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RELICS OF THE OLDEST GLACIOFLUVIAL SEDIMENTS OF THE CZARNY DUNAJEC RIVER IN PODHALE (WESTERN CARPATHIANS)

Abstract: Described are relics of glaciofluvial deposits related to the Mindel glaciation in the Tatra Mountains, preserved along the course of the Czarny Dunajec River in Podhale (Western Carpathians). Distribution, spatial relations, hypsometry and petrography are described for eleven selected sites in Pogórze Gubałowskie and Kotlina Orawska. The mechanisms and the degree of their removal are discussed in the context of their position relative to the pattern of drainage. Their predominantly quartzitic composition is attributed to selective weathering. Local disturbances of their hypsometric position are related to neotectonic movements.

Keywords: glaciofluvial deposits, Pleistocene, Czarny Dunajec valley, Podhale, Western Carpathians

INTRODUCTION

Repeated glaciation episodes in the Tatra Mountains during the Pleistocene caused deposition of glaciofluvial deposits at the northern foreland of the range. Rock debris from the moraines of the valley glaciers in the western part of the range were transported by the Czarny Dunajec River and laid down as local accumulations in Pogórze Gubałowskie (Gubałówka Foothills) and as extensive outwash fans within Kotlina Orawska (Orava Basin). At the foothills and at the margin of Kotlina Orawska the oldest sediments containing material from the Tatra lie at the highest elevations above the valley bottom as the highest of the several glaciofluvial covers. Starting with the place where the Czarny Dunajec leaves the foothills, the surface of the oldest fan descends to the north and merges with the younger fans in the west or plunges beneath them in the east (Watycha 1975).

Multifaceted studies on the deposits related to the glaciations in the Tatra Mountains have been conducted for more than a century, but debate still continues on the number and extent of the glaciations within the range and even beyond it. Three (Halicki 1930; Gotkiewicz, Szaflarski 1934; Gołąb 1959; Klimaszewski 1967, 1988; Baumgart-Kotarba 1983) or four (Romer 1929; Watycha 1976; Baumgart-Kotarba 1991–1992) glacial episodes in the valleys of the Tatra have been postulated in studies conducted up to the 1980. of the 20th century, based on the number of the successions of glaciofluvial deposits recognised in the foreland of the range. Application of new dating methods to Pleistocene sediments resulted in distinction of as much as eight (Lindner et al. 1993) glacial phases in the Tatra Mountains. The methods of numeric dating using cosmogenic isotopes, combined with numerical reconstructions of the glacial geometry and paleoclimate (Gądek 1998; Dzierżek et al. 1999; Zasadni 2009; Kłapyta, Zasadni 2018), have markedly advanced the studies on the history of the glaciations. Nevertheless, the question of the extent of the oldest glacial deposits beyond the limits of the Tatra Mountains, especially in the Białka Valley (Lindner et al. 2008; Pliszczyńska 2012; Zasadni et al. 2021, 2022) and the Biały Dunajec valley (Małkowski 1924, 1928; Romer 1929; Wójcik 2022) is still the subject of debate.

Following the view of most researchers that there were three or four glaciations in the Tatra: Günz, Mindel, Riss, Würm, we have accepted herein that the oldest glaciofluvial sheets and fans correspond to the Günz and Mindel glaciations. As the Günz deposits are scarcely preserved and are similar in the type of sediments and locations to those of the Mindel, both are often considered as one glaciofluvial horizon of the oldest glaciation – Mindel (Halicki 1930; Gołąb 1959; Klimaszewski 1967). This is why when the Mindelian deposits are referred to as the oldest glaciofluvial sheet, one must remember that some its fragments (eg. at Sucha Hora, Domański Wierch, Szaflary) have been assigned older age – Günz (Romer 1929; Birkenmajer 1958; Birkenmajer et al. 2008; Baumgart-Kotarba 1991-92; Lindner et al. 1993). Our attribution of the Mindelian age to the deposits described here follows the morphostratigraphical use of the earlier authors and is based on their highest position among the sedimentary covers in the foreland of the Tatras. We do not assume that this determines their oldest chronological position.

Mindelian deposits in the Tatra foothills are preserved as largely reduced in extent, thickness and petrographic composition. They are preserved on the flanks of the transit valleys of the Czarny Dunajec, Biały Dunajec and Białka as both massive patches and as fields of dispersed loose components. This is the result of prolonged denudation of these sediments after their deposition ca. 440-330 ka ago (Lindner et al. 1993), but other factor seem to have been involved, such as postdepositional displacements.

The aim of this paper is to present the actually discernible characteristics of the Mindelian deposits. Local variations in preservation, including the degree of disintegration by weathering and mass movements, reduction in thickness, selection of clast size and alteration in petrographical composition have been described. These mostly postdepositional characteristics are explained in terms of the position in relief and of the hydrological and tectonic processes affecting the deposits. This study is limited to the Mindelian deposits in the Czarny Dunajec valley within the limits of Pogórze Gubałowskie and Kotlina Orawska near the border with Slovakia. Glaciofluvial deposits of the same age in the other two transit valleys in Podhale, those of Biały Dunajec and Białka have already been the subject of recent studies (Baumgart-Kotarba 1983; Lindner et al. 1993).

METHODS

Information on the Mindelian deposits along the Czarny Dunajec is contained in numerous geological and geomorphological studies published during the last 100 years. Nearly all these studies used the characteristics of the deposits to restore the chronology of the glaciations in the Tatra Mountains. The data from these publications have been reviewed, summarized and checked with respect to the location, structure of sediments and the state of preservation. Our own field investigations were used to complement the previous data. Mindelian deposits at eleven sites have been selected for detailed presentation, in most cases the ones studied earlier. We have aimed at presenting actual accessibility of the glaciofluvial deposits and at comparing their actual state with that at timeof the original studies. We have added some new information and corrected some topographical names. Synthetic compilations of the elevation data for the studied sites and of their distribution along the valley illustrate disturbances in the longitudinal profile of the Mindelian horizon.

A particularly rich set of information on the Mindelian deposits along the Czarny Dunajec valley, useful for comparison with present state, is contained in the pioneering papers by E. Romer (1927, 1929) and B. Halicki (1930). Even though E. Romer ascribed to some deposits older age then B. Halicki did, locations and descriptions conform to each other. B. Halicki presented morphometric data on gravels at most locations, studied their petrographical composition and evaluated the degree of weathering for individual lithological varieties. Basing on these data he had proposed a so called quartzite index for the study of the glaciofluvial sediments. He amended the method later (Halicki 1948). Locations and characteristics of the sediments in the Mindelian deposits at the sites described by both authors have been confirmed by the works of M. Gotkiewicz and J. Szaflarski (1934) and J. Gołąb (1959). Gravel morphometry and detailed descriptions of individual sites have been also provided by K. Birkenmajer (1958) and K. Birkenmajer et al. (2008). Hypsometry and structure of the Mindelian horizon are dealt with in the papers by B. Halicki (1930) and M. Baumgart-Kotarba (1991-1992), aimed at the reconstruction of the geomorphological evolution of this part of Podhale. Maps of the distribution of the Mindelian deposits are present in the papers by L. Watycha (1975, 1976, 1977); a later revision has been provided by P. Nieścieruk 2019).

STUDY AREA

The Czarny Dunajec River drains the Western Tatra Mountains and after leaving the range to Podhale it first crosses flysch area of Pogórze Gubałowskie foothills, then enters the flat intramontane depression of Kotlina Orawska. There the river enters the area of the Pieniny Klippen Belt, where massive bodies of limestones are manifest as steep hills in the landscape. Near the town of Nowy Targ the Czarny Dunajec joins the Biały Dunajec thus giving birth to the Dunajec River. At the 8 km long foothills section, the Czarny Dunajec valley passes through two wind gaps: the upper one between Mietłówka (1109 m a.s.l.) and Magura Orawska (1233 m a.s.l.) and the lower one between Beskid (905 m a.s.l.) and Cyrhlica (898 m a.s.l.). The distinctly widened section between the two is occupied by the Witów village. Valley slopes in the gaps are steep – 15–25°, with active mass movements, while along the wide fragment of the valley, boarded by broad passes in the side ridges and by the gentle apron of the Ostrysz mountain (1025 m a.s.l.), gentle slopes favour deposition of slope deposits and alluvium. The Czarny Dunajec valley markedly widens below the lower gap passing into a flat, widely spread, terraced outwash fan in Kotlina Orawska. The course of the river turns at the fan apex from S–N to SW–NE, then from Długopole village to W-E. The altitude of the river channel decreases from 750 m a.s.l. in the gap to 600 m a.s.l. at Nowy Targ, 25 km downstream. Progressively older terraces of the Pleistocene fan diverge away from the present-day river channel. They form distinct terraces near the gap and then they coalesce into a plane gently sloping to the north.

AREAL DISTRIBUTION OF DEPOSITS CONSIDERED COEVAL WITH THE MINDEL GLACIATION

The cover of the oldest glaciofluvial deposits in the foothills section of the Czarny Dunajec valley is discontinuous. Its relics are present as patches on the slopes of the valley, alternatively on one or another flank, at progressively lower elevations above the valley bottom in the downstream direction. Their characteristics have been studied in detail at 11 sites (Fig. 1) and the results are presented in the next chapter.

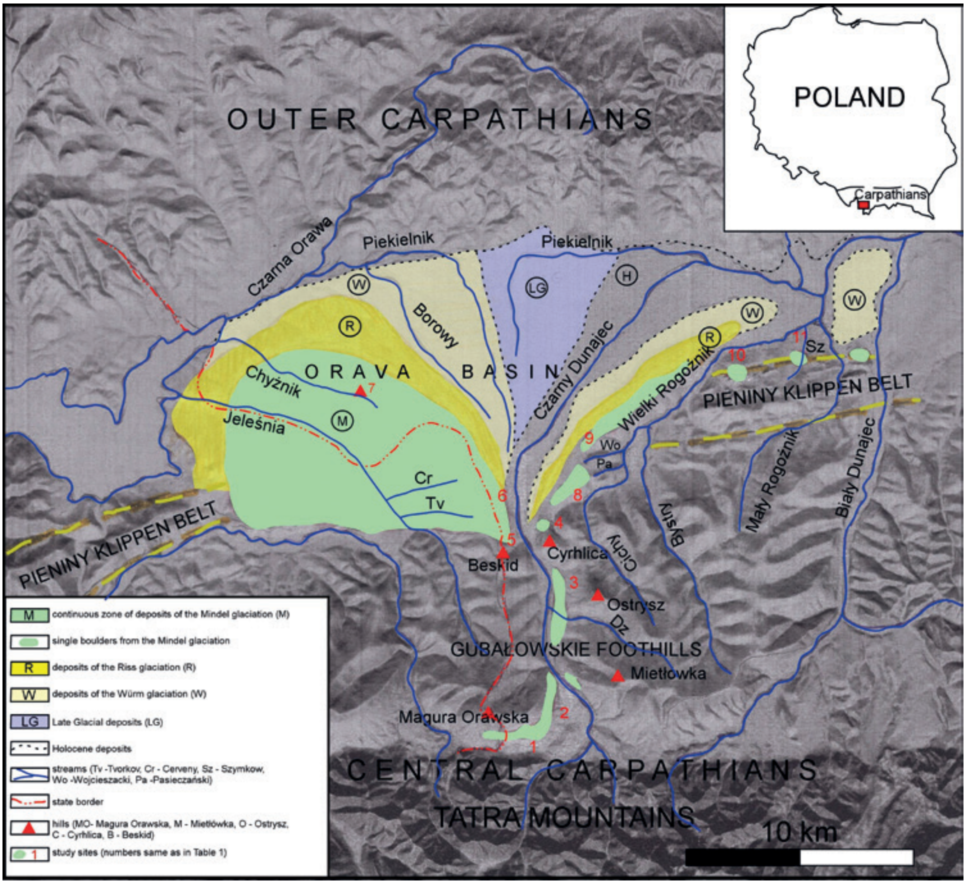

Fig. 1. Locations of the Mindelian glaciofluvial deposits of the Czarny Dunajec River at Podhale: 1 – continuous zone of deposits of the Mindel glaciation (M); 2 – single boulders from the Mindel glaciation; 3 – deposits of the Riss glaciation (R) ; 4 – deposits of the Würm glaciation (W); 5 – Late Glacial deposits (LG); 6 – Holocene deposits; 7 – streams (Tv –Tvorkov, Cr – Cerveny, Sz – Szymkow, Wo -Wojcieszacki, Pa -Pasieczański); 8 – state border; 9 – hills (MO- Magura Orawska, M – Mietłówka, O – Ostrysz, C – Cyrhlica, B – Beskid); 10 – study sites (numbers same as in Table 1)

Starting from the boundary of the Tatra Mountains, the Mindelian deposits extend on the left – western – side of the valley from the Molkówka Glade to the Magura Stream. The Molkówka Glade (site 1) lies on a pass in water divide, shaped as a shallow trough with a continuous cover of boulders and clay. The glaciofluvial sediments are draped with a thin mantle of slope clays and locally with a transitional peat bog. Farther down the valley toward the Magura Stream the Mindelian cover becomes discontinuous until it becomes only a stripe of dispersed numerous large boulders of the Tatra-derived rocks. The upper limit of their vertical extent becomes gradually lower to the north.

Farther to the north, the Mindelian deposits are present on the right side of the valley all the way to the exit of the Czarny Dunajec from Pogórze Gubałowskie to Kotlina Orawska at Chochołów. They occur in a wide stripe on both sides of the Dzianiski Stream's junction with the Czarny Dunajec. They lie on gently inclined foots of the hills: Mietłówka – up to altitude 900 m a.s.l. at Pindele hamlet, Ostrysz – up to 880 m a.s.l. at Bugaj hamlet and Cyrhlica – up to 845 m a.s.l. at Zagrody hamlet – site 3. They are elevated 35–60 m above the channel of the Czarny Dunajec (Halicki 1930).

Below the gap in Chochołów the Mindelian deposits occupy hilltop position (site 4) within the uppermost horizon of the extensive outwash fan of the Czarny Dunajec. At the fan's apex they form the alluvial part of the uppermost composite, erosional-depositional terrace 50–35 m above the river level (site 5). Distally, the height of the terrace diminishes so that the boundary in relief with the younger (Riss) fan is lost.

The Mindelian deposits within Kotlina Orawska extend unevenly on both sides of the river. Their presence is patchy and limited on the right side and very extensive on the left side. The Mindelian deposits stretch westward in a wide unbroken belt to NW, as far as the Czarna Orawa and Orawica valleys in Slovakia (Watycha 1977; Gross ed. 1994; Nieścieruk 2019). Their westward extension has been explained by the prevailing westward drainage of the Czarny Dunajec to the Orawa River in Pleistocene (Halicki 1930; Gotkiewicz, Szaflarski 1934; Baumgart-Kotarba 1991–1992). The surface of the fan is there wide, flat, dissected only by narrow valleys of the tributaries of Orawa and Jeleśnia. The Tatra-derived gravels and boulders are there covered with a layer of loam 1-2 m thick. It is exposed only at the margins of the erosional incisions of the Orawa's tributaries: Tvorkov, Cerveny, Jeleśnia, Chyżnik (site 7) and in ditches excavated to drain peat bogs (site 6).

The Mindelian deposits on the right, eastern, side of the Czarny Dunajec are present in a narrow discontinuous stripe from the village of Chochołów through the Pieniny Klippen Belt. These deposits now lie on the watershed between the Czarny Dunajec and its tributaries Cichy and Wielki Rogoźnik. Patches of residual gravels are there preserved on the elevations, such as

Pasieka (778 m a.s.l.) – site 8 and Domański Wierch (749 m a.s.l.) – site 9. Also the whole NE slope of the Pasieka elevation (actual name - Wierchowina) is strewn with large boulders, derived from these deposits, and draped with a thin layer of loam. Within the gaps in this cover, large boulders and pebbles of the Tatra-derived rocks occur only as dispersed fragments in depressions at altitudes 740–730 m a.s.l.. Noteworthy are there rich accumulations of large boulders in the headwater gullies of the streams Pasieczański and Wojcieszacki, close to the water divide. The blocks either have been eroded from the Mindelian deposits or belong to the Riss deposits. No clear morphological boundary between the Mindelian and the Rissian deposits is discernible on the Czarny Dunajec fan (Halicki 1930; Watycha 1977), hence the presence of deposits of the Riss glaciation in the depression between Pasieka and Domański Wierch is very likely.

The Mindelian deposits are present over the whole top surface of the Domański Wierch Hill. The belt of their extent is interrupted only by the deeply incised Wielki Rogoźnik valley, but similar deposits appear again on the northern slopes of hills belonging to the Pieniny Klippen Belt. A greater accumulation is present only at Szelągówka (site 10); farther to the east they become less and less abundant and are simply marked by the presence of dispersed loose pebbles (site 11). According to B. Halicki (1930) gravels of this type do not occur above the altitude of 720 m a.s.l. within the area of the Pieniny Klippen Belt. L. Watycha (1976) relates the deposits on the slopes of the hills belonging to the Pieniny Klippen Belt to the Riss glaciation. Farther east, in the breakthrough of the Mały Rogoźnik Stream through the Pieniny Klippen Belt, they continue as the Mindelian alluvial fan of the Biały Dunajec at Szaflary.

MATERIAL

Detailed data on the Mindelian deposits are presented for eleven sites shown in Figure 1. The data come from the descriptions 60-90 years old (Halicki 1930; Gotkiewicz, Szaflarski 1934; Gołąb 1959) because at many sites the Mindelian deposits are no more available for examination in outcrops because of the effects of human activity and plant growth. Basic data on hypsometry, form of preservation and the sources of data are compiled in Table 1. Data on the vertical extent on slopes have been revised.

Lithology of the Mindelian sediments in the Czarny Dunajec valley and fan is variable. Usually they consist of poorly sorted, rounded or angular clasts embedded in weathering loam. The size range of the clasts is wide, including cobbles in the range of 20-40 cm (sites 4, 9 and 11), rarely boulders above 0.5 m

Table 1.
Basic characteristics of the studied sites

Site	Altitude (m a.s.l.)	Elevation above the river (m)	Form of deposit	Sources
1. Molkówka	970–955	85–70 (70/Ch)	in situ	1, 2, 5, 9
2. Magura	915–890	70–45	loose blocks on slope	1, 2, 5, 9
3. Zagrody	845–800	60–35	in situ/loose blocks	1, 2, 5, 6, 9
4. Cyrhlica	820–810	58–53	loose blocks on slope	2, 3, 9
5. Sucha Hora	815–805	48–38	in situ	1, 2, 5, 6, 9
6. Rudne	762–760	30–28	in situ	3, 6, 9
7. Chyżne	681–679	80–78/O	in situ	6, 7, 9
8. Pasieka	778–720	48–25	in situ	2, 5, 6, 9
9. Domański W.	745–740	40–35	in situ	1, 2, 5, 4, 6, 9
10. Szeligówka	710–690	90–65	in situ	1, 2, 6, 9
11. Maruszyna	680–650	75–50	loose blocks on slope	2, 6, 9

1 – E. Romer (1929), 2 – B. Halicki (1930), 3 – M. Gotkiewicz and J. Szaflarski (1934), 4 – K. Birkenmajer (1958), 5 – J. Gołąb (1959), 6 – L. Watycha (1975), 7- M. Baumgart-Kotarba (1991–1992), 8 – L. Lindner et al. (1993), 9 – authors' data; Ch –Chochołowski Stream, O – Czarna Orawa River.

Phot. 1. Quartzite boulder on the DomańskiWierch (site 9)

(sites 1, 2 and 5). Locally the sediments contain more sand with single boulders up to 1 m (sites 5 and 8) (Phot. 1). No segregation or stratification is present (Gołąb 1959). The proportion of gravel clasts varies between 5% and 35%. The coarser clasts are more common in the foothill section of the valley and at the apex of the Mindelian fan (sites 1, 2, 4, 5, 8 and 9) than in its distal part (site 7). According to E. Romer (1929), boulders 30–40 cm in size are present in the relatively well preserved deposits of the Mindelian deposits *in situ*, while exclusively metric-size boulders are present in strongly degraded deposits.

Weathering-resistant rocks from the Tatra Mountains, mainly quartzites (the term applied to the silica-cemented Werfenian and Liassic refractory quartz sandstones) and granites, predominate in the composition of the gravel-boulder sediments. Sporadically present are clasts of strongly weathered gneisses and shists. Most granite clasts are in the state of advanced weathering. The quartzites predominate over granites at all sites, regardless of the clast size. The marked predomination of quartzites over other rock types and the high content of the boulder size-class are the distinctive characteristics of the sediments in this series (Halicki 1930).

The unbroken patches of the Mindelian glaciofluvial deposits are 1.5 m (sites 8 and 9) to 3 m (site 5), locally even to more than ten metres (Halicki 1930 – site 1), thick. They are best preserved in local depressions and on tops of watershed ridges (sites 5, 8 and 9). The original thickness has been reduced by denudation at all sites; at some sites their only relics are quartzite or granite boulders dispersed on slopes (sites 2, 3, 4 and 11). The finer sediments have been washed out (Phot. 2).


Phot. 2. Quartzite boulders at Szeligówka (site 1)

Site 1. *Molkówka* – Accumulation of boulders and loam on the watershed ridge between Orawica and Chochołowski Potok: two patches of glaciofluvial sediments on the Molkówka and Cicha glades are composed of large boulders and pebbles of quartzite and weathered granite. It is overlain with a thin layer of slope loam, locally with a peat bog. Boulders up to 50–60 cm in diameter are present along the glade margins (Halicki 1930). Only erosional incisions by the streams on the Cicha glade provide now insight into the structure of the deposit.

Site 2. *Magura Orawska* – a series of large boulders dispersed on slope; also accumulations in the channels of small streams, exposures of yellow loams with boulders in holloways (entrenched forest roads) and along the stripes of forest felled in the sixties of the twentieth century. Most boulders (65–70%) are quartzite, less numerous are of granite at various stages of weathering. According to B. Halicki (1930) the boulders reach the altitude 915 m a.s.l., 89 m above the valley bottom. The extent and structure of the deposits are now recognisable.

Site 3. *Zagrody* – excavations for buildings, cellars and wells; two patches of sandy loams with rounded and angular boulders of Tatra-derived rocks, on both sides of the Dzianiski Stream. According to B. Halicki (1930) the southern patch attains altitudes of 905–845 m a.s.l. (70–80 m above the river channel) and the northern one – 880–845 m a.s.l. (70 m above the river). The higher the elevation of the sediments, the more eroded they are, the boulders are greater, up to one metre, and more dominated by quartzite. Closer to the river channel half-weathered granites are present and the loam cover is thicker, up to 1.5 m. The saddle between the Ostrysz (1025 m a.s.l.) and Cyrhlica (896 m a.s.l.) has only single quartzite boulders preserved, without loam. The extent of the deposits and the structure of sediments are now hard to recognize and even this at some points only.

Site 4. *Cyrhlica* – exposures in the bottom and walls of a holloway: at altitude 810–820 m a.s.l. up to 60 cm below the surface, single well rounded quartzite boulders, above 20 cm in size are present in regolith composed of sand and grus. This a relic of the apex of the Mindelian outwash preserved in a small area at the base of a mountain slope, well accessible now for inspection.

Site 5. *Sucha Hora (Slovakia*) – excavations for frontier-related buildings, incisions of the Tvorkov and Cerveny streams: at the apex of the Mindelian outwash fan, covered with sandy loam lies a 1–1.5 m thick layer of loam, overlying, in turn, blocky gravel with intercalation of fine gravel with loam. The loam layer includes isolated quartzite and granite boulders near to 1 m in size, slightly weathered (Phot. 3). In erosional cuts in the fan surface

Phot. 3. Quartzite boulder in construction excavation at Sucha Hora (site 5)

made by tributaries of Jeleśnia, the Tvorkov and Cerveny streams, the Mindelian sediments are more than 8 m thick. B. Halicki (1930) estimated the maximum thickness of the deposits at several tens of metres at least. The sediment in unsorted, composed of well-rounded pebbles of various size. Quartzites predominate, with a significant amount of granites – 40–50%. Dispersed are granite boulders 30–40 cm, exceptionally even 80 cm in size (the Cerveny stream). The sediments may be now investigated near their margin in an erosional incision of a stream on the Slovak side or in sporadic excavations on the hilltop surface.

Site 6. *Rudne* – exposure in the trench that drains a peat bog: under a 1–1.5 m thick layer of yellowish, or light grey loams, quartzite pebbles are present, 3–20 cm in size, exceptionally up to 35 cm. Most qartzites are coarse-grained. The pebbles have bleached rims (Phot. 4). The finer-grained pebbles are weathered to a greater depth beneath their surface. The pebbles lie within the zone of migration of the waters from beneath the peat-bog. The site is accessible for examination.

Phot. 4. Quartzite boulders in loam beneath Rudne peatbog (site 6)

Site 7. *Chyżne* – exposures in excavation for loam extraction: a continuous, one metre thick layer of gravel is covered with light-brown clayey loam. The pebbles are 5–10 cm in size, mainly of granite, strongly weathered. Their surfaces are dull, some break easily. The Mindelian sediments are there largely eroded, even on wide top surface of the outwash fan. The site is accessible for examination.

Site 8. *Pasieka* – exposures in walls of excavations and in a holloway: It is now the richest accumulation of blocky gravel among the Mindelian deposits on the right margin of the Czarny Dunajec outwash fan. The gravel lies directly on the flysch base as a disordered layer 0.5 to 2 m thick, in local depressions even up to 3–4 m thick (Wojcieszacki and Pasieczański streams). The gravel is composed mainly of quartzite (up to 90%) with only a subordinate admixture of weathered granites (Kukulak 2010). Most pebbles are 7–15 cm in size, single boulders of violet or light-gray quartzites reach as much as one metre. The exposures are now accessible for examination (Phot. 5).

Phot. 5. Accumulation of quartzite and granite boulders in the channel of the Wojcieszacki stream

Site 9. *Domański Wierch* – top section of the deep borehole Domański Wierch IG1 (Urbaniak 1960) and a shallow borehole Domański Wierch 0–7 m (Wiewióra, Wyrwicki 1980), headwall of the Wąwóz Jaszczurów ravine (Birkenmajer 1958) and a wall of an aqueduct excavation (Kukulak 1998): glaciofluvial deposits overlie there discordantly Neogene deposits (Phot. 6). The glaciofluvial sediments are 1–3 m thick, with a series of yellowish-rusty clayey muds 0.3–0.4 m thick, overlain with grey sandy regolith loam, cut by frost wedges filled with sediment. These deposits are now hardly accessible for examination.

Phot. 6. Glaciofluvial deposits with quartzite boulders on top of flysch-derived gravel in the Domański Wierch Neogene alluvial fan (site 9)

Site 10. *Szeligówka* – accumulations of Tatra-derived rock debris around klippen hills at Szeligów: they lie as a patch in the middle of the height of the northern slope of the Maruszyna ridge at altitudes 680–700 m a.s.l. (70–90 m above the Wielki Rogoźnik channel). According to E. Romer (1927) quartzite debris is widely dispersed and at Szeligów it fills depressions in karstified surface of the klippen limestone. Boulders 20–35 cm in size are present in headwater gullies of intermittent streams and as clusters in wet depressions between the klippen. Composed of quartzite, well rounded, the boulders display visible evidence of weathering only along joints. An extant example is the accumulation of boulders on the western side of the highest klippen hill (721 m a.s.l.) in Szeligów (Photo 2).

Site 11. *Maruszyna* – Tatra-derived rock debris dispersed on slope: loose quartzite cobbles 15–25 cm in size are present between the Trawny and Mały Rogoźnik streams. They are mostly preserved in stream headcuts and channels and in wooded places. They are present in a wide belt at elevations of 670–630 m a.s.l. (60–30 m above the channel of the Wielki Rogoźnik), expanded as a result of redeposition by running water. The cobbles are well rounded, barely weathered. An example available now for examination are quartzite cobbles in the channel of the upper course of the Szymków stream.

DISCUSSION

The description of the Mindelian glaciofluvial deposits along the Czarny Dunajec valley shows that at most sites they are loams with coarse clastics. Though the poorly sorted loams in the massive outwash accumulations seem to have been mostly originated by weathering, a question remains how many of their characteristics have been their original depositional features? This question seems particularly valid for the loams that lie on the top surfaces of the hummocky hills in Kotlina Orawska (sites 8 and 9). Their origin may be complex as is the case with the silty loams that are blanketing the younger alluvial fans and terraces (Baumgart-Kotarba 1991–1992; Chmielowska, Woronko 2019).

Quartzite material predominates in the petrographical composition of the Mindelian boulder loams at all sites, the more so the farther a site is removed from the Tatra mountains. The amount of granite clasts diminishes in the same direction. This is explained by the long-known lithological selection according to the resistance to weathering (Halicki 1930, 1948). Quartzites as the most refractory type of rock gain in share relative to the other rock types, including granites. Quartzite clasts in the Mindelian deposits are often embedded in weathering loam with groat-like mass of granite component minerals, a residuum after disintegration of granite clasts. Other types of the Tatra-derived rocks weather still faster and only rarely can be found in the glaciofluvial deposits: gneisses, amphibolites, shists or limestones (Kukulak 2001).

The degree of weathering depends not only on time but also on the supply of water and air in connection with the depth of burial. A high supply of water and acidity of the environment accelerate the chemical alteration. At wet sites, especially beneath peat, granite clasts weather faster than the quartzite ones because their components are susceptible to hydrolysis and kaolinization (Kukulak 2010) (site 6). Also under thick mantles of solifluction loams granite clasts are weathered to a higher degree than without such burden (Halicki 1948; Baumgart-Kotarba 1983). It thus reasonable to suppose that a large part of loam in the Mindelian sediments originated by weathering (Phot. 7).

Local variations in the thickness of the Mindelian deposits may be explained in terms of variations in slope angle. On the steeper slopes of the Czarny Dunajec valley thickness of the deposits is reduced by solifluction (sites 2, 4 and 11). At sites on less inclined ground the loams are preserved better (sites 1, 3, 5 and 6). Exceptionally high is the degree of reduction in thickness on the northern slopes of the limestones hills within the Pieniny Klippen Belt.

Phot. 7. Weathering rim on a granite boulder from the Pasieczański stream

The nearly complete removal of the loams, gravels and boulders from the Mindelian deposits at sites 10 and 11 may be due to exceptionally effective action of slope processes and erosion. This increased effectiveness of the destructive processes could be the result of the location near the contact of two basement blocks separated by vertical tectonic faults active in Pleistocene – the uplifted block of the Pieniny Klippen Belt and the sinking block of Kotlina Orawska (Halicki 1930; Watycha 1973; Birkenmajer 1976, 1978; Baumgart-Kotarba 1991-92, 1996; Pomianowski 1995). The fault line runs through the Wielki Rogoźnik valley at the feet of the slopes covered with the Mindelian deposits (Watycha 1976; Baumgart-Kotarba 1991–1992). Active denudation on the surface of the uplifted Pieniny block was reinforced by the contemporaneous sinking of the erosional base in the adjacent Kotlina Orawska. The dense mosaic of rocks contrasting in resistance contributed to the denudation so intense that the northern slope is now strongly dissected and almost devoid of regolith. This is in contrast with the southern slope. Also the elevation of the relics of Mindelian deposits above the river level in the Pieniny Klippen Belt is the highest, up to 90 m, in the whole length of the Czarny Dunajec valley. Also the elevation of the Domański Wierch ridge has been attributed to tectonic uplift along young faults (Baumgart-Kotarba 1991–1992, 1996), (Fig. 2).

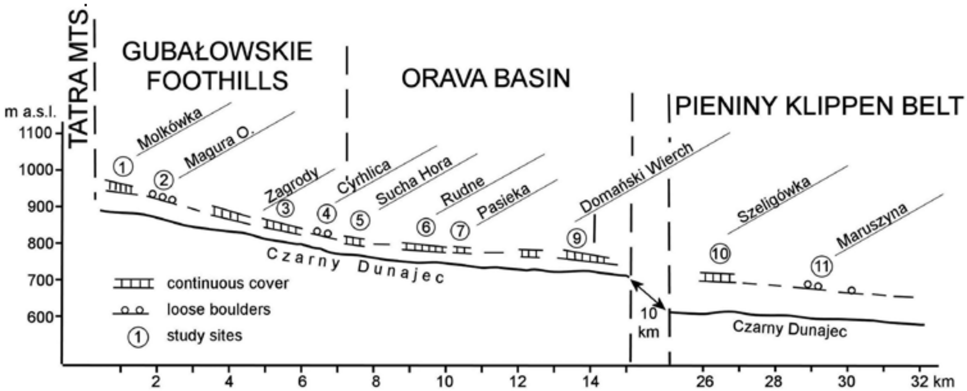

Fig. 2. Long section of the Mindel deposits in the Czarny Dunajec valley

Continuity of the sheet of Mindelian deposits along the eastern margin of Kotlina Orawska is broken by two gaps. One – “Ku Cerhli” – between the hummocks of Pasieki and Domański Wierch may be accepted as a low pass created in post-Mindel time when the ridge was dissected by headward erosion of the headwaters of the Wojcieszacki and Pasieczański streams. The abundant accumulation of well-preserved quartzite and granite debris suggests that the pass was within the reach of outwash deposition during the Riss glaciation. Difficult to explain is, however, which was the course of the Wielki Rogoźnik valley at the time of deposition of the Mindelian outwash, now lying transgressively in the valley. Possibly, the belt of the glaciofluvial deposits was continuous at this section during the Mindelian glaciation, but now it is dissected by the Wielki Rogoźnik valley to the depth of 70–50 m. It is difficult now to settle the dilemma if this only the result of the later activity of the river or of a rearrangement of the river network or were tectonic movements also involved? The separation of the roles of the climatic and geologic factors on river activity in an area of active tectonic movements is difficult and prone to controversy (Baumgart-Kotarba 1991–1992).

Elevations of the Mindelian deposits above the river channel decrease downstream at a rate lower than the present-day gradient of the river, which suggests that the upstream section of the valley was uplifted at a higher rate after their deposition, but it also may be solely due to the hydrological effect of the downcutting of the river in the wind gap between Magura Orawska and Kojsówka.

We have accepted herein that the oldest sheet of glaciofluvial deposits along the Czarny Dunajec valley corresponds to the Mindel glaciation, without separating them from the scarcely preserved deposits of the Günz glaciation. Nevertheless both sheets at the foreland of the Tatra Mountains are still being separated in recent publications (Baumgart-Kotarba 1991–1992; Lindner et al. 1993; Birkenmajer et al. 2008; Wójcik 2022). Sediments similar to those described by A. Wójcik (2022) from Szaflary have been exposed in excavations for construction at Sucha Hora (site 5) just at the Slovak-Polish border. Sandy loams in the digs up to 1.5 m deep included single quartzite and granite boulders up to 1 m in size, poorly rounded, scarcely weathered. Their dimensions, position in relief and altitude, state of preservation and occurrence in loams, all suggest analogy to the sediments from Szaflary and an attribution to the Günz glaciation.

The acceptance that the hilltop boulders at Szaflary and at Sucha Hora belong to a glaciofluvial cover of the same age is only hypothetical. Recent studies on moraine boulders around the Tatra Mountains (Hurkotne, Rusinowa Polana) demonstrate that even morphostratigraphy, boulder size and the index of their surface weathering, measured using a Schmidt hammer, do not unequivocally determine chronology of their deposition (Zasadni et al. 2021, 2022). Disputed are (Kłapyta, Zasadni 2018) even their ages obtained by the use of cosmogenic isotopes (Dzierżek 2009). It is being suggested that the postdepositional processes of boulder exhumation and denudation on their surfaces may corrupt age determination. Even in the Podhale Depression, where morphostratigraphy of the glaciofluvial covers in clearer, chronostratigraphy and ages of the deposits are locally uncertain too (Lindner et al. 1993; Olszak et al. 2016).

CONCLUSIONS

The glaciofluvial deposits composed of Tatra-derived rock debris and attributed to the time of the Mindel glaciation have been preserved along the whole course of the Czarny Dunajec River, more fully in Kotlina Orawska, fragmentarily over the section of Pogórze Gubałowskie. Within the foothills section they are present near the river channel, while in Kotlina Orawska their accumulations spread out from the apex of the outwash fan to its extremities. Their state of preservation is variable – from scarcely denudated sheets of bouldery gravels and loams at the sites of flat relief to patchy relics of isolated boulders and gravel on slopes. The rock variety most resistant to weathering proved to be quartzites, hence they predominate in the petrographical composition, though locally granite boulders are also present. Favourable for persistence of granite boulders could be shallow burial in relatively dry solifluction loams.

Explanation of the irregularities in the present day altitude distribution of the studied deposits within the limits of Kotlina Orawska and Pieniny Klippen

Belt needs taking into account the role of post-Mindelian vertical tectonic movements of basement blocks along the faults bordering the young depression of Kotlina Orawska. Pieniny Klippen Belt and the ridge of Domański Wierch are distinguished by the exceptionally high elevation of the Tatra-derived rock debris. The altitude pattern in distribution of the studied deposits does not confirm uplift of the western part of Kotlina Orawska at site 7 (cf. Baumgart-Kotarba 1991-1992), only subsidence of its eastern part.

It remains as an interesting goal for future investigations how evolved the Wielki Rogoźnik valley section situated upstream of its crossing through the belt of the Mindelian deposits. The Wielki Rogoźnik valley is there much deeper than the Czarny Dunajec valley on the other side of their water divide, and the headwater sections of its tributaries has shifted the watershed line. The presence of the Mindelian deposits of the Czarny Dunajec on the southern slopes of the Pieniny Klippen Belt has been not confirmed. Hypsometric data do not exclude this.

The more than hundred years old descriptions of the Mindelian deposits of the Czarny Dunajec River (Romer 1927, 1929; Halicki 1930, 1948; Gotkiewicz, Szaflarski 1934; Gołąb 1959) are for many localities more detailed than what is possible now from surface observations, and even applying hand drilling tools. The scale of the exposures diminished. Some of the data from the old papers for sites 3, 10 and 11 cannot even be verified. Many ancient exposures disappeared or are masked by vegetation.

REFFERENCES

Baumgart-Kotarba M., 1983. *Kształtowanie koryt i teras rzecznych w warunkach zróżnicowanych ruchów tektonicznych (na przykładzie wschodniego Podhala).* Prace Geograficzne IGiPZ PAN 145, 1–133.

Baumgart-Kotarba M., 1991-1992. *Rozwój geomorfologiczny Kotliny Orawskiej w warunkach ruchów neotektonicznych.* Studia Geomorphologica Carpatho-Balcanica 25–26, 3–28.

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

Birkenmajer K., 1958. *Przewodnik geologiczny po pienińskim pasie skałkowym, cz. I–IV*. Wydawnictwo Geologiczne, Warszawa.

Birkenmajer K., 1976. *Plejstoceńskie deformacje tektoniczne w Szaflarach na Podhalu*. Rocznik Polskiego Towarzystwa Geologicznego 46, 309–323.

Birkenmajer K., 1978. *Neogene to Early Pleistocene subsidence close to the Pieniny Klippen Belt, Polish Carpathians.* Studia Geomorphologica Carpatho-Balcanica 12, 17–28.

Birkenmajer K., Derkacz M., Lindner L., Stuchlik L., 2008. *Sesje terenowe. Stanowisko 1: Szaflary wapiennik – żwiry wodnolodowcowe zlodowacenia Mindel i starsze osady organiczne*. [in:] *Stratygrafia plejstocenu Polski. XV Konferencja: Plejstocen Tatr i Podhala (Zakopane, 1–5 IX 2008*. Państwowy Instytut Geologiczny, Warszawa, 149–154.

Chmielowska D., Woronko B., 2019. *A source of loess-like deposits and their attendant palaeoenvironment – Orava Basin, Western Carpathian Mountains, S Poland*. Aeolian Research 38, 60–76.

Dzierżek J., 2009. *Paleogeografia wybranych obszarów Polski w czasie ostatniego zlodowacenia.* Acta Geographica Lodziensia 95, 96–105.

Dzierżek J., Nitychoruk J., Zreda-Gostyńska G., Zreda M., 1999. *Metoda datowania kosmogenicznym izotopem 36Cl – nowe dane do chronologii glacjalnej Tatr Wysokich.* Przegląd Geologiczny 47, 11, 987–992.

Gądek B., 1998. *Würmskie zlodowacenie Tatr w świetle rekonstrukcji lodowców wybranych dolin na podstawie prawidłowości glacjologicznych*. Prace Naukowe Uniwersytetu Śląskiego w Katowicach 1741, 1–151.

Gołąb J., 1954. *Flisz Podhala na zachód od Białego Dunajca*. Archiwum Instytutu Geologicznego Oddział Karpacki w Krakowie.

Gotkiewicz M., Szaflarski J., 1934. *Dyluwialne i predyluwialne poziomy dolinne na Orawie*. Wiadomości Służby Geograficznej 5, 3-4, 187–227.

Gross P. (ed.), Filo I., Halouzka R., Haško J., Havrila M., Kováč P., Magaly J., Mello J., Nagy A., 1994. *Geologická mapa južnej Oravy.* MŽP SR – GÚD, Bratislava.

Halicki B., 1930. *Dyluwialne zlodowacenie północnych stoków Tatr*. Sprawozdania Państwowego Instytutu Geologicznego 5, 464–477.

Halicki B., 1948. *O właściwej roli kwarcytów w żwirowiskach przedpola Tatr*. Rocznik Polskiego Towarzystwa Geologicznego 17, 89–102.

Klimaszewski M., 1967. *Polskie Karpaty Zachodnie w okresie czwartorzędowym*. [in:] R. Galon, J. Dylik (eds.*), Czwartorzęd Polski*. PWN, Warszawa, 431–497.

Klimaszewski M., 1988. *Rzeźba Tatr Polskich*. PWN, Warszawa.

Kłapyta P., Zasadni J., 2018. R*esearch history on the Tatra Mountains glaciation.* Studia Geomorphologica Carpatho-Balcanica 51–52, 43–85.

Kukulak J., 1998. *Charakterystyka sedymentacyjna stropowych osadów stożka Domańskiego Wierchu (neogen/plejstocen) w Kotlinie Orawskiej*. [in:] K. Birkenmajer (ed.), *Budowa geologiczna pienińskiego pasa skałkowego i Tatr*. Studia Geologica Polonica 111, 83–111.

Kukulak J., 2001. *Weathering of gravels in the CzarnyDunajec alluvial cone in Podhale, Polish Carpathians.* Quaestiones Geographicae 21, 69–78.

Kukulak J., 2010. *Trwałość otoczaków skał krystalicznych w terasach i stożkach Czarnego Dunajca na Podhalu*. [in] W. Wilczyńska-Michalik (ed.) *Antropogeniczna transformacja środowiska przyrodniczego. Księga Jubileuszowa dedykowana Profesorowi Janowi Lachowi*. Attyka, Kraków: 117–127.

Lindner L., Nitychoruk J., Butrym J., 1993. *Liczba i wiek zlodowaceń tatrzańskich w świetle datowań termoluminescencyjnych osadów wodnolodowcowych w dorzeczu Białego Dunajca*. Przegląd Geologiczny 41,10–21.

Lindner L., Dzierżek J., Pliszczyńska K., 2008. *Sesje terenowe. Stanowisko 4: Ślady* środkowoplejstoceńskich *lodowców tatrzańskich w widłach Białki i Potoku Jaworowego (Podhale)* [in:] *Stratygrafia plejstocenu Polski*. *XV Konferencja: Plejstocen Tatr i Podhala. Zakopane, 1–5 IX 2008*. Państwowy Instytut Geologiczny, Warszawa, 162–164.

Małkowski S., 1924. *O morenie lodowca tatrzańskiego w okolicy Nowego Targu*. Kosmos 49, 1–8.

Małkowski S., 1928. *Odsłonięcia utworów dyluwialnych w kamieniołomie szaflarskim pod Nowym Targiem*. Zabytki Przyrody Nieożywionej 1, 62–64.

Nieścieruk P., 2019.*Objaśnienia do Szczegółowej Mapy Geologicznej Polski, arkusz Czarny Dunajec (1048)*. Państwowy Instytut Geologiczny- Państwowy Instytut Badawczy, Warszawa.

Olszak J., Kukulak J., Alexanderson H., 2016. *Revision of river terrace geochronology in the Orawa-Nowy Targ Depression, south Poland: insights from OSL dating*. Proceedings of the Geologists' Association 127, 595–605.

Pliszczyńska K., 2012. *Tarasy Białki w rejonie Jurgowa i ich związki z lodowcami tatrzańskimi*. Przegląd Geologiczny, 60, 2, 103–109.

Pomianowski P., 1995. *Budowa depresji orawskiej w świetle analizy wybranych materiałów geofizycznych.* Annales Societatis Geologorum Poloniae 64, 67–80.

Romer E., 1927. *Najstarszy okres lodowy w Tatrach.* II Zjazd Słowiańskich Geografów i Etnografów w Polsce w roku 1927, 342–344.

Romer E., 1929. *Tatrzańska epoka lodowa.* Prace Geograficzne 11, Lwów, 3–186.

Urbaniak J., 1960. *Wiercenie na Domańskim Wierchu w Kotlinie Nowotarskiej koło Czarnego Dunajca*. Kwartalnik Geologiczny 4, 3, 787–799.

Watycha L., 1973. *Utwory czwartorzędowe w otworze wiertniczym Wróblówka na Podhalu*. Kwartalnik Geologiczny 17, 2, 335–347.

Watycha L., 1975. *Szczegółowa Mapa Geologiczna Polski w skali 1 : 50 000, arkusz Nowy Targ (1049).* Wydawnictwa Geologiczne, Warszawa.

Watycha L., 1976. *Szczegółowa Mapa Geologiczna Polski 1:50 000, ark. Czarny Dunajec (1048).* Instytut Geologiczny, Warszawa.

Watycha L., 1977. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1:50 000, ark. Czarny Dunajec (1048*). Instytut Geologiczny, Warszawa.

Wiewióra A., Wyrwicki R., 1980. *Minerały ilaste osadów neogenu niecki orawsko-nowotarskiej.* Kwartalnik Geologiczny 24, 2, 333–348.

Wójcik A., 2022*. Morena szaflarska w świetle nowych danych z odsłonięcia i wierceń w 100-lecie jej odkrycia.* Przegląd Geologiczny 70, 458–467.

Zasadni J., 2009. *Krytyczne uwagi na temat rekonstrukcji geometrii powierzchni lodowców w polskich Tatrach Wysokich.* Przegląd Geologiczny 57, 607–613.

Zasadni J., Kałuża P., Kłapyta P., 2021. *Evolution of the Białka valley Pleistocene moraine complex in the High Tatra Mountains.* Catena 207, 105704.

Zasadni J., Kłapyta P., Kałuża P., Makos M., 2022*. The Tatra Mountains: glacial landforms prior to the Last Glacial Maximum*. [in:] D. Palacios, P.D. Hughes, J.M. García-Ruiz, N. de Andrés (eds.), *European glacial landscapes: maximum extent of glaciations*. Elsevier, Amsterdam, Oxford, Cambridge, 271–275.

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