FORMATION AND ROLE OF NEOGENE SEDIMENTS FROM TATRA MOUNTAINS IN THE SHAPING OF CZARNA ORAWA RIVER ALLUVIAL PLAIN

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Abstract. The paper presents researches that were conducted in Czarna Orawa River catchment, situated within the Tatra and Beskidy Mountains. Czarna Orawa River channel is segmental meandering system with the index of tortuosity up to 1.6. The aim of the article is to characterize gravels which were transported from the Tatra Mountains and their role in valley bottom formation.
The gravels; originating from Beskidy and Tatra mountains, supply the alluvial cone of Czarny Dunajec. In Czarna Orawa Valley we meet coarser gravel (the Tatra Mountains gravel) and more angular than grains from the Beskidy Mountains. On the Holocene terraces in the valley gravel layer is 1-2 m thick. The grains are 1-6 cm in diameter and the biggest are found on the south bank (up to 20 cm). Between Jabłonka and Orawa Reservoir the change of petrographic composition is observed. Beneath Jabłonka village flysh gravels are common, and in the lower part, in the neighbourhoods of Orawa Reservoir, more than 55% are granites and gneisses. Gravel sediments are basic material building Holocene plain, showing fast erosional incision into the higher terrace level

Key words: alluvial fan, gravel shape, petrography, sediments source, Czarna Orawa River catchment

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1. Introduction

Sedimentation patterns in the Orawa Basin have been geomorphologically studied for decades. Most researches tend to focus on the whole range of deposits and sedimentary formations, but not many looked at the structure of particular units and processes shaping contemporary relief. The presented research on the structure and formation of the Czarna Orawa alluvial plain started during the summer of 2007. The purpose of the research was to discover the original sources of the sediments found in the basin, especially coarse-grained (>0Φ), deposited in the main stream channel formed within Holocene plain, in the center of the valley. Gravel analyses were made primarily according to methods developed by Rutkowski (1995).

2. Study area

Czarna Orawa Valley is located at the contact between two geographic regions: Orawa – Podhale Beskidy Mountains and Orawa – Nowy Targ Basin (Kondracki 2002). The former is a fragment of the flysch-type Western Beskidy Mountains, while the latter is a large depression filled with Neogene sediments topped with Quaternary series. The area of Czarna Orawa catchment is 232.9 km² (Fig. 1).

The upper part of the basin is a flysch-type area built of thin and medium thickness Magura and Submagura sandstones along with spilosite schists and marlstones.

Czarna Orawa River has source on the slope of Mt. Żeleźnica at the elevation of about 865 m a.s.l. First, it tends to flow north through a very shallow valley. The river flows through a subsequent valley towards northwest and west, before turning southwest, to cut across layers of flysch. The stream enters the Orawa Basin after about 25 km, in the vicinity of the village of Jabłonka. The total length of Czarna Orawa River within boarders of Poland is 32.2 km – counting from its spring area to Orawa Reservoir. The reservoir is nowadays filled to an average capacity. Another 17 km of the river run needs to be added to this total length because of streambed flooded during the construction of the reservoir – counting to the point of the connection with Biała Orawa River, north of the dam at Ustie nad Priehradou.

Characteristic features of Czarna Orawa Valley are the location of its northern part (source area) within Działy Orawskie zone and its southwestern part in Orawa – Nowy Targ Basin. Czarna Orawa River reaches Orawa Basin below the town of Jabłonka, cutting across 500–700 m thick Neogene deposits topped with 2–5 m layer of Quaternary sediments. The sediments are both flysch-type and Tatra-type and have been moved to the basin by postglacial waters from the contemporary Czarny Dunajec River drainage basin.

In Orawa Basin, Czarna Orawa River forms a meandering channel in most of its parts. The

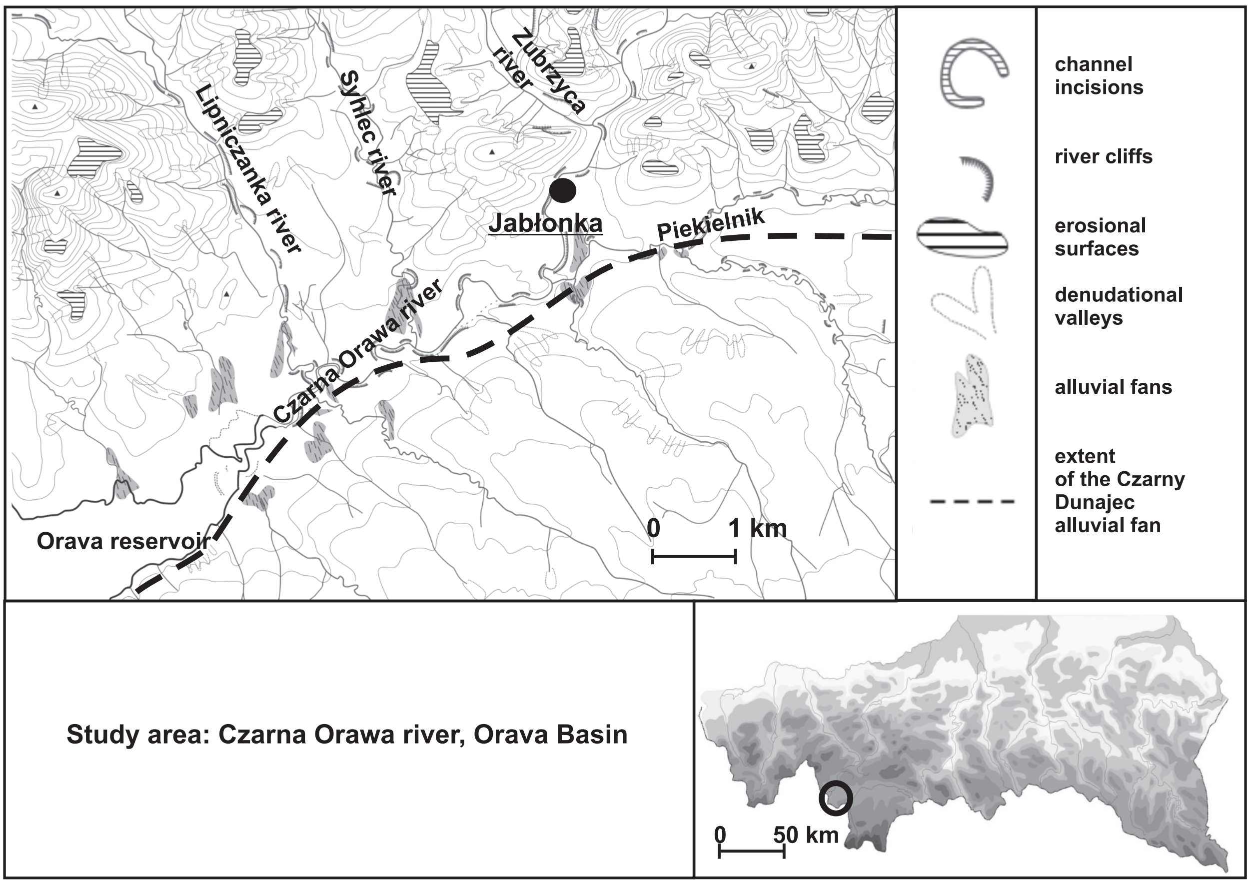

Fig. 1. Location of the study area and main relief forms.

winding index remains 1.42 on average (maximum 1.65). At the distance of eight kilometers the stream cuts across sediments forming a floodplain. In this particular area the alluvial fan of Czarny Dunajec River is also located (Baumgart-Kotarba 1992), which lateral section reaches the floor of the Czarna Orawa Valley. The fan's western part is lifted tectonically (Struska 2008) and dates back to the Würm glaciation. This part of the fan is primarily formed with gravels transported from the Tatra Mountains.

Gravels can be found in erosion induced undercuts formed by the meandering Czarna Orawa River. The southern bank is 6 to 7 m high. The gravel sediments are delivered mainly during flood events, when mean water level rise by 3–4 m. Mean discharge in the stream is 2.2 m^3s^{-1} and maximum discharge, for the past 40 years, is 93 m^3s^{-1}.

3. Current state of research

First researches were carried in Orawa – Nowy Targ Basin in the first half of 20th century. Halicki (1930) analyzed the structure and formation history of Orawa – Nowy Targ Basin floor, denoting the presence of sedimentary strata along Biały Dunajec River and Czarny Dunajec River. Klimaszewski (1948) was next working in the study area. In Orawa Valley, located in the western part of the basin, the principal issue of his interest was the formation process of Czarny Dunajec alluvial fan, which evolved from the west to the east. Czarny Dunajec River used to flow westward during Mindel and Günz glaciations, and turned east just before Würm.

River behavior has been confirmed by researches conducted by Klimaszewski (1950/1951), Watycha (1976), and Baumgart-Kotarba (1992). The key question that needed to be answer was: how did the different terraces form? Two distinct terrace levels were identified for further analysis. The two selected terraces slope down towards Czarna Orawa Valley and are linked to westbound discharge in Czarny Dunajec River. Pebbles that line the strata underneath the clay layer are proving this regularity. The pebbles come from the Tatra Mountains and include white quartzites, light granites (alaskite), and granitic-gneisses (2–8 cm, maximum 20 cm of diameter).

The thickness of the riverbed cover is estimated on 2–10 m. This is based on data from private wells excavation as well as geologic and hydrogeologic maps by Watycha (1977). Very important information on the strata layout is that it is dipping down along the channel of Czarna Orawa River, moving from southwest towards northeast.

After Günz glaciation, Czarny Dunajec River flew around the hill on the northern side of the valley and then turned to the north and northwest into the syncline of the contemporary Orawa Basin, entering Czarna Orawa Valley. The river deposited material, including gravels, in the far western part of the fan, near the contemporary towns of Chyżne, Jabłonka, and Piekielnik. Gravels supply took place under specific climate conditions. Periods of intensified gravels movement will be the subject of further research.

The western part of the fan is supposed to be still tectonically uplifted at a rate of several millimeters per year. The time of the formation of Orawa Basin has been divided into three stages, with the most important stage three (Pliocene – Quaternary), when tectonic (pull-apart) movements were the main landform shaping forces (Struska 2008). According to Baumgart-Kotarba (1992), radial valley incut (as wide as 40 m) into Neogene formations is a proof of tectonic basin lifting during the Quaternary. The presence of granites, gneisses, and quartzites pebbles indicate the movement of sediments from the Western Tatra Mountains, proving that Czarny Dunajec River used to flow towards west (Baumgart-Kotarba 1992).

4. Methods

Works on sedimentation patterns were preceded by detailed geomorphological mapping (scale: 1:10,000) of Czarna Orawa Valley. The mapping process was followed by establishing reference points on both sides of the river. The purpose of this was to study the rate of lateral erosion in river bends as well as along straight stretches. Gravel analyses included the use of the planimetric method, to determine their grain size and petrography. A method introduced by Olszewski (1974) who developed a five-point scale as part of his gravel-rock rounding method was applied. Classes defined by Olszewski are: 0 – all rough walls; 1 – the wall sedate are coating from walls of class 0; 2 – all similarly polished walls, 3 – all walls in polished the whole; 4 – the whole polished surface.

The diversity of fractions was studied based on typical classes – every 0.5Φ, from –10Φ to 0Φ. The sieve method was also employed in order to verify the granulometric distribution of grains. Measurements on the largest grain sizes were conducted in the field, while smaller grain sizes were analyzed in the laboratory. The degree of rounding was key to the understanding of sediment characteristics.

5. Granulometric and petrographic variability of gravel fraction

The top layer of the alluvial plain is composed of two small-grain series, including fine sands and silts that can reach a thickness of about 1.3 m. Layers of gravel (average diameter ranging from 2.5 to 4 cm; –4,7Φ in average) can be found at greater depths, with blocks as large as 20 cm in diameter being found on the southern bank of the river. The average thickness of the gravel layers is 30–60 cm, while maxima can reach 1.6 m (Fig. 2). Among all the sediments studied, the gravel layers found along Czarna Orawa River, in the village of Jabłonka, northeast of Orawa Reservoir are characterized by a low degree of sorting.

The grain size distribution standard deviation ranges from 2.6 to 4.5. The degree of sorting decreases at lower elevations in the direction of the reservoir and increases from north to south. The thickness of the gravel layers, buried under the plain deposits, ranges from 30 to 160 cm. Coarse dust and fine sand can be found between the layers of gravel. The finer fractions, averaging from +3 to +5Φ in diameter, are sorted much better (σ: 1.4–1.9) than the gravel fractions and are positive skewed, which suggests the presence of coarser sediments among those most frequently encountered.

Flood-induced facies deposited on the plain were identified. The thickness of fine sediments found between layers of gravel ranges from 25 to 45 cm. A characteristic feature of the sediments in the area of interest is a significant percentage of coarse fractions on the southern bank of the river.

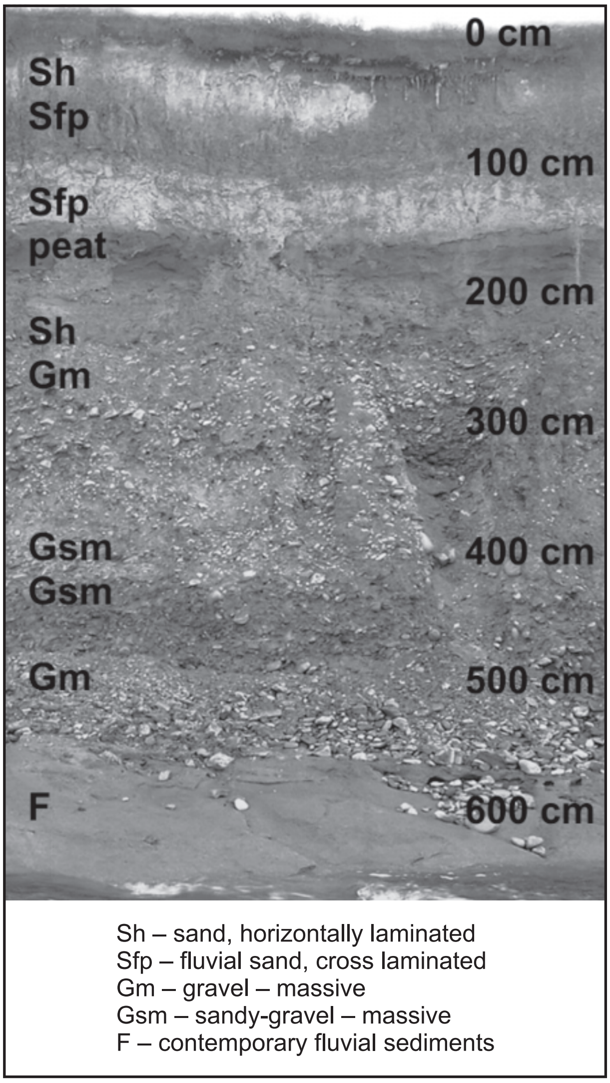

Fig. 2. Sediments profile on the Czarna Orawa River south bank, neighbourhoods of Orawa Reservoir.

Granulometric analysis of gravels collected in the vicinity of the town of Jabłonka indicates a large percentage of pebbles from –2 to –3Φ in diameter. A larger percentage of smaller pebbles (less than 3Φ) has been found along the northern bank of the river, while on the southern bank more balanced distribution of pebble sizes occurs. There is one exception, however, a larger accumulation of sediments in the following two size classes: <–3;–2Φ and –10;–9Φ >. Both cross section series were found to contain gravel and rock particles ranging anywhere from –10 to 0Φ.

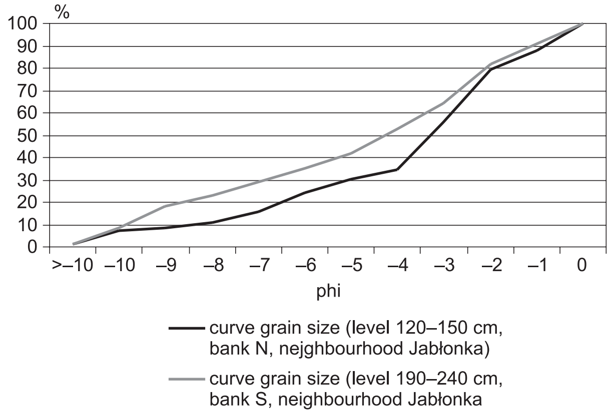

Fig. 3. The grain size analysis of gravels in the neighbourhoods of Jabłonka.

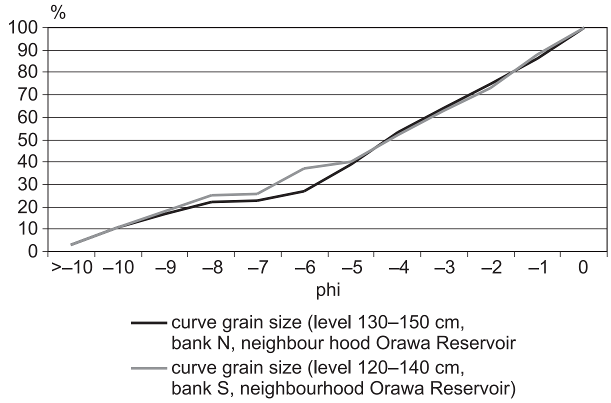

Fig. 4. The grain size analysis of gravels in the neighbourhoods of Orawa Reservoir.

Larger sediment sizes tend to be found in larger number along the southern bank of the river, usually buried at depths of 1.3–2.2 m. Some of them supply the channel at places where the river undercuts its banks. In such cases, larger sediments can be accumulated on the river terrace, where they can be identified by their size and 30–40% lower degree of rounding.

Downstream of Jabłonka village, participation of the gravel sediments increases. At the point where the river enters Orawa Reservoir, the most commonly encountered gravels are within <–5; –6Φ> (Fig. 4). The tendency to find larger gravels along the southern bank of the river and smaller along the northern remains true.

Olszewski's (1974) scale was used to show that the degree of rounding of gravels in Czarna Orawa Valley depends, first of all, on their petrographic composition. Flysch sediments were most often classified as Class 2 or Class 3 (in 82%). Tatra Mountain sediments were usually classified as Class 1 or Class 2 (91%). This type of classification approach is used to help to identify the proper form. It is used in situations where it is difficult to unequivocally identify the degree of rounding and polishing because of numerous fractures and crushing.

Petrographic research was done using the planimetric method in the field. The main purpose of the research was to identify the degree of diversity among coarse grained petrographic sediments, in relation to the course of the river, both banks, and the alluvial plain. From a petrographic perspective, virtually 100% of the sediments in the Beskidy Mountains area are sandstone pebbles with diameters ranging from 4 to 9Φ (5.1Φ in aver-

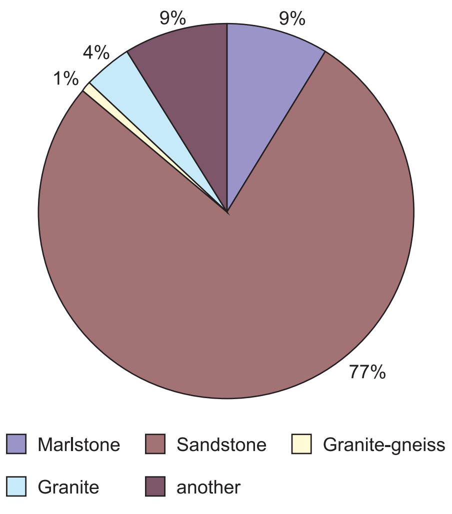

Fig. 5. The petrographic analysis of sediments on the northern bank of Czarna Orawa River, from the depth 120–150 cm, in the neighbourhoods of Jabłonka.

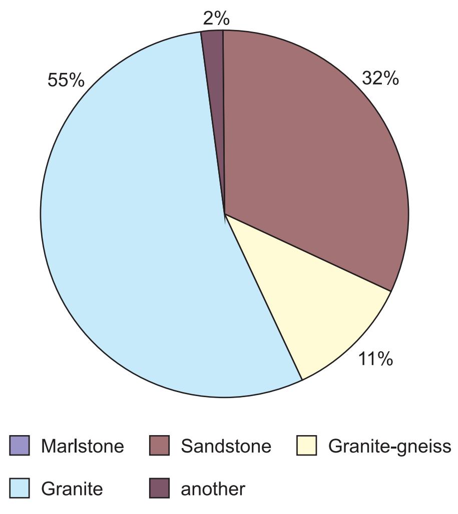

Fig. 6. The petrographic analysis of sediments on the southern bank of Czarna Orawa River, from the depth 120–140 cm, in the neighbourhoods of Orawa Reservoir.

age). In Czarna Orawa Valley, on the other hand, the coarse-grained flysch gravel range is between 38% and 45% as a result of the presence of gravels cut from within the slope (e.g. sandstones and marlstones). Granodiorites and gneisses make up over 50% of the sediments while limestone accounts less than 5%. A characteristic feature of the area is a larger percentage of Tatra Mountain sediments along the southern bank of the river versus the northern bank (Fig. 5–6).

The percentage of granitic-gneisses ranges from 11% to 55% along the southern bank of the river (in the outcrop on the slope) and from 4% to 50% along the northern bank. The most rapid increment of percentage of crystalline material is noticed downstream from the point where Piekielnik Stream flows into Czarna Orawa River. The stream delivers sediments originating from the Tatra Mountains. This sediments are transported only from the outside of the catchment. The supply exist only during flood events, when Czarna Orawa River banks are intensively undercut. The stream's banks recede at a rate of almost 1.5 m per year.

6. Final remarks

In some places, the riverbank undercutting process can lead to the retreat up to 150 cm along internal sections of meanders. A retreat of 100 to 160 cm is considered to be quite extreme, taking into account the average rate between 30 and 70 cm per year. This range of process occur along low riverbanks of Holocene age, floodplains, and upper alluvial floodplains.

Another process has been observed along the southern bank of the river, which is also undercut by Czarna Orawa River. The undercuts are 6–7 m high. The gravels buried within them become exposed in the form of two layers, each 30–50 cm thick. The undercutting process takes place more slowly at sites that contain buried gravel versus sites built up of fine grained sediments.

Here, the undercutting rate is about 30% less. In larger undercuts, gravel layers can take the form of eaves hanging above removed layers of finer sediments. This is a sign that *in situ* gravel along the southern bank of the river has undergone a hardening, where fine sediments have cemented larger particles to form a stable structure. On the other hand, gravel that is identical in granulometric and petrographic terms, but found within Holocene layers and redeposited, does not present the same type of stable structure.

This research can be compared with data from other valleys, like Dunajec and Wisłoka (Baumgart-Kotarba & Kotarba 1979, Sobiecki 2000), and also from Slovak Carpathians (Bizubova *et al.* 2003). The existence of Tatra Mountain gravels found in Czarna Orawa Valley is very important for this mountain river sedimentary system development. The greatest influence can be observed in the rate of lateral erosion, which is undoubtedly affected by the presence of gravel facies.

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