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Conglomerate Fabric and Paleocurrent Measurement in the Braided Fluvial System of the Promina Beds in Northern Dalmatia (Croatia)

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Key words: Braided river environment, Braid delta, Paleocurrent directions, Promina beds, Conglomerate Unit, Northern Dalmatia

Ključne riječi: okoliš prepletene rijeke, prepletena delta, Promina slojevi, Konglomeratna jedinica, sjeverna Dalmacija

Abstract

In the alluvial part of the Promina beds of northern Dalmatia (Late Eocene to possible Early Oligocene age) the main, SW-ward paleocurrent pattern was determined from clast orientation measurements within massive and flat-bedded conglomerates. Preferred clast fabric, facies characteristics, and downward transition into shoreline and shallow-marine sandstone and conglomerate suggest a prograding, braid delta system.

Sažetak

Glavni pravci paleostruja jugozapadnog smjera određeni su mjerenjima orijentacije klasta unutar masivnih i ravno slojevitih konglomerata aluvijalnog dijela Promina slojeva (starost gornji eocen do vjerojatno donji oligocen) u sjevernoj Dalmaciji. Preferirana građa klasta, karakteristike facijesa, te njihov kontinuirani prijelaz u podinu izgrađenu od obalnih i plitkomorskih pješčenjaka i konglomerata sugerira okoliš progradirajuće, prepletene delte.

1. INTRODUCTION

In northern Dalmatia, within the Benkovac - Obrovac sector, the Promina beds (Upper Lutetian to possibly Early Oligocene age, IVANOVIĆ et al., 1969) are a sedimentary succession, about 2000 m thick, which either conformably overlies the Flysch formation or unconformably covers with onlapping relationships Cretaceous and Paleogene carbonates in the internal part of northern Dalmatia (Figs. 1b and 1c). The geologic and stratigraphic setting indicates an Eocene tectonic deformation which caused deformation in the Obrovac - Promina region.

The Jelar breccia which covers a marginal part of northern Dalmatia (Fig. 1b) contains Mesozoic and Paleogene carbonate clasts, and is a massive unit, generally lacking internal organization. It overlies deformed Triassic, Jurassic and Cretaceous deposits (Fig. 1b). Its age is probably Middle Eocene - Early Oligocene, based on the age of the youngest clasts (BABIĆ & ZUPANIČ, 1983) and on the general geotectonic evolution of the Outer Dinarides (HERAK & BAHUN, 1980). It is generally considered that the Jelar breccia represents deposits located close to the area of strong tectonic deformation, and also represents the source of carbonate detritus for the Promina beds and Flysch formation (BAHUN, 1974; HERAK & BAHUN, 1980; BABIĆ & ZUPANIČ, 1983).

The Promina beds include marine and alluvial strata and can be subdivided into three informal units (Fig. 1c): the Carbonate Turbidite Unit, the Transitional Unit and the Conglomerate Unit (BABIĆ & ZUPANIČ, 1983). The lower part of Conglomerate Unit reflects predominant shallow-marine and shoreline environments, whereas the upper part is primarily made up of conglomerates and minor amounts of breccias, sandstones and fine-grained sediments, deposited by a braided fluvial system which is generally characterized by low-sinuosity channels and intervening bars (BABIĆ & ZUPANIČ, 1983, 1985, 1988). The bars are thought to be mainly of a longitudinal type, composed of coarse, moderately- to well-sorted gravels with massive to subhorizontally layered structure (MRINJEK, 1989). Cross-bedded but finer-grained gravel and sandy gravel units probably represent falling-stage features generated by lateral accretion at the margins of longitudinal bars and are slightly less abundant and usually without a distinctive clast orientation; in most cases only the dip direction of cross beds can be detected; it is commonly quite different from flow direction infered from the imbrication of coarse gravels involved in longitudinal bars, and may reflect a reorganization of the flow at falling or low stages. Bar and channel orientations can rarely be determined in ancient fluvial conglomerates (RUST, 1975), so that the clast fabric usually remains as the only way of estimating the main paleocurrent trend. For these reasons this paper is concerned with the measurement of gravel imbrications.

The main purpose of this study is to find out the primary characteristics of the alluvial environment and its vertical and lateral changes by establishing the paleocurrent pattern. Within the Benkovac - Obrovac area,

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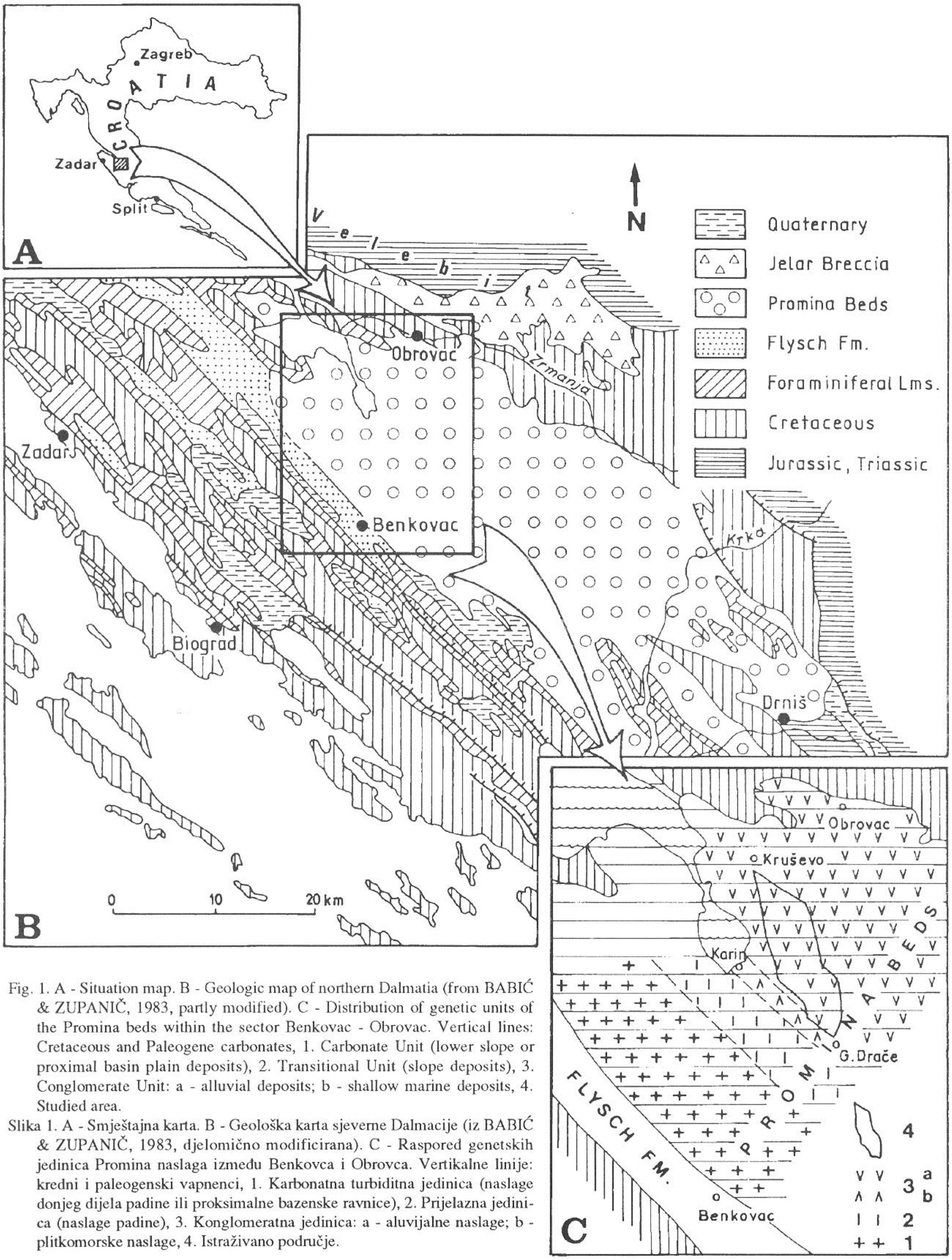


Fig. 1. A - Situation map. B - Geologic map of northern Dalmatia (from BABIĆ & ZUPANIČ, 1983, partly modified). C - Distribution of genetic units of the Promina beds within the sector Benkovac - Obrovac. Vertical lines: Cretaceous and Paleogene carbonates, 1. Carbonate Unit (lower slope or proximal basin plain deposits), 2. Transitional Unit (slope deposits), 3. Conglomerate Unit: a - alluvial deposits; b - shallow marine deposits, 4. Studied area.

Slika 1. A - Smještajna karta. B - Geološka karta sjeverne Dalmacije (iz BABIĆ & ZUPANIČ, 1983, djelomično modificirana). C - Raspored genetskih jedinica Promina naslaga između Benkovca i Obrovca. Vertikalne linije: kredni i paleogenski vapnenci, 1. Karbonatna turbiditna jedinica (naslage donjeg dijela padine ili proksimalne bazenske ravnice), 2. Prijelazna jedinica (naslage padine), 3. Konglomeratna jedinica: a - aluvijalne naslage; b - plitkomorske naslage, 4. Istraživano područje.

fluvial conglomerates are approximately 600 m thick, and display very extensive lateral and vertical exposures and continuous transition downwards into shallow-marine and shoreline sandstones and conglomerates (Figs. 1b and 1c) (BABIĆ & ZUPANIČ, 1983, 1985, 1990).

2. TEXTURAL CHARACTERISTICS

Conglomerates are by far the most abundant lithology in the upper part of the Conglomerate Unit, as they make up about 64% of the succession, whereas sandstones, fine-grained sediments and breccias make up the rest. They contain various carbonate clasts mostly, of Cretaceous age and subordinately of Paleogene and Triassic age. Clasts of sandstone, marl, chert and dolomite, as well as rudist fragments are present but very rare.

The mean maximal clast size (BLUCK, 1967) within individual units ranges from 2.1 cm to 32.4 cm, but mostly from 10 cm to 15 cm, although exceptionally, clasts may reach 45 cm in length. Sandstone and fine-grained clasts are mostly disc- or blade-shaped. The matrix is sandy or even sometimes muddy.

Conglomerates are mostly moderately to well sorted, and consist of subrounded to rounded clasts. Transverse upstream imbrications are common, and are especially shown by the larger and discoidal clasts (Figs. 2, 3, 6 and 7). Most conglomerates are clast - supported (with point and planar clast contacts). Concernig the matrix-clast relationships, three types of conglomerates can be distinguished: (1) clast-supported conglomerates with sandy matrix are by far the most abundant (Figs. 3, 6 and 7); (2) clast-supported conglomerates with openwork fabric; these are restricted to isolated horizons within clast-supported units with sandy matrix, and together with overlying matrix-filled horizons (Fig. 3) can represent one cycle of deposition (SMITH, 1974). Clast orientation established from this kind of fabric is the most reliable indicator of the mean paleocurrent direction; (3) matrix-supported conglomerates with small clasts floating in a sandy matrix; these rarely occur, and only in cross-bedded conglomerate sets, where rarely observed preferred clast orientation significantly diverges from that of the previously mentioned conglomerate types.

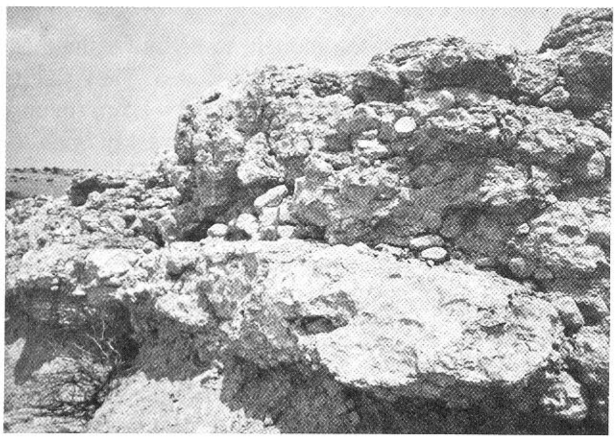


Fig. 2. Coarse imbricate clasts inside an inferred longitudinal bar (facies Gm). The flow was towards the observer. The scale is 22 cm long. Sample AII.

Slika 2. Krupni, imbricirani klasti unutar longitudinalnog pruda (facijes Gm). Tok je bio prema motritelju. Mjerilo je dugačko 22 cm. Uzorak AII.

Fig. 3. Coarse imbricate clasts inside a longitudinal bar (facies Gm). Alternation of beds with a different clast size, sorting and matrix content. A matrix filled horizon (in the middle of the picture) overlies a horizon with an openwork fabric, both representing one cycle of deposition. The flow was from right to left. The scale is 19 cm long. Sample J3e.

Slika 3. Krupni, imbricirani klasti unutar longitudinalnog pruda. Izmjena slojeva različite veličine klasta, sortiranosti i količine matriksa. U sredini je horizont s matriksnom potporom koji pokriva horizont bez matriksa, a zajedno predstavljaju jedan ciklus taloženja. Tok je bio s desna na lijevo. Mjerilo je dugačko 19 cm. Uzorak J3e.

3. METHODS

The gravels of the investigated areas have a high degree of contact with the larger clast (Figs. 2 and 3). Measurements were limited to the direction and angle of dip of AB planes by selecting discoidal clasts (with A : B : C ratios of at least 2 : 2 : 1). The measurement of orientation was done using the AB plane rather than the B-axis (Fig. 4).

Taking into account the work by WHITE (1952), RUST (1975) and others who observed that the orientation of smaller pebbles was more scattered then that of larger particles, observations were mostly limited to clasts with long axes greater than 5 cm. Inclinations of AB planes lower than 5 or greater than 85 degrees were omitted because clast orientation with respect to the current direction could not be reliably determined. These omissions could affect the mean dip value, but horizontal clasts are rare because of the high concentration of large clasts. A vertical orientation is even rarer.

The measurements were made within uniform sedimentary units and taken from approximately rectangular outcrop areas about 50 - 100 cm high and 1.5 - 5 m long (Fig. 5). The vector mean and magnitude were calculated for each sample using CURRAY's (1956) method, and the significance of each distribution was determined from a graph provided by the same author keeping in mind that each resulting vector mean is only an estimate of the current direction at the point of measurement, and that current direction could significantly vary in both space and time. It is obvious that an increase in the size of the sample improves chances for an accurate estimate of the flow direction, but it has been considered more significant to increase the num-

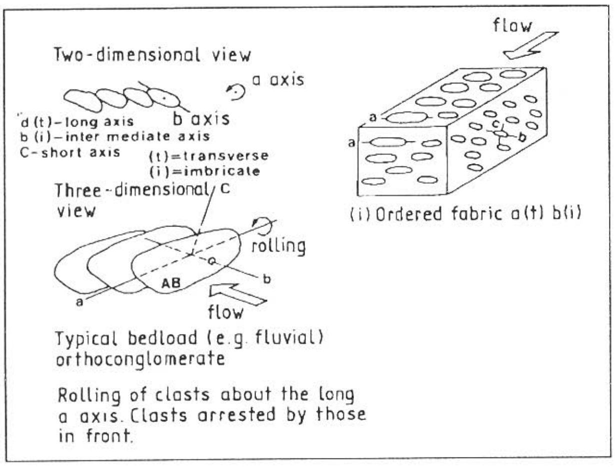


Fig. 4. The fabric of fluvial conglomerates and the nature and processes responsible for imbrication in disc- and blade-like clasts (from COLLINSON & THOMPSON, 1989, partly modified).

Slika 4. Građa fluvijalnih konglomerata, te uzrok i način imbriciranja diskoidalnih i listićavih klasta (iz COLLINSON & THOMPSON, 1989, djelomice modificirano).

ber of sites at which observations are made (RUST, 1975). An average sample size of 20, which was used in this study, is considered by RUST (1975) to be satisfactory enough. Twenty-five out of 26 samples have a significant preferred orientation (Table 1).

Samples were either taken from layers of measured sections, or from laterally extensive outcrops (Figs. 5 and 8b). In the former case, positions of samples are in the relative columns (initial capital letter and number); small letters refer to particular parts of the sections, and Roman numbers to particular parts of the outcrops (Fig. 5; Table 1).

All measurements are corrected by stereonet because of the tectonic tilt of the whole conglomerate succession.

4. ANALYSIS OF ORIENTATION DATA

Statistics derived from the orientation data are shown in Table 1 and Figs. 5 and 8a. For the sake of clarity, the dip directions of AB planes are treated separately from the dip angles.

4.1. DIP DIRECTION OF THE AB PLANE

Analysis of data from individual clast samples displays some characteristic trends. It is significant that the more preferred orientation with an average vector magnitude of 83.74% (Table 1) was mostly shown by the larger clasts (mean max. A-axes from 10.1 cm to 32.4 cm). For the samples with smaller clasts (mean max. A-axes less than 10.1 cm), the average vector magnitude was 74.52%, and in one case (sample S2a, Table 1), the preferred orientation is not significant. In a mixed-size population (poorly sorted) the orientation of the finer fraction has greater variance than the coarse fraction that possesses a stronger preferred orientation. The explanation for the more strongly preferred orientation of larger clasts is that they are only moved during high stages of flow, when current direction is not significantly reflected from the channel axis.

Taking all samples into consideration, their vector means vary between 203° and 254° and their grand vector mean is 226° (Fig. 5; Table 1), and taking samples from vertical succession into consideration, the vector means vary between 203° and 254° (Fig. 5), while the grand vector is 225° (Table 1).

The samples with larger clasts (mean max. a-axes more than 10 cm) have mean vectors between 216° and 254° while their grand mean vector is 228° (Table 1).

Contemporaneous or approximately contemporaneous samples (BI, BII, BIII, CI, CII, J2a) have the mean vectors from 209° to 235° (Fig. 5) and their grand mean vector is 224° (Table 1).

4.2. INCLINATION OF THE AB PLANE

The average dip angle for each sample, and also the overall average dip angle (from 15.1° to 29.9° and 24.3°, respectively) (Table 1) are not much lower than those obtained in similar earlier works (FOLK & WARD, 1957; LAMING, 1966; RUST, 1975).

The data from this study do not display conclusive relationships between the clast size or shape and inclination (CAILLEUX, 1945; JOHANSSON, 1965). The only observed relationship is between the packing and dip angles, steeper inclinations occurring in tighter-packed conglomerates, as they are a stable depositional feature only at a higher degree of packing (RUST, 1975).

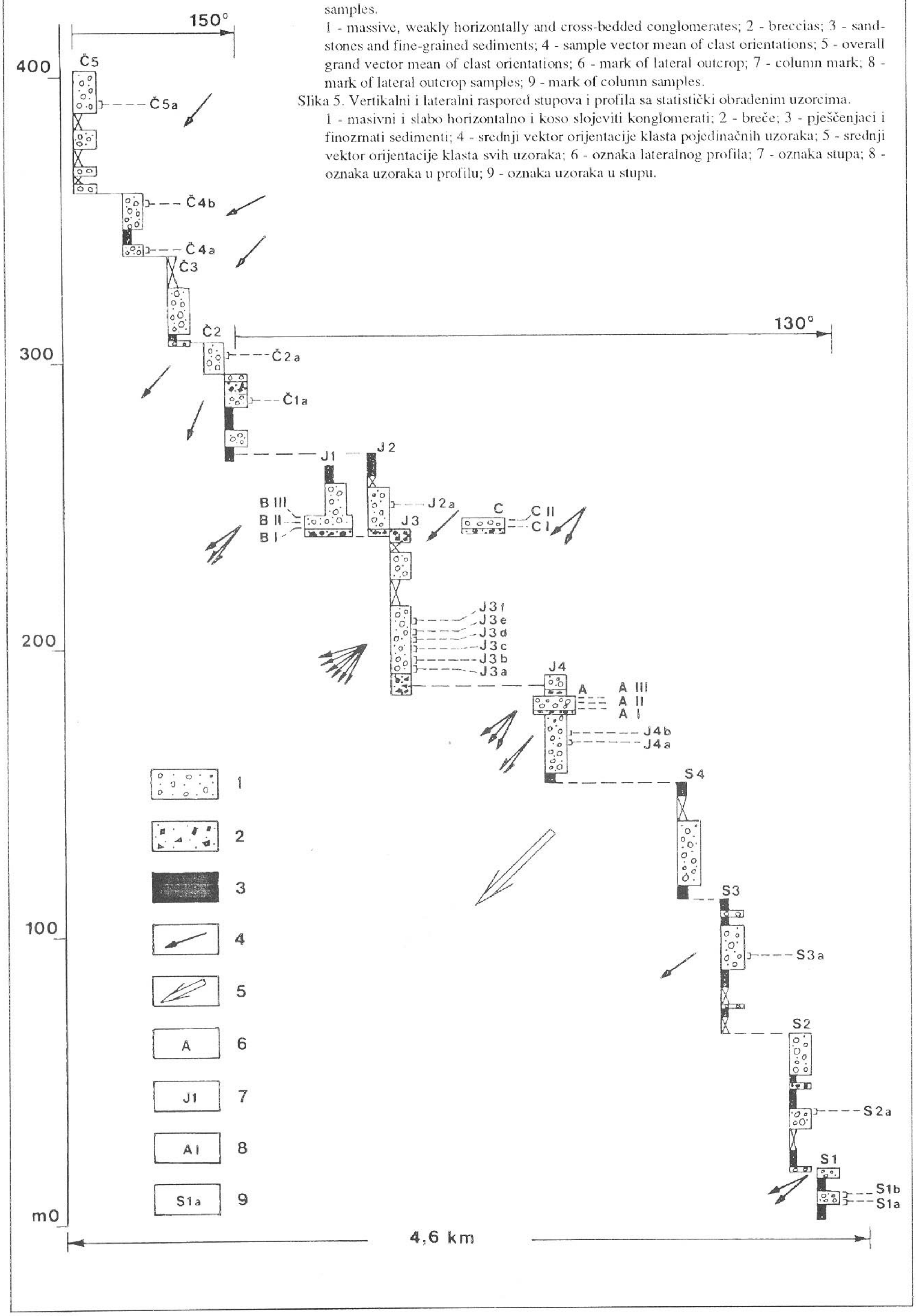
5. BAR MORPHOLOGIES AND THEIR INTERNAL STRUCTURES

Longitudinal bars are thought to be by far the most abundant type of bars in the studied area. They should be recorded by conglomerate sheets 0.3 - 1.5 m (mainly 0.5 - 1 m) thick, and with massive or weakly horizontally or subhorizontally bedded interior. Their internal beds have a short extension in flow direction (from several dm to about ten m) and thickness proportional to the clast size (from several cm to 0.5 m) (Figs. 2, 6 and 7). This flat internal stratification is due to the alternation of "beds" displaying different clast size, clast sorting or matrix content. In the vertical successions composed entirely of coarse conglomerates, individual units may be distinguished by scoured or slightly erosive surfaces or by very thin sandstone sheets between them.

The modern longitudinal bars are elongate, diamond - shaped in plan with a slightly convex upper surface, and range size from several metres to a few tens or a few hundreds of metres in length and width. The coars-

Fig. 5. The vertical and lateral arrangement of columns and profiles with indication of studied samples.
1 - massive, weakly horizontally and cross-bedded conglomerates; 2 - breccias; 3 - sandstones and fine-grained sediments; 4 - sample vector mean of clast orientations; 5 - overall grand vector mean of clast orientations; 6 - mark of lateral outcrop; 7 - column mark; 8 - mark of lateral outcrop samples; 9 - mark of column samples.

Slika 5. Vertikalni i lateralni raspored stupova i profila sa statistički obrađenim uzorcima.
1 - masivni i slabo horizontalno i koso slojeviti konglomerati; 2 - breče; 3 - pješčenjaci i finozrnati sedimenti; 4 - srednji vektor orijentacije klasta pojedinačnih uzoraka; 5 - srednji vektor orijentacije klasta svih uzoraka; 6 - oznaka lateralnog profila; 7 - oznaka stupa; 8 - oznaka uzoraka u profilu; 9 - oznaka uzoraka u stupu.



Sample	Number of clasts	Mean max. size (cm)	Vector mean (°)	Vector magnitude (%)	Mean dip angle (°)	Significance	Lithofacies
AI	25	14.3	222	71.42	28.2	$<10^{-5}$	Gm
AII	27	8.4	235	68.30	29.8	$<10^{-5}$	Gm
AIII	24	10.6	216	79.57	19.8	$<10^{-5}$	Gp
BI	21	14.8	217	81.59	20.0	$<10^{-5}$	Gm
BII	20	12.9	221	67.60	23.3	$<10^{-3}$	Gm
BIII	21	10.3	235	79.93	20.5	$<10^{-5}$	Gp
CI	20	9.3	233	85.44	34.2	$<10^{-5}$	Gm
CII	23	9.5	209	72.69	29.9	$<10^{-4}$	Gm
S1a	13	2.1	229	64.93	19.1	$<10^{-2}$	Gp
S1b	20	6.5	244	85.57	18.6	$<10^{-5}$	Gm
S2a	17	9.8	167	36.44	26.2	$>10^{-1}$	Gm
S3a	14	7.9	234	65.59	18.4	$<10^{-3}$	Gm
J4a	20	8.0	223	94.12	28.3	$<10^{-5}$	Gm
J4b	10	11.3	222	96.60	26.0	$<10^{-5}$	Gm
J3a	25	22.7	244	73.89	24.4	$<10^{-5}$	Gm
J3b	12	10.1	229	95.62	24.6	$<10^{-5}$	Gm
J3c	33	4.4	216	76.90	27.2	$<10^{-5}$	Gm
J3d	11	32.4	254	87.22	24.8	$<10^{-4}$	Gm
J3e	11	20.0	232	90.31	27.7	$<10^{-5}$	Gp
J2a	24	15.2	226	78.02	15.1	$<10^{-5}$	Gm
Č1a	25	6.9	203	76.44	21.5	$<10^{-5}$	Gm
Č2a	16	12.3	225	84.61	28.6	$<10^{-5}$	Gm
Č4a	15	12.3	223	93.85	24.6	$<10^{-5}$	Gm
Č4b	16	15.5	241	90.78	22.1	$<10^{-5}$	Gm
Č5a	20	12.5	219	85.07	25.5	$<10^{-5}$	Gm

Overall grand vector mean - 226°
Grand vector mean of samples in vertical succession - 225°
Grand vector mean of contemporaneous samples - 224°

Table 1. Clast orientation data.
Tablica 1. Podaci o orijentaciji klasta.

est material is concentrated on the upstream apex of the bar, with a downflow decrease in grain size (RUST, 1972; SMITH, 1974; BOOTHROYD & ASHLEY, 1975). The mean orientation of the long bar axes is almost the same as the mean vector of their coarse clast orientation (RUST, 1975).

At falling stages, a lateral accretion of bar margins, or construction of microdeltas into slough channels is more important than a downstream bar migration and leads to forming cross-bed sets with less coarse gravels and sandy gravels. The cross-bed sets are planar, with an average thickness between 0.1 - 1 m and are usually thicker at their bases. Their lateral extension is up to 5 m and the inclination of foresets between 15° and 25°. The foreset beds are 5-15 cm thick, angularly based, and display in places very thin sand lenses and reactivation surfaces between them. The sets have flat or slightly erosive bases while their tops are horizontal or roughly erosive. They pass laterally into sheet-like or channel fill conglomerates. Since the foreset dip directions andclast fabric were created at falling stage, they could not be reliable indicators of the current direction at high stage or the channel axis.

Fig. 6. Cross-stratified conglomerate. Note the alternation of foresets characterized by different clast size, sorting and matrix content. The scale is 22 cm long. Sample BII.
Slika 6. Koso stratificirani konglomerati. Vidljiva izmjena kosih setova s različitom veličinom klasta, sortiranjem i količinom matriksa. Mjerilo je dugačko 22 cm. Uzorak BII.

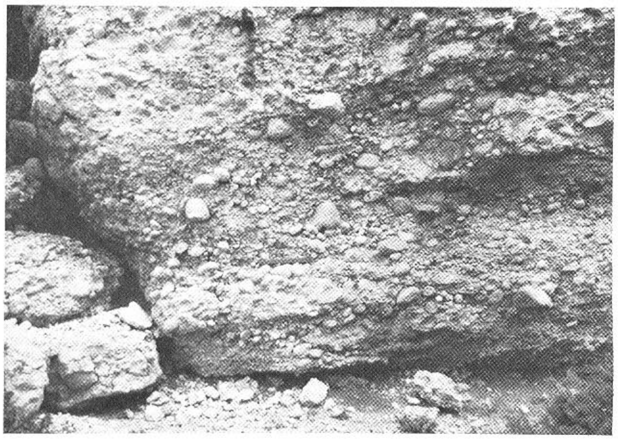


Fig. 7. Weakly horizontally stratified conglomerates (facies Gm). Note the alternation of unit with different clast size, sorting and matrix content. The coarsest clasts are imbricated towards observer. The scale is 22 cm long. Sample BI.

Slika 7. Slabo horizontalno stratificirani konglomerati (facijes Gm). Izmjena kratkih slojeva s različitom veličinom klasta, sortiranjem i količinom matriksa. Najveći klasti su imbricirani prema motritelju. Mjerilo je dugačko 22 cm. Uzorak BI.

6. FORMATION OF GRAVEL BRAID BARS

Acording to many authors (ORE, 1964; WILLIAMS & RUST, 1969; SMITH, 1974; RUST, 1975, 1978; RAMOS & SOPEÑA, 1983) conglomerate sheets are the remnants of ancient longitudinal bars that may have been initiated as a diffuse sheet or primary bedform during or immediately after the high flood stage when the stream was strong enough to move all bed material (LEOPOLD & WOLMAN, 1957; SMITH, 1974; HEIN & WALKER, 1977; RAMOS & SOPEÑA, 1983). The coarsest fraction within the bed load was deposited and acted as a trap for other clasts (LEOPOLD & WOLMAN, 1957; SMITH, 1974) or as a stable, primary bed form (RUST, 1975, 1978). In any case, a bar developed with a crude horizontal stratification and imbricate clasts; the sheet-like geometry and absence of cross stratification suggests that most of the clasts tended to move horizontally and accrete vertically during the high flow stage, rather than by avalanching at bar margins (EYNON & WALKER, 1974).

A B-axis imbrication is common inside sheets and gives information about paleocurrent directions. The large and discoidal clasts are particularly reliable indicators because they were oriented at high stage and were not later removed at low stage, thus showing a minimum deviation from the trend of the main channel.

The clasts inside the bars are in mutual contact with little or no matrix (openwork gravels) or more commonly with sandy matrix; sand was carried in suspension above gravels during flow stage and later deposited at falling stage inside gravels, infilling pores but not reaching the lower part of gravel beds. As a consequence, composite beds were originated with the lower openwork gravels and upper sand-filled gravels that actually represent one cycle of deposition (SMITH, 1974).

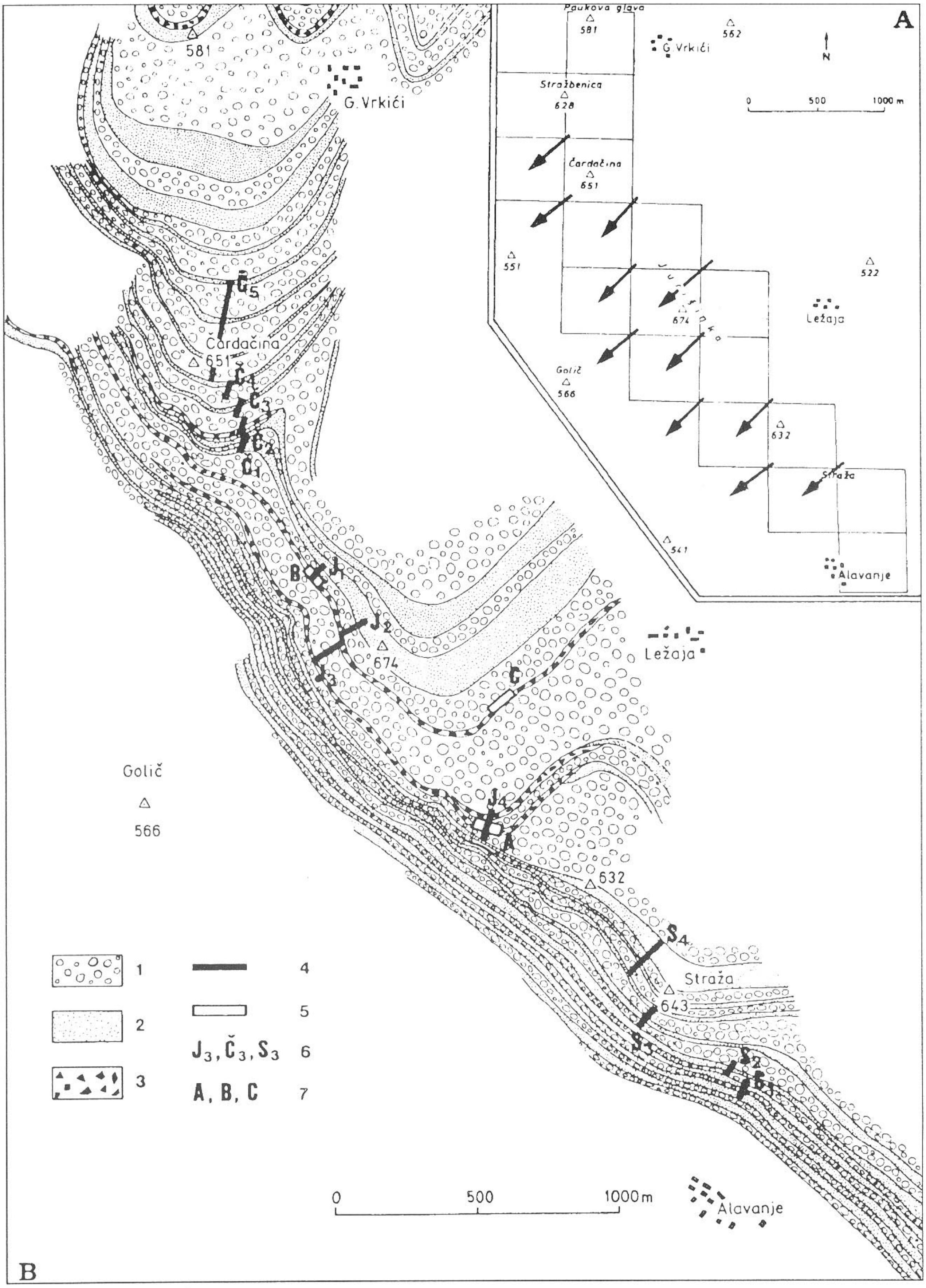
The planar cross-bedded conglomerates that are found laterally and on the top of longitudinal bars represent the gradual modification of these bars by lateral accretion during falling stage. Because of the decrease in flow velocity or emergence of the bar, less clasts could be moved over the bar, but in the same time the flow was strong enough to move relatively small clasts laterally along the bar margins (SMITH, 1974). By continuing lateral accretionary processes, lateral foresets gradually developed dipping towards the channel at an angle of less than 90° to the direction of the main flow as established by imbrication of larger clasts (RUST, 1975, 1978; HAINE & WALKER, 1977; RAMOS & SOPEÑA, 1983).

7. ALLUVIAL MODEL: DISCUSSION

A few papers were concerned with the Conglomerate Unit of the Promina formation in northern Dalmatia. They describe facies characteristics and vertical and lateral relationships (BABIĆ & ZUPANIČ, 1983, 1985, 1988, 1990; POSTMA et al., 1988; MRINJEK, 1989). These works along with the detailed study of clast orientation in this paper seem to be sufficient for considering the alluvial succession as the subaerial part of a braid delta (in the sense of McPHERSON et al., 1987). This section will try to demonstrate it and also propose a depositional model in this part of northern Dalmatia during the Late Eocene - Early Oligocene period.

Continuous but cyclically repeated prograding transition from shelf muds and sands through shoreface sands and Gilbert-type foreset conglomerates into the alluvial (braided-type) conglomerate succession (topic of this study) was established and in detail described by BABIĆ & ZUPANIČ (1990) between the villages of Karin and Gornje Drače (Fig. 1c), several kilometres south of Obrovac. During the study of this large-scale prograding sequence, the mentioned authors found hummocky cross-stratified or low-angle laminated shoreface and shelf sandstones with thin conglomerate lenses, grading upwards into large-scale (metres thick) foreset conglomerates comparable to Gilbert-type bodies; the latter show evidence of a high rate of coarse sediment input by debris flow, turbidity current, slumping or sliding (POSTMA et al., 1988) and of partial reworking by marine fair-weather and especially storm processes. Prograding small-scale sequences are separated by erosional surfaces covered by thin transgressive and bioturbated lags of conglomerates and pebbly sandstones with benthic foraminifers. According to BABIĆ & ZUPANIČ (1990) the stacking of sequences has been caused by alternating progradational and transgressive tendencies and represents a typical style of basin filling.

Previous works (BABIĆ & ZUPANIČ, 1983, 1985, 1988; MRINJEK, 1989) established that the studied alluvial succession has a thickness in excess of 600 m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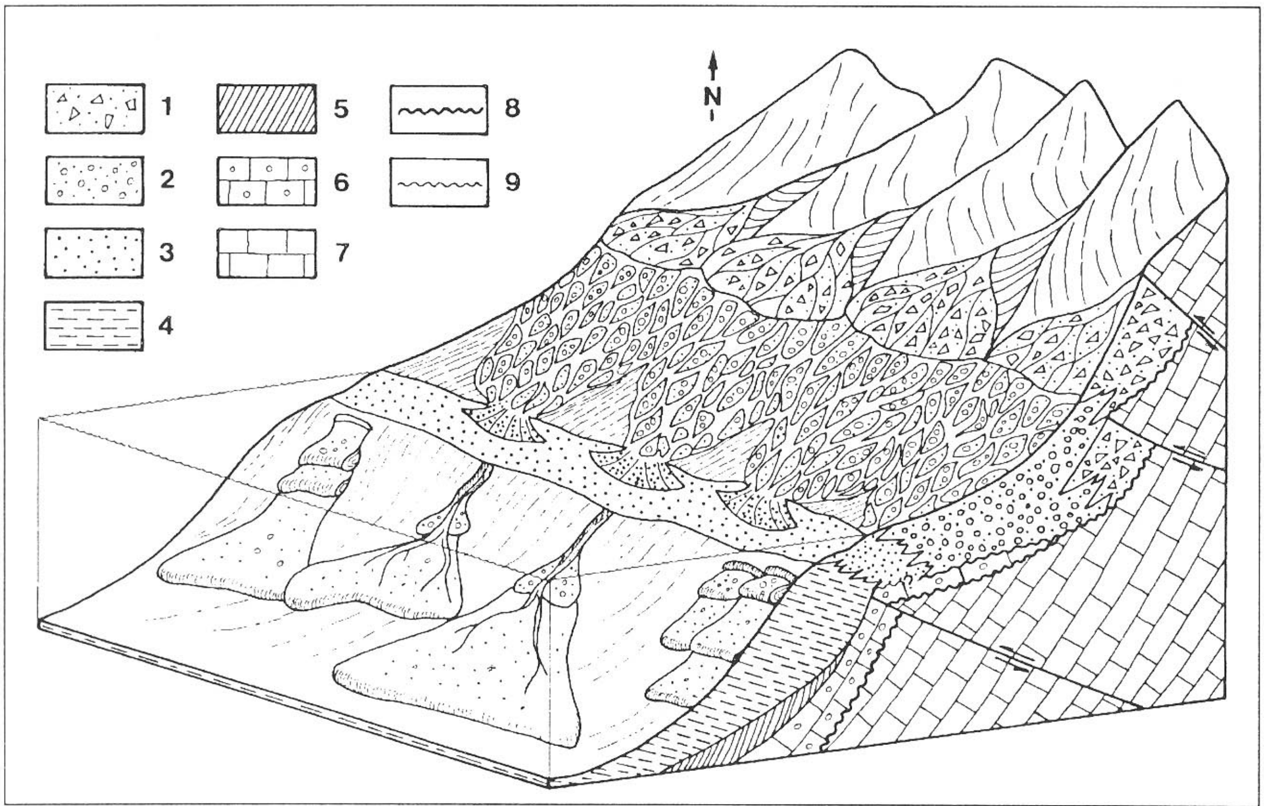

Fig. 9. Hypothetic depositional model of the Promina beds within the sector Benkovac - Obrovac. 1. Jelar breccia, 2. Alluvial Promina beds, 3. Shallow-marine Promina beds, 4. Deep-marine Promina beds, 5. Flysch, 6. Foraminiferal limestone, 7. Cretaceous and Jurassic carbonates, 8. Subaerial unconformities, 9. Submarine uncofomities.

Slika 9. Hipotetički model taloženja Promina naslaga izmedu Benkovca i Obrovca. 1. Jelar breče, 2. Aluvijalne Promina naslage, 3. Plitkomorske Promina naslage, 4. Dubokomorske Promina naslage, 5. Fliš, 6. Foraminiferski vapnenac, 7. Kredni i jurski karbonati, 8. Kopnena diskordancija, 9. Podmorska diskordancija.

and covers a vast area. The studied part of alluvial succession is either found far from the fault zone or did not have direct associaton with it. The alluvial suite contains sheet-like and channel fill conglomerates (facies Gm), in common association with cross-bedded conglomerates and sandstones (facies Gp, Gt, Sp, St), and very rare sheet-like breccias (facies Gms) whereas overbank sediments (Sh, Fl, Fm) are subordinate (BABIĆ & ZUPANIČ, 1988; MRINJEK, 1989). Coarsening upwards and coarsening-fining upwards cycles (BABIĆ & ZUPANIČ, 1988; MRINJEK, 1989; KURTANJEK, 1992) and a vertical alternation of proximal and distal facies associations can be attributed to the superimposition of short-term eustatic (or climatic?) fluctuations to the progradation of the alluvial system; the latter which was caused by a thrust emplacement in the northern part of the Promina basin coupled with rapid subsidence of the basin in front of the carbonate thrust sheets (Figs. 1b and 9). The facies associations, high lateral continuity of some lithofacies, and a very rare occurrence of sheet-like massive debris flow breccias (BABIĆ & ZUPANIČ, 1988) are characteristic of braided-river and braided-plain environments that are highly channelized with a deeper and more sustained flow than alluvial-fan environments (BOOTHROYD & ASHLEY, 1975; MIALL, 1978; RUST, 1978). The preferred clast orientation through the vertical succession, pointing to consistent SW-ward flow direction, also supports a gravelly braided river and braided plain environment, rather than an alluvial-fan setting.

The Jelar formation is closely related to a tectonically active mountain front (fault zones) forming alluvial fans and serving as a source of the carbonate detritus for the Promina beds (Figs. 1b and 9).

The earlier-mentioned vertical transition from shallow-marine to braided-river and braided-plain sediments, together with facies characteristics and paleocurrent pattern suggest deposition in an extensive and com-

Fig. 8. A - Moving average paleocurrent map based on the clast orientation data.
B - Map of the main lithofacies distribution.
1 - conglomerates (facies Gm, Gp, Gt); 2 - sandstones and fine-grained sediments (facies Sp, St, Sh, Sr, Fl, Fm); 3 - breccias (facies Gms);
4 - position of column; 5 - position of outcrop showing lateral relationships; 6 - column mark; 7 - lateral outcrop mark.

Slika 8. A - Karta srednjih smjerova paleostruja na osnovi podataka o orijentaciji klasta.
B - Karta rasporeda glavnih litofacijesa.
1 - konglomerati (facijesi Gm, Gp, Gt); 2 - pješčenjaci i finozrnati sedimenti (facijesi Sp, St, Sh, Sr, Fl, Fm); 3 - breče (facijes Gms);
4 - položaj stupa; 5 - položaj lateralnog profila; 6 - oznaka stupa; 7 - oznaka lateralnog profila.

plex coarse-grained braid-delta system (McPHERSON at al., 1987). In this case, and according to McPHERSON et al. (1987), the alluvial conglomerates are the subaerial component that progrades into a standing body of water, whereas the repeatedly prograding sequences described by BABIĆ & ZUPANIČ (1990) represent the shoreline and subaqueous component of coarse-grained deltas.

8. CONCLUSIONS

From the above described results and discussions it is possible to draw following conclusions:

1. Statistical analysis of numerous clast-imbrication measurements shows consistent paleoflow direction towards the SW (the sample vector means are between 203° and 254° with magnitudes between 64.93% and 96.60%).

2. Previous works as well as data presented in this paper suggest deposition in a complex and broad braided river environment where large amounts of coarse-grained materials were supplied from tectonically active and elevated basin margins.

3. The vertical transition from shallow-marine and shoreline sandstones and conglomerates into the studied alluvial succession suggest that the complex braided river system is the subaerial component of a cyclically prograding braid-delta.

4. The vertical alternation of proximal and distal facies associations in the alluvial succession and repeated progradation of shallow-marine and shoreline sequences suggest short-term eustatic fluctuations superimposed on an overall tectonically-induced deltaic progradation.

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9. REFERENCES

BABIĆ, Lj. & ZUPANIČ, J. (1983): Paleogene clastic formations in Northern Dalmatia. In: Contributions to sedimentology of Some Carbonate and clastic Units of the coastal Dinarides.- In: BABIĆ, Lj. & JELASKA, V. (eds.): Excursion Guide-book, 4. I.A.S. Regional Meeting (Split 1983), 37-61.

BABIĆ, LJ. & ZUPANIČ, J. (1985): Promina-naslage sjeverne Dalmacije: raznolikost sedimentacijskuih okoliša i litostratigrafskih nomenklatura.- Geol. glasnik, Sarajevo, 28, 139-142.

BABIĆ, LJ. & ZUPANIČ, J. (1988): Coarse-grained alluvium in the Paleogene of Northern Dalmatia (Croatia, Yugoslavia).- Rad Jugosl. akad. znan. umjetn., Zagreb, 441, Razr. prir. znan., 23, 139-164.

BABIĆ, LJ. & ZUPANIČ, J (1990): Progradational sequences in the Paleogene clastic basin of the Outer Dinarids, from Northern Dalmatia to Western Hercegovina.- Rad Jugosl. akad. znan. umjetn., Zagreb, 449, Razr. prir. znan., 24, 319-343.

BAHUN, S. (1974): Tektogeneza Velebita i postanak Jelar-naslaga.- Geol. vjesnik, 27, 35-51.

BLUCK, B.J. (1967): Deposition of some Upper Old Red Sandstone conglomerates in the Clyde area: A study in the significance of bedding.- Scott. J. Geol., 3/2, 139-167.

BOOTHROYD, J.C. & ASHLEY, G.M. (1975): Processes, bar morphology, and sedimentary structures on braided outwash fans, northeastern Gulf of Alaska.- In: JOPLING, A.V. & McDONALD, B.C. (eds.): Glaciofluvial and Glaciolacustrine Sedimentation. Soc. Econ. Pal. Mineral., Spec. Publ., 23, 193-222.

CAILLEUX, A. (1945): Distinction des galets marins et fluviatiles.- Bull. Soc. Geol. France, 15, 375-404.

COLLINSON, J.D. & THOMPSON, D.B. (1989): Sedimentary structures.- Unwin & Hyman, London, 207 p.

CURRAY, I.R. (1956): The analysis of two-dimensional orientation data.- J. Geol., 64, 117-131.

EYNON, G. & WALKER, R.G. (1974): Facies relationships in Pleistocene outwash gravels, Southern Ontario: a new component of the braided river model.- J. Sediment. Petrol., 42, 389-400.

FOLK, R.L. & WARD, W.C. (1957): Brazos River bar: study in the significance of grain size parametres.- J. Sediment. Petrol., 27, 3-26.

HEIN, F.J. & WALKER, R.G. (1977): Bar evolution and development of stratification in the gravelly, braided, Kicking Horse River, British Columbia.- Can. J. Earth Sci., 14, 562-570.

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

IVANOVIĆ, A., MULDINI-MAMUŽIĆ, S., SAKAČ, K., VRSALOVIĆ-CAREVIĆ, I. & ZUPANIČ, J. (1969): Razvoj paleogenskih naslaga na širem području Benkovca i Drniša u sjeverozapadnoj Dalmaciji.- 3. simp. Dinarske asoc., Zagreb, 1 (1968), 51-71.

JOHANSSON, C.F. (1965): Structural studies of sedimentary deposits.- Geol. foren. Forh., Stockholm, 87, 3-61.

LAMING, D.J.C. (1966): Imbrication, paleocurrents, and other sedimentary features in the Lower New Red Sandstones, Devonshire, England.- J. Sediment. Petrol., 36, 940-957.

KURTANJEK, D. (1992): Značajke i postanak sitnozrnatih sedimenata mlađe Promine kod Karina u sjevernoj Dalmaciji.- M.Sc. Thesis, University of Zagreb, 54p.

LEOPOLD, L.B. & WOLMAN, M.G. (1957): River channel patterns: braided, and straight.- Prof. Pap. U.S. Geol. Surv., 282-B, 85 p.

McPHERSON, J.G., SHANMUGAM, G. & MOIOLA, R.J. (1987): Fan-deltas and braid deltas: Varieties of coarse-grained deltas.- Bull. Geol. Soc. Amer., 99, 331-340.

MIALL, A.D. (1978): Lithofacies types and vertical profile models in braided river deposits.- In: MIALL, A.D. (ed.): Fluvial Sedimentology. Mem. Can. Soc. Petrol. Geol., Calgary, 5, 587-604.

MRINJEK, E. (1989): Alluvial conglomerates in Promina Formation.- 4. Int. Confer. on Fluv. Sediment., Barcelona, Sitges, 189.

ORE, H.J. (1964): Some criteria for recognition of braided stream deposits.- Univ. Wyoming Contr. Geol., 3, 1-14.

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 and Son, 91-102.

RAMOS, A. & SOPEÑA, A. (1983): Gravel bars in low-sinuosity streams (Permian and Triassic, central Spain).- Int. Assoc. Sediment., Spec. Publ., 6, 301-312.

RUST, B.R. (1972): Structure and process in a braided river.- Sedimentology, 18, 221-245.

RUST, B.R. (1975): Fabric and structure in glaciofluvial gravels.- In: JOPLING, A.V. & McDONALD, B.C. (eds.): Glaciofluvial and Glaciolacustrine Sedimentation. Soc. Econ. Pal. Mineral., Spec. Publ., 23, 238-248.

SMITH, N.D. (1974): Sedimentology and bar formation in the Upper Kicking Horse River, a braided outwash stream.- J. Geol., 82, 205-223.

WHITE, W.S. (1952): Imbrication and initial dip in a Keweenawan conglomerate bed.- J. Sediment. Petrol., 22, 189-199.

WILLIAMS, P.F. & RUST, B.R. (1969): The sedimentology of a braided river.- J. Sediment. Petrol., 39/2, 649-679.

Građa konglomerata i mjerenje smjerova paleostruja u prepletenom riječnom sustavu Promina naslaga u sjevernoj Dalmaciji (Hrvatska)

E. Mrinjek

U sjevernoj Dalmaciji, unutar sektora Benkovac-Obrovac, otkrivene su naslage formacije Promina (gornji lutet do vjerojatno donji oligocen, IVANOVIĆ et al., 1969) u slijedu debelom oko 2000 m. One konkordantno pokrivaju naslage fliša ili su diskordantne na krednim i paleogenskim vapnencima (u istočnijem dijelu sjeverne Dalmacije). Promina naslage obilježava i prijelaz iz marinskog u aluvijalni okoliš, te su stoga podijeljene u tri jedinice: Karbonatna turbiditna jedinica, Prijelazna jedinica i Konglomeratna jedinica (BABIĆ & ZUPANIČ, 1983), (sl. 1b and 1c).

Donji dio Konglomeratne jedinice taložio se u plitkomorskom i obalnom okolišu (BABIĆ & ZUPANIČ, 1990), dok je njezin gornji dio, koji je predmet ovog istraživanja, stvaran u prepletenom riječnom sustavu prudova i blago sinusoidnih kanala (BABIĆ & ZUPANIČ, 1988; MRINJEK, 1989). Konglomerati su dominirajući član u istraživanom slijedu (više od 60%), dok pješčenjaci, sitnozrnati sedimenti i breče čine ostatak slijeda.

Glavni cilj rada bio je opisati osnovnu građu konglomerata kao i otkriti paleosmjerove glavnih struja, tj. vertikalnu i lateralnu stalnost ili promjenjivost njihovih smjerova. To je postignuto mjerenjem imbrikacije klasta unutar fosilnih prudova, u svrhu utvrđivanja osnovnih značajki aluvijalnog okoliša.

Srednja maksimalna veličina klasta (BLUCK, 1967) varira između 2,1 cm i 32,4 cm, ali većinom između 10 do 15 cm, a pojedini mogu doseći i do 45 cm. Klasti su uglavnom srednje do dobro zaobljeni, također srednje do dobro sortirani i često transverzalno imbricirani, što se može dobro uočiti kod većih diskoidalnih klasta. Klasti su gotovo u pravilu u međusobnoj potpori, pri čemu je najvećim dijelom prostor između klasta ispunjen pješčanim ili sitnozrnatim matriksom (sl. 2, 3, 6 i 7). Rjeđe se mogu uočiti izolirani horizonti bez matriksa (sl. 3), koji, zajedno s horizontom klasta s matriksom ispod sebe, predstavljaju jedan cjeloviti taložni ciklus (SMITH, 1974).

Smjer nagiba klasta određivan je mjerenjem smjera nagiba AB plohe klasta. Mjeren je i njezin kut nagiba (sl. 4). Mjerenja su bila ograničena na klaste diskoidalnog oblika, ili na one koji su bliski tom obliku, kao i na klaste s osi a dužom od 5 cm. Klasti s nagibom AB plohe manjim od 5° i većim od 85° nisu uzimani u obzir. Analizirano je 26 uzoraka odabranih iz detaljno opisanih stupova i lateralnih profila raspoređenih na vrlo širokom prostoru (sl. 5 i 8; tablica 1). Mjerenja su obavljena unutar uniformne jedinice konglomerata, tj. unutar zamišljenih pravokutnika dužine 1,5-5 m i visine 0,5-1 m. Nastojalo se da se unutar svakog uzorka obavi 20 ili više mjerenja (tablica 1). Srednji vektor i magnituda uzoraka izračunati su Currayevom metodom, dok je značenje svakog uzorka određeno grafičkom metodom (CURRAY, 1956), pri čemu se pokazalo da samo jedan uzorak nije signifikantan (uzorak S2a). Glavni srednji vektor svih uzoraka iznosi 226°, a njihovi srednji vektori variraju između 203° i 254°. Uzorci s većim klastima (srednja vrijednost a osi veća od 10 cm) imaju manju raspršenost svojih srednjih vektora (između 216° i 254°), a glavni srednji vektor iznosi 228° (sl. 5; tablica 1). Podaci mjeranja kod uzoraka s većim klastima imaju veću važnost, jer ukazuju na smjer jačih, odnosno glavnih tokova. Rezultati mjerenja ukazuju na jako preferiranu orijentaciju glavnih struja u jugozapadnom smjeru (sl. 5 i 8).

Longitudinalni prudovi su najčešći tip prudova u istraživanom području. Morfološki oni predstavljaju pokrove konglomerata debljine 0,3-1,5 m, dekametarskog lateralnog pružanja, masivne ili nejasno horizontalno ili subhorizontalno slojevite unutarnje građe. Njihovi slojevi su relativno kratkog lateralnog pružanja (od nekoliko cm do najviše 10 m), a debljina je u proporcionalnom odnosu s prosječnom veličinom klasta (od nekoliko cm do 0,5 m). Unutarnja stratifikacija je posljedica izmjene razina s različitom veličinom klasta, količinom matriksa i stupnjem sortiranja (sl. 2, 3 i 7). Poznato je da su recentni longitudinalni prudovi izduženog oblika, blago konveksne površine, dužine i širine od nekoliko metara pa čak do nekoliko stotina metara (RUST, 1972; SMITH, 1974; BOOTHROYD & ASHLEY, 1975). Orijentacija osi pružanja paralelna je sa smjerom struje i ista ili vrlo slična srednjem vektoru imbrikacije najvećih klasta unutar samog pruda (RUST, 1975). Prema mnogim autorima (ORE, 1964; WILLIAMS & RUST, 1969; SMITH, 1974; RUST, 1975, 1978; RAMOS & SOPEÑA, 1983) pokrovi konglomerata su fosilni ostaci longitudinalnih prudova, te predstavljaju njihov začetak za vrijeme ili neposredno poslije najjačih struja koje su nosile sav materijal, uključujući i najkrupnije klaste. Takvi su pokrovi dalje služili kao jezgra ili primarni sloj koji se daljnjim slabljenjem toka kretao niz tok, kao i u visinu vertikalnim prirastom klasta (LEOPOLD & WOLMAN, 1957; SMITH, 1974; RUST, 1975, 1978; EYNON & WALKER, 1974). Transverzalna imbrikacija klasta unutar pokrova je česta pojava, a posebice je važna imbrikacija većih klasta koji su taloženi i orijentirani za najjačih i glavnih tokova. Oni su stali nepromijenjena položaja za vrijeme slabih tokova koji u smjeru mogu znatno odstupati od onih najjačih.

Slabljenjem struje i lateralnim prirastom klasta na rubovima pruda dolazi do formiranja forsetova izgrađenih od sitnijih klasta i više pijeska. Smjerovi nagiba takvih forsetova mogu znatno odstupati od srednjeg vektora orijentacije klasta, odnosno od smjera glavnog toka (RUST, 1975, 1978; HAINE & WALKER, 1977; RAMOS & SOPEÑA, 1983).

Velika lateralna rasprostranjenost istraživanog slijeda, karakteristike facijesa, ciklična izmjena konglomerata (facijesi Gm, Gp i Gt) s pješčenjacima (facijesi Sp, St, Sh i Sr) i sitnozrnatim sedimentima (facijesi Fm i Fl), tj. izmjena proksimalnih i distalnih karakteristika, vrlo rijetke pojave pokrova breča (facijes Gms) (BABIĆ & ZUPANIČ, 1988; MRINJEK, 1989), kao i vrlo preferirana orijentacija krupnih klasta u jugozapadnom smjeru, ukazuje na kompleksan i prostran taložni okoliš prepletenih tekućica i ravnice koji je bio pod utjecajem snažne tektonike u zaleđu, sjeverno i sjeveroistočno od istraživanog područja (sl. 9). Kontinuirani prijelaz iz plitkomorskih i obalnih naslaga u istraživane aluvijalne naslage (BABIĆ & ZUPANIČ, 1990) govore u prilog tvrdnji da je istraživani prepleteni okoliš zapravo kopnena komponenta složene i prema jugozapadu progradirajuće prepletene delte (McPHERSON et al., 1987), koja je bila pod dominatnim utjecajem tektonike u zaleđu (sl. 9).

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