual transitions of limestones to dolomite and undolomitized relics of limestones in dolomites, practically constant structures and composition of dolomites in large areas formed by dolomitization of different structural, genetic and stratigraphic types of limestones, as well as their high Ca–excess (these are usually $\text{Ca}_{52-57}\text{Mg}_{43-48}$ dolomites).

Megafacies J–9 is the dominant megafacies unit of the Lower Oxfordian and Upper Tithonian of Velika Kapela Mt. and the Senj–Ogulin profile (locality 6b–c), the Lower and Middle Lias in Karlovac area (locality 6a), Upper Malm of the central and southern Adriatic coast – Biokovo Mt. and Dubrovnik area (localities 11 and 18a–c), and the Upper Malm in the offshore well IM–1 (locality 2b). It is also very common in the Lower Lias and Lower Dogger of the Gorski Kotar area (locality 6d – Platak–Gornje Jelenje), Velika Kapela Mt. and the Senj–Ogulin profile (localities 6b–c), Vele-

bit Mt. (localities 3a–b), Biokovo Mt. (locality 11) and in the southern Adriatic region (Island of Lastovo – locality 19, Dubrovnik area – localities 18a–c).

In central Croatia, from the vicinity of Vrbovsko, Ogulin, Plaški and Lička Jesenica to the wider region of the Plitvička jezera lakes (the area between localities 6c and 4 and S of locality 4), a belt from a few hundred m to more than 10 km wide, composed of late-diagenetic dolomites of Upper Malm to Neocomian age crops out. Within this belt in the area between Josipdol, Modruš and Plaški an almost complete Jurassic succession (from the Middle Lias to the end of the Malm) is completely dolomitized. The age has been determined since within these dolomites lenses and interbeds of undolomitized limestones comprising index fossils are more or less common. In the Liassic part of this succession there are indications for occurrences of early-diagenetic dolomites.

3. CARBONATE, CLAY-BEARING AND SABKHA ANHYDRITE MEGAFACIES OF THE LOWER CRETACEOUS AND CARBONATE MEGAFACIES OF THE UPPER CRETACEOUS DEPOSITS

Cretaceous carbonate deposits of the Karst Dinarides can be divided into 10 megafacies units:

K–1: Megafacies of supratidal early-diagenetic dolomites, which can be subdivided into 3 different sub lithofacies types:

K–1a: Facies of supratidal early-diagenetic dolomites without evaporites,

K–1b: Facies of supratidal early-diagenetic dolomites with evaporites, i.e. sabkha cycles, and

K–1c: Facies of supratidal laminated early-diagenetic dolomites with crystal moulds of evaporite minerals;

K–2: Megafacies of peritidal and vadose limestones, black-pebble breccia/conglomerates, emersion breccia, clays, swamp deposits and palaeosols, long-lasting emersions and bauxites;

Fig. 4 Megafacies units of the Malm, Cretaceous and Palaeogene deposits: correlation of the off-shore well IM–1 (northern Adriatic sea, deep marine succession – partly modified after VESELI, 1999) with megafacies of western and southern Istria and western Gorski Kotar (Platak area) (partly modified after TIŠLJAR et al., 1994, 1998). Legend: P–3: Megafacies of Foraminiferous limestones; P–2: Megafacies of peritidal/lagoonal stromatolitic, pelletal and skeletal micritic limestones; KP–1: Megafacies of emersions with bauxites, and terrestrial, fresh-water and brackish (Liburnian) deposits; K–9a: carbonate debrites and coarse-grained carbonate turbidites; K–9b: middle- to fine grained carbonate turbidites or allodapic limestones; K–8: Megafacies of late-diagenetic dolomites; K–7: Megafacies of limestones with pelagic fauna which originated during phases of temporary platform drowning; K–6: Megafacies of rudist coquinas/coquinites with small rudist biostromes and lithosomes; K–5: Megafacies of intraclastic/peloidal and skeletal foreshore and shoreface grainstones and packstones; K–4: Megafacies of inner platform lagoonal and shallow subtidal oncoid and peloidal micritic limestones; K–3: Megafacies of peritidal – tidal flat pelletal and stromatolitic limestones forming shallowing-upward cycles; K–2: Megafacies of peritidal and vadose limestones, black-pebble breccia/conglomerates, emersion breccia, clays, swamp deposits and palaeosols, long-lasting emersions and bauxites; K–1: Megafacies of supratidal early-diagenetic dolomites; J–9: Megafacies of late-diagenetic dolomites; J–6: Megafacies of skeletal and intraclastic grainstone/rudstones deposited in shallows with agitated water; J–5: Megafacies of ooid grainstones deposited in environments with agitated water and ooid bars; J–2: Megafacies of lagoonal and subtidal inner platform oncoid, pelletal and skeletal mudstones/wackestones; J–1: Megafacies of peritidal micritic, fenestral and vadose limestones with interbeds of early-diagenetic dolomites and emersion breccia, emersions and occasional bauxites.

- K-3: Megafacies of peritidal–tidal flat pelletal and stromatolitic limestones forming shallowing-upward cycles;
- K-4: Megafacies of inner platform lagoonal and shallow subtidal oncoid and peloidal micritic limestones;
- K-5: Megafacies of intraclastic/peloidal and skeletal foreshore and shoreface grainstones and packstones;
- K-6: Megafacies of rudist coquinas/coquinites with small rudist biostromes and lithosomes;
- K-7: Megafacies of limestones with pelagic fauna which originated during phases of temporary platform drowning;
- K-8: Megafacies of late-diagenetic dolomites;
- K-9: Megafacies of slope carbonates: debrites and turbidites, and
- K-10: Megafacies of calclithite–marly flysch.

3.1. Megafacies of supratidal early-diagenetic dolomites

Deposits of *megafacies K-1* occur within Cretaceous platform carbonates of the Dinaric karst region as three types, differing according to their origin and depositional environments.

3.1.1. Facies of supratidal early-diagenetic dolomites without evaporites (K-1a)

Deposits of *facies K-1a* only occur in Lower Cretaceous carbonates in the Berriasian succession of western Istria (locality 1a), Berriasian and Valanginian carbonates of southern Slovenia (OREHEK & OGORELEC, 1979, 1981; DOZET, 1992a, b; DOZET & ŠRIBAR, 1998b), Upper Albian/Vraconian of Biokovo Mt. (locality 11), offshore well Kate-1 in the Kornati area (locality 2f) and in the Dubrovnik area (locality 18d).

3.1.2. Facies of supratidal early-diagenetic dolomites with evaporites, i.e. sabkha cycles (K-1b)

Deposits of *facies K-1b* only occur in the Lower Cretaceous deposits in wells drilled in the Ravni Kotari area (locality 25a: wells RK-1, RK-3, RK-4, locality 25b: Nin-1) and wells in the Adriatic region: OL-1 (locality 26a – Island of Olib), and DO-1 (locality 27 – Island of Dugi Otok). Lower Cretaceous sabkha anhydrites are represented by typical sabkha cycles (TIŠLJAR, 1984³, 2001), composed of member A (kerogenous ostracod wackestones/mudstones deposited in subtidal–lagoon), member B (homogenous and stromatolitic intertidal/supratidal early-diagenetic dolomite) and member C (nodular sabkha anhydrite).

Cretaceous sabkha anhydrites from deep wells have significantly different mineralogical, petrological, sedimentological and geochemical properties from Upper Permian anhydrites (PAPEŠ, 1985; ŠUŠNJARA et al., 1992; TIŠLJAR, 1992) or “Permo–Triassic(?)” evaporites of central and northern Dalmatia and Una valley in Lika and Bosnia (SAKAČ et al., 1970; HERAK, 1973, 1983; IVANOVIĆ et al., 1977; PAPEŠ et al., 1982; BAHUN, 1985).

3.1.3. Facies of supratidal laminated early-diagenetic dolomites with crystal moulds of evaporite minerals (K-1c)

Deposits of *facies K-1c* only crop out within Upper Santonian–Lower Campanian peritidal deposits in the area of Sućuraj on the island of Hvar (locality 28 on Fig. 1). This megafacies is characterised by the typical alternation of thin (0.2–6 mm), very wavy laminae of light and dark coloured dolomites (therefore it is called “zebra dolomite”), as well as fenestral fabric and desiccation cracks, resulting from recurrent dehydration and moisturisation by high and storm tides in supratidal environments.

Occurrence of this type of deposits within Upper Santonian–Lower Campanian peritidal carbonates of *megafacies K-3* has very important sedimentological, palaeomorphological and palaeoclimatological significance for the interpretation of sedimentary environments and evolution of the Adriatic Carbonate Platform in the Late Cretaceous.

3.2. Megafacies of peritidal and vadose limestones, black-pebble breccia/conglomerates, emersion breccia, clays, swamp deposits and palaeosols, long-lasting emersions and bauxites (K-2)

Deposits of *megafacies K-2* without long-lasting emersion and bauxites are most common within limestones of the Upper Aptian, and in some parts of Hauterivian, Barremian, and Lower Albian successions in the continental part of the Karst Dinarides (Figs. 4 and 5). They also occur on the islands of Brijuni, Cres, Lošinj, Vis, Hvar, Korčula, Mljet and the Pelješac peninsula (localities 1e, 29, 31a, 33, 28, 34, 35 and 36), as well as in onshore and offshore wells Pula-1, Susak-1, Premuda-1, Kate-1 and Boraja-1, i.e. on localities 1d, 2d–f and 12 (TIŠLJAR, 1978a, b, 1980, 1986; TIŠLJAR et al., 1981, 1997; VELIĆ & TIŠLJAR, 1987; VELIĆ et al., 1989, 1995; TIŠLJAR & VELIĆ, 1991; VESELI et al., 1991; FUČEK et al., 1995; VESELI, 1994; VLAHOVIĆ et al., 2000; HUSINEC et al., 2000).

After important relative sea level falls connected with emersions, e.g. after the regional Aptian emersion, several shallowing-upward cycles were initiated

³ TIŠLJAR, J. (1984): Sedimentološka i litofacijsna interpretacija karbonatno–anhidritnog kompleksa dubokih bušotina Ravni Kotari–3, Dugi Otok–1, Nin–1, Brač–1 i Lastovo–1 [Sedimentological and lithofacies interpretation of the wells RK–1, DO–1, Nin–1, Brač–1 and Lastovo–1 – in Croatian]. – Unpubl. Study, INA–Naftaplín, Zagreb, 64 p.

composed of peritidal limestones alternating in vertical, partially even in lateral succession with soft pebble conglomerates, black-pebble breccias, emersion breccias, grey and dark clay intercalations and palaeosols. This was a consequence of oscillatory relative sea level fluctuations caused by the interaction of eustatic changes, tidal flat and shoreline progradation and gentle synsedimentary tectonics (TIŠLJAR et al., 1995, 1998; MATIČEC et al., 1996).

The frequent short-lived emersions in Lower Cretaceous limestones were connected with interruptions of sedimentation, temporary emersions of incompletely consolidated carbonate deposits and the appearance of thin intercalations of soft pebble conglomerates, black-pebble breccias, emersion breccias, grey and dark green clay intercalations and palaeosols. The black-pebble conglomerates and breccias consist of poorly sorted angular to more or less rounded fragments or pebbles of stromatolites, pelletal and fenestral wackestones to packstones and mudstones originating from underlying or lateral beds, in a clayey and/or marly matrix. Usually they occur as channel or depression fills on eroded (or in the case of longer hiatuses even karstified) surfaces of peritidal limestones. Black-pebbles are frequently 10 to 50 mm in diameter, which were originally intertidal or subtidal limestone clasts blackened by organic matter and pyrite in coastal swamps, bogs or pools (TIŠLJAR, 1986).

The grey, greenish and dark clays were deposited during relative sea level fall when swamp environments were developed in the coastal area (TIŠLJAR, 1986; TIŠLJAR et al., 1997). Greenish clays associated with Lower Cretaceous peritidal and lagoonal carbonates, especially within the Late Aptian to middle Albian long-lasting emersion in Istria (VELIĆ et al., 1989), but also in other parts of the platform (e.g., Slovenia – JURKOVŠEK et al., 1996), show evidence of subaerial exposure and pedogenesis, and are considered palaeosols. The very high smectite content in these deposits indicate an additional volcanic contribution before and during the subaerial exposure (OTTNER et al., 1999; DURN et al., 2000).

Vast tidal flats interfingering with shallow subtidal areas and coastal swamps in the area of present day Istria represented during the Cretaceous, suitable settings for dinosaurs, traces of which have been documented in deposits of *megafacies* K-2 and K-3 within the Hauterivian (including bones preserved in swamp environments – DALLA VECCHIA, 1998; DINI et al., 1998; DALLA VECCHIA et al., 2000a), Barremian, Albian and Upper Cenomanian (BACHOFEN-ECHT, 1925; POLŠAK, 1965b; TIŠLJAR et al., 1983a; VELIĆ & TIŠLJAR, 1987; DALLA VECCHIA et al., 1993, 2000b, 2002; DALLA VECCHIA & TARLAO, 1995). In neighbouring Slovenia there are even younger occurrences of dinosaurs of Upper Campanian to Lower Maastrichtian age (DEBELJAK et al., 1999, 2002). Such an important time span with

appropriate conditions for dinosaur survival represents a very important fact for the interpretation of palaeogeomorphological and sedimentological relationships in the NW part of the Adriatic Carbonate Platform (DALLA VECCHIA & TARLAO, 1995; MATIČEC et al., 1996).

In the Karst Dinarides area, long-lasting emersions with bauxites have also been documented within Cretaceous deposits. There are several stratigraphic levels characterised by emersions and significant karstification. The oldest level is represented by the previously mentioned emersion at the Jurassic–Cretaceous boundary (Kupres area – locality 20, Fig. 5), where Tithonian limestones represent the footwall and Valanginian limestones the hanging wall of the bauxites. In the area of Grmeč Mt. in W Bosnia (E of locality 22) bauxites have been found between Malm and Barremian–Aptian limestones (SAKAČ, 1969; SAKAČ et al., 1969). Lower Cretaceous bauxites have been found in Montenegro (Stara Crna Gora – GRUBIĆ, 1969), and W of Nikšić (locality 7) bauxite deposits occur between Barremian and Upper Cenomanian limestones (RADOIČIĆ & VUJISIĆ, 1970; VUJISIĆ, 1972). Bauxites between Lower and Upper Cretaceous deposits in SE Slovenia (Metlika, Vinica) have been documented by BUSER & LUKACS (1969). DRAGIČEVIĆ (1987) has determined that the largest bauxite deposits in the area of Jajce in central Bosnia (Bešpelj–Liskovica – locality 38c) occur between Albian (or rarely Cenomanian) limestones and rudist limestones of Santonian age (Fig. 2). A similar situation occurs in the area of Grmeč Mt. in W Bosnia (E of locality 22), where in the footwall of the bauxites Cenomanian limestones prevail, and they are overlain by Santonian–Campanian rudist limestones and clastic–carbonate flysch deposits of Maastrichtian–Palaeocene age (SAKAČ, 1969; SAKAČ et al., 1969).

From Istria, the northern Adriatic islands, Dalmatia and Herzegovina to SE Montenegro, the most frequent bauxite deposits are located between Cenomanian (more rarely Turonian and Santonian) limestones and Palaeogene deposits (Foraminiferal limestones and Promina deposits); these bauxites are usually called “Palaeogene bauxites” (SAKAČ & ŠINKOVEC, 1991).

3.3. Megafacies of peritidal–tidal flat pelletal and stromatolitic limestones forming shallowing-upward cycles (K-3)

Deposits of *megafacies* K-3 are mostly characterised by the alternation of thin-bedded pelletal wackestones/packstones to grainstones and LLH-stromatolites. They occur within all Cretaceous chronostratigraphic units on the entire carbonate platform region. They often occur especially in the Lower Cretaceous of Istria, Dinara Mt., Biokovo Mt., Kamešnica Mt., Pelješac peninsula, Dubrovnik area, wells Kate-1 and Boraja 1 (Figs. 4–6) and the Adriatic islands Cres, Korčula, Mljet, i.e. localities 29, 34 and 35 (FÜCHTBAUER & TIŠLJAR, 1975; TIŠLJAR, 1978a, b, 1986; MAGAŠ,

1980; TIŠLJAR et al., 1983b; ŠEBEČIĆ et al., 1983; TIŠLJAR & VELIĆ, 1986, 1991; VELIĆ et al., 1995; VLAHOVIĆ, 1999; HUSINEC, 2002).

In the Lower Cretaceous shallowing-upward cycles composed of pelletal or skeletal wackestones and LLH-stromatolites with fenestral fabric and desiccation cracks within mudstone laminae are most frequent. Skeletal wackestones are characterised by abundant green-algae (especially *Salpingoporella dinarica*), gastropods, ostracods and benthic foraminifera, among which palorbitolinas and mesorbitolinas are very important. These limestones were deposited in very shallow subtidal and intertidal flat environments (TIŠLJAR, 1978b; TIŠLJAR & VELIĆ, 1991; VLAHOVIĆ, 1999).

In the Upper Cretaceous, deposits of *megafacies K-3* very often occur on the entire carbonate platform within the Middle and Upper Cenomanian and Upper Turonian to Lower Santonian deposits (Figs. 4 & 6). Good examples can be found in southern and northern Istria – localities 1a, 1b (TIŠLJAR et al., 1983a, 1995, 1998; VLAHOVIĆ et al., 1994), the Island of Cres – locality 29 (MAMUŽIĆ et al., 1982; FUČEK et al., 1995), Olib and Ist islands – localities 26a–b (MORO & JELASKA, 1994), central and southern Dalmatia (RADOVČIĆ et al., 1983; MAMUŽIĆ et al., 1983), Island of Brač – locality 13 (JELASKA & OGORELEC, 1983; GLOVACKI-JERNEJ, 1988; GUŠIĆ & JELASKA, 1990), the island of Hvar – locality 28 (MAMUŽIĆ et al., 1981) and the island of Korčula – locality 34 (MAMUŽIĆ et al., 1980).

In the Upper Cretaceous deposits the first member of a shallowing-upward cycle is usually foraminiferal–peloidal wackestone/packstone with green-algae *Thaumatoporella* and *Aeolisaccus*, in some places with chondrodonts mostly oriented parallel to the bedding planes and/or with rudist fragments. The upper member of each cycle is represented by laminated limestones (frequently late-diagenetic dolomitized), consisting of very thin microbial and mudstone laminae totally without fossil remains or containing very rare *Thaumatoporella* and *Aeolisaccus* remnants.

During the Late Cretaceous within the peritidal parts of restricted shallows and lagoons with weak circulation and poor water aeration, i.e. oxygen deficiency, there are sporadic occurrences of “platy limestones with fishes”. They occur especially often in the Turonian and Senonian of the hinterland near Primošten in central Dalmatia (locality 37), the island of Hvar (locality 28 – HEMLEBEN & FREELS, 1977; RADOVČIĆ et al., 1983), and the Cenomanian of western Slovenia (Komen limestones – OGORELEC et al., 1987; JURKOVŠEK et al., 1996; CAVIN et al., 2000).

3.4. Megafacies of inner platform lagoonal and shallow subtidal oncoid and peloidal micritic limestones (K-4)

Within the Cretaceous succession of the Karst Dinarides deposits of *megafacies K-4* are the most widespread

type, especially in the Valanginian, Hauterivian and Lower Aptian, but they are also very frequent in Berriasian, Barremian, Lower Albian, Cenomanian, Turonian and Coniacian–Lower Campanian deposits (Figs. 2, 4–6).

They are represented by thick beds (0.4–3 m) or even massive mudstones, oncoid, pelletal and skeletal wackestones/packstones to floatstones. The limestones of *megafacies K-4* were deposited in lagoons and restricted shallows in the inner part of the carbonate platform.

In the Lower Cretaceous these limestones are mostly micritic rocks consisting predominantly of carbonate mud, i.e. micrite, and algal oncoids, faecal pellets, peloids and skeletons and/or bioclasts of restricted marine flora and fauna: green-algae (especially *Salpingoporella dinarica*), gastropods, ostracods and micritized benthic foraminifera – primarily palorbitolinas and mesorbitolinas (ŠRIBAR, 1979; KOCH, 1988; KOCH et al., 1989, 2002; TIŠLJAR & VELIĆ, 1991; TURNŠEK et al., 1992).

During the Late Cretaceous, limestones of *megafacies K-4* were deposited within a complex pattern of lagoons and restricted shallows behind areas with abundant rudist and chondrodont communities and shallows characterised by the rapid deposition of bioclastic debris produced by these assemblages. Micritic deposits of *megafacies K-4* were therefore characterised by variable amounts of fine-grained rudist debris, peloids, benthic foraminifera, *Thaumatoporella*, *Aeolisaccus* and oncoids. Within such a complex pattern of different small-scale environments rhythmical alternations characterised by shallowing-upward trend were deposited mostly by autocyclic mechanisms, usually composed of mudstones/wackestones with frequent *Thaumatoporella* and *Aeolisaccus*, rudist floatstones (sometimes in life-position as biostromes or thickets) and/or peritidal laminated limestones. Alternations of this type are very common within Cenomanian and Senonian deposits throughout the Karst Dinarides (TIŠLJAR, 1978b; PLENIČAR, 1979; MAMUŽIĆ et al., 1981, 1983, 1984; JELASKA & OGORELEC, 1983; GUŠIĆ & JELASKA, 1990; ŠRIBAR & PLENIČAR, 1990; VLAHOVIĆ, 1993; MORO & JELASKA, 1994; VESELI, 1994; JURKOVŠEK et al., 1996).

Within the Upper Albian inner platform, lagoonal and shallow subtidal oncoid and peloidal mud-bearing limestones of *megafacies K-4* the occurrence of “quartz diagenetic sediments” (TIŠLJAR, 1985⁴, 1994; VLAHOVIĆ et al., 2002a) or “quartz sediments” (ŠUŠNJARA et al., 1971; GALOVIĆ, 1991) is very characteristic. They occur in central and southern Istria (localities 1a, 1b), Čičarija Mt. in NE Istria (locality

⁴ TIŠLJAR, J. (1985): Litološke i sedimentološke karakteristike podine, krovine i sloja kvarcnoga sedimenta u Istri [*Lithology and sedimentology of the underlying and overlying limestones and quartz sediments in Istria* – in Croatian]. – Unpubl. Study, Archive of the Institute of Geology Zagreb, 87 p.

1c) and on the island of Vis (locality 33), as well as authigenic quartz in Dinara Mt. (locality 10a) and Svilaja Mt. (SE of locality 23). In earlier papers these deposits were known as “quartz sands” and “quartz sandstones” (POLŠAK, 1965b, 1970) or “mechano-chemogenic quartz sediments” (CRNKOVIĆ, 1967). Besides authigenic quartz and chalcedony they are composed of variable amounts of limestone relics, and in some places also well preserved silicified remains of green algae, benthic foraminifera, gastropods and bivalves.

The origin of “Quartz sediments” is probably connected with processes of early-diagenetic silicification of carbonate sediments, caused by the aeolian input of very fine volcanic ash mixed with carbonates, which was gradually dissolved in restricted alkaline lagoonal environments (TIŠLJAR, 1985⁴, 1994, 2001; GALOVIĆ, 1991).

3.5. Megafacies of intraclastic/peloidal and skeletal foreshore and shoreface grainstones and packstones (K-5)

Deposits of *megafacies* K-5 are predominantly composed of well-sorted and rounded intraclasts and/or peloids, benthic foraminiferal tests and in some places mollusc bioclasts (bivalves and gastropods).

In the Lower Cretaceous succession of the Karst Dinarides *megafacies* K-5 is a typical megafacies unit in the Upper Albian of Istria (Fig. 3), Lower Aptian of the Dinara Mt. (locality 10a), Upper Aptian of Biokovo Mt. (locality 11), and the Albian of the entire carbonate platform region, especially of the Dinara Mt., Biokovo Mt. and Korčula Island (locality 34) (Fig. 5).

Well-sorted and rounded grains (intraclasts, peloids and miliolid tests), cross-lamination and cross-bedding, small-current ripples and wave ripples indicate the existence of foreshore and shoreface environments with agitated water, tidal channels and carbonate sand bars (TIŠLJAR et al., 1983b; TIŠLJAR & VELIĆ, 1991).

In the Upper Cretaceous succession, deposits of *megafacies* K-5 occur only sporadically (Fig. 6), e.g. in the Kate-1 and Boraja-1 wells (localities 2f and 12; VESELI, 1994).

3.6. Megafacies of rudist coquinas/coquinites with small rudist biostromes and lithosomes (K-6)

Deposits of *megafacies* K-6 are mostly composed of thick-bedded to massive floatstones, wackestones/pack-

stones and rudstones. They usually contain a large quantity of rudist, and in some places chondrodont, debris of variable size, rounding and sorting, with very variable amounts of matrix and calcite cements. These deposits are very common in Cenomanian, Turonian and Santonian–Campanian deposits over the entire area of the Mesozoic carbonate platform (Figs. 2, 4 and 6).

Alternations of rudist coquinas and thinner or thicker rudist biostromes and/or thickets with rudist shells in life position are common, and in some localities are even the predominant lithologies. During the Late Cretaceous, rudist assemblages, in some places accompanied by chondrodonts and gastropods, colonized vast areas of inner platform shallows and flourished along inner marginal areas towards intra-platform troughs and platform margins. For example, “rudist limestones” or rudist coquinas and thinner or thicker rudist biostromes and/or thickets with rudist shells in life position were described by POLŠAK (1965b, 1970), MAMUŽIĆ et al. (1970, 1980, 1981, 1982, 1983), MAGAŠ (1973), PLENIČAR (1973, 1974, 1975, 1977), TIŠLJAR (1978b), KOCH (1978, 1988), JELASKA & OGORELEC (1983), DRAGIČEVIĆ (1987), GUŠIĆ & JELASKA (1990), VESELI et al. (1991), VLAHOVIĆ (1993, 1999), VESELI (1994), VLAHOVIĆ et al. (1994, 2002b), MORO & JELASKA (1994), JURKOVŠEK et al. (1996), PLENIČAR & JURKOVŠEK (1996, 1997, 1998, 2000a, b, 2001), KOCH et al. (1998), KORBAR et al. (2001, 2002), MORO et al. (2002), TIŠLJAR et al. (2002a, b), etc.

Disintegration of rudist and chondrodont shells by bioerosion and other physical processes produced enormous quantities of bioclastic material, both coarse-grained which accumulated within shallows with agitated water, and fine-grained, well-sorted material within lagoons and platform margins. Migration and accumulation of skeletal detritus was commonly very intensive, resulting in some places with the formation of clinoform bodies within high-energy foreshore–shoreface environments (TIŠLJAR et al., 1998).

Fine-grained detritus was redistributed by currents and waves, sometimes over large distances, and accumulated within low-energy inner platform deposits of *megafacies* K-4 or deeper environments characterised by pelagic fossil assemblages (*megafacies* K-7 and K-9a).

Along the N–NE margin of the platform, e.g. in NW and central Bosnia, from the Upper Santonian to the Maastrichtian there were occurrences of reefs and

Fig. 6 Correlation of the Cretaceous platform carbonate megafacies units of the Adriatic area: well Kate-1 (Kornati), well Boraja-1 (partly modified after VESELI, 1994) and the island of Brač (partly modified after GUŠIĆ & JELASKA, 1990). Legend: P-3: Megafacies of Foraminifer limestones; P-2: Megafacies of peritidal/lagoonal stromatolitic, pelletal and skeletal micritic limestones; KP-1: Megafacies of emersions with bauxites, and terrestrial, fresh-water and brackish (Liburnian) deposits; K-8: Megafacies of late-diagenetic dolomites; K-7: Megafacies of limestones with pelagic fauna which originated during phases of temporary platform drowning; K-6: Megafacies of rudist coquinas/coquinites with small rudist biostromes and lithosomes; K-5: Megafacies of intraclastic/peloidal and skeletal foreshore and shoreface grainstones and packstones; K-4: Megafacies of inner platform lagoonal and shallow subtidal oncoid and peloidal micritic limestones; K-3: Megafacies of peritidal – tidal flat pelletal and stromatolitic limestones forming shallowing-upward cycles; K-2: Megafacies of peritidal and vadose limestones, black-pebble breccia/conglomerates, emersion breccia, clays, swamp deposits and palaeosols, long-lasting emersions and bauxites.

peri-reefal deposits composed of corals, hydrozoans, stromatoporoids and abundant rudists. Destruction of these deposits produced enormous quantities of material, redeposited during the Late Cretaceous in the form of flysch deposits on platform slopes and in the proximal part of the basin (see *megafacies K-9* and *K-10* and DRAGIČEVIĆ & VELIĆ, 2002 – this Vol.).

3.7. Megafacies of limestones with pelagic fauna which originated during phases of temporary platform drowning (K-7)

Deposits of *megafacies K-7* are most common around the Cenomanian/Turonian boundary and within the Late Santonian–Campanian succession (Figs. 4, 6). They are composed of micritic limestones with pelagic fossil assemblages, formed during temporary drowning of the platform caused by the interaction of eustatic sea-level rise and synsedimentary tectonics. Because of the latter, the influence of eustatic changes was not constant over all areas of the platform.

Within Lower Cretaceous platform carbonates of the Karst Dinarides, the oldest pelagic fauna is recorded in the Lower Aptian deposits of the Ogulin area in central Croatia (locality 6c; VELIĆ & SOKAČ, 1978). This episode represents evident pelagic influence during the deposition of lagoonal limestones with palorbitolinas, characterised by frequent hedbergellas and saccocomas.

The first Late Cretaceous pelagic episode is recorded within Lower Cenomanian deposits of the island of Cres (locality 29; KORBAR et al., 2001).

However, the most important are two regional episodes of platform drowning. Older deposits of a drowned platform system (Upper Cenomanian–Lower Turonian) occur at numerous localities along the Adriatic coast and islands (GUŠIĆ & JELASKA, 1990; 1993; FUČEK et al., 1990; VESELI et al., 1991; TIŠLJAR et al., 1995, 1998; VLAHOVIĆ et al., 1994, 2002b; ŠRIBAR, 1995; CAVIN et al., 2000). They are represented by thick-bedded, in some places nodular micritic limestones (mostly wackestones and packstones) containing calcisphaeres, rare crinoids, echinoderm remains and spicules of siliceous sponges, and very rare ammonites; in some places chert nodules are common.

Younger levels of *megafacies K-7* deposits mostly correspond to the Upper Santonian–Lower Campanian. These micritic limestones, mudstones, wackestones and packstones, containing numerous pelagic fossils (calcisphaeres, globotruncanids) and fine rudist debris, are well-developed on the Adriatic islands, especially the island of Brač (locality 13 – GUŠIĆ & JELASKA, 1990) and Island of Dugi Otok (locality 27 – FUČEK et al., 1990).

3.8. Megafacies of late-diagenetic dolomites (K-8)

Deposits of *megafacies K-8* are very frequent and occur in large bodies (Figs. 4–6), especially at the beginning and at the end of the Lower Cretaceous – in the Berriasian and Albian of Istria (locality 1), in the Berriasian, Valanginian and Upper Albian–Lower Cenomanian of the Velika and Mala Kapela Mts. (locality 6b), in the Kordun and Lika areas (south of locality 6a and between localities 4 and 3, respectively), in central Dalmatia (Murter–Pirovac–Vodice – between localities 25a and 37), Dinara Mt. (locality 10a), Biokovo Mt. (locality 11), the Dubrovnik area (locality 18d), and the islands of Cres, Krk, Dugi Otok (localities 29, 30, 27), Rava, Pašman, Prvić, Zlarin (between localities 24 and 37), Hvar, Korčula and Mljet (localities 28, 34, 35), and in the Upper Cretaceous of the islands of Brač, wells Kate-1 and Boraja-1, and island of Vis (localities 13, 2f, 12, 33).

All the Cretaceous examples are hypidiotopic and xenotopic mosaic macrocrystalline and/or microcrystalline dolomites with high Ca-excess and a low degree of lattice ordering. They very often contain relics of more or less intensely dolomitized limestones of *megafacies K-3*, *K-4*, *K-5* and *K-6*.

However, late-diagenetic dolomites of *megafacies K-8* are frequently dedolomitized or calcitized and transformed into microcrystalline “limestones of recrystallized texture”. This process is connected to the near surface zone, reaching a maximum at depths of 10 to 40 m, but also in the vicinity of intensely tectonized zones, since in these areas there is intense circulation of fresh-water, characterised by a low Mg/Ca molar ratio and rapid removal of Mg²⁺ ions.

3.9. Megafacies of slope carbonates: debrites and turbidites (K-9)

Deposits of *megafacies K-9* mostly occur within the Upper Cretaceous, most frequently the Upper Santonian and Campanian, in some places in deposits of Maastrichtian age or transitional Cretaceous–Tertiary sequences along the platform margins, or along fault escarpments within the platform (Fig. 2). They can be traced along the NE margin from the Slovenian trough in the NW, through Slovenia and central Croatia, SE of Karlovac, Slunj and Bihać to central Bosnia, Hercegovina and Montenegro. The best outcrops can be found in the area of Karlovac–Slunj–Bihać–Banjaluka–Jajce–Kupres (localities 6a, 4, 22, 39, 38b,c and 20), while along the SW margin they have been documented from offshore wells.

Megafacies K-9 can be subdivided into two types according to its lithological and sedimentological properties:

- K-9a – carbonate debrites and coarse-grained carbonate turbidites, and

- K-9b – middle- to fine-grained carbonate turbidites or allodapic limestones.

Along the NE margin deposits of *facies K-9a* are represented by coarse-grained (2–60 cm) carbonate breccias composed of angular to subangular, weakly sorted clasts (up to small blocks) of shallow-water Jurassic and Cretaceous limestones and dolomites. These deposits are of Albian to Santonian–Campanian age, and are, in all localities, covered by middle- to fine grained carbonate turbidites (*facies K-9b*) and pelagic limestones and marls and Campanian–Palaeocene flysch deposits (DRAGIČEVIĆ, 1987; DRAGIČEVIĆ & VELIĆ, 1994), which are in this paper separated into *megafacies K-10*. For more information on the stratigraphic relationships and sedimentary environments along the NE margin of the Adriatic Carbonate Platform see DRAGIČEVIĆ & VELIĆ (2002 – this Vol.).

In the area of the SW margin of the platform, deposits of *megafacies K-9* have been found in numerous offshore wells in the northern and central Adriatic.

In the northern Adriatic area, W and SW of Istria in offshore wells, deposits of this megafacies are several hundred metres thick, e.g. a 740 m thick sequence in IM-1 well (locality 2b), was deposited throughout the complete Cretaceous and Palaeogene periods. However, there are some exceptions (e.g. the 300 m thick sequence in J-86/1 – locality 2a, was deposited in a shorter time-interval – from the Maastrichtian to the Early Eocene). Generally, these deposits accumulated in environments ranging from carbonate platform, carbonate ramp with distributary channels and the transition into the basin plain (VESELI, 1999).

In the central Adriatic area in an offshore well Koraljka-1 (locality 32) a continuous sequence from the Maastrichtian to the Upper Eocene was recorded within deep marine deposits of *facies K-9b* and *megafacies K-10*. These deposits consist of fossiliferous pelagic micrites and chalky limestones containing numerous planktonic foraminifera and nannoplankton (in some levels with cherts), and intercalations and thin beds of resedimented bioclastic limestones. This alternation of pelagic and bioclastic limestones were interpreted as carbonate turbidite deposits (LUČIĆ et al., 1993).

FUČEK et al. (1991) documented resedimented Middle Turonian carbonate deposits (which could represent *facies K-9b*) in Brbišnica cove on the island of Dugi Otok (locality 27) within a succession of pelagic limestones.

3.10. Megafacies of calcilithite–marly flysch (K-10)

Deposits of *megafacies K-10* are predominantly composed of calcilithite sandstones and marls forming typical Bouma T_{a-d} sequences. Intervals T_{a-c} are usually represented by calcirudites to calcisiltites, and T_d intervals by marls and silty marls. Within such flysch

deposits in some places, e.g. in the region of Karlovac and the river Vrbas in NW and central Bosnia (Figs. 1 & 2), there are occurrences of coarse-grained turbidites, i.e. breccias and breccio–conglomerates composed of poorly-sorted fragments, with or without large olistoliths of Jurassic and Cretaceous limestones and dolomites. These occurrences indicate synsedimentary tectonics with the formation of steeper slopes in the initial phase of flysch trough formation (DRAGIČEVIĆ & VELIĆ, 1994).

Deposits of *megafacies K-10* were predominantly deposited from turbidity currents of low density, although occasionally there are deposits accumulated from high-density currents.

In the deeper parts of the basin, farther from the mainland and islands deposition of carbonate muds took place in the same period. These mudstone and wackestone limestones contain pelagic fauna and grains of fine sand, silt or clay, and usually diagenetic chert nodules and layers. These are so-called “Scaglia” limestones, which laterally and vertically gradually pass into flysch deposits (OGORELEC et al., 1976).

4. CARBONATE AND SILICICLASTIC MEGAFACIES OF THE UPPERMOST CRETACEOUS AND PALAEOGENE DEPOSITS

Although the main topic of this paper is a discussion of Jurassic and Cretaceous deposits, we decided to add a short review of the overlying Uppermost Cretaceous and Palaeogene deposits, to enable better insight into the post-platform evolution. Cretaceous deposits are directly overlain by the following megafacies units (Figs. 2, 4 and 6):

- KP-1: Megafacies of emersions with bauxites, and terrestrial, fresh-water and brackish (Liburnian) deposits,
- P-2: Megafacies of peritidal/lagoonal stromatolitic, pelletal and skeletal micritic limestones,
- P-3: Megafacies of Foraminiferal limestones, and
- P-4: Megafacies of pelagic limestones and carbonate turbidites – allodapic limestones.

4.1 Megafacies of emersions with bauxites, and terrestrial, fresh-water and brackish (Liburnian) deposits (KP-1)

Deposits of *megafacies KP-1* comprise very variable rocks, united by their non-marine environments of origin, either during long-lasting emersion with or without bauxites, or within fresh-water or brackish environments before the final Palaeogene transgression. Non-marine conditions prevailed for very variable periods of time in different parts of the former carbonate platform. The emersion commenced at different times (mostly from the Cenomanian to San-

tonian, rarely to the Maastrichtian, but in some parts it had already started in the Early Cretaceous), while the Palaeogene transgression in the Croatian parts of the Karst Dinarides started mostly in the early Eocene. Additionally, it is not easy to speculate on the proportion of the former carbonate platform, which was covered by the Palaeogene sea, because in this period the area was morphologically diverse.

In the northern Adriatic area (IM and J wells – locality 2b–c, Fig. 1) the youngest Cretaceous deposits are of Upper Cenomanian age, and are covered by Pliocene deposits (VESELI, 1999). In northern Istria, (locality 1b) emersion occurred from the Cenomanian (Savudrija–Buzet anticline, lower part of the Učka Mt.), Coniacian (Ćićarija Mt. – locality 1c) to the Santonian (top of the Učka Mt.). In central Istria there are several occurrences of Palaeogene limestones covering Lower Cretaceous deposits (Valanginian, Hauterivian, Barremian, and Albian – MATIČEC et al., 1996), and depressions in the palaeorelief of karstified Cenomanian limestones are filled by bauxites and brackish Palaeogene Liburnian deposits (MARINČIĆ & MATIČEC, 1989), while in southern Istria the youngest Cretaceous rocks are of Upper Santonian age (MORO et al., 2002). In the northern part of the island of Cres (locality 29) bauxites overlie Upper Cenomanian deposits, while in the southern part the youngest Cretaceous deposits are of Turonian–Coniacian age or even slightly younger (KORBAR et al., 2001). On the island of Krk (locality 30) bauxites cover Upper Cenomanian to Lower Turonian deposits, while on the islands of Lošinj and Pag (localities 31a and 31b) the youngest Cretaceous deposits are of Senonian age, similar to the situation in the Ravni Kotari area. In Dalmatia and Herzegovina emersion commenced differently from place to place, and bauxites, if present, and Palaeogene fresh-water, brackish and marine deposits cover emerged and more or less palaeokarstified Upper Cretaceous rocks of different stratigraphic levels – from the Cenomanian to the Maastrichtian. On the island of Brač (locality 13) there are outcrops of Maastrichtian rocks (GUŠIĆ & JELASKA, 1990), and in Herzegovina bauxites and brackish deposits cover Turonian–Senonian limestones (DRAGIČEVIĆ et al., 1992).

Bauxite deposits occur as sedimentary bodies of various shapes and sizes. They were formed in palaeorelief recesses on the underlying limestones and represent a regional palaeogeographical and sedimentological marker connected with emersion phases. Their stratigraphic position – as defined by the age of underlying and overlying rocks – is very variable.

Liburnian deposits resulted from oscillatory ingression, and are mostly represented by fresh-water and brackish deposits of Lower Eocene age composed of alternating layers of gastropod wackestones/packstones and algal wackestones, and occasionally bivalve floatstones or packstones and *Microcodium*-bearing wacke-

stones/mudstones. They were deposited only in the lowermost parts of the palaeorelief. At some localities in SW Slovenia there is almost a continuous succession from the Cretaceous to the Palaeogene (DROBNE et al., 1989, 1998; DROBNE, 1979; DELVALLE & BUSER, 1990; OGORELEC et al., 1995, 2001; JURKOVŠEK et al., 1996, 1997; PUGLIESE et al., 1995), but in Croatia Palaeocene rocks are practically missing (DROBNE, 1977; DROBNE et al., 1991, 2000; ČOSOVIĆ & DROBNE, 1998; VELIĆ et al., 2002c), and Maastrichtian deposits are relatively rare.

4.2. Megafacies of peritidal/lagoonal stromatolitic, pelletal and skeletal micritic limestones (P–2)

Deposits of *megafacies P–2* represent the first Palaeogene marine deposits, in some places overlying a sequence of *megafacies KP–1*, while elsewhere they represent the oldest Palaeogene rocks infilling the lowest parts of the palaeorelief. They are characterised by the alternation of laminated and/or thin-bedded wackestones/mudstones with characean gyrogonites and frequent *Microcodium* with LLH-stromatolites and miliolid wackestones deposited in intertidal and shallow subtidal environments (OGORELEC et al., 2001).

4.3. Megafacies of Foraminiferal limestones (P–3)

Deposits of *megafacies P–3* can be subdivided into four lithostratigraphic types, mostly deposited from the Early to Middle Eocene, named after the prevailing biota as *Miliolid limestones*, *Alveolinid limestones*, *Nummulite limestones* and *Discocyclinid limestones*. Since these facies units penecontemporaneously occupied different environments, from restricted shallows to carbonate slopes in the investigated carbonate successions characterised by a general transgressive trend, they are mostly in superpositional relations.

Foraminiferal limestones are mostly composed of the complete and disintegrated tests of benthic foraminifera, while the detritus of molluscs, echinoderms and bryozoans, as well as glauconite in the uppermost (i.e. youngest) part, are subordinate. Such a composition is typical of a foramol association.

Miliolid limestones represent the restricted inner part of the carbonate platform, *Alveolinid limestones* and *Nummulite limestones* the shallower and deeper parts of shoreface environments and *Discocyclinid limestones* the deeper parts of relatively open carbonate ramps. The same types in different areas are usually of somewhat different ages, but a general deepening-upward trend is always present. This trend is a consequence of the interaction of several causes, mainly intense synsedimentary tectonics (restricting the carbonate factory to the relatively narrow zones along the basin margins and ensuring appropriate accommodation space was available for the redistribution of shallow-water material to the basin), and relatively low net

sedimentation rate as a consequence of deposition in environments which were no longer ideal for biogenic carbonate production. Additionally, large quantities of foraminiferal tests and their remains were resedimented into the deeper parts of the basin by turbidity currents.

Deposits of this megafacies are most common in the coastal area and hinterland of the Karst Dinarides, especially in SW Slovenia (PAVLOVEC, 1963; DROBNE, 1977; DROBNE & PAVLOVEC, 1991), along the Adriatic coast in Croatia (central and N Istria – locality 1, Vinodol area – locality 24, Dalmatia and Adriatic islands) in Herzegovina and SE Montenegro.

4.4. Megafacies of pelagic limestones and carbonate turbidites – allodapic limestones (P-4)

Deposits of *megafacies P-4* are composed of mud-supported pelagic limestones and intercalations of thinner or thicker calcarenite layers. In the lowermost part they are usually characterised by the so-called “transitional beds” – marls with frequent crabs and glauconite grains.

Megafacies P-4 rocks are common along the Adriatic coast, on islands and in western Herzegovina (e.g. MAMUŽIĆ & SOKAČ, 1973; MAMUŽIĆ, 1975; MARINČIĆ, 1981; BABIĆ & ZUPANIĆ, 1990; BABIĆ et al., 1993), as well as in numerous offshore wells, e.g. J-86/1 and IM-1, 2, 3, 4 and 5 (localities 2a and 2b – VESELI, 1999), and Koraljka-1 (locality 32 – LUČIĆ et al., 1993). Similar deposits also occur along the NE platform margin (DRAGIČEVIĆ, 1987; DRAGIČEVIĆ & VELIĆ, 1994).

Pelagic limestones of mudstone, wackestone to packstone types contain a rich planktonic fauna (especially planktonic foraminifera) and variable amounts of very fine-grained detritus. Usually they have thin intercalations of calcarenites with variable amounts of siliciclastic grains. This alternation can be interpreted as fine-grained or muddy carbonate turbidites of a Piper type.

In some localities within pelagic limestones and marls there are 5–20 cm (in some places several metres thick) calcarenite beds deposited from gravitational flows, representing T_{a-c} and T_{b-c} intervals of Bouma sequences of middle-grained carbonate turbidites or allodapic limestones. These beds contain a large quantity of fine-grained carbonate detritus (complete and disintegrated benthic foraminifera tests, as well as bioclasts of echinoderms, molluscs, peloids, intraclasts, etc.), transported from marginal areas of the flysch basin.

In some areas pelagic and allodapic limestones contain chert nodules, e.g. in northern Adriatic offshore wells (localities 2a and 2b – VESELI, 1999).

6. DISSCUSSION AND CONCLUSIONS

The lateral and vertical pattern of different megafacies, their thickness and the duration of sedimentary conditions suitable for their origin, provide very important data on the palaeogeomorphological evolution of the carbonate platform.

Penecontemporaneous occurrences of different megafacies on different parts of the carbonate platform during the long period studied, from the Jurassic to the Middle Eocene, clearly indicate the diverse environments and depositional conditions present during the same periods (Fig. 7). Additionally, deposits of the same megafacies units in different areas are commonly characterised by the variable duration of similar conditions. This is especially true for the Late Cretaceous and Palaeogene (characterised by the final disintegration of the platform). However, even during a period of optimal platform development, approximately from the Lias to the Albian, there are numerous examples of facies variation in the platform realm.

Minor changes of platform conditions and environments represented the consequence of various factors, e.g. variable accumulation and subsidence rates, changes in water-energy, variability of local morphology, influence of sporadic storms and ecological changes controlling the different roles of organisms in the production of skeletal and non-skeletal allochems. However, interference of small changes in different factors within such a complex sedimentary system of the carbonate platform produced very important changes in sedimentary record.

In some periods regressive tendencies resulted in shorter or longer emersions recorded in different areas of the platform – practically throughout the entire studied stratigraphic range a smaller or larger area of the platform was emerged at any given time (Fig. 7):

- from the Middle Lias to Kimmeridgian a large area from Trnovski Gozd (locality 5f) and Suha Krajina (locality 5a) in Slovenia, through central Croatia (Karlovac area – locality 6a) and from NW to central Bosnia and central Montenegro;
- from the Oxfordian to the Late Tithonian in southern Slovenia (Suha Krajina, Nanos, Hrušica, Logaška Planota – localities 5a, c, d and e), in Croatia (western Istria – locality 1a, and Biokovo Mt. – locality 11), in Bosnia and Herzegovina (Drvar, Srnetica Mt., Glamoč and Trebinje area – localities 14–17) and in Montenegro (Nikšić and Cetinje area – localities 7 and 9);
- from the Late Tithonian to the Valanginian in the Dinara Mt. and Kamešnica Mt. (localities 10a and 10b), and from the Late Kimmeridgian to the Barremian in Grmeč Mt. in W Bosnia (E of locality 22).
- from the Early or Late Aptian to the Middle Albian in western and central Istria (locality 1), but also shorter

hiatuses (Late Aptian to Early Albian) at numerous other localities on the Adriatic Carbonate Platform;
 – from the Late Triassic, Late Malm, Barremian, Aptian and Albian to the Santonian–Campanian along the

northern platform margin in Bosnia (Banjaluka–D. Bešpelj–Jajce–Janj–Kupres – localities 39, 38c-b-a and 20);
 – from the Cenomanian, Turonian, Santonian–Cam-

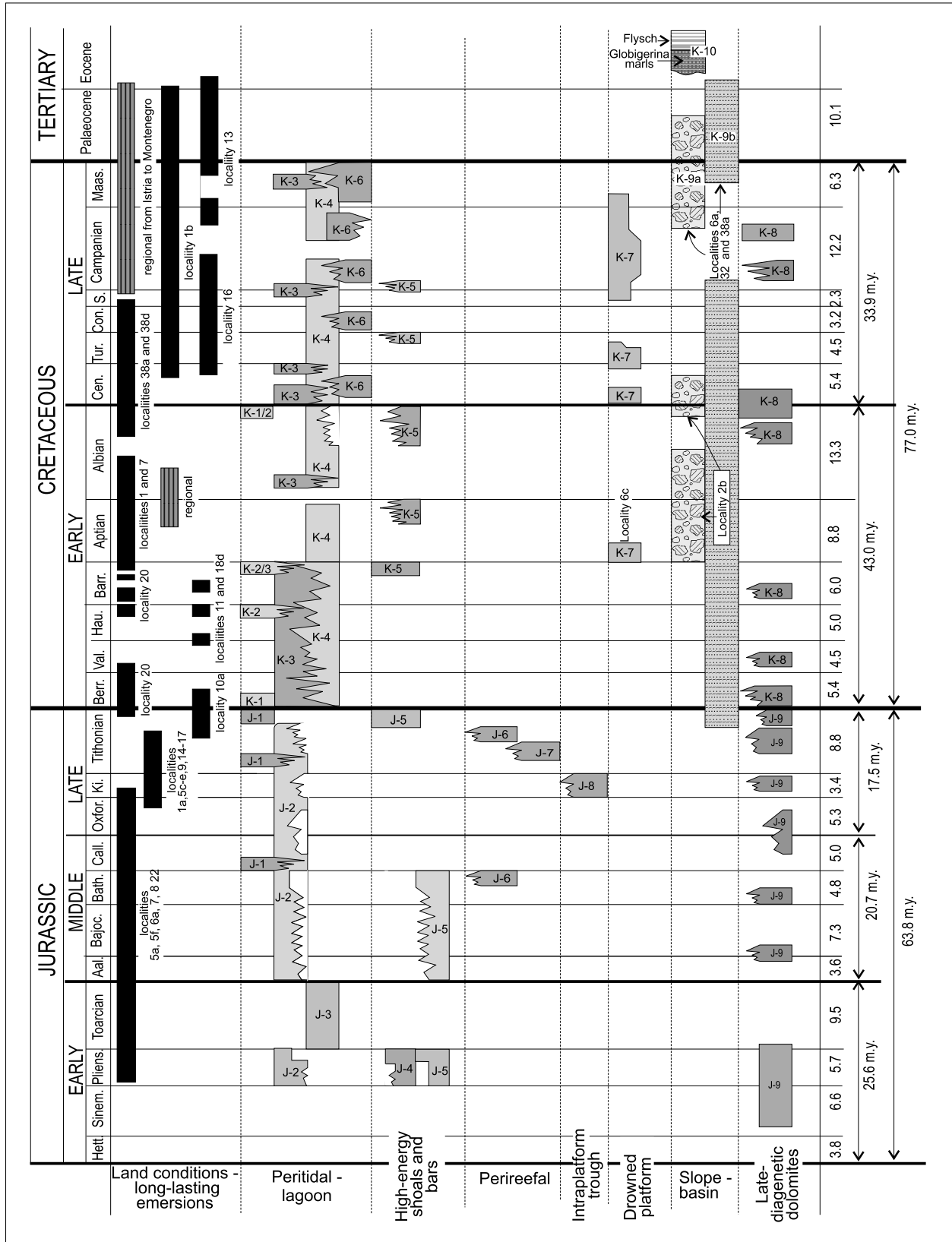


Fig. 7 Time distribution of long-lasting emersions (terrestrial conditions) and Jurassic, Cretaceous and Palaeogene units of the Karst Dinarides (time scale after GRADSTEIN & OGG, 1996).

panian or Maastrichtian to the Eocene in the entire coastal area and Adriatic islands, as well as in western Herzegovina. In Istria there are some localities with stratigraphic hiatus from the Valanginian, Hauterivian, Barremian or Albian to the Eocene.

The opposite situation is recorded in periods characterised by eustatic sea-level rise resulting in establishment of drowned platform environments (*megafacies K-7*), e.g. near the Cenomanian/Turonian boundary or from the Late Turonian–Santonian to the earliest Campanian.

However, both the aforementioned regionally important phases of emersion and platform drowning had different consequences on different parts of the Adriatic Carbonate Platform, since the regional or global eustatic signal was significantly corrected by local factors, especially synsedimentary tectonics.

Although the influence of synsedimentary tectonics on the carbonate platform is rarely clearly visible, especially because of the high organic production enabling fast infilling of any available accommodation space, its understanding is essential for the correct interpretation of the geological history of the platform. By careful examination of different penecontemporaneous successions it is possible to extract the tectonic signal resulting in the formation of environments which otherwise would not be possible.

A very good example of the influence of synsedimentary tectonics can be seen in the Upper Jurassic successions in different parts of the karst Dinarides. The Latest Oxfordian (or earliest Kimmeridgian) was, in the area of present Istria (locality 1a on Fig. 1), characterised by the beginning of the long-lasting emersion – shallow-marine deposition recurred in the Late Tithonian, i.e. practically the complete Kimmeridgian and Lower Tithonian deposits are missing. At Biokovo Mt. (locality 11) there are two emersions: from the Early Oxfordian to the Early Kimmeridgian and from the Late Kimmeridgian to the Middle Tithonian, divided by a relatively thin sequence of Kimmeridgian deposits (TIŠLIJAR & VELIĆ, 1991).

In the same period the western part of the Gorski Kotar area (Platak–Gornje Jelenje and Zlobin – localities 6d and 6f) was characterised by continuous shallow-water sedimentation, while in its eastern part (Velika Kapela Mt. and Senj–Ogulin area, localities 6b–c) an intraplatform trough was formed. It was characterised by deposition of limestones with cherts (*megafacies J-8* – see VELIĆ et al., 2002b for more information). Somewhat deeper marine environments in this area prevailed only temporarily – intense progradation of calcitic detritus (ooids, intraclasts, and especially peri-reefal bioclasts) from marginal areas gradually filled in the sedimentary basin, resulting in the final recovery of shallow-water deposition in Tithonian (*megafacies J-5, J-6, J-7* and *J-2*).

Along the northern margin the Kimmeridgian was characterised by a transgression over an area emergent

for a long period (emersion started in the Middle Lias). Such variability in the sedimentary record definitely cannot be interpreted without the important influence of local synsedimentary tectonics. Namely, the Oxfordian deposits are more or less similar throughout the area, while during the Kimmeridgian completely different environments were formed. Some parts were affected by emersion, in others shallow-marine deposition continued, some parts were characterised by deepening and an open marine influence, while in others transgression over areas which had been exposed for a long time was recorded. Tithonian successions are again similar throughout the area, represented mostly by shallow-water algal limestones.

An interesting example of the influence of extensive organic production on a carbonate platform is provided by a study of Late Cretaceous environments colonized by flourishing rudist communities. According to their ecological preferences, different rudist types usually accompanied by different molluscs (mostly chondrodonts and nerineids) occupied a wide range of different environments, from the inner, restricted parts of the platform, shallows with agitated water, somewhat deeper lagoons and inner parts of the platform margins. Their carbonate production was very high, and the material produced by disintegration of their skeletons by bioerosion and mechanical processes represented an important part of the total carbonate production in the Late Cretaceous. This material was reworked and continuously removed to other areas by waves and currents, enabling infilling of former smaller or larger depressions and the formation of a variable sea-bottom morphology by different mechanisms, e.g. migration of subaqueous dunes, but also transportation to far distances by turbidity currents. In this way organic production interacted with the environment, since it was influenced by its environment, but also the environment was significantly changed by organic production.

The very complex vertical and lateral alternation of different megafacies units therefore indicate the significant palaeogeographical dynamics of the Karst Dinarides. This variability resulted from the interaction of a global eustatic signal and local factors, first of all extensive organic production on carbonate platform and synsedimentary tectonics controlled by the specific palaeogeographic position of the platform during its geological history.

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