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# „MIDDLE POLISH FLUVIAL HIGH TERRACE" IN THE RIVER VALLEYS OF THE KIELCE–ŁAGÓW DEPRESSION (HOLY CROSS MOUNTAINS, POLAND) – FACT OR MYTH?

**Abstract**: The article is a commentary on the current state of knowledge of the formation conditions, origin and stratigraphic position of the „Middle Polish fluvial, fluvioperiglacial high terraces" being relief elements of the river valleys of the Kielce–Łagów Depression (KŁD) in the southern part of the Holy Cross Mountains (HCM), i.e. the Belnianka, Lubrzanka and Łagowica river valleys. The former conception and criteria of distinguishing them are no longer fully valid. The "high terraces" were formed in the studied valleys in periglacial conditions of the Vistulian Glaciation and not, as it was previously considered, during the "Middle Polish Glaciation". They are entirely or partially composed of slope deposits or formed within the cover of glacial and/or slope deposits (toe-cut terraces) of different ages (including derived from the Odra Glaciation). Their hypsometric position is determined by the features of structural relief and the possibility of deposition of slope sediments on the alluvial series. The formation and structure of these terraces are the outcome of the location and pattern of river valleys in relation to the morphostructural elements of the KŁD as well as the changes of climate and environmental conditions in the Quaternary. The presented results were obtained owing to the fact that the investigations were conducted both in the profiles of hillslopes (slope environment) and river valleys (fluvial environment) as well as in the bottom of the KŁD (glacial environment). Only such an integrated approach gives an opportunity to find the relationship between the elements of the local litho- and morphogenetic system of the HCM: *hillslopes ↔ river valleys ↔ bottoms of structural depressions.*

**Key words**: fluvial terrace, Pleistocene, Holy Cross Mountains, Poland

## INTRODUCTION

Numerous investigations have been conducted in the last 20 years in order to verify the litho- and chronostratigraphy of the Quaternary deposits in the Kielce–Łagów Depression (KŁD; called the Kielce–Łagów Valley) (Fig.1A, B), in the southern part of the Holy Cross Mountains (HCM). The conclusions indicate the need to revise many traditional views on the structure and features of

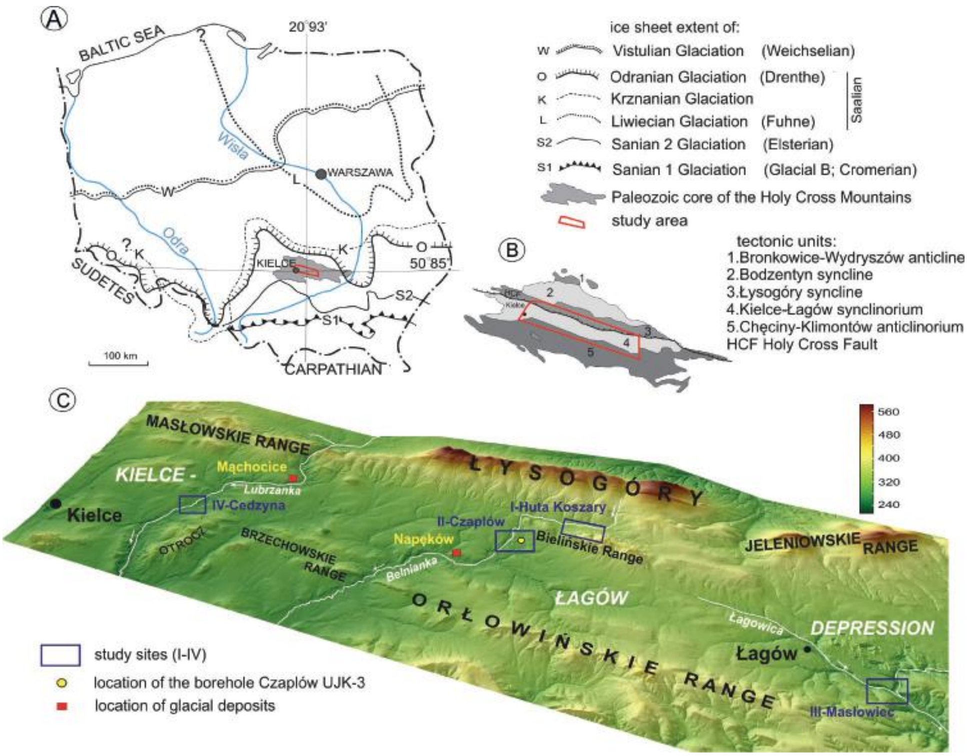



Fig. 1 Location of the detailed research area in relation to the extents of glaciations in Poland (after L. Lindner 2004; L. Marks 2011) (A) and the tectonic units of the Paleozoic massif of the HCM (B). Location of the river valley sections in the KŁD, which are described in the text: Belnianka River valley near Huta Koszary (I) and Czaplów (II), Łagowica River valley near Masłowiec (III), Lubrzanka River valley near Cedzyna (IV) (C)

fluvial landforms in this area and the development conditions of river valleys during the Quaternary. The results of this stage of investigations (e.g. Ludwikowska, Olszak 1997; Ludwikowska-Kędzia 2000, 2018; Kowalski 2002a; Ludwikowska-Kędzia et al. 2006) undermine, for example, the reasonableness of distinguishing "the fluvioperiglacial, accumulation high terrace", related to "the Middle Polish (Riss) Glaciation", in the river valleys of the southern part of the HCM (c.f. Łyczewska 1971; Kowalski 1978; Lindner 1984).

Several significant issues, among numerous still unsolved problems concerning the Quaternary stage of the fluvial environment evolution in the southern part of the HCM, are presented below, i.e. the sediment source area of the alluvia of the "Riss fluvioperiglacial facies" (Łyczewska 1971), which compose "high terraces", the possibility, conditions and time of formation of these terraces in the river valleys, and the verification of hypsometric criterion of their classification.

## FLUVIOPERIGLACIAL, HIGH TERRACE OF THE MIDDLE POLISH GLACIATION –HISTORICAL PERSPECTIVE OF RESEARCH

The fluvioperiglacial, accumulation high terrace, related to the Middle Polish (Riss) Glaciation, is not only an important relief element of the bottoms of river valleys in the HCM region (e.g. Łyczewska 1971; Lindner 1984; Kowalski 1988, 1990; Dzierżek et al. 2019) but it consists of equally important, typical of it lithofacies – sandy-gravelly "Riss fluvioperiglacial facies" (Łyczewska 1971). It was assumed that this high level of aggradation in the HCM river valleys was formed when river water was dammed as a result of blocking the Middle Vistula River valley by the ice sheet of the Middle Polish (Riss) Glaciation. At that time, the river valleys were filled with deposits. Flowing water deposited the transported material in all depressions, gradually rising up to about 300 m a.s.l., and moved also the weathered material supplied by solifluction processes. This stage was called the Riss fluvioperiglacial accumulation phase, with the typical sandy-gravelly "Riss fluvioperiglacial facies" (Łyczewska 1971).

After the ice-sheet retreat, the first deep incision of rivers into this deposit cover and the development of a terrace system (continued during the Eemian interglacial) took place: the accumulation high terrace (V) (of a relative height of 8–10 m in the upper sections of river valleys, and 14–18 m in the lower sections) and, for example in the Middle Nida River valley, the erosion-accumulation lower terrace (IV) (of a relative height of 4–6 m and 12–14 m, respectively) (Lindner 1984). The later phase of aggradation, which took place in the river valleys of the HCM during the North Polish Glaciation, and was represented by the "Würm fluvioperiglacial facies", did not exceed the edges of the Eemian valleys. It was postulated that the southern part of the HCM was outside the extent of the ice sheet of the "Middle Polish (Riss) Glaciation", in the periglacial zone (Łyczewska 1971; Lindner 1984). It should be mentioned that a long time ago it was already one of the most debatable problems in the Quaternary paleogeography of this part of the HCM and some researchers working in this region did not accept the assumed extent of this glaciation (e.g. Czarnocki 1927, 1931; Kotański 1959; Walczowski 1964, 1968; Kosmowska-Sufczyńska 1972; Filonowicz 1980a, b). The highest level of aggradation of sandy-gravelly deposits and/or the highest situated terraces (taking into account the hypsometric criterion) in the river valleys were considered to be the equivalent of „high terraces" with fluvial-fluvioperiglacial origin and Middle Polish age. These terraces were often the only point of reference for the interpretation of origin and age of the Quaternary younger deposit series and landforms in the river valleys and so they functioned as the morphostratigraphic elements.

Until the mid-1990s, the system of Quaternary levels and terraces in the river valleys of the southern part of the HCM was described and interpreted in relation to the main glacial-interglacial rhythm of climate and hydrological regime changes, according to the accepted at that time scheme of aggradation in cold (glacial) stages and erosion in warm (interglacial) stages. The picture became complicated not so much by the later findings indicating the synchronous functioning of the erosion and accumulation phases in fluvial environment as by the changes in the climatostratigraphic schemes of the Quaternary in Poland and in the HCM. These schemes evolved towards the increased number of the distinguished glaciations, i.e. from one Middle Polish (Riss) Glaciation, through two (Odranian-Riss I and Wartanian-Riss II, separated by the Lublinian interglacial), finally to three, which were described as the Middle-Polish Complex (Liwiecian, Krznanian, Odranian Glaciation, separated by the Mazovian, Zbójnian and Lublinian interglacials) (Lindner et al. 1995; Lindner, Marks 2012; Lindner et al. 2013; Marks et al. 2016, 2019). On the assumption that the extents of the three Middle Polish glaciations were situated to the north of the Main Range of the HCM, it was accepted that the southern part of the HCM was permanently outside the direct influence of ice sheets, i.e. in the cold periods it still functioned under periglacial conditions (Fig.1A).

The beginning of significant changes in the litho- and chronostratigraphy of the Quaternary deposits in the river valleys of the southern part of the HCM was the research on the Holocene stage of evolution of these valleys conducted, among others, as part of the IGCP Project No. 158: *Palaeohydrological changes in the temperate zone in the last 15,000 years, (subproject A: fluvial environment)* (e.g. Starkel et al. 1991, 1999). The results of investigations conducted then in the Middle Belnianka River valley indicated that the silt series exposed in the river channel, which were previously presented in geological cartographic materials and regional literature as stagnant-water facies accumulated during the South Polish Glaciation, were of Late Glacial and Holocene age (Ludwikowska 1993, Ludwikowska-Kędzia 2000; Starkel et al. 1999). This fact completely changed the approach to the previously accepted opinions concerning the litho- and chronostratigraphy of the Quaternary deposits, especially in the river valleys of the southern part of the HCM, and above all it changed the previous idea about the scale of erosion and aggradation in the bottoms of these valleys.

However, the main deficiency of the research on the facies of the genetically and lithologically different Quaternary deposits in the HCM was the lack of knowledge of the sedimentary environments and spatial relationships between these facies. Difficulties in the unambiguous determination of the deposit systems in the HCM resulted from the fact that in this small area many various sedimentary and morphogenetic environments (e.g. fluvial, slope, aeolian, glacial, periglacial) functioned simultaneously. This resulted in the interfingering of different depositional processes and deposits typical of each of these environments. Therefore, the facies adjacent to each other, despite their similar lithology, did not have to be the elements of the same sedimentary environment or represent the same time of events. Thus, the lacking or wrong determination of depositional environment of the Quaternary deposits in the HCM resulted in the difficulties or even possible mistakes in defining the nature of deposition and the age of facies adjacent to each other. Therefore, the gradual verification of the litho- and chronostratigraphy of the Quaternary deposits, actually initiated at the end of the 20th century, was carried out using a set of sedimentological methods (appropriate for the particular type of sedimentary environment) (cf. Mycielska-Dowgiałło, Rutkowski 1995, 2007; Harasimiuk, Terpiłowski 2003) and modern methods of deposit age determination, i.e. radiocarbon, palynological, thermoluminescence (TL) and optically stimulated luminescence (OSL) methods (e.g. Kowalski 1993; Ludwikowska 1993; Jaśkowski 1996; Ludwikowska, Olszak 1997; Sołtysik 1998, 2002; Ludwikowska-Kędzia 2000; Szczepanek 2001; Żurek, Kloss 2001; Kowalski 2002a; Jaśkowski et al. 2002; Ludwikowska-Kędzia, Nita 2002; Gruszczyński et al. 2004;). However, it was difficult to unambiguously interpret and spatially correlate the obtained research results due to their inconsistency with the accepted opinions and views concerning the litho- and chronostratigraphy of the Quaternary deposits and the Quaternary paleogeography of the HCM, e.g. the new results of the investigations verifying the structure and age of high terraces in the river valleys in the southern part of the HCM were difficult to interpret (cf. Ludwikowska, Olszak 1997; Kowalski 2002a; Ludwikowska-Kędzia et al. 2006; Ludwikowska-Kędzia 2007a, 2013; Wachecka-Kotkowska, Ludwikowska-Kędzia 2007; Ludwikowska-Kędzia, Olszak 2009). A wider view and more complete interpretation of the obtained results of the research on the age and origin of deposits and landforms in the river valleys were possible due to the detailed investigations of glacial and slope sedimentary environments, which were conducted in the southern part of the HCM only in recent years (Ludwikowska-Kędzia 2007b, 2013, 2018; Ludwikowska-Kędzia, Pawelec 2014; Ludwikowska-Kędzia et al. 2015; Pawelec, Ludwikowska-Kędzia 2016). Already at this stage they can serve as a pretext for open discussion concerning a) the reasonableness of distinguishing high terraces based on the former genetic, stratigraphic and paleogeographic assumptions, b) the conditions of the functioning of fluvial and slope systems in this part of the HCM in the Pleistocene (especially during the Middle Polish glaciations), and also c) the possibility of correlation of the deposits and landforms along the slope profiles and longitudinal profiles of river valleys in order to obtain information about climate changes in the Quaternary.

## STUDY AREA

The detailed research on the litho- and chronostratigraphy of the deposits of the „Riss fluvioperiglacial facies" were conducted in the upper and partially middle sections of the Belnianka, Lubrzanka and Łagowica river valleys, situated in the KŁD (Fig. 1C), where the relative height of the high terraces is 8–15 m. These rivers are small upland rivers (total length of each is 30–35 km), typical of the HCM, which belong to the drainage basins of the Nida and Czarna rivers (tributaries of the Vistula River). The rivers flowing through the KŁD cross numerous lithological, tectonic and morphological boundaries due to the varied lithology, structure and relief of this depression.

It should be stresses that the KŁD is a structural/tectonic depression (Kowalski 2000b) in which the accumulation of deposit cover and the preservation of its original features is favoured by the transversal and oblique pattern of rivers as well as their short length resulting in a short distance of the transport and transformation of mineral material.

The KŁD is characterized by the alternate occurrence of parallel complexes of clastic rocks (mainly Cambrian, Lower Devonian and Lower Carboniferous sandstones and shales) and carbonate rocks (Middle and Upper Devonian limestones and dolomites) (Walczowski 1964, 1968; Filonowicz 1969, 1973a, b, 1980a, b). The Paleogene-Neogene and Quaternary cover is a mosaic of deposits of various origin, debatable age, and spatially varying thickness (Fijałkowska, Fijałkowski 1965).

The KŁD has block-fold structure of the bedrock. Its bottom coincides with the extent of the Kielce-Łagów synclinorium, i.e. a tectonic unit of the Kielce region (Czarnocki 1919; Znosko 1962) – Kielce Fold Zone (according to Konon 2008) of the Paleozoic massif of the HCM (Fig.1A). It is divided into several block domains by longitudinal, transverse and oblique faults. The southern boundary of the KŁD runs in the zone of the Chęciny–Klimontów anticlinorium of the Kielce region, while its northern boundary is marked by the Łysogóry syncline, i.e. a tectonic unit of the Łysogóry region of the Paleozoic massif of the HCM (Fig. 1B).

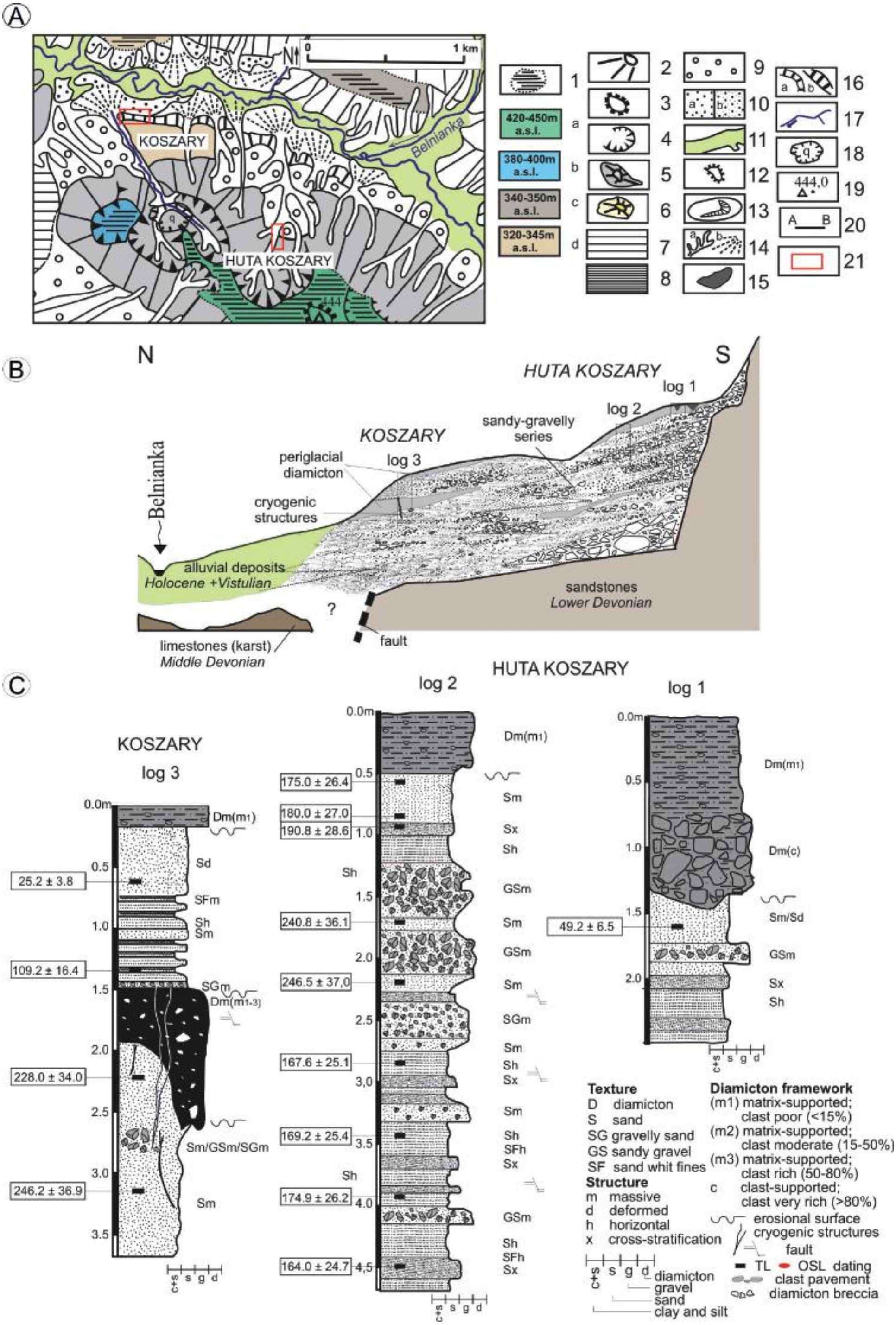
The KŁD is bounded by the Masłów Range, Łysogóry Range and Jeleniów Range in the north, and by the Brzechów Range, Orłowiny Range and Iwaniska Range in the south (Fig. 1C). In the bottom of this depression, both on the surface and under the Quaternary deposit cover, there are the forms of karst relief (e.g. ravines, sinkholes, blind karst valleys, ponors, karst springs, caves, karst remnant hills) (e.g. Urban 2013) and the inselbergs composed of clastic rocks.

The pattern of river valleys relative to tectonic forms and orographic directions of the KŁD is transversal and oblique, rarely concordant. According to B.J. Kowalski (2002b), it is the result of the „Young Tertiary and Quaternary cycle" of river network transformation in the HCM, which is related to the neotectonic rejuvenation of the Paleozoic structural pattern. It is also determined by the spatial pattern of structural relief in the bottom of the KŁD (Ludwikowska-Kędzia 2000), mainly karst relief (Klatka 1976) (contact karst: fluviokarst and stripe karst; Ludwikowska-Kędzia 2018).

## SEDIMENT SOURCE AREA OF "FLUVIOPERIGLACIAL FACIES" (IN THE MIDDLE-POLISH COMPLEX)

Identification of the sediment source areas of different facies of the Quaternary deposits in the HCM, usually based on the content of the Scandinavian or Miocene material, remains still an important and current issue in the Quaternary paleogeography of the HCM (c.f. Lindner 1984, Ludwikowska-Kędzia 2018). It is especially important in the case of „Riss fluvioperiglacial facies" (Łyczewska 1971), which, as it was assumed, constituted the "Middle Polish high terraces" in the river valleys of the southern part of the HCM. It was assumed that deluvia, derived from the exposures of the bedrock and older Quaternary deposits, constituted a significant part of this deposit facies. They were mainly accumulated in the upper sections of river valleys, at the top of fluvial and glaciofluvial deposits, as a result of denudation processes in periglacial conditions (e.g. Klatkowa 1955; Filonowicz 1973a, b; Kowalski 1978). The scale and intensity of these processes were recorded in the deposits of the denudation-erosion flattenings occurring at 340–360 m a.s.l. at the foot of the northern slopes of the Bieliny Range in the KŁD (Klatka 1962; Filonowicz 1973a, b; Ludwikowska-Kędzia, Olszak 2009; Pawelec, Ludwikowska-Kędzia 2016) (Fig. 1C, 2A-C). These slope deposits were formed and accumulated in the tectonically determined depression (graben), with a narrow, partially karstified bottom and relatively high asymmetric slopes composed of clastic rocks (cf. Wiatrak 2011). With time, the Belnianka River valley was developing in this depression (Fig. 2A,B).

The investigations of the depositional environment of the sediments of this high accumulation level near Huta Koszary and Koszary indicate that they are mainly represented by the sandy and sandy-debris series of alluvial


A
0
1 km
N
KOSZARY
HUTA KOSZARY
Belnianka
444
420-450m a.s.l.
380-400m a.s.l.
340-350m a.s.l.
320-345m a.s.l.
a
b
c
d
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
444,0
A
B
B
N
S
HUTA KOSZARY
log 1
log 2
sandy-gravelly series
KOSZARY
log 3
periglacial diamicton
cryogenic structures
Belnianka
alluvial deposits
Holocene +Vistulian
?
sandstones
Lower Devonian
limestones (karst)
Middle Devonian
fault
C
HUTA KOSZARY
KOSZARY
log 3
log 2
log 1
0.0m
Dm(m1)
25.2 ± 3.8
Sd
SFm
Sh
Sm
109.2 ± 16.4
SGm
Dm(m1-3)
228.0 ± 34.0
Sm/GSm/SGm
246.2 ± 36.9
Sm
175.0 ± 26.4
180.0 ± 27.0
190.8 ± 28.6
Sx
Sh
GSm
240.8 ± 36.1
246.5 ± 37,0
SGm
167.6 ± 25.1
169.2 ± 25.4
SFh
174.9 ± 26.2
164.0 ± 24.7
Dm(c)
49.2 ± 6.5
Sm/Sd
c+s
s
g
d
Texture
D diamicton
S sand
SG gravelly sand
GS sandy gravel
SF sand whit fines
Structure
m massive
d deformed
h horizontal
x cross-stratification
Diamicton framework
(m1) matrix-supported; clast poor (<15%)
(m2) matrix-supported; clast moderate (15-50%)
(m3) matrix-supported; clast rich (50-80%)
c clast-supported; clast very rich (>80%)
erosional surface
cryogenic structures
fault
TL OSL dating
clast pavement
diamicton breccia
diamicton
gravel
sand
clay and silt

fans and/or braided channels and by the diamicton series formed by various processes, e.g. high-energy overland flow, solifluction or active-layer detachment – mass displacement (Ludwikowska-Kędzia 2007b; Pawelec, Ludwikowska-Kędzia 2016) (Fig. 2B,C). These deposits are composed exclusively of local material. They were formed and redeposited in periglacial conditions as evidenced by the occurrence of numerous cryogenic structures (visible in the macro- and micro-scale) and strong aeolization of the deposits.

Both series occur in two slope deposit complexes of different ages (Ludwikowska-Kędzia, Olszak 2009; Ludwikowska-Kędzia 2013; Pawelec, Ludwikowska-Kędzia 2016): a) Middle-Polish, TL dated at 246–228 ka (Krznanian Glaciation, MIS8), about 201 ka and 179–164 ka (Lublinian Interglacial, MIS7 and Odranian Glaciation, MIS6) (cf. Lindner 2004), and b) North-Polish, TL dated at 53–25 ka (Vistulian Glaciation, Interpleniglacial, MIS3 and Upper Pleniglacial, MIS2)(cf. Lindner 2004) (Fig. 2C). They represent the stages C, B and A of the development of periglacial processes and congelifluction slope covers in the HCM (cf. Lindner, Bogucki 2002).

The Devonian local weathered clastic rocks and loess of the Bieliny Range were the sediment source material for both complexes of different ages of this autochthonous, periglacial slope facies. The genetic relationship between the bedrock and weathered material is indicated by their similar grain size distribution of sand fraction and similar heavy mineral spectra (Ludwikowska-Kędzia 2013). The weathered material was moved and deposited in periglacial conditions coexisting with the ice sheet of the Odranian Glaciation (MIS6), which was present in the KŁD (Ludwikowska-Kędzia 2013; Ludwikowska-Kędzia, Pawelec 2014, Ludwikowska-Kędzia et al. 2015) (Fig. 3A-C). Taking into account this fact, it can be supposed that

Fig. 2. Geomorphological sketch of the Belnianka River valley between Huta Stara and Koszary (A); Schematic structure of the flattening levels at the foot of the Bieliny Range (B) and sedimentological logs with TL age of the slope deposits at the Huta Koszary and Koszary sites (C) (modified after M. Ludwikowska-Kędzia 2007; M. Ludwikowska-Kędzia and I. Olszak 2009; H. Pawelec and M. Ludwikowska-Kędzia 2016; the lithofacies codes by T. Zieliński and M. Pisarska-Jamroży 2012). 1 – polygenic flattening levels at different altitudes on the slopes of the ranges (a–d), 2 – slope surfaces with polygenic deposit cover (also loess), 3 – remnant tors in the near-top flattening levels of the ranges, 4 – probable spring niches and/or traces of nival niches, small glacial cirques?), 5 – inselberg ridges, 6– remnant hills, 7 – denudation-erosion surfaces of glacial deposits, 8 – accumulation-denudation surfaces of glaciofluvial deposits, 9 – denudation-erosion surface of slope and glaciofluvial (marginal?) deposits, transformed in para-, peri- and interglacial conditions, locally platform of alluvial fans, 10 – a) Vistulian accumulation-erosion terrace, b) former „Middle Polish high terrace"; 11 – Holocene floodplain, 12 – erosion-denudation hill in the valley bottom, 13 – aeolian sand field with dune, 14 – a) erosion-denudation small valleys, b) alluvial fans; 15 – mire, 16 – a) distinct edge of terrace, b) slope of ravine; 17 – river channel, 18 – quarry, 19 – spot heights, 20 – profile lines, 21 – sites of study

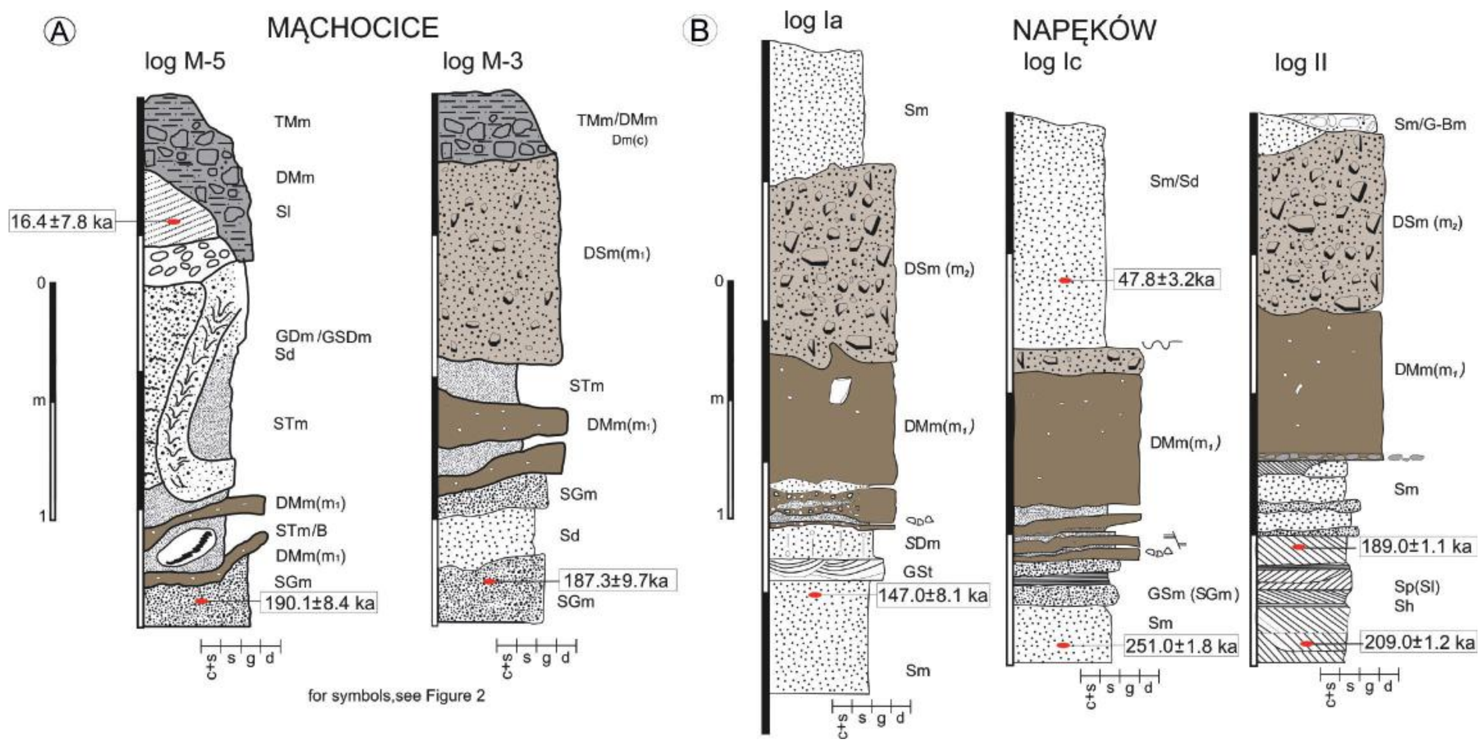



Fig. 3. Sedimentological logs of the glacial series at the Mąchocice (A) and Napęków sites (B) (modified after M. Ludwikowska-Kędzia 2013; M. Ludwikowska-Kędzia and H. Pawelec 2014; M. Ludwikowska-Kędzia et al. 2015)

episodic water (depending on the origin of water: glacial, nival and/or pluvial) contributed to the dissection and partial removing of this autochthonous, deluvial-colluvial material. Consequently, the existence of conditions resulting in the formation of exclusively fluvial equivalent of high terraces at that time is questionable. Fluvial origin should not be attributed to the terraces formed in the Belnianka River valley within the autochthonous, deluvial-colluvial, thick slope covers (Ludwikowska-Kędzia 2018). They represent the toe-cut terrace type – they are the truncated toes of tributary alluvial fans (cf. Larson et al. 2015). It should be expected that the terraces of this type occur in such sections of river valleys, which are situated between or at the foot of the ridges of the HCM (in the depressions or in their marginal zones).

The research results indicate that the HCM is an integral lithogenetic environment, the formation area of the autochthonous deposit cover, and the KŁD is a depression with an individual history of the youngest, Quaternary stage of its infilling with deposits. The sedimentological features of the deposit cover in the KŁD were determined not only by the climate and environmental changes in the last 2.58 million years but also by the lithological and structural features of sedimentary rocks of the Paleozoic (and also Mesozoic?) substratum and the total duration of lithogenetic processes (measured at least since the Paleogene). These facts are reflected and evidenced by the heavy mineral assemblages of the Quaternary deposits in the KŁD (Ludwikowska-Kędzia 2013). It has been shown that their characteristic feature is a high proportion or the predominance of transparent minerals resistant to mechanical weathering. This fact does not have to be interpreted as the result of long-lasting weathering processes and repeated transformation of deposits such as the deposits in the upland belt were subjected to (cf. Ludwikowska-Kędzia 2007b; Racinowski 2010). It can only indicate that their sediment source areas are in the HCM, and the varied composition of this heavy mineral group depended on the mineral composition of the Paleozoic source rocks and the Paleogene-Neogene sediment covers, too. The proportion of heavy mineral assemblage typical of glacial environments is low in the Quaternary deposits of the KŁD, which point to the slight influence of ice sheet on the mineralogical features of this deposit cover.

## FORMATION CONDITIONS AND AGE OF HIGH TERRACE

From the moment when the Middle-Polish Complex (three glaciations and three interglacials) was distinguished in the stratigraphic division of the Pleistocene, the formation conditions and stratigraphic position of the high terrace occurring in the bottoms of river valleys in the southern part of the HCM (which was formerly related to only one period – Middle-Polish, i.e. Riss, Glaciation) have become disputable. In order to verify and revise the previously accepted formation conditions and age of the „high terrace" in river valleys it has been necessary to determine the features of glacial sedimentary environment of the Odranian Glaciation (Saalian, MIS 6) in the KŁD (near Mąchocice and Napęków) (Ludwikowska-Kędzia, Pawelec 2011, 2014; Ludwikowska-Kędzia 2013; Ludwikowska-Kędzia et al. 2015; Pawelec, Ludwikowska-Kędzia 2016) (Fig.1C, 3A,B). The deposit complex of this glaciation constitutes the vast and often the highest situated accumulation and/or erosion-denudation surfaces (280–320 m a.s.l.) in the bottom of this depression, which are cut by river valleys (among others the Lubrzanka and Belnianka rivers).

Near Mąchocice (Lubrzanka River valley) there was proved the existence of local glacimarginal zone (end moraine according to P. Filonowicz 1969), represented by the deposit series of end moraine fan (Ludwikowska-Kędzia, Pawelec 2014), „dry" end moraine type (according to D. Krzyszkowski and T. Zieliński 2002). The deposition of glacial series was preceded by the stage when ice-dammed lake functioned in the pre-Lubrzanka River ravine. The series of sands and sandy silts was accumulated in this lake. The glacial complex of end moraine fan consists of the lower and upper diamicton facies diagnostic of it, which are underlain by the sandy-gravelly series deposited by grain flows at the ice front, with a high content of the Miocene and Cretaceous material (Fig. 3A). The lower muddy diamicton is flow till, which was formed as a result of cohesive debris flows and occurs as several beds. Each of the diamicton beds is accompanied by sandy-silty beds (fluid-flow deposits), which were deposited by sheet flow and partially meltwater stream, under freezing conditions. The upper sandy diamicton is interpreted as ablation till of cohesionless debris flow type. It was formed as a result of strongly water-saturated flow in supraglacial conditions (Ludwikowska-Kędzia, Pawelec 2014).

Near Napęków (Belnianka River valley) the complex of glacial deposits consists of the series of glaciofluvial sands and gravels as well as the lower muddy diamicton and the upper sandy diamicton (Ludwikowska-Kędzia et al. 2015) (Fig. 3B). The diamictons were formed in the subglacial conditions. They are interpreted as subglacial traction till (cf. Evans et al. 2006; Benn, Evans 2010; Narloch et al. 2013; Evans 2017). Diamictic material was released directly from the bedrock and/or ice. Then it was homogenized as a result of various, complex subglacial processes (deposition, deformation and melting), which were variable in time and space, and depended on the relief and lithology of the sub-Quaternary basement in the KŁD as well as on the ice thickness.

The glacial and glaciofluvial, sandy-gravelly series underlying the glacial diamicton complex in Mąchocice was OSL dated at 192–188 ka (Ludwikowska-Kędzia 2013) and in Napęków at 147–209 ka (251 ka) (Ludwikowska-Kędzia et al. 2015) (Fig. 3A,B). Taking into account the OSL age and deposition conditions of the whole deposit complex representing glacial sedimentary environment, it was postulated that the diamictons occurring in both sites, despite their different facies development, were formed and deposited in the same glacial episode, i.e. during the Odranian Glaciation (Saalian, MIS6), the youngest of the glaciations of the Middle-Polish Complex (cf. Lindner 2004; Lindner, Marks 2012; Marks et al. 2016, 2019).

It can be assumed that after the Odranian ice-sheet retreat, the accumulation cover of glacial deposits concealing the diverse relief of the KŁD bottom became the surface on which the reorganization of river and valley network took place in the changing climate conditions – possibly from the end of Odranian Glaciation, the Eemian, through the Vistulian to the Holocene. It had to be subjected to a set of processes (fluvial, aeolian, slope) in changing interglacial and periglacial conditions. Such course of events was evidenced by the results of investigations of the sedimentary environment and age of the deposits series, which a) constitute the high terraces in the river valleys cut in this glacial complex, and b) accompany the glacial complex.

The highest terrace (relative height of 8–10 m) in the terrace system of the river valleys in the KŁD, i.e. the Lubrzanka River near Cedzyna (Kowalski 2002b), the Łagowica River near Masłowiec (Ludwikowska-Kędzia et al. 2006) (Fig. 4A-C) or the Belnianka River near Czaplów (Ludwikowska-Kędzia 2018)(Fig. 5A-B), regarded as the "Middle Polish high terrace", is bipartite. Its bottom part consists of overbank facies represented by silt series, and locally underlain by gravel series, with locally preserved cryogenic structures. The upper part (or the whole terrace profile) consists of sandy and sandy-gravelly channel facies. In the near-surface part of the terrace the channel facies alternates with the series of aeolian silts/sands and slope deposits (deluvia, colluvia). In places the slope deposits form the whole near-surface part of the terrace. The deposition time of these alluvial and/or slope series was different, e.g. in the Lubrzanka River valley the TL age was 69–61 ka and 58–52 ka (Kowalski 2002b), in the Łagowica River valley the TL age was 62–60 ka, 34–28 ka and 19–14 ka (the OSL age was 15–21 ka) (Ludwikowska-Kędzia et al. 2006) (Fig. 4C), and in the Belnianka River valley the OSL age was 22–15 ka and about 11.5 ka (Ludwikowska-Kędzia 2018) (Fig. 5B), i.e. they were deposited in periglacial conditions of the Vistulian Glaciation (MIS4–MIS2).

The deposits accompanying both glacial complexes in Mąchocice and Napęków are mainly a) sandy series: aeolian cover sands (filling the erosional and/or cryogenic forms occurring in glacial deposits) and b) deluvial-colluvial series, represented by silty and diamictic sands as well as silty-sandy diamictons, often with debrite features, which were formed, among others, as a result of slope wash. These deposits were OSL dated at 47.8 ± 3.2 ka in Napęków, and at 16.4±7.8 ka in Mąchocice (Ludwikowska-Kędzia 2013). Their age indicates that they belong to the Vistulian Glaciation, Interpleniglacial (MIS3–MIS2) (Fig. 4C, 5B).

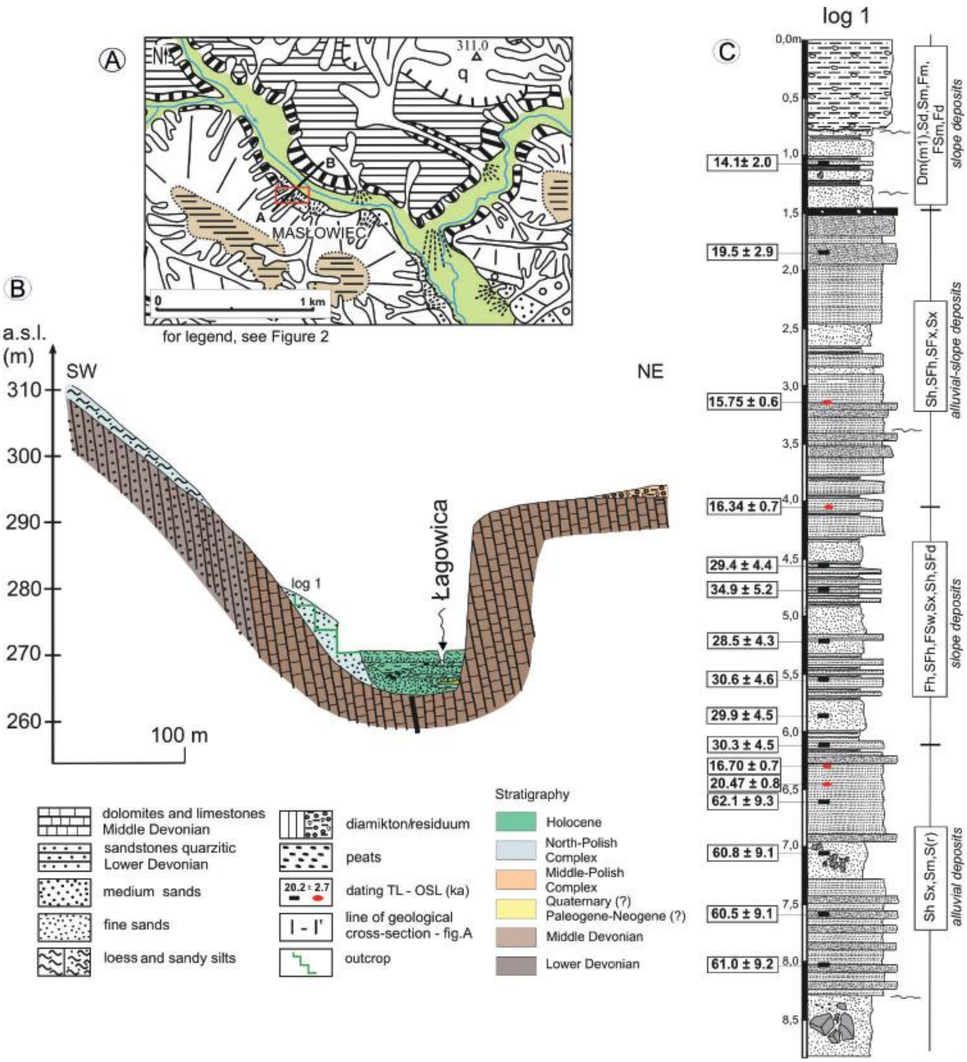



Fig. 4. Geomorphological sketch (A), the cross-section of the Łagowica River valley near Masłowiec (B), and sedimentological log with TL,OSL age of the terrace deposits at the Masłowiec site (C) (modified after M. Ludwikowska-Kędzia et al. 2006; M. Ludwikowska-Kędzia and M. Wiatrak 2012)

The results of the research on the depositional environment and age of the Odranian glacial deposit complex and accompanying deposits in Mąchocice and Napęków and the Pleniglacial deposit series constituting the high terraces in the Lubrzanka, Łagowica and Belnianka river valleys in the KŁD verify each other. These results excluded the formation of the „Middle Polish, fluvioperiglacial high terrace" in the KŁD at that time and in such paleogeographic conditions that were formerly accepted because a) during the Odranian Glaciation the river regime in the KŁD could have been glacial (mainly proglacial), nival or mixed (nival-glacial), b) periglacial conditions, which coexisted with the ice sheet in the KŁD at that time, favoured activation

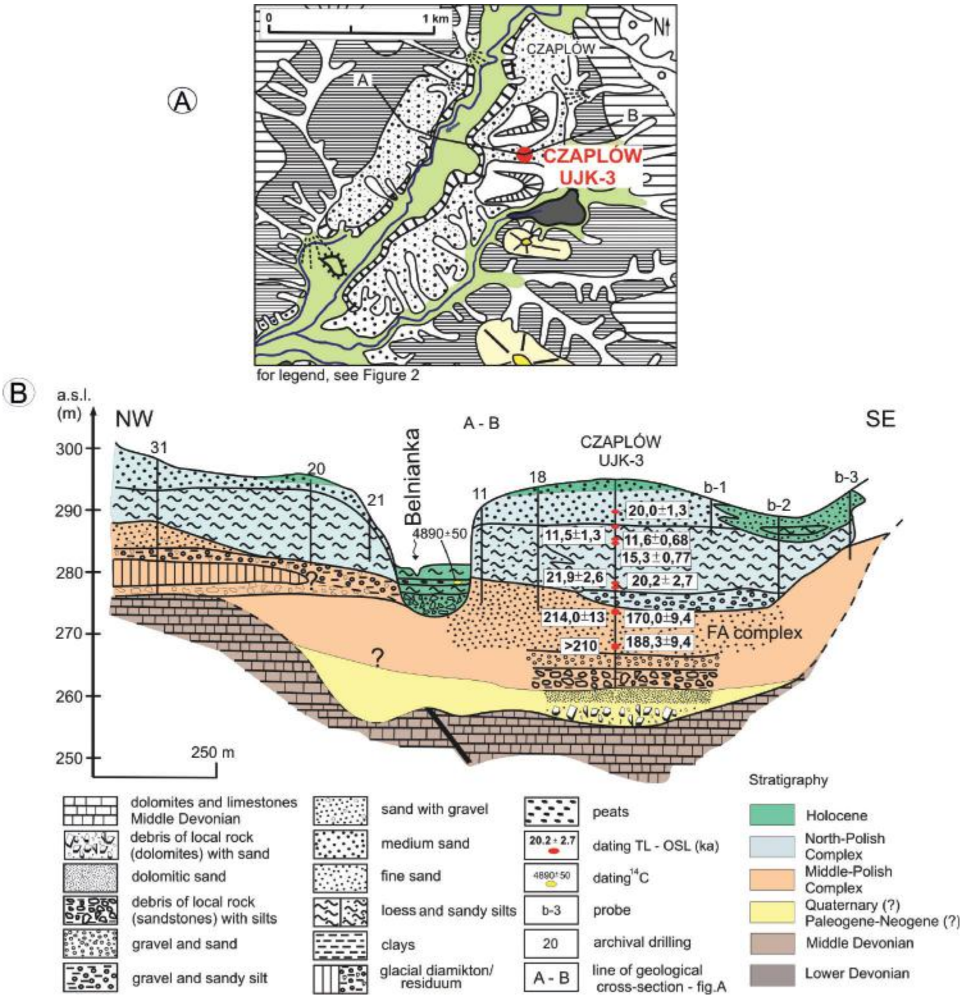



Fig. 5. Geomorphological sketch (A) and the cross-section (B) of the Belnianka River valley near Czaplów (modified after M. Ludwikowska-Kędzia 2018)

of weathering and denudation processes, and consequently slope processes, c) sandy-gravelly mineral material transported by water at that time was allochthonous (supplied from the outside to the integral environment of the HCM and deposited as glacigenic deposits), as well as autochthonous (weathered material of the local bedrock), d) the covering of the karstified bedrock with loose deposits favoured the organization of river network.

The record of the response of integral morphogenetic environment (including fluvial environment) of the KŁD to climate changes in the older stages of the Middle-Polish Complex is still an open issue. This stage of the development of river valleys has been partially identified in the Czaplów UJK–3 borehole in the Belnianka River valley (Fig.5B). The fluvio-aeolian complex (FA) found at this site, dated at 214 – >210 ka (Lublinian Interglacial, MIS7 and older?), is slightly older than the glacial complex at the Napęków and Mąchocie sites. It fills a karst depression of the faulted sub-Quaternary basement. The textural-structural features of the FA complex indicated that the cold climate conditions existing earlier in the KŁD favoured the long-lasting development of aeolian processes and/or intensive chemical weathering (Ludwikowska-Kędzia 2018). The slightly younger deposits, constituting the flattening levels at the foot of the Bieliny Range near Huta Koszary, are also characterized by a high degree of aeolization (Ludwikowska-Kędzia 2007b). The FA complex was also identified in the Jabłonna UJK–1 and Słopiec UJK-2 boreholes, which are located in the lower section of the longitudinal profile of the Belnianka River valley, near Słopiec Szlachecki (Słopiec Basin – Białe Ługi Valley) (Ludwikowska-Kędzia 2018). The mineral material of these deposits was probably subjected to aeolian processes in the older glacial periods of the Middle-Polish Complex, and even in the South-Polish Complex.

## DISCUSSION AND CONLUSIONS

The investigations of the depositional environment, sediment source area and formation age of the „Middle Polish, fluvioperiglacial high terraces" in the upper sections of the Lubrzanka, Łagowica and Belnianka river valleys in the KŁD in the southern part of the HCM have indicated that the former conception and criteria of distinguishing them are no longer valid. The studied „high terraces" in the river valleys of the KŁD were mainly formed under periglacial conditions of the Vistulian. Their source material derived mainly from the autochthonous covers of weathered local bedrock, which were slightly enriched with allochthonous glacigenic material. These terraces, considered as accumulation landforms, have a complex (mainly not fluvial) origin – they are entirely or partially composed of slope and aeolian deposits, and/or formed within the cover of slope and glacial/fluvioglacial deposits of different ages (the core of the terrace). Their hypsometric position is determined by the features of structural relief and/or the occurrence of slope deposit cover on the alluvial or glacial series. Therefore, the high terraces in the terrace system of river valleys in the KŁD should not be uncritically related to the high fluvioperiglacial accumulation during the Middle Polish Glaciation.

In the investigations of the relief of river valley bottoms in the KŁD, it should be taken into account that the HCM is the area with the integral litho- and morphogenetic environment, in which the features of structural relief were inherited from the Paleogene–Neogene stage of the HCM morphogenesis and controlled mainly by the various lithology and fold-block structure of this Paleozoic massif. These features determined the course of different morphogenetic processes functioning in the changing climate and environmental conditions in the Quaternary. The evolution of the fluvial environment in the KŁD was also controlled by these factors. The formation and features of the terrace system in the studied fragments of river valleys was the outcome of a) the location and pattern of these valleys relative to the differing in size and geological structure morphostructural elements of the KŁD, and b) the changes of climate and environmental conditions in the Quaternary.

In the longitudinal sections of river valleys, concordant with the arrangement of tectonic forms and following the orographic directions in the KŁD (such as the Upper Belnianka River valley near Huta Koszary), which are situated in the narrow depressions formed between the ridges (or at the foot of ridges), the occurrence of erosion-accumulation high terraces is the fact. However, these terraces are mainly composed of the autochthonous, deluvial-colluvial slope series of different ages, which were formed in periglacial conditions that coexisted with the ice sheet of the Odranian Glaciation in the KŁD. Therefore, they are not of fluvial and/or probably glaciofluvial origin but they represent the toe-cut terrace type and in the studied case also debris flow dominated alluvial fans (debris flow fans). Their height in the valley bottoms may be additionally falsified due to the local occurrence of a thick cover of the younger, Vistulian slope deposits in periglacial conditions of the Vistulian Glaciation.

In the valley sections that are transversal or oblique in relation to the tectonic forms and orographic directions of the KŁD, which are situated in the central part of its bottom, and which were cut in the cover of glacial deposits of the Odranian Glaciation (such as the Belnianka River valley near Czaplów, the Lubrzanka River valley near Cedzyna), the occurrence of high terraces is the fact. However, they were formed in periglacial conditions of the Vistulian Glaciation, not the “Middle Polish Glaciation”. The deposits composing these terraces derived not only from the local weathered bedrock (autochthonous material) but also from the residua of glacigenic deposits (allochthonous material from different glacial environments). In this way the mixed type of alluvia (autochthonous-allochthonous) was formed. The similar situation is in the transversal-oblique sections of the valleys, which were cut directly in the exposed Paleozoic bedrock of the KŁD. In these sections, with rocky, short sides (such as in the ravine of the Łagowica River near Masłowiec), the height of terraces is the outcome of the aggradation in the narrow valley bottoms and the occurrence of a thick cover of deluvial-colluvial slope deposits. This fact results in the falsification of not only the actual size of alluvia aggradation in the valley bottoms but also the origin of the terraces.

It should be stressed that in the Quaternary the optimal development of the surface river network in the KŁD occurred probably when the Paleozoic karstified carbonate substratum in its bottom became covered with deposits. The accumulation of poorly permeable or impermeable series of slope and glacial deposits (mainly silty-clayey debrites, diamictons, clays) was especially important. They sealed the zones of water infiltration into the karstified substratum, and thus influenced the water regime (surface and underground). Therefore, it should be emphasized that the spatial variability of the lithology, lithofacies and thickness of the Quaternary deposit cover in the KŁD (taking into account the diverse structural relief of the area) influenced the local features of relief of the small river valleys, which were developing in it.

Fluvial processes responsible for the formation of terraces system in the studied river valleys of the KŁD (but also slope processes) functioned in periglacial conditions of the Vistulian Glaciation (Interpleniglacial and Upper Pleniglacial, MIS3–MIS2). They were subjected to the climate and environmental changes occurring in this time of the Pleistocene. The Interpleniglacial (MIS3) was characterized by the occurrence of frequent high-amplitude temperature fluctuations and changes in the vegetation cover (cf. Rasmunssen et al. 2014; Granoszewski, Winter 2016; Starkel et al. 2017). They can be considered the factor, which determined the activation of denudation processes and degradation of the hillslopes in the HCM at that time (due to alternating freezing and melting, and then transport of slope deposits by debris flow, active layer detachment, solifluction and slope wash). As in many sections of river valleys in the southern part of the HCM the hillslopes are often also the sides of river valleys or structural/tectonic depressions, the material from the degraded slopes was delivered directly to the bottoms of these forms. In the Interpleniglacial the outflow was periodic and not very dynamic (Turkowska 2006), so the rivers could not have removed all material that was intensively supplied to the valley bottoms by denudation processes. The valleys were then being transformed into denudation basins (Klatkowa

1981). The Upper Pleniglacial (MIS2) was a short and the coldest period of in the Vistulian Glaciation, which favoured the development of permafrost, and especially the activation of aeolian processes (e.g. Dylik 1967; Manikowska 1995; Goździk 2007; Jary 2007; Woronko 2012; Zieliński et al. 2014). In the HCM these processes were additionally controlled by the tectonic activity (Jaśkowski 1999) and probably by the reactivation of karst processes in the zones of the carbonate rock complex in the sub-Quaternary basement (Ludwikowska-Kędzia 2018). The interrelations between the patterns of river valleys and morphostructural elements, taking into account the climate and environmental changes in the Quaternary, explain the irregular occurrence of the zones with thick alluvial and/or deluvial deposit series in the river valleys (cf. Rühle 1957).

It is worth noting that the impact of the Vistulian climate and environmental conditions on the functioning of fluvial processes as well as their record in the structure and age of fluvial landforms in the KŁD are similar to those documented in the river valleys in the Central-Eastern Europe (e.g. Starkel et al. 2015), including the areas of southern Poland (e.g. Superson 1996, Gębica 2004, Turkowska 2006, Gębica et al. 2015). However, it is beyond the scope of this article to take a position on this issue.

KŁD is a structural/tectonic depression of complicated geological structure and varied relief of the Paleozoic bedrock where many different depositional environments and morphogenetic processes functioned simultaneously and/or successively in a relatively small area resulting in the occurrence of a mosaic of genetically diverse sediments and landforms of different ages. An integrated approach to the investigations conducted in the profiles of hillslopes (slope environment) and river valleys (fluvial environment) as well as in the bottom of the KŁD (glacial environment) give an opportunity to find the relationship between the elements of this local litho- and morphogenetic system: *hillslopes ↔ river valleys ↔ bottoms of structural depressions*. It is also possible to reconstruct the record of individual response of these elements (in the landforms and deposits of each of these environments) to the changes of climate conditions in the Quaternary, including their reaction to the „disturbance" which was the interference of the Pleistocene ice sheets. At the current stage of verifying the litho- and chronostratigraphy of the Quaternary deposits in the southern part of the HCM, systemic methodology should be applied treated as a standard approach to the identification of the regional picture of the youngest, climatically controlled transformation of deposit cover and relief of the HCM.

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