Geologia Croatica | 64/2 | 101–119 | 28 Figs. | Zagreb 2011

Sedimentary evolution of an inner foreland basin margin: Palaeogene Promina Beds of the type area, Mt. Promina (Dinarides, Croatia)

Jožica Zupanič[1] and Ljubomir Babić[2]

[1]Institute of Mineralogy and Petrography, Department of Geology, Faculty of Science, University of Zagreb, Horvatovac 95, 10000 Zagreb, Croatia

[2]Institute of Geology and Paleontology, Department of Geology, Faculty of Science, University of Zagreb, Horvatovac 102a, 10000 Zagreb, Croatia; (ljubomir.babic@zg.htnet.hr)

doi: 104154/gc.2011.09

Geologia Croatica

ABSTRACT

Mt. Promina became famous for its coal mines, vertebrate remains and fossil flora, and for the use of its name in denoting sediments covering a wide area of the Dinaric coastal range. The Promina Beds of the type area, Mt. Promina, are up to 1 km thick and evolved in the context of propagating Dinaric deformation towards the foreland. They consist of eight sedimentary units differing in facies, i.e. depositional environments and systems, which include alluvial, lacustrine, deltaic, lagoonal and shelf deposits. The sedimentary units constitute three depositional cycles. Cycle I is represented by a late lowstand alluvium, while Cycles II and III consist of transgressive and highstand (regressive) systems tracts. Cycle III also includes a coastal onlap of limestones and an alluvial onlap. Transgressive tracts are specific in being represented by lacustrine deposits and having non-erosive bases. Falling-stage sediments have not been identified.

The Promina Beds of Mt. Promina represent an example of sedimentary and sequence evolution at a foreland basin margin. The evolution of this margin is characterised by structural and stratigraphic complexities including syndepositional folding, growth strata, angular unconformities, intraformational faulting, alluvial and marine onlaps onto deformed basement, and tectonically induced, proximal-distal variations in facies and sediment thickness. The origin of lacustrine transgressive tracts may have been related to backtilting in the proximal part of the basin.

High sediment supply and subsidence pulses are proposed to have been the two main factors which shaped the depositional styles, sequence development and distribution of sediments. The dominant role of tectonism in the sedimentary evolution was related to the position of the area within deforming; marginal parts of the foreland basin, situated in close vicinity to the main, active Dinaric thrust units.

Keywords: Foreland basin, sedimentary cycles, sequence stratigraphy, synsedimentary tectonics, Dinarides

1. INTRODUCTION

During the late stage evolution of foreland basins, usually called the molasse stage, sedimentation rates outpace subsidence rates, and deposition occurs in shallow-marine and continental settings (e.g. FLEMINGS & JORDAN, 1989; ALLEN et al., 1991; CRAMPTON & ALLEN, 1995). At the same time, the basin, especially its orogen side, commonly experiences deformation which provokes specific structural and stratigraphic complications (review in MIALL, 1978). This study deals with the Promina Beds (PB), which are regarded as representing Palaeogene molasse deposits of the Dinaric orogen (e.g. MARINČIĆ, 1981). The focus is on successions up to 1 km thick, exposed on Mt. Promina (MtP), the type area of the PB (Figs. 1–3). The first purpose of this contribution is to provide basic data on various shallow-marine, deltaic, lacustrine, and alluvial facies, their vertical pattern and lateral variability, as well as their arrangement in eight distinct sedimentary units. Using these data, the successions of these units are shown to reflect specific changes in the relationship between accommodation and sediment supply, which define depositional cycles based on sequence stratigraphic concepts (POSAMANTIER & VAIL, 1988; POSAMENTIER & ALLEN, 1999; EMBRY, 2002; CATUNEANU, 2006). Later the development of complex relationships between sedimentary, stratigraphic and structural features characterising the type area of the PB are described. The question of dominant factors controlling the sedimentary evolution and sequence development of the studied basin are also addressed. While some authors proposed a variation in subsidence rates related to tectonic loading (HELLER et al., 1988), other workers suggested that eustasy generates progradational to aggradational cycles in the proximal part of the foreland basin, where the subsidence always exceeds the eustatic falls (POSAMANTIER & ALLEN, 1993). Variation in sediment supply coupled directly with tectonic loading is the third principal factor suggested to dominantly influence the origin of transgressive-regressive sequences in a foreland basin (LOPEZ-BLANCO et al., 2000; MARZO & STEEL, 2000). The complex history of the type area of the PB is discussed in the context of its specific, marginal position in the foreland basin, which was strongly influenced by tectonism.

2. GEOLOGICAL SETTING AND STUDY AREA

The PB is situated in the outer part of the Dinaric orogen, in the imbricate-folded belt, which roughly corresponds to the Dinaric coastal range (Figs. 1, 2). This belt consists of Cretaceous to Eocene platform carbonates, Eocene-Oligocene foreland basin clastics, and minor Neogene and Quaternary deposits (e.g. MAMUŽIĆ, 1975; IVANOVIĆ et al., 1978). On its inner side, it is bounded by larger Dinaric thrust units. Along its Adriatic side, it is bounded by the foreland, which is a common to both the Dinarides and the Apennines (Fig.

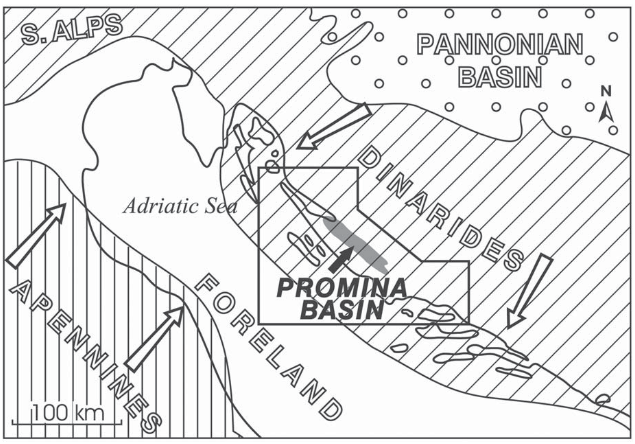

Figure 1: Location of the Promina basin within the Adriatic coastal range and Dinaric orogen. Framed area is shown in Fig. 2.

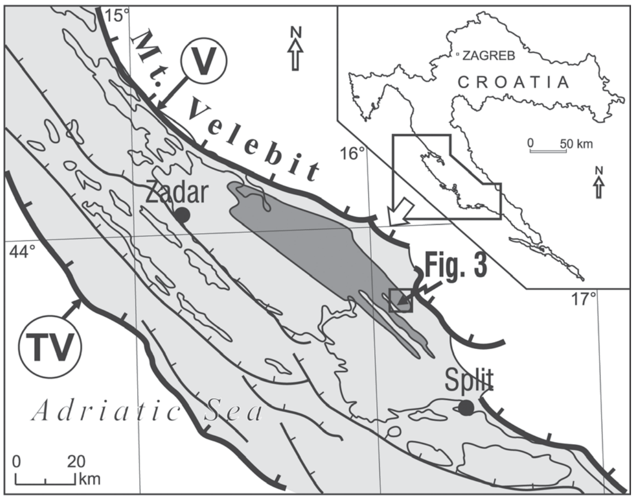

Figure 2: Location of the Promina basin (dark grey) within the imbricate-folded belt (light grey), which is bounded by important thrust faults: V, Velebit-Knin-Mosor Thrust to NE, and TV, Trieste-Vis Fault Zone to SW. Simplified after PRELOGOVIĆ et al. (2003; with references). Framed area is shown in Fig. 3.

1). For most of the Mesozoic to Eocene period, the area of the imbricate-folded belt was part of the carbonate platforms, which characterised a major part of the future Outer Dinarides (VLAHOVIĆ et al., 2005; KORBAR, 2009). The SW-directed (present-day orientation) propagation of tectonic deformation of the Dinaric orogen, and related migration of foreland basins, led to basin formation in the area of the present-day imbricate-folded belt during the Middle Eocene (e.g. IVANOVIĆ et al., 1977; MAMUŽIĆ, 1975). The basin was filled by deep-water clastics known as the Eocene flysch (e.g. MARINČIĆ, 1981; BABIĆ & ZUPANIČ, 2008), and by more than 2 km of Middle Eocene-Early Oligocene PB (IVANOVIĆ et al., 1978; MAMUŽIĆ, 1975; SAKAČ et al., 1993) regarded as representing a molasse (CHOROWICZ, 1977; HERAK & BAHUN, 1979; MARINČIĆ, 1981). It is possible that the Promina basin was carried piggyback (BABIĆ et al., 1995) on a huge, complex nappe (KORBAR, 2009). Parts of the PB originated in alluvial, coastal, deltaic, and shelf settings, and the successions of PB display a cyclic arrangement of sedimentary units related to the fluctuation of relative sea-level (ZUPANIČ, 1969; BABIĆ & ZUPANIČ, 2007 with ref.; MRINJEK, 2008). Two main "orogenic phases" have been cited for the area: before the PB, in the Middle Eocene, and after the PB, in the Oligocene-Miocene (IVANOVIĆ et al., 1978). The recently proposed Miocene age of the coastal flysch, and a younger age for fan deltaic and alluvial deposits of the PB (MIKES et al., 2008), challenged previous, Palaeogene dating, and requires caution and additional confirmation.

The study area coincides with the type area of the PB in Mt. Promina (MtP) (Fig. 3). This area became famous for its coal mines, vertebrate remains, fossil flora (reviews in KERNER, 1901, and MARKOVIĆ, 2002), as well as for a debate on the location of an unconformity which would be related to the main deformation of the coastal Dinarides (SAKAČ et al., 1993 with ref.). Several papers have described the suc-

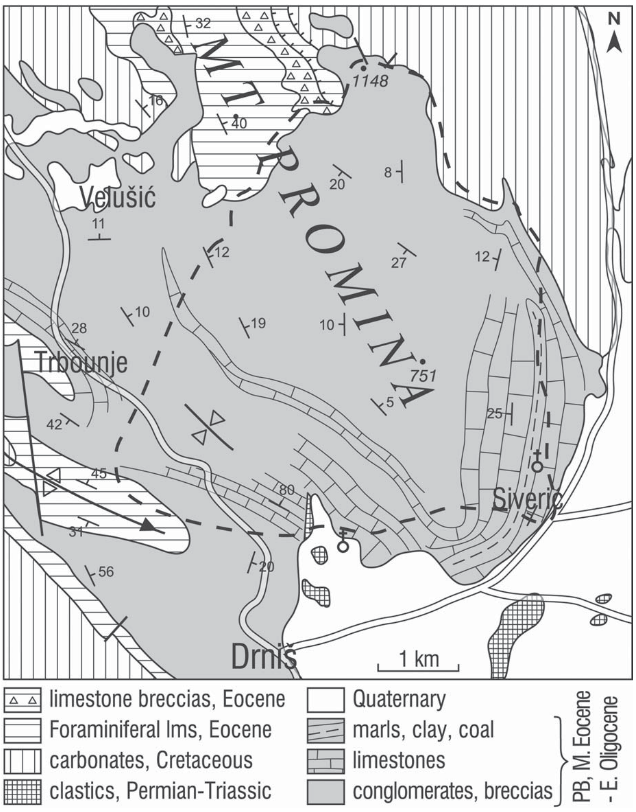

Figure 3: Outline geology of MtP and its vicinity. Simplified after IVANOVIĆ et al. (1977). Age of PB after KÜHN (1946) and SAKAČ et al. (1993). Thick, dashed line delineates the study area presented in Fig. 5.

cessions of PB in MtP (Fig. 4). However, knowledge on the sedimentary and basin evolution of this critical area for the evolution of the Dinaric orogen has remained fragmentary. This also applies to the dating of the sediments for which the age has loosely been defined as spanning the late Middle Eocene to Early Oligocene (KÜHN, 1946; SAKAČ et al., 1993). Since the 19th century, the Promina name has also been used for much thicker successions exposed in a considerably larger area (Fig. 2). However, a correlation along the Promina basin has shown that the MtP area contains the upper part of the entire PB (BABIĆ & ZUPANIČ, 2007). This is related to an overall, NE trending onlap of PB (QUITZOW, 1941), and the location of MtP in the NE, marginal part of the basin. A previous study of the PB, which covered only parts of MtP, reported on an alluvial unit, lacustrine unit, and shelf/delta cycles, which were compared to lowstand, transgressive, and highstand systems tracts, respectively (Fig. 4). The work presented here includes the entire succession, from the basal unconformity to the youngest strata on the mountain top. It is based on the study of a considerably larger area of the mountain, and takes into account important lateral changes reported by ZUPANIČ (1969).

3. METHODS

MtP displays well exposed individual segments of sedimentary successions at different locations, while more continuously exposed sections are uncommon. This hampered the work, especially in finer grained rocks and in transitions between sedimentary units, as well as for correlation. This was partly overcome by mapping at a scale of 1/25000 and locally at 1/5000 scale, and by studying rather closely located sections. Twelve logs have been measured at 1:100, and 1:50 scales. Field data were complemented by the study of more than 200 thin-sections.

4. GROSS COMPOSITIONAL DATA

Most of the studied clastics commonly contain lithoclasts which are almost exclusively carbonate in composition, with a high dominance of Cretaceous and Middle Eocene limestone clasts. There are exceptions which are specified at appropriate places in the text.

5. DESCRIPTION AND INTERPRETATION OF SEDIMENTARY UNITS

This section presents the basic data on the facies of sedimentary units and the main aspects of their depositional environments and systems. The units have been separated based on sharp vertical changes in facies. They are therefore lithostratigraphic units and, at the same time, are allostratigraphic and “mappable” (Figs. 5 and 6). Their areal distribution, cyclic organisation and bounding surfaces are discussed below in section 6.1.

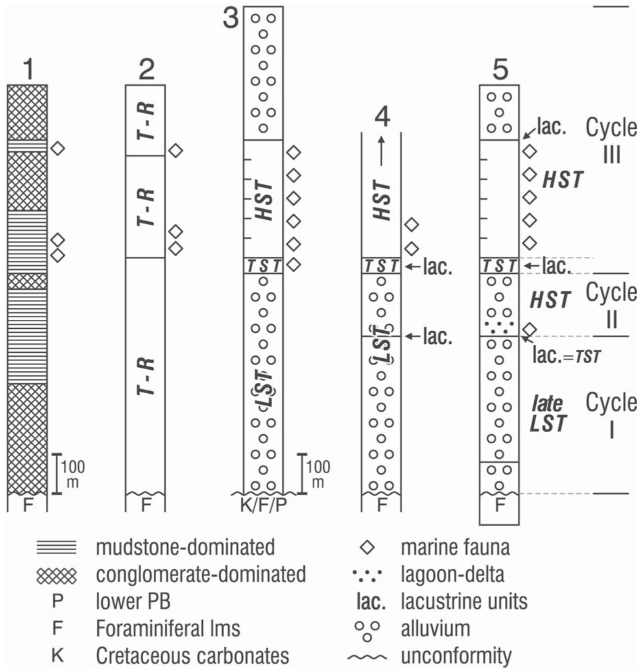

Figure 4: Current and earlier subdivisions of upper PB (simplified). 1, MtP: reconstructed from KERNER’s data (1894, 1986). 2, MtP: from ZUPANIČ (1969); T-R, Transgressive-regressive cycles start with marine strata and end with either lagoonal, swamp, deltaic, or alluvial deposits. 3, Largest part of the Promina basin: compiled from BABIĆ & ZUPANIČ (1990, 2007), ZUPANIČ et al. (1988), and BABIĆ et al. (1995). 4, MtP: after BABIĆ & ZUPANIČ (2007). 5, MtP, this work. Logs from MtP refer to its main, southern part. LST, TST and HST are lowstand, transgressive and highstand (regressive) systems tracts, respectively. Small marks in the upper HST of logs 3 and 5 symbolise subcycles (schematically). For details see text.

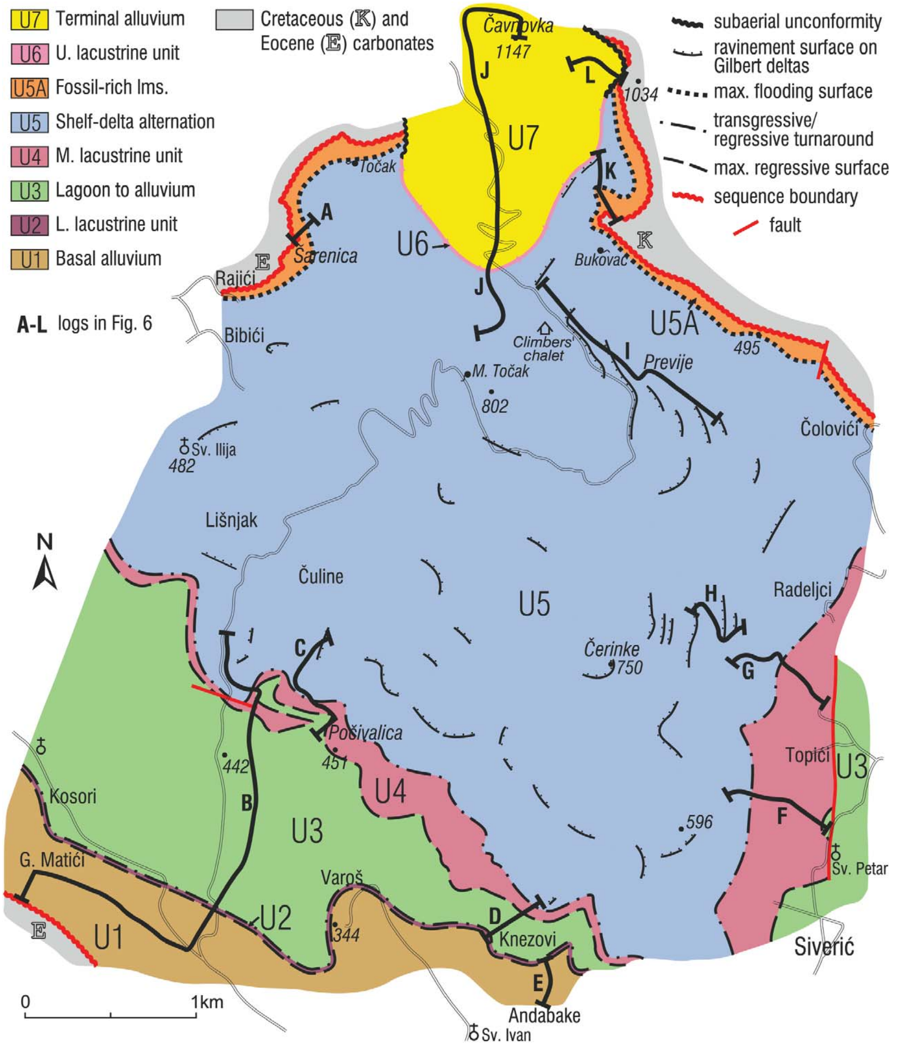

Figure 5: Geological map of stratigraphic units of the PB in MtP described here. Areas close to and including the Lower lacustrine unit (U2) is poorly exposed and structurally complex and its boundaries may be tectonised. Gilbert deltas are more numerous than presented. For discussion see text.

5.1. Basal alluvium (U1)

5.1.1. Description

Unit 1 is up to 400 m thick, starts above the Middle Eocene Foraminiferal Limestones and local bauxite deposits (Figs. 5, 6), and consists of two alternating facies associations. The first one is represented by sheet-like conglomerate bodies, up to several metres thick, and more than 100 m wide, which include lenses and thin intercalations of horizontally and cross-laminated calcarenites (Fig. 7/1). The conglomerates of these bodies are horizontally bedded to gently inclined, with b-axis imbrication pointing towards the S to SW, and are rarely, cross-bedded. They may be erosionally based with up to 40 cm deep scours, and may pinch out. The second facies association includes mudstones, calcarenites, and minor conglomerates. The mudstones may contain silt and calcarenite laminae, are bioturbated, and display rhizocretions, pedotubules, reddish mottling and pedogenic nodules. Calcarenites are up to 30 cm thick and either horizontally laminated, cross-bedded or current-ripple laminated. They commonly display plant debris, leaves, stems, and branches, as well as pedogenic alteration. Conglomerates and calcarenites rarely form less than 1 m thick channel-fills encased in calcarenites and mudstones. A few, up to 60 cm thick, matrix-supported conglomerates occur in the middle-upper part of the unit. Locally deformed bedding might represent traces of former tree stumps.

In contrast to the high predominance of Cretaceous and Middle Eocene lithoclasts typical for the PB as a whole, the upper part of the unit contains clasts of other formations. They include Triassic dark limestones and dolomites, similar carbonates which may be Jurassic and/or Permian in age, Eocene limestone breccias, as well as conspicuous Lower Triassic, violet sandstones and ooid grainstones. Some calcarenites are composed of 5-30% non-carbonate particles. There are also minor coated pebbles, oncoids, cylindrical stromatolites and stromatolite intercalations (Fig. 8). The later may include calcified cyanobacterial filaments, gastropods and ostracods.

5.1.2. Interpretation

The features of sheet-like conglomerate bodies suggest the activity of braided streams, characterised by longitudinal bars and intervening channels, with cross-bedded conglom-

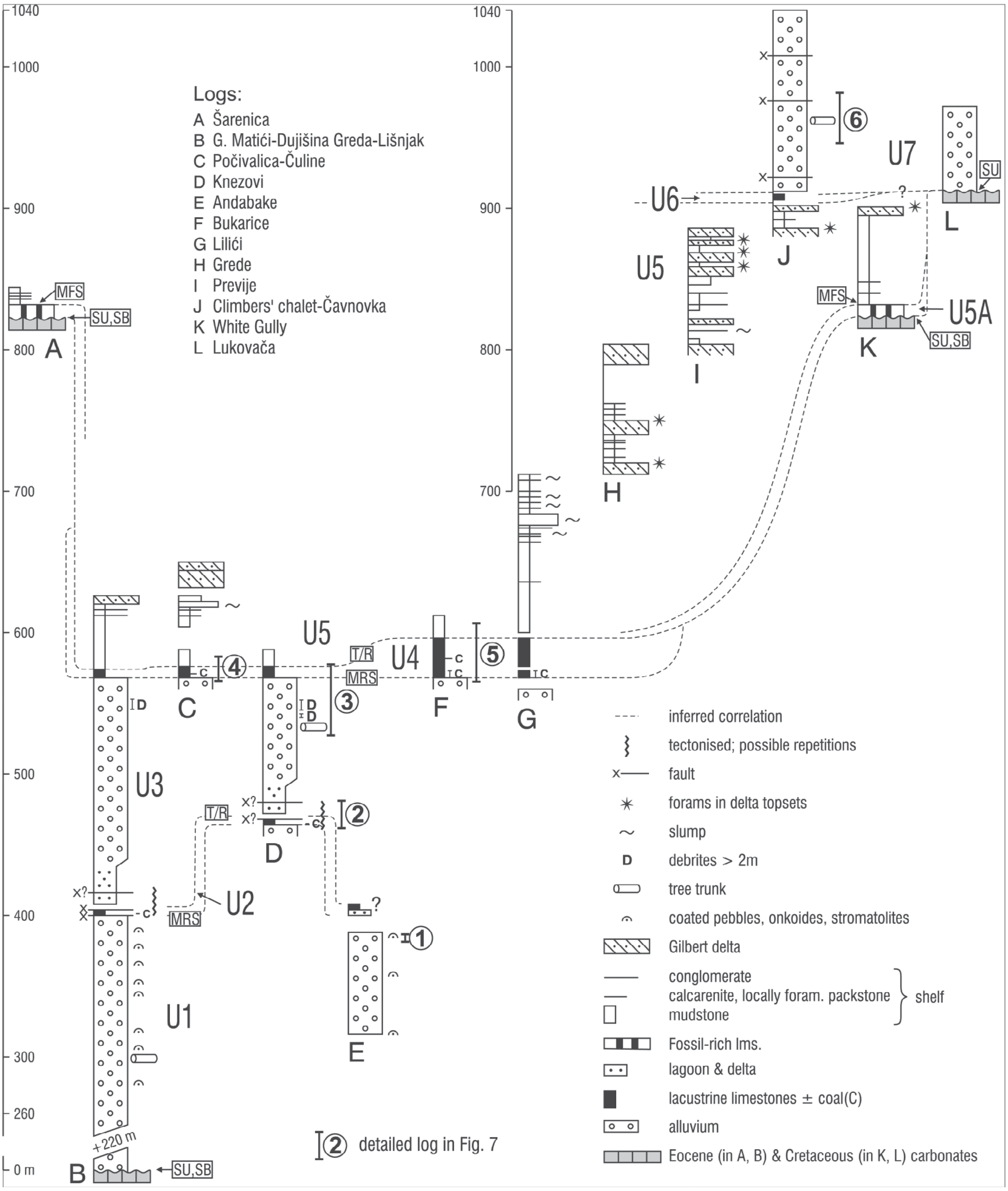

Figure 6: Successions of the PB in MtP. U1-U7, sedimentary units. SU, subaerial unconformity. SB, sequence boundary. MRS, maximum regressive surface. T/R, transgressive-regressive turnaround. MFS, maximum flooding surface. Some bodies assigned as Gilbert deltas may possibly represent beach deposits. For location see Fig. 5. For explanation see text.

erates deposited at fronts and/or flanks of the bars (reviews in COLLINSON, 1996; MIALL, 1996). Some calcarenites in these bodies are erosional relics, while others fill scours originated during the falling river floods. The sheets indicate wide channel belts. The second facies association originated in floodplains most of which have been vegetated as indicated by pedogenic alteration, and locally contained smaller channels. Laminated and cross-bedded calcarenite beds have been deposited by sheet-floods over the floodplains. The palaeotransport was directed towards the SSW. Rare debris-flow conglomerates possibly indicate a short-term proximity to alluvial fans.

Carbonate precipitation during the upper part of the unit took place in stream channels, while some stromatolite intercalations may indicate short-lived ponds (cf. ANADÓN & ZAMARREÑO, 1981). The precipitation was mediated microbially, as suggested by cyanobacterial filaments. These carbonates indicate a lot of available water and dense veg-

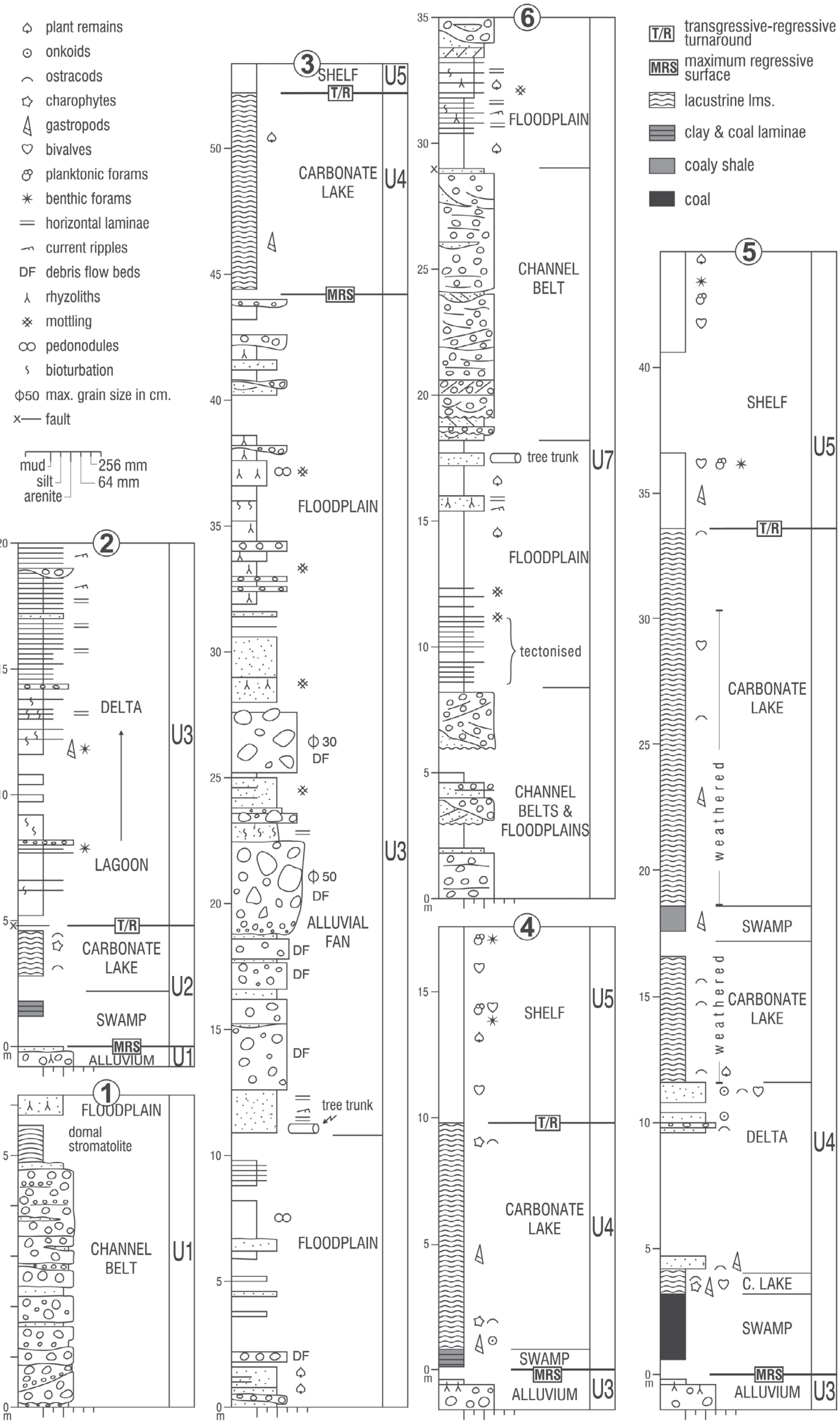

Figure 7: Illustrative segments of successions in Fig. 6. For vertical position of logs see Fig. 6.

Figure 8: Stromatolite intercalation in alluvial conglomerates of U1 is laterally (right) combined with protruding and domal forms. Lens cap is 4.4 cm in diameter. Sv. Ivan in Fig. 5.

Figure 9: Laminated lacustrine limestone of U2. Hammer is 32 cm long. Log D, 466 m in Fig. 6 (see also Fig. 7/2).

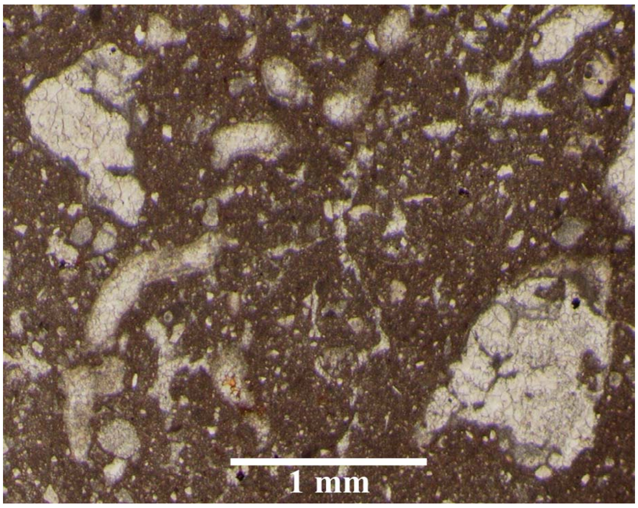

Figure 10: Floodplain palaeosol mudstone with calcite cemented tubes of former root hairs and partly developed alveolar-septal fabric (upper left and lower right). U3. Log B, 565 m in Fig. 6.

etation. NIKLER (1982) and MARKOVIĆ (2002) cite a thin coal seam ("3rd Bed" of miners), which seemingly belongs to the upper part of the unit. If so, a floodplain swamp also existed.

5.2. Lower lacustrine unit (U2)

Unit 2 (Figs. 5, 6, 7/2) includes a 0.2 m thick clay horizon with coal laminae containing gastropods, and overlying, laminated limestones, a few metres thick (Fig. 9), with ostracods, cyanobacterial filaments, characean encrustations and gyrogonites, gastropods, bivalves, and plant leaves. The clay with coal laminae is probably a lateral equivalent of the "2nd Bed" or "Lower Bed" of miners cited by NIKLER (1982), and MARKOVIĆ (2002).

The clay layer with coaly intercalations probably originated in a swamp. It was followed by a shallow carbonate lake characterised by microbial mats, and typical lacustrine biota (review in TUCKER & WRIGHT, 1990).

5.3. Lagoon to alluvium (U3)

5.3.1. Description

The thickness of Unit 3 varies from 80–150 m. Its lowermost part is either tectonised with possible small-scale repetitions, or covered by vegetation. It possibly includes an isolated outcrop ("?" in Fig. 6E), consisting of 3 m of marl and 1.3 m of stromatolites. Above the covered interval there is an alternation of mudstones, calcarenitic mudstones, and calcarenites which may contain very rare, smaller benthic foraminifera (Fig. 7/2). Minor conglomerate intercalations also occur. In the upper part of this segment, rhizoliths, nodular palaeosols, and plant remains become common, while foraminifera disappear. Conglomerates may show basal scours, and occasionally fill shallow channels oriented N-S. The thicker, upper part of the unit is laterally variable. It may be dominated by alternating sheet conglomerates with an average palaeotransport towards the South, and pervasively pedified calcarenites and mudstones (Fig. 10), thus resembling Unit 1. The upper part may also include a package of massive, poorly sorted, pebble to boulder conglomerates (Fig. 11), with clasts attaining 2 m in diameter and minor, pedified calcarenites (Fig. 7/3). Some of the later conglomerates show inverse grading in their basal part, and others have protruding large clasts at the top (Fig. 7/3). This sediment package forms prominent rocky walls on the SW mountain slopes.

5.3.2. Interpretation

A rare marine fauna, represented by smaller benthic foraminifera, contrasts its common occurrence in other shallow-

Figure 11: Detail of a debris flow unit. U3. Hammer is 32 cm long. Log B, 525 m in Fig. 6.

marine deposits of PB, and might reflect restricted marine conditions for the lower part of the unit, where clastics presumably derived from a river mouth. The setting was probably a lagoon. It subsequently evolved into a vegetated coastal plain, as suggested by pedogenic features occurring upwards. Hence, one might envisage a delta ("shelf delta" of ETHRIDGE & WESCOTT, 1984) prograding into the lagoon. This environment was followed by alluvial settings including floodplains and channel belts, similar to those in U1, as well as a local, interfingering alluvial fan(s) characterised by common debris flows. The isolated outcrop of marls and stromatolites possibly corresponding to the lowermost part of the unit could represent a local lacustrine episode following the lagoonal onset of the unit.

5.4. Middle lacustrine unit (U4)

5.4.1. Description

Unit 4 (Figs. 5 and 6) is laterally variable. To the SW (Figs. 7/3, 7/4) there is a discontinuous, up to 1 m thick clay horizon with lignite laminae and 8 m of brown limestones. The later are mostly laminated, and display cyanobacterial filaments, ostracods, bivalves, and gastropods, less characean encrustations and gyrogonites (Fig. 12a), and leaves. Packstones and wackestones with the same components also occur, as well as minor oncoidal limestones.

To the E, there is succession of coaly rocks, clastics, and limestones (Fig. 7/5) up to 34 m in thickness. Of two subunits of coaly sediments, the lower one is lignite, while the upper one is coaly shale with molluscs. Together they have been referred to as the "Main Bed" or "1st Bed" by miners (NIKLER, 1982; MARKOVIĆ, 2002). Limestones comprise three subunits. They are strongly weathered, except for a 4 m thick, upper segment which is similar to limestones in the SW area (Fig. 12b). Weathered sediments locally include stromatolites with molluscs, characean encrustations, gastropods, bivalves and ostracods, traces of carbonaceous material, as well as marly and clayey laminae and possible lacustrine chalk intercalations. Organic material was probably responsible for dissolution of much of the carbonate, and for the strong weathering. The sub-unit of calcarenites and conglomerates is 2 - 4 m thick. The calcarenites include lime-

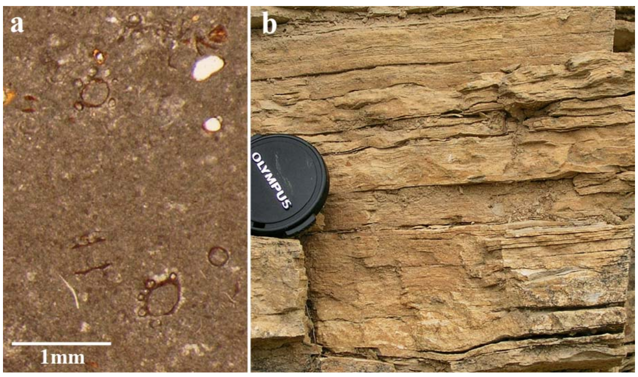

Figure 12: Lacustrine limestones of U4. (a) Thin section of mudstone with characean gyrogonites. Log C, 576 m Fig. 6. (b) Horizontally and wavy laminated limestone. Lens cap is 4.4 cm in diameter. Log F, 595 m in Fig. 6.

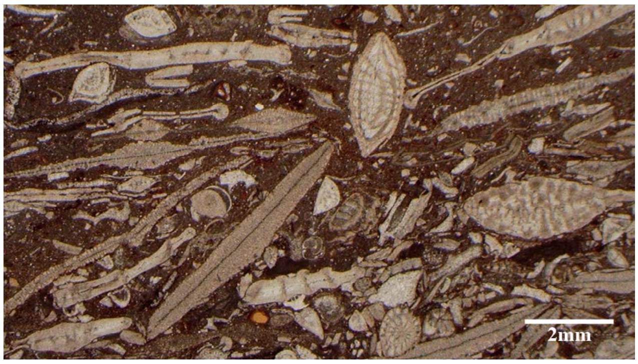

Figure 13: Bioturbated foraminiferal packstone from a tempestite intercalation in shelf mudstones. Tests of *Discocyclina, Operculina* and *Nummulites* (among others) are readily observed. U5. Log K, 844 m in Fig. 6.

Figure 14: Below the prominent bedding plane, calcareous mudstones with three calcarenite intercalations (CA), and one foraminiferal packstone (F) are visible. Above, there is a 14 cm thick calcarenite overlain by a debris flow conglomerate. U5. Lens cap is 4.4 cm in diameter. Log G, 668 m in Fig. 6.

stone clasts, coated grains, stromatolite fragments, ostracods and mollusc debris, and 5–30% non-carbonate particles. Pebbles in the conglomerates may be coated by microbial laminae.

5.4.2. Interpretation

The lignite (NIKLER, 1982) originated from peat accumulated in forest swamps (e.g. TUCKER, 2001). Hogs and crocodiles (KERNER, 1901) inhabited such environments. Laminated limestones including microbial laminae originated in carbonate lakes (review in TUCKER & WRIGHT, 1990), and the same is true for weathered carbonates. A transitional setting with seasonally(?) alternating swamp and lake conditions resulted in alternating carbonate and carbonaceous laminae. As the clastic sub-unit lacks typical marine biota and is associated with lacustrine and swamp deposits, it may represent a lacustrine delta episode.

5.5. Shelf/delta alternation (U5)

5.5.1. Description

Unit 5 is up to 300 m thick and wedges out laterally (Figs. 5, 6, 24, 26). It starts with marls, which contain common plant debris and leaves, smaller benthic and planktonic foramin-

Figure 15: A 2 m thick slump unit involved alternating calcarenites and mudstones, which also occur below and above the slump. U5. SW slope of MtP.

Figure 16: Most of the prominent rocky walls are formed by conglomerate-dominated bodies including bottomset, foreset and topset beds of Gilbert deltas. Some of these bodies possibly originated as beach deposits. They alternate with intervals of shelf deposits which are mostly covered by vegetation. U5. The thickest body (up to 12 m) in the middle shows left-inclined traces of foreset beds. Log H in Fig. 6 includes sediments of the lower and middle parts of the photo (between 740 and 804 m).

ifera, and scattered molluscs (Figs. 7/4, 7/5), and may be dark at the very base. Upwards, mudstones may be intercalated by bioturbated lime packstones (Fig. 13) up to 8 cm thick containing larger foraminifera (e.g. *Operculina, Discocyclina, Nummulites, Asterigerina, Sphaerogypsina*), smaller benthic and planktonic foraminifera, molluscs, corallinaceans, rare *Microcodium* debris, and limestone clasts. These are overlain by an alternation of mudstones, thin, graded, and horizontally laminated calcarenites, slumps including mudstones and calcarenites, massive, graded, and inverse to normally graded conglomerates, and foraminiferal packstones (Figs. 14, 15). The calcarenites may be rich in plant debris and leaves, and may contain foraminifera. There are also up to 2 m thick packages of mudstones intercalated with calcarenite laminae which contain plant material. In a restricted area (Čolovići, Fig. 5) intercalations of specific massive conglomerates can be seen, which include clasts of limestone breccia, bored pebbles, molluscs, corals and benthic foraminifera. They disappear basinwards.

The main part of the unit consists of (A) lensoid, mainly conglomeratic bodies consisting mostly of bottomset, foreset and topset beds, and (B) a heterogeneous facies of alternating mudstones, calcarenites, and lesser conglomerates, which displays features similar to the lower part of the unit. Lensoid bodies appear either isolated within the heterogeneous facies, or closely stacked vertically and/or laterally (Fig. 16). Towards the NE, the unit becomes thinner, highly dominated by mudstones, and includes only one lensoid body (Fig. 6K).

The bottomsets of the lensoid bodies include up to 50 cm thick, massive conglomerates, and up to 30 cm thick, horizontally laminated calcarenites, locally rich in plant debris and leaves. Both of them may wedge out (Fig. 17). Foresets are 4–15 m thick (Fig. 18), with most common inclina-

Figure 17: Toeset to bottomset transition of a Gilbert delta. Debris flow conglomerates alternate with laminated calcarenites. The prominent conglomerate wedge thinning from left to right is a termination of a flow tongue. U5. Between logs I and J, about 875 m in Fig. 6. Hammer is 32 cm long.

Figure 18: Up to 15 m high delta foresets. U5. Log I, about 865 m in Fig. 6.

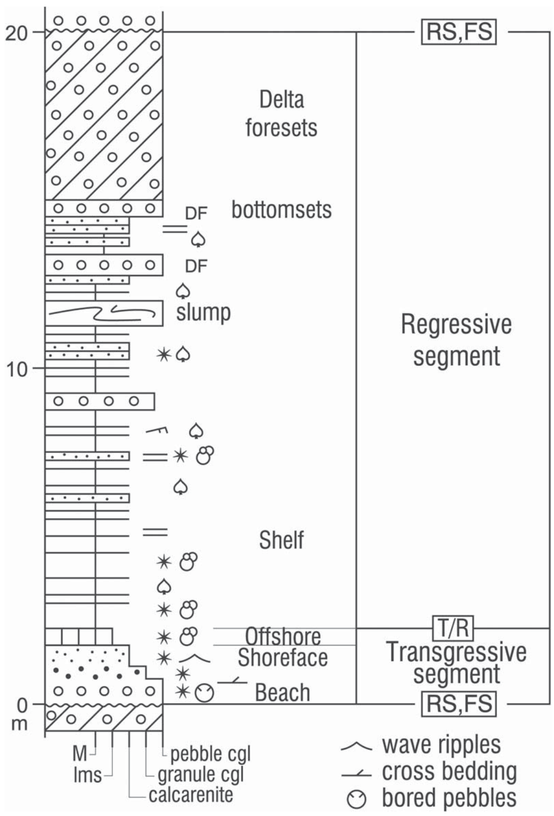

Figure 19: Ideal shelf-delta cycle (subcycle), i.e. lower order T-R sequence, based on examples from MtP. Variants of this sequence constitute U5 (=Shelf-delta alternation). RS, FS are transgressive ravinement, and flooding surfaces, respectively. T/R: transgressive/regressive turnaround. For symbols not explained above, see Fig. 7. For discussion see paragraph on sedimentary cycles.

tions of 15° to 26°. Directions of inclinations are scattered between N and S with an average direction towards the WSW. They include massive to crudely stratified conglomerates, and occasional calcarenites. The foresets are unconformably overlain by up to 30 cm thick conglomerates and/or calcarenites, which may display fining upward successions (Fig. 19). An exemplary section includes an imbricate conglomerate with a transport direction towards the ENE which is followed by a cross-bedded conglomerate bed, a one pebble thick layer, and a wave-rippled calcarenite. The clastic topsets may be overlain by 1 to 30 cm thick limestones (Fig. 20). Both the clastic topsets and limestone may contain benthic foraminifera and molluscs. Lensoid bodies may be distorted and/or faulted at their margins, and broken into rotated blocks.

5.5.2. Interpretation

The lowermost part of the unit reflects a shelf setting based on muddy sediments with smaller benthic and planktonic foraminifera. Local, dark mudstones of the very base have presumably been deposited in a restricted (lower salinity?) environment, related to initial, marine ingression into previous, lacustrine areas. Subsequently, the shelf became influenced by occasional, storm-related processes, which collected and concentrated particles from both the marine (e.g. foraminifera) and subaerially exposed (e.g. *Microcodium*) areas, and deposited them as tempestite lime packstones. Graded and laminated calcarenites may have resulted from surge-type flows, while segments of alternating mudstone/calcarenite laminae might reflect fluctuating hyperpycnal flows. Both processes were presumably related to river floods. The modifying influence of storms inferred for correlative sediments in other parts of the Promina basin (BABIĆ & ZUPANIČ, 2007) has not clearly been recognised in these calcarenites. Conglomerates have been deposited by debris flows and high density turbidity currents which may be related to delta slope failures (see below). Local intercalations of fossiliferous, massive conglomerates (Čolovići) are debris-flow deposits, possibly derived from a locally existing, fault-bounded coast.

The origin of the majority of lensoid bodies (A) is related to processes operating in Gilbert-type deltas (cf. POSTMA & ROEP, 1985; MASSARI & COLELLA, 1988; NEMEC, 1990; CHOUGH et al., 1990; POSTMA, 1990). They prograded by accretion of steeply inclined, mass-flow conglomerates over bottomset beds, which in turn, overly shelf sediments (Fig. 19). The bottomset conglomerates indicate deposition from debris-flows originating from delta slope failure events (cf. POSTMA & ROEP, 1985; POSTMA et al., 1988), while associated, upper plane bed calcarenites may have been deposited from hyperpycnal flows related to river floods (e.g. PRIOR & BORNHOLD, 1990). Truncation surfaces, and clastic topsets with marine fossils reflect marine erosion, reworking, production of a transgressive lag, probable beach deposits (pebble-thick units), probable bars (cross-beds), and shoreface sands (wave ripples). The fining upward trend suggests an upward decreasing marine energy and increasing depth. This was followed by deposition of limestone, probably still farther from the shoreline. Marine topsets are well known from Gilbert deltas (e.g. MASSARI & COLELLA, 1988; POSTMA & CRUICKSHANK, 1988), including those reported from other parts of the Promina basin (POSTMA et al., 1988; ZUPANIČ et al., 1987, 1988; BABIĆ & ZUPANIČ,

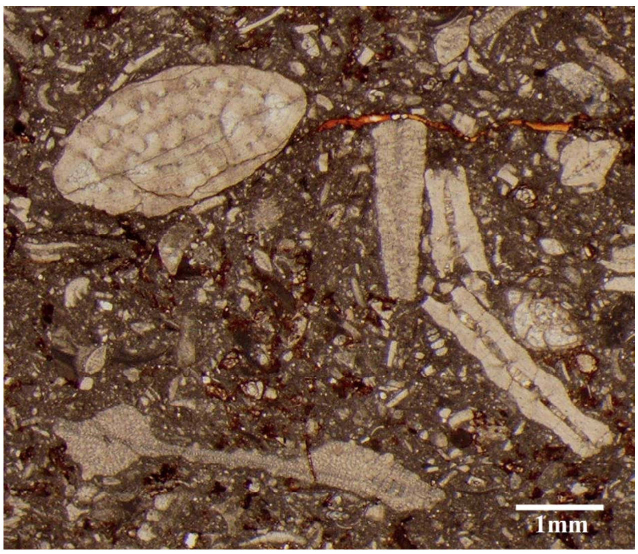

Figure 20: Bioturbated foraminiferal packstone with *Nummulites, Discocyclina, Operculina* and *Asterocyclina* of the Gilbert delta topsets. U5. Log H, 752 m in Fig. 6.

1990, 2007). Such marine topsets differ from those originally described as fluvial topsets (GILBERT, 1885). The similarity of the heterogeneous facies (B) to the lower part of the unit suggests a shelf setting influenced by sediment supply from rivers and delta slope failure events. The origin of the alternation of (A) and (B) facies associations is discussed in sections 6.1.3.2. and 6.2.

Aside from the lensoid bodies discussed above, there are conglomerate lensoid bodies which probably represent beachface deposits comparable to those described by MASSARI & PAREA (1988) from the Apenninic Pleistocene. Their "foreset" beds display lower inclination angles, while their other features are generally poorly visible and they are not discussed further.

Deformation of the lensoid bodies was probably related to instability of deltaic systems. Instability events may have been the result of seismic activity at the basin margin, which could also be the case for common slumping, as well as common delta slope failures.

5.6. Fossil-rich limestones (U5A)

Unit 5A consists of up to 10 m thick, poorly bedded limestones which overly Eocene and Cretaceous platform carbonates, local bauxites, and sporadic carbonate breccias and conglomerates. The unit is restricted to the N part of the study area (Figs. 5, 6). The limestones are bioclastic packstones, rudstones and wackestones, and include larger foraminifera (e.g. common *Discocyclina*), smaller benthic foraminifera, bivalves, corals, gastropods, echinoids, and corallinaceans. Glauconite and planktonic foraminifera are found on top of the limestones, just below the marls of U5 (Figs. 21, 22).

The rich shallow-marine biota suggest shallow-marine, carbonate environments established above former terrestrial areas, while glauconite and planktonic foraminifera at the top of the unit imply sediment starved conditions at the transition to overlying shelf marls of U5.

Figure 21: Poorly bedded sediments of the fossil-rich limestones (U5A) (below geologist) are overlain by a 60 cm thick condensed unit (below geologist's hand) of packstones and wackestones with glauconite. The later are overlain by regressive shelf mudstones with calcarenite intercalations (U5). NE part of MtP (between point 495m and Bukovac in Fig. 5).

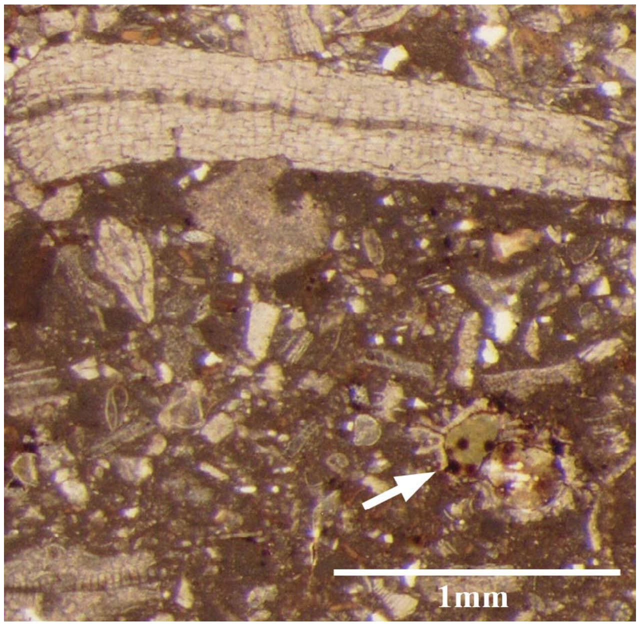

Figure 22: Foraminiferal packstone of the condensed horizon in Fig. 21 includes green glauconite (arrow).

5.7. Upper lacustrine unit (U6)

Small, isolated outcrops, which might be one to a few metres thick, occur within a smaller area on the SW slope of the mountain, between units 5 and 7. Unit 6 is not reliably identified along the entire line shown on the map (Fig. 5), and it possibly pinches out landwards. The outcrops include lime wackestones and mudstones with characeans, ostracods, molluscs, probable cyanobacterial filaments, and plant leaves. These features reflect deposition in a shallow carbonate lake (review in TUCKER & WRIGHT, 1990).

5.8. Terminal alluvium (U7)

5.8.1. Description

Outcrops of unit 7 display sheets of massive to crudely bedded conglomerates (Figs. 7/6 and 23), which include calcarenite lenses. They alternate with packages consisting of horizontally laminated, cross bedded and current-rippled calcarenites and mudstones. B-axis imbrication in conglomerates points towards the W to SW. The sheets may include cross-bedded conglomerates. Many mudstones and some calcarenites display reddish mottling, rhizocretions, and pedogenic nodules (Fig. 7/6). Plant remains are common in the mudstones and calcarenites, which include a reworked tree trunk replaced by calcarenite. Calcarenites containing up to 30% non-carbonate particles are exceptional, as well as conglomerates including isolated sandstone clasts. There are also shallow scours filled by conglomerates. In the NE part of the study area, the unit overlies U5A and the Cretaceous basement (Figs. 5, 6) (for discussion see section 6.1.3). The total thickness of U7 is about 120 m.

Figure 23: Crudely bedded conglomerates deposited in a longitudinal bar of a braided system. U7. Hammer is 32 cm long. Log J, 965 m in Fig. 6.

5.8.2. Interpretation

Sheet conglomerates may have originated in braided channel belts, while the association of calcarenites and mudstones reflects deposition in vegetated floodplains. The depositional processes and environments resemble those of U1 and uppermost U3. Similar alluvial sediments have been described from the continuation of this unit, in the NW part of the basin (Fig. 4).

6. DISCUSSION

6.1. Depositional cycles

The vertical succession(s) of sedimentary units of the PB of MtP described above shows a cyclicity related to variations in accommodation space and sediment supply, which is the objective of sequence stratigraphic analysis, as defined by POSAMANTIER & ALLEN (1999). Three main cycles have been recognised, in which the sedimentary units are treated as sequence stratigraphic units (Fig. 24).

6.1.1. Cycle I (U1)

The unconformity and coincident sequence boundary, which separate Middle Eocene carbonates and Basal alluvium (U1), extend basinwards, away from MtP, by truncating lower, marine PB (older than PB at MtP), with a distally diminishing hiatus (Fig. 25A) (BABIĆ & ZUPANIČ, 2007). Still farther basinwards, there is an erosional surface interpreted as the basal surface of forced regression of HUNT & TUCKER (1992) which is overlain by forced regressive sediments (MRINJEK, 2008). It seems to represent a distant continuation of the basal sequence boundary at MtP. The Basal alluvium (U1) therefore, might have been deposited during the relative sea-level rise of the late lowstand by onlap onto the deformed basement (Fig. 25A). A high water table during the upper part of the unit (section 5.1) may be related to high sea-level, which continued to rise further during the next cycle.

In the NW part of the Promina basin, alluvial deposits of similar stratigraphic position have not been recognised (MRINJEK & PENCINGER, 2008), and Cycle I of MtP possibly continues laterally and seaward into alternating shelf and shoreface deposits reported by these authors.

6.1.2. Cycle II (U2, U3)

The origin of swamp and carbonate lake environments (U2) above former alluvium (Cycle I; Fig. 25B) must have been related to a rise of the water table and related sea-level, which were already high. Namely, the rising base level will concomitantly raise the groundwater table, and cause poorer drainage in alluvial systems, which lead to widespread development of swamps and lakes (SHANLEY & MCCABE, 1994). The process also caused a landward shift of alluvial systems. The coastal lowlands with lacustrine environments were subsequently submerged becoming a lagoon (lower U3) by further rise of relative sea-level. The base of Cycle II, therefore, corresponds to the transgressive surface of sequence stratigraphic systematics (POSAMANTIER & VAIL, 1988; POSAMANTIER & ALLEN, 1999). This type of stratigraphic surface is typically formed by marine ravinement processes, while in our case, the onset of the low-energy settings of swamps and lakes didn't cause reworking and/or erosion, hence, the relevant boundary may be better termed maximum regressive surface (HELLAND-HANSEN & MARTINSEN, 1996). While the carbonate lake above the swamp deposits (U2) reflects an increase in the rate of relative sea-level rise compared to sedimentation rate, i.e. a transgression, the subsequent lagoon-delta-alluvium succession (U3) displays an overall progradation related to an increased sedimentation rate compared to relative sea-level rise, i.e. a regression. Transgressive to regressive turnaround may be located at the top of lacustrine limestones, while maximum flooding might correspond either also to this surface or it occurs a little bit higher

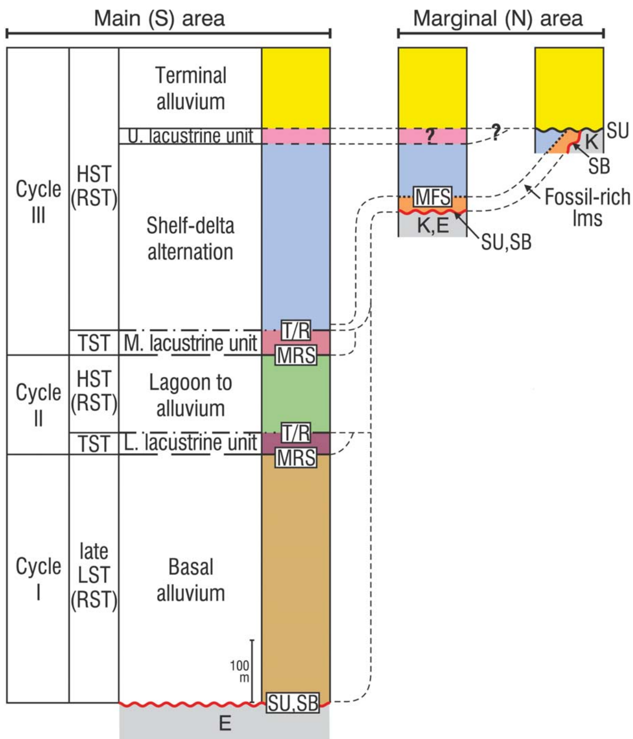

Figure 24: Stratigraphy of the PB of the main (southern) and marginal (northern) parts of MtP. K and E are Cretaceous and Eocene carbonates, respectively. Thickness of lacustrine units and Fossil-rich limestones (U5A) is exaggerated. For explanation see text.

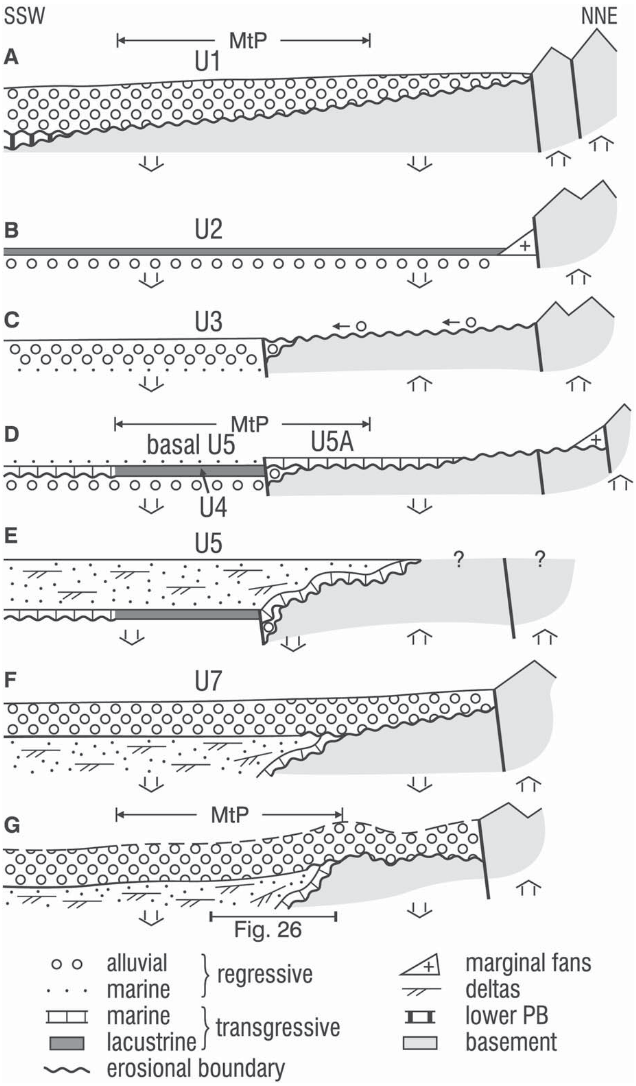

Figure 25: Evolution of the inner part of the Promina basin including MtP area. U1 to U7 are sedimentary units. Fig. D shows correlation of lacustrine TST (U4) in MtP and marine TST basinwards. The same figure includes the proposed correlation of transgressive fossil-rich limestones (U5A) and the basal, dark, muddy part of the shelf-delta alternation (U5). In Fig. G, dashed line at the top of alluvial sediments (U7) highlights the youngest deformation (it marks neither the top of the unit nor a depositional surface). Thick arrows indicate relative movement of tectonic units. Not to scale. For explanation see text. See also Figs. 26 and 28.

(see discussion by CATUNEANU, 2006). Possible repetition of lake and lagoonal sediments at the very base of the cycle, might suggest the presence of a small, transgressive-regressive subcycle before the onset of the main part of the succession discussed above.

In general (Fig. 24/Main area), the lower part of Cycle II (U2) corresponds to the transgressive systems tract of the sequence stratigraphic approach (e.g. POSAMANTIER & VAIL, 1988; POSAMANTIER & ALLEN, 1999; CATUNEANU, 2006), and its upper part may be designated either as a highstand or a regressive systems tract. The first choice considers a depositional sequence of POSAMANTIER & VAIL (1988), which would consist of a lowstand tract (Cycle I) and a transgressive plus highstand tract (Cycle II). The later option considers Cycle II as a transgressive-regressive (T-R) type of sequence (EMBRY & JOHANNESEN, 1992; EMBRY, 2002), with the sequence boundary coinciding with the maximum regressive surface.

In other parts of the basin, the lower part of Cycle II can not be clearly identified. In the NW basin area, it is possibly represented by shelf to shoreline cycles reported by MRINJEK & PENCINGER (2008). In contrast, its upper, alluvial part, as well as its termination at the transgressive surface is easily recognised throughout most of the basin (BABIĆ & ZUPANIČ, 2007; Fig. 4).

6.1.3. Cycle III (U4-U7)

6.1.3.1. Lower part (U4). The transition from Cycle II to Cycle III resembles the transition from Cycle I to Cycle II in the change from alluvial to lacustrine deposition (U4) at the maximum regressive surface (Fig. 24/Main area). At this point, the increase in accommodation space surpassed the sedimentation rate, but didn't yet enable a marine ingression (see discussion on Cycle II, section 6.1.2). This surface and the overlying Middle lacustrine unit (U4) in MtP correlate basinwards with the transgressive surface (= ravinement surface = transgressive surface of erosion of POSAMANTIER & VAIL, 1988; POSAMANTIER & ALLEN, 1999), and the overlying TST consisting of wave-worked clastics and limestones (BABIĆ & ZUPANIČ, 2007)(Figs. 4, 25D). Hence, the Middle lacustrine unit (U4) is regarded as a non-marine, proximal segment of the transgressive tract.

Where U4 consists of several smaller units of swamp, carbonate lake, and lacustrine delta (Fig. 7/5), this may reflect very restricted, short-term changes in the relationship between accommodation space and sedimentation within the overall transgressive trend.

6.1.3.2. Middle part (U5, U5A*)*. The change from lacustrine to shelf/delta settings marks the onset of progradation, i.e. the onset of a highstand or regressive systems tract. Maximum flooding may be regarded as occurring within basal mudstones (a few metres thick), with benthic and planktonic foraminifera (BABIĆ & ZUPANIČ, 2007) (Fig. 6). The sea flooded not only previous lacustrine realms, but also spread farther landwards (NNE), which resulted in the coastal onlap of fossil-rich limestones (U5A) onto the basement, and related subaerial unconformity (Figs. 5, 6A, 6K, 24, 25D). KERNER (1901) placed these limestones at the base of the PB, while for QUITZOW (1941), they are a coastal equivalent of mudstones (equivalent here to the lowermost U5). Deposition of these limestones ended with sediment starvation, i.e. maximum flooding (Figs. 21, 22).

Alternating shelf and delta deposits (U5) reflect repetitions of lower order cycles or subcycles, within an overall trend of rising relative sea-level. A "modal" subcycle of this type consists of two parts (Fig. 19). The transgressive part starts above a ravinement surface, and includes a fining upward succession reflecting decreasing marine energy levels associated with landward shift of facies, and limestones which may be regarded as a condensed section related to maximum flooding. This part reflects increasing accommodation space and decreasing sediment supply. The regressive part embraces shelf deposits and overlying delta. Repetition of such T-R cycles or subcycles was related to an overall relative sea-level rise, which was punctuated by stillstands when deltas prograded (POSTMA, 1995). The driving factors are discussed in section 6.2.

Lower delta bodies appear isolated in shelf sediments, and are only exceptionally closely superimposed or juxtaposed, while deltas higher in the succession are more densely distributed (Fig. 6). This suggests a gentle, average upward decrease in overall relative sea-level rise.

6.1.3.3. Upper part (U6, U7). As neither lateral continuity, nor bounding surfaces of the Upper lacustrine unit (U6) have been identified, one can only speculate on possible trends. The first scenario envisages a continuation of an overall regression, from previous shelf to delta (U5), to the coastal-plain and/or delta-plain lakes (U6), and to the alluvium (U7). The later display a landward onlap (Figs. 24, 25F, 26), and the conditions would correspond to the late highstand of POSAMENTIER & ALLEN (1999). A second scenario includes a smaller fall in relative sea-level which ended marine deposition, provoked erosion (not identified as yet) and the origin of a sequence boundary (*sensu* POSAMENTIER & ALLEN, 1999). Subsequent lacustrine and alluvial deposits would correspond to the late lowstand. This scenario implies the end of Cycle III and the onset of a new cycle at an envisaged unconformity i.e. sequence boundary. In the third scenario, the lake(s) succeeded deltas, and were followed by the sequence boundary and alluvium. This would imply the end of Cycle III and the onset of a new cycle, at the base of the alluvium (U7). The first scenario is favoured, however, with only modest support by the presumable lack of sediments deposited during relative sea-level fall.

As a whole, and if the favoured scenario is accepted, Cycle III consists of transgressive and regressive segments (Fig. 24) which might be denoted either as transgressive and highstand systems tracts or as the transgressive-regressive sequence as discussed for Cycle II (section 6.1.2).

6.1.3.4. Other parts of the basin. Cycle III extends along the entire Promina basin. Marine TST represented by wave-worked clastics and fossiliferous limestones, which replaces lacustrine TST (U4) of MtP basinwards (Figs. 4, 25/D), also occurs in the distant, NW basin area (Fig. 4) where MRINJEK & PENCINGER (2008) describe a transgressive tract consisting of mudstones with rare calcarenites (at the base of their Unit 4). These deposits, however, belong to the lower part of the subsequent, regressive unit, which is similar in character across the entire Promina basin (BABIĆ & ZUPANIČ, 2007), and corresponds to U5 in MtP. Similarity in the sedimentary evolution along the basin is also shown by reconnaissance data on lacustrine sediments occupying the same stratigraphic position in the NW basin area as they do on MtP (U6), i.e. between marine and alluvial units (U5 and U7 on MtP). Other features, identical for both MtP and the 80 km long NE basin margin, include marine and alluvial onlaps (U5A and U7 on MtP), both of which are related to an unconformable surface above bauxite deposits and the Cretaceous to Eocene basement (BABIĆ et al., 1995). This indicates a similar stratigraphy along the inner basin margin.

6.2. The main controls on sedimentary evolution

Structural and stratigraphic relationships, together with other features described above, as well as the available data from other parts of the Promina Basin, are used in an attempt to detect which factors were dominant in the sedimentary evolution of the basin margin.

Deposition of PB in the study area was preceded by important deformation, which was responsible for a major basinward shift of the shoreline, i.e. the subaerial exposure of a major part of the basin. The subsequent onlap by a thick, dominantly coarse-grained alluvial unit (U1) regarded as corresponding to the late lowstand conditions (see 6.1.1, Fig. 25A), reflects a high sediment supply from a mountainous catchment area in the orogen. This and the vertical change in the detritus composition may suggest active tectonics during deposition. The upper part of U1 contains additional, older detritus compared to its lower part (section 5.1.1.). The change does not seem to have been caused solely by the erosion of deeper basement rocks and lowering of relief, as the average grain size didn't decrease. It is proposed that a near-continuous tectonism in the catchment area had a direct sedimentary response in the form of a thick, coarse-grained alluvial unit (Fig. 25A) in the subsiding basin. The conditions might have been similar to those proposed for some fan-delta wedges in the Ebro foreland basin, Spain, where the depositional dynamics are regarded to have been principally influenced by high sediment supply related to continuous tectonic activity (LOPEZ-BLANCO et al., 2000; MARZO & STEEL, 2000).

The origin of the subsequent lacustrine TST (U2), which is presumably replaced basinwards by a marine TST (section 6.1.2, Fig. 25B), may be related to a backtilting of the proximal part of the basin, which generated a "ponded" area, isolated from direct marine influence. This might have occurred by a tectonic pulse which caused increased subsidence rates and a landward shift of coarse-grained sedimentation, as proposed in models by HELLER et al. (1988) and BURNS et al. (1997). A similar effect might have resulted from a eustatic rise, which accelerated relative sea-level rise in the proximal part of the foreland basin characterised by increased subsidence rates compared to the distal part (POSAMENTIER & ALLEN, 1993). The sharp, but non-erosive transition from the coarse-grained alluvial to lacustrine settings seems to favour the fast tectonic process as dominant.

The subsequent regressive unit (U3) doesn't seem to have been deposited in the N area, and lower units (U1, U2) are also lacking there. Alternatively, the latter could have been deposited in that area, at least in small thickness, and were erosionally removed from the uplifting block and resedimented basinwards (Fig. 25C). The rarity of older detritus types, which were quite common in the upper part of U1, may be explained by an important contribution from the denudation of the Cretaceous and Eocene basement uplift, additional contribution

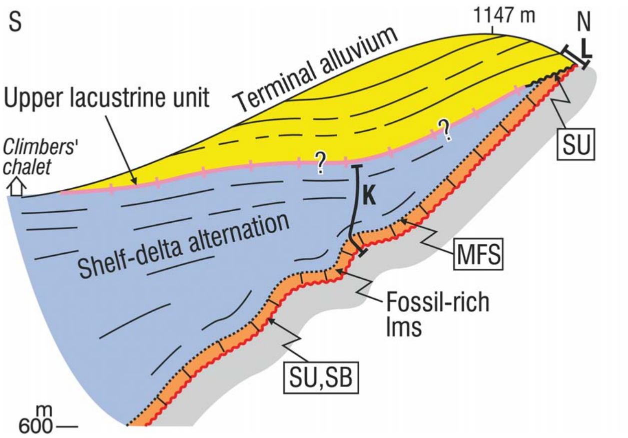

Figure 26: Geological sketch of the northern MtP (view towards the W), showing the complex stratigraphy and structure of the basin margin. Lower part shows growth folds with associated growth strata. They were subsequently deformed again and cut by an angular unconformity at their N end (SU, upper right). The youngest deformation involved the entire succession. Thickness of fossil-rich limestones is exaggerated. Symbols as in Fig. 24. Length of the area is about 1.5 km. K and L are locations of two logs in Fig. 6. Point 1147 m is the top of MtP. Based on field data and photographs. See also Fig. 28.

from the hinterland, and a partial transfer to the distal basin. A laterally impersistent alluvial fan(s) indicates local, more intense, short-term fault activity within the uplift or at its margin. The envisaged situation is partly similar to the "post-orogenic phase" of HELLER'S et al. (1988) two-phase model of foreland-basin sequences, in which reworked, coarse deposits in distal foreland basin correlate with erosion and an unconformity in the proximal part of the basin. However, the syndepositional faulting inferred to be related to the origin of coarse-grained alluvial fans, may have been a part of a near-continuous tectonic loading and subsidence, reflected in the dominant role of high sediment supply in generating the regressive trend (as previously discussed in relation to U1).

Abrupt termination of the alluvial deposits (U3), and the following lacustrine TST (U4) resemble the transition from the alluvial U1 to lacustrine U2, and are considered to reflect the same main driving process. These include a tectonic pulse, which was responsible for backtilting and the development of lacustrine TST in the proximal part of the basin, and marine ravinement with marine TST in its distal part (Fig. 25D: left, lower part). As this transgressive trend characterises a major part of the basin (Fig. 4; BABIĆ & ZUPANIČ, 2007), local and/or intrinsic processes were not critically relevant. At the local scale however, gentle tectonism may have been influential, as suggested by the lateral difference in sedimentary succession and thickness of U4 (Figs. 6, 7/3, 7/4, 7/5) which resulted from small-scale, syndepositional downwarping. Subsequently, there was a short transitional evolutionary interval, when the very beginning of the regression correlates with marine onlap onto the basin margin (basal U5 and U5A; Fig. 25D: upper left and right).

During deposition of U5 the proximal part of the basin experienced complex processes and specific changes which include the origin of growth folds and associated growth strata, and proximal-distal difference in the character and thickness of the unit (Figs. 5, 6, 24, 25E, 26). These processes were probably related to advancing thrusts which increased subsidence rates and induced an overall relative sea-level rise. As the average WSW direction of the progradation of deltas (with a variation between N and S) contrasts S to SW palaeotransport directions in U3 alluvium, a major part of the detritus appears to have been supplied from source areas which appeared roughly ENE of today's MtP (diagonal to the section in Fig. 25E) (Fig. 27). The envisaged structural bending was possibly combined with dextral, transpressive faulting which might represent an earlier stage of the large, diagonal fault system, which today passes several kilometres E of MtP (CHOROWICZ, 1977).

The modulation of overall relative sea-level rise during U5, by lower-order relative sea-level changes, which produced lower-order T-R cycles (section 6.1.3.2.), may have resulted from episodic subsidence along the marginal fault(s). This is in agreement with the opinion that vertical stacking of Gilbert deltas reflects high subsidence rates close to tectonically active basin margins (COLELLA, 1988; GAWTHORPE & COLELLA, 1990; DORSEY et al., 1995). Moreover, the model for Gilbert delta stacking in the Loreto Basin, Baja California Sur by DORSEY et al. (1997) relates alternating episodes of rapid subsidence and transgressions with closely repeating slips along marginal faults which induced earthquake clustering, while deltas prograded during tectonic stillstands. This model may be relevant for the examples on MtP. However, local differences in sediment supply and intrinsic factors such as switching of delta lobes may have induced the origin of some T-R sequences. In general, the overall regressive trend of U5 together with its internal T-R dynamics may have been dominantly induced by the combination of subsidence and sediment supply.

Before or at the very beginning of U7, the marginal part of the basin experienced uplift and erosion which involved deformed carbonate basement, U5A, U5 and U6(?) of that area. The resulting truncation surface was onlapped by alluvial U7 and also represents an angular unconformity, which quickly dies out basinwards (SSW) (Figs. 25F, 26, 28). It corresponds to the "progressive and angular unconformity" described by RIBA (1976) from the SE Pyrenees, where it

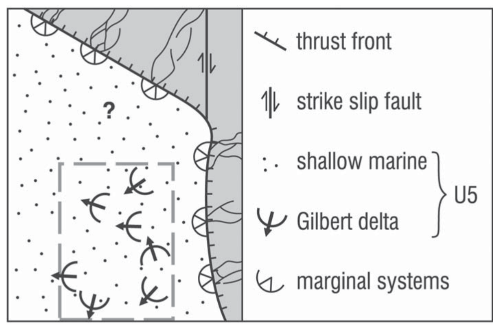

Figure 27: Presumed position of MtP (framed) relative to hypothetical basin margins during deposition of the shelf-delta alternation (U5). Symbols for deltas show representative directions of their progradation. Deltas belong to different time intervals. The average WSW progradation is assumed to indicate the existence of N-S and NNW-SSE oriented basin margin. Not to scale. For details see text.

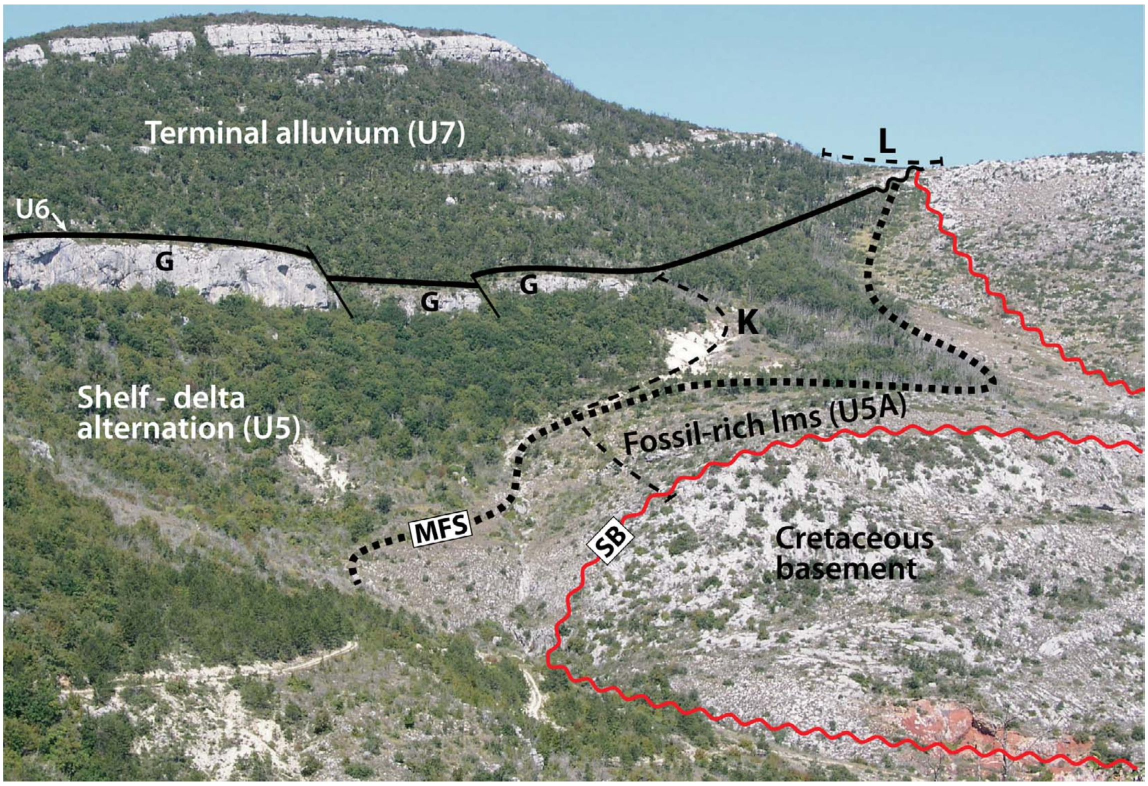

Figure 28: View towards the N looking upon the SE (left) and S (right) slopes of northeastern MtP. Cretaceous basement and fossil-rich limestones (U5A) in the lower right constitute a smaller anticline inclined S, towards the viewer, and gently plunging left (W, into the mountain). Two gullies in the middle show mudstone-dominated shelf deposits (U5), which were involved in the folding in their lower part. G, Gilbert delta; highest wall (15 m) shows foresets steeply inclined towards the left (SSW). U6 (Upper lacustrine unit) has not been clearly identified in this area. Unconformity in the upper right is restricted to this proximal area, where it cuts previously deformed units, and was later involved in deformation. Logs K and L are shown in Fig. 6. See also Fig. 26. For further explanation see text.

may represent part of a series of synsedimentary unconformities related to deformational pulses (RIBA, 1976; FORD et al., 1997).

The present-day thickness and extent of regressive U7 on MtP resulted from considerable denudation during the Neogene to Recent (Figs. 5, 6). Based on data from neighbouring and other parts of the basin this unit assumed a thickness of more than 300 m and extended about 5 – >10 km basinwards (Fig. 4/3; BABIĆ et al., 1995). This suggests that the regressive trend of this unit was dominantly induced by a high sediment supply. It was presumably related to near-continuous tectonic loading and erosion of thrust units, as suggested by LOPEZ-BLANCO et al. (2000) and MARZO & STEEL (2000) for some fan-delta clastic wedges in the Ebro Basin, Spain.

A younger deformation postdating the PB at MtP involved the marginal, NNE basin area. The resultant, gentle folding is similar in orientation to the previous one, and also decreases in intensity basinwards (Figs. 25G, 26, 28).

7. CONCLUSION

In their type area, MtP, the PB are represented by 8 sedimentary units, which differ in facies and/or facies associations, i.e. depositional environments and systems. They are both lithostratigraphic and allostratigraphic units, are objectively identifiable and mappable. They are: Basal alluvium (U1), Lower lacustrine unit (U2), Lagoon to alluvium (U3), Middle lacustrine unit (U4), Shelf/delta alternation (U5). Fossil-rich limestones (5A), Upper lacustrine unit (U6), and Terminal alluvium (U7). There is a considerable variation in sedimentary successions laterally: in the proximal part of the basin U1-U4 is missing, U5 varies in character, while U5A is exclusive only to this part of the basin.

The sedimentary units are arranged in 3 depositional cycles. Cycle I (U1) is believed to correspond to late lowstand conditions, while Cycles II (U2, U3) and III (U4-U7) include transgressive and highstand (regressive) systems tracts. Transgressive tracts are specific in being represented by lacustrine deposits. Falling-stage sediments have not been identified, and the entire sedimentary successions originated during relative sea-level rise.

The PB of MtP represents an example of sedimentary and sequence evolution at a deforming foreland basin margin. The evolution of this margin is characterised by structural and stratigraphic complexities which include growth strata, angular unconformities, syndepositional folding, intraformational faulting and uplift, alluvial and marine onlaps onto deformed basement, and tectonically induced, proximal-distal variations in facies and sediment thickness. The origin of lacustrine transgressive tracts may have been related to the backtilting of the proximal part of the basin.

Among three principal factors which control the history of a basin infilling, i.e. supply, subsidence and eustasy (GALLOWAY, 1989), we suggest that there was no single factor which would have been dominant throughout the entire sedimentary evolution. The majority of the regressive trends were presumably dominated by high sediment supply which was a direct response to near-continuous loading and orogen erosion. The origin of one regressive segment might have been mainly influenced by a combination of subsidence and sediment supply. The principal factor for transgressive trends was presumably subsidence, related to tectonic pulses. The overall dominance of tectonism in shaping depositional styles, sequence development and distribution of sediments was related to sedimentary evolution within deforming, marginal parts of the foreland basin which was situated in close proximity to and influenced by the main, active Dinaric thrust units.

ACKNOWLEDGEMENT

This work is part of the project "Evolutionary changes of the Dinarides from subduction to modern Adriatic beaches" supported by Ministry of Science, Education, and Sport of the Republic of Croatia. Comments by Reinhard ROETZEL (Geological Survey of Austria) and Aleksander HORVAT (University of Ljubljana) helped in improving the paper. We thank M.Sc. M. HERNITZ-KUČENJAK (INA, Zagreb) for her help in making the microphotographs, and Mr. R. KOŠĆAL (Institut of Geology and Paleontology, Faculty of Science, Zagreb) for the artwork. Dr. B. LUŽAR-OBERITER and Dr. J. ROBSON kindly corrected the English text.

REFERENCES

ALLEN, P.A., CRAMPTON, S.L. & SINCLAIR, H.D. (1991): The inception and early evolution of the North Alpine Foreland Basin, Switzerland.– Basin Res., 3, 143–163.

ANADÓN, P. & ZAMARREŇO, I. (1981): Paleogene nonmarine algal deposits of the Ebro Basin, Northeastern Spain.– In: MONTY, C. (ed.): Phanerozoic Stromatolites. Springer, Berlin, 140–154.

BABIĆ, LJ. & ZUPANIČ, J. (1985): Promina-naslage sjeverne Dalmacije: raznolikost sedimentacijskih okoliša i litostratigrafska nomenklatura.– Geol. Glasnik, 28, Sarajevo, 139–141.

BABIĆ, LJ. & ZUPANIČ, J. (1990): Progradacijski slijedovi u paleogenskom klastičnom bazenu vanjskih Dinarida, od sjeverne Dalmacije do zapadne Hercegovine.– Rad Jugoslavenske akademije, 449, 319–343. (in Croatian, English summary).

BABIĆ, LJ. & ZUPANIČ, J. (2007): Major events and stages in the sedimentary evolution of the Paleogene Promina basin (Dinarides, Croatia).– Nat. Croat., 16/4, 215–232.

BABIĆ, LJ. & ZUPANIČ, J. (2008): Evolution of a river-fed foreland basin fill: the North Dalmatian flysch revisited (Eocene, Outer Dinarides).– Nat. Croat., 17/4, 357–374.

BABIĆ, LJ., ZUPANIČ, J. & KURTANJEK, D. (1995): Sharply-topped alluvial gravel sheets in the Palaeogene Promina Basin (Dinarides, Croatia).– Geol. Croat., 48/1, 33–48.

BURNS, B.A., HELLER, P.L., MARZO, M. & PAOLA, C. (1997): Fluvial response in a sequence stratigraphic framework: example from the Montserrat fan delta, Spain.– J. Sediment. Res., 67/2, 311–321.

CATUNEANU, O. (2006): Principles of Sequence Stratigraphy.– Elsevier, Amsterdam, 375 p.

CHOROWICZ, J. (1977): Étude géologique des Dinarides le long de la transversale Split-Karlovac (Yougoslavie).– Soc. Géol. Nord, Publ. 1, Villeneuve D'Asq, 331 p.

CHOUGH, S.K., HWANG, I.G. & CHOE, M.Y. (1990): The Miocene Doumsan fan-delta, Southeast Korea: a composite fan-delta system in back-arc margin.– J. Sediment. Petrol., 60/3, 445–455.

COLELLA, A. (1988): Pliocene-Holocene fan deltas in the Crati Basin, southern Italy: a consequence of varying tectonic conditions.– In: NEMEC, W. & STEEL, R.J. (eds.): Fan Deltas: Sedimentology and Tectonic Settings. Blackie, Glasgow, 50–74.

COLLINSON, J.D. (1996): Alluvial sediments.– In: READING, H.G. (ed.): Sedimentary Environments. 3. Ed. Blackwell, Oxford, 37–82.

CRAMPTON, S.L. & ALLEN, P.A. (1995): Recognition of forebulge unconformities associated with early stage foreland basin development: example from the North Alpine foreland basin.– Am. Assoc. Petr. Geol. B., 79/10, 1495–1514.

DORSEY, R.J., UMHOEFER, P.J. & RENNE, P.R. (1995): Rapid subsidence and stacked Gilbert-type fan deltas, Pliocene Loreto basin, Baja California Sur, Mexico.– Sediment. Geol., 98, 181–204.

DORSEY, R.J., UMHOEFER, P.J. & FALK, P.D. (1997): Earthquake clustering inferred from Pliocene Gilbert-type fan deltas in the Loreto basin, Baja California Sur, Mexico.– Geology, 25/8, 679–682.

EMBRY, A.F. & JOHANNESSEN, E.P. (1992): T-R sequence stratigraphy, facies analysis and reservoir distribution in the uppermost Triassic-Lower Jurassic succession, western Sverdrup Basin, Arctic Canada.– In: VORREN, T.O., BERGSAGER, E., DAHL-STAMNES, O.A., HOLTER, E., JOHANSEN, B., LIE, E. & LUND, T.B. (eds.): Arctic Geology and Petroleum Potential. Norw. Petrol. Soc. Spec. Publ., 2, 121–146.

EMBRY, A.F. (2002): Transgressive-regressive (T-R) sequence stratigraphy.– In: ARMENTROUT, J.M. & ROSEN, N.C. (eds.): Sequence Stratigraphic Models for Exploration and Production: Evolving Methodology, Emerging Models and Application Histories. 22. Ann. Gulf Coast Sect. SEPM Foundation Bob F. Perkins Res. Conf., Conf. Proc., 151–172.

ETHRIDGE, F.G. & WESCOTT, W.A. (1984): Tectonic setting, recognition and hydrocarbon reservoir potential of fan delta deposits.– In: KOSTER, E.H. & STEEL, R.J. (eds.): Sedimentology of Gravels and Conglomerates. Can. Soc. Petroleum Geol. Mem., 10, Calgary, 217–235.

FLEMINGS, P.B. & JORDAN, T.E. (1989): A synthetic stratigraphic model of foreland basin development.– J. Geophys. Res., 94 (B4), 3851–3866.

FORD, M., WILLIAMS, E.A., ARTONI, A., VERGES, J. & HARDY, S. (1997): Progressive evolution of fault-related fold pair from growth strata geomteries, Sant Llorenc de Morunys, SE Pyrenees.– J. Struct. Geol., 19/3–4, 413–441.

GAWTHORPE, R.L. & COLELLA, A. (1990): Tectonic controls on coarse-grained delta depositional system in rift basins.– In: COLELLA, A. & PRIOR, D.B. (eds.): Coarse-grained Deltas. Int. Assoc. Sediment. Spec. Publ., 10, Blackwell, Oxford, 113–127.

GALLOWAY, W.E. (1989): Genetic stratigraphic sequences in basin analysis I: architecture and genesis of flooding-surface bounded depositional units.– Am. Assoc. Petrol. Geol. B., 73/2, 125–142.

GILBERT, G.K. (1885): The topographic features of lake shores.– Ann. Rep. U.S. geol. Surv., 5, 75–123.

HEDBERG, H.D. (1976): International Stratigraphic Guide.– Willey, New York, 200 p.

HELLAND-HANSEN, W. & MARTINSEN, O.J. (1996): Shoreline trajectories and sequences: description of variable depositional-dip scenarios.– J. Sediment. Res., 66/4, 670–688.

HELLER, P.L., ANGEVINE, C.L. & WINSLOW, N.S. (1988): Two-phase stratigraphic model of foreland basin sequences.– Geology, 16/6, 501–504.

HERAK, M. & BAHUN, S. (1979): The role of calcareous breccia (Jelar Formation) in the tectonic interpretation of the High Karst zone of the Dinarides.– Geol. vjesnik, 31, 49–59.

HUNT, D. & TUCKER, M.E. (1992): Stranded parasequences and the forced regressive wedge systems tract: deposition during base-level fall.− Sediment. Geol., 81/1, 1−9.

IVANOVIĆ, A., SIKIRICA, V., MARKOVIĆ, S. & SAKAČ, K. (1977): Osnovna geološka karta SFRJ 1:100000, list Drniš [*Basic Geological Map of SFRY 1:100000, Drniš sheet* − in Croatian].− Geološki zavod, Zagreb, Savezni geološki zavod, Beograd.

IVANOVIĆ, A., SIKIRICA, V. & SAKAČ, K. (1978): Osnovna geološka karta SFRJ 1:100000, Tumač za list Drniš [*Basic Geological Map of SFRY 1:100000, Geology of the Drniš sheet* − in Croatian, English Abstr.].− Geološki zavod, Zagreb, Savezni geološki zavod, Beograd, 59 p.

KERNER, F. v. (1894): Ueber die geologischen Verhältnisse der Gegend von Dernis in Dalmatien.− Verhandlungen der geologischen Reichsanstalt, 1894/2, 75−81.

KERNER, F.v. (1896): Geologische Specialkarte der Oesterr.-ungar. Monarchie, 1:75.000. Kistanje und Drniš.− Geol. Reichsanst., Wien.

KERNER, F. v. (1901): Erläuterungen zur Geologischen Karte der Oesterr.-ungar. Monarchie. Kistanje-Dernis, 1:75.000.− Geol. Reichsanst., Wien, 40 p.

KORBAR, T. (2009): Orogenic evolution of the External Dinarides in the NE Adriatic region: a model constrained by tectonostratigraphy of Upper Cretaceous to Paleogene carbonates.− Earth-Science Reviews (2009) doi: 10.1016/.earscirev.2009.07.004, 1−17.

KÜHN, O. (1946): Das Alter der Prominaschichten und der innereozänen Gebirgsbildung.− Jahrbuch der Geologischen Bundesanstalt, 91/1−2, 49−94.

LOPEZ-BLANCO, M., MARZO, M. & PIÑA, J. (2000): Transgressive-regressive sequence hierarchy of foreland, fan-delta clastic wedges (Montserrat and Sant Llorenç del Munt, Middle Eocene, Ebro Basin, NE Spain).− Sediment. Geol., 138, 41−69.

MAMUŽIĆ, P. (1975): Osnovna geološka karta Jugoslavije 1:100000, Tumač za list Šibenik [*Basic Geological Map of SFRY 1:100000, Geology of the Šibenik sheet* − in Croatian].− Geološki zavod, Zagreb, Savezni geološki zavod, Beograd, 37 p.

MARINČIĆ, S. (1981): Eocenski fliš jadranskog pojasa.− Geol. vjesnik, 34, 27−38.

MARKOVIĆ, S. (2002): Hrvatske mineralne sirovine.− Institut za geološka istraživanja, Zagreb, 544 p.

MARZO, M. & STEEL, R. (2000): Unusual features of sediment supply-dominated, transgressive-regressive sequences: Paleogene clastic wedges, SE Pyrenean foreland basin, Spain.− Sediment. Geol., 138, 3−15.

MASSARI, F. & COLELLA, A. (1988): Evolution and types of fan-delta systems in some major tectonic settings.− In: NEMEC, W. & STEEL, R.J. (eds.): Fan Deltas: Sedimentology and Tectonic Settings. Blackie, Glasgow, 103−122.

MASSARI, F. & PAREA, G.C. (1988): Progradational gravel beach sequences in a moderate- to high-energy, microtidal marine environment.− Sedimentology, 35, 881−913.

MIALL, A.D. (1978): Tectonic setting and syndepositional deformation of molasse and other nonmarine-paralic sedimentary basins.− Can. J. Earth Sci., 15, 1613−1632.

MIALL, A.D. (1996): The Geology of Fluvial Deposits.− Springer, Berlin, 582 p.

MIKES, T., BÁLDI-BEKE, M., KÁZMÉR, M., DUNKL, I. & VON EYNATTEN, H. (2008): Calcareous nannofossil age constraints on Miocene flysch sedimentation in the Outer Dinarides (Slovenia, Croatia, Bosnia-Herzegovina and Montenegro).− In: SIEGESMUND, S., FÜGENSCHUH, B. & FROITZHEIM, N. (eds.): Tectonic Aspects of the Alpine-Dinaride-Carpathian System. Geol. Soc. Spec. Publ., 298, London, 335−363.

MRINJEK, E. (2008): Excursion 3A, Split-Rab, Promina Beds in Canyon of Krka River and Bribirske Mostine.− In: MARJANAC, M. (ed.): 5. Int. ProGEO Symp. Conserv. Geol. Heritage. Rab, Guideb. ProGEO Croatia, Zagreb, 37−77.

MRINJEK, E. & PENCINGER, V. (2008): Excursion 3B, Rab-Split, The Benkovac Stone - a building stone from the Promina Beds: A Late Eocene succession of storm-dominated shelf deposits with highly diverse trace fossils.− In: MARJANAC, M. (ed.): 5. Int. ProGEO Symp. Conserv. Geol. Heritage. Rab, Guideb. ProGEO Croatia, Zagreb, 105−125.

NEMEC, W. (1990): Aspects of sediment movement on steep delta slopes.− In: COLELLA, A. & PRIOR, D.B. (eds.): Coarse-grained Deltas. Int. Assoc. Sediment. Spec. Publ. 10, Blackwell, Oxford, 29−73.

NIKLER, L. (1982): Značaj i karakteristike smeđih ugljena Dalmacije.− Geol. vjesnik, 35, 181−194.

NORTH AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE (NACSN) (1983): North American Stratigraphic Code.− Am. Assoc. Petrol. Geol. Bull., 67, 841−875.

POSAMENTIER, H.W. & VAIL, P.R. (1988): Eustatic controls on clastic deposition II - Sequence and systems tract models.− In: WILGUS, C.K., HASTINGS, B.S., KENDALL, C. G. ST. C., POSAMENTIER, H.W., ROSS, C.A. & VAN WAGONER, J.C. (eds.): Sea-Level Changes: an Integrated Approach. SEPM, Spec. Publ. 42, Tulsa, 125−154.

POSAMENTIER, H.W. & ALLEN, G.P. (1993): Sliciclastic sequence stratigraphic patterns in foreland ramp-type basins.− Geology, 21/5, 455−458.

POSAMENTIER, H.W. & ALLEN, G.P. (1999): Siliciclastic Sequence Stratigraphy-Concepts and Applications.− SEPM Concepts in Sedimentology and Palaeontology, 7/5, Tulsa, 204 p.

POSTMA, G. (1990): Depositional architecture and facies of river and fan deltas: a synthesis.− In: COLELLA, A. & PRIOR, D.B. (eds.): Coarse-grained Deltas. Int. Assoc. Sediment. Spec. Publ. 10, Blackwell, Oxford, 13−27.

POSTMA, G. (1995): Sea-level-related architectural trends in coarse-grained delta complexes.− Sediment. Geol., 98/1, 3−12.

POSTMA, G. & ROEP, T.B. (1985): Resedimented conglomerates in the bottomsets of Gilbert-type gravel deltas.− J. Sediment. Petrol., 55/6, 874−885.

POSTMA, G. & CRUICKSHANK, C. (1988): Sedimentology of the late Weichselian to Holocene, terraced fan delta, Varangerfjord, northern Norway.− In: NEMEC, W. & STEEL, R.J. (eds.): Fan Deltas: Sedimentology and Tectonic Settings. Blackie, Glasgow, 144−157.

POSTMA, G., BABIĆ, LJ., ZUPANIČ, J. & ROE, S-L. (1988): Delta-front failure and associated bottomset deformation in a marine, gravelly Gilbert-type fan delta.− In: NEMEC, W. & STEEL, R.J. (eds.): Fan Deltas: Sedimentology and Tectonic Settings. Blackie, Glasgow, 91−102.

PRELOGOVIĆ, E., PRIBIČEVIĆ, B., IVKOVIĆ, Ž., DRAGIČEVIĆ, I., BULJAN, R. & TOMLJENOVIĆ, B. (2003): Recent structural fabric of the Dinarides and tectonically active zones important for petroleum-geological exploration in Croatia.− Nafta, 55/4, 155−161.

PRIOR, D.B. & BORNHOLD, B.D. (1990): The underwater development of Holocene fan deltas.− In: COLELLA, A., PRIOR, D.B., (eds.): Coarse-grained Deltas. Int. Assoc. Sediment. Spec. Publ. 10, Blackwell, Oxford, 75−90.

QUITZOW, H.W. (1941): Stratigraphisch-tektonische Untersuchungen im norddalmatinischen Alttertiär.− Jahrbuch der Reichsstelle für Bodenforschung, 62, 422−437.

RIBA, O. (1976): Syntectonic unconformities of the Alto Cardener, Spanish Pyrenees: a genetic interpretation.− Sediment. Geol., 15/3, 213−233.

SAKAČ, K., BENIĆ, J., BAHUN, S. & PENCINGER, V. (1993): Stratigraphic and tectonic position of Paleogene Jelar Beds in the Outer Dinarides.− Nat. Croat., 2/1, 55−72.

SHANLEY, K.W. & MCCABE, P.M. (1994): Perspectives on sequence stratigraphy of continental strata. Am. Assoc. Petrol. Geol. B., 78/4, 544−568.

TUCKER, M.E. (2001): Sedimentary Petrology. An introduction to the Origin of Sedimentary Rocks. 3. ed.− Blackwell, Oxford, 262 p.

TUCKER, M.E. & WRIGHT, V.P. (1990): Carbonate Sedimentology.− Blackwell, Oxford, 496 p.

VLAHOVIĆ, I., TIŠLJAR, J., VELIĆ, I. & MATIČEC, D. (2005): Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics.– Palaeogeogr., Palaeoclimatol., Palaeoecol., 220/3–4, 333–360.

ZUPANIČ, J. (1969): Promina naslage planine Promine.– Geol. vjesnik, 22, 477–498.

ZUPANIČ, J., BABIČ, L., ROE, S.L. & POSTMA, G. (1987): Wave-cut platform and wave-built terrace succeeding a Gilbert delta.– Abstracts, Int. Symp. Fan-deltas, Sedimentology and Tectonic Settings. Univ. Bergen, Bergen, Norway, 1987, p. 48.

ZUPANIC, J., BABIC, L., ROE, S.L. & POSTMA, G. (1988): Construction and destruction of Gilbert-type deltas during transgression. An example from the Eocene Promina Formation, Yugoslavia.– Abstracts Int. Workshop Fan Deltas, Univ. Calabria, Calabria, 1988, 58–59.

APPENDIX: FORMAL STRATIGRAPHIC NAMES?

1. LITHOSTRATIGRAPHY

As the PB of the entire North Dalmatian foreland basin includes a variety of sedimentary units, the PB has been proposed to be designated as a group (BABIĆ & ZUPANIČ, 1985), i.e. the Promina Group, if formal lithostratigraphic naming (HEDBERG, 1976; NACSN, 1983) is applied. Following the same rules, the first lower-rank units, i.e. those presented in this work from the type locality of the Promina Beds, may be treated as formations. Namely, they have been adequately described using their lithology, boundaries, stratigraphic position, age (KÜHN, 1946), areal distribution, mappability and reference sections (stratotypes). The latter are represented by the relevant segments of logs (Figs. 6, 7) located closest to the localities (Fig. 5) which are given below as the first part of the names of the relevant formations. So called supplementary sections of some of these formations are located laterally (Fig. 5). Most of these units coincide with those previously separated in both MtP and other parts of the North Dalmatian foreland basin (BABIĆ et al., 1995; BABIĆ & ZUPANIČ, 2007 with references). The poorly known U6 was not given a name. Lithostratigraphic names would be as follows:

Kalun Conglomerate (U1; Basal alluvium)
Varoš Formation (U2; Lower lacustrine unit)
Knezovi Conglomerate (U3; Lagoon to alluvium)
Počivalica Formation (U4; Middle lacustrine unit)
Previje Formation (U5; Shelf/delta alternation)
Bukovac Limestone (U5A; Fossil-rich Limestone)
Unnamed formation (U6; Upper lacustrine unit)
Čavnovka Conglomerate (U7; Terminal alluvium)

2. ALLOSTRATIGRAPHY

As the units described in this work are defined and identified on the basis of laterally traceable bounding discontinuities, other attributes being the same as for the formations cited above, these units are materially identical to allostratigraphic units introduced by NACSN (1983). Genetic interpretations are not obligatory for defining allostratigraphic units, however, such interpretations may influence the choice of their boundaries (NASCN, 1983, Article 58, remark (f)). The units identified here are defined on the basis of their genesis. Their bounding surfaces are prominent, well defined genetically and their types are restricted to specific kinds of changes across them. Hence, these units are not poorly defined in contrast to the wide definition of changes which are possible across the bounding discontinuities using the Code of NACSN (1983) (see relevant comments by POSAMNATIER & ALLEN, 1999 and CATUNEANU, 2006).

The rules for naming allostratigraphic units are the same as those for naming lithostratigraphic units (NACSN, 1983). Thus, the names for the units in MtP, which would constitute the Promina Allogroup, may be as follows:

Kalun Conglomerate Alloformation (U1; Basal alluvium)
Varoš Alloformation (U2; Lower lacustrine unit)
Knezovi Conglomerate Alloformation (U3; Lagoon to alluvium)
Počivalica Alloformation (U4; Middle lacustrine unit)
Previje Alloformation (U5; Shelf/delta alternation)
Bukovac Limestone Alloformation (U5A; Fossil-rich Limestone)
Unnamed alloformation (U6; Upper lacustrine unit)
Čavnovka Conglomerate Alloformation (U7; Terminal alluvium)

3. SUBDIVISION AND NAMING OF UNITS OF THE PROMINA BEDS: A COMPARISON

The lithostratigraphic subdivision may be useful, as generally confirmed by its widespread use. The allostratigraphic subdivision, using specific types of bounding discontinuities, may be regarded as more natural, as well as more appropriate for interpretative purposes, because it uses important, natural attributes. In fact, the two classifications, if applied to successions described here, differ in formal naming, not in material facts, and the choice between them does not seem to be of paramount importance and primary interest. However, it is believed that the classification and names used here (most of the relevant units have been separated and defined in a similar way previously (BABIĆ et al., 1995; BABIĆ & ZUPANIČ, 2007); see also Fig. 4) are more suited for communication and study of relevant geological objects and geological evolution, as they convey more relevant information in accordance with the present level of research and practical needs.

Manuscript received October 22, 2010
Revised manuscript accepted February 24, 2011
Available online June 09, 2011