Suprafan and channel-and-levee deposits near Tichý Potok, Levoča Mts.; Central-Carpathian Paleogene Basin, Slovakia

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Abstract. Deposits in the Levoča Mts. represent the uppermost part of the Central-Carpathian Paleogene Basin fill. The biostratigraphical analyses reveal plankton of NP 25 and NN 1 zones suggesting a Late Oligocene - Early Miocene age. The deposits originated in a submarine fan channel-and-levee and suprafan (apron) subenvironments. Channel-and-levee deposits are composed of thick-bedded sandstones (channel fill) and alternating thin beds of sandstones and shales (levee deposits). Their thickness is as much as 40 m. Suprafan deposits consist of thick, mostly massive and normal-graded sandstones and sparse pebbly sandstones and conglomerates. They are as much as 150 m thick. The correlation of deposits in sections and boreholes suggests alternation of the two types of deposits which was probably caused by fluctuation of the sediment input into the basin as well as tectonic activity on the basin margins.

Key words: West Carpathians, Paleogene, turbidites, suprafan, apron, channel-and-levee deposits

Introduction

The Central-Carpathian Paleogene Basin (CCP Basin) is one of the most potential economic areas in Slovakia for hydrocarbon accumulations and hydrothermal prospects. Suitable hydrocarbon source rocks are present and geological structure and facies changes are favorable for potential hydrocarbon reservoirs. Numerous studies were done in the area in the last three decades. The studies were aimed at both basic research and economic prospects which were later drilled (e.g. Marschalko, 1964, 1968, 1970, 1978, Leško et al., 1982, 1983, Koráb et al., 1986, Janků et al., 1987, Rudinec et al., 1988, 1989, Nemčok et al., 1996, Soták et al., 1996). The sedimentologic investigation of Marschalko (1964) suggested the still valid concept of prevailing deep-water deposition by gravity flows during the basin history. The last comprehensive study of the eastern part of the CCP Basin has included both a geologic map of the area at a scale 1:25 000 (Gross et al. 1996) and the assesment of the area for hydrocarbon potential (Soták et al. 1996).

The report gives preliminary results of a sedimentological study of the thick sandstone bodies of the CCP Basin fill. Extensive hydrogeological drilling in the past years and well exposed outcrops near Tichý Potok village located in the Levoča Mts. (Fig. 1) provided data for sedimentological evaluation. The main objective of this study is to document the facies succession and biostratigraphy in drillholes and outcrops near Tichý Potok village. Interpretation of depositional environment has been made on the basis of the data obtained.

General geological setting

The CCP Basin lies in the northern part of the Slovakian Inner West Carpathians (Fig. 1). To the south it is bounded by the pre-Paleogene, Mesozoic and Paleozoic formations of the Inner Carpathians. In the north it is separated from the Outer-Carpathians Flysch zone by the Pieniny Klippen Belt (Fig. 1). The basin is developed as a forearc basin on the proximal part of the accretionary wedge above the southwestward subducting oceanic slab attached to the European Platform. The kinematic history of the basin is complex and is connected with the escape tectonics of the North-Pannonian unit caused by the oblique subduction of the oceanic crust of the Outer Carpathian Flysch trough beneath the North-Pannonian unit (Csontos et al., 1993). Because the basin lies on the rigid block, strata deformation is minimal. The pre-Paleogene areas of the Tatra and Čierna Hora Mts. forming "islands" in the CCP Basin (Fig. 1) are the result of postdepositional uplift. The elongated, crescent-shaped basin is about 200 km long, the maximum width is about 60 km. The maximum thickness of deposits in the basin is about 4 000 m and their local preservation depends on the post-depositional tectonic history. The vitrinite reflectance data done on the samples from the north-eastern part of the basin (borehole PU-1) suggest the removal of 1.5 to 2 km of overburden deposits (Franců & Müller, 1983).

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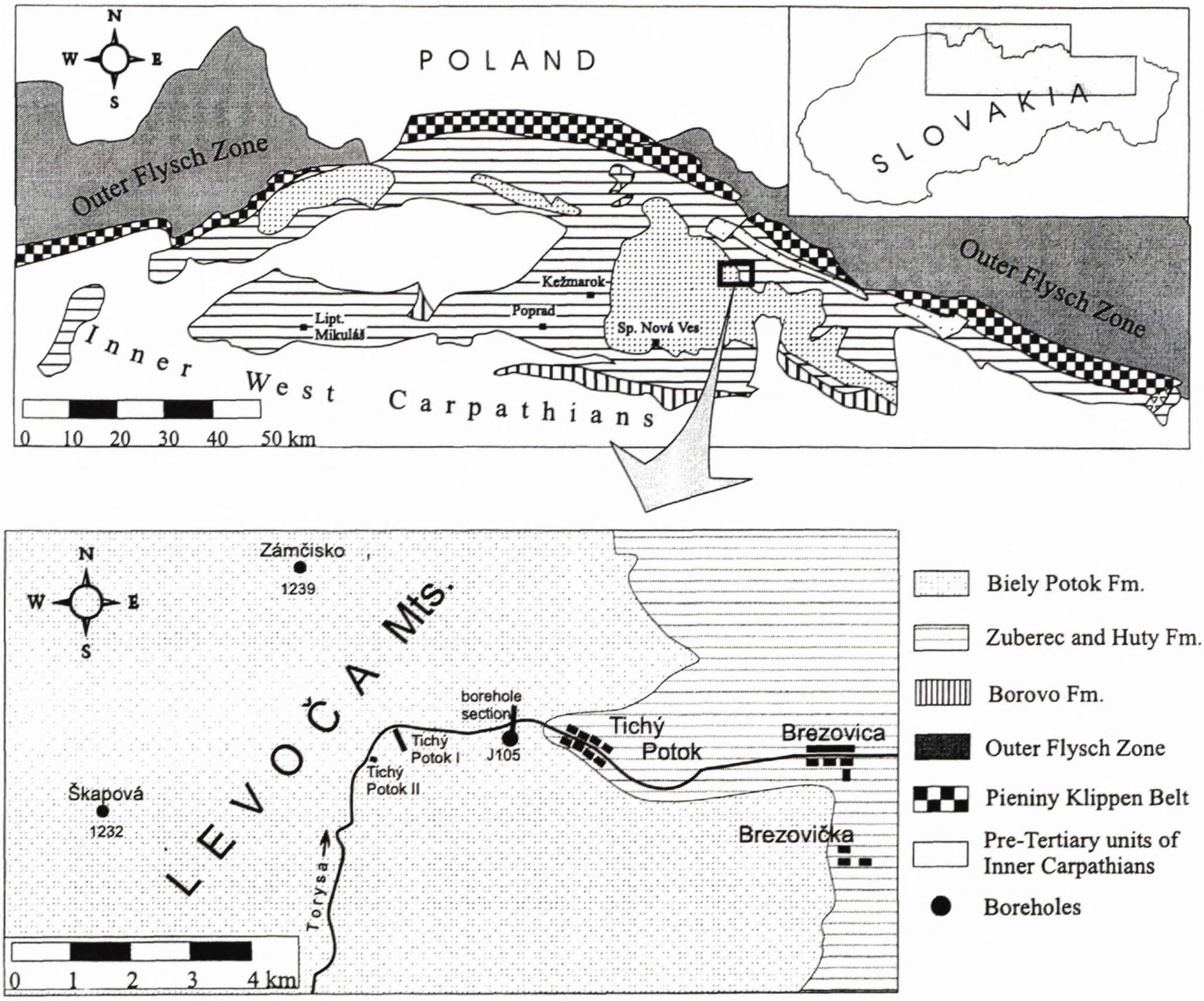

Fig. 1: Map of the studied area showing location of the outcrops and boreholes. The map showing geological units and Central-Carpathian Paleogene Formations is constructed after Biely et al. (1996).

Deposits in the CCP Basin comprise the Subtatric Group consisting of four formations (Fig. 2, Gross, Köhler & Samuel, 1984) deposited in shallow (Borové Fm.) and deep-marine environments (Huty, Zuberec and Biely Potok Fms.).

The lowermost Borové Formation consists of a basal terrestrial deposits (mainly alluvial fan and lacustrine) and shallow-marine transgressive deposits. The age of the formation is Middle and Late Eocene (Ypressian to Priabonian), the lowermost terrestrial deposits might have been deposited during the Late Paleocene and Early Eocene (Gross in Polák et al., 1992). The time-transgressive character of the deposits and their areal distribution suggest the connection between the CCP Basin and the Outer-Carpathian Flysch zone during deposition. The Pieniny Klippen Belt was not elevated at the time of transgression or, at least, there were sea ways between the Outer-Carpathian Flysch zone and the CCP Basin.

The overlying Huty Formation (Late Eocene - Early Oligocene) consists of claystones and siltstones with minor interbedded thin sandstone or conglomerate beds. We believe the sedimentation of the Huty Formation was in the subenvironment of basin plain and outer submarine fan.

Zuberec Formation (Late Eocene - Early Oligocene) consists of alternating thin, laterally persistent sandstone and shale beds (rhythmical flysch). The formation occurs only in some parts of the basin where it overlies the Huty Formation. The deposits of this formation are thought to have been deposited in the subenvironment of an outer submarine fan. Recently, the thick (1 - 3 m) sandstone beds alternating with "rhythmical flysch" (zebra facies) were defined as a member of Zuberec Formation (Kežmarok beds, Gross, 1997). Kežmarok beds represents a mid-fan channel-and-levee subenvironment.

The Biely Potok Formation is the uppermost part of the basin fill. Our biostratigraphical analyses indicate a Late Oligocene - Early Miocene (NP 25 - NN1) age for the formation. The deposits mostly consist of sandstones and subordinate conglomerates and shales. According to

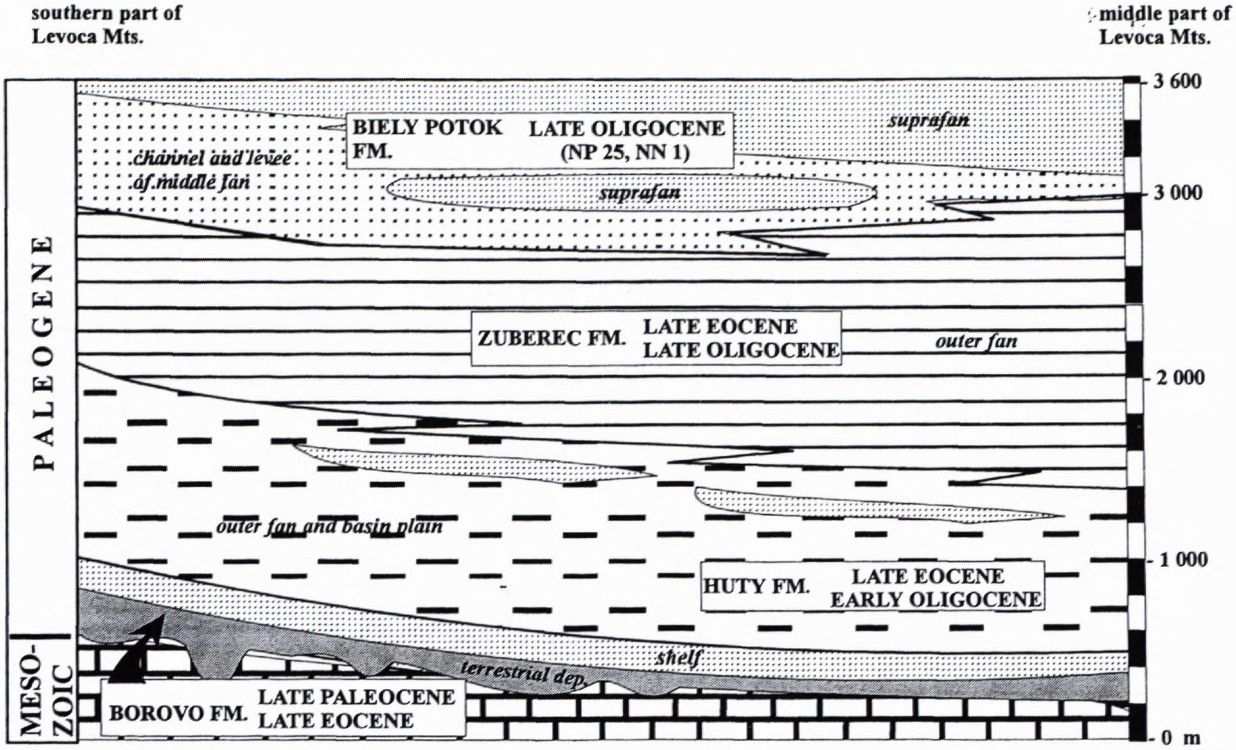

Fig. 2: Lithostratigraphic column of the studied area.

our observations the formation includes deposits laid down in suprafan lobes (aprons?), basin slope and possibly canyon subenvironments.

Methodology

At the beginning of the work a few cross-sections through the entire basin were studied in order to evaluate the older interpretations and to define the main structure of the basin. After that our study has been focused on the investigation of the Biely Potok Fm. and the upper part of the Zuberec Fm. (Kežmarok beds of Gross, 1997) near Tichý Potok village (Fig. 1). We used data from existing boreholes and geophysical logs SP and Gamma curves. Two thick outcrop sections were logged in detail (Fig. 1) and numerous smaller sections were described in order to find the lateral continuity of deposits. The logging was done in cm scale in order to recognize any subtile changes of sedimentary style. The different facies are indicated on the logs (Figs. 4 and 5) using division codes (Table 1) slightly modified after Bouma (1962) and Lowe (1982). The logs were compared to the sedimentary architecture of the area derived from photomosaics. Petrography and microstructures were studied in 13 oriented thin sections. The age of the deposits was determined by nanoplankton analyses. Ten samples prepared in laboratory of Geological Survey of Slovak Republic were studied by LM (Amplival) at a magnification of 1200x. We did detailed mapping of the area in order to find the areal distribution of the strata and to find any structures. On the basis of data obtained from the boreholes and outcrops we determined the vertical and lateral continuity of the depositional bodies and the change of depositional subenvironments.

Results

Drill data and seismic profiles indicate the thickness of the CCP Basin fill ranging from 700 m to 3 500 m in the Levoča Mts. (Polák et al., 1994, Gíret et al., 1991, Neupauer et al., 1990, Gross et al., 1996). The thickness and lithology of deposits in the central part of the Levoča Mts. is only inferred from the seismic profiles (Gross et al., 1996). This is interpreted as transgressive deposits at the base of the sedimentary succession (Borové Fm.) overlain by thick (up to 1 000 m) shales of Huty Fm. and rhythmical flysch of Zuberec Fm. which is about 1 600 m thick (Gross et al., 1996). The Zuberec Fm. is locally missing and the whole succession is capped by predominantly sandstone of Biely Potok Fm. The thickness of the Biely Potok Fm. deposits, estimated from boreholes and outcrops, is about 700 m. Near Tichý Potok village a thickness of more than 500 m of prevailingly coarse-grained strata was measured which consists of sandstones, minor pebbly sandstones and conglomerates.

The preliminary structural study of the area showed NE - SW strike with monoclinal 5 - 15 degrees dip toward SE. The strata are displaced by a NE-SW fault system with offset ranging from a few decimeters to a few meters. The fault system has a steep dip toward NW, and does not show any indicator of movement direction. An associated joint system has E-W direction and a steep dip toward N. Some striae suggest sinistral motion. Another NW-SE fault system with a steep dip toward SW is less

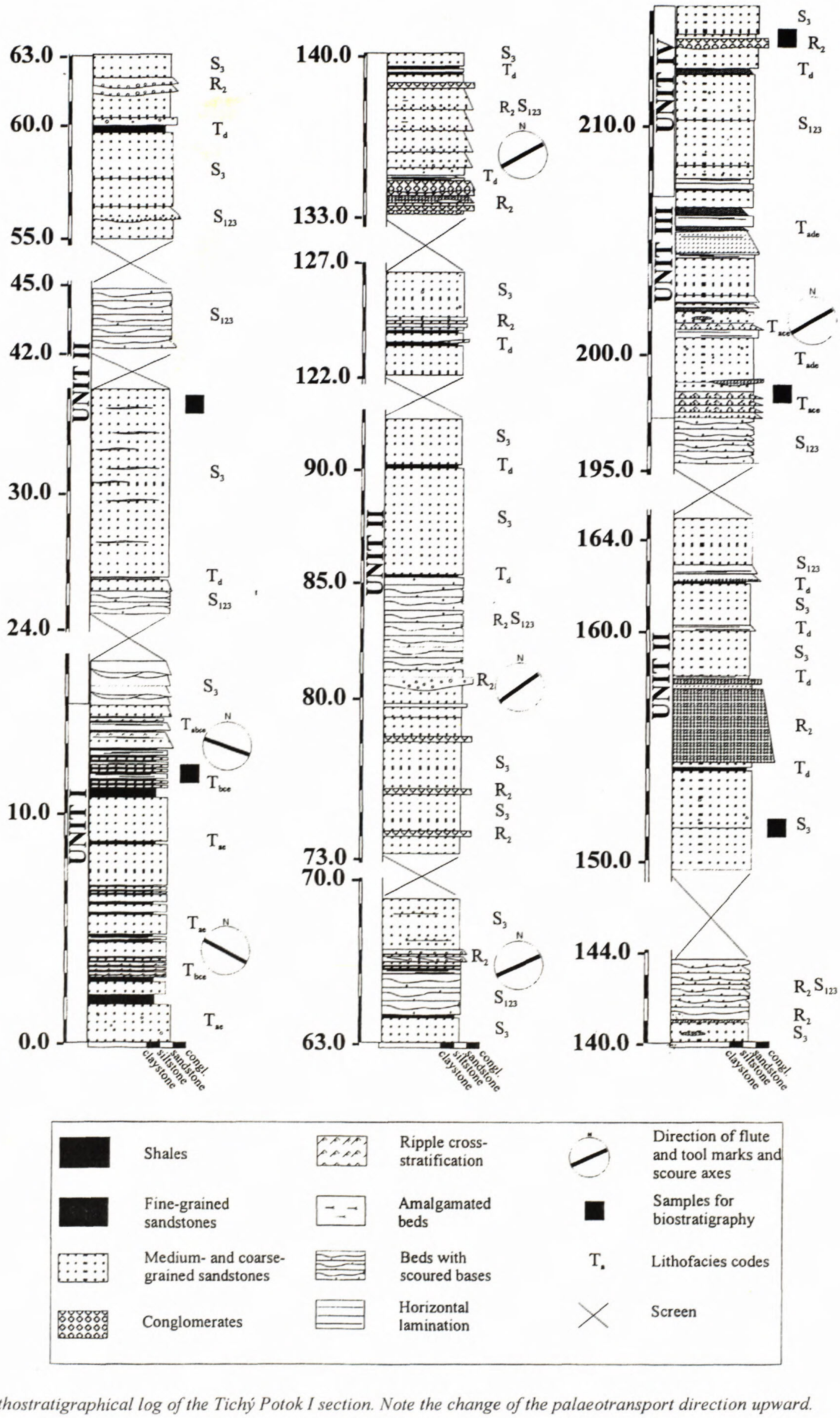

Fig. 3: Lithostratigraphical log of the Tichý Potok I section. Note the change of the palaeotransport direction upward.

common. The faults locally are filled with veins of white calcite. Striae suggest two kinds of movement: the older movement represents dip-slip fault toward NW, the younger system represents a sinistral fault. The palaeostress analysis of deformation implies a maximum stress axis (δ_1) in NW-SE direction and a minimum stress axis (δ_3) in NE-SW direction. The palaeostress axes orientation is consistent with mineralization of the NW-SE faults system which is oriented in the direction of maximum tension stress. The structural analyses are preliminary, however, they show possible correlation of NE-SW and E-W fault systems with faults in Biely Potok Formation having the same regional character. This is supported by a Neogene age of movement on the fault systems. The measured palaeostress directions are consistent with the orientation of palaeostress axes in the Late Karpatian - Early Badenian strata of the nearby East-Slovakian Neogene Basin as described by Kováč et al. (1994). The orientation of fault systems in both Levoca Mts. and East-Slovakian Basin is also similar.

Fig. 4: Photograph of levee deposits at the Tichý Potok I section. Note the pinching out of the sandstone bed lying underneath the hammer.

Section 1

Section 1 is located 4.5 km to the North of Tichý Potok village on the right side of Torysa river (Fig. 1). More than 210 m of strata are almost completely exposed. The sedimentary succession is divided into four lithological units, numbered from bottom to top (Fig. 3).

Unit I

Description. - Unit I extends from the base of the outcrop to 16.5 m. It consists of thick sandstone beds alternating with thin sanstone and shale beds (zebra facies, Figs. 4 and 5).

The thick sandstone beds varies from 20 cm to 1 m in thickness. The beds are aften amalgamated with a sharp and erosional base. Flute and tool marks are very common at the base of sandstones and suggest palaeocurrent direction toward northwest (Fig. 3). The sandstones are medium- and coarse-grained, massive or normally graded. Usually they represent Bouma's T_a division with scarce T_{ab} divisions. The sandstones are classified as medium-grained, sublithic arenites as defined by Pettijohn and others (1972). The sandstones consist of quartz, sericitic feldspars and rock fragments. Rock fragments are composed of quarzites, chloritic phylites, graphitic phylites, basic volcanics, granitoids, carbonates and muscovites. The matrix is calcite or minor clayey calcite. The grain roundness varies from 2 to 3 in the 6 degree scale of Leeder (1982). Quartz prevails in the samples and plagioclase feldspar is more common than orthoclase and microcline. Scarce conglomerates or pebbly sandstones occur at the base of the beds. The thickness of the thick sandstone bed sequence is from 50 to 200 cm.

The interbedded thin sandstone and shale bed sequence is termed as zebra facies (Nelson & Nilsen, 1997). The sandstones are fine- to medium-grained and show Bouma's T_{ae}, T_{be} and T_{bce} divisions. Starved ripples are common. Sandstone beds are 2 cm to 20 cm thick, with sharp bases. The sandstone beds are very irregular and they commonly pinch out laterally (Fig. 4). Soft-sediment deformation is very common (Fig. 5). The interbedded shales have sharp bases and the strata are about the same thickness as the sandstone beds. Shales are massive with minor parallel and ripple cross-lamination.

Interpretation. - The facies association suggests deposition of unit I in a submarine fan channel and levee subenvironment. The channel-fill deposits are the thick sandstone bed sequences. The sandstone locally has conglomerates or pebbly sandstones at the base. The conglomerates are associated with initial erosion in the early depositional phase of the channel deposits (Clark & Pickering, 1996). The overlying channel fill deposits mostly consist of medium-grained massive sandstone. The alternating thin sandstone and shale beds of the zebra facies are interpreted as levee deposits. They were deposited on flanks of channels where turbidity currents spilled over from the channels. This interpretation is supported by the occurrence of starved ripples, indicating a lack of sand in suspension which is typical for overbank deposits. The irregular continuity of beds which pinch out laterally as

Fig. 5: Photograph showing sedimentary deformation in the levee deposits at the Tichý Potok I section.

well as soft-sediment deformations are often found in levee deposits.

Unit II

Description. - Unit II extends from 16.5 m to 201.5 m. Unfortunately, lithologic details are incomplete because of cover on the outcrop, which is marked on the log (Fig. 3). Thick to very thick bedded medium-grained to granule-sized sandstones and pebble sandstones separated by discontinuous fine-grained sandstone partings or beds are characteristic of unit II (Fig. 6). The beds are often amalgamated. Individual sandstone beds are 10 - 15 m thick. The internal structure of these beds consists of 20 - 70 cm thick amalgamated sandstone beds. The sandstones and pebbly sandstones are mostly normally graded and massive. The sandstones are generally medium-grained lithic arenites. They prevailingly consist of quartz with lesser amounts of feldspars (orthoclase, sericite) and rock fragments. The rock fragments are composed of quartzites, granitoids, chloritic and graphitic phylites, serpentine, basic volcanics and carbonates. The grain roundness is 2 -3 (Leeder, 1982). Generally a matrix is absent but where present it is composed of clay. Many beds, which on visual inspection show massive structure, were found to be normally graded in oriented thin sections. The most common are R_2, S_1, S_2 and S_3 divisions of Lowe (1982), interspersed with fine-grained horizontal laminated (Bouma's T_d division) sandstone partings (see Table 1 for lithofacial codes). In pebbly sandstones pebbles are either organized into discrete layers or randomly distributed. Sole marks are rare and all indicate paleocurrent direction toward southwest. Water-escape structures and soft-sediment deformation are common. The sandstone beds have either a flat sharp or scour basal contact. The scours do not erode the entire underlying bed suggesting only weak erosion. The beds vary in thickness laterally and typically cannot be correlated over wide areas because they form discontinuous lenses.

The conglomerates, consisting of quartz, sandstone, mudstone, limestone and dolomite clasts, are mostly matrix-supported. Only rarely clast-supported conglomerates occur. Massive structure prevails. At places, the conglomerates are positively graded. They fill scour surfaces or form sharp-based beds and do not make channels in the report area.

Fig. 6: Pebbly sandstone and sandstone beds of suprafan. Note the scoured bases and normal grading.

Tab. 1: Lithofacies (division) codes, modified after Bouma (1962) and Lowe (1982).

T_a	massive sandstone
T_b	horizontally laminated sandstone
T_c	ripple cross-stratified sandstone
T_d	horizontally laminated fine sandstone and shale
T_e	massive shale
S_1	cross-stratified sandstone
S_2	horizontally laminated sandstone
S_3	massive coarse-grained sandstone
R_1	cross-stratified conglomerate
R_2	massive and inversely graded conglomerate

Interpretation. - The sediment succession, its vertical and lateral development, the character of beds and the lack of channelization suggest deposition in a suprafan lobe subenvironment. Prevailing conglomerates, pebbly conglomerates and massive sandstone, representing S_1, S_2, S_3 and R_2 divisions of Lowe (1982), suggest deposition by high-density turbidity currents (Lowe, 1982, Walker, 1978). Most of the beds probably originated from traction and traction-carpet stage of deposition as described by Lowe (1982). The occurrence of the T_d division of Bouma suggests deposition from suspension in dilute turbidite flow, probably in a subsequent sedimentation stage. The lack of matrix in some sandstones may indicate grain flow during deposition.

Unit III

Description. - The unit III deposits extends from 201.5 m to 206.8 m. Generally they are finer-grained than underlying unit II deposits. The deposits comprise beds 10 to 50 cm thick with sharp and loaded bases. The beds consist of medium-grained sandstone which is often capped by fine-grained sandstone or shale. The petrography of the sandstones does not differ from the sandstones in unit II. The sandstone intervals are composed of massive sandstones and parallel laminated and ripple cross-laminated sandstones. Wavy and convolute lamination is also common. The finer-grained deposits are laterally discontinuous and they frequently only comprise finer-grained partings in coarser grained successions. The sedimentary succession comprises T_{abde}, T_{ade} and T_{ace} divisions of Bouma.

Interpretation. - The occurrence of Bouma's divisions in the sedimentary succession suggests deposition by dilute turbidity flows. The weakly preserved T_e divisions may have been caused by other factors like high erosive activity of turbidity flows or high frequency of turbidity flow which did not allow final suspension stage sedimentation or shortage of finer-grained fraction in the turbidity flow. The absence of channelization and the prevailing sharp bases of beds do not indicate high erosive activity of flows. We interpret these deposits as originating on the flank of a suprafan.

Unit IV

Description. - Unit IV extends from 206.8 m to 215 m. The unit has features similar to unit II. The deposits are dominately thick to very thickly bedded medium- and coarse-grained sandstones separated by fine-grained sandstone partings. The sandstone is massive and normally graded. Sandstone beds are amalgamated, the lower contacts are sharp, loaded or scoured. The petrography of sandstones is similar to the petrography of sandstones from unit II. At places, matrix-supported massive and normaly graded conglomerates and pebbly sandstone occur. Like unit II, R_2, S_1, S_2 , S_3 and sporadic fine-grained parallel laminated T_d divisions are most common. The well exposed section shows relatively high lateral persistence of individual beds (over 100 m).

Interpretation. - The prevailingly coarse-grained deposits, normal-graded sandstones capped by parallel laminated fine-grained sandstone, pebbly sandstones, massive and normally graded sandstones and some cross-bedded clast-supported conglomerates suggest deposition by high-density turbidity flows. This interpretation is supported by sediment succession throughout the section. We believe that deposits of unit IV have originated in a deep-marine suprafan subenvironment.

Section 2

Section 2 is located NW from the village Tichý Potok on the right side of Torysa river near a former quarry (Fig. 1). It lies 500 m to the west of section 1. The exposed section is 20 m high and 50 m wide. The strata in the section were divided into two units (Fig. 7).

Unit I

Description. - Unit I extends from the base of the outcrop to 11.8 m. It consists of thick sandstone beds and thin, alternating sandstone and shale beds resembling zebra the facies.

The thick sandstone beds have sharp bases and at places the bases show flute and tool marks. The flute marks suggest palaeoflow toward northwest. The thickness of individual beds is about 30 cm with a maximum thickness of 100 cm. The thickness of bed complexes is about 2 m. The sandstone is medium- and coarse-grained, massive and horizontally laminated. Normal grading occurs infrequently. Some of the beds contain pebbly sandstone at the base.

Thin beds of alternating sandstones and shales form 2 m thick sequences between the thick sandstones. The beds are 5 - 10 cm thick, have a sharp base, are laterally nonpersistent and are generally deformed. The sandstone is medium grained but some is fine-grained. Usually it is massive, parallel laminated and ripple cross-laminated. Starved ripples are common. Shales are massive or parallel laminated. The deposits comprise T_{ace} and T_{ce} divisions of Bouma.

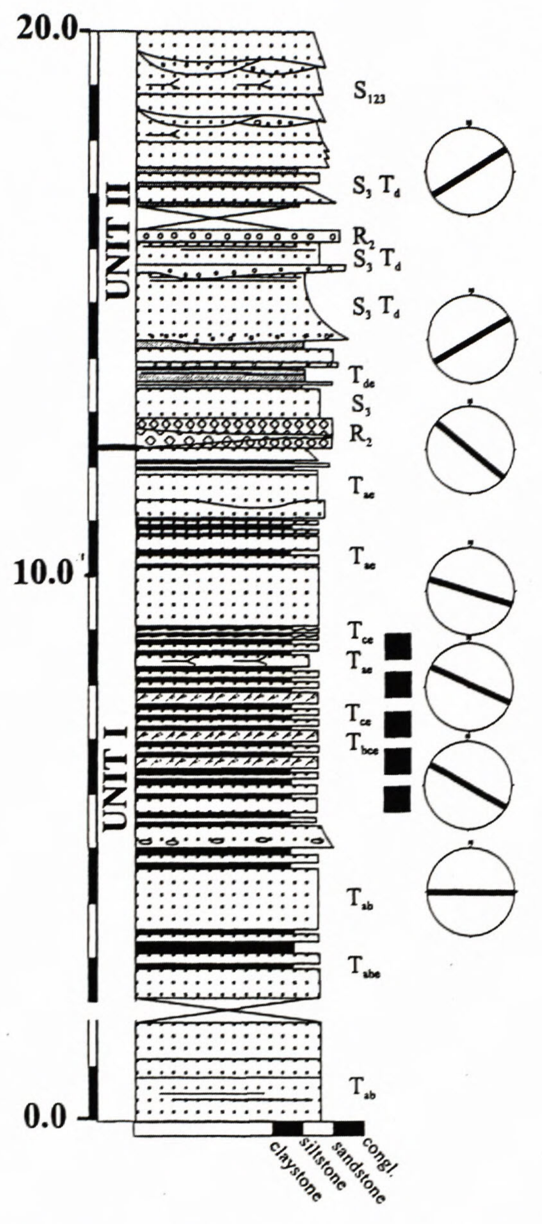

Fig. 7: Lithostratigraphical log of the Tichý Potok II section. Legend as on Fig. 3.

Interpretation. - The described sedimentary succession is thought to represent channel-and-levee deposits of a submarine fan. Thick-bedded sandstones comprise channel fill facies which laterally pass into alternating thin beds of finer sandstone and shale representing levees. The levee interpretation is supported by the occurrence of starved ripples suggesting lack of sand in suspension. The lenticular beds and soft-sediment deformations are also typically developed on levee slopes.

Unit II

Description.- Unit II extends from 11.8 m to the top of the section at 20 m. Unit II consists of thick sandstone and minor pebbly sandstone and conglomerate beds. The base of beds is sharp, scoured and loaded. The beds are from 20 cm to 100 cm thick and generally are amalgamated. Sandstone is medium- to coarse grained. Sandstone beds are massive and normally graded. The top of beds are commonly faintly parallel laminated comprising Bouma's divisions T_{ab}. Pebbly sandstone and matrix-supported conglomerate occur either at the base of sandstone beds or in fills of small scours. The thickness of deposits in scours is not more than 30 cm.

Interpretation. - The strata are mostly massive and normally graded sandstones with sharp bases and infrequent load and scour surfaces suggesting deposition by high-density turbidity currents. Some of the massive sandstones may have been deposited by grain flow. The absence of finer deposits (T_e divisions) probably indicates high sediment input into the basin, insufficient time for suspension sedimentation and high erosive flow capability. The lack of channelization together with the occurrence of coarse deposits suggest deposition in a submarine suprafan.

Borehole descriptions

Sedimentologic studies from the measured sections were supplemented by data obtained from a series of 50 - 100 m deep hydrogeologic boreholes which were recently drilled near Tichý Potok village (Gíret et al., 1991, Neupauer et al., 1990). The boreholes drilled northwest from Tichý Potok revealed: 1) up to 25 m of thick sandstone, pebbly sandstone and conglomerate; 2) up to 5 m of thick sandstone, pebbly sandstone and conglomerate consisting of thick beds; 3) interbedded thin bedded sandstones and shales (Gíret et al. 1991, Fig. 8). Athough we did not examine samples from the boreholes, the available descriptions imply an origin in the suprafan subenvironment (up to 25 m thick sandstone complexes), and an origin in a channel-and-levee subenvironment (up to 5 m thick sandstone complexes and complexes consisting of alternating thin beds of sandstones and shales).

Biostratigraphy

Ten samples were taken from section I and II for nanoplankton analyses. Five samples are from the channel-and-levee deposits, five samples are from suprafan deposits (see marks on logs, Figs. 3 and 7). The samples from channel-and-levee deposits contained nannoplankton of NP 25 / NN1 zones. This suggests Late Oligocene - Early Miocene (Egerian) age for the channel-and-levee deposits. All samples from the suprafan deposits showed only rare reworked Cretaceous and Eocene nanofossils or were barren. This probably reflects very intensive sedimentation rates from high-density flows which were poor conditions for planktonic life. The following assemblages were found in the samples:

Sample 1/97: *Cyclicargolithus floridanus, Helicosphaera euphratis, Coccolithus pelagicus Helicosphaera* sp. - Late Eocene - Oligocene

Sample 2/97: *Cyclicargolithus floridanus, Dictyococcites bisectus, Helicosphaera euphratis, Cyclicarglithus abisectus, Dictyococcites lockerii, Sphenolithus moriformis, Helicosphaera* cf. *scissura, Triquetror-*

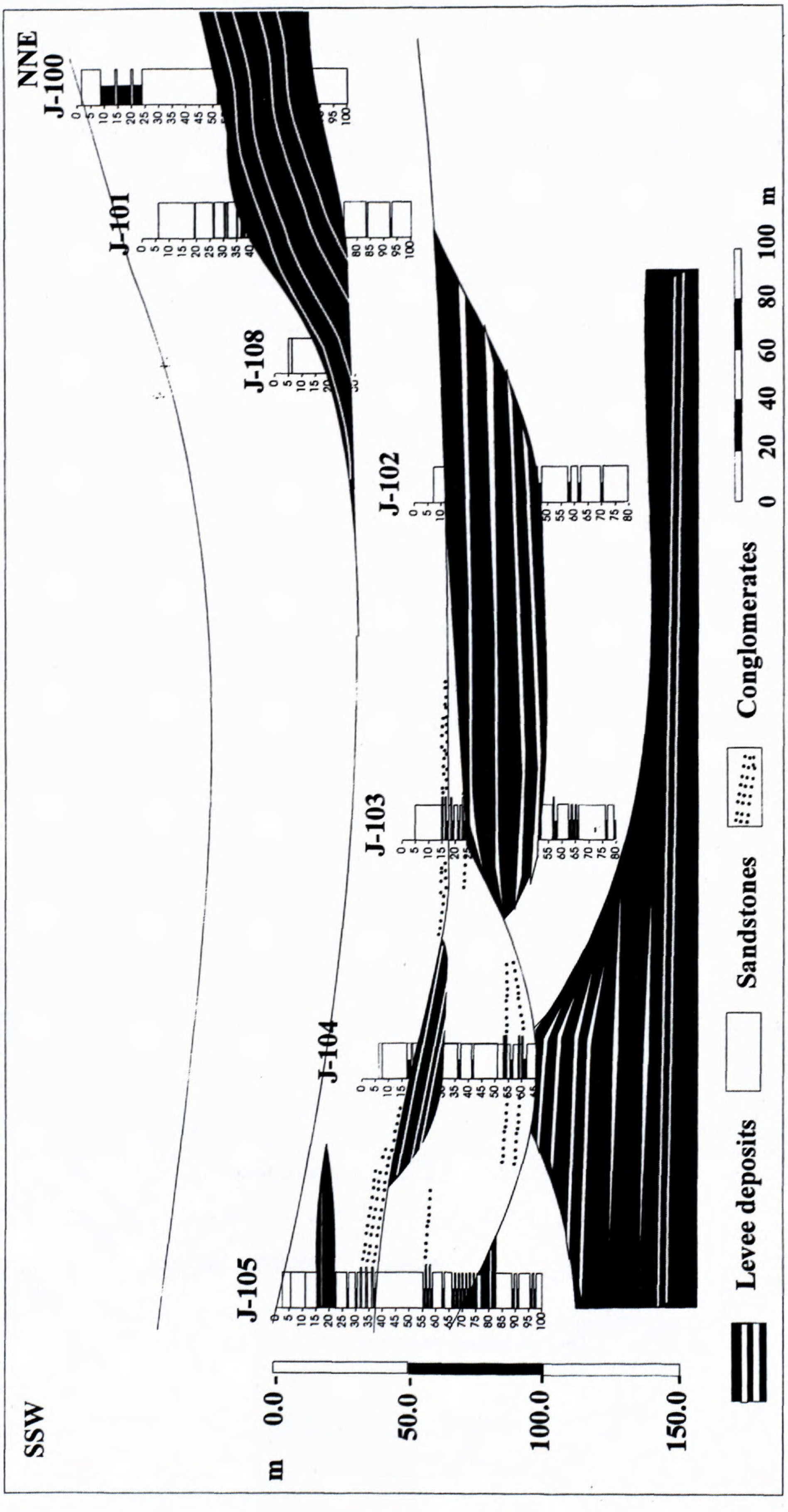

Fig. 8: Cross-section showing sediments recovered by drillings and geological interpretation of studied deposits. For location of the section see Fig. 1.

habdulus cf. *carinatus* + rare reworked Cretaceous forms - poor assemblage of Late Oligocene - Early Miocene NP 25/NN1 (Egerian)

Sample 3/97: *Cyclicargolithus floridanus, Dictyococcites bisectus, Helicosphaera euphratis, Dictyococcites lockerii, Helicosphaera scissura* + rarely Cretaceous redepositions - very poor assemblage of Late Oligocene - Early Miocene NP 25/NN1 (Egerian)

Sample 4/97: *Cyclicargolithus floridanus, Dictyococcites bisectus, Helicosphaera euphratis, Dictyococcites lockerii, Reticulofenestra umbilicus, Helicosphaera* cf. *scissura, Triquetrorhabdulus carinatus* + rarely reworked Cretaceous forms, poor assemblage probably of Late Oligocene - Early Miocene age NN1

Sample 5/97: *Cyclicargolithus floridanus, Coccolithus pelagicus, Coccolithus formosus, Dictyococcites bisectus, Cyclicargolithus abisectus, Triquetrorhabdulus carinatus, Helicosphaera euphratis, Helicosphaera scissura* + rare reworked Cretaceous forms, poor assemblage of Late Oligocene - Early Miocene age NN1

The markers (*Cyclicargolithus abisectus, Triquetrorhabdulus carinatus, Helicosphaera scissura*) point to the Late Oligocene/ Early Miocene (Egerian) age of the strata under study. This is in accordance with the older studies by B. Hamršmíd on the material from Tichý Potok village supplied by J. Soták (Slovak Academy of Science) and also with the results by A. Nagymarosy (Eötvös Univ., Budapest) (Soták, pers. commun.).

Discussion

The sedimentary succession at the measured sections and in the boreholes consists of channel-and-levee deposits and suprafan deposits. The association of channel-and-levee facies suggests either the existence of depositional and erosional channels (Normark, 1970) or aggradational channels (Clark & Pickering, 1996). The aggradational channels channels are associated with large terrestrial drainage areas Kenyon, 1992), high channel sinuosity, lower slopes and finer-grained sediments that aid suspension in turbidity currents (Clark & Pickering, 1996). The correlation of borehole cores shows sandstone bodies progressively merging toward the top of the section (Figs. 8 and 9). This may be a result of multilateral channel coalescing causing connection of individual channel-fill deposits or, more likely, it reflects alternation of channel-and-levee and suprafan deposits (see below). The width of the channels in the lower part of the section is estimated to vary from 200 m to 2 km. Depth of the channels ranges from 20 to 40 m. The thickness of levee complexes is variable. The borehole profiles suggest a thickness of up to 40 m, the thickness of deposits observed in outcrops does not exceed 12 m. A greater thickness of levee deposits is usually expected downfan because larger amounts of coarser material can be transported across the channel margins where the channels are shallower (Nelson & Nilsen, 1997). The stratigraphic arrangement suggests a progradational submarine fan system where the thickness of

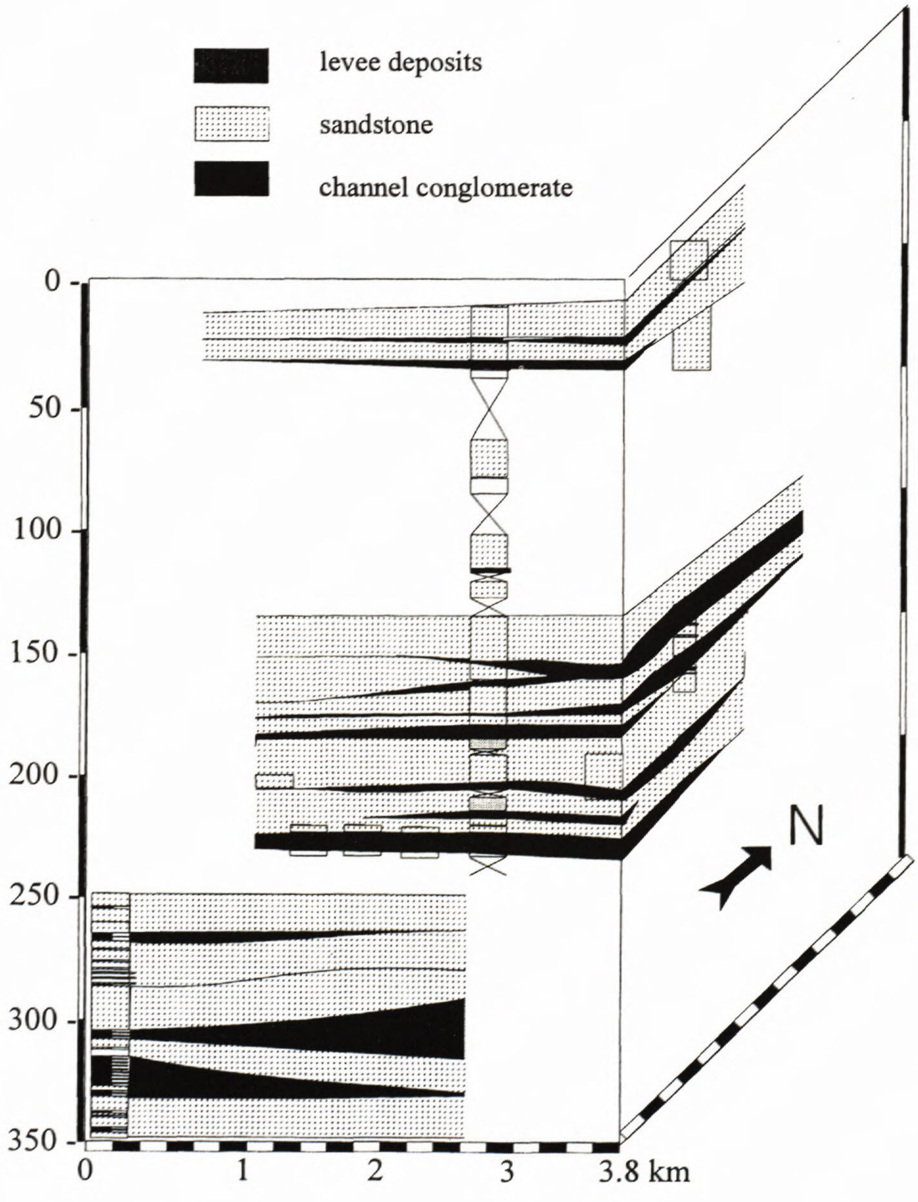

Fig. 9: Blockdiagram showing vertical and lateral relationship of channel-and-levee and suprafan deposits. Note the alternation of lower and higher interconnectivity of sandstone bodies.

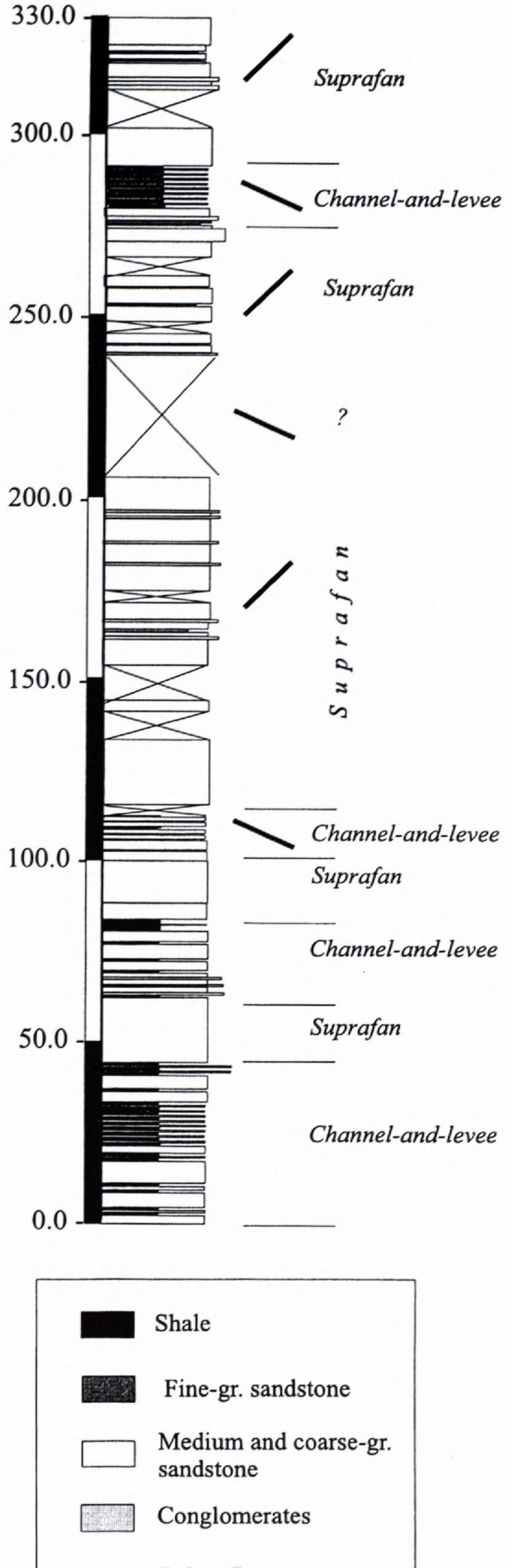

Fig. 10: Composite log showing the sedimentary succession in the Tichý Potok area. For the construction the data from the borehole J-105 and sections Tichý Potok I and II were used.

levee complexes decreases upward with a gradual shift of depositional system toward the basin depocenter.

The suprafan deposits indicate a change of depositional style resulting from high-density unchannelized gravity (mostly turbidity) flows. This kind of deposition is typical for areas with intensive uplift of basin margins (source areas) and a narrow shelf. It is often described from tectonically-controlled basins where abrupt uplift/subsidence events result in formation of turbidity aprons (Chan & Dot, 1983, Reading & Richards, 1985, Stow, 1985). The formation of such aprons originated by flows entering the basin perpendicular to the basin axis would be consistent with the palaeoflow indications found in the channel-and-levee deposits and in the suprafan deposits. The change of the palaeoflow direction from the SE - NW in the channel-and-levee deposits to the NE - SW in the suprafan deposits suggests a palaeoflow pattern perpendicular to the basin axis in some phases of the basin development.

The correlation of deposits between the two measured sections and boreholes shows an alternation of channel-and-fill deposits and suprafan deposits (Figs. 8 and 9). The alternation may have been caused by other factors such as basinward or lateral shift of the suprafan, change in sediment input or tectonics. It can explain the gradual merging of sandstone bodies upward in the borehole because the lower part of the section is formed by channel-and-levee deposits and the upper part by suprafan deposits. The alternation of channel-and-fill and suprafan deposits may have implication for the interpretation of basin stratigraphy. The deposits resembling channel-and-fill deposits from the measured sections were described as Kežmarok beds (member) which are the uppermost part of the Zuberec Formation (Gross, 1997). However, at the studied localities these deposits are overlain by 160 m of strata typical of the Biely Potok Formation, which are, in turn, overlain by channel-and-levee deposits, possibly the Kežmarok beds (Fig. 10). According to this correlation the Kežmarok beds (channel-and-levee deposits) should be a part of Biely Potok Formation. The correlation of these deposits also suggests the Late Oligocene - Early Miocene age (NP 25 / NN 1) for all investigated deposits.

Conclusion

The deposits at the measured sections located near Tichý Potok village in the eastern part of the CCP Basin (Fig. 1) are composed of gravity (mostly turbidity) flow deposits of Late Oligocene and Early Miocene age (nanoplankton zones NP 24/25 and NN 1). The deposits were laid down in suprafan and channel-and-levee subenvironments of a submarine fan. Suprafan deposits consist of thick sandstone bodies with minor pebble sandstones, conglomerates and shale partings. The sandstones, which may be up to 50 m thick, are composed of thick amalgamated beds with sharp and scoured bases. The prevailing normal grading, the presence of R_2, $S_{1,2,3}$ divisions of Lowe and the T_d division of Bouma strongly suggest turbidity flows as the main agent responsible for their deposition. Channel-and-levee deposits consist of thick-bedded sandstones, some pebble sandstones and conglomerates (channel fill) and alternation of thin-bedded sandstones and shales (zebra facies).

The composite log of deposits in the studied area (Fig. 10) shows alternation of suprafan and channel-and-levee deposits. The alternation suggests possible assignment to the Biely Potok Formation of the channel-and-levee deposits described as the Kežmarok beds by Gross, 1997. However, the assignment requires further, more detailed investigation.

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