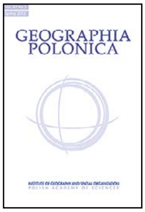

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RELIEF OF THE ORAWA-NOWY TARG BASIN, WESTERN CARPATHIANS

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Abstract

This paper relies on the literature to outline the main properties of the relief of the intramontane Orawa-Nowy Targ Basin which is dominated by three fluvioglacial fans. The focus, however, was on the genetically-varied landforms, mostly found within the limits of the fluvioglacial fans, which contribute to the diversity of the basin's geomorphological landscape. Based on the results of geomorphological mapping of the area and the area's digital elevation model, an explanation was provided for the distribution of particular landform types, with specification of their parameters. Building on this exercise, the three chief morphometric properties of the Orawa-Nowy Targ Basin, i.e. local relative height, slope, and aspect, were analysed. In the area occupied by the fluvioglacial fans, these morphometric parameters were found to display the greatest variety along the S-N and W-E axes. The results presented combine qualitative and quantitative approaches to geomorphological studies in the first such attempt regarding the Orawa-Nowy Targ Basin and as such fill a significant gap in the existing geomorphological studies of the area.

Keywords

relief • landform • fluvioglacial fan • geomorphometry • relative height • slope • aspect • Orawa-Nowy Targ Basin • Western Carpathians

Introduction

In professional literature in the field of geomorphology, a complex analysis of the relief of large mountainous geomorphological units is seldom undertaken in a way that would combine a detailed description of various types of landforms, a determination of their origin and the relief development process and, finally, a quantitative assessment of their configuration, that is, with morphometrics. Such a geomorphological analysis is found in a few publications related to selected mountain ranges; for instances, in the Sudetes (Kasprzak & Traczyk, 2010; Kasprzak & Migoń 2015; Różycka 2015; Migoń et al., 2016) and the Carpathians (Łajczak, 2024; Łajczak & Wałek, 2024), but even there little coverage is devoted to low-lying areas of the mountains, and in the case of the Carpathians and Sudetes, they have been ignored.

The present study is an attempt at defining the geomorphological characteristics of the Orawa-Nowy Targ Basin in the Western Carpathians, taking into account a qualitative and quantitative description of the relief of this area. The qualitative characteristics of the relief of the basin includes an indication of the origin of the various types of landforms and a determination of their distribution and reach, taking into account the tectonics of the bedrock. In their turn, the quantitative characteristics – that is, the morphometrics of this area – comprise the determination of the horizontal and vertical dimensions of particular types of landforms, as well as of the relative heights, slope angles and aspect of individual parts of the basin. Paying heed to the remarks by M. Klimaszewski (1981, p. 15), the above scope of geomorphological analysis of the Orawa-Nowy Targ Basin combines the four elements of geomorphology taken into account in the Polish literature on the subject, namely, morphography, morphometry, morphogenesis, and morphochronology. The Authors focus their attention on the first two of the above-mentioned elements of geomorphology.

To date, the Orawa-Nowy Targ Basin has been the subject of numerous geomorphological studies in which attention was paid to the origin of the prevailing types of landforms, their transformations in the Quaternary, their distribution in relation to the stratigraphy and tectonics of the bedrock and to anthropogenic changes (Klimaszewski, 1972, 1988; Mojski & Watycha, 1984; Watycha & Mojski, 1984; Baumgart-Kotarba, 1991-1992, 1996, 2000; Nagy et al., 1996; Zuchiewicz et al., 2002; Mojski, 2005; Zawiejska et al., 2024; Cieszkowski et al., 2025; Łajczak, 2025a; Zarychta et al., 2025; Zuchiewicz, Kania, 2025). In this context, the available professional literature is clearly short of studies in text and, even more significantly, cartographic form covering the distribution of all types of landforms. Particular emphasis needs to be placed on determining their morphometric features (relative falls, slope angles, and aspect). Such an approach to the geomorphological analysis would afford possibilities for detecting interdependences between the qualitative and quantitative features of the relief of the Orawa-Nowy Targ Basin, i.e. something that is still missing in relation to this area in the professional literature. The present paper is an attempt to fill that gap.

Location of study area

The Orawa-Nowy Targ Basin (ONTB) is one of the thirty-one intramontane basins in the Western Carpathians (Fusan et al., 1967; Poprawa & Nemčok, 1988; Kondracki, 1989; Lehotský & Boltižiar, 2022) and the largest of this type in the Polish part of the Carpathian Mountains (Kondracki 2000). It is located in the Central Carpathians, near the border with the Outer Carpathians (Fig. 1). With other basins, the ONTB forms a series of tectonic depressions surrounding the ridge of the Tatra Mountains from the north, east, and south (Geomorfologicke členienie SSR, 1986; Klimaszewski, 1988; Kondracki, 1989, 2000; Lehotský & Boltižiar, 2022), which results in the largest relative heights within the Carpathians that exceed 2150 metres. The ONTB occupies the lowest part of the Podhale Basin, between the Tatras in the south and the Beskid Żywiecki and the Gorce Mountains in the north, and it slopes down towards the north (Klimaszewski, 1972, 1988; Gilewska & Starkel, 1980; Poprawa & Nemčok, 1988; Kondracki, 1989, 2000; Gilewska, 1991; Mojski, 2005; Balon & Jodłowski, 2014). Two thirds of the ONTB

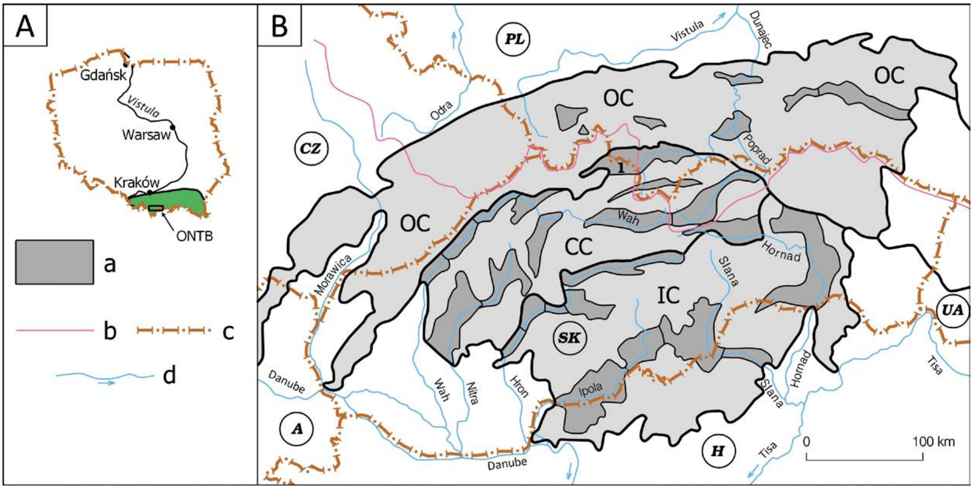

Figure 1. Location of the Orawa-Nowy Targ Basin (ONTB)
A – in Poland, against the background of the limits of the Carpathians (in green); B – within the Western Carpathians, against the background of the limits of other basins (*according to Starkel, 1972; Geomorfologicke členienie SSR, 1986; Kondracki, 1989*). OC – Outer Carpathians (flysch); CC – Central Carpathians; IC – Inner Carpathians. a – basin (1- ONTB); b – European watershed; c – international border; d – main river.

area is located within the borders of Poland, and one third lies in Slovakia.

Summary of existing knowledge on the research area within the scope of the topic discussed

ONTB area, division, and altitude range

The ONTB area is 643 km^2. The basin is divided into three sections: (1) the Orawa Basin (OB), with an area of 470 km^2; (2) the Nowy Targ Basin (NTB), with an area of 145 km^2; and (3) the Biela Orava-Hruštinka Depression (BOHD) with an area of 28 km^2 (Cieszkowski et al., 2025; Łajczak, 2025a) (Fig. 2). The ONTB is 78 kilometres long from east to west, and its maximum width from north to south is 13 km. The lengths and maximum widths of its sections are, respectively: (1) 36 by 13 km; (2) 24 by 6 km; and (3) 18 by 1.6 km. Extreme altitudes in the ONTB area are: 853 m a.s.l. in the western part of section (3), and 487 m a.s.l. in the eastern part of section (2). In the largest section of the basin, the extreme altitudes are 640 m a.s.l. in the north, 830 m a.s.l. in the south, and 576 m a.s.l. in the west. Mean height (Hmean) of the ONTB amounts to 644 m a.s.l. with the median (Hme) of 639 m a.s.l. The Hmean and Hme values of further sections of the basin decrease towards the east; in the BOHD they are 679 and 675 m a.s.l. respectively; in the OB they are 657 and 648 m a.s.l.; in the NTB they are 600 and 599 m a.s.l. (Fig. 2B). The largest relative height in the ONTB along the axis from west to east is 366 m, and in section (1) is 254 m along the axis from west to east and 190 m along the axis from south to north.

Origin and composition

The Orawa-Nowy Targ Basin is an intramontane depression formed in the Upper Miocene and lain upon geological units connecting the Central Carpathians and the Outer Carpathians (Zuchiewicz et al., 2002; Zuchiewicz, 2010). The largest section in the ONTB, the Orawa Basin, is a tectonic depression bordered to the north and south by parallel-running systems of longitudinal normal

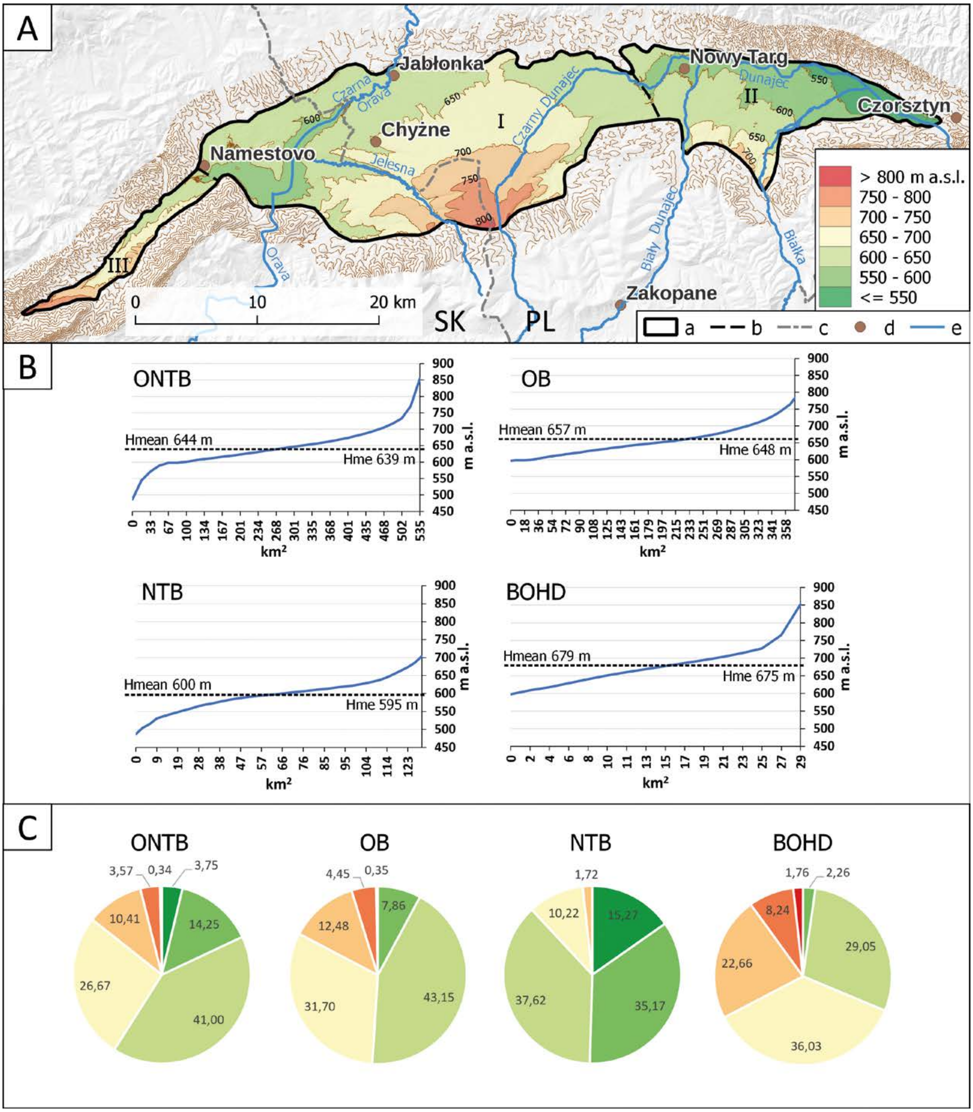

Figure 2. The division of the Orawa-Nowy Targ Basin (ONTB) into sections against the background of the hypsometry of the basin and its surroundings
A – border of the ONTB and its sections (I – Orawa Basin (OB), II – Nowy Targ Basin (NTB), III – Biela Orava-Hruštinka Depression (BOHD)); B – hypsographic curves in the ONTB and its sections (Hmean – mean height, Hme – median height); C – share [%] of the 50-m intervals of a.s.l. altitudes in the ONTB area and its sections. a – ONTB boundary; b – boundaries between the ONTB sections; c – Polish-Slovak border; d – town and main village; e – river. Contour lines – every 50 m.

faults with thrusts reaching several hundred metres (Pomianowski, 1995). These faults are intersected by transverse strike-slip faults orientated along NW-SE and NE-SW axes. On the northern edge of the Orawa Basin, these detachment faults form an échelon pattern of faults (Pomianowski, 1995, 2003). Formed during the post-orogenic collapse of the rock mass during the Upper Miocene, the faults of the Orawa-Nowy Targ Basin became active again during the Pliocene and Quaternary (Zuchiewicz et al., 2002). The Nowy Targ Basin, is also a tectonic depression bordered by faults (Niedzielski, 1971). In its turn, the Biela Orava-Hruštinka Depression, comes in the shape of a wide valley without distinctive tectonic features. The axes of the three sections of the Orawa-Nowy Targ Basin coincide with the axis of the gravimetric minimum in the Western Carpathians (Poprawa & Nemčok, 1988).

From the beginning of its formation in the Neogene, the Orawa-Nowy Targ Basin has been a destination where material carried out from the surrounding mountain ranges has accumulated (Baumgart-Kotarba, 1991-1992, 1996, 2000; Zuchiewicz et al., 2002; Pomianowski, 2003); it has also provided an area for biogenic accumulation (Łajczak, 2007, 2011, 2013a,b). Two of the ONTB sections – the Orawa Basin and Nowy Targ Basin – are filled with fresh-water Neogene lacustrine deposits (such as sands, silts, loams, plus inserts of lignite and brown coal), whose extent was then reduced as a result of their erosion. The Neogene deposits take the form of a basin; they reach higher levels in the southern and northern zones where the dips of their layers reach 10-15°, and in the Orawa Basin even as much as 20-25° (Watycha, 1976; Potfaj, 2003). In the Pleistocene, these formations were covered with fluvioglacial deposits forming three extensive fluvioglacial fans in the ONTB (Halicki, 1930; Klimaszewski, 1988). The Neogene and Quaternary deposits are thickest in the Orawa Basin (950 and 117 m, respectively) (Watycha, 1973, 1976, 1977a,b). They are covered with dusty deposits (Chmielowska, 2015) and with alluvia along the water courses (Zawiejska et al., 2024). A large part of the Nowy Targ Basin, and especially of the Orawa Basin, is covered with peats; individual raised bogs began to develop at various stages of the Holocene (Łajczak, 2013a,b; Lipka & Zając, 2014). In the Biela Orava-Hruštinka Depression section of the ONTB, there is a minimal thickness of lacustrine and fluvial deposits, while organic deposits do not occur at all (Fusan et al., 1967; Geomorfologicke členienie SSR, 1986; Poprawa & Nemčok, 1988; Lexa et al., 2000).

Neotectonics

The lowest northern areas of the ONTB are prone to subsidence (Gilewska & Starkel, 1980; Zuchiewicz, 2010) amounting to 150 m in the Orawa Basin within the latest one million years (Watycha, 1973, 1977a,b; Watycha & Mojski, 1984). In their turn, the southern sections of the Orawa Basin and Nowy Targ Basin are being uplifted (Gilewska & Starkel, 1980) at a maximum rate estimated at 0.5 mm per year in the western and southern parts of the Orawa Basin (Vanko, 1988). During the evolution of the Orawa Basin, tectonic processes migrated in an easterly direction (Baumgart-Kotarba, 2000), which, in the north-eastern part of this section of the basin, led to the formation of tectonic grabens running from West to East (the Wróblówka and Pieniążkowice grabens) beginning from the Pliocene/Quaternary boundary. The development of those grabens, which constantly deepened, is still continuing and is migrating in a north-easterly direction (Watycha, 1973, 1977a,b; Watycha & Mojski, 1984; Baumgart-Kotarba et al., 2001, 2004), which is evidenced by the subsidence of this area, still apparent in the Holocene.

River network

Rivers and streams flowing into the ONTB from the north drain the flysch areas of the Beskid Żywiecki Mts. (1725 m a.s.l.), the Gorce Mountains (1311 m a.s.l.) and the neighbouring plateaux (Fig. 3). Two sections of the ONTB, the Orawa Basin and Nowy Targ Basin, receive four rivers flowing from the south and draining the high-mountain area of the Tatras which is built from crystalline, metamorphic, and sedimentary rocks. From West to East, those rivers are the Oravica, Czarny Dunajec, Biały Dunajec, and Białka. These flow through the flysch area of plateaux and then through the narrow zone of the Pieniny Klippen Belt, formed mostly of limestones. The highest peak

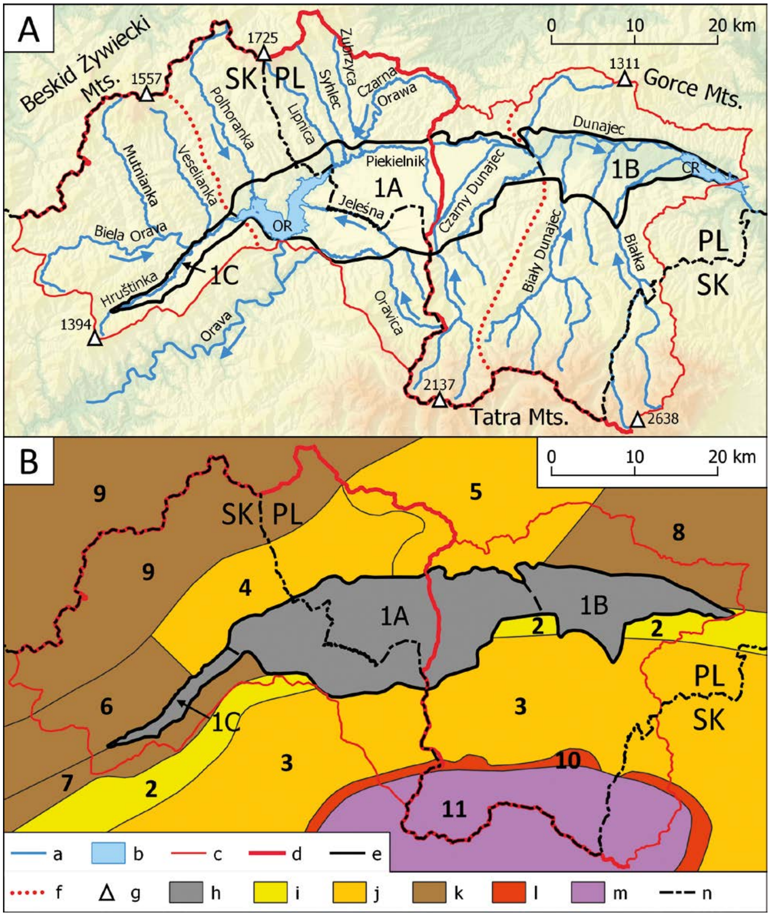

Figure 3. The Orawa-Nowy Targ Basin (ONTB) in relation to the outer reach of: A – its catchment; B – the neighbouring geomorphological units. a – main river; b – dam reservoir (CR – Czorsztyn Reservoir, OR – Orava Reservoir); c – watershed of the catchment of the basin; d – European watershed; e – boundary of the ONTB and its sections (1A – Orawa Basin (OB), 1B – Nowy Targ Basin (NTB), 1C – Biela Orava-Hruštinka Depression (BOHD)); f – boundary of the catchment of basin section; g – highest culminating point on watershed of the basin and its elevation [m a.s.l.]; h – limit of the intramontane Orawa-Nowy Targ Basin; I – Pieniny Klippen Belt; j – plateaux and low-altitude mountains; k – mid-altitude mountains, l – depression adjoining the high-altitude mountains; m – high-altitude mountains; n – Polish-Slovak border. Geomorphological units (*according to Klimaszewski, 1972; Starkel, 1972; Geomorfologicke členienie SSR, 1986*): 1 – Orawa-Nowy Targ Basin (ONTB sections: 1A – Orawa Basin, 1B- Nowy Targ Basin, 1C – Biela Orava-Hruštinka Depression); 2 – Pieniny Klippen Belt; 3 – Przedtatrzańskie Foothills; 4 – Działy Orawskie Foothills; 5 – Sieniawskie Foothills; 6 – Oravska Plateau; 7 – Magura Oravska Mts.; 8 – Gorce Mts.; 9 – Beskid Żywiecki Mts.; 10 – Sub-Tatra Graben; 11 – Tatra Mts.

in the Tatras on the watershed of the area of the Białka catchment reaches 2638 m a.s.l. The hydrographic axis of the Orawa Basin is formed by the Czarna Orawa, a river flowing in a south-westerly direction. In the Nowy Targ Basin, that role is played by the Dunajec river, which flows towards the East, while in the Biela Orava-Hruštinka Depression this part is played by the Biela Orava river and its tributary the Hruštinka river which flow in a north-easterly direction (Fig. 3A). Three rivers flow out from the ONTB. The Nowy Targ

Basin and eastern part of the Orawa Basin are drained by the Dunajec river. The western part of the Orawa Basin, together with Biela Orava-Hruštinka Depression, is drained by the Orava river. Only a small southern part of the Orawa Basin is drained by the Oravica river. The outflow from the Nowy Targ Basin and Orawa Basin leads through river gorges, i.e. through the Niedzicki Gorge and Ustianskie Gardło Gorge respectively.

The catchment area of the ONTB is 2700 km^2 (catchment of the Orawa Basin together with the Biela Orava-Hruštinka Depression: 1950km^2, and catchment of the Nowy Targ Basin: 750 km^2). The area of the ONTB and its catchment which is supplied by rivers flowing from the Tatra Mountains is much more abundant in water (Łajczak, 2025b). The European watershed separating the drainage areas of the Baltic Sea and Black Sea runs through the ONTB from North to South (Fig. 3A). The eastern part of the basin, constituting 41% of its area, is drained by the Dunajec river towards the East and then to the Baltic Sea, while the western part – forming 59% of its area – by the rivers Orava and Oravica in a south-westerly direction to the Black Sea. In the lowest part of the Orawa Basin, the Orava Dam Reservoir has been in use since 1953, and in the lowest part of the Nowy Targ Basin, the Czorsztyn Dam Reservoir has been operating since 1997.

General information relating the basin sections

The Orawa Basin, occupying 73% of the whole area of the ONTB, is in the form of a parallelogram (Fig. 2) corresponding to the line of faults and of rivers and streams that often flow along their strike. The borders of the Orawa Basin adjoin undercut slopes along its boundaries, particularly in the flysch areas (Baumgart-Kotarba, 1991-1992). The fluvioglacial fan of the Czarny Dunajec river occupies 60% of the area of the Orawa Basin (Halicki, 1930; Gilewska & Starkel, 1980; Baumgart-Kotarba, 1991-1992). In the south-western, southern, and also northern part of the basin, Neogene formations are visible where they are being exposed in the lower sections of erosional dissections more than 50 m deep (Baumgart-Kotarba, 1991-1992). The biggest local relative heights in the Orawa Basin, a difference of more than 70 m, occur in the vicinity of the head of the fluvioglacial fan of the Czarny Dunajec river, while the smallest ones, only amounting to several metres, are found in the northern and north-eastern parts of the basin.

The Nowy Targ Basin occupies 22% of the whole ONTB area. The northern boundary of this section, forming a sharp concave turn with flysch slopes at the foot of the Gorce Mountains, stands out more markedly in the countryside than the southern boundary with the Pieniny Klippen Belt. Two fluvioglacial fans of the rivers Biały Dunajec and Białka occupy almost the whole area of the basin (Halicki, 1930; Gilewska & Starkel, 1980; Baumgart-Kotarba, 1991-1992) (Fig. 2). The combined area of those two fluvioglacial fans is two and a half times smaller than the area of the Czarny Dunajec fan. In addition, the relative heights in this basin are greatest in the vicinity of the fan heads, where they exceed 40 m, and they decrease towards the north in the vicinity of the Dunajec river channel. The Neogene-age deposits are covered with Quaternary formations over almost the whole area of the basin.

The Biela Orava-Hruštinka Depression occupies 5% of the total area of the ONTB. This section, resembling a long and wide valley, is neither flat-bottomed nor separated from the surrounding slopes by a distinct concave knickpoint (Łajczak, 2025a). The area has Neogene deposits of minimal thickness, and no fluvioglacial deposits, while the bottom of the depression is covered with fluvial deposits ((Fusan et al., 1967; Poprawa & Nemčok, 1988; Lexa et al., 2000).

State of research on the basin relief

An analysis of the professional literature on the relief of the Orawa-Nowy Targ Basin indicates that their authors focused on qualitative descriptions of selected types of landform, typically the most extensive ones. Starting from the late 18th century, which saw the onset of scientific observation in the ONTB, the area's flat-bottomed relief was widely noted, as was its domination by peatbogs (Fichtel, 1791 – In: Gustawicz, 1883). The relief of the basin was already being graphically illustrated at the beginning of the 19th century (Staszic, 1815) (Fig. 4). The ONTB was originally called the 'Nowy Targ and Orawa Valley,' or 'Orawa-Nowy Targ Valley'. The term 'Orawa-Nowy Targ Basin', indicating the relief type of this area as standing out from the surroundings, was only introduced in the mid-20th century (Klimaszewski, 1948; Szafer, 1959).

In various publications concerning the relief of the ONTB, attention was mostly paid to general features of the relief of the area, the outer extent of the fluvioglacial fans and the composition of those landforms (Romer, 1929; Halicki, 1930; Klimaszewski, 1972; Gilewska & Starkel, 1980; Baumgart-Kotarba, 1991-1992; Kukulak & Augustowski, 2022-2023) (Fig. 5A). In the area of the fluvioglacial fans, the research was related to the outer extent of terraces; the geomorphological results of the neotectonics of the area also being noted (Halicki, 1930; Klimaszewski, 1972, 1988; Mojski & Watycha, 1984; Baumgart-Kotarba, 1991-1992, 1996, 2000; Zuchiewicz et al., 2002; Mojski, 2005; Chrustek, 2006; Zawiejska et al., 2024; Cieszkowski et al., 2025; Łajczak, 2025a) (Fig. 5B). In the Orawa Basin and Nowy Targ Basin, eight morphological levels (terraces/areas) were singled out. They were of the following ages (Baumgart-Kotarba, 1991-1992): a1– early Quaternary; a2 – Günz glaciation; a3 – Mindel glaciation; a4 – Riss glaciation(?); a5 – Riss glaciation; a6 – Würm glaciation; a7 – Late Glacial; a8 – Holocene (Fig. 5B). The relative heights of the escarpments separating the above areas range from several to more than ten metres; while the highest escarpments, separating the area a6 from the areas a1-a5, as well as areas a1 and a3 from the area a8, exceed 50 m in some places.

Erosional dissections of various depths were reported in the fluvioglacial fan of the Czarny Dunajec river – the largest landform in the study basin. Other features were also noted including the occurrence of denudation bowls on the terrace escarpments, as well as of palaeochannels and Holocene alluvial fans, the extent of the flat bottom of the basin with only a minimal angle of dip, as well as certain anthropogenic landforms (Łajczak, 2025a). The research in the basin also involved its river channels (Krzemień, 2003; Kościelniak, 2004; Zawiejska & Krzemień, 2004; Krzaklewski, 2008; Gorczyca et al., 2011). Limestone rocks and caves were also objects of interest, as was the epigenetic gorge of the Białka river; without, however, any morphometric analysis (Birkenmajer, 1979; Valde-Nowak et al., 1987; Nyka, 2006) (Fig. 5C). Much attention was devoted to the distribution and configuration of only the more extensive raised bogs and post-peat areas in the basin, without, however, a quantitative analysis of their relief (Łajczak, 2007, 2011, 2013a,b).

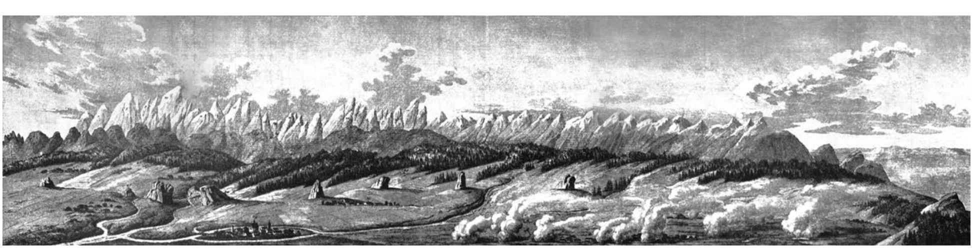

Figure 4. Drawing from a publication by S. Staszic (1815) showing the Orawa-Nowy Targ Basin as seen from the Gorce Mountains (view towards the South). In the background are the Pieniny Klippen Belt, Gubałowskie Foothills, and Tatra Mts. The figure also shows the flat-bottomed type of relief of the basin and burning peatbogs

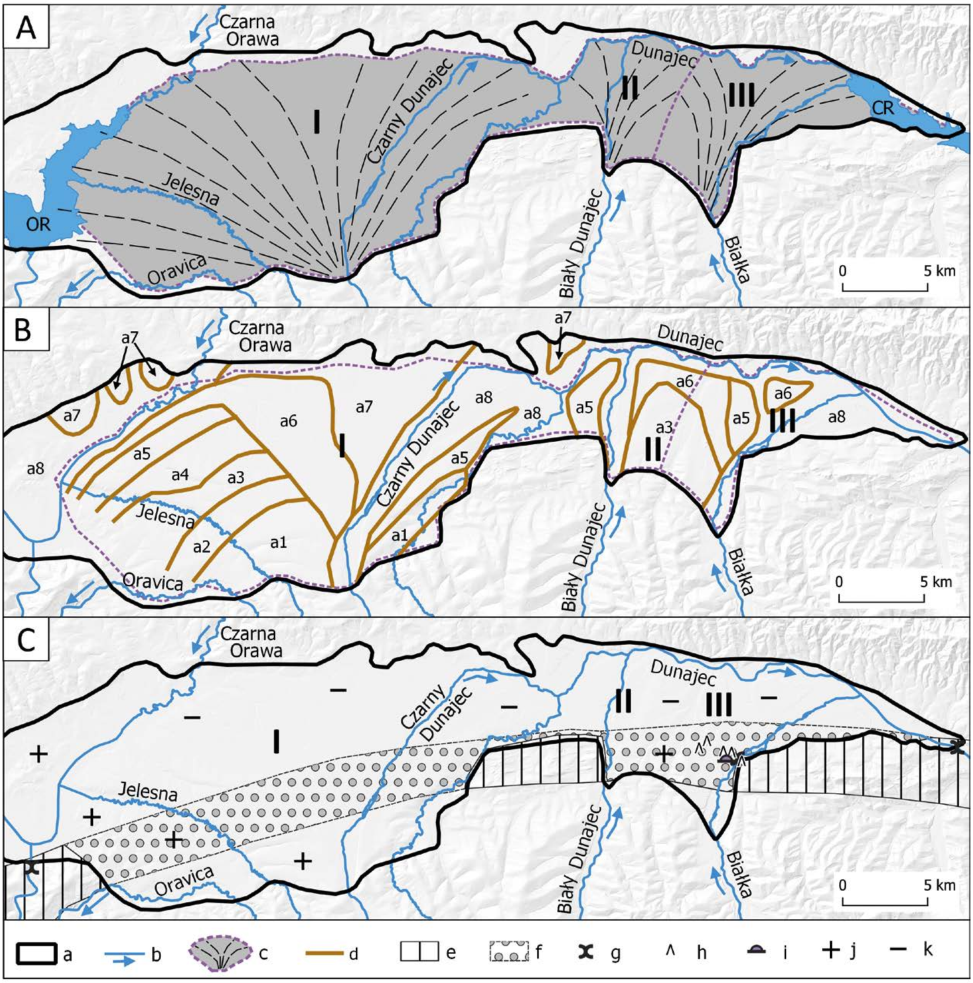

Figure 5. Distribution of those landforms in the Orawa-Nowy Targ Basin (ONTB) to which attention has mostly been paid in existing publications

A – extent of fluvioglacial fans (I – of the Czarny Dunajec river; II – of the Biały Dunajec river; III – of the Białka river); B – extent of morphological levels (terraces), explanations of a1-a8 can be found in the text; C – the distribution of landforms in the Pieniny Klippen Belt zone. a – ONTB boundary; b – river; c – extent of a fluvioglacial fan; d – boundary between morphological levels (terraces); e – exposed part of the Pieniny Klippen Belt; f – part of Pieniny Klippen Belt covered with Neogene and Quaternary deposits; g – river gorge; h – limestone rock; I – cave; j – tectonic uplift area; k – tectonic depression area.

To conclude, an assessment of the vertical and horizontal dimensions of landforms, their relative heights, slopes, and aspects is missing in the descriptions of individual types of landform. No detailed geomorphological map of the ONTB has yet been published, and the review studies in that field, carried out at a small scale, present only a schematic distribution of the selected types of landforms, mostly fluvioglacial fans, and of the morphological levels (terraces) within their limits (Fig. 5A,B) (Halicki, 1930; Klimaszewski 1972; Gilewska & Starkel, 1980; Baumgart-Kotarba, 1991-1992). Numerous issues related to the geomorphology of the basin have not yet been explained; for instance, why the fluvioglacial fan of the Czarny Dunajec river is many times larger than the fluvioglacial fan of the Białka river, in spite of the more intensive transport of clastic material in the latter river. There is a shortage of such studies analysing the distribution of all types of landforms that would present the conditions of their development and the part those landforms played in the formation of the morphometry of the ONTB.

Aim of the present study, research questions and hypotheses

The aim of the present study is to carry out analysis of the relief of the ONTB taking into consideration a combined qualitative and quantitative description of all types of landforms. The detailed analysis thus presented is based firstly on the results of the geomorphological mapping of this area at a scale of 1:10,000, performed by the corresponding author of the present study, and secondly on an analysis of the basin's digital elevation model. The research results presented constitute the first findings of this kind in relation to the ONTB. In some cases they were shown against the background of the results of studies by other authors.

On the basis of the findings thus obtained, the following general issues were addressed in the study: (1) the distribution of all the types of landform distinguished within the basin with an indication of the conditions under which they developed and their current extent; (2) the spatially dominant types of landform in the ONTB and their distribution; (3) the spatial differentiation of morphometric parameters of individual types of landform (relative heights, slope angles, and aspects); (4) the individual types of landform differentiate the morphometric parameters of the ONTB across the whole area of the basin.

The publications cited above include a statement that in the area of the ONTB including the fluvioglacial fans, the relative heights diminish in a northerly direction, that is, along the axes of those landforms. Hence the following hypotheses are tested in the present paper: (1) that the fact that this morphometric parameter reaches lower and lower values in a northerly direction results in substantial changes to other morphometric parameters; (2) that the changes of morphometric parameters (relative heights, slope angles, and aspects) are also observable athwart the axes of the fluvioglacial fans, i.e. towards the West and East.

Materials and methods

The assessment of the Orawa-Nowy Targ Basin relief was performed in four phases. First, a general outline of the relief of the area was considered, as presented in many publications (Klimaszewski, 1972, 1988; Mojski & Watycha, 1984; Baumgart-Kotarba, 1991-1992, 1996, 2000; Nagy et al., 1996; Zuchiewicz et al., 2002; Mojski, 2005). The next phase involved the analysis of the distribution and range of all landform types present in the basin. This was performed using the results of geomorphological mapping of the area at a scale of 1:10,000 in accordance with the applicable geomorphological standards. Terrain penetration was always preceded by the analysis of all publications presenting, to a varying degree of accuracy, the distribution of various landform types, as well as an analysis of a shaded relief exposure map of the relief presenting particular sections of the Orawa-Nowy Targ Basin. In this way, the research covered all landforms within the basin which were classified into five types: denudational; fluvial; biogenic; anthropogenic; fluvial and denudational landforms developing exclusively in areas exposed to human impacts. In the third time-intensive phase of the study, using generally accepted measurement methods, morphometric parameters of smaller landforms were determined in the field, in each case along two profiles: local relative height ΔH, mean slope α, and aspect A. The horizontal dimensions (length L, width W) of all landforms were additionally determined during the analysis of the digital elevation model (DEM). Sinuosity of watercourses was calculated as a quotient of a real length of a watercourse to a section connecting fringe sites of a watercourse.

Morphometric analysis applied the digital elevation model developed with the use of the cloud of points from airborne laser scanning (ALS LiDAR) within Polish borders acquired from the Head Office of Geodesy and Cartography (GUGiK, 2018), and within the Slovak borders acquired from the Geodesy, Cartography and Cadastre Authority of the Slovak Republic. The vertical accuracy tolerance of digital elevation models made from the LiDAR data is 15 cm (Kurczyński, 2012). The digital elevation model with a resolution of 1 m that was downloaded has been turned into a mosaic format and resampled to 5 m resolution to generalise the very detailed data from laser scanning.

The fourth phase of the study involved calculation, in QGIS and the SAGA GIS software environment, of basic morphometric parameters: local relative height ΔH, mean slope α, and aspect A (Hengl & Reuter, 2009). The analysis was performed on the Orawa-Nowy Targ Basin and, additionally, in the adjacent zone 3 km in width in order to identify differences between the morphometry of the basin and the adjacent area.

Local relative height ΔH and mean slope α values were determined on a hexagonal grid with distances between the centres of adjacent cells of 500 m. The area of a single mesh of the grid amounts to 21.65 ha. Using zonal statistics from the DEM and slope map values from each grid mesh, maximum values, minimum values, and the range of altitudes and slope angle values were determined. The boundaries between the relative height and mean slope intervals in maps were determined using jenks natural breaks method. When determining the aspect, the analysis included areas with a slope angle of >3°, while other areas with a minimum slope angle were considered to be areas with no aspect. Four aspects were identified: N, E, S, and W, with azimuths covering the ranges of 315°-45°, 45°-135°, 135°-225°, and 225°-315° respectively.

Results of own studies

Landforms – genesis, distribution, parameters

Five landform types have been identified in the Orawa-Nowy Targ Basin (Fig. 6). Among the ***denudation landforms***, the most visible in the basin relief are valleys of different order and size, which only in sections of the Orawa Basin and Nowy Targ Basin are of a flat bottom type. Valleys prevail across the basin and have been formed in all directions. The bottom width of such landforms (W) remains within the range from several metres to over 1 km (max. up to approx. 5 km); the relative height (ΔH) in relation to other areas elevated higher within the basin ranges from several up to approximately 100 m with a decreasing trend towards the north. Slope (α) in the valleys ranges from several to over 30° with the aspect in all directions. In the area of the fluvioglacial fans, the valleys have a fan-type spatial pattern (Fig. 7A). In the area occupied by terraces a1-a5, the valleys are formed crosswise to the morphological edges of the terraces with variation in their relative heights and hence the valley depth changes throughout their course. In turn, in the area occupied by terraces a6-a8 the valleys run parallel to the morphological edges of the terraces, whereas their depth is smaller and more even. In the tectonically elevated, peripheral areas of the Czarny Dunajec fluvioglacial fan, between the deepest valleys in this area, there are hummocks of 4-8 km in length, running approximately along NW-SE and SW-NE axes and with an asymmetrical cross-section (Fig. 7B,C). These landforms are similar to low homoclinal ridges. In this part of the Orawa Basin, whose entire area forms a bowl-shaped depression, the front of the Pliocene silt deposits and the overlay of Quaternary gravels constitute the geological substratum of the ridge slopes which are oriented approximately in the direction South (an analogue of a scarp slope), whereas the younger layers of the Quaternary deposits constitute the geological substratum of the

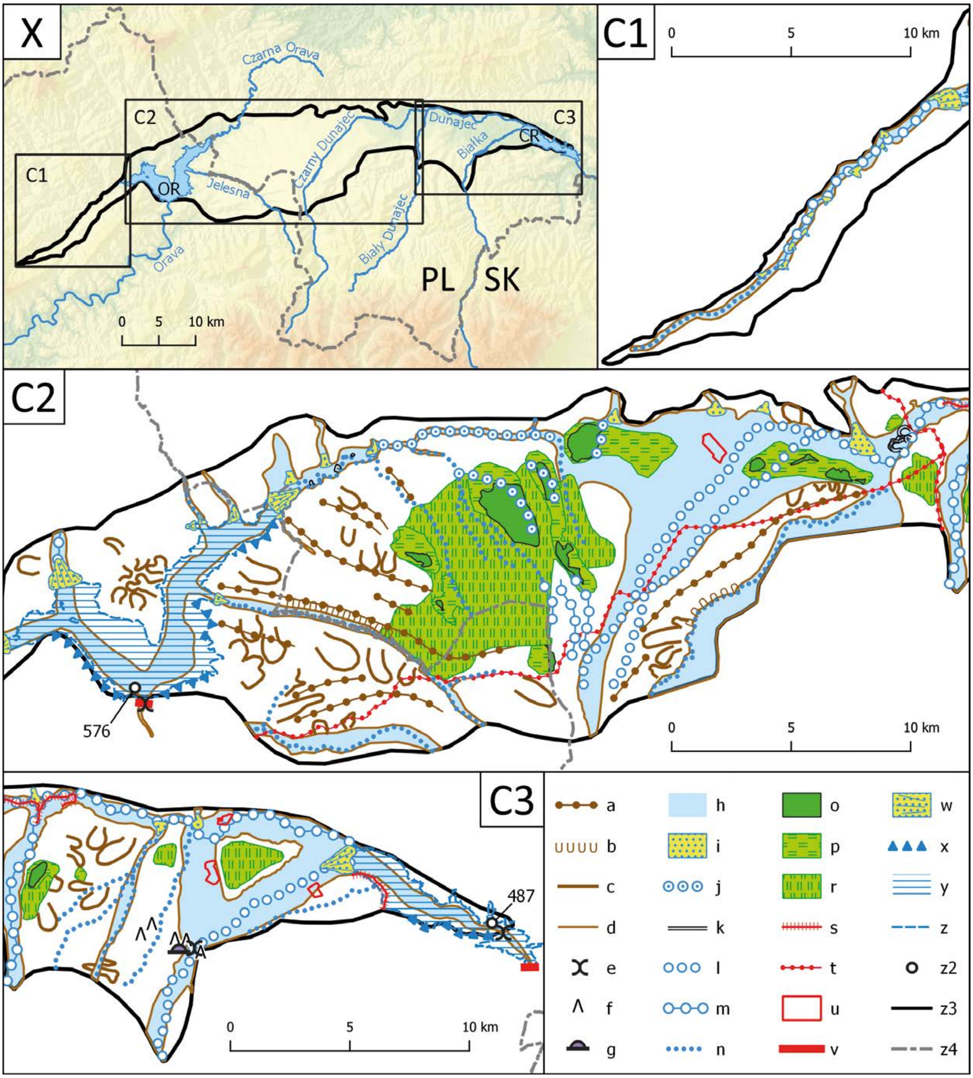

Figure. 6. Geomorphological map of the Orawa-Nowy Targ Basin (ONTB) – simplified version. Sections of the ONTB

C1 – Biela Orava-Hruštinka Depression, C2 – Orawa Basin, C3 – Nowy Targ Basin. X – location of C1, C2, C3. Denudation landforms: a – hummock with asymmetrical cross-section; b – landslide landforms; c – limit of bowl-shaped depression; d – limit of valley bottom, e – river gorge; f – limestone rock formation; g – cave. Fluvial landforms: h – alluvial valley bottom with Holocene river terraces; I – alluvial fan; j – palaeochannel of braided river; k – palaeochannel of meandering river; l – functioning braided river bed; m – partly regulated braided river bed; n – meandering river bed. Biogenic landforms: o – remnant of peatbog dome; p – post-peat area; r – fen. Anthropogenic landforms: s – flood control embankment; t – embankment of standard gauge railway; u – gravel pit (mining pit, heaps); v – water dam. Denudation and fluvial landforms which require human impact for their development: w – alluvial fan of river flowing into a dam reservoir; x – high cliff; y – bed of dam reservoir remodelled as a result of the accumulation of supplied material; z – low cliff. Other features: z2 – the lowest point in the basin and its altitude [m a.s.l.]; z3 – ONTB boundary; z4 – Polish-Slovak border (PL/SK).

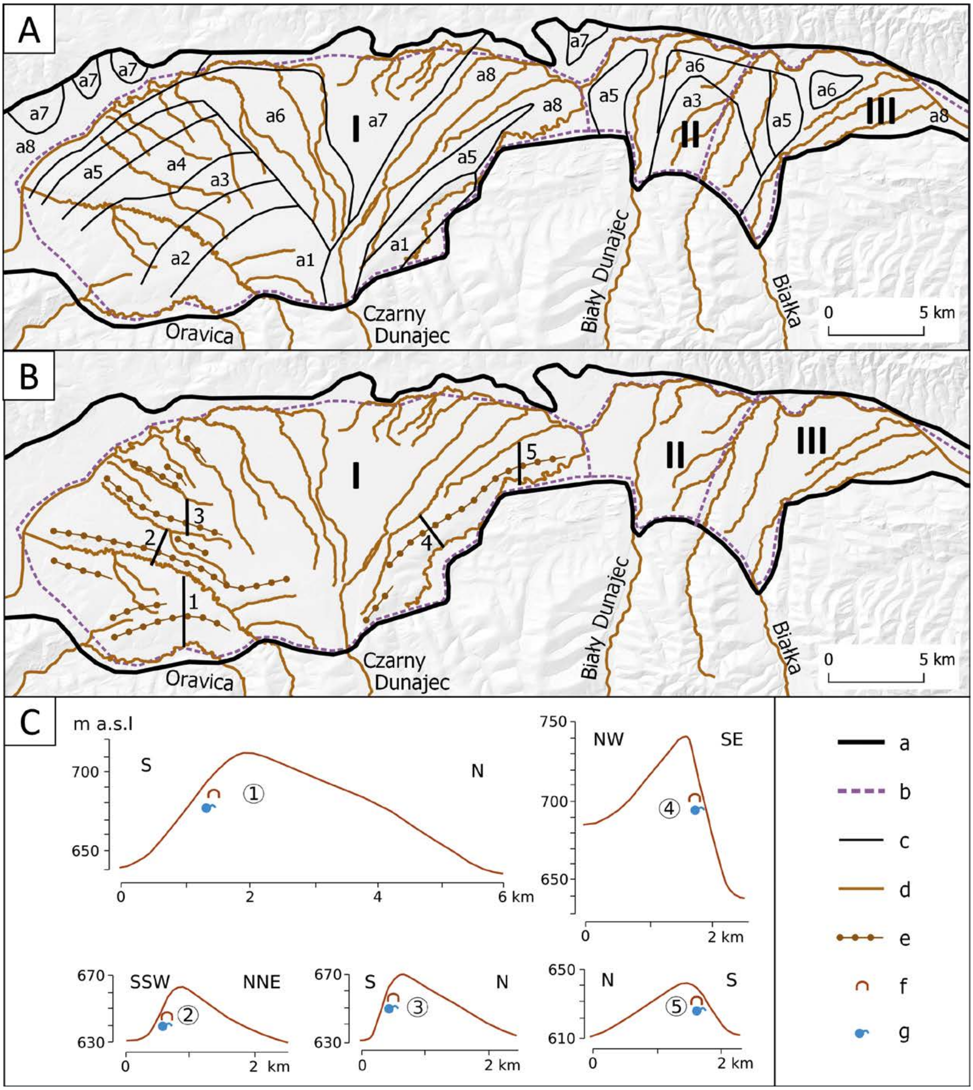

Figure 7. Distribution and morphometric properties of the denudation landforms found in the Orawa-Nowy Targ Basin (ONTB) – continued

A – valley axes (>2 km long) versus terrace edges (legend for the terraces: a1-a8 in the text); B – hummocks with an asymmetrical cross-section (with marked location of lateral profiles 1-5 presented in Part C); C – selected lateral profiles (1-5) – ridge cross-sections. a – ONTB boundary; b – limit of fluvioglacial fan; c – terrace edge; d – axis of valley; e – axis of asymmetrical hummock; f – landslide; g – ground water outflow.

opposite slopes. The slope angles of the steep concave slopes reach up to 30°, while on the opposite convex-concave slopes the angle is below 10°. The convex-concave slopes of homoclinal ridges are up to four times longer than the steep slopes. Local hydrogeological conditions produce small landslides which cause local modelling of the steep slopes of asymmetrical hummocks. On the slopes of asymmetrical hummocks, as well as on the slopes of terraces in the Orawa Basin and Nowy Targ Basin, there are depressions and small denudation valleys of 0.5-2.0 km in length which were formed during the Pleistocene. These are up to approximately 10 m deep, and vary in terms of aspect (Fig. 6). The inventory of denudation landforms in the area investigated is complemented by miniature landforms: limestone rock formations (Cisowa, Grzebieniowa, Obłazowa, Kramnica, and Okrągła Rock) elevated above the flat surface of the fluvioglacial fan of the Białka river and reaching up to 65 m; an epigenetic gorge of the Białka river of minimum width 70 m; Obłazowa Cave (9 m in length), and two smaller caves. The prevailing features of such landforms include rock walls and the full range of their aspects.

Among the ***fluvial landform*** types identified in the Orawa-Nowy Targ Basin, the largest (area-wise) are the Holocene valley bottoms (Fig. 6) which are found in the tectonically lowered NE section of the Orawa Basin and the Nowy Targ Basin, as well as occupying large surfaces in the W section of the Orawa Basin and in the valleys of inflowing rivers from the Tatra Mountains. On the borders of the basin, there are small alluvial fans of rivers and streams which date back to the Holocene and which catch waters from the neighbouring higher elevated areas. At the feet of the terrace edges, there are miniature proluvial fans. Silt material in the peripheral areas of the alluvial fans constitutes the substratum of some peat bogs. Within the fluvioglacial fan of the Czarny Dunajec river, on the terraces formed during the Würm glaciation and on the Late Glacial terrace, there are palaeochannels of the Czarny Dunajec river which are a trace of the former alignment of the river towards the NW. Channels of the former rivers on the terraces from the Würm glaciation are often filled with peat, currently with a decreased range and thickness. Bores into peat deposits have allowed a reconstruction of the palaeochannel shape. For example, under the dome of the largest peat bog in the basin, there are palaeochannels of 2-4 m in depth, located 2-8 m above stream beds around the peat bog. The longest recognised palaeochannel of a braided river at the terrace from the Würm glaciation is 5 km long, 40-60 m wide, and 5 m deep. The former meandering course of the Czarny Dunajec river in the western section of the Nowy Targ Basin is testified to by traces of river bends visible in the morphology of the Holocene terrace. This type of palaeochannel has been exposed on the territory formed during the Würm glaciation in the post-peat areas near the Bór na Czerwonem raised bog. Among the currently-functioning riverbeds in the Orawa-Nowy Targ Basin, the widest (over 50 m) are the rivers of the Czarny Dunajec, Biały Dunajec and Białka. Before regulation works undertaken in the mid-20th c., the rivers used to have braided channels. In the Orawa-Nowy Targ Basin this type of riverbed has only been preserved on the Białka river. The abovementioned rivers, inflowing from the Tatra Mountains, run along the axial zones of the fluvioglacial fans. In turn, there are meandering riverbeds at the edges of the fluvioglacial fans, as well as in the western part of the Orawa Basin and in the Biela Orava-Hruštinka Depression (Fig. 6).

Biogenic Holocene landforms add variety at the local scale to the relief of the Orawa-Nowy Targ Basin. These include remnants of raised bogs and fens. In addition, in the areas where peat mining was the most advanced in the past (post-peat areas), there are also peat outliers, escarpments, peat depressions, and field drainage ditches. Biogenic forms or traces thereof occur within the altitude range of 592-769 m a.s.l. in two sections of the basin, the Orawa Basin and the Nowy Targ Basin, mainly in the area of the fluvioglacial fans (Fig. 6). Biogenic landforms occur on all the terraces identified (a1-a8) in the following morphological conditions of terrain: on local watersheds, in palaeochannels, in small denudation bowls and valleys within terrace slopes, at the foot of terrace slopes, and on the lowest flat parts of the terraces. Elements of the relief within the fragments of raised bogs that are preserved include slightly convex tops with minimum slopes with a surrounding convex-concave slope of relative height up to 10 m and, when considering its entire area, with aspects facing in all directions. Fens surrounding raised bogs or occurring independently and occupying large areas have minimum slopes and, in the latter situation, are mainly oriented to the north. A different morphology is observed for landforms within the post-peat areas. Peat outliers are up to 6 m high, and are surrounded by an escarpment often having a zigzag course and with a vertical or stepped profile, while in many cases also with an already smoothened profile. Peat depressions and field drainage ditches up to 3 m deep are often filled with water. The area of individual remnants of raised bogs ranges from 0.5 to 356 ha, or from 5.5 to 660 ha fen-inclusive. Their total areas in the Orawa-Nowy Targ Basin amount to 1312 and 2836 ha respectively. The central part of the largest section of a basin is located on an area 9x9 km in size and is almost entirely covered by biogenic landforms.

Another group of landforms in the study area, namely ***anthropogenic landforms***, includes: (a) – a dam on the River Orava in the Ustianskie Gardło Gorge–Oravska Priehrada and a dam on the River Dunajec in the Niedzicki Gorge–Czorsztyn Reservoir (Fig. 6); (b) – the embankments of two standard-gauge railway lines of a total length of 50 km (the railway from Nowy Targ to Trstena has been dismantled); (c) – the embankment under the narrow-gauge railway from Czarny Dunajec village to the peat mine on the Puścizna Wielka peat bog; (d) – flood control embankments along the Czarny Dunajec river near Nowy Targ and along the southern bank of the Czorsztyn Reservoir; (e) – gravel pits (mines, heaps) on the N side of the Czarny Dunajec village and near Nowa Biała village; (f) – road embankments and undercuts, roadside ditches, bridgehead abutments; (g) – levelled areas on developed land; (h) – bowls occupied by fish ponds near Ludźmierz and Krauszów. The locations of landforms “a”, “b”, “d”, and “e” are presented on Figure 6. As regards relative height, landforms “a” stand out, followed by landforms “e” at a smaller scale, whereas longitudinal landforms “b”, “c” and “d” prevail. All the aforementioned landforms have high slope angles, in some of their fragments reaching up to 90°, and with a varied aspect.

The last group covering ***denudation and fluvial landforms*** in the Orawa-Nowy Targ Basin ***that required human impact to develop*** includes the following landforms (Fig. 6): (a) alluvial fans developing in river estuaries on the edge of the Orava Reservoir (five major forms) and the Czorsztyn Reservoir (two major forms); (b) sections of the banks of the reservoirs where, as a result of abrasion, steep cliffs are formed with wide erosion platforms at their base; (c) other sections of the banks of the reservoirs where, as a result of erosion, low cliffs are formed with narrower erosion platforms at their bases; (d) underwater valley bottoms within the range of the back water from reservoirs where, as a result of the accumulation of both fluvial material and the material supplied from eroded reservoir banks, the bottom becomes increasingly shallow with an accompanying change to its morphology. In terms of area, landforms “a” and “d” are dominant whereas the greatest relative heights (over 10 m) and slope angles (locally of over 30°) are recorded for landforms “b”. Fragments of all landforms feature a full range of aspect.

Patterns of distribution of the largest landforms, and the angle and aspect of slopes within these landforms

In the largest sections of the Orawa-Nowy Targ Basin (the Orawa Basin and the Nowy Targ Basin) which are dominated by the fluvioglacial fans, local denivelations point to spatial pattern which has not to date been investigated by geomorphologists. Therefore, the analysis involved landforms with a relative height >5 m and reaching a maximum of 40 m or even approximately 100 m. Relative height at a local scale across the area of fluvioglacial fans reveals fluctuations along the S-N axis of such landforms, and to a similar extent also along the W-E axis. The landforms with the largest relative height differences on particular fragments of the area of fluvioglacial fans mainly include denudation landforms: valleys and the ridges separating them, river gorges, isolated limestone rocks, escarpments of terraces and depression bowls within their range. Among anthropogenic landforms, such a role is given to water dams, as well as pits and heaps in gravel pits. This group of landforms also includes high cliffs on the banks of dam reservoirs, as well as the remnants of raised bogs. Other convex or concave landforms, such as railway embankments, flood control embankments, or bowls occupied by fish ponds, or field drainage pits and ditches within the post-peat areas, have a marginal role.

Consideration is now given to the distribution of the individual abovementioned landforms, or groups thereof (Fig. 6), along the axes of the fluvioglacial fans. Starting from their highest elevated sections in the south to their lowest sections in the north, one can observe fluctuations in their relative heights. Local height differences at the apex of fluvioglacial fans reach 50-100 m and decrease towards the north to as much as 10-20 m. Still further N, but exclusively in the Nowy Targ Basin near the limestone rocks and the river gorge of the Białka river, they again move up to over 60 m. Further to the north in the Orawa Basin and Nowy Targ Basins there is again a decreasing trend in relative height, but in the lowest areas of the basins, the value increases locally near the river gorges of the Orava and Dunajec rivers as well as near the anthropogenic landforms (heaps in gravel pits, water dams).

The fluctuating changes in relative height are also observed crosswise to the axes of the fluvioglacial fans, namely along a W-E axis. Along the axial zone of fluvioglacial fans, located much lower than their apices, the depth of the valleys and height of the separating ridges and terraces are much smaller than in the W and E peripheral areas of the fans. Such a differentiation of relative height is also linked to the occurrence in these peripheral eastern and western areas of certain single landforms, such as water dams, high cliffs along the banks of the reservoirs, as well as some remnants of raised bogs.

In the smallest section of the Orawa-Nowy Targ Basin (the Biela Orava-Hruštinka Depression), which is morphologically similar to the bottom of a long and wide valley, the predominant landform types include numerous alluvial fans with a relative height <5 m, occurring below the mouths of side valleys. Therefore, this area is marked with a decrease in the local relative height from the foot of the slopes towards the axis of the bottom of this section of the basin.

The abovementioned landform types with the greatest relative heights, due to their curved or even closed borders, as well as steep or even fault-like slopes, show the greatest variation in slope angle and aspect values. Therefore, the areas where such landforms occur must be deemed as having the greatest mosaic of all morphometric parameters.

The sinuosity of water courses

Water courses longer than 5 km in the Orawa-Nowy Targ Basin feature a characteristic differentiation of sinuosity (Fig. 8). On the fluvioglacial fans, braided rivers flowing from the Tatra Mountains feature a sinuosity of <1.2. Rivers inflowing into the Orawa-Nowy Targ Basin from the surrounding catchments built of flysch rocks have higher sinuosity within the basin, which in many cases, shows an increasing trend through their course reaching even a value as high as 2.0. The same is observed for local water courses in the Orawa Basin and the Nowy Targ Basin; in the lower section of such water courses, sinuosity even exceeds 2.0. In the Orawa Basin and Nowy Targ Basin, another trend can be observed within the fluvioglacial fans. The sinuosity of water courses follows a trend to increase from the axial zone of these vast landforms towards their western and eastern edges, increasing from values just exceeding 1.0 up to 2.0 or more. In the Biela Orava-Hruštinka Depression, the sinuosity of the main water courses (the Hruštinka and further on the Biela Orava) increases along their course.

To conclude, water courses with a sinuosity >1.5 prevail in the western and eastern areas of the fluvioglacial fans in the Orawa Basin and the Nowy Targ Basin, and in the

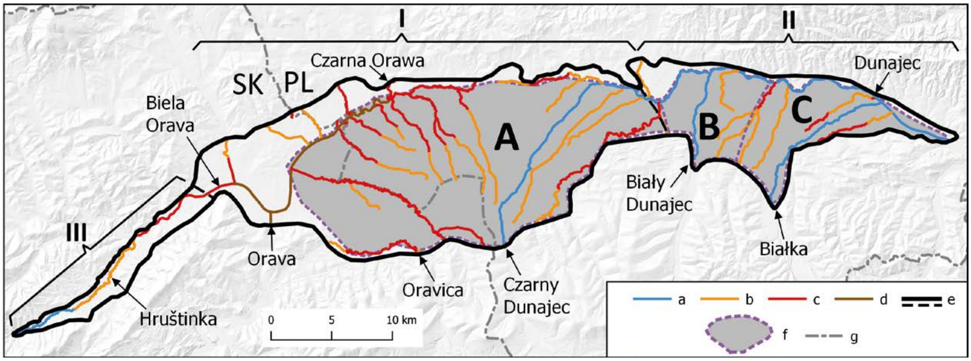

Figure 8. Variation in the sinuosity of water courses with a length exceeding 5 km in the Orawa-Nowy Targ Basin (ONTB). In sections of valleys with the dam reservoirs, the Figure presents the situation before construction of such hydrotechnical facilities

Sinuosity, a – 1.0-1.2; b – 1.2-1.5; c – 1.5-2.0; d – 2.0-2.5. e – boundary of the ONTB and sections within the basin (I – Orawa Basin, II – Nowy Targ Basin, III – Biela Orava-Hruštinka Depression); f – limit of fluvioglacial fan (river: A – Czarny Dunajec, B – Biały Dunajec, C – Białka); g – Polish-Slovak border.

former area also in the northern part of the fluvioglacial fan. The greater sinuosity value of water courses in such areas is related to their more stable inflow from underground waters flowing out of Quaternary gravels as well as from vast raised bogs, while also to a lesser extent from post-peat areas and fens. Such a hydrographic situation, as well as the occurrence of dusty layers on gravels, encourages the formation of meandering rivers. In turn, the minimum sinuosity values of transit rivers flowing through the axial zones of fluvioglacial fans are affected by the high outflow dynamics of such rivers. The impact of the neotectonics of the area on the differentiation in the sinuosity of water courses, which was identified, seems to be limited; the greatest values of this morphometric parameter are observed for water courses occurring both in tectonically lowered areas (some features in the NE part of the Orawa Basin and the Nowy Targ Basin), and in elevated areas (most features in the W section of the Orawa Basin). However, rivers with braided channels with a minimum sinuosity value occur in both tectonically elevated and in lowered areas (Figs. 5C, 6 and 8).

Greater sinuosity of water courses generates great variation in other morphometric parameters of the area, such as local relative height, slope and aspect, particularly if the water courses occur in high density on a small area. In the case of meandering rivers in the Orawa-Nowy Targ Basin, the heights of river banks range from approximately 1 m to over 10 m, the width of river channels – between 1 m and 30 m, the slopes of the river banks locally achieve 90° (particular in areas covered with peat), whereas their aspects involve all directions. Therefore, the areas with the highest density of high-sinuosity water courses in the Orawa-Nowy Targ Basin stand out as regards relative height, slope, and aspect. An entirely different situation is observed in areas dominated by braided rivers with minimum sinuosity, where river bank height does not usually exceed 3 m, with the slope of river banks usually achieving just 60°, and their aspect in river sections of up to 2 km shows just two opposite orientations, e.g. W and E or S and N.

Differentiation of relative height ΔH in the basin on the basis of the hexagonal grid

Based on the relative height ΔH developed from the hexagonal grid with a grid mesh of 21.65 ha, a contrast was revealed between the topography of the Orawa-Nowy Targ

Basin (ONTB) and the external zone 3 km in width (Fig. 9). In the area occupied by the ONTB where a flat-bottomed valley type prevails, regardless of tectonic tendencies (movements elevating or lowering the terrain level – Fig. 5), a local relative height ΔH <22 m is predominant across the area. Areas with a relative height ΔH >22 m and reaching up to 100 m occupy large areas in the western, southern, and south-eastern parts of the Orawa Basin (OB), in the southern parts of the Nowy Targ Basin (NTB), in the narrow belt of the land along the northern border of the OB and the NTB sections, and almost right across the Biela Orava-Hruštinka Depression. In the 3 km zone neighbouring the ONTB, the ΔH value exceeds 200 m. The gradual change in the ΔH value between the ONTB area and its surrounding areas indicates the fact, noted in the literature, that the boundaries of the basin are set along faults that follow W-E, NW-SE, and NE-SW axes.

The spatial differentiation of relative height in the Orawa-Nowy Targ Basin correlates with the extent of landforms with the largest or smallest vertical dimensions (Fig. 6). These principally include valleys with asymmetrical hummocks separating them and Holocene valley bottoms. In this respect, one must also consider isolated limestone rocks, river gorges, terrace slopes, as well as heaps in gravel pits.

Differentiation of mean slope *α* in the basin based on the digital elevation model

In the predominant area of the Orawa-Nowy Targ Basin (ONTB), the mean slope value does not exceed 3°, whereas within vast areas in the NE part of the Orawa Basin (OB) and the Nowy Targ Basin (NTB), it is <1° (Fig. 10A). A mean slope >6°, and locally >15°, is observed in the western, southern, and south-eastern parts of the OB, while also in southern areas of the NTB. Mean slope within that range is also recorded for the narrow zone along the northern border of those two sections of the ONTB. Significant mean slope values are characteristic of the Biela Orava-Hruštinka Depression (BOHD).

The mean slope at the scale of the entire area of the ONTB is most affected by the situation in its largest sections: the Orawa Basin and the Nowy Targ Basin (Fig. 10B). In these three areas, mean slope <3° is observed in 76%, 79%, and 80% of their total area, respectively, which points to the domination of the flat bottom of the Orawa-Nowy Targ Basin. In turn, the areas with a mean slope >10° occupy just 3% of the ONTB area, whereas in the OB and NTB sections they occupy 2% and 4% respectively. With respect to mean slope, the BOHD section stands out, as its area with a mean slope < 3° occupies just 29% of its total area, and the areas with a mean slope >10° occupy over 13% of the area of this

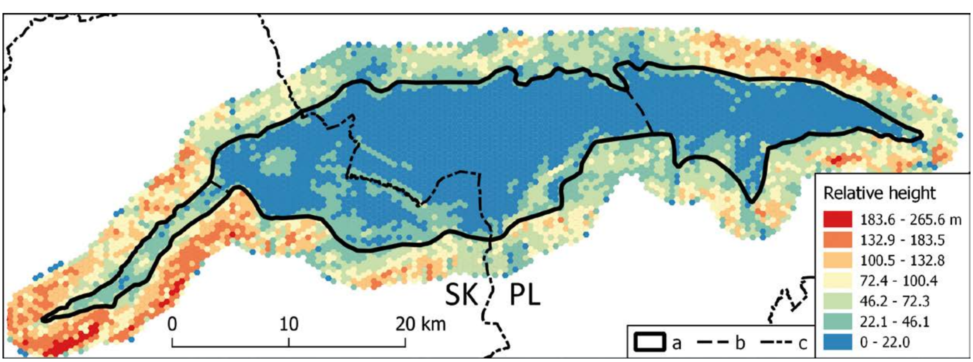

Figure 9. Relative height ΔH in hexagonal grid in the Orawa-Nowy Targ Basin (ONTB) and the 3 km buffer zone around its borders
a – ONTB boundary; b – boundary between sections of the basin; c – Polish-Slovak border.

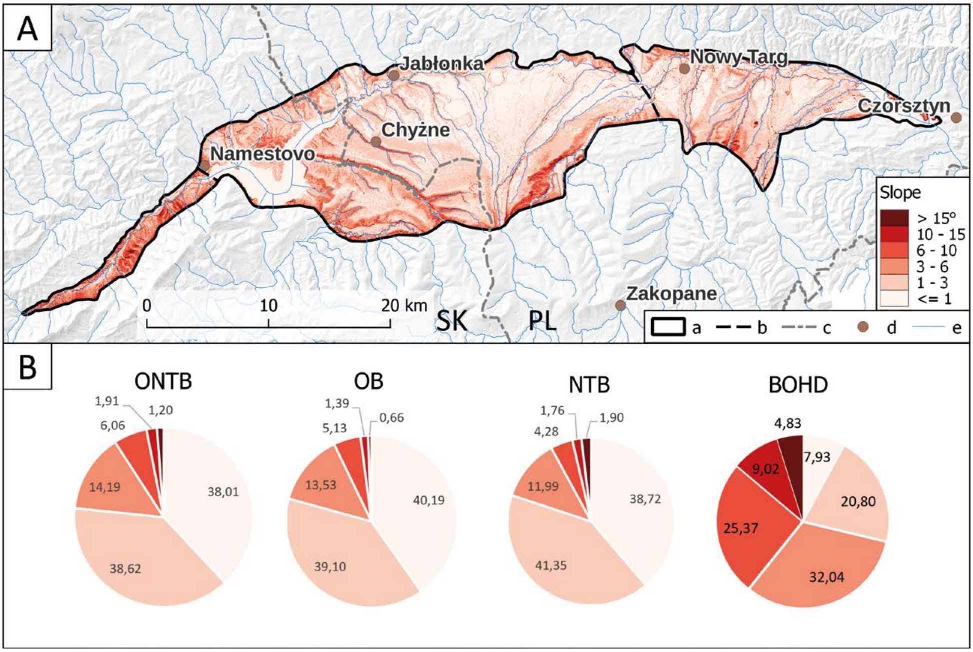

Figure 10. Slopes α in the Orawa-Nowy Targ Basin (ONTB)
A – variation in slope; B – slope structure in the ONTB and its sections: Orawa Basin (OB), Nowy Targ Basin (NTB), Biela Orava-Hruštinka Depression (BOHD). a – ONTB boundary; b – boundary between sections of the basin; c – Polish-Slovak border; d – town and main village; e – river, stream.

section. Land with a mean slope within the range between 3° and 10° occupies the largest area (57%) within the BOHD. Areas with a mean slope within such a range occupy just 20% of the ONTB area, while in the case of the OB and NTB sections, such areas cover 19% and 16% respectively (Fig. 10B).

Spatial variation of mean slope values in the Orawa-Nowy Targ Basin correlates with the extent of landforms with high or low relative height. In this respect, the most important assessment refers to the range of areas with the highest or lowest energy of relief. The comparison of Fig. 10A and Fig. 6, in analogical fashion to the case of relative height ΔH (Fig. 9), points to the prevailing (in this respect) distribution of landforms with the highest vertical dimensions (valleys, asymmetrical hummocks, isolated limestone rocks, river gorges, terrace slopes, heaps in gravel pits), as well as landforms with the lowest vertical dimensions (Holocene valley bottoms).

Differentiation of mean slope *α* in the basin based on the hexagonal grid

Mean slope in the Orawa-Nowy Targ Basin (ONTB), determined from the hexagonal grid, points to spatial differentiation correlating with the image obtained from the digital elevation model (Fig. 11). The ONTB is dominated by a mean slope not exceeding 3°, and only locally achieves 12°, whereas in the 3 km zone external to the boundary of the basin, it exceeds 20°. In the ONTB areas with elevating tectonic movements, the mean slope significantly exceeds 3°. Such a situation is typical of areas with landforms featuring the greatest vertical dimensions in the basin. Nevertheless, in such sections of the ONTB, there are large areas, particularly valley bottoms, with a mean slope <3°. In turn, there are vast areas in the northern and north-eastern parts of the Orawa Basin (OB) and the Nowy Targ Basin (NTB) with a mean slope <3°. Set against

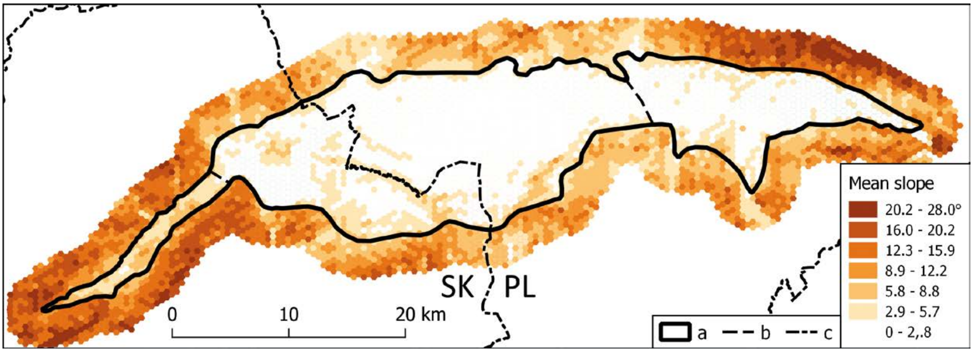

Figure 11. Mean slope α in hexagonal grid in the Orawa-Nowy Targ Basin (ONTB) and the 3 km buffer zone around its borders
Explanation of a-c as in Fig. 9.

the largest sections of the basin, the mean slope value within the Biela Orava-Hruštinka Depression is relatively high. The results presented confirm the opinions regarding tectonic conditioning of the edges of the largest sections of the Orawa-Nowy Targ Basin, particularly in the Orawa Basin.

Differentiation of aspect A in the basin based on the digital elevation model

When considering the very large areas with slopes <3°, and locally <1° which occur in the largest sections of the Orawa-Nowy Targ Basin (Figs. 10 and 11: Orawa Basin, Nowy Targ Basin), an assumption has been adopted that these sections of the basin should be classified as areas with no aspect (Fig. 12A). They occupy very large areas in the northern, north-eastern, and western parts of the Orawa Basin, as well as the northern part of the Nowy Targ Basin. Lands considered as areas with no aspect overlap with the extent of the broad Holocene valley bottoms, as well as the flat tops of wide hummocks. It should be noted that there is a compact area with an area of over 100 km^2 with no aspect in the central part and in large NE areas of the Orawa Basin. Areas with concave or convex landforms, regardless of their vertical dimensions, have varied aspects within all ranges. Attention must be drawn in this respect to the valleys and asymmetrical hummocks present in the western, southern, and south-eastern parts of the Orawa Basin. Variation in the aspects of the slopes, with the S aspect being dominant, are also visible in the northern zone adjoining the edge of the Orawa Basin and the Nowy Targ Basin. Fig. 12A also shows the variation in the aspect of other landforms, e.g. isolated limestone rocks, heaps in gravel pits, cliffs on the edges of dam reservoirs, or railway embankments. A different situation with regards to aspect is observed in the Biela Orava-Hruštinka Depression in which the N and W aspects are dominant, whereas the area with no aspect is limited to a narrow zone at the bottom of this section of the basin.

The situation with regard to aspect seen in the Orawa-Nowy Targ Basin, in a similar manner as in the case of the angle of slope, very largely depends on the situation in the largest sections of the basin (the Orawa Basin and the Nowy Targ Basin) (Fig. 12B). In the Orawa Basin, areas with no aspect occupy 79% of the area, whereas in the Nowy Targ Basin, this is 80%. Across the Orawa-Nowy Targ Basin as a whole this land category occupies 77% of the area, a result of the small proportion of areas with no aspect (29%) in the section covering the Biela Orava-Hruštinka Depression. In the Orawa Basin and the Nowy Targ Basin, and as a result across the whole Orawa-Nowy Targ Basin, areas with N, E, S, and W aspects occupy just several % of the land area, with none of these aspects clearly

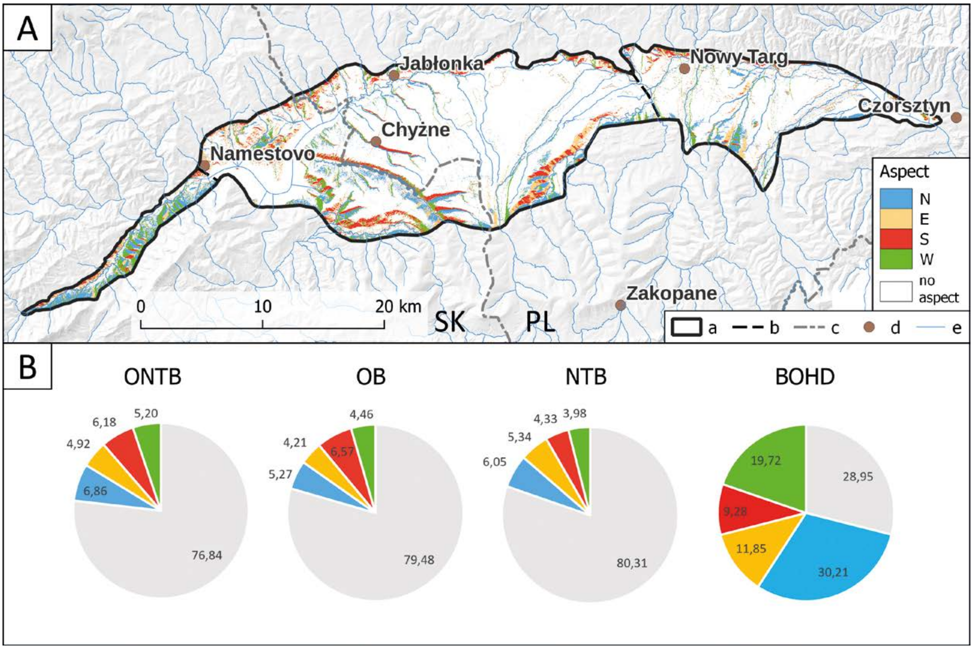

Figure 12. Aspects A in the Orawa-Nowy Targ Basin (ONTB). A – variations in aspect; B – aspect structure in the ONTB and its sections: Orawa Basin (OB), Nowy Targ Basin (NTB), Biela Orava-Hruštinka Depression (BOHD)
Explanation of a-e as in Fig. 10.

being predominant. This points to a homogeneity of almost the entire Orawa-Nowy Targ Basin, considering this feature of its geomorphometry. The exception is formed by the Biela Orava-Hruštinka Depression, where areas with N and W aspects occupy, in total, half of the area of this section of the basin.

Discussion

The analysis of the relief of the Orawa-Nowy Targ Basin, presented in the qualitative and quantitative aspect based on the results of the geomorphological mapping of this area at a scale of 1:10,000 as well as on the digital elevation model and hexagonal grid methods, goes beyond the framework of previous geomorphological studies of the area investigated. Because of a limited volume framework of the paper, the interpretation of the obtained results have only been signalled. Such a spatial pattern of landforms and morphometric values in the Orawa-Nowy Targ Basin reflects the history of geomorphological development of this area. Existing publications, even the most recent ones, regarding the Orawa-Nowy Targ Basin, focus on a qualitative assessment of the landforms (Baumgart-Kotarba, 2000; Łajczak, 2011, 2013a,b; Kukulak & Augustowski, 2022-2023; Zawiejska et al., 2024) and the earliest attempt to provide a morphometric analysis of the area is only found in (Zarychta et al., 2025). In addition, the present study stands out in both the methodological and content-related aspect when compared with descriptions of the reliefs of other intramontane basins across the Carpathians and Alps (including Kondracki, 1989, 2000; Balteanu et al., 1998; Novak et al., 2018). In the latest studies on the reliefs of the largest intramontane basins in the Slovak Carpathians, the Turčianska Basin, Žiarska Basin, and Podtatranská Basin (Sládek et al., 2022; Vitovič et al., 2022), the authors focus on the geological factors affecting the development of relief, particularly neotectonics, as well as on describing the structural landforms. The studies cited do not include geomorphological maps, or a morphometric analysis of even the largest landforms.

Conclusions

With reference to this study, it can be stated that its goal has been achieved because: (a) basing on the results of the own research and taking into account information from literature, it explains the distribution of various landform types within the Orawa-Nowy Targ Basin, identifying landforms of different sizes; (b) spatial differentiation of morphometric parameters of various landform types was explained; (c) on the basis of this, it explains the influence of the landforms on the spatial differentiation of the morphometry of the entire basin that is being examined. The results have been presented graphically.

The spatial differentiation of the size of morphometric parameters (local relative height, slope, aspect) of the Orawa-Nowy Targ Basin (ONTB) points to a connection with the distribution and size of all types of landforms as well as tectonics. The ONTB can be classified into three areas with different histories of relief development, differing in distribution, range, and vertical size of the landforms, and thus morphometric parameters. The largest area in the ONTB is occupied by three fluvioglacial fans occurring in the Orawa Basin (OB) and the Nowy Targ Basin (NTB), of which the fluvioglacial fan of the Czarny Dunajec river covers the largest area. The second area in the ONTB is the remaining part of sections of the OB and the NTB, occupying their northern peripheries outside the fluvioglacial fans. The third area in the ONTB, with different landforms, is its smallest section: the Biela Orava-Hruštinka Depression. The earliest of those is subject to upward tectonic movements in its western and southern part, whereas in the central and eastern part such movements are directed downwards. Areas subject to downward tectonic movements have the lowest relative height and slope values across the ONTB. The other two areas in the ONTB have been subject to upward tectonic movements, and have more varied relative heights, slopes and aspects. For these reasons, the entire Orawa-Nowy Targ Basin area cannot be treated as homogenous on the basis of minimum relative height and slope values.

The results of the studies allow previous hypotheses to be verified. Within the framework of the fluvioglacial fans prevailing in the Orawa-Nowy Targ Basin, their slope decreases along an axis towards the north, with a consequential decrease of their relative height in this direction. Considering the deepest landforms within the fluvioglacial fans, namely the valleys, this morphometric parameter indeed decreases in this direction. However, if we were to consider other landforms of similar vertical size, but occurring on small areas, their local relative height within the alluvial fans indicates undulation on a S-N axis. This results in variation in slope and aspect at a local scale. Due to the characteristic distribution of the landforms of the highest vertical dimensions within the fluvioglacial fans, another direction of change to the local relative height, slope and aspect is indicated across the axes of the fluvioglacial fans in the Orawa Nowy Targ Basin. In this situation, one can observe a trend developing in these morphometric parameters running from the axes of the fluvioglacial fans towards their eastern and western peripheries.

The Orawa-Nowy Targ Basin continues to present a promising area for comprehensive studies on the relief of the area with respect to its geomorphology, including, inter alia, its morphography and morphometry, with special consideration of the various types of landforms found in the geomorphological landscape.

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References

Balon, J., & Jodłowski, M. (2014). Regionalizacja fizycznogeograficzna Karpat Zachodnich – studium metodologiczne. In W. Ziaja, & M. Jodłowski (Eds) *Struktura środowiska przyrodniczego a fizjonomia krajobrazu*, (pp. 85-105). Kraków: Wydawnictwo Instytutu Geografii i Gospodarki Przestrzennej UJ.

Balteanu, D., Jelenicz, M., & Popescu, N. (1998). Geomorphology of the Romanian Carpathians. New Trends and Evolution. *Studia Geomorphologica Carpatho-Balcanica, 32*, 89-109.

Baumgart-Kotarba, M. (1991-1992). Rozwój geomorfologiczny Kotliny Orawskiej w warunkach ruchów neotektonicznych. *Studia Geomorphologica Carpatho-Balcanica, 25-26*, 3-26.

Baumgart-Kotarba, M. (1996). On origin and age of the Orawa Basin, West Carpathians. *Studia Geomorphologica Carpatho-Balcanica, 30*, 101-116.

Baumgart-Kotarba, M. (2000). Tectonique quaternaire de la dépression d'Orava (Carpathes occidentales). *Géomorphologie: Relief, Processus, Environnement. 1*, 61-68.

Baumgart-Kotarba, M., Dec, J., & Ślusarczyk, R. (2001). Quaternary tectonic grabens of Wróblówka and Pieniążkowice and their relation to Neogene strata of the Orava Basin and Pliocene sediments of the Domański Wierch Series in Podhale, Polish West Carpathians. *Studia Geomorphologica Carpatho-Balcanica, 35*, 101-119.

Baumgart-Kotarba, M., Marcak, H., & Márton, E. (2004). Rotation along the transverse transforming Orava strike-slip fault: based on geomorphological, geophysical and paleomagnetic data (Western Carpathians). *Geologica Carpathica, 55(3)*, 219-226.

Birkenmajer, K. (1979). *Przewodnik geologiczny po pienińskim pasie skałkowym*. Warszawa: Wydawnictwo Geologiczne.

Chmielowska, D. (2015). Próba interpretacji litogenetycznej osadów diamiktonowych w Kotlinie Orawskiej (Karpaty Zachodnie). *Landform Analysis, 28*, 3-14. https://doi.org/10.12657/landfana.028.001

Chrustek, M. (2006). Tectonic deformations in the Orava Basin margins in the Western Carpathians, based on the DEM analysis and geological research. *GeoLines, 20*, 26-27.

Cieszkowski, M., Golonka, J., Struska, M., Szczęch, M., & Kania, M. (2025). Budowa geologiczna. In A. Łajczak, & R. Zarychta (Eds.) *Kotlina Orawsko-Nowotarska. Przyroda nieożywiona i zmiany antropogeniczne.* Wydawnictwo Uniwersytetu Komisji Edukacji Narodowej w Krakowie (in preparation).

Fusan, S., Kodym, O., Matejka, A., & Urbanek, L. (1967). Geologicka mapa ČSSR 1:500,000. Praha.

Geomorfologicke členienie SSR. (1986). Mapa 1:500,000. Bratislava.

Gilewska, S., & Starkel, L. (Eds) (1980). *Przeglądowa Mapa Geomorfologiczna Polski, skala 1:500,000*. Arkusz Kraków. Warszawa: Instytut Geografii i Przestrzennego Zagospodarowania PAN.

Gilewska, S. (1991). Rzeźba. In L. Starkel (Ed.), *Geografia Polski. Środowisko Przyrodnicze* (pp. 248-296). Warszawa: Wydawnictwo Naukowe PWN.

Gorczyca, E., Krzemień, K., & Łyp, M. (2011). Contemporary trends in the Białka River channel development in the Western Carpathians. *Geographia Polonica, 84*, Special Issue Part 2, 39-53.

GUGiK. (2018). Geoportal. Główny Urząd Geodezji i Kartografii. www.geoportal.gov.pl/

Gustawicz, B. (1883). Pomiary tatrzańskie. *Pamiętnik Towarzystwa Tatrzańskiego, 8*, 40-90.

Halicki, B. (1930). La glaciation quaternaire du versant nord de la Tatra (Dyluwialne zlodowacenie północnych stoków Tatr). *Sprawozdanie Państwowego Instytutu Geologicznego, 5(3-4)*, 377-534.

Hengl, T., & Reuter, H. I. (Eds) (2009). *Geomorphometry: concepts, software, applications*. Amsterdam: Elsevier.

Kasprzak, M., & Traczyk, A. (2010). Geomorfometria granitowej części Karkonoszy. *Landform Analysis, 13*, 33-46.

Kasprzak, M., & Migoń, P. (2015). DEM-based analysis of Geomorphology of a stepped sandstone plateau, Stołowe Mountains (SW Poland). *Zeitschrift für Geomorphologie, 59(1)*, 245-2268. https://doi.org/10.1127/zfg_suppl/2015/S-00183

Klimaszewski, M. (1948). *Polskie Karpaty Zachodnie w okresie dyluwialnym*. Prace Wrocławskiego Towarzystwa Naukowego, B 7.

Klimaszewski, M. (1972). Karpaty Wewnętrzne. In M. Klimaszewski (Ed.) *Geomorfologia Polski. T. 1: Polska Południowa – góry i wyżyny* (pp. 21-52). Warszawa: Państwowe Wydawnictwo Naukowe.

Klimaszewski, M. (1981). *Geomorfologia*. Warszawa: Państwowe Wydawnictwo Naukowe.

Klimaszewski, M. (1988). *Rzeźba Tatr polskich*. Warszawa: Państwowe Wydawnictwo Naukowe.

Kondracki, J. (1989). *Karpaty*. Warszawa: Wydawnictwa Szkolne i Pedagogiczne.

Kondracki, J. (2000). *Geografia regionalna Polski*. Wydanie 2 poprawione. Warszawa: Państwowe Wydawnictwo Naukowe.

Kościelniak, J. (2004). Influence of river training on functioning of the Biały Dunajec River channel system. *Geomorphologia Slovaca, 4(1)*, 62-67.

Krzaklewski, P. (2008). Rola zdarzeń ekstremalnych w kształtowaniu meandrowych koryt górskich na przykładzie Czarnej Orawy w okresie 2007-2008. *Landform Analysis, 8*, 45-48.

Krzemień, K. (2003). The Czarny Dunajec River, Poland, as example of human-induced development tendencies in a mountain river channel. *Landform Analysis, 4*, 57-64.

Kukulak, J., & Augustowski, K. (2022-2023). Relics of the oldest glaciofluvial sediments of the Czarny Dunajec River in Podhale (Western Carpathians). *Studia Geomorphologica Carpatho-Balcanica, 56-57*, 79-98.

Kurczyński, Z. (2012). Produkty pozyskiwane w ramach realizacji projektu ISOK. In *Nowoczesne Technologie Pozyskiwania i Aktualizacji Danych z PZGiK* (pp. 28-29). Stowarzyszenie Geodetów Polskich, Wisła – Malinka, 5-7.09.2012.

Lehotský, M., & Boltižiar, M. (Eds) (2022). *Landscapes and Landforms of Slovakia*. World Geomorphological Landscapes. Cham: Springer. https://doi.org/10.1007/978-3- 030- 89293-7

Lexa, J., Bezák, V., Elečko, M., Mello, J., Polák, M., Potfaj, M., & Vozár, J (Eds.) (2000). Geological map of Western Carpathians and adjacent areas. 1:500,000. Publication of Ministry of the Environment of Slovak Republic and Geological Survey of Slovak Republik.

Lipka, K., & Zając, E. (2014). *Stratygrafia torfowisk Kotliny Orawsko-Nowotarskiej*. Kraków: Agencja Wydawniczo-Poligraficzna Art-Tekst, Mariusz Sierpień.

Łajczak, A. (2007). *The Orawsko-Podhalańskie peatlands*: *Natura 2000 in Poland area PLH120016*. Kraków: W. Szafer Institute of Botany. Polish Academy of Sciences.

Łajczak, A. (2011). Contemporary changes in the relief of raised bogs on the example of the Polish Carpathians. *Geographia Polonica, 84*, Special Issue Part 2, 5-22. https://doi.org/10.7163/GPol.2011.S2.6

Łajczak, A. (2013a). The role of bedrock and local topography in development of raised bogs in the Carpathian Mountains. *Landform Analysis, 22*, 61-73.

Łajczak, A. (2013b). Changes in raised bog relief during the Holocene. Case study: Polish Carpathian Mountains. In M. C. Hernandez-Soriano (Ed.) *Soil Processes and Current Trends in Quality Assessment* (337-363). IntechOpen. https://doi.org/10.5772/54988

Łajczak, A. (2024). Mt. Babia Góra – The Highest Flysch Ridge in the Western Carpathians. In P. Migoń, & K. Jancewicz (Eds.) *Landscapes and Landforms of Poland* (pp. 249-268). World Geomorphological Landscapes. Cham: Springer. https://doi.org/10.1007/978-3-031-45762-3_13

Łajczak, A., & Wałek, G. (2024). Morfometria. In A. Łajczak (Ed.) *Przyroda nieożywiona Babiej Góry* (pp. 109-120). Monografie Babiogórskie. Zawoja – Kraków: Babiogórski Park Narodowy, Instytut Systematyki i Ewolucji Zwierząt PAN.

Łajczak, A. (2025a). Współczesne ukształtowanie kotliny (ogólne informacje). In A. Łajczak, & R. Zarychta (Eds) *Kotlina Orawsko-Nowotarska. Przyroda nieożywiona i zmiany antropogeniczne*. Wydawnictwo Uniwersytetu Komisji Edukacji Narodowej w Krakowie (in preparation).

Łajczak, A. (2025b). Wody powierzchniowe. In A. Łajczak, & R. Zarychta (Eds) *Kotlina Orawsko-Nowotarska. Przyroda nieożywiona i zmiany antropogeniczne*. Wydawnictwo Uniwersytetu Komisji Edukacji Narodowej w Krakowie (in preparation).

Migoń, P., Różycka, M., & Jancewicz, K. (2016). Zespół osuwisk na Toczku (Góry Bystrzyckie) w świetle analizy geomorfometrycznej. *Przyroda Sudetów, 19*, 167-188.

Mojski, E. (2005). *Ziemie polskie w czwartorzędzie: Zarys morfogenezy*. Warszawa: Państwowy Instytut Geologiczny.

Mojski, E., & Watycha, L. (1984). Eoplejstocen. Mezoplejstocen. Tatry i Kotlina Nowotarska. In E. Mojski (Ed.) *Budowa geologiczna Polski, T. 1, Stratygrafia, cz. 3b, Kenozoik, Czwartorzęd* (pp. 81-153). Warszawa: Wydawnictwo Geologiczne.

Nagy, A., Vass, D., Petrik, F., & Pereszlényi, M. (1996). Tectogenesis of the Orava Depression in the light of latest biostratigraphic investigations and organic matter alteration study. *Slovak Geological Magazine, 1*, 49-58.

Niedzielski, H. (1971). Tektoniczne pochodzenie wschodniej części Kotliny Nowotarskiej. *Rocznik Polskiego Towarzystwa Geologicznego, 41*, 397-408.

Novak, A., Popit, T., & Šmuc, A. (2018). Sedimentological and geomorphological characteristics of Quaternary deposits in the Planica-Tamar Valley in the Julian Alps (NW Slovenia). *Journal of Maps, 14(2)*, 382-391. https://doi.org/10.1080/17445647.2018.1480975

Nyka, J. (2006). *Pieniny: Przewodnik*. Latchorzew: Trawers.

Pomianowski, P. (1995). Budowa depresji orawskiej w świetle analizy wybranych materiałów geofizycznych. *Annales Societatis Geologorum Poloniae. 64(1-4)*, 67-80.

Pomianowski, P. (2003). Tektonika Kotliny Orawsko-Nowotarskiej – wyniki kompleksowej analizy danych grawimetrycznych i geoelektrycznych. *Przegląd Geologiczny, 51(6)*, 498-506.

Poprawa, D., & Nemčok, J. (1988). *Geological Atlas of the Western Outer Carpathians and Their Foreland. Scale 1:500,000.* Warszawa: Państwowy Instytut Geologiczny.

Potfaj, M. (2003). Geology of the Slovakian part of the Orava – an overview. In J. Golonka, & M. Lewandowski (Eds) *Geology, geophysics, geothermics and deep structure of the West Carpathians and their basement* (pp. 51-56). Publications of the Institute of Geophysics, Polish Academy of Sciences, Monographic Volume, 28(363).

Romer, E. (1929). *Tatrzańska epoka lodowa*. Lwów: Książnica-Atlas.

Różycka, M. (2015). Wskaźniki morfometryczne w geomorfologii tektonicznej. *Landform Analysis, 30*, pp. 3-20.

Sládek, J, Vitovič, L, Holec, J., & Hók, J. (2022). Results of the Morphotectonics and Fluvial Activity of Intramountain Basins: The Turčianska Kotlina and Žiarska Kotlina Basins. In M. Lehotský, & M. Boltižiar (Eds) *Landscapes and Landforms of Slovakia* (pp. 207-233). World Geomorphological Landscapes. Cham: Springer. https://doi.org/10.1007/978-3-030-89293-7_11

Starkel, L. (1972). Karpaty Zewnętrzne. In M. Klimaszewski (Ed.) *Geomorfologia Polski. T. 1: Polska Południowa – góry i wyżyny* (pp. 52-115). Warszawa: Państwowe Wydawnictwo Naukowe.

Staszic, S. (1815). *O ziemiorództwie Karpatów i innych gór i równin Polski*, Warszawa: Drukarnia Rządowa.

Szafer, W. (1959). *Szata roślinna Polski*. T. II, Warszawa.

Valde-Nowak, P., Nadachowski, A., & Wolsan, M. (1987). Upper Palaeolithic boomerang made of a mammoth tusk in south Poland. *Nature, 329*(6138), 436-438. https://doi.org/10.1038/329436a0

Vanko, J. (1988). Mapa recentných vertikálnych pohybov Západných Karpát na Slovensku pre epochu 1952-1977. *Geodetický a kartografický obzor, 34*(76), 216-222.

Vitovič, L., Minár, J., Bella, P., & Littva, J. (2022). Polygenetic Relief in the Foreland of Glacially Sculptured Mountains – Podtatranská Kotlina Basin. In M. Lehotský, M. Boltižiar (Eds) *Landscapes and Landforms of Slovakia* (pp. 163-188). World Geomorphological Landscapes. Cham: Springer. https://doi.org/10.1007/978-3-030-89293-7_9

Watycha, L. (1973). Utwory czwartorzędowe w otworze wiertniczym Wróblówka na Podhalu. *Geological Qurterly, 17*(2), 335-347.

Watycha, L. (1976). Neogen niecki Orawsko-Nowotarskiej. *Geological Qurterly, 20*(3), 575-587.

Watycha, L. (1977a). *Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1: 50,000*. Arkusz Czarny Dunajec. Warszawa: Wydawnictwa Geologiczne.

Watycha, L. (1977b). *Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1: 50,000*. Arkusz Jabłonka. Warszawa: Wydawnictwa Geologiczne.

Watycha, L., & Mojski, J. E. (1984). Ogólna charakterystyka geologiczna i podstawy stratygrafii. Tatry i Kotlina Nowotarska. In J. E. Mojski (Ed.) *Budowa geologiczna Polski, T. I, Stratygrafia, cz. 3b, Kenozoik – czwartorzęd* (pp. 49-51). Warszawa: Wydawnictwa Geologiczne.

Zarychta, R., Łajczak, A., Wałek, G.,& Zwoliński, Z. (2025). Geomorfometria. In A. Łajczak, R. Zarychta (Eds) *Kotlina Orawsko-Nowotarska. przyroda nieożywiona i zmiany antropogeniczne*. Wydawnictwo Uniwersytetu Komisji Edukacji Narodowej w Krakowie (in prepartion).

Zawiejska, J., & Krzemień, K. (2004). Man-induced changes in the structure and dynamics of the Upper Dunajec River channel. *Geografický časopis, 56*(2), 111-124.

Zawiejska, J., Wyżga, B., Kukulak, J., & Chmielowska-Michalak, D. (2024). Hills, Gravelly Floodplains and Peat Bogs of the Podhale – A Unique Landscape Mosaic Between the Tatra, the Beskidy and the Pieniny Mountains. In P. Migoń, & K. Jancewicz (Eds) *Landscapes and Landforms of Poland* (pp. 301-313). World Geomorphological Landscapes. Cham: Springer. https://doi.org/10.1007/978-3-031-45762-3_16

Zuchiewicz, W. (2010). *Neotektonika Karpat polskich i zapadliska przedkarpackiego*. Kraków: Wydawnictwa AGH.

Zuchiewicz, W., Tokarski, A. K., Jarosiński, M., & Márton, E. (2002). Late Miocene to present day structural development of the Polish segment of the Outer Carpathians. *EGU Stephen Mueller Special Publication Series, 3*, 185-202.

Zuchiewicz, W., & Kania, M. (2025). Czwartorzęd i neotektonika. In A. Łajczak, & R. Zarychta (Eds) *Kotlina Orawsko-Nowotarska. Przyroda nieożywiona i zmiany antropogeniczne*. Wydawnictwo Uniwersytetu Komisji Edukacji Narodowej w Krakowie (in preparation).

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