ANALYSIS OF FLUVIAL SYSTEMS IN THE VICINITY OF BEŽAN HILL (LIPTOVSKÁ KOTLINA BASIN, WESTERN CARPATHIANS)

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Abstract

The Liptovská kotlina Basin (LKB), as one of the intermountain basins of the Western Carpathians, belongs to the most active regions together with the Tatra Mts. during the neotectonic phase. It is recorded, besides other features, in character of fluvial systems, which are frequently applied in morphotectonic studies. Plateau terrace T-IX located on the Bežan hill, records the oldest evolution stage of fluvial systems of the LKB. To specify the Plio-Quaternary evolution of the western part of the LKB, sedimentological and geomorphological analysis of fluvial systems was conducted. Man-made outcrops together with 14.5 m drilling enabled to detect fluvial, not fluvio-limnic character of accumulation implying the alternating influence of the Váh River and Ľupčianka Stream. Spatial distribution of deposits points to progressive shifting of the Váh River to north, whereas tendency of the Ľupčianka Stream migration towards the northeast was subsequently changed to western direction. Neotectonic processes are considered to control the fluvial system of the Sliačanka Stream as well.

Keywords: Western Carpathians, Liptovská kotlina Basin, fluvial system, Bežan hill, Váh River, Ľupčianka Stream

Introduction

Fluvial depositional systems in intermountain basins of the Western Carpathians are important component of the Quaternary basin fill. Furthermore, fluvial deposits play an important role as stratigraphic markers, which enable to assess morphotectonic evolution of particular drainage basin. Generally, fluvial systems can be developed in terrace or superposition sequence recording regional uplift or subsidence (Galloway, Hobday, 1996; Maglay et al., 2011).

Analyses of fluvial systems are frequently applied in various morphotectonic studies (e.g. Minár, Bizubová, 1994; Salvany, 2004; Roštinský et al., 2016; Šujan, Rybár, 2016). As the tectono-sedimentary evolution of intermountain basins and lowlands of Western Carpathians is recorded mostly in fluvial sediments, the investigation of their spatial distribution and character is crucial for assessment of neotectonic evolution of the study area as well.
Regional settings and state of the art

The Liptovská kotlina Basin (LKB), as a subunit of the Podtatranská kotlina Basin (Mazúr, Lukniš, 1978), is considered as one of the most neotectonically active territory of the Western Carpathians, which repeatedly subsided in relation to adjacent mountains during the Quaternary (Halouzka et al., 1999). Neotectonic processes controlling the evolution of the LKB are recorded in character of its fluvial system as well. Quaternary dynamics of the western part of the LKB was influenced by regional stress field changes. Extension oriented in NNE–SSW direction operating during Pleistocene changed into NE–SW and E–W operating in Holocene (Pešková, Hók, 2008). Quaternary sediments of various genesis and thickness cover the Paleogene basement of the LKB formed by flysch Subtatric Group (Gross, 1979).

In the vicinity of Bežan hill (Map 1), fluvial systems of three rivers (streams) occur: the Váh River, the Lúpčianka Stream and the Sliačanka Stream. River terraces are developed along the Váh River, whereas terraced alluvial fans are developed along its tributaries.

The highest river terrace of the Váh River is preserved on the Bežan hill (670 m a.s.l., Figure 1, 2). Based on its relative elevation (~155 m) and general morphoposition within the fluvial system, the terrace remnant was within the terrace system of the Western Carpathians (Halouzka, 1986) assigned to terrace T-IX (Vitovič, Minár, 2018). Traditionally, terrace T-IX, termed as plateau terrace, is considered to record the Early Pleistocene evolution of the river valleys (Halouzka, 1986; Maglay et al., 2011). Based on relative elevation, the accumulation on the Bežan (“Beran“ during that times) was correlated with Háje hill (~176 m rel.), situated south of the Liptovská Mara dam (Map 1 B) by Vitásek (1932). However, the presence of terrace sediments on Háje hill (714.5 m a.s.l.) wasn’t proved.

Opinions on the thickness of the terrace remnant accumulation significantly vary, from estimation of ~30 m (Vaškovský, 1980) and detection by excavating ~18 m (Droppa, 1970), to precise drill-inferred assessment of 11 m (Páleník, 1988). Therefore, estimations of the value of relative elevation of terrace base were various as well (e.g. Droppa, 1964, 1970).

The accumulation of this terrace remnant was traditionally considered to have a fluvio-limnic origin, which records the pre-Quaternary (Pliocene) stage of evolution of the LKB (e.g. Gross, 1979; Vaškovský, 1980). In order to specify the chronology and character of tectono-sedimentary evolution of the LKB, the 14.5 m deep core drilling in plateau terrace T-IX, associated with geomorphological and sedimentological analysis was carried out (Figure 3, 4).

The aim of the paper is to identify the evolution of the fluvial system in the study area. However, the oldest stage of evolution of the western part of the LKB inferred from analysis of the plateau terrace accumulation is crucial part of study.
Methods

The analysis of the fluvial system of the study area was conducted by compilation of the previous geological and geomorphological studies together with own field research. The focus was put on identification of the oldest stage of development, as there is relatively a lack of evidence resulting from small number of preserved accumulations within the Western Carpathians.

The evaluation of spatial distribution and classification of terrace system of the Váh River was conducted in accordance with Vitovič, Minár (2018). To evaluate character of fluvial system of tributaries, inventory together with unification of accumulations had to be carried out, regarding heterogeneous terrace system classifications.

The initial analysis of the terrace sediments was carried out in June 2017, when analysis of gravel material from shallow outcrop in northern part of T-IX accumulation (Site 1, Map 1 C) was conducted (Vitovič, Timko, 2018). Here, the gravel clasts (n=153) were collected from 0.5–0.7 m depth. To identify the character of sediments from entire profile of the terrace accumulation, the core drilling was subsequently (in August 2018) executed (Figure 3). Position of the drilling was measured with GPS device (Garmin eTrex Touch 35), while its altitude was inferred from digital elevation model (derived from vectorized contours of 1:10,000 topographic map of Slovakia).

Initial sedimentological description of the drill core sediments was executed together with geologist Dr. J. Littva. The gravel analysis in concert with Vitovič, Timko (2018) from man-made outcrop (Figure 4) at drilling site (Site 2, Map 1 C) was carried out as well. Here, the gravel clasts (n=115) were collected from 0.8–1 m depth. Lithology, total stage of weathering and stage of roundness of the gravelly fraction of granitoid and silicic material from shallow outcrops (Site 1 and 2) was evaluated within this study. Granitoid clasts from both sites were compared in total stage of weathering with other river terraces, regarding that granitoid group of rocks is generally the most numerous within the Váh River terraces (Vitovič, Timko, 2018). Stage of roundness (1–6) was analysed in line with Power (1953), where 1 is very angular and 6 is well-rounded. Subsequently, the samples for dating and further analyses were collected from selected depths of the drill core: 0 cm (surface), 50, 100, 150, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1350 and 1380 cm. Within this study, the weight percentage of each lithological group of gravelly fraction (size ≥ 10 mm), obtained by sieving, at mentioned samples was calculated.
Map 1 A: Location of broader study area within Slovakia. B: Location of the study area and drilling site within the Liptovská kotlina Basin. Settlements in the map: LM: Liptovský Mikuláš, RK: Ružomberok. A huge water body is Liptovská Mara dam. C: Position of drilling site within the fluvial system of the study area. Terrace system of the Váh River in line with Vitovič, Minár (2018). Terraced fans modified according to Droppa (1964, 1970, 1972), Gross (1979) and Biely (1992). Faults and travertines according to Gross (1979)
Figure 1: Position of remnants of plateau terrace T-IX within the long profile of the Váh River terrace bases. Black dots represent the base of T-IIa, gray squares base of T-Ic remnants. Segments of the valley are denoted above the profile (Arabic numerals). Vertical lines denote tectonic faults disrupting the terraces. Modified according to Vitovič, Minár (2018)

Figure 2: View on the valley of the Váh River in the western part of the Liptovská kotlina Basin. The Nízke Tatry Mts. are in the background

Source: author

Results

In spite of several discrepancies in classifications of terrace and terraced fans accumulations, unification of fluvial systems was conducted. Location of the highest terrace accumulation is in the middle of the study area, on the drainage divide of mentioned streams and river. Thus, potential influence from all the catchments is present. Fluvial system of the trunk river and its tributaries consists of terraces, terraces alluvial fans and recent floodplains. The fluvial system of the
Váh River (northern part of the study area), as a trunk river of the LKB, consists of composite terraces preserved in 11 levels with separate bases. Within the valley bottom, three erosional steps are developed with uniform rock base, consisting of low terrace and two levels of Holocene floodplain (Droppa, 1964; Vaškovský, 1980; Vitovič, Minár, 2018). Study area is located in the 4th segment of the Váh River valley (Figure 1), where mostly unpaired left-bank remnants remained (Vitovič, Minár, 2018). Terraced alluvial fans are typical for the fluvial system of the Váh River tributaries. The terraced fans of the Ľupčianka Stream (eastern part of the study area), preserved along its entire length within the LKB, are partially interconnected with the Váh River terraces. Terraced fans of Sliačanka in southwestern part of the study area are connected with the trunk river valley only by relatively narrow floodplain (Gross, 1979; Littva, 2017).

Successive shift of former confluence area towards north-east can be visible from spatial distribution of accumulations preserved along the Ľupčianka Stream, which join the Váh River terraces north of Partizánska Ľupča village (Map 1 C). Progressive migration of Ľupčianka towards the northeast was altered after formation of right-bank terrace T-III by shifting towards the west, resulting in spatial distribution of terraces, where older deposits (mostly levels T-VI and T-IVb) are preserved on the left bank, whereas younger ones (T-III and T-IIb) on the right bank. The asymmetric preservation of the unpaired terraces points to influence of neotectonic activity (ground tilting), which is partially confirmed by Pešková, Hók (2008), Littva (2017) and Vitovič, Minár (2018). Tilting resulted in terrace (T-III and T-IIb) stepping to the west together with stream migration. According to Droppa (1970), left-bank terrace T-IVa was removed by landslide activity. An eastern branch of the Ľupčianka Stream passing the village (Map 1 C) is only artificially maintained (Droppa, 1970). Its valley bottom in Bežan hill vicinity reaches 500–700 m.

The Váh River valley is controlled mostly by ENE–WSW trending fault disrupted by younger transverse faults into several segments. Therefore, predominantly left-bank remnants remained preserved, which is the evidence of progressive migration of the Váh River towards the north during the Quaternary. Width of floodplain of the Váh River in Bežan vicinity reaches 1000–1300 m. Neotectonic activity is recorded in travertines as well (Map 1 C, Pešková, Hók, 2008; Gross, 1979, 1980).

Alluvial fans of the Sliačanka Stream are significantly limited in a wedge-shaped depression in southwestern part of the study area. They are represented by a uniform generation of fans classified to T-III level. Older generations were probably eroded. Shape of the fans was controlled by young generation of faults resulting in their separation from the Váh River valley. Only narrow floodplain of Sliačanka (100–150 m) connects the trunk valley with the alluvial fans (Gross, 1979; Droppa, 1972; Littva, 2017).
Surface altitude of the drilling site (Site 2) is 667 m a.s.l., which results in its relative elevation 169.5 m above the recent floodplain of the Váh River. The drilling reached the pre-Quaternary rock (Paleogene claystone) 14 m under the surface. Thus, the value of altitude and relative elevation of the terrace base was specified, resulting in 653.0 m a.s.l. and 155.5 m, which was consequently applied in long profile of the terraces (Vitovič, Minár, 2018, Figure 1) and calculation of regional uplift rate (Vitovič, 2018).

Based on the macroscopic sedimentological analysis of material from outcrops and drill core, the genesis of the terrace accumulation was evaluated as fluvial. Deposits consist mostly of gravelly and sand fraction of a stream-bed facies, while fine-grained sediments of floodplain facies weren’t found. No lacustrine sediments (e.g. lacustrine clay or silt) or similar sediments with their structure or texture (Růžičková et al. 2003) were detected within the entire accumulation. Therefore, a limnic or fluvio-limnic origin of the accumulation was negated.

Position of outcrops at Site 1 and Site 2 within the accumulation differs in its altitude and distance from the Váh River valley thalweg. Site 1 is located close to the terrace base (~650 m a.s.l), whereas the Site 2 is close to its top (as already mentioned). Concerning the distance, Site 1 is located ~2100 m, while Site 2 ~2600 m from the thalweg. In regard with the distance of the accumulation from its potential source, Site 2 is located on the ~65th km of the Váh River (from the Biely Váh River source), ~21st km of the Łupčianka Stream and ~8th km of the Sliačanka Stream. For Łupčianka and Sliačanka, Site 1 is ~500 m further than Site 2 along the streams.

Lithology of gravel inferred from analysis from outcrops is denoted in Graph 1. At Site 1, the most numerous are carbonates (42.6 %), silicic (27.8 %)
and granitoid (20.0 %) rocks, whereas at Site 1 silicic (36.6 %), granitoid (29.4 %) and metamorphic (15.7 %) rocks dominate. 5.2 % of metamorphic rocks are represented by mylonites. The largest portion for both localities is silicic group of rocks. The most apparent differences are in percentage of carbonate, metamorphic and vulcanite rocks. Certain variations occur in the rest of rock types as well.

Graph 1: Lithological composition of gravel from Site 1 and 2. Numbers in columns are referred to portions (in %). Explanation to numbers in legend, types of rocks: 1: granitoid (granite, granodiorite), 2: silicic (quartzite, quartz and quartzite conglomerate), 3: carbonate (limestone, dolomite), 4: sandstone (Paleogene, Permian), 5: volcanic (paleobasalt, paleoandesite), 6: metamorphic (gneiss, mylonite)

The values of total stage of weathering (W) (Graph 2), inferred from gravel analysis from outcrops, range from 349 (Site 1) to 376 (Site 2) resulting in average value 362.5. The values of the plateau terrace are considerably higher compared to the rest of terraces.

Graph 2: The total stage of weathering of the Váh River terraces. Denoted range of measured W values is based on mentioned analyses of plateau terrace. Partly modified according to Vitovič, Timko (2018)
There are differences in stage of roundness of granitoid clasts from Site 1 and Site 2 (Graph 3 and 4). Increased portion of more rounded clasts assigned to class 4 and 5 can be found at Site 1, whereas significantly higher portion of more angular clasts assigned to class 2 is at Site 2. It follows, that generally better rounded clasts occur at Site 1, which indicates a longer transport of gravel.

Differences in stage of roundness of silicic clasts from Site 1 and Site 2 (Graph 5 and 6) occur as well. Differences between Site 1 and Site 2 have very similar tendency compared to granitoid gravel. Thus, more rounded silicic clasts occur at Site 1, whereas more angular clasts can be found at Site 2.

Graph 3: Percentage of granitoid rocks (n=45) in selected classes of roundness from Site 1

Graph 4: Percentage of granitoid rocks (n=23) in selected classes of roundness from Site 2

Graph 5: Percentage of silicic rocks (n=52) in selected classes of roundness from Site 1
Graph 6: Percentage of silicic rocks (n=32) in selected classes of roundness from Site 2

Based on depth-related variations of lithological composition inferred from analysis of drill core sediments (Graph 7), three considerable trends can be outlined.

Graph 7: Lithological composition of terrace gravel inferred from drill core analysis. Numbers in columns are referred to portions (in %). Explanation to numbers in legend, types of rocks: 1: granitoid (granite, granodiorite), 2: silicic (quartzite, quartz and quartzite conglomerate), 3: carbonate (limestone, dolomite), 4: sandstone (Paleogene, Permian), 5: volcanic (paleobasalt, paleoandesite), 6: metamorphic (amphibolite, green schist)

At first, a very low portion (compared to gravel analyses according to Vitovič, Timko (2018)) of metamorphic rocks is present in this part of
accumulation. Metamorphic rocks were detected only in depth of 600, 1100 and 1200 cm with maximum 1.8 %. Secondly, portion of granitoid, silicic, carbonate and sandstone rocks significantly changes with depth. The highest portion of granitoids is in the uppermost (from surface to 300 cm) and lowermost (from 1100 cm to the base) layer. In the middle part (400–1000 cm), the carbonates are in contrary in predominance; with the maximum ~83 % in 400 cm depth. Similar trend to granitoids can be visible in silicic rocks as well. The highest portion of sandstones occurs in depth around 700–1000 cm. The third trend is associated with volcanic rocks, which were detected mostly in the lowermost part (from 1100 cm to the base) represented by ~4–13 % portion. They occur rarely and only in low portion (≤ 0.6 %), in middle and upper part as well.

Lower part of the accumulation is presumed to be influenced mainly by the Váh River, whereas the higher parts of accumulation were influenced mostly by the tributary(ies), as it is evidenced by lithology and stage of roundness of the terrace gravel.

Discussion

Based on the analyses of sediments collected from outcrops and drill core, the basic tendency of evolution of fluvial system in the plateau terrace area and adjacent surroundings can be outlined. Morphoposition together with apparently high stage of weathering of the T-IX accumulation can be considered as evidence of the oldest stage of evolution of fluvial system within the study area as well as in the LKB. A finding, that accumulation has no limnic or fluvio-limnic origin is in line with presumption of Vitásek (1932), that development of the LKB during Pliocene and Quaternary had terrestrial erosional character without presence of any lake.

Considering that the differences in stage of roundness are not extremely dissonant, the influence of the Ľupčianka Stream, not the Sliačanka Stream, is presumed, taking into account their lengths (~21 km vs. ~8 km) and geology settings of source areas. From the catchment of Sliačanka Stream, markedly more angular clasts are expected. Less rounded gravel is mentioned also by Droppa (1972). Furthermore, its catchment doesn’t reach the crystalline core of the Nízke Tatry Mts., from which granitoids would come from. Sediments of Sliačanka are represented by various types of limestones, dolomites and flysch sandstones and claystones (Droppa, 1972). Moreover, influence of the Ľupčianka Stream on the Bežan area was estimated also by Droppa (1964, 1970).

As the basic sedimentalogical attribute of the Váh River terraces in the LKB is the presence of paleovulcanite rocks (Droppa 1964, 1970, Vitovič, Timko, 2018), their increased portion in lower part of the accumulation indicates the predominance of the Váh River in initial stage of the terrace development. This
was later altered by increased influence of the Ľupčianka Stream, which is recorded in considerably lowered portion of paleovulcanites and increased portion of carbonates. A low portion of vulcanites in upper parts of terrace are presumed to be deposited by the Ľupčianka Stream as well, regarding small areals of Cretaceous vulcanites occur in its catchment (Biely et al., 1992). Furthermore, a very low portion of vulcanites (1%) was detected in terrace accumulation of its upper course (in the Nízke Tatry Mts.) as well.

Terraced fans of tributaries overlaying the Váh River terraces were detected also in other parts of the LKB, e.g. in confluence area of the Demänovka Stream (Droppa, 1970, Map 1 B).

Higher content of metamorphic rocks (from which 5.2% are mylonites) from Site 1 in comparison with gravel from outcrop and drill core at Site 2 can result from even stronger influence of the Váh River considering its location, which is 500 m closer to its thalweg.

Different estimations and assessments of accumulation thickness rising from various methods of research can be explained by indeed variable thickness as well, resulting probably from incised paleochannel into the terrace base. Nevertheless, an estimation of 30 m (Vaškovský, 1980) is presumably highly overestimated.

Regarding the terrace development of fluvial sediments, regional uplift is considered as an important factor controlling the evolution of the study area. However, there is morphotectonic and geological evidence (e.g. slope facets, travertines) of relative subsidence of the LKB in relation to the Nízke Tatry Mts. (Littva, 2017) as well.

Regarding the previous age estimations (e.g. Gross, 1979; Halouzka, 1986), we presume that the plateau terrace preserved on the Bežan hill records the Late Pliocene to Early Quaternary development. However, lithological composition of terrace gravel assigned to Pliocene age in other parts of the Western Carpathians (e.g. in the Zvolenská kotlina Basin and Žiarska kotlina Basin), is markedly different. There, a significantly higher portion of silicic rocks (quartzites and quartzes) occurs (Halouzka, 1998a, b), which can implies older stage of development in comparison with Bežan hill.

The precise numerical age of the terrace T-IX still hasn’t been assessed, regarding the samples are still being processed.

**Conclusion**

Evolution of fluvial systems in the western part of the LKB was studied applying geomorphological and sedimentological approach. In the vicinity of the Bežan hill (670 m a.s.l), fluvial systems of the Váh River and its tributaries (Ľupčianka and Sliačanka Streams) occur.
The Váh River, as a trunk river, has developed a flight of 11 river terraces recording fluvial and neotectonic activity in the LKB along its course. In the Bežan hill area, plateau terrace T-IX is preserved, recording its oldest tectono-sedimentary development. Based on sedimentological analyses of terrace gravel from outcrops and drill core, several important features were detected.

By means of drilling, thickness of terrace accumulation together with elevation of its base was identified, which was subsequently applied in further research. The accumulation is 14 m thick and situated 155.5 m above recent floodplain of the Váh River and ~96 m in relation to floodplain of the Ľupčianka Stream. Age of plateau terrace is considered to be Late Pliocene to Early Quaternary.

Genesis of terrace sediments was, based on macroscopic sedimentological analysis, assessed as fluvial stream-bed facies, without any presence of lacustrine deposit. Thus, traditionally regarded fluvio-limnic origin of the accumulation was negated. Therefore, development of the western part of the LKB during Late Pliocene and Quaternary had terrestrial erosional-accumulation character.

Development of the terrace T-IX was mostly influenced by the Váh River, later altered by the Ľupčianka Stream, as it is recorded in stage of roundness and lithology of gravel. Evolution of fluvial systems of the Váh River and the Ľupčianka Stream was controlled by neotectonics as it is evidenced by unpaired preservation of accumulations gradually stepping to one direction. Regional uplift together with ground tilting operated during their formation. Fluvial system of the Sliačanka Stream was determined by triangular shaped depression.

Obtained results confirm the utility of applied methods, which implies importance of continuation in more detailed revision of former geological surveys in other parts of the Western Carpathians. In general, the most important appears the verification of genesis and age of accumulations, consequently reflected in interpretation of georelief evolution.

Outlined trends of evolution of fluvial systems can be used not only in subsequent investigation of morphotectonic structure of the LKB, but in applied scientific branches as well (Maglay, Pristaš, 2004). Identified long-term tendency of river migration can contribute to prognosis of further development of landscape and georelief. Therefore, it can be applied in construction, infrastructure and urban planning as well as in management of other socio-economic activities.

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