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EVOLUTION OF A RIVER-FED FORELAND BASIN FILL: THE NORTH DALMATIAN FLYSCH REVISITED (EOCENE, OUTER DINARIDES)

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The sedimentary evolution of the Eocene, Outer Dinaric foreland basin of N Dalmatia began with carbonate deposition on a retreating foreland ramp. The clastic deposition starts with an early or flysch stage represented by orogen-related, river-fed, distal prodelta sand lobes, and associated hemipelagites. The subsequent, filling stage reflects the shallowing caused by the progradation of the proximal prodelta. It is followed by deposition in front of the braidplain delta or braid deltas, which might have resulted from the continuation of the filling stage, or possibly indicates the steady state (filled stage). This sedimentary evolution is comparable to the evolutionary trend typical for peripheral foreland basins, especially those of the alpine realm, and is closely related to the foreland and orogen tectonic evolution. The clastic deposition mainly occurred from flood-generated density underflows ensuing from multiple delta outlets. These flows may have been influenced by oscillatory flows. The relevant drainage basin was characterised by intense erosion in a mountainous area, related to active compressional tectonics in the rising orogen, and by powerful streams.

Key words: foreland basin, hyperpycnal underflows, prodelta, delta front, flysch, Paleogene, Outer Dinarides

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Taložna evolucija eocenskog predgornog bazena Vanjskih Dinarida u sjevernoj Dalmaciji započinje karbonatnom sedimentacijom na predgornoj rampi, koja se povlačila. Klastična sedimentacija počinje s ranim ili fliškim stadijem, koji je predstavljen distalnim, prodeltnim pješčanim režnjevima s pridruženim hemipelagitima, koji su vezani za orogen i hranjeni rijekama. Naredni stadij punjenja odražava se u oplićavanju, koje je izazvala progradacija proksimalne prodelte. Slijedi taloženje ispred delti pletenih ravnica ili pletenih delti, što je vjerojatni nastavak stadija punjenja ili možda upućuje na stabilno stanje (ispunjeni stadij). Ovakva taložna evolucija može se usporediti s evolucijskim stilom, kakav je tipičan za periferne predgorne bazene, osobito one alpske domene, i usko je povezana s tektonskim razvitkom predgorja i orogena. Glavni procesi taloženja klastita bili su vezani za guste tokove niz dno, koji su nastajali iz poplava i proizlazili iz brojnih deltnih ušća. Ti tokovi mogli su biti utjecani oscilatornim tokovima. Odnosni riječni sliv označavala je snažna erozija u planinskim predjelima, što je bilo vezano za aktivnu kompresijsku tektoniku uzdizanog orogena i snažne tekućice.

Ključne riječi: predgorni bazen, hiperpiknalni tokovi, prodelta, deltno čelo, fliš, Paleogen, Vanjski Dinaridi

INTRODUCTION

The evolution of foreland basins situated in front of an evolving orogen is accompanied by a succession of tectonic and sedimentary changes. The process typically starts with the formation of a forebulge, and is followed by the subsidence in response to the load imposed by an advancing orogen (BEAUMONT, 1981; FLEMINGS & JORDAN, 1990). In the early stage, the subsidence rate outpaces sedimentation, which leads to deepening, and change in the depositional facies, from continental and/or shallow marine to deep water, where the later is represented by clastics primarily supplied from the orogen, and commonly called flysch or classic flysch (BEAUMONT, 1981; FLEMINGS & JORDAN, 1990; ALLEN *et al.*, 1991; SINCLAIR & ALLEN, 1992). During the subsequent evolution, the deformation and related subsidence slow down or stop, which enables the sedimentation to outstrip the subsidence. The depositional settings become shallow to continental, and classic molasse results. The two stages are known as underfilled and overfilled stages respectively (*op. cit.*). A transitional stage between the two has also been described, and is characterised by the filling and shallowing trend in the basin (COVEY, 1986). The present work describes the lower part of a Dinaric, Eocene, foreland basin clastic succession, which is inferred to correspond to the underfilled stage, and the shallowing stage (filling stage). We suggest that the sedimentation processes were dominated by flood-generated hyperpycnal flows. This style of sediment supply has been recognised in many basins, and may result in thick sediment accumulations in front of deltas (e.g. HELLER & DICKINSON, 1985; READING & RICHARDS, 1994; SINCLAIR, 2000; PLINK-BJÖRKLUND *et al.*, 2001; MUTTI *et al.*, 2003). Furthermore, the studied sediments are included in a general evolutionary picture of the N Dalmatian foreland basin fill.

GEOLOGICAL SETTING AND PREVIOUS WORK

Among the three main Eocene flysch areas of the Dinaric coastal belt of Croatia, the N Dalmatian flysch occupies a central position (Fig. 1A). In this area (Fig. 1B), SCHUBERT (1905, 1908, 1909) identified and mapped Lutetian Marls and Sandstones, which have also been designated as flysch (SCHUBERT, 1905; IVANOVIĆ *et al.*, 1969), and, in their W part, as molasse (MAJCEN & KOROLIJA, 1970). The reports cite a thickness of about 900 m. In the E part of the area (Fig. 1C), three subunits have

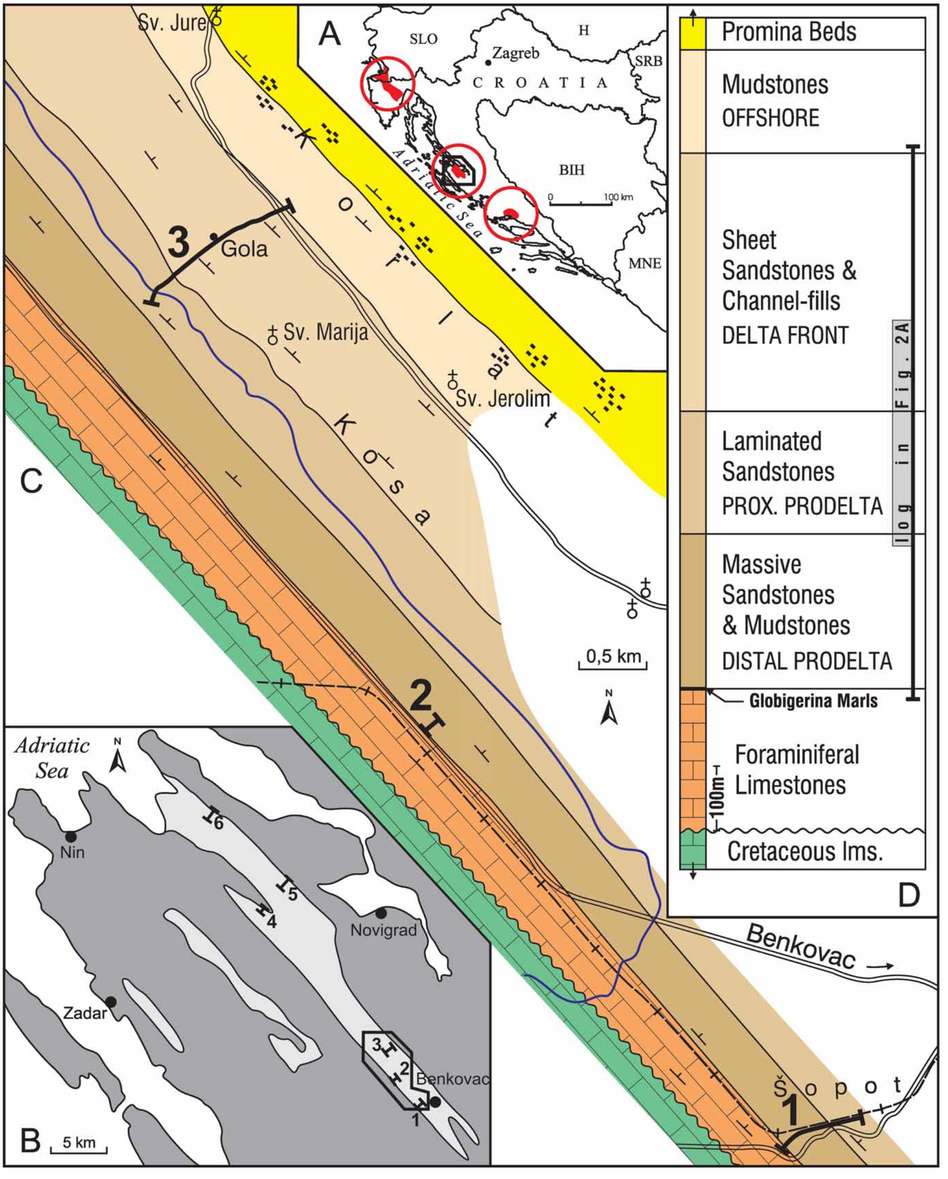


Fig. 1. A, The main fields of the Paleogene flysch in the coastal Dinarides of Croatia. Framed area is shown in 1B. **B**, Main flysch fields in N Dalmatia (in light grey) (simplified after SAVEZNI GEOLOŠKI ZAVOD, 1970), with location of Sections 1-6. For location of Sections 1-3 see Fig. 1C. Sections 4 and 5 are along the highway, and Section 6 is by Jovići village. Framed area is shown in 1C. **C**, The map of four Eocene clastic lithozones, with location of Sections 1-3. Cretaceous and Paleogene limestones, and Promina Beds after IVANOVIĆ *et al*. (1973). **D**, Simplified log of the area in 1C, with interpreted depositional settings.

later been recognised and mapped (BABIĆ & ZUPANIČ, 1983). The first one (here treated as two units) was presumed to represent sand lobes of a sand-rich, deep-water system (poorly efficient system of MUTTI, 1979), and overlying thin-bedded turbidites and slumps. The second unit was described as an association of sheet-like sandbodies, channel-fills, and thin turbidites presumably representing a channellised portion of the system with associated sheet-flow sands (BABIĆ & ZUPANIČ, 1983). The description of the third unit was not provided. This succession is the main topic of the present work, which provides a revised interpretation of relevant sediments. It also includes a comparison with the data from the NW continuation of the same clastic belt (Fig. 1B), where the upper part of the succession is represented by shelf and delta-related, near-shore deposits (BABIĆ & ZUPANIČ, 1998).

The controversy provoked by the recently proposed Miocene age (MIKES *et al.*, 2008) instead of the previous, Eocene age dating (SCHUBERT, 1905, 1909; KRAŠENINNIKOV *et al.*, 1968; IVANOVIĆ *et al.*, 1969; MAJCEN & KOROLIJA, 1973) of the studied sediments is out of the scope of this paper, which follows the previous dating.

The studied clastics are underlain by Early-Middle Eocene brackish to marine limestones, which overly karstified Cretaceous platform carbonates (e.g. IVANOVIĆ *et al.*, 1976), and overlain by 2 km thick Promina Beds (Figs. 1C, 1D), which include a variety of depositional systems, predominantly shallow marine, coastal/deltaic, and alluvial (ZUPANIČ, 1969; ZUPANIČ & BABIĆ, 1981; BABIĆ & ZUPANIČ, 1988, 1990, 1998, 2007; POSTMA *et al.*, 1988; BABIĆ *et al.*, 1995; MRINJEK *et al.*, 2005; MRINJEK, 2008).

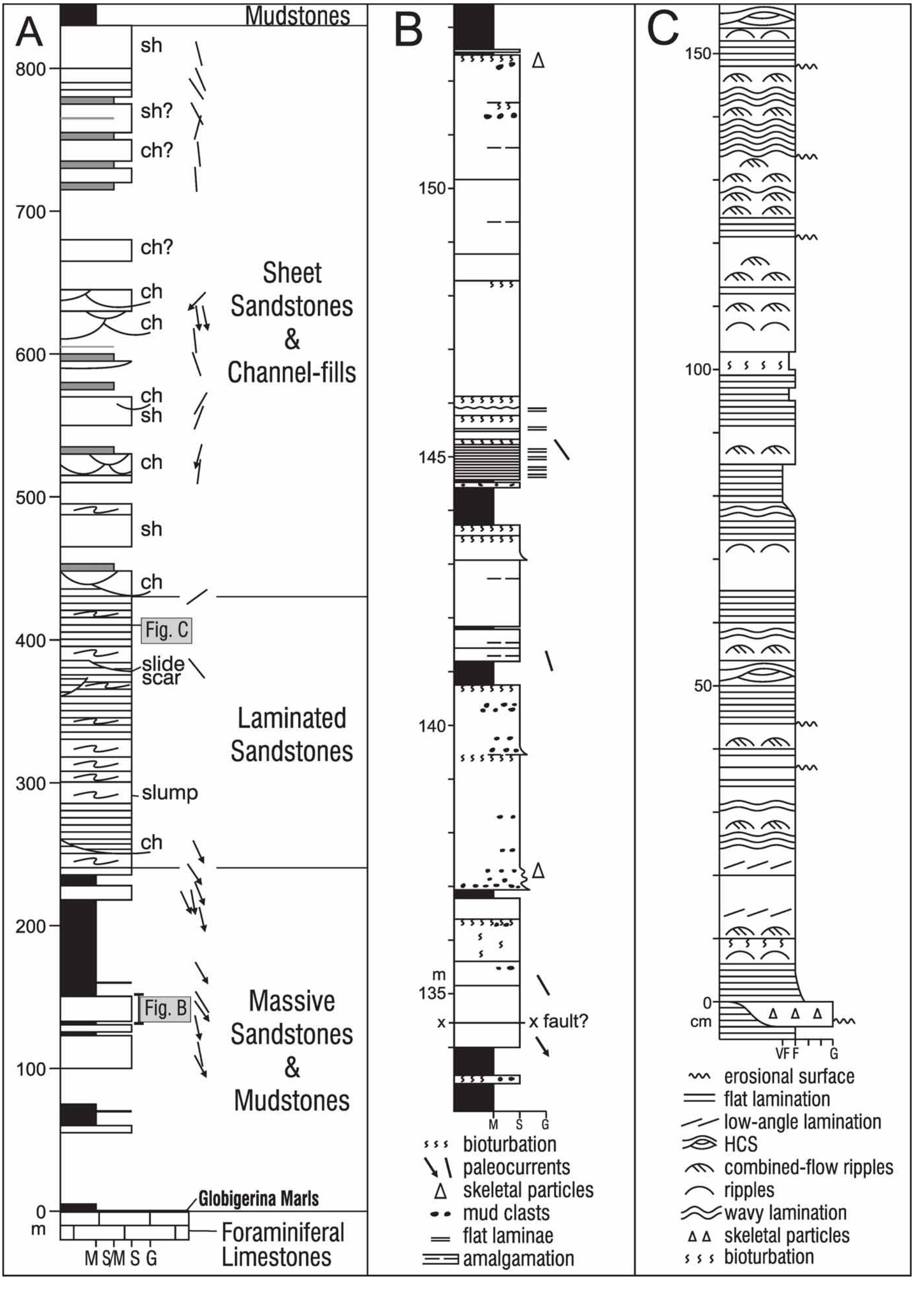
STUDY AREA AND METHODS

Six sections have been studied along the Benkovac clastic belt (Figs. 1B, 1C), while the most relevant observations have been made at the railway cut by Šopot village, and at the Gola section (Fig. 1C: Sections 1, and 3). The work included the study of sedimentary features, mapping of four lithozones (Fig. 1C), and the inspection of 60 thin sections.

DESCRIPTION AND INTERPRETATION OF SEDIMENTARY UNITS

Four lithozones have been separated and mapped: (1) Massive Sandstones and Mudstones, (2) Laminated Sandstones, (3) Sheet Sandstones and Channel-fills, and (4) Mudstones (Figs. 1C, 1D, 2A).

Fig. 2. A, The clastic succession of the area in Fig. 1C. s, sheet sandstones; ch, channel-fills; M, M/S, S, and G are mudstone, mudstone/sandstone alternation, sandstone, and gravel, respectively. Segment 55-75 m is from Section 2, segment 100-430 m from Section 1 (simplified after BABIĆ & ZUPANIČ, 1983), the rest is from Section 3; locations in Fig. 1C; **B**, Detailed log of a part of the Massive Sandstones and Mudstones unit shown in Fig. 2A. M, S, and G as in Fig. 2A. **C**, Detailed log from the upper Laminated Sandstone unit (396-397.6 m in Fig. 2A). For details see text. ⇒


A
Mudstones
sh
sh?
ch?
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sh
ch
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Sheet Sandstones & Channel-fills
Fig. C
slide scar
Laminated Sandstones
slump
ch
Fig. B
Massive Sandstones & Mudstones
Globigerina Marls
Foraminiferal Limestones
m
M S/M S G
B
Δ
150
145
140
m
135
x
x fault?
Δ
M S G
bioturbation
paleocurrents
skeletal particles
mud clasts
flat laminae
amalgamation
C
150
100
50
0
cm
VF F G
erosional surface
flat lamination
low-angle lamination
HCS
combined-flow ripples
ripples
wavy lamination
skeletal particles
bioturbation

Fig. 3. A sandstone body of the Massive Sandstones and Mudstones unit (215-228 m in Fig. 2A) almost exclusively consisting of ungraded sandstones. Underlying are hemipelagic mudstones with thin sandstone intercalations, and the same sediments overlying the body are here covered by concrete. Persons for scale. Loc. 1 in Fig. 1B and 1C.

1. Massive Sandstones and Mudstones

Description

The sandstone beds are mostly 10 to 150 cm thick, display a sharp base, and an entirely bioturbated top. They show S- to SE-directed flutes and similarly orientated grooves (Figs. 2A, 2B). Amalgamation is common. The sandstones are predominantly massive, i.e. ungraded, while vertical grading is rare. Mud clasts and plant debris are common, while molluscs, and nummulites are rare. Thin, flat laminated sandstones occur only exceptionally (Fig. 2B). The mudstones are rich in planktonic foraminifera, and may be intercalated by rare, thin sandstones.

The sandstone beds commonly constitute several metres thick, compact bodies separated by mudstone intervals (Fig. 3). Two sandbodies have been traced along inferred shore-parallel, NW-SE sections for 1 and 1,25 km respectively. Some bodies show a thickening-upward trend of component beds, while some others a thickening plus thinning trend. A thin slump occurs in the uppermost part of the unit.

Interpretation

The massive sandstones are regarded to reflect deposition from sustained, steady turbidity currents by processes described by KNELLER & BRANNEY (1995). After these authors, the deposition of massive beds may be performed by gradual aggradation, mainly due to grain interactions, hindered settling, and shear, and occurs as long as the grain flux to the depositional flow boundary is balanced by the grain supply. Some mud clast horizons are related to amalgamation process, while their distribution at different heights in the sandstone bed would support the aggradational deposition of the bed (KNELLER & BRANNEY, 1995). Rare, graded sandstones reflect a waning of otherwise similarly depositing flows. The sustained character of the flows related to the studied sandstones suggests a direct input from sand-laden streams during river flood periods, and thus represent hyperpycnal underflows. Rare, flat laminated sands might have originated by tractional processes, from sustained, unsteady flows.

The isolated sandbodies encased in hemipelagites, and largely consisting of ungraded sandstones lacking fines, together with their inferred lobe-like shape, and thickening upward and thickening plus thinning trends in some bodies, have previously been assumed (BABIĆ & ZUPANIČ, 1983) to represent parts of a poorly efficient, sand-rich turbidite system of MUTTI (1979). However, the sustained character of depositing flows fits a relation to the delta(s) of sand-rich alluvial feeding systems. The close association of the sand lobes and hemipelagites rich in plankton, and the absence of structures typical of settings above storm wave base, imply deposition below this depth. The above data and discussion, together with the position of the unit below the inferred, more shallow, sandy prodelta deposits (interpreted below as the proximal prodelta) suggest a progradation by which the proximal prodelta advanced above the distal prodelta represented by the Massive Sandstones and Mudstones unit. Hence, the sand lobes could be designated as distal prodelta lobes (Fig. 9). Delta-related lobes dominated by turbiditic, massive sandstones in contrast to the lobes related to submarine fans, have first been recognised by HELLER & DICKINSON (1985) as a part of their »delta-fed submarine ramp model«. They have also described the adjacent slope facies (similar to our proximal prodelta), which prograded over the ramp, as is the case with our example (see also below). Sand lobes containing massive sandstones deposited from flood-generated flows have also been reported from the Eocene Central Basin, Spitsbergen, where they are located on the lower slope to basin-floor (PLINK-BJÖRKLUND *et al.*, 2001).

The alternating lobes and mudstones may reflect either a lateral shifting of the fluvial effluents, relative sea-level fluctuations or both. A thick mudstone-dominated segment (Fig. 2A: 153-219 m) probably originated during a sea-level highstand period. A thin slump unit in the upper part of the unit heralds common sliding phenomena upsection.

2. Laminated Sandstones

Description

The sandstones in this unit are characterised by flat and ripple laminated structures (Fig. 2C), common slumps and slides, as well as slide scars in its upper part (Fig. 4). There are also decimetres thick intervals dominated by alternating laminae of sandy mudstones and muddy sandstones. Flat laminated sandstones may be either up to 1 m thick, or make up several cm thick lower parts of units, whose upper part is represented either by combined-flow ripples (CFR), wavy laminae, low-angle laminae, or small-scale hummocky cross-stratification (HCS) (Figs. 5, 6). Such

Fig. 4. Truncation surfaces in the Laminated Sandstones unit representing slide scars and/or channels. 382-385.5 m in Fig. 2A. Hammer (30 cm) for scale.

Fig. 5. Sandstone bed in the middle is sharply based and shows quasi-flat to low-angle laminae followed by wave ripple structures, the later grading laterally (out of the photo) into CFR. Laminated Sandstones unit, above 120 cm in Fig. 2C. Lens cap is 4.4 cm in diameter.

units may show erosional bases, and a very thin, graded basal part, which occasionally contains larger foraminifera, and molluscs. Sandstone beds may also begin with a rippled or wavy laminated interval, and continue with flat laminae. In other cases, flat and CFR lamination may alternate without erosional interruptions (Fig. 2C). The sandstones are rich in plant remains, and are commonly muddy. A truncation surface observed in the lower part of the unit (Fig. 2A) may represent a part of the channel wall. Some of the conspicuous concave-upward truncation surfaces in the upper part of the unit (Fig. 2A) probably also represent channels.

Interpretation

Thick, flat laminated sandstones must have been deposited by tractional processes from sustained density underflows which were related to prolonged river flood periods. The alternation of flat lamination with either CFR lamination, wavy lamination, or HCS, may indicate intermittent modifications of the sustained flows by oscillatory flows (»wave-modified turbidites« of MYROW & SOUTHARD, 1996). Various processes may be responsible for generating the oscillatory component of hyperpycnal flows (review in TINTERRI, 2007), while the influence of storms have commonly been cited. This is because many similar examples are found in smaller basins, where the storm and flood-related flows may occur at about the same time, thus enabling the combination of the hyperpycnal and storm-related flows (MYROW *et al.*, 2002). The origin of erosionally-based units may be related either to short-term intensification of otherwise sustained, flood-generated flows, or to the onset of new flood-related flows (MULDER *et al*. 2003; TINTERRI, 2007). The intervals of thin, muddy sandstones and sandy mudstones reflect intermittent decreases in the sediment supply to the relevant depositional areas. Some of them may have been deposited from hypopycnal, buoyant plumes, and/or from dilute underflows during

Fig. 6. Alternation of CFR, wavy laminae, and flat laminae in the lower part is sharply overlain by quasi-planar laminae, and subsequent HCS. 135-155 cm in Fig. 2C. Laminated Sandstones unit. Lens cap is 4.4 cm in diameter.

normal river discharges (PRIOR & BORNHOLD, 1989). The abundance of the land-derived plant material is consistent with a direct supply from flooding rivers. The bioclastic material was entrained by erosion in shallow environments located landwards, thus documenting the erosive character of the flows in those areas.

The absence of indications of processes typically operating above fair-weather wave base and probable influence of storms, may reflect a deposition in the offshore transition zone. Common slumps, and slide scars, indicate frequent mass movements related to a high sedimentation rate on an unstable, sloping depositional setting. Probable channels in some parts of the unit may represent conduits for the river-derived flows bringing sediment to the distal part of the system. Based on the above discussion, the depositional setting of this unit is interpreted as a prodelta slope related to sand-rich alluvial and delta systems (Fig. 9). Its position above the more distal prodelta facies, i.e. the sand lobes and hemipelagites of the previous unit, and below the delta front facies discussed below, together with the appearance of slide scars in its upper part, suggest a progradational trend. The facies of the unit, as well as its vertical position resemble the slope facies of the »delta-fed submarine ramp model« of HELLER & DICKINSON (1985), as already mentioned above.

3. Sheet Sandstones and Channel-fills

Description

Various types of sediments of this unit are described in terms of three facies (BABIĆ & ZUPANIČ, 1983). (1) The sandbodies (Fig. 2A) are up to 30 m thick, and up to 1 km wide in sections transverse to diagonal to the main paleotransport directions, and may be either sheet-like or lensoid. The component sandstone beds show erosional bases, and low-angle truncation surfaces, as well as flutes directed S to SW. Their top is commonly bioturbated, while burrows may also occur within the beds. They are flat laminated (up to 1 m in thickness), may be graded and laminated, and may contain stripes of imbricate nummulites, occasional thin pebble interbeds, and mud clasts. HCS is also present. The sandstones in other sandbodies are rich in molluscs, larger foraminifera and other skeletal particles, and are intensely bioturbated (Fig. 7). Plant debris is very common. (2) The channel-fills (Fig. 8) are 2–13 m thick, and up to 50 m wide, elongated NE-SW, and encased in the other two facies. They consist of erosionally based, pinching-out packages of flat laminated sandstones with broadly S to SW-directed flutes and occasional rippled top, similar sandstones with bioclastic basal portion, and scour-filling conglomerates, which may contain bioclastic particles. (3) Thin-bedded facies includes sandstone- and mudstone-dominated sequences. The sandstones may show flat and ripple laminae, HCS, and variously orientated grooves. Plant debris may be abundant. Intercalated are thin sandstones rich in bioclastic particles. The unit comprises very rare slumps.

Interpretation

(1) Thick, flat laminated sandstones with abundant plant debris may have been deposited from sustained, steady density underflows, under the plane bed regime. The waning character of some flows is reflected in graded, laminated beds. Low-

Fig. 7. Bioturbated, fossiliferous sandstones in a sheet sandbody proposed to represent a delta front lobe. About 480 m in Fig. 2A. The unit of Sheet Sandstones and Channel-fills.

Fig. 8. A part of a channel-fill showing the intersection of two sandstone packages. Hammer (30 cm) is at the truncation surface. The lower part of the Sheet Sandstones and Channel-fills unit.

-angle scours caused by the passage of powerful, turbulent flows ensuing from the river mouths, might represent chute-like features (MELLERE *et al*., 2002). The influence of oscillatory flows is indicated by HCS. During quiet periods, the bed tops experienced intense bioturbation. These data, in the absence of features indicating processes above the fair-weather wave base, indicate a setting below this wave base, and probably, an offshore transition setting. The sandbodies dominated by fossiliferous, bioturbated sandstones may indicate locations less frequented by the sediment supplying flows. In general, therefore, the sandbodies mark the areas of considerable accumulations located in front of deltas of sand-rich fluvial systems. (2) The association of the channels with the other two facies suggests their function of funnelling fluvially supplied sediments to different parts of the delta front, and also to the prodelta. The channel incision, and the complex evolution of composite channel-fills are due to the action of powerful flows related to catastrophic floods, when the bioclastics were also caught from shallower environments. Thus, the flood-related flows both fed and dissected the delta front area. (3) The close association of thin bedded facies including laminated and HCS sands with the other two facies, suggests a related depositional setting, where the deposition likely occurred by both hyperpycnal underflows and oscillatory flows. The fine sands and muds could have been deposited from hypopycnal, buoyant plumes, and/or from dilute turbulent underflows during normal river discharge (PRIOR & BORNHOLD, 1989). The intercalations of beds rich in bioclastic particles might represent tempestites.

The lateral distribution of isolated channels and paleocurrents reveals multiple effluents of the fluvial feeding system, i.e. the braid delta or braidplain delta outlets, as well as their shifting positions along the coast (Fig. 9). The vertical alternation of the three facies probably reflects changes in relative sea level.

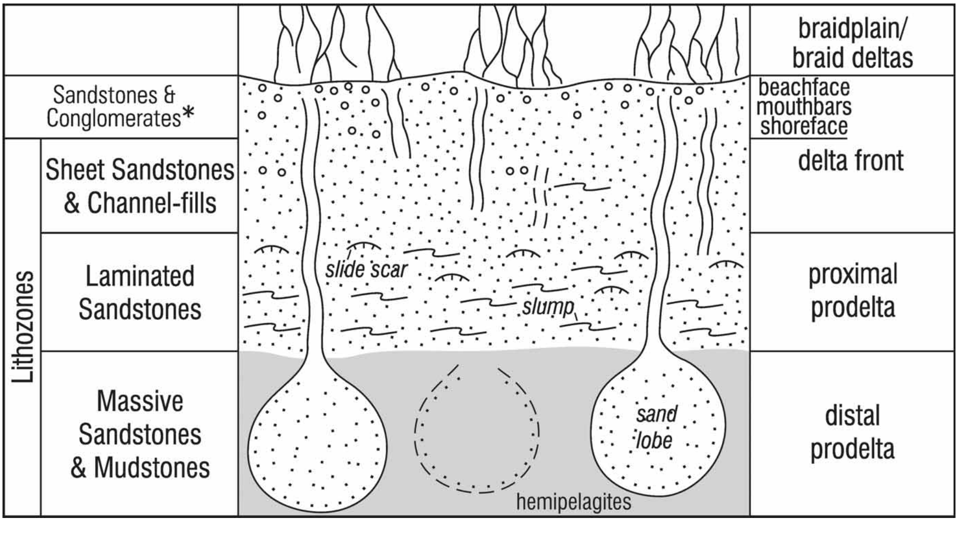

Fig. 9. Depositional model for the N Dalmatian foreland basin-fill based on the succession of the lithozones shown in Figs. 1C, 1D, and 2A. The asterix marks the unit exposed only in the NW area (Section 6 in Fig. 1B). For details see text. Scale not implied.

The delta front sandbodies deposited on a shelf ramp by sand-rich, flood-generated flows discussed above, might be designated as delta-related sand lobes. They differ from the distal, prodelta lobes in the Massive Sandstone and Mudstones unit not only by sedimentary features, but also by associated facies, and a closer position to the river mouths. The interpretation of the studied unit bears similarity to the channel and chute-mouth lobes described from the Paleogene of the Central Basin of Spitsbergen, which originated by flood-generated flows on a deeper shelf, inclined by 3°–4° (MELLERE *et al.*, 2002). Flood-related, shelfal, delta front sandstones have otherwise been recognised in a number of foreland basins (e.g. MUTTI *et al.*, 2003).

4. Mudstones

The sandstones of the previous unit are overlain by more than 50 m of mudstones (Fig. 2A) with very rare, thin sandstone intercalations. The mudstones contain small molluscs, and smaller benthic and planktonic foraminifera. These mudstones therefore reflect deposition in an offshore shelf setting, which abruptly replaced the previous, sandy, delta front. The relevant transgressive event was due to a relative sea level rise, which caused a landward shift of the coast.

DISCUSSION: SEDIMENTARY EVOLUTION OF THE FORELAND BASIN

The influence of orogenic deformation can be considered to have been reflected in the present-day coastal area of N Dalmatia by the subaerial exposure of the Cretaceous platform carbonates, which may have been caused by the formation of a forebulge. The following Paleogene limestones with basal brackish limestones, followed by limestones dominated consecutively by miliolids, alveolinas, and nummulites (IVANOVIĆ *et al.*, 1973; MAJCEN & KOROLIJA, 1973) reflect a deepening of a carbonate ramp as previously proposed for a similar, Outer Dinaric foreland area (Istria peninsula: ŽIVKOVIĆ & BABIĆ, 2003; ĆOSOVIĆ *et al.*, 2004), and correspond to the first member of the »underfilled trinity« (SINCLAIR, 1997), when the subsidence rate outpaces the sedimentation rate due to the advance of the orogenic load (Fig. 10). The transition to several metres thick Globigerina Marls marked by the disappearance of larger foraminifera, increase in the non-carbonate component, and appearance of plankton reflects a deepening (SCHUBERT, 1905; IVANOVIĆ *et al.*, 1976) caused by the inability of carbonate production to keep pace with the subsidence, which finally led to the deposition of hemipelagic Globigerina Marls, the second member of the underfilled trinity (Fig. 10). The third, turbiditic or flysch member of SINCLAIR's (1997) underfilled trinity is represented by the unit of Massive Sandstones and Mudstones mainly originated by sediment input by flood-generated, sustained, steady, density underflows, which deposited their load below the storm wave base, in distal prodelta sand lobes (Figs. 9, 10), whose locations shifted laterally depending on the activity of different river mouths. The associated hemipelgites deposited in areas and during intervals deprived of sand supply. The situation subsequently

LITHOZONES	DEPOSITIONAL SETTINGS	DEPOSITIONAL STAGES IN THE BASIN			
Mudstones	Offshore muds	Offshore muds			
	discontinuity	transgressive event			
Sheet Sandstones & Channel-fills	Delta front	Filling Stage (Filled Stage?)	Covey (1986)		
Laminated Sandstones	Proximal prodelta	Filling Stage			
Massive Sandstones & Mudstones	Distal prodelta	Early (Deep-water) Stage		Turbidites (classic flysch)	Underfilled trinity (Sinclair, 1997)
Globigerina Marls	Offshore muds	Transition		Hemipelagites	
Foraminiferal Lms.	Foreland ramp	Ramp Limestones		Ramp Limestones	
	subaerial exposure	forebulge			
Cretaceous Lms.	Foreland platform	Foreland			

Fig. 10. Lithostratigraphic units, depositional settings, and depositional stages of the N Dalmatian foreland basin sedimentary evolution. For details see text. Scale not implied.

changed with the progradation of the prodelta slope represented by the unit of Laminated Sandstones (Figs. 9, 10). This setting was supplied with sand by flood-generated flows influenced by oscillatory flows, situated below the fair-weather wave base, and characterised by frequent mass wasting processes. Its progradation reflects the onset of the filling stage of the basin, i.e. the transitional stage in the sedimentary evolution of the foreland basin, when the steady state i.e. the balance between uplift and erosion, is attained in the orogen (COVEY, 1986). The steady state in the basin had not been attained as yet, as the sedimentation and subsidence were still not at balance. The following delta front settings resulted in the origin of the unit of Sheet Sandstones and Channel-fills. During this stage, the domination of flood-generated hyperpycnal flows related to braidplain delta or braid deltas of sand-rich fluvial systems continued (Figs. 9, 10), as well as the influence of oscillatory flows, both of them mainly operating below the fair-weather wave base. The progradation of delta settings may be related to the continuation of the imbalance between the sedimentation and subsidence, i.e. the continuation of the COVEY's (1986) filling stage, i.e. his steady state in the orogen (Fig. 10). Alternatively, the entire basin may have become shallow, and thus reached the steady state in the basin, i.e. the balance between the sedimentation and subsidence (COVEY, 1986).

The evolutionary trend described above was halted by a transgressive event, when the coast shifted landwards as indicated by the deposition of the offshore shelf muds. The mudstones therefore mark the onset of a new episode in the depositional and tectonic evolution of the basin.

Parts of the succession described above may be traced along the strike towards the NW, and have been studied there at three sections (4, 5, and 6 in Fig. 1B). They show the unit of Massive Sandstones and Mudstones with the features described and discussed here. Besides, the upper part of the Section 6 (Fig. 1B) contains sandstones of the offshore transition to lower shoreface zones, as well as the shoreface and beachface sands and gravels (described as the »Sandstone-Conglomerate Unit«) related to the shelf-type, wave-dominated, coarse-grained fan-delta or braid delta systems, which were connected to short-headed, high-gradient streams directed SW, towards the NW-SE oriented coast (BABIĆ & ZUPANIČ, 1998). The later also contains gravelly-sandy sediments, which originated from gravity-flows related to river floods. The sandstones of the offshore transition zone may be compared to those in the unit of the Sheet Sandstones and Channels described here, while the sandy-gravelly part is regarded to represent coarser grained, more shallow and coastal correlatives of the delta front facies of the same unit (Fig. 10). Even farther to the NW (Island of Pag; BABIĆ *et al.*, 1993), there is an association of shallow-marine sandstones deposited by tractional processes and those deposited by gravity flows reflecting the influence of river floods. This association must have also been related to the sand-rich deltas, and might also represent a correlative of the unit of Massive Sandstones and Mudstones.

CONCLUSION

The sedimentary fill of the Eocene, Outer Dinaric foreland basin of N Dalmatia shows a general evolutionary trend typical for peripheral foreland basins, especially those of the alpine realm. This evolution is closely dependent on the tectonic evolution of both the foreland and orogen. The formation of the forebulge was followed by a deepening from the foreland carbonate ramp to the »basinal« setting below the storm wave base. The later is here represented by orogen-related, distal prodelta sand lobes and associated hemipelagites. The subsequent shallowing was related to the progradation of a sandy prodelta slope, which was followed by delta front settings connected with the braidplain delta or braid deltas. The foreland basin filling processes were dominated by flood-generated density underflows throughout the studied evolution, which were ensuing from multiple braidplain delta or braid delta outlets. The relevant drainage basin was characterised by intense erosion in a mountainous area, related to active compressional tectonics in the rising orogen, and by powerful, high-gradient streams.

The early basin fill, i.e. the sand lobes with associated hemipelagites, is comparable to the classic flysch stage of the alpine foreland basins evolution. It was followed by a transitional, filling stage of the basin sedimentary evolution, when the sedimentation became able to cause a shallowing by the progradation of clastics (proximal prodelta), but was still not able to overcome the rate of creation of accommodation space entirely. Subsequent continuation of the basin filling marked by installation of delta front settings may reflect a continuation of the imbalance between the sedimentation and subsidence, i.e. a continuation of the filling stage. However, the delta front settings might possibly, but less probably, be related to the shallowing of the entire basin, i.e. to the steady state (filled stage) in the basin.

The overall progradational trend was cut by a transgressive event, and followed by shelf sediments of the subsequent episode of the sedimentary basin evolution.

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