Fluvial and alluvial fandeposits in the Hornád and Torysa river valleys; relationship and evolution

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Abstract: Well developed fluvial terrace and alluvial fan systems in the Torysa and Hornád river valleys in the Košice Depression provide oportunity to analyze mutual relationship between these systems. The Torysa river formed five terrace steps which may be well correlated with toe parts of alluvial fans deposited by lateral tributaries. Alluvial fans have telescopic structure in the Torysa river valley suggesting tectonically stable source area. The Hornád river has similarly to the Torysa river five terrace steps. However, the structure of alluvial fans, deposited by the Hornád tributaries, is different. It shows gradual uplift of the source area resulting in shift of depocentrum closer to the mountain margin. Correlation of fluvial and alluvial fan deposits suggested time lag of alluvial fan sedimentation and deposition to the end of the accumulation cycle. Correlation of terrace steps between the Torysa and Hornár river valleys suggests prevailingly climatic driven erosion-accumulation cyclicity.

Key words: Quaternary, fluvial deposits, alluvial fan deposits, climate, tectonics, erosion-accumulation cycle, Hornád and Torysa rivers, Košice Depression

Introduction

Alluvial fan deposits and deposits of axial river system show distinct relationship described in many works (e.g. Schumm, 1973, Flint, 1995). The most common situation described in ancient deposits is interfingering of fluvial and alluvial deposits caused by fluctuation of deposition intensity in individual depositional systems. In the Pleistocene periglacial areas additional driving mechanisms play important role in depositions of alluvial fan and fluvial systems - high-frequency fluctuation of climate and glacial isostasy. This complicates relationship between marginal alluvial fan and axial river systems.

The main objectives of the paper are the geomorphological and geological analyses of the Torysa and Hornád terrace and alluvial fan systems in the Neogene Košice Depression and the establishment of their mutual relationship. A model of their development is given at the end of the paper.

Geological setting

The Hornád river and its left-side tributary the Torysa river are two main flows draining Košice Depression situated in the Eastern Slovakia (Fig. 1). During their Pleistocene evolution, they formed several terrace steps consisting of erosional plinths overlain by sediment bodies. Fluvial terrace steps are closely related to alluvial fans developed at the margin of the basin where high-energy relief of surrounding mountains passes into slightly undulated low relief of basin.

The Košice Depression is a part of the East Slovakian Neogene Basin bounded to the west and north by the pre-Tertiary units of the Inner Carpathians, the Central Carpathian Paleogene Basin and by flysch deposits of the Outer Carpathians (Fig. 1). The Neogene basin fill consists of marine and terrestrial mud, mudstone, sand, sandstone, gravel and conglomerate. The western part of the basin, isolated from the basin eastern area by a chain of volcanic Slanské vrchy Mountains, forms a partial Košice Depression. Two N-S extending positive morphostructures, laterally restricted by N-S faults, governed the development of three main N-S directed fluvial valleys in this region during the Quaternary period (Figs. 1 and 2).

The Hornád river and its left side tributary the Torysa river, representing axial river system in two N-S valleys, are medium-sinuosity meandering rivers with prevailing gravely and sandy load. The Torysa river flows 100 km before confluences with Hornád river, a 150 km long tributary of the Tisza river. Geologically and tectonically different areas crossed by both rivers govern extension and characters of fluvial deposits as well as morphological development of river valleys. Relatively narrow valleys with several terrace steps of the Hornád river are developed in areas consisting by crystalline and Mesozoic rocks. Broad alluvial plains with terrace flight are developed in areas composed of the Tertiary (Paleogene and Neogene) rocks.

In Košice Depression both rivers formed several terrace steps during their Pleistocene evolution. High energy relief of mountains surrounding Hornád and Torysa valleys governed development of steep-gradient perpendicular tributaries to axial rivers depositing system of alluvial fans during the Pleistocene and Holocene. Alluvial fans, hugging volcanic Slanské vrchy Mts. in the Torysa river valley, consists exclusively of monomictic

Slovak Geol. Mag., 7, 3 (2001),221 – 230

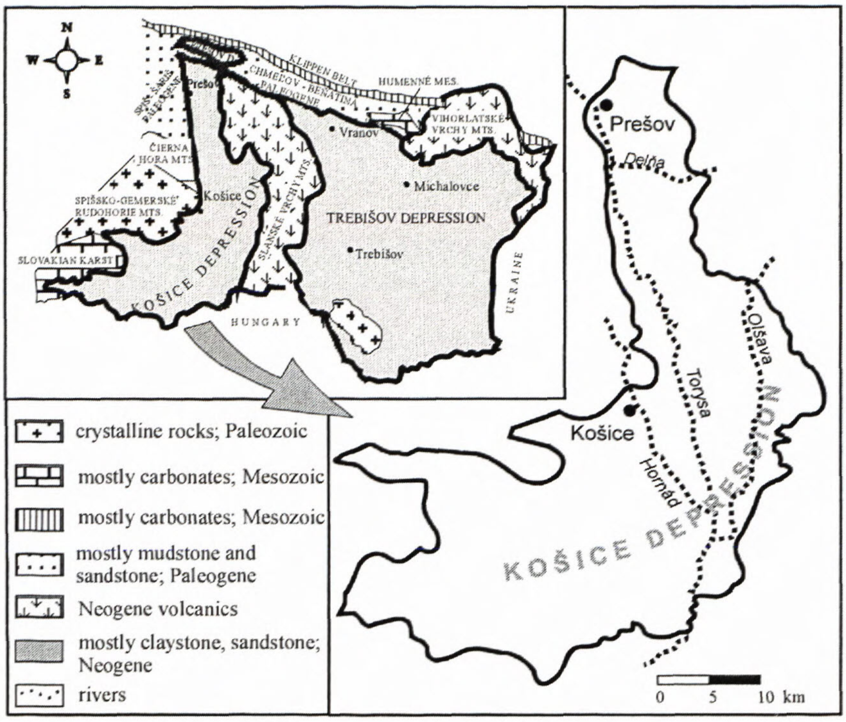

Fig. 1 Location of the Košice Depression. The Košice and Trebišov Depressions separated by the Slanské vrchy Mts. comprise the East-Slovakian Neogene Basin.

Several authors have studied different river reaches, mainly from a geomorphological point of view (Kvitkovič & Plančár 1975, Pristaš 1979, Harčár 1972, Janočko 1989, 1990, Petro et al. 1988 1990, Spišák et al. 1990), but the lack of reliable dating analysis hampers the correlation between them. The present study is focused on the river reaches in the Neogene Košice Depression where they have built a system of terraces. The confluence of the river valleys in the southern part of the Košice Basin, facilitates correlation of both river terraces and alluvial fan systems and comparison of their Quaternary evolution. The relationship between fluvial sediments consisting of polymictic material and monomict rocks of alluvial fan sediments (exclusively volcanic material) is especially exemplary in the Torysa valley.

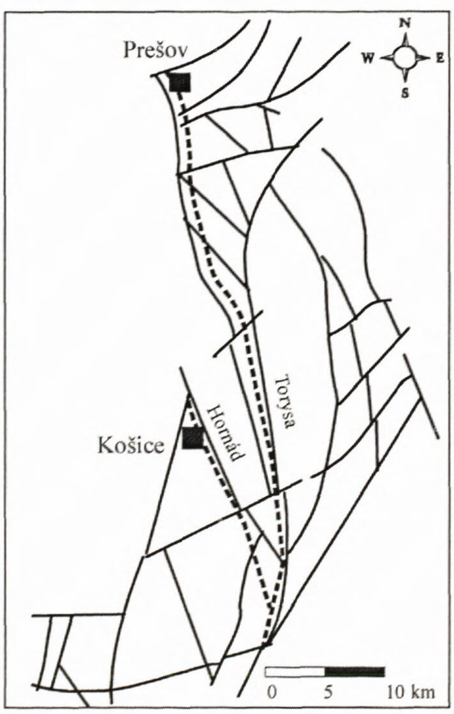

Fig. 2 Structural scheme showing neotectonically active faults in the Košice Depression. Note the N-S trending faults restricting valleys of the Hornád and Torysa rivers. Transverse faults determined origin of small depressions and elevations resulting in change of thickness of Quaternary sediments. Dashed lines represent Hornád and Torysa streams.

volcanic, mainly andesitic rocks. The difference in petrographic composition between sediments of alluvial fans and sediments of axial river system (Torysa) gave an opportunity to study lateral relationship between fluvial and alluvial fan systems.

Methods

Both geomorphological and geological methods have been applied during the research. The terrace steps and alluvial fans were identified by mapping and aerial photographs. The geomorphological analysis included observation of relative altitude of the terrace base (bedrock bench) and surface above the recent flow and construction of longitudinal and perpendicular cross sections. The relative altitude of the base of alluvial fan deposits at the fan toe position, type of radial profiles of alluvial fans and their geomorhological development (telescopic, superimposed) have been studied. The geological methods comprise facies analysis of fluvial and alluvial fan deposits, analysis of grain-size and carbonate content, clasts morphology measurements and analyses of heavy minerals. More than 100 shallow mapping drillings (up to 30 m depth) have been used to study spatial distribution of deposits. Fossil soils were studied where present in order to get more precise dating of sediments. Two ^{14}C datings were performed on the Holocene, carbon rich fluvial overbank deposits.

Terrace and alluvial fan systems

Torysa river valley

Fluvial deposits

The Torysa river enters the Neogene Košice Depression by gateway at the northern part of the basin (Fig. 1). The gateway separates two main fluvial basins of the river. The fluvial sediments are more widespread to the north of the break-through, in the Paleogene basin extending from Brezovica to Veľký Šariš comparing to the Košice Depression to the south. This sediment distribution suggests prevailing deposition at the highland front in the middle river reach and more balanced equilibrium regime in the lower reach resembling small-scale example of three-fold catchment basin model (Starkel 1990). Four terrace steps except recent valley fill are preserved in the investigated area (Tab. 1). They comprise three steps of of the middle and one step of the low terraces. Terrace steps are disconnected and consist of erosional bench incised into the Miocene bedrock and fluvial accumulation (Fig. 3). The stratigraphy of terraces is not firmly established because of lack of pollen and fauna in the terrace accumulations older than the radiocarbon range. The main stratigraphic criteria were morphostratigraphy and correlation to overlying alluvial fan deposits dated on the base of fossil soils and to the terrace steps developed in the eastern, Paleogene part of the basin (Harčár 1974).

Tab. 1 Fluvial systems in Torysa and Hornád rivers with nomenclature and base and surface relative altitudes of individual terrace steps. Age of the fluvial accumulations in individual steps is also given.

Hornad river

Terrace system	Terrace step	Relative altitude		Age	
		Base	Surface		
Lower	1	-3 (-13)	5 - 8	Late	Pleistocene
Middle	3	7 - 10	9 - 12	Middle	
	2	17 -20	13 - 20		
	3	25	30 - 32		
Upper	1	50	52	Early	

Torysa river

Terrace system	Terrace step	Relative altitude		Age	
		Base	Surface		
Lower	1	-4 - -8	2 - 5	Late	Pleistocene
Middle	3	5 - 8	7 - 12	Middle	
	2	18 - 21	20 - 24		
	1	35 - 45 60	37 60.5		

The middle terrace system consists of three terrace steps occurring at relative altitudes 35 – 45 m (1st middle terrace), 18 – 23 m (2nd. middle terrace) and 5 m (3rd. middle terrace; Table 1). The correlation with overlying alluvial fan deposits, eolic deposits and fossil soils and the comparison to their analogue in the northern Paleogene basin (Harčár 1974) implies Middle Pleistocene age (Janočko 1991).

The first middle terrace step occurs at altitudes 35 – 45 m and is overlain by alluvial fan deposits covered by loess-like loams containing rubeficated fossil soil of Holsteinian age (Janočko 1990). The fluvial accumulation has a patchy distribution, its largest thickness, indicated by drillings, is 3.5 m. The sediment consists of erosive-based massive gravel with subrounded clasts of crystalline and Paleogene origin. The unsufficient exposures of the fluvial accumulation do not allow more precise interpretation of the fluvial sedimentary environment.

The second middle terrace step is the most conspicuous terrace in the studied region developed at the altitude 23 - 18 m. It consists of 2 – 6 m thick fluvial accumulation. The typical section has been exposed in the Prešov brick kiln in the relative altitude 20 m. Erosive based, positive graded massive gravel consists of subrounded and rounded crystalline (quartz, quartzite, chert), Paleogene (sandstone and mudstone) and neovolcanic clasts. A sharp boundary divided 2 m thick gravel bed from overlying massive matrix-supported gravel bed about 0.7 m thick. The subrounded and rounded, up to 3 cm large clasts are scattered in the medium to coarse-grained, extremely poorly sorted σ = 4.04) sandy matrix. The upper sedimentary boundary marks a slow transition from this facies to planar cross-stratified sand. The succession is capped by 1 – 1.5 m thick massive, sharply-based silt. The massive, upward-fining gravel is interpreted as a channel fill and the overlying facies probably show two types of overbank deposits. Matrix-supported gravel passing into planar cross-stratified sand represent overbank deposition during high-peak flood discharge with gradual waning of the flow energy indicated by the evolution of the small-scale planar cross-stratification indicating ripple migration. The overlying massive silt is interpreted as overbank deposit representing vertical flood plain accre-

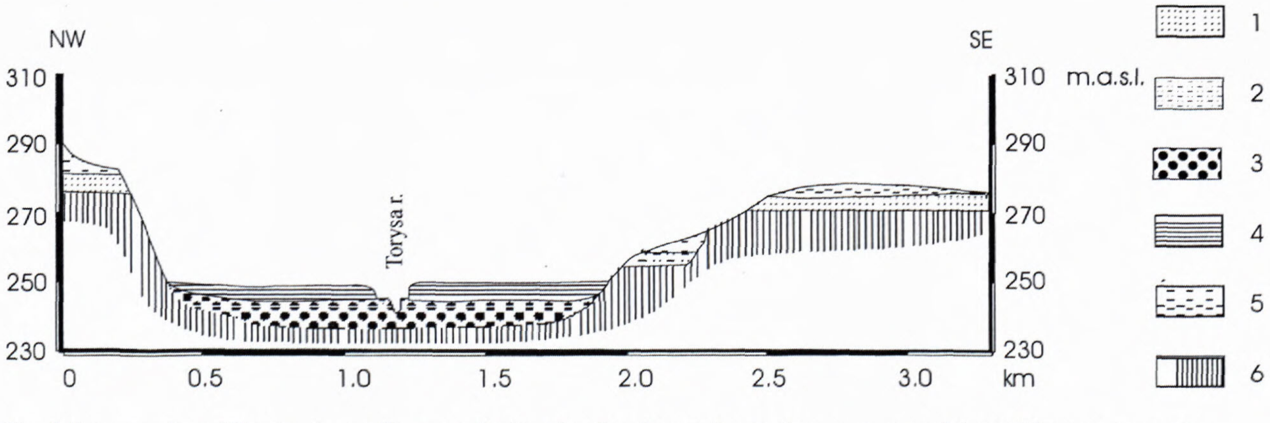

Fig. 3 Cross-section of Torysa river valley near Prešov showing first and second terrace steps of the middle terrace system. 1 – Middle Pleistocene fluvial deposits, 2, 3 – Late Pleistocene fluvial deposits, 4 – recent flood plain deposits, 5 – loess-like loams, 6 – Pre-Quaternary deposits.

tion during the low-peak floods. Although the channel facies is not sufficiently exposed to provide more detail type of sedimentary environment, the well-developed overbank deposits suggest deposition in higher sinuosity gravel bed river system. „Flashy flood" deposits suggest high fluctuation in the river discharge during the sedimentation.

Third middle terrace occurs at level 4 – 6 m above the recent floodplain. Only the gravel accumulation is preserved from the whole fluvial sequence. It consists of erosive based upward-fining massive gravel passing into moderately sorted (σ = 0,921) massive and faintly planar cross-stratified medium and fine sand. The total thickness of sediments does not exceed 3 m. The upward fining trend of gravel capped with occasionally cross-stratified sand suggests the deposition on the point bar. The channel pattern of the river was probably the same like during the deposition of older, second middle terrace deposits.

The lower terrace was formed in the coarse-grained fluvial deposits of the Late Glacial which also comprise the recent valley fill. The surface of the terrace, which is usually covered by Holocene overbank deposits, is about 2 – 5 m above the flow, the base of the terrace is about 4 – 8 m below the flow. The information about the gravely fill came only from drillings what hampered a more precise facies analysis. It shows prevailing massive, occasionally upward-fining gravel, consisting of subrounded to rounded polymictic clasts. The average thickness of gravel bed is 7 m. The gravel is overlain by 2 – 3 m thick layer of overbank silt and silty sand . Typically, two tchernozem soil horizons are developed in these sediments. The ^{14}C dating of the upper horizon yielded 5 700 years B.P. The present day river is incised into these sediments and in some sections cuts about 0.5 m of underlying gravel bed.

Alluvial fan deposits

Sharp transition between slightly undulated, low energy relief prevailing in the Torysa river valley and a high energy, sharply dissected relief of volcanic Slanské vrchy mountain neighbouring the valley from the east (Fig. 1), determined alluvial fan sedimentation recorded since the Middle Pleistocene. The almost uniform petrographic composition of alluvial fan deposits, consisting mainly of andezites, rendered a unique possibility to study their relationship to fluvial sediments of the Torysa river. The development of alluvial fans was determined by local erosive base given by the incision of axial Torysa river system. This is reflected by a very consistent morphometric characteristic of terrace steps and alluvial fan toes. Alluvial fans deposited by Delňa river, a left-side Torysa river tributary (Fig. 4) are morphologically most conspicuous. They have telescopic structure with the head of younger, lower fan segment inserted into upper fan segment (Fig. 5). The radial fan profiles reflecting erosional and tectonic changes in its source area (Bull 1963) are slightly concave (Fig. 6). This type of fan structure indicates a relatively stable position between alluvial fan and the source area (Bull 1964). The fan surface slope angle is

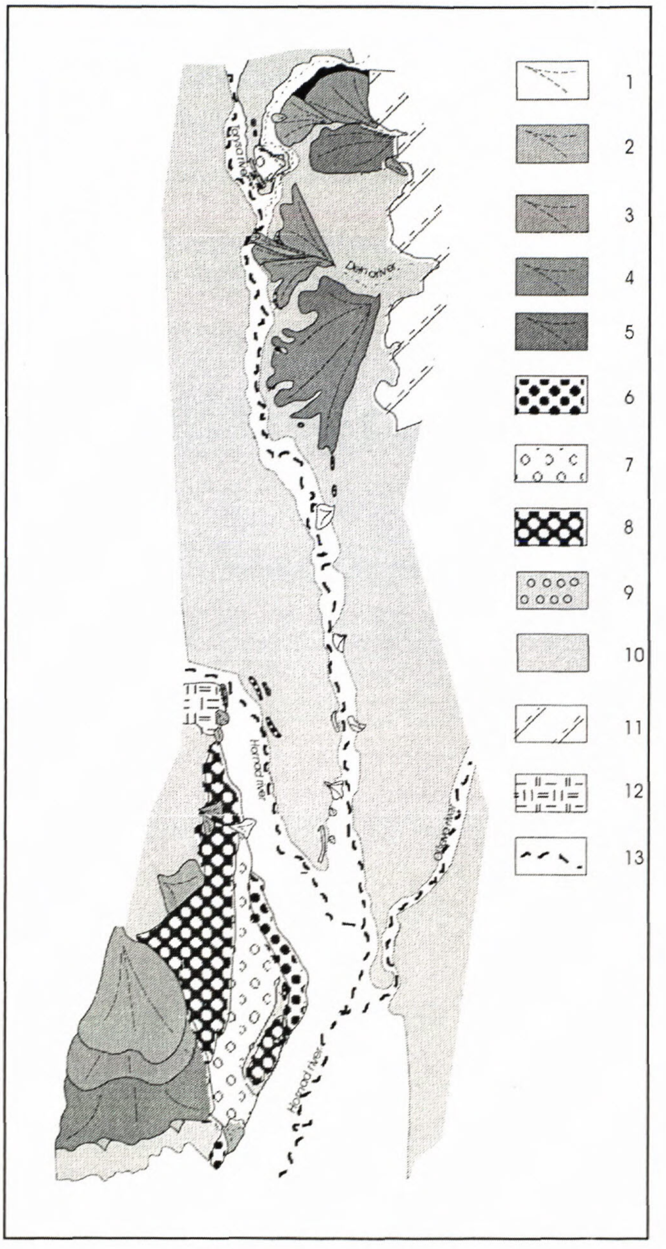

Fig. 4 Location map of the study area and the map of fluvial and alluvial fan sediments in the Košice Basin. 1–5 – alluvial fans (1 – Holocene, 2 – Late Pleistocene, 3, 4, 5 – Middle Pleistocene; 6 – 9 – fluvial sediments (6 – Late Pleistocene, 7, 8 – Middle Pleistocene, 9 – Early Pleistocene; 10 – Paleogene and Neogene sediments; 11 – Neogene volcanic rocks; 12 – Mesozoic and crystalline rocks; 13 – rivers.

small, it varies between 2 and 0.5 degrees. The ratio between the source area (21.28 km^2) to fan area (37.52 km^2) is 0.56. The fan system consists of five segments that are according to the altitude of their toe divided into middle and low alluvial fan segments.

The middle alluvial fan system comprises three fan segments (generations) which toe relative altitude 40, 20 and 6 m is consistent with the altitude of middle terrace system steps (Tab. 2). The morphometry suggests division of this fan system into first, second and third segment analogicaly to the division of middle terrace system. The

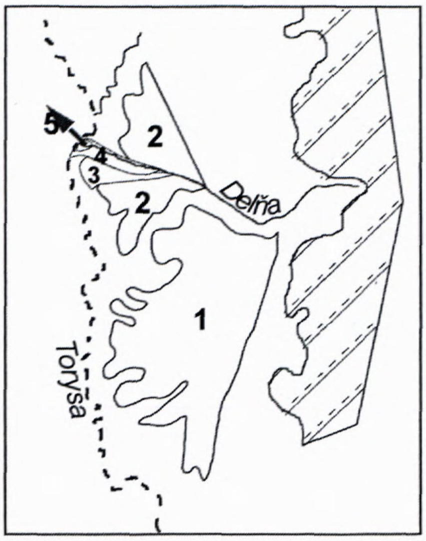

Fig. 5 Telescopic structure of alluvial fans in the Torysa river valley. The older fans are closer to the source area represented by the Slanské vrchy Mts. The oldest fan segment is labelled by number 1, the youngest one is labelled by number 5.

overlying the Torysa second middle terrace step. The low-angle cross-bedded planar beds of clast-supported gravel interlayered with massive gravelly sand are interpreted as foresets of longitudinal bars typical for braided river environment (Mial 1977). Massive, erosive-based very poorly sorted gravel fills either large channels (5 – 10 m wide, 1 m deep) or chutes. The gravelly infill occassionally contains large, up to 50 cm in diameter rip-up clay clasts of Neogene origin. Their location in the upper part of the alluvial fan sequence indicates high competence of the stream. The high energy environment is also demonstrated by massive, horizontal-bedded gravel and clast-supported gravel filling large shallow througs interpreted as flood deposits of the interchannel areas. Very scarce matrix-supported gravel with sharp or erosive base show prevailing sedimentation in the braided river system and relatively distal position on the alluvial fan.

The toe of the third middle alluvial fan segment is in the relative altitude 6 - 4 m and corresponds to the third terrace step of Torysa river. The sediments have been studied only from drillings where showed clast-supported

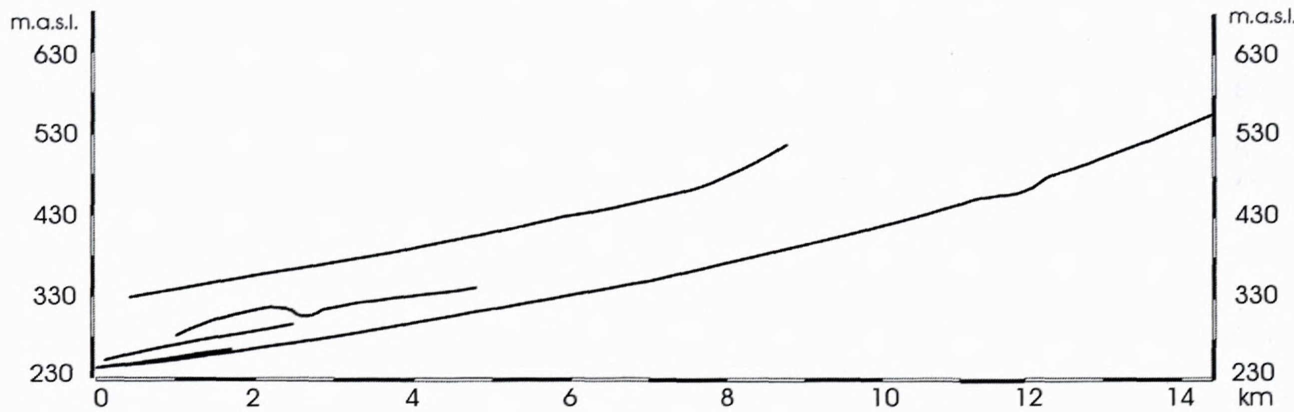

Fig. 6 Radial profile of Delna alluvial fan system.

morphometric criteria and the occurrence of Holsteinian fossil soil covering the highest fan segment demonstrate the possible correlation of middle fan system segments with middle terrace system steps.

The first middle fan segment is represented by a huge fan with the toe at the level about 40 m above the recent Tories river floodplain. Sediments of this segment superpose the first middle terrace of the Torysa river (Fig. 4). The fan is covered by thick loess-like sediments with preserved Holsteinian pseudogleyficated, illimerizated fossil soil (Janočko 1990). The fan sediments are assigned to lower part of the Middle Pleistocene. Scarce outcrops show massive clast-supported gravel with erosive and sharp base arranged into beds up to 1 m thick representing probably flood sediments deposited on the fan interdistributary area. Clasts, composed mostly of andesite, are highly weathered, easily crumbling in the hand. Occasional lateral restricted layers of massive or cross stratified coarse and medium sand originated probably during the waning of the flood.

The toe of the second middle alluvial fan segment is about 20 m above the recent Torysa flood plain and is

Tab. 2 Alluvial fan systems in the Hornád and Torysa river valleys. The table shows nomenclature of fan segments, relative altitude of fan segment toe and age of individual segments.

Torysa river

Alluvial fan system	Alluvial fan segment	Relative altitude of fan toe	Age	
Lower	2	3	Holocene	
	1	-2	Late	Pleisto-
Middle	3	8		
	2	22	Middle	cene
	1	37		

Hornad river

Alluvial fan system	Alluvial fan segment	Relative altitude of fan toe	Age	
Lower	1	60	Late	Pleisto-
Middle	1	40		cene
	2	32 - 35	Middle	

gravel with massive structure, occasionally fining-upward into granules. The bed thickness is 50 – 150 cm. They are interpreted as flood deposits in the braided river system. Both second and third fan segments are supposed to be deposited in the upper part of the middle Pleistocene.

The lower alluvial fan system is divided into first and second low alluvial fan segments. The toe of the first low alluvial fan segment has a relative altitude - 2 m and stratigraphically it is below the floodplain deposits but above the base of the fluvial fill of the valley. This segment represents part of the last sedimentation cycle from the Late Glacial.

The second lower alluvial fan segment is superimposed to Holocene Torysa flood plain deposits and represents the most recent alluvial fan deposition. Both low fan segments consist of very poorly sorted loamy, clast-supported massive gravel without distinctive bedding. This type of sediment has probably been deposited during high-magnitude floods when high amount of particles was in suspension and then abruptly settled down resembling diluted debris flows. The deposition of low alluvial fan system suppresses the Torysa river sedimentation and caused the turn of its channel westward (Fig. 4).

Hornád river system

Fluvial deposits

The Hornád river emerges from the crystalline and Mesozoic Čierna Hora geological unit to the Neogene Košice Basin at the gateway north of Košice (Fig. 1). The flat relief of the Košice basin bounded to the Bodva Horst in the south and uplifted during the Early and Middle Pleistocene (Janočko 1990), determined widespread occurrence of the Hornád river fluvial deposits. A system of five terraces except Holocene flood plain has been preserved from the Pleistocene period (Tab. 1, Fig. 7). On the base of overlying fossil soils, correlation with other fluvial and alluvial fan sediments in the Košice Basin as well as on the base of the morphostratigraphic criteria they have been grouped into the system of the upper, middle and lower terraces (Tab. 1).

The upper terrace system is preserved only in relics at the altitude 50 m above the recent flood plain. It consists of erosive-based clast-supported gravel. The gravel, consisting of resistant clasts (Permian conglomerates, cherts, quartz) shows massive structure and upward fining trend, bedding is indistinctive. It passes into 2 m thick bed of sandy silt with clasts. The shortage of good outcrops does not allow a more detail interpretation of depositional environment, but the possible interpretation of silt with gravel as overbank deposit suggests its origin in a river system with higher sinuosity.

The middle terrace system consists of three terrace steps in the relative altitudes 25, 17 – 20 and 7 – 10 m divided into first, second and third middle terrace (Table 1). The thickness of sediments in the single terrace steps is 2 – 5 m.

The first middle terrace is a most widespread terrace step in the Košice Basin (Fig. 4) having the base 25 m above the recent flow. The clast composition is similar to rocks of the upper terrace enriched in less consistent dolomites and limestones. Cross-bedded gravel overlain by cross-stratified sand suggests sedimentation on the point bar. The lateral shift of channel is well documented by the development of lateral accretion surfaces. Typical are large-scale channels reaching more than 10 m width and 60 cm height and smaller chute channels filled by poorly sorted silty and sandy gravel. The gravel is commonly overlain by silt and sandy silt with scattered small clasts interpreted as overbank deposits. The point bar structures and the development of overbank deposits indicate meandering river depositional system.

The drillings in the weakly-preserved second middle terrace accumulation shows massive, occasionally upward-fining gravel bed up to 4 m thick probably representing channel fills. Additional data are needed for more detail interpretation of sedimentary environment of this terrace step.

The sediments of the third middle terrace are exposed in numerous gravel pits in the southern part of the depression (Photo 2). They show structure typical for large channels up to 20 m long and 0,7 m high filled by massive and

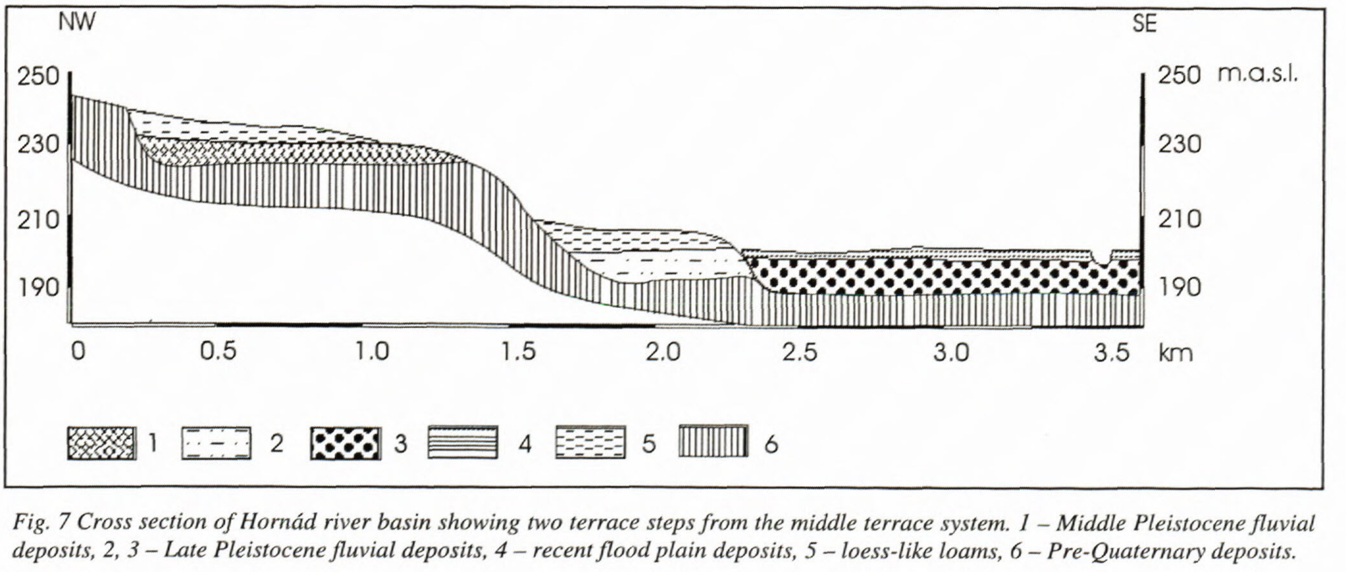

Fig. 7 Cross section of Hornád river basin showing two terrace steps from the middle terrace system. 1 – Middle Pleistocene fluvial deposits, 2, 3 – Late Pleistocene fluvial deposits, 4 – recent flood plain deposits, 5 – loess-like loams, 6 – Pre-Quaternary deposits.

Photo 1 Deposits of the lower terrace step in the Hornád valley. Typical are wide channels filled by cross-bedded sandy gravel suggesting lateral acretion process.

planar cross-bedded sandy gravel. Conspicuous lateral accretion surfaces indicate a lateral migration of channel typical for meandering rivers. The development of more channels at the same stratigraphical level points to both channel migration and switching typical for mobile channel belt built up by meandering or braided river system. Less common are smaller hollows filled by massive gravel representing probably chutes in the bars or crevasses. The absence of flood deposits indicates switching of river channels eroding the lateral flood plain deposits

The surface of *lower terrace system* is about 3 to 5 m above the recent river flow, the base is identical with the base of contemporary river valley, varying from the relative altitude -5 to -10 m. Weekly exposed sediments of this terrace step show only massive gravel with a gradual transition to well-developed silt and sand of flood plain. The good preservation of the overbank facies suggests more stable channel system with less frequent channel migration.

The Holocene fluvial sediments are represented by gravel and widespread fines of overbank deposits building up a broad, well-developed flood plain wide up to 5 km. Gravel is massive , occasionally fining upward. Flood plain facies consists of massive silt and sandy silt, usually commencing at the base with a silty clay layer thick up to 30 cm.

Alluvial fan deposits

The uplift trend of the main source area of the largest alluvial fans debauching into the Hornád valley caused different structure of the fans comparing to the fans in the Torysa river valley. The most extended is the oldest fan segment deposited during the middle Pleistocene and correlated to the first middle terrace step. Younger fan segments were deposited closer to valley mouth and overlies the older segment (Fig. 4). The material of all fan segments consists of quartz, quartzite and chert, occasionally dolomites and limestones. The difference against Hornád river fluvial clast material is the absence of violet conglomerates derived into fluvial deposits from the Permian deposits of the Čierna Hora Mts.

The oldest fan segment is composed of clast-supported horizontal bedded massive gravel with vague boundaries marking beds of average thickness 60 cm. This facies suggests deposition of the gravel sheets during high flood stages.

Photo 2 Fluvial deposits of the 2nd terrace step of the Torysa river overlain by alluvial fan deposits. Fluvial deposits are composed of sandy conglomerate at the base passing into overlying silt representing overbank facies.

Two younger fan segments, stratigraphically correlated to the third middle terrace step and first lower terrace step (Janočko 1990) overlie the oldest fan segment. The scarce outcrops show the layer of brown silt between the oldest and younger segments and similar structures of deposits like in the oldest segment indicating prevailing sheet flood deposition in the braided ? river environment.

The relationship between fluvial and alluvial fan deposits

Different lithology of alluvial fans and fluvial terrace sediments as well as high number of mapping drillings render a good correlation between terraces and alluvial fans. Two types of alluvial fans with „telescopic„ and superimposed fan segment structures are present. The typical relationship between alluvial fans and terrace steps is recorded in Torysa river valley where during a relative stable tectonic conditions the climatic changes were the main factor governing fluvial and alluvial fan sedimentation in the Middle and Late Pleistocene and Holocene. Every segment of the alluvial fan system is superimposed to its fluvial terrace counterpart of the Torysa river (Photo 2). The preservation of this sediment succession in all stages of valley development suggests that the most active alluvial fan sedimentation took place at the end of fluvial - alluvial fan accumulation phase in the erosion - accumulation cycle of the valley development and was followed by the period of river incision. The fluvial and alluvial fan sediments were partly destroyed during the next erosive-accumulation cycle, but the erosion has never expanded laterally as far to destroy all older sediments becoming a new, lowest terrace step. Analogy to the recent relationship between fluvial and alluvial fan sedimentation and to the shift of the main river channel to the opposite side of the valley (Fig. 8) as the response to the alluvial fan invasion onto the flood plain suggest a slow migration of the river channels towards the valley side where the tributary confluences during the main period of river sedimentation, and a fast shift of the channel to the opposite side of the valley at the end of the sedimentation period.

The terrace flight with alluvial fan veneer shows a cyclicity in the sedimenta- tion of the fluvial - alluvial fan succession. Two periods of fluvial incision at the start of cold and warm periods with the prevailed sedimentation during the glacial and interglacial time are generally accepted as the explanation of the cyclic river activity in the Pleistocene (Starkel 1990, Vandenberghe 1993). The development of alluvial fan sedimentation depends on many factors among which are the most important morphology (relief), a sufficient amount of detritus in the rock drainage basin and the suitable climatic conditions (hydrological regime favouring high rainfall amount). These factors form a „geomorphological threshold“ that has to be exceeded in term the alluvial fan sedimentation can start (Leeder 1982). Assuming that the main fluvial aggradation phase took place during the glacial period, the main alluvial fan deposition occurred at the end of the glacial. This indicates that the conditions favouring excess of geomorphological treshold were present particularly at that time. An intensive frost weathering during the glacial period revealed a high amount of loose detritus. A sparse herbaceous vegetation at the end of the glacial has not been able to stabilise weathered material on the steep slopes of mountains adjacent to the low relied basin and all „prepared„ material has been redeposited during the increased rainfall governing the development of the alluvial fans at the foots of the mountains (Fig. 8). The main trend of the axial river in the main valley, suppressed by the alluvial fan to the opposite side of the valley, was incision during a time of increased runoff (Vandenberghe 1993) and therefore it has already not switched back and recovered alluvial fan sediments (Figs. 8 and 9). A new valley „storey„ has been developed after the incision representing the beginning of the new erosion - accumulation cycle.

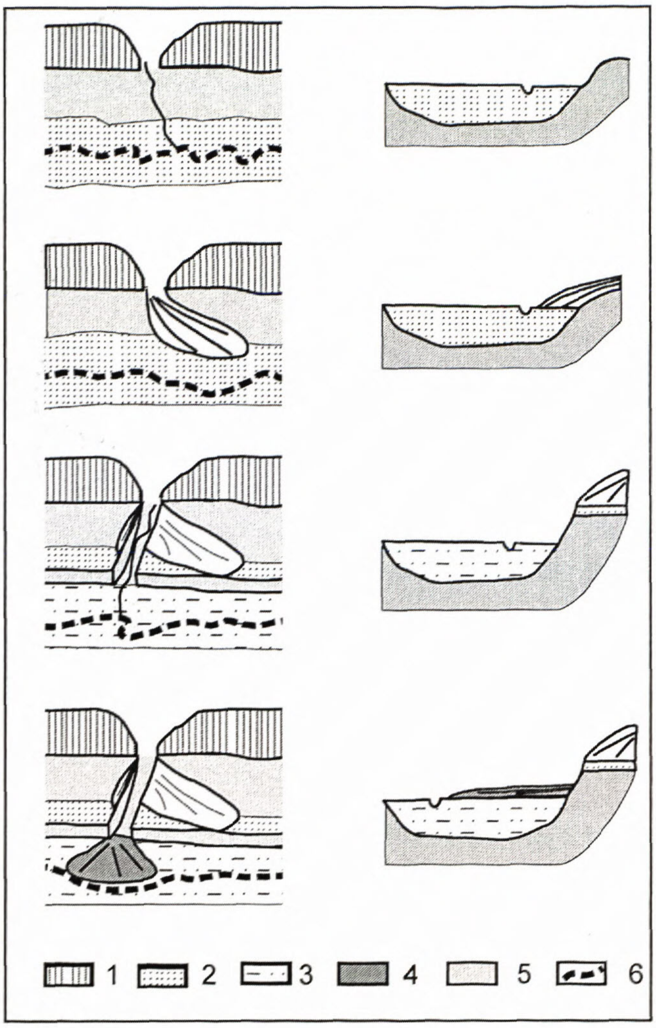

Fig. 8 Scheme of lateral shifting of axial river channel (Torys river) in interaction with deposition of alluvial fans. 1 – volcanics of the Slanské vrchy Mts., 2 – older fluvial deposits, 3 – recent fluvial deposits, 4 – recent alluvial fan, 5 – pre-Quaternary rocks, 6 – axi al river

Correlation of river terraces and alluvial fans of Torysa and Hornád river valley

The Torysa river is confluencing with the Hornád river in the southern part of Košice basin. There are four

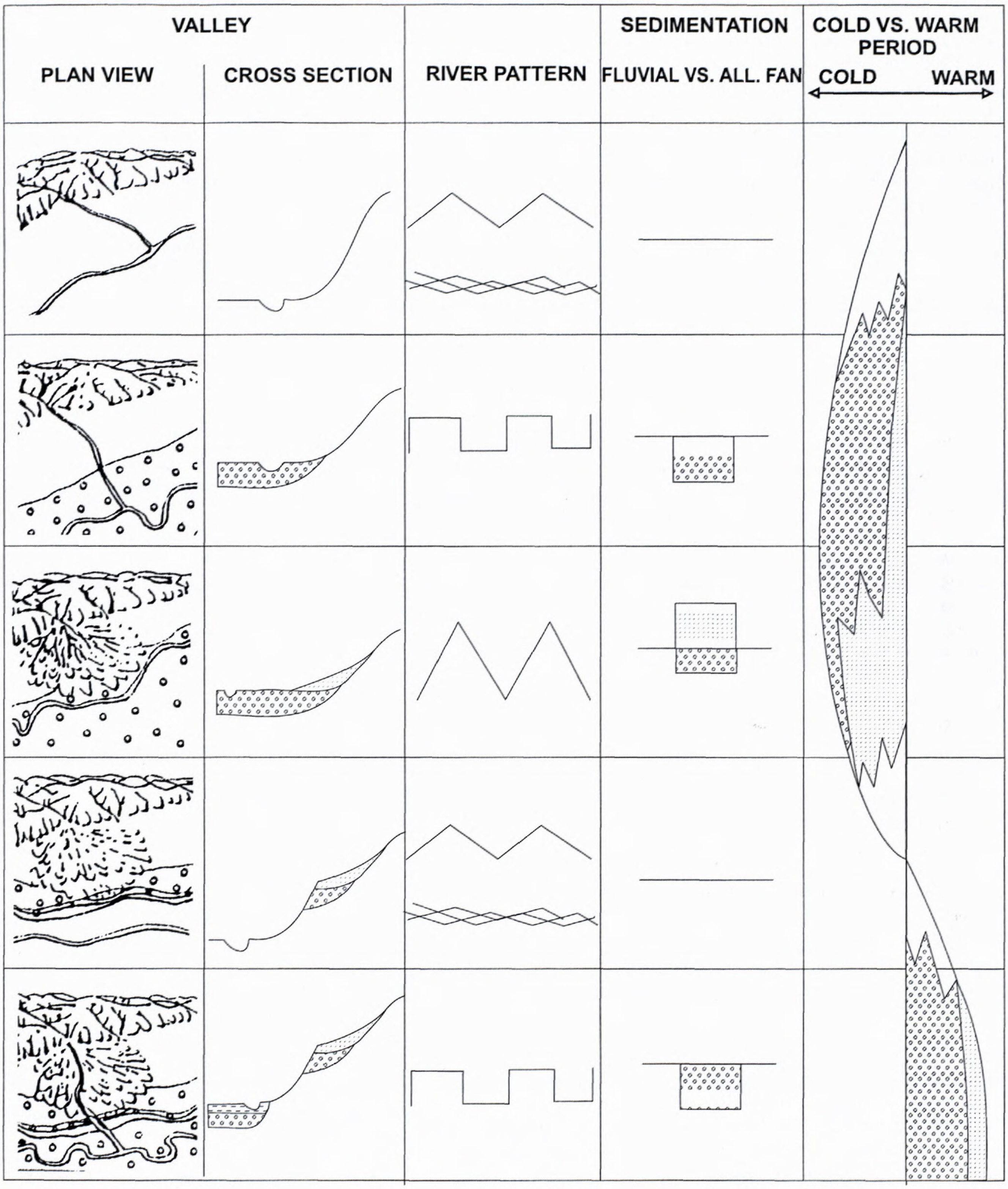

Fig. 9 Model showing succession in sedimentation of alluvial fans and fluvial sediments of axial valley rivers in the Košice Depression. Inferred river pattern and relationship to cold and warm periods is also shown.

terrace steps developed in the Torysa river and five steps in the Hornád valley. Their morphometry shows very similar evolution history of both valleys. The oldest fluvial accumulation is represented by step of the upper terrace system in the relative altitude 50 m above the recent flood plane. The Pliocene level is preserved in both valleys in about 120 m of relative altitude indicating the river incision about 70 m during the period of the lower Pleistocene. The missing sediments from this period suggest gradually increasing wide of the valleys responsible for the erosion of older fluvial deposits. Both rivers had maximum thickness of the flood plain in the lower part of the Middle Pleistocene. The broad flood plain of the Hornád river that emerged from the gateway into a low depression relief north of the Košice (Fig. 1), resembled a large alluvial fan. At the end of the lower Middle Pleistocene glacial period (Mindelian), the fluvial sedimentation in this valley was suppressed to the east and the valley never reached the lower Middle Pleistocene expansion. Similar narrowing trend after the Early Pleistocene period is observed in the Torysa river valley and it was only interrupted in the Late Pleistocene when the increased erosion was responsible for denudation of the third middle terrace. The relative elevation of the terrace systems shows that the value of river incision between the accumulation periods has been very consistent in both valleys. A small difference between the incision values between the high and first middle terraces of rivers was caused by differentiated tectonic movements after the deposition of lower Middle Pleistocene fluvial and alluvial fan deposits (Janočko 1990). The consistent morphometry of younger terrace steps in both valleys suggests that this tectonic uplift took place in a very limited time span. A good correlation between the river systems in both valleys suggests that probably main factor causing the cyclic river incision and sedimentation was climatic change and tectonic development contributed only by a smaller extension to the valleys development. The different tectonic regime of the surrounding mountains in the Quaternary period is indicated by the different development of the alluvial fans in investigated valleys. The „telescopic„ structure of alluvial fans is typical for the Torysa river valley where the older fan segment has been entrenched in its head area and a lower segment has been developed in the lower position. The shift of the deposition loci away from the fan head and the concave surfaces of single segments suggests a relative stable fan - source area position during the development of the fan system. Different development is indicated by the alluvial fan structure in the Hornád valley. The oldest fan, related to the first middle terrace step, underlies the younger fans, which deposition locus has been shifted upstream, closer to the fan head. An active tectonic uplift of the source area during the fan development has been responsible for this type of fan structure.

Conclusion

The terraces of the Torysa river are arranged into four terrace steps and record evolution of the Torysa river valley since the Middle Pleistocene. In the Hornád valley five terrace steps record evolution of the valley since the Early Pleistocene. About 70 m deep vertical incision during the Early Pleistocene, indicated only by the difference of the Pliocene niveau and the first middle terrace, suggests widening of the valley connected to lateral erosion. This trend changed in the lower part of the Middle Pleistocene (Mindelian) when maximum width of both valleys has been reached as indicated by the most widespread fluvial and alluvial fan sediments. The vertical river incision between accumulation phases inferred from the terrace morphometry has almost been consistent in both river valleys and varies from 10 to 20 m. Well preserved overbank deposits suggest higher sinuosity river system. Superposition of alluvial fan deposits above the river terraces indicates sedimentation close to river incision phase, when there already was not enough time (and sediments) to overlie fan deposits. This suggests fan deposition at the end of the main fluvial sedimentation cycle at the glacial (stadial) termination. The different structure of fans in the Torysa and Hornád valleys resulted from tectonic activity of their source areas.

Acknowledgement

The study is a partial result of the project „Tectogenesis of sedimentary basins of the Western Carpathians" financed by the Ministry of Environment of the Slovak Republic. I am grateful for helpful reviews by Michal Kováč and Ivan Baráth.

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