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Quaternary exhumation of the Carpathians: a record from the Orava-Nowy Targ Intramontane Basin, Western Carpathians (Poland and Slovakia)

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Abstract: The Neogene-Quaternary infill of the Orava-Nowy Targ Intramontane Basin comprises two tiers showing contrasting lithologies. The Neogene tier is largely composed of claystones and siltstones, whereas the Quaternary tier is dominated by gravels. The two sequences are separated by an erosional surface underlain by a regolith. Deposition of the Neogene sequence took place during subsidence of the basin. No prominent relief existed in the area of the present-day mountains actually surrounding the basin at that time. The regolith started to form at the onset of basin inversion. Still, no prominent relief existed in the present-day mountains. The onset of deposition of Quaternary gravels in the basin corresponds to acceleration of uplift of the surrounding mountains, which has been continuing until now. The Pieniny Klippen Belt has been subject to erosion, at least locally, from the deposition of the basal part of the Neogene sequence filling the Orava-Nowy Targ Basin until present times. In contrast, the Paleogene cover of the Tatra Mts was removed only during the Quaternary.

Key words: Neogene, Quaternary, Western Carpathians, Orava-Nowy Targ Basin, exhumation, gravels.

Introduction

This paper discusses the results of the first systematic studies of the gravels comprised within Neogene and Quaternary fill of the Orava-Nowy Targ Intramontane Basin (ONT). The ONT is an important structure of the Western Carpathians. First, the ONT is the only basin, except the Vienna Basin, which straddles across the junction of the Inner and Outer Carpathians (Fig. 1A). Therefore, the Neogene through Quaternary infill of the ONT records the behaviour of major tectonic units of the Western Carpathians during regional collapse, which represents the last stage of the structural development of the Carpathians (Zuchiewicz et al. 2002 and references therein; Zattin et al. 2011 and references therein). Second, the ONT is located at the NE termination of the Mur-Žilina fault zone of prominent historical seismic activity (Lenhardt et al. 2007). The NE segment of the zone corresponds to the Vienna Basin Fault System, which had been locus of sinistral strike-slip from 17 Ma until 9–8 Ma, and again since the middle Pleistocene times (Fodor 1995; Decker et al. 2005). The activity of this fault zone has been essential for the structural development of the Outer Western Carpathians and Carpathian Foredeep (Márton et al. 2011). The Neogene to recent tectonic activity within the ONT is attested by: (1) occurrence of fractured clasts (Tokarski & Zuchiewicz 1998; Kukulak 1999) within the Neogene strata and small-scale normal faults cutting the latter (Pešková et al. 2009), (2) moderate rotations around the vertical axis of Neogene strata (Baumgart-Kotarba et al. 2004), and (3) moderate historical seismic activity (Guterch 2006, 2009). Unfortunately, the geology of the ONT is poorly known to international geological society. This is because the relevant information on the basin has been published largely in Polish and Slovak, usually in low-circulation journals.

Geological setting

The Orava-Nowy Targ Intramontane Basin straddles across major tectonic units of the Western Carpathians (from the south to the north): the Inner Carpathians, the Pieniny Klippen Belt and the Outer Carpathians (Fig. 1). The Inner Carpathians comprise a number of north-verging nappes composed of metamorphic and plutonic Paleozoic rocks and largely unmetamorphosed Paleozoic to Cretaceous strata. The nappes were formed during the Late Jurassic through Late Cretaceous times (Froitzheim et al. 2008 and references therein). Subsequently, the Inner Carpathians were covered by the Upper Cretaceous, Paleogene and lowermost Neogene strata (mostly of flysch type), which are partially preserved in several intramontane basins. Within the study area, the Inner Carpathian nappes are

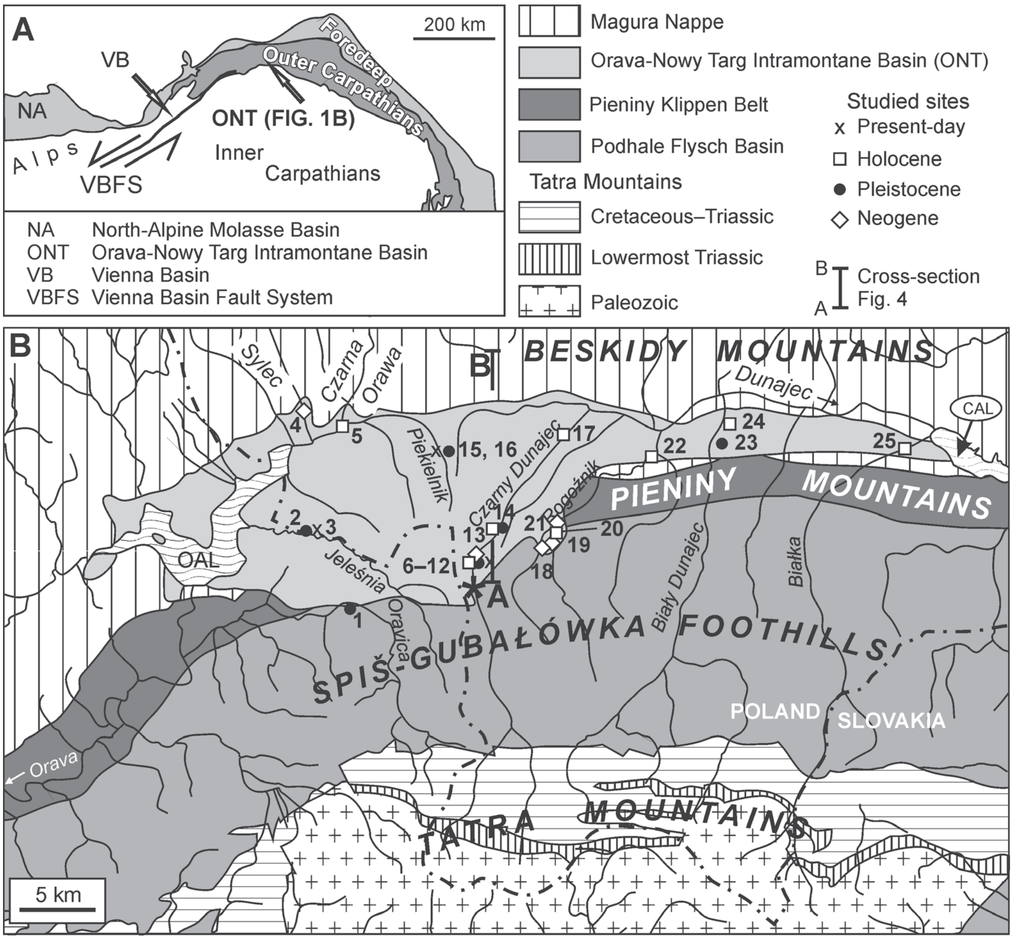

Fig. 1. Orava-Nowy Targ Intramontane Basin (ONT). **A** — position of the ONT within the Carpathian-Alpine orogenic system; Vienna Basin Fault System after Hinsch & Decker (2011); **B** — geological sketch-map of the ONT and adjacent tectonic units showing location of localities where clasts were studied; asterisk marks the location of a small-scale fault (Fig. 2B) at the southern boundary of the ONT. **OAL** — Orava artificial lake. **CAL** — Czorsztyn artificial lake. Geology after Lexa et al. (2000), simplified.

covered by Paleogene strata of the Podhale Flysch Basin. The Outer Carpathians are composed of several north-verging nappes consisting largely of Lower Cretaceous to Lower Miocene flysch. The innermost of the nappes is the Magura Nappe, which was largely formed during Eocene times (Świerczewska & Tokarski 1998). The Inner Carpathians are separated from the Outer Carpathians by the Pieniny Klippen Belt, which is a narrow zone of extreme shortening and wrenching (Birkenmajer 1986). Tectonic development of the belt is a subject of debate. According to Birkenmajer (1986), the belt was folded twice, during the Late Cretaceous and Tertiary times, whereas Oszczypko et al. (2010) state that the belt was being deformed continuously from the Late Cretaceous until the late Miocene. Finally, Plašienka & Mikuš (2010) demonstrated Late Cretaceous to Early Eocene thrusting, followed by post-Paleogene transpression.

The Orava-Nowy Targ Intramontane Basin

The architecture of the ONT is fairly well known owing to geological mapping and drillings (Watycha 1975, 1976b, 1977a–d; Pulec 1976; Gross et al. 1993) supplemented by the results of gravity and electric resistivity studies (Pomianowski 1995, 2003). The basin is filled by Neogene terrestrial and freshwater sequence, up to 1300 m thick (Watycha 1977a). The sequence is largely composed of claystones and siltstones with subordinate intercalations of sands, gravels (Fig. 2A) and conglomerates and occasional intercalations of brown coal. Only locally, in the Rogoźnik Stream catchment area (Fig. 1B), the sequence is dominated by gravels. The Neogene sequence is considered to be Miocene or Miocene to Pliocene in age (Birkenmajer 2009 and references therein). The oldest strata filling the ONT are considered to be Karpatian–Badenian (Watycha 1976a; Oszast & Stuchlik 1977; Worobiec 1994; Potfaj 2003) or Sarmatian (Nagy et al. 1996) in age. The sequence is usually mantled by a regolith topped by *ferruginous* crust (Fig. 2D). The latter is up to 30 cm thick. The Neogene sequence is discordantly covered (Watycha 1977a; Kukulak 1999; Birkenmajer 2009 and references therein) by Quaternary to recent fluvial strata, composed mostly of gravels (Watycha 1973, 1976b, 1977b,d) (Figs. 2C, 4). The latter are at least 117 m thick (Watycha 1973).

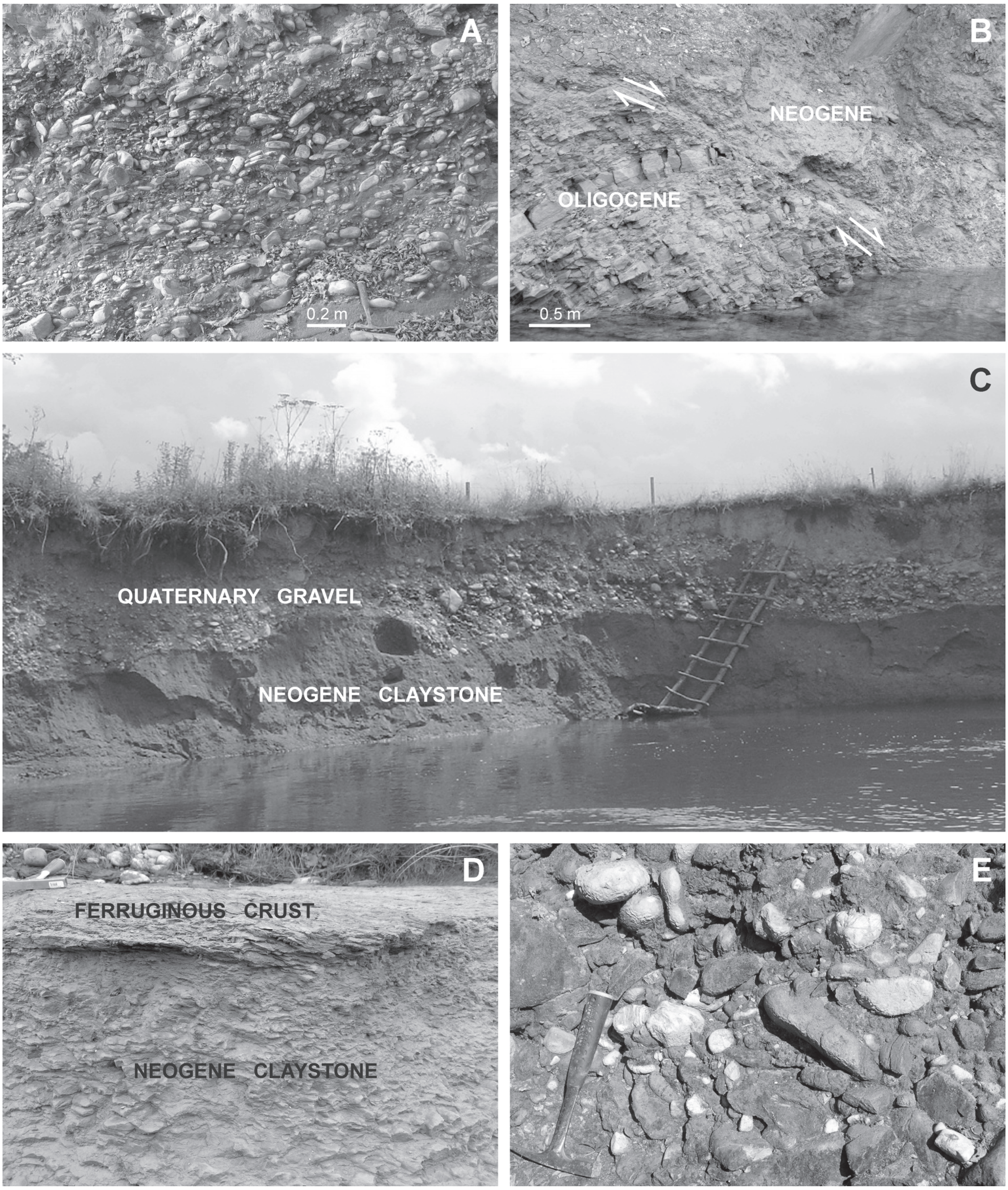

Fig. 2. Neogene strata within the ONT. **A** — Neogene gravel at site 21; **B** — fault contact (arrowed) between Oligocene flysch strata and Neogene claystone; **C** — contact between the Neogene claystone and Quaternary gravel, exposure is 4.5 m high; **D** — *ferruginous* crust at the top of Neogene claystone, hammer for scale; **E** — Neogene gravel at site 4, note numerous limestone clasts (white), hammer for scale; for location of A, B and E see Fig. 1.

The architecture of the ONT is, however, a subject of debate. According to the results of geological mapping and drillings, the sedimentary infill of the ONT represents an open syncline (Fig. 4) whereas the results of geophysical studies (Pomianowski 1995, 2003; cf. also Baumgart-Kotarba 1991–1992, 1996 and references therein; Nagy et al. 1996) imply that the basin is a composite graben. During the fieldwork discussed in this paper we observed a normal fault in the Czarny Dunajec River valley on the southern boundary of the ONT (Fig. 1B). The fault separates Neogene strata of the basin from Oligocene flysch of the Podhale Flysch Basin (Fig. 2B) (cf. Birkenmajer 1979; Kukulak 2011). The strata in the central part of the basin dip sub-horizontally, whereas those close to the basin borders dip moderately towards the basin centre. The flat-lying Neogene-Quaternary infill of the ONT discordantly overlies, from the south to the north, (1) open-folded Eocene to Oligocene (Gedl 2000) strata filling the intramontane Podhale Flysch Basin, (2) tightly folded Jurassic to Lower Miocene strata of the Pieniny Klippen Belt (Oszczypko et al. 2010), and (3) tightly folded Cretaceous to Lower Miocene flysch of the Magura Nappe (Oszczypko & Oszczypko-Clowes 2010 and references therein). The origin of the ONT is widely believed to be related to strike-slip faulting in the basement of the basin (see discussion in Golonka et al. 2005).

Material filling the ONT has been derived from areas which surround the basin. These source areas (Fig. 1) are built up of different lithologies: (1) pre-Tertiary rocks of the Inner Carpathians — mostly crystalline ones (Paleozoic), and some quartzites (lowermost Triassic) and limestones (Mesozoic), presently exposed in the Tatra Mts (Fig. 3A); (2) largely Oligocene flysch strata of the Podhale Flysch Basin, presently exposed in the Spiš-Gubałówka Foothills; (3) Jurassic to Miocene strata of the Pieniny Klippen Belt (largely limestones), presently exposed in the Pieniny Mts; and (4) Cretaceous to Miocene flysch strata of the Magura Nappe, presently exposed in the Beskidy Mts (Fig. 3B). Material derived from these source areas has been transported at first towards the axis of the ONT and, afterwards, out of the basin, both towards the east (Dunajec River) and the west (Orava River).

State of research

Up to now, the lithology of gravels within the ONT infill has been studied in detail at one site (site 1) only (Fig. 1B), where quantitative study of Pleistocene gravels was undertaken by Baumgart-Kotarba et al. (1996). In addition, data based on qualitative studies of the lithology of Neogene and/or Quaternary gravels were published by Plewa (1969), Niedzielski (1971), Watycha (1976b, 1977b,d), Baumgart-Kotarba (1991–1992 and references therein), Kukulak (1998), and Birkenmajer (2009 and references therein), whereas the results of semi-quantitative analysis of Quaternary gravels were presented by Watycha (1973).

Material and methods

We examined the lithology of Neogene and Quaternary gravels at 18 localities where, altogether, gravels at 25 sites were analysed (Fig. 1B, Appendix 1), comprising 5 Neogene sites, 7 Pleistocene sites, 9 Holocene sites, and 4 present-day gravel bar sites. At each site, a population of at least 100 clasts, more than 1 cm large, was studied. The only exception is site 52/10 where only 58 clasts were examined. Additionally, at some of the sites we studied the size of clasts as well.

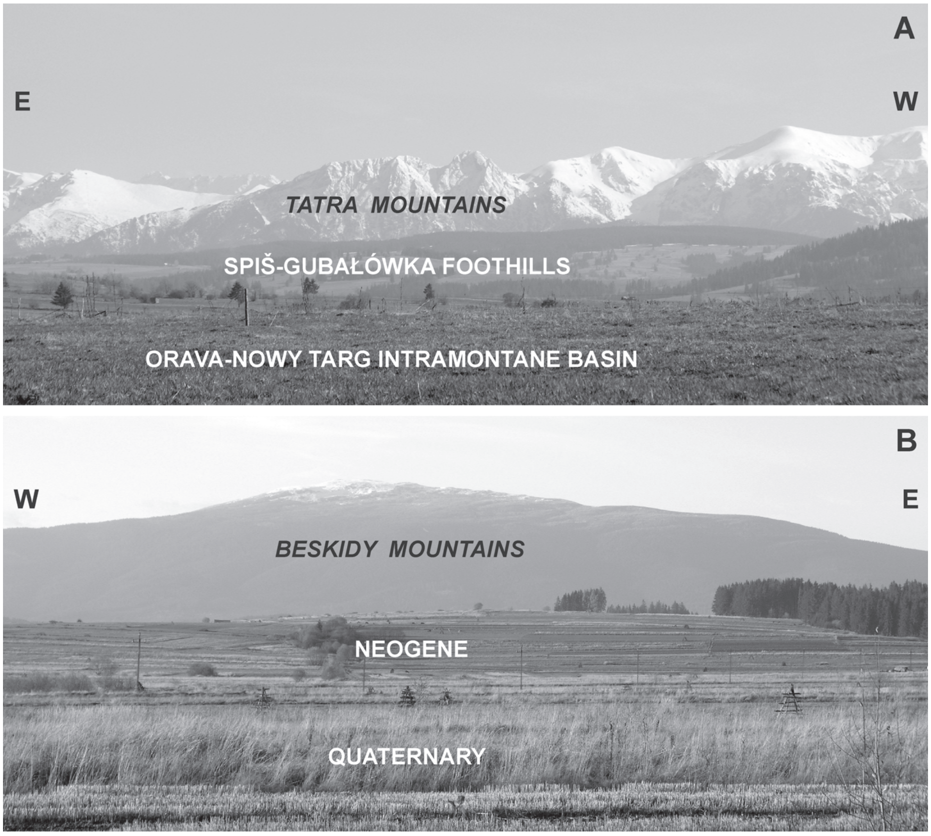

Fig. 3. Views out of the ONT. **A** — towards the south; **B** — towards the north.

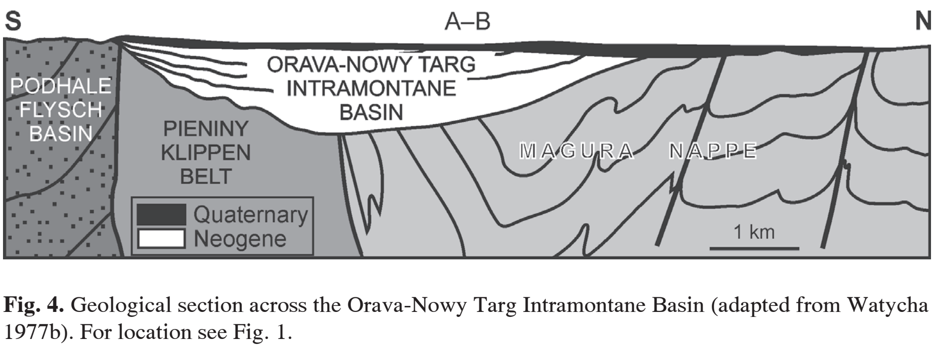

Fig. 4. Geological section across the Orava-Nowy Targ Intramontane Basin (adapted from Watycha 1977b). For location see Fig. 1.

Lithology of gravels

The following classes of clast lithology were distinguished for provenance studies: crystalline rocks, quartzite, flysch sandstone and mudstone, limestone, and others (Figs. 5, 6). The amount of clasts of the last class is negligible (0–5 %), with the exception of site 1 where the share of these clasts amounts to 22 %. This class will not be discussed in the following text.

The clasts in Neogene gravels (Fig. 5) are composed exclusively of flysch sandstone and mudstone, except site 4 where the share of limestone clasts amounts to 29 %, crystalline rocks to 2 %, and quartzite to 1 %. In contract, clasts in Quaternary and present-day gravels (Fig. 6) are largely composed of: (1) flysch sandstone and mudstone (up to 100 %), (2) crystalline rocks (up to 73 %), and (3) quartzites (up to 65 %), with a minor share of limestone (up to 31 %). Proportions between shares of clasts of particular classes differ both between particular river and stream valleys and within these valleys. Therefore, descriptions of clast lithology will be presented separately for the following river and stream valleys: (1) Oravica Stream, (2) Jeleśnia Stream and Czarny Dunajec River, (3) Piekielnik Stream, (4) Rogoźnik Stream, and (5) Biały Dunajec River and Białka River valleys.

In the Oravica Stream valley (Fig. 6A), gravels were studied at one site (site 1) only. These are Pleistocene gravels composed of: limestone (31 %), quartzite (24 %), flysch sandstone and mudstone (21 %), and crystalline rocks (2 %).

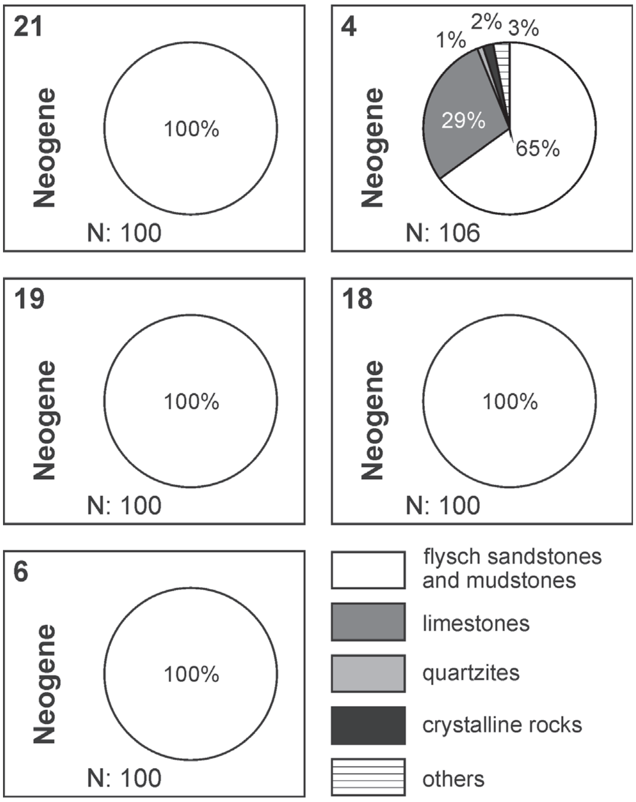

Fig. 5. Lithology of clasts in the Neogene gravels. For location of studied sites see Fig. 1.

In the valleys of Jeleśnia Stream and Czarny Dunajec River (Fig. 6B), gravels were examined at 11 sites. Two of these sites are located in the Jeleśnia Stream valley. These are present-day gravel bar (site 3) and Pleistocene (site 2) gravel. At both sites, quartzite clasts are most common (>60 %). Pleistocene gravel contains: (1) less flysch sandstone and mudstone clasts (3 %) than the present-day gravel (15 %), and (2) more clasts of crystalline rocks (32 %) than the present-day gravel (18 %). In the valley of Czarny Dunajec River, Pleistocene to present-day gravels were studied at 4 localities where, altogether, 9 sites were analysed (sites 7–14, 17). The share of crystalline rocks and quartzite clasts are similar at all sites, being 58–73 % and 11–23 %, respectively. In contrast, the share of flysch sandstone and mudstone clasts varies both with the age of gravel and along the river valley. At the uppermost sites (sites 7–12), the share of these clasts increases from 7–10 % in the Pleistocene gravel to 16–21 % in the Holocene and present-day bar gravels. Farther downstream (sites 13, 14), the share of the clasts increases from 15 % in Pleistocene gravel to 18 % in Holocene gravel. Furthermore, the share of flysch sandstone and mudstone clasts in the Holocene and present-day gravels decreases downstream from 16–21 % (9–14) to 9 % (17). In most of the studied sites, gravels are devoid of limestone clasts or these clasts appear in minor quantities. The only exception is site 17 where the share of limestone clasts amounts to 12 %. The size of clasts was studied at sites 7–12 only. The size of clasts increases there from 1 cm (Pleistocene) to 10 cm (Holocene), and up to 12 cm (present-day gravel bar).

In the Piekielnik Stream valley (Fig. 6C), clasts were studied at two localities where three sites were analysed (sites 5, 15, 16). The share of quartzite clasts increases there both up the stratigraphic sequence, from 24 % in Pleistocene gravel (15A) to 34 % in the present-day gravel bar (site 16) and, downstream, from 24 % (site 15) and 34 % (site 16) to 41 % (sites 11/10). The share of flysch sandstone and mudstone clasts is considerably larger at site 5 (28 %) than at sites 15 (7 %) and 16 (6 %).

In the Rogoźnik Stream valley (Fig. 6D), clasts were examined at two sites. Holocene gravel at site 20 is composed exclusively of flysch sandstone and mudstone clasts, whereas Holocene gravel at site 22 contains, besides flysch clasts, a minor amount of limestone (4 %) and quartzite (4 %) clasts as well.

In valleys of the Biały Dunajec and Białka rivers (Fig. 6E), clasts in Quaternary gravels were studied at three sites (23–25). At all sites gravels show a considerable share of flysch sandstone and mudstone clasts (28–57 %). Both sites located in the Dunajec River valley contain a minor share of limestone (6 %) as well.

Discussion and conclusions

The lithology of clasts within the Neogene and Quaternary gravels studied in particular valleys of streams and rivers flowing towards the axis of the ONT corresponds to the lithology of rocks exposed in respective drainage basins (cf. Baumgart-Kotarba et al. 1996). For example, the Quaternary

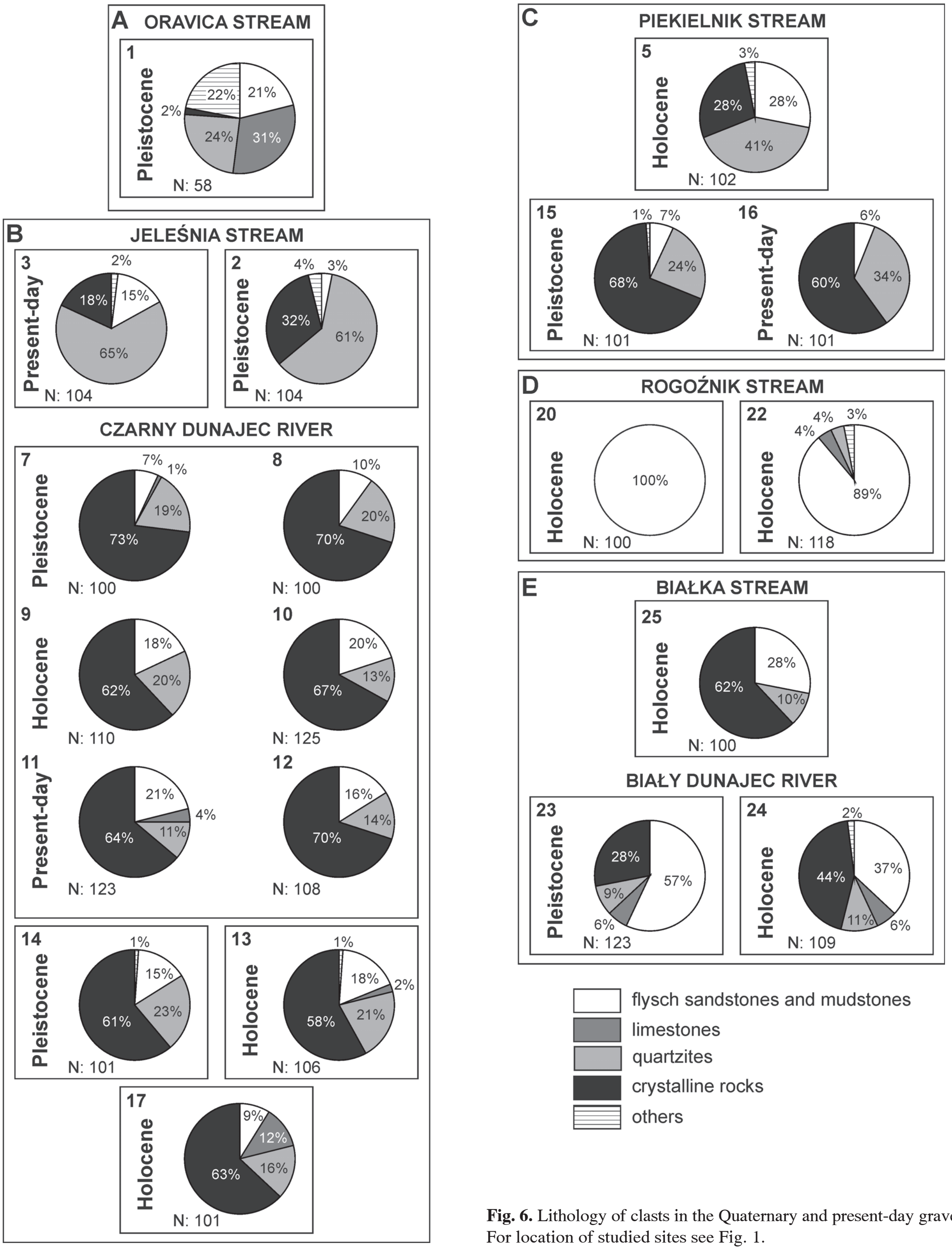

Fig. 6. Lithology of clasts in the Quaternary and present-day gravels. For location of studied sites see Fig. 1.

to present-day gravels studied in the Rogoźnik Stream valley (Fig. 6D) are composed either exclusively of flysch clasts derived from the Spiš-Gubałówka Foothills (site 20) or also contain clasts derived from the Pieniny Mts (site 22). In contrast, gravels of the same age studied in the Czarny Dunajec River valley (Fig. 6B) comprise, besides flysch clasts derived from the Spiš-Gubałówka Foothills and clasts derived from the Pieniny Mts, also crystalline rocks, and quartzite and limestone clasts derived from the Tatra Mts. It follows that the drainage basin of the Rogoźnik Stream during Quaternary times was restricted to the Spiš-Gubałówka Foothills and Pieniny Mts, whereas that of the Czarny Dunajec River also comprised part of the Tatra Mts during these times.

The Pleistocene to present-day gravels studied in the Piekielnik Stream valley (Fig. 6C) contain exceptionally large shares of quartzite clasts. Moreover, the number of these clasts increases up the section. Within the study area, quartzite clasts are most resistant to erosion. We believe, therefore, that a large share of the quartz clasts in the gravels studied in the Piekielnik Stream valley is due to redeposition, possibly multiple redeposition of the gravels (cf. Watycha 1977d).

The Quaternary to present-day gravels studied in valleys of streams and rivers flowing from the south towards the axis of ONT show considerable share of flysch clasts. In the Czarny Dunajec River valley, the number of these clasts decreases downstream from 16–21 % (sites 7–12, 13 and 14) to 9 % (site 17). We believe, therefore, that these flysch clasts are derived exclusively from the Spiš-Gubałówka Foothills. On the other hand, the Quaternary to present-day gravels studied at the outlet of the Piekielnik Stream to the Czarna Orava River (site 5) and close to the outlets of the Białka and Biały Dunajec rivers to the Dunajec River (sites 23–25) show very large shares of flysch clasts (28–57 %). We infer that the flysch clasts in gravels studied at the latter sites are derived not only from the Spiš-Gubałówka Foothills, but also from the Beskidy Mts (cf. Niedzielski 1971; Watycha 1973, 1976b).

At all the studied sites, Neogene gravels are devoid of clasts derived from the Tatra Mts (Fig. 5). It follows that during Neogene times the pre-Paleogene rocks of the Tatra Mts were still covered by strata of the Podhale Flysch Basin. This conclusion confirms the opinion of Birkenmajer (2009 and references therein).

Neogene gravels studied at site 4 contain a considerable share of limestone clasts derived from the Pieniny Mts (Fig. 2E), which measure up to 40 cm (cf. Watycha 1976b, 1977b,d). The site is located at the base of the Neogene sequence. It follows that during deposition of the basal part of the Neogene sequence, the Pieniny Mts were already subject to erosion, at least locally.

In contrast to the Neogene gravels, the Pleistocene to present-day gravels of most of the studied sites (Fig. 6A–C, E) display large shares of crystalline rocks and quartzite clasts derived from the Tatra Mts (cf. Niedzielski 1971; Watycha 1973, 1976b, 1977b,d; Baumgart-Kotarba 1991–1992 and references therein; Kukulak 1998; Birkenmajer 2009 and references therein). It follows that during the Pleistocene times the Paleogene cover of the Tatra Mts was already largely removed.

In the Czarny Dunajec River and Jeleśnia Stream valleys, within the Pleistocene to present-day sequence, both the share and size of flysch clasts increase up the sequence. It is likely that during Quaternary times the southern part of the Neogene fill of the ONT was eroded. On the other hand, at some of the studied sites (13, 17, 22, 23, 24), the Pleistocene to present-day gravels contain limestone clasts derived from the Pieniny Mts. We believe, therefore, that during Quaternary times the Pieniny Mts were subject to erosion.

Summing up, it appears that from the deposition of the basal part of the Neogene sequence until the present time, the Pieniny Mts have been subject to erosion. Moreover, the size of limestone clasts derived from these mountains at Quaternary sites is considerably smaller than that of the clasts in the Neogene gravels (site 4). It follows that the relief of the Pieniny Mts was more prominent during deposition of the basal part of the Neogene sequence than during Quaternary times.

On the other hand, during Neogene times, the pre-Paleogene rocks of the Tatra Mts were still overlain by their Paleogene cover. This cover was removed only during Quaternary times. At the same time, the Neogene strata in the southern part of the ONT became eroded. We suggest that removal of the Paleogene cover from the Tatra Mts and removal of Neogene strata from the southern part of the ONT resulted from uplift of the area.

The Neogene-Quaternary fill of the ONT comprises two tiers showing contrasting lithologies. The Neogene tier is largely composed of claystones and siltstones (except locally) whereas Quaternary tier is dominated by gravels. The top surface of the Neogene complex shows subdued topography (Fig. 4), whereas the overlying Quaternary complex comprises a flight of river terraces (Fig. 7).

The present-day structure of the Neogene-Quaternary fill of the ONT was formed during three successive stages.

(i) Deposition of the Neogene sequence took place during subsidence of the ONT. This subsidence was already inferred by Nagy et al. (1996) from the results of vitrinite reflectance study. The dominantly fine-grained lithology of the Neogene sequence implies that no prominent relief existed either in the area of the present-day Tatra Mts and Spiš-Gubałówka Foot-

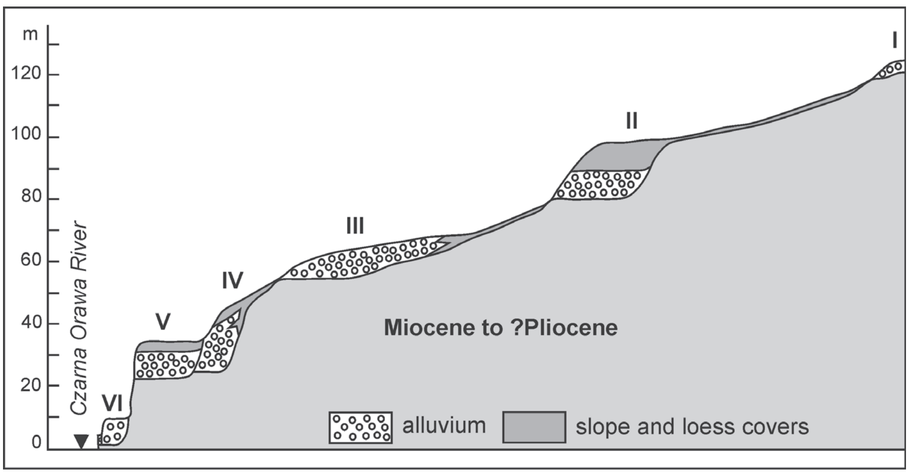

Fig. 7. Idealized stratigraphic scheme of fluvial terraces preserved in the SW part of the ONT, based on Baumgart-Kotarba (1991–92, 1996, 2001); stratigraphic control of these terraces is very poor, except the lowermost terrace (VI) which dates probably from MOIS 5d-2.

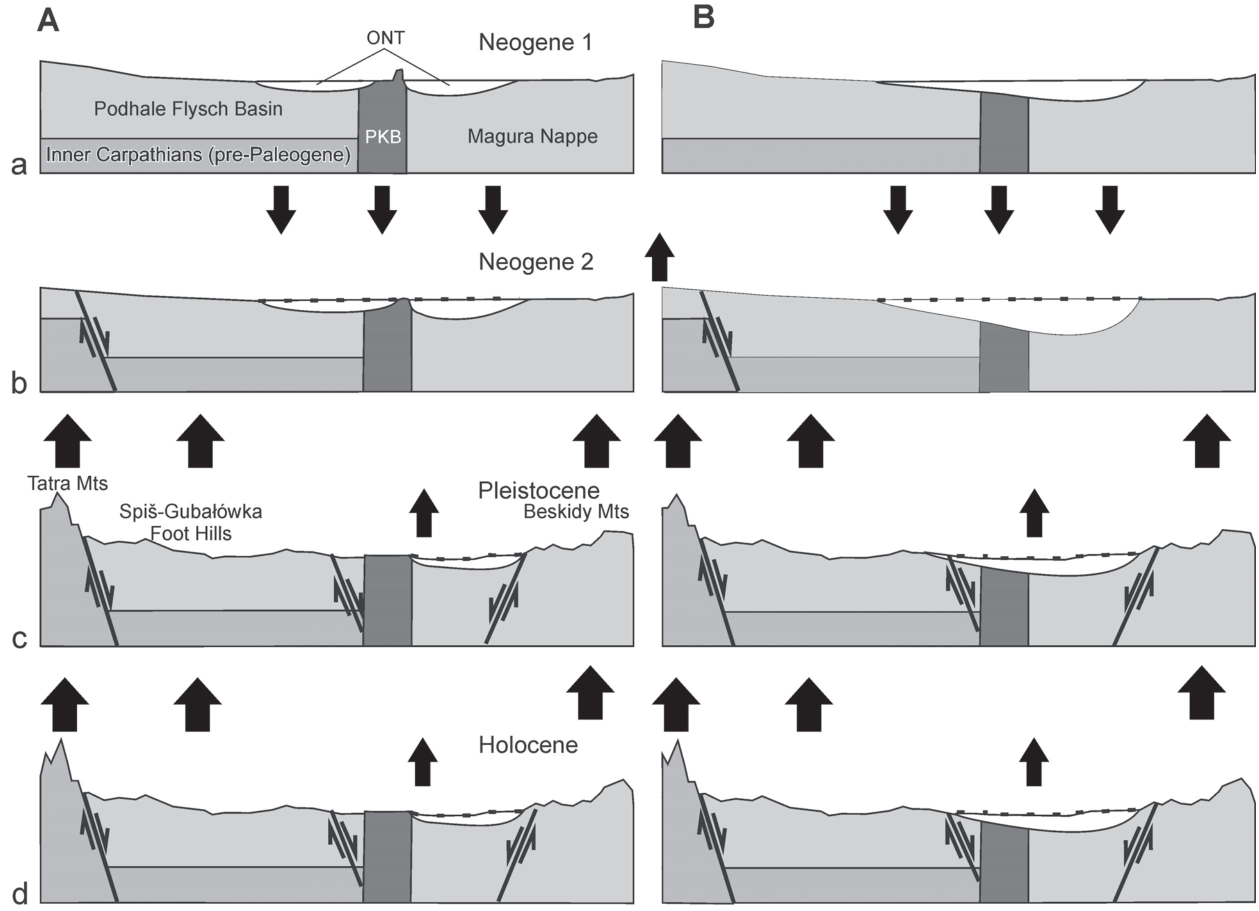

Fig. 8. Cartoon showing inferred vertical movements in the Orava-Nowy Targ Intramontane Basin (ONT) and adjoining areas in the eastern and western parts of the basin (**A**) and in the central part of the basin (**B**); **PKB** — Pieniny Klippen Belt; thick broken line at the top of the ONT denotes ferruginous crust; locations of faults separating: (1) Tatra Mts from Spiš-Gubałówka Foothills and (2) ONT from Beskidy Mts are arbitrary; timing of uplift of the Beskidy Mts is based on the results of smectite-illite analysis (Świerczewska 2005).

hills (except locally) or in the present-day Beskidy Mts (Fig. 8a). Local alluvial fans (Kukulak 1998 and references therein) indicate only locally dissected topography.

(ii) The beginning of formation of the regolith at the top of the Neogene sequence is related to the onset of inversion of the ONT (cf. Nagy et al. 1996). Still, no prominent relief existed in the present-day Tatra Mts, Spiš-Gubałówka Foothills, and Beskidy Mts (Fig. 8b).

(iii) The onset of deposition of Quaternary gravels in the ONT corresponds to uplift of the Tatra Mts, Spiš-Gubałówka Foothills and Beskidy Mts (Fig. 8c). Coarsening of clasts derived from the Tatra Mts and Spiš-Gubałówka Foothills up the Quaternary sequence suggests continuation of the uplift after Pleistocene times, at least of the latter areas (Fig. 8d). The Quaternary uplift could have been differentiated due to normal faulting (Fig. 2B).

We conclude that at least the stages (ii) and (iii) took place during regional collapse of the Western Carpathians (Zuchiewicz et al. 2002 and references therein; Zattin et al. 2011 and references therein). Moreover, the proposed scenario of vertical movements in the ONT and surrounding areas fits very well into a concept of worldwide acceleration of uplift since the Middle Pleistocene times, documented by Bridgland & Westaway (2008) and is in accord with prominent Quaternary normal faulting in the Inner Western Carpathians (Vojtko et al. 2011a,b). The amount of Neogene-Quaternary uplift, calculated for the discussed part of the Spiš-Gubałówka Foothills and Tatra Mts based on the results of illite-smectite studies (Środoń et al. 2006), is around 4 km. It is likely that considerable part of this uplift took place during Quaternary times.

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Appendix 1

Location of studied sites.

Site	Age	Latitude N	Longitude E
1 Oravica Stream 52.10	Pleistocene	49°21.554′	19°41.978′
2 Jeleśnia Stream 10.10	Pleistocene	49°24.161′	19°41.455′
3 Jeleśnia Stream 9A.10	Present-day	49°23.988′	19°41.616′
4 Sylec Stream 4.95	Neogene	49°29.388′	19°39.398′
5 Piekielnik Stream 11.10	Holocene	49°28.079′	19°41.410′
6 Czarny Dunajec River 4.06A	Neogene	49°23.193′	19°48.494′
7 Czarny Dunajec River 4.06 B	Pleistocene	49°23.193′	19°48.494′
8 Czarny Dunajec River 4.06C	Pleistocene	49°23.185′	19°48.494′
9 Czarny Dunajec River 4.06D	Holocene	49°23.190′	19°48.504′
10 Czarny Dunajec River 4.06E	Holocene	49°23.195′	19°48.505′
11 Czarny Dunajec River 4.06F	Present-day	49°23.193′	19°48.507′
12 Czarny Dunajec River 4.06G	Present-day	49°23.200′	19°48.502′
13 Czarny Dunajec River 9.10	Holocene	49°24.310′	19°49.889′
14 Czarny Dunajec River 8.10	Pleistocene	49°24.340′	19°49.992′
15 Piekielnik Stream 12.10A	Pleistocene	49°28.082′	19°41.418′
16 Piekielnik Stream 12.10B	Present-day	49°27.752′	19°46.410′
17 Czarny Dunajec River 7.10	Neogene	49°27.858′	19°52.180′
18 Rogoźnik Stream 5.05	Neogene	49°24.136′	19°52.180′
19 Rogoźnik Stream 5.95	Neogene	49°23.960′	19°53.117′
20 Rogoźnik Stream 53.10	Holocene	49°24.754′	19°53.401′
21 Rogoźnik Stream 2.95	Neogene	49°24.786′	19°53.233′
22 Rogoźnik Stream 54.10	Holocene	49°26.463′	19°56.412′
23 Biały Dunajec River 57.10	Pleistocene	49°27.928′	20°02.245′
24 Biały Dunajec River 58.10	Holocene	49°27.979′	20°02.256′
25 Białka River 55.10	Holocene	49°26.203′	20°09.024′