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Lower Miocene Alluvial Deposits of the Požeška Mt. (Pannonian Basin, Northern Croatia): Cycles, Megacycles and Tectonic Implications

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Key words: Braided alluvial fan, Synsedimentary tectonics, Sava fault, Early Miocene, Pannonian Basin, Croatia.

Abstract

In the area of the present Požeška Mt. braided alluvial fans were formed during the Early Miocene above the subsiding Cretaceous-Palaeogene basement. Due to autocyclic processes, i.e. lateral migration of flows due to vertical aggradation of longitudinal bars, or migration of the main trench, small-scale fining-upward cycles were formed. The complete succession of the alluvial deposits is composed of two fining-upward megacycles, which are the consequence of allocyclic influences, i.e. the pulsating character of synsedimentary tectonics. Megacycles were developed parallel to backstepping of the front of the fault scarp towards the mountain massif, caused by normal faulting along the active margin of an extensional basin. This kind of depositional style indicates that the Sava fault operated as a normal fault at the beginning of its life during the Early Miocene, probably the Ottnangian.

1. INTRODUCTION

The Miocene complex of the Požeška Mt. (Figs. 1 and 2) represents a part of the SW marginal zone of the Pannonian Basin (Fig. 3), as part of Central Paratethys. Formation of the Pannonian Basin commenced in the Early and Middle Miocene, due to the collision of the African (Apulian) and European plates. The basin is located along the concave side of the A-type subduction arc, and is surrounded by the Alps, Carpathians and Dinarides (HORVÁTH & ROYDEN, 1981; HORVÁTH, 1984, 1993; ROYDEN et al., 1982, 1983a, b; ROYDEN, 1988; CSONTOS et al., 1992). It is superimposed on the older Palaeogene basinal complex as the result of the back-arc extension, and during the Miocene - Pliocene period it existed as one of many Mediterranean back-arc basins (STEGENA et al., 1975; HORVÁTH & ROYDEN, 1981; ROYDEN et al., 1982; TARI et al., 1992a, b). According to these aforementioned authors, deposition in the entire Pannonian Basin was strongly influenced by extensional tectonics. On the basis of its depositional history, PAVELIĆ (1998) attributed Early Miocene extensional processes in the area between the Sava and Drava rivers, to the formation of a rift-type basin generated by passive continental rifting (Early Miocene North Croatian Basin).

Up to the present there have been no published data on the sedimentology of the Lower Miocene (?Ottnangian) fresh-water deposits of Požeška Mt. Some characteristics of these deposits can be found in former regional works (ŠPARICA et al., 1980; ŠPARICA & BUZALJKO, 1984), where they are divided into lower and upper part, and their origin attributed to disintegration of the basement caused by intense tectonic activity. In the lower part of the succession coarse-grained clastics are common: frequent alternations of conglomerates, breccia and sandstone, as well as gravel and sand. This level is characterized by a lack of fossils, and the deposits are interpreted as "prolluvial" in origin. The upper part of these sections is composed of intercalations of marl, gravel, sand, clay and coal. This level is characterised by a fossil fauna typical for fresh-water environments, which was interpreted as lacustrine by KOCHANSKY-DEVIDÉ (1978) and KOCHANSKY-DEVIDÉ & SLIŠKOVIĆ (1978). Fresh-water deposits are probably conformably overlain by Karpatian marls, sands and gravel of marine origin (ŠPARICA et al., 1979), as a consequence of the transgression that affected vast areas of the Central Paratethys (RÖGL & STEININGER, 1983). The entire Lower Miocene sedimentary complex of Požeška Mt. is situated near the Sava fault, which was determined as a dextral strike-slip fault (HORVÁTH & ROYDEN, 1981; JAMIČIĆ, 1988, 1995; ROYDEN, 1988; RUMPLER & HORVÁTH, 1988; BERGERAT, 1989; HORVÁTH, 1993 - Fig. 3).

Considerable lithological variability of the alluvial deposits, their genetic relationship to tectonic activity, as well as their proximity to the Sava fault, made it neccessary to undertake facies analysis of these deposits. Results indicate the depositional style which enables recognition of the vertical trends and allows interpretation of autocyclic and allocyclic control on sedimentation.

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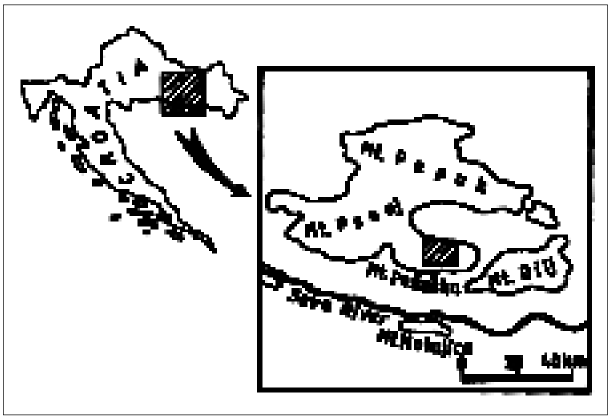

Fig. 1 Location map of the study area.

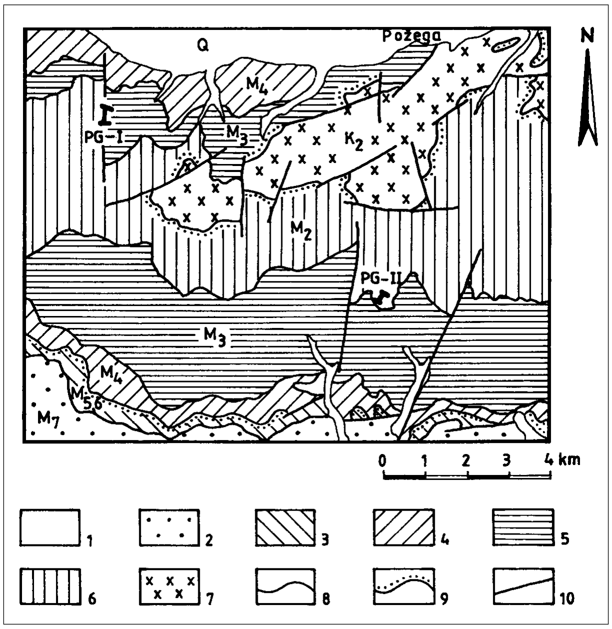

Fig. 2 Geological sketch-map of the part of Požeška Mt. (from ŠPARICA et al., 1979) with locations of sections PG-I and PG-II. Legend: 1) Quaternary; 2) Pontian; 3) Sarmatian, Pannonian; 4) Badenian; 5) Karpatian; 6) Ottnangian; 7) Upper Cretaceous; 8) normal boundary; 9) transgressive boundary; 10) fault.

2. GEOLOGICAL SETTING AND STRATIGRAPHY

Lower Miocene fresh-water deposits cover vast areas in northern Croatia, both on the surface and in the subsurface (PAVELIĆ, 1998). On the surface they are most widespread in the central and NW part of Požeška Mt. (Fig. 2).

The age of these deposits is not precisely defined by chronostratigraphic methods. In their upper part, KOCHANSKY-DEVIDÉ (1978) determined endemic species of a lacustrine macrofauna. Based on superposition and correlation with some localities in northern Croatia and northern Bosnia, these deposits are thought to be Ottnangian to Karpatian in age. ŠPARICA et al. (1980) and ŠPARICA & BUZALJKO (1984) considered these deposits as "Lower Helvetian", because of their gradual transition into the clastic sediments, the age of which is determined by foraminiferal assemblages as being of "Upper Helvetian", i.e. marine Karpatian. Later, ŠPARICA & PAMIĆ (1986) attributed an Ottnangian age to the entire fresh-water complex, but without new stratigraphic data.

The Lower Miocene sedimentary complex of Požeška Mt. (Fig. 2) unconformably overlies the pre-Miocene basement (ŠPARICA et al., 1979; HALAMIĆ et al., 1990), which in a geotectonic sense represents a part of the Supradinaric (HERAK, 1986), i.e. northern margin of the Inner Dinarides (HERAK et al., 1990; ŠIKIĆ, 1995). The Miocene basement is composed of Upper Cretaceous (ŠPARICA et al., 1979, 1980) and probably Palaeogene rocks (HALAMIĆ et al., 1993). The Upper Cretaceous deposits comprise limestones and clastic rocks (ŠPARICA et al., 1979, 1980), although a part of the clastic sequence could be Oligocene in age (HALAMIĆ et al., 1993). According to PAMIĆ & ŠPARICA (1983), ŠPARICA & PAMIĆ (1986) and PAMIĆ et al. (1990) the volcano-sedimentary complex is also of Late Cretaceous age, while BELAK et al. (1998) indicate the possibility of a continuation of the volcanic activity into the Palaeogene. Basement rocks were intensely folded during the Laramian phase of the Alpine orogeny, as well as during the post-Cretaceous tectonic activity (JAMIČIĆ et al., 1985).

After the Early Miocene, deposition continued into the Middle Miocene. During the Badenian, marine clastics and carbonates were deposited, while Sarmatian clastics and carbonates were deposited in brackish environments (ŠPARICA et al., 1980; ŠPARICA & BUZALJKO, 1984). The transition from the Early to Middle Miocene is gradual, although Pannonian deposits sporadically transgressively overlie older rocks (ŠPARICA et al., 1980; ŠPARICA & BUZALJKO, 1984). According to these authors Pannonian carbonates and marls were deposited in brackish environments, while occurrences of clastic rocks are infrequent. During the Pontian, marls and sands were also deposited in brackish, and later in fresh-water environments. They are conformably overlain by fresh-water clastic deposits of Pliocene age (ŠPARICA et al., 1980; ŠPARICA & BUZALJKO, 1984).

3. FACIES

Characteristics of the Lower Miocene alluvial deposits are well illustrated in two geological sections (Fig. 4 and Table 1), measured in the central part of Požeška Mt. (Fig. 2). Their superposition is clearly defined by detailed geological mapping. The depositional sequence measured at Požeška Gora I (PG I) is 109 m thick, and at the Požeška Gora II (PG II) its thickness is 50 m (Fig. 4). The main characteristics of these deposits are as follows: a domination of clastics over carbonates and

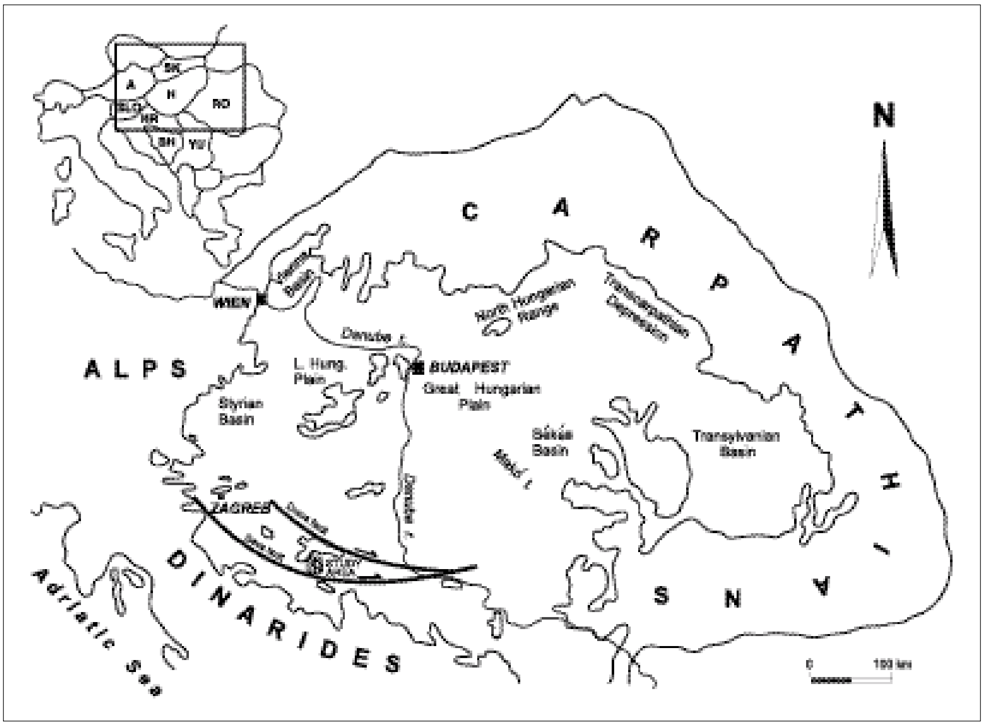

Fig. 3 Index map of the Pannonian Basin and surrounding mountain systems. The position of the Sava and Drava faults has been added (simplified after HORVÁTH, 1993).

coarse-grained over fine-grained deposits; conspicuous variations in grain size; very rapid lateral and vertical facies alternations; occurrences of red beds; changes in composition; and lack of fauna. During geological mapping it has been determined that the investigated deposits pass upward into massive unfossiliferous silts, with rare lenses of gravel exhibiting low-angle cross-bedding and massive fabric. These deposits are overlain by lacustrine fossiliferous silts and marls with interbeds of gravel, sand, clay and coal lenses (ŠPARICA et al., 1980).

Deposits in the measured sections were grouped into nine facies units: 1) massive matrix-supported conglomerates (Gmu - plastic debris flow), 2) massive

Code	Facies	Position in sections	Sediment structure and main characteristics	Interpretation
Gmu	massive conglomerates, matrix-supported	PG-I: 14-86 m PG-II: 14-17 m	no grading, reddish colour, fragments up to 10 cm long	plastic debris flow
Gmi	massive conglomerates, matrix-supported, rare clast-supported	PG-I: 23-94 m	inverse to normal grading, reddish colour, fragments up to 40 cm long	pseudoplastic debris flow
Bcn	massive breccia, clast-supported	PG-I: 0-5 m and 99-109 m	crude normal grading, fragments up to 70 cm long	rock-fall
Gc	massive conglomerates, clast-supported	PG-I: 23-95 m PG-II: 0-50 m	crude normal grading, imbrication $a_{(t)}$ $b_{(i)}$, low-angle cross-bedding; no grading; fragments up to 200 cm long	main fan-trench; longitudinal bar
Ge	pebble to granule conglomerates	PG-I: 13-97 m PG-II: 2-49 m	lenses	stream flows; crevasse channels
Sh	fine- to coarse-grained sandstones	PG-I: 15. and 99. m PG-II: 1-49 m	horizontal lamination	upper flow regime
F1	silt	PG-I: 18-96 m	massive, brown colour	flood plain; abandoned channel
F2	silt, scattered granules, rare calcrete	PG-I: 11-99 m PG-II: 7-49 m	indications of a soil-forming processes, reddish colour	palaeosol
P	calcrete	PG-I: 14. m and 96-98 m	horizontal lamination	palaeosol

Table 1 Facies, their main characteristics and interpretation. Codes are modified after MIALL (1978a) and WARESBACK & TURBEVILLE (1990).

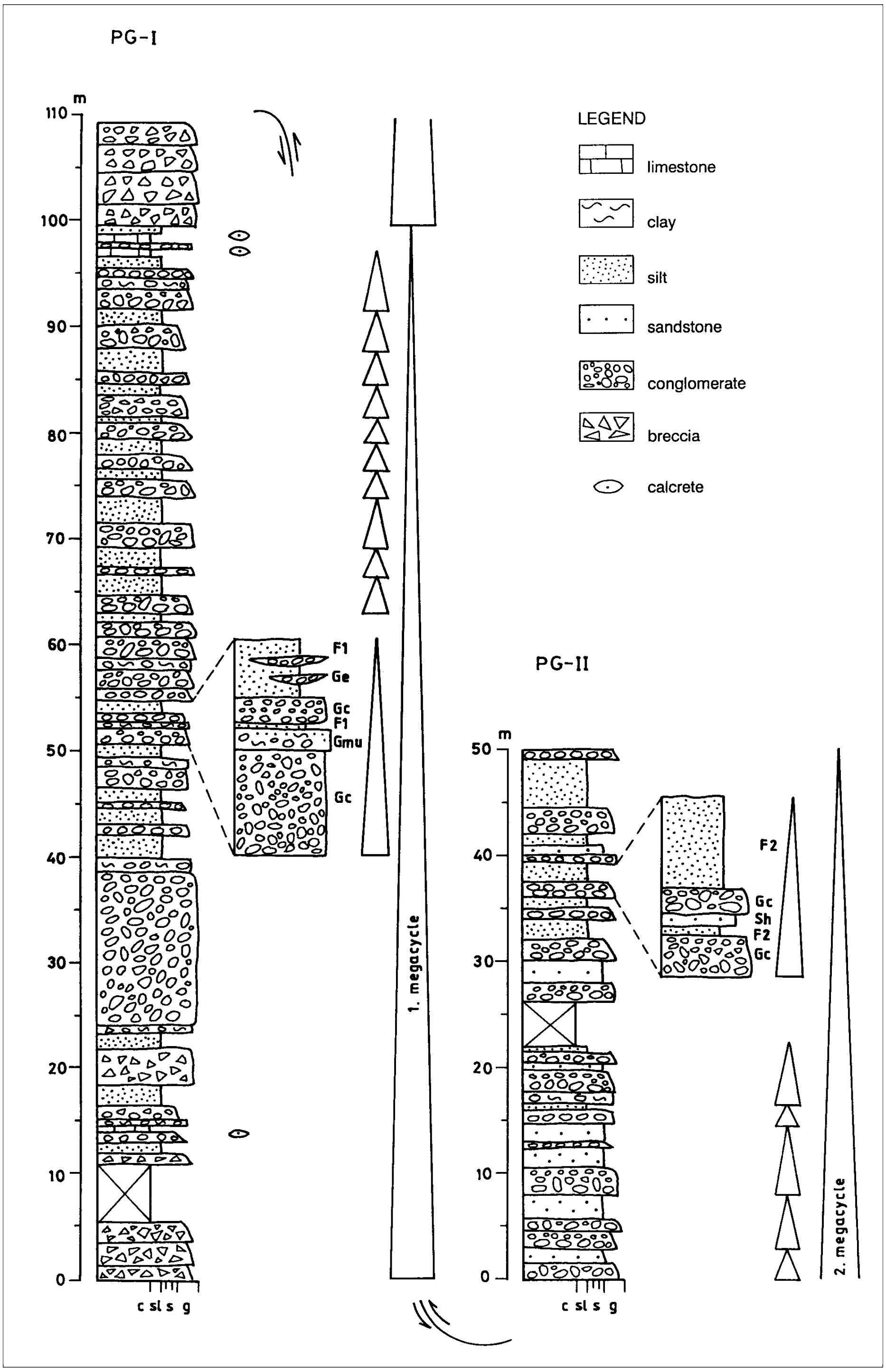

Fig. 4 Measured sections PG-I and PG-II with typical fining-upward cycles and megacycles. For explanation of the facies codes see Table 1.

matrix- to clast-supported conglomerates (Gmi - pseudoplastic debris flow), 3) massive clast-supported breccia (Bcn - rock-fall), 4) massive clast-supported conglomerates (Gc - main fan-trench, longitudinal bar, channels), 5) lenses of pebble to granule conglomerates (Ge - stream flows), 6) horizontally laminated sandstones (Sh - upper flow regime), 7) massive silts (F1 - flood plain), 8) modified silts (F2 - palaeosol), and 9) calcrete (P - palaeosol). These facies were described in detail and interpreted by PAVELIĆ (1998). Their main lithological characteristics, position in the sequence and interpretation are presented in Table 1.

The vertical succession of the deposits is dominantly composed of small fining-upward cycles (Fig. 4). These cycles are recognised within a general, gradual decrease in grain-size upwards, which is followed by a thinning of beds composed of coarse-grained sediments and corresponding thickening of beds composed of fine-grained sediments. Generally, fining-upward cycles begin with deposits of the river bar (Gc), commonly formed on the channel lag, followed by deposits of the bar cover (Sh), and are capped by sediments deposited on the flood-plain (F1, F2 and P), shallow channels on the bar or crevasse channels (Ge) (Fig. 4). Conglomer-

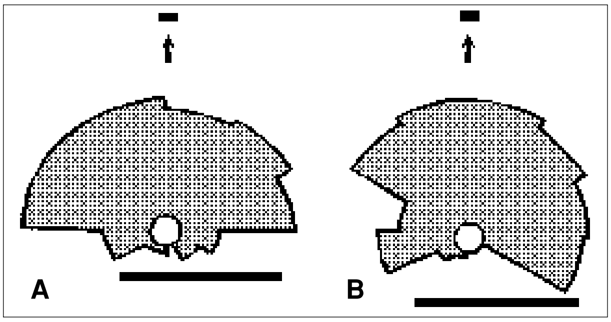

Fig. 5 Rose diagram measured as dip of imbrication shows palaeotransport from the south to the north in deposits of the PG-I section (a), and from the south-west to the north-east in deposits of the PG-II section (b).

ates deposited by gravitational mechanisms (Gmu and Gmi) occur in various parts of the cycles, from the basal and middle to the upper part, irrespective of the trend. Cycle thicknesses range from 0.5-7.8 m, most frequently from 2-4 m. In some places cycles are not developed, e.g. in a 14.5 m thick complex unit of conglomerates of facies Gc (Fig. 4, PG-I section from 24-38.5 m), which comprises the largest fragments in the entire succession. In addition, fining-upward cycles were not found in the basal part of the PG-I section, and at some other places.

4. PALAEOTRANSPORT

Flow directions are reconstructed by measurements of the dip direction of imbricated platy fragments in coarse-grained facies (Gc, Ge and Bcn).

A total of 676 fragment orientations were measured - 438 in the section PG-I, and 238 in the section PG-II (Fig. 5). In the entire succession a very wide dispersion of flow orientation data was recorded. The results indicate a general palaeotransport direction towards the north, with a weak NE tendency in deposits of the PG-II section (Fig. 5b).

5. FACIES ASSOCIATIONS AND INTERPRETATION

Two facies associations were separated in the investigated deposits. The facies association A is composed of facies Bcn, Gc, Ge, F1, F2 and P. This facies association occurs in the basal and upper part of section PG-I (0-40 m and 99-109 m - Fig. 4). The facies association B is composed of facies Gmu, Gmi, Gc, Ge, Sh, F1, F2 and P. This association comprises the middle part of section PG-I (40-99 m) and the entire succession of the PG-II section (Fig. 4).

The association of sediments deposited by debris flows mechanisms (facies Gmu, Gmi and Bcn) with deposits of traction currents (facies Gc, Ge and Sh) and sediments of flood-plains (F1, F2 and P) indicates deposition in alluvial environments, relatively close to the source area, probably in the alluvial fan (BULL, 1972; RUST, 1978; HEWARD, 1978; MIALL, 1978a, 1990, 1996; NEMEC & POSTMA, 1993; STANISTREET & McCARTHY, 1993). Previously these deposits were interpreted as "prolluvial" (ŠPARICA et al., 1980).

According to the subdivision of alluvial fans, which was on the basis of predominant depositional mechanisms as proposed by STANISTREET & McCARTHY (1993), this fan could be assigned to the mixed form between the debris flow dominated alluvial fan and the braided alluvial fan model. Considering the predominance of sediments deposited by traction in the succession, the Požeška Mt. fans seem closer to the braided alluvial fan. The fan evolved in a semi-arid climate, as indicated by the associated occurrence of calcretes, common gravitational flows, red pigmentation and lack of coal (for discussion of climate related characteristics of alluvial fans see MIALL, 1996).

Sediments of the facies association A were deposited in the proximal part of the braided alluvial fan. This interpretation is testified by the occurrence of rock-fall breccia (Bcn), and very large fragments, up to 200 cm in size, in the complex facies unit Gc (Fig. 4, PG-I section from 24-38.5 m). Sediments of the facies association B were deposited in the medial part of the braided alluvial fan, as indicated by the predominance of sediments deposited by traction currents (facies Gc and Ge), over debris flows deposits (facies Gmi and Gmu), as well as relatively thicker units composed of fine-grained sediments, which were exposed to pedogenic processes.

The erosional base of sediments comprising the small fining-upward cycles suggests an abrupt incision by strong currents into the flood-plain deposits. Sediments of the Gc facies in the basal part of the cycle indicate formation on longitudinal bars. The remainder of the depositional sequence (excluding deposits of Gmu and Gmi facies), which is composed of fine-grained deposits of the F1, F2 or P facies in the top of the cycle, can be interpreted as a result of vertical bar aggradation, and subsequent formation of the flood-plain. Vertical aggradation could have been stopped when the bar rose (due to the large input of the material) above the highest water level. In the investigated deposits there are no traces of the lateral accretion of the macroforms, thus meandering, with gradual filling and abandonment of channels can be excluded. Therefore, fining-upward cycles could indicate lateral shifts of flows caused by the formation of bars. However, flow shifts may also be caused by lateral shift of the main trench located in the proximal part of the fan (cf. MASSARI et al., 1993). The occurrence of sediments deposited by gravitational flows (Gmu and Gmi) within these cycles can be explained by individual events within the fan (sensu HEWARD, 1978). They were initiated locally, from the fan top or associated slopes, perhaps during rain as a consequence of a sudden destabi-

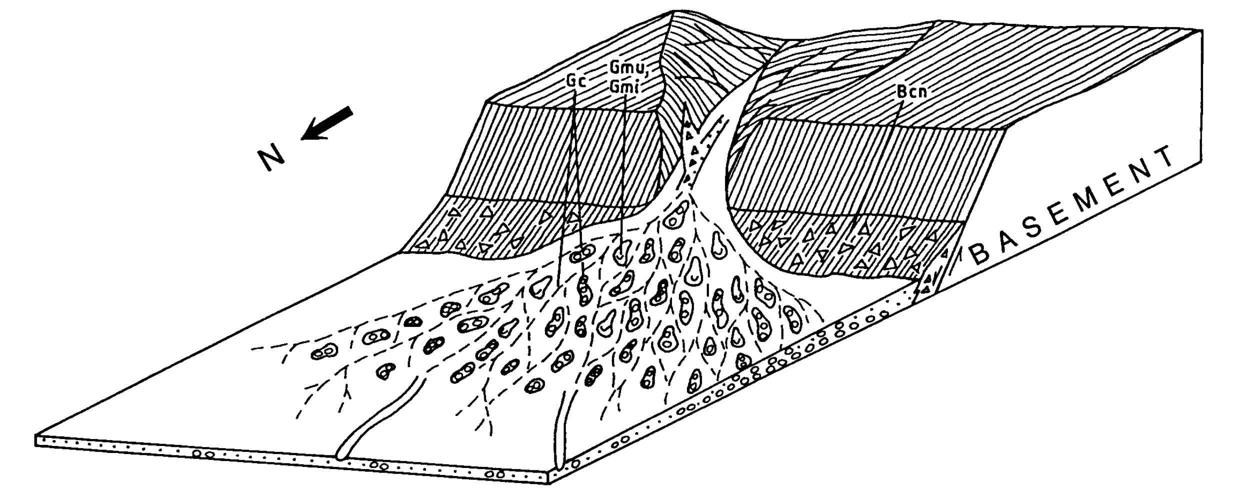

Fig. 6 A model of the Požeška Mt. braided alluvial fan in the phase of dispersed flow. Only facies of coarse-grained deposits are presented: Gmu and Gmi facies are locally initiated debris-flows, Bcn facies represents rock-fall breccias, and Gc facies indicates channels and longitudinal bars.

lization of the undercut channel walls, or by a different cause of destabilization of previously deposited, unconsolidated material, similar to the examples presented by LARSEN & STEEL (1978) and NEMEC & POSTMA (1993).

This type of cycle is typical for braided alluvial fans as a consequence of the autocyclic process on the surface (HEWARD, 1978; MIALL, 1996). It occurs in the second phase of fan development, when backfilling of the main fan-trench and flow dispersion commence (DeCELLES et al., 1991) (Fig. 6). A 14 m thick conglomerate unit of facies Gc indicates very strong flows and long-lasting vertical aggradation. Conglomerates of this facies are located between the rock-fall breccia (Bcn) and deposits constituting fining-upward cycles formed in the phase of flow dispersion. Therefore conglomerates of the aforementioned unit could belong to the main trench, formed in the first phase of fan development ("entrenchment", after DeCELLES et al., 1991).

6. MEGACYCLES AND TECTONICS

The measured succession can be divided into two fining-upward megacycles (Fig. 4). The beginning of the megacycle is marked by facies of normally graded breccia (Bcn - Fig. 4, PG-I section, basal and top part). The fining-upward trend in the first megacycle (Fig. 4, PG-I section except the top) is expressed by a general decrease in the fragment size in coarse-grained deposits and the occurrence of thick calcretes near the top of the cycle (Fig. 4, PG-I section, 96.5-98 m), followed by gradual decreasing of the conglomerate unit thickness. In the second megacycle this trend is indicated by more common occurrences and thickening of facies unit F2 in respect to facies Gc and Ge towards the upper part of the succession (Fig. 4, top of the PG-I section and PG-II section).

Fining-upward megacycles indicate the gradual migration of the source area away from the environment of deposition. This succession could be attributed to the backstepping of the fault scarp towards the source mountain massif (cf. HEWARD, 1978), or gradual lowering of the relief by normal faulting along the active margin of the extensional basin (cf. MIALL, 1978b). The initial deposition of rock-fall breccias in the base of megacycles indicate the very high intensity of tectonic activity, and trapping of coarse-grained clastics near the steep slopes in the proximity of the source area (sensu BLAIR, 1987; BLAIR & BILODEAU, 1988; HELLER & PAOLA, 1992). A relative decrease in tectonic activity is shown by the development of flows in the mountain massif, and the formation of the alluvial fan at the margin of the basin (sensu BLAIR, 1987; BLAIR & BILODEAU, 1988; HELLER & PAOLA, 1992). These processes are in congruence with the change in sediment composition recorded in the PG-II section with respect to the PG-I section. Namely, the main characteristics of the sediment composition suggest that the source area of deposits observed in the PG-I section was predominantly composed of metamorphic rocks, while deposits found in the PG-II section mostly originated by erosion of sedimentary and volcanic rocks. According to the available data (ŠPARICA et al., 1980; HALAMIĆ et al., 1990; HALAMIĆ et al., 1993; PAMIĆ et al., 1990; BELAK et al., 1998), the basement of Požeška Mt. below the Miocene deposits is composed of sedimentary and volcanic rocks of Late Cretaceous and Palaeogene age. Therefore, it may be concluded that a source area for deposits of the PG-I section, according to the reconstructed palaeotransport directions, was probably located south of the present Požeška Mt. The change in sediment composition in the PG-II section indicates a shift of the source area, which may have been caused by tectonic events along the

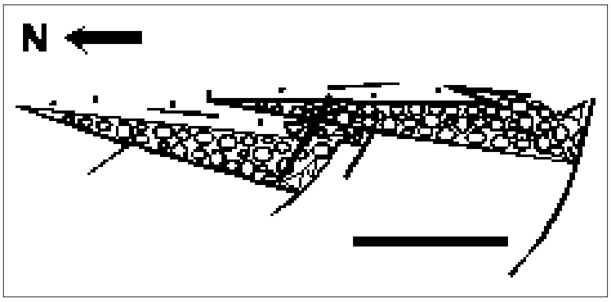

Fig. 7 Backstepping of the Požeška Mt. braided alluvial fans caused by successive normal faulting. The stratigraphic position of the compiled sections PG-I and PG-II is marked by thick black line.

basin margin (cf. LAWTON, 1986). Normal faulting in the period of enhanced tectonic activity, resulted in gradual subsidence of the block which represented the source area for formation of deposits recorded in the PG-I section (Fig. 7). In this way the other block, composed of different rocks, became the highest. In the period of weaker tectonic activity between two megacycles a newly exposed block was eroded, which resulted in rapid progradation. Reactivation of tectonics resulted in intensified normal faulting and the successive lowering of the relief, and therefore sediments deposited in the fan had the composition reflecting a new eroded block (Fig. 7). The boundary between these megacycles could be compared to a boundary surface of the 5th order, and represents a consequence of allocyclic processes (sensu MIALL, 1996). Composition of the alluvial deposits of the Požeška Mt. and reconstructed palaeotransport directions could indicate the now uplifted core of the Motajica Mt. as the source area (Fig. 1), which is composed of granites, metamorphic and clastic rocks (PAMIĆ & PROHIĆ, 1987).

If the geological position of the alluvial deposits of Požeška Mt. is related to the defined zone of the Sava fault, which is characterised as a dextral strike-slip fault (HORVÁTH & ROYDEN, 1981; JAMIČIĆ, 1988, 1995; ROYDEN, 1988; RUMPLER & HORVÁTH, 1988; BERGERAT, 1989; HORVÁTH, 1993 - Fig. 3), development of the fan would primarily depend on its lateral shift along the fault, as well as the systematic progradation of the fan itself (STEEL, 1988). In the example presented by STEEL (1988), contemporaneous lateral shift and progradation of the fan will result in the likely possibility of the formation of predominantly coarsening-upward or coarsening-fining-upward cycles and megacycles. In the case of the Požeška Mt. alluvial deposits, these types of cycles and megacycles are not developed - deposits are composed of fining-upward cycles and megacycles (Fig. 4). Formation of the fining-upward megacycles is interpreted as the result of the normal faulting along the active margin of the subsiding basin (Fig. 7), indicating that the Sava fault operated as a normal fault in the Early Miocene. This type of faulting in extensional geotectonic units is characteristic for the rift-type basins (BLAIR & BILODEAU, 1988; MIALL, 1990; FROSTICK & STEEL, 1993; LEEDER, 1995).

7. CONCLUSION

1) In the Early Miocene (?Ottnangian), a braided alluvial fan developed in the area of Požeška Mt., as represented by deposits of main trench, braided channels, longitudinal bars and the flood-plain. The fan evolved in a semi-arid climate, and flows were oriented generally towards the north.
2) Autocyclic processes, such as the lateral migration of flows due to the vertical aggradation of longitudinal gravely bars or a shift of the main trench of the fan, produced small-scale fining-upward cycles.
3) The entire measured succession of deposits is composed of two fining-upward megacycles, which are the consequence of allocyclic control, i.e. the pulsatory character of the synsedimentary tectonics. Megacycles were formed by backstepping of the fault scarp towards the source mountain massif, caused by normal faulting along the active margin of the extensional basin.
4) The determined depositional style suggests that the Sava fault operated as a normal fault at the beginning of its formation during the Early Miocene (?Ottnangian).

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