Studia Quaternaria, vol. 36, no. 2 (2019): 109–118 DOI: 10.24425/sq.2019.126383

QUATERNARY VALLEY LEVELS AND RIVER TERRACES IN THE WESTERN PART OF THE HOLY CROSS MOUNTAINS

Jan Dzierżek*, Leszek Lindner, Krzysztof Cabalski

University of Warsaw, Faculty of Geology, Żwirki i Wigury 93, 02-089 Warszawa, Poland;
e-mails: j.dzierzek@uw.edu.pl, l.lindner@uw.edu.pl; krzysztof.cabalski@uw.edu.pl

** corresponding author*

Abstract:
According to the current state of research five sand-gravel accumulation levels of Quaternary age are visible in the morphology of the western part of the Holy Cross Mountains, within the Wierna Rzeka, Hutka and Bobrza river valley systems and the lower stretches of the Biała Nida and Czarna Nida river valleys. Two upper levels (V and IV) correspond to valleys formed during the Odranian Glaciation-Saalian, MIS6 and its reccesional phases under the influence of proglacial and extraglacial waters beyond the extent (to the east) of the maximal ice-sheet limit of this glaciation, reaching to the present-day Leśnica-Gnieździska-Łopuszno line. Two lower levels (III and II) are terraces that were typically formed during the climatic conditions thatprevailed during Vistulian stadials. Sands and gravels of the three upper levels (V−III) contain numerous debris flow deposits and cryoturbation structures documenting periglacial conditions during their accumulation. The lowermost level (I) is a typical Holocene floodplain.

Key words: Holy Cross Mountains, Quaternary, palaeogeography, valley sediments, fluvial forms

Manuscript received 9 October 2018, accepted 22 June 2019

INTRODUCTION

The western part of the Holy Cross Mountains (Fig. 1) is a perfect study area of the Pleistocene valley morphology in reference to geology, especially tectonics and successive phases of ice sheet advance. So far, geological research in the area has documented presence of two levels (V–IV) and three terraces (III–I), referred to interglacial and glacial environments. Progressive development of the area caused that some archival, well examined sites do not exist anymore; in turn, new sites that may shed light on the topic appeared. This paper presents state of knowledge on morphology and geology of valleys in this part of the Holy Cross Mountains in reference to a recent stratigraphic subdivision of the Quaternary in Poland (Marks *et al.*, 2016). The presented data not only exemplify development of a river network in mid-range mountains, but are also a starting point for prospective regional correlation and further detailed studies of fluvial deposits in the Holy Cross Mountains. Due to the assumed scope and aim of the research it is not currently possible to compare in full the investigated and neighboring areas, among them especially the southern part of the Holy Cross Mountains (cf. Ludwikowska-Kędzia and Olszak, 2000; Krupa, 2013, 2015; Kalicki *et al.*, 2019).

STUDY AREA

The studied area is located in the western part of the Holy Cross Mountains, between Kielce and Małogoszcz, Oblęgorek and Chęciny. It embraces Wierna Rzeka and Bobrza River valleys and their tributaries as well as the lower sections of Biała Nida and Czarna Nida valleys. The location of the above mentioned valleys is determined by structure of the main ranges in the western part of the Holy Cross Mountains. The analysed valley deposits occur at 280–285 m a.s.l. (8–14 m a.r.l.) and 208–210 m a.s.l. (0.5–2 m a.r.l.). A detailed cartographical analysis was conducted for the area between Gnieździska and Małogoszcz to present deposits of valley levels and river terraces (Fig. 2).

GEOLOGICAL SETTING

The pre-Quaternary basement of the described area belongs mainly to the Mesozoic margin of the Holy Cross Mts. and partly also to their Palaeozoic core (Czarnocki, 1938; Hakenberg, 1973; Filonowicz and Lindner, 1986). Several distinct faults cut the pre-Quaternary rocks (Czarnocki, 1938; Konon, 2008). Both lithology and tectonics of the

Fig. 1. Location of the study area in the western part of the Holy Cross Mountains in relation to the limits of the Sanian 2, Odranian and Vistulian Glaciations (*cf.* Fig. 5).

bedrock influenced the Pleistocene glacial and fluvial accumulation (Lindner, 1972; Lindner and Mastella, 2002). Quaternary deposits are represented by glacial tills, glaciofluvial sand and gravel, loess, slope deposits and fluvial sand (Czarnocki, 1938; Klatka, 1965; Lindner, 1972, 1977a; Hakenberg, 1973; Filonowicz and Lindner, 1986; Krupa, 2015; Kalicki *et al.*, 2019).

The western part of the Holy Cross Mountains (Fig. 1) is characterised by presence of five (V–I) levels and terraces within the main valleys. Geological and geomorphological studies of these issues, began by Czarnocki (1931), Klatka (1965), Hakenberg and Lindner (1971, 1973) and continued by Lindner and Braun (1974), Giżejewski and Lindner (1977) and Lindner (1977a, b) indicated that the lower three levels (III–I) are typical river terraces. Two upper levels (V–IV) are linked with glaciofluvial discharges in the Wierna Rzeka and Biała Nida catchments, whereas the contemporary flows in the Hutka, Bobrza and Czarna Nida catchments are of fluvioperiglacial origin (connected with a periglacial environment) (Łyczewska, 1971; Lindner and Dzierżek, 2013, 2019).

The largest glaciofluvial flow (18–14 m relative altitude, Fig. 2) was created by meltwater flowing from the Odranian ice sheet during its maximum limit from the west to the Leśnica-Gnieździska-Łopuszno line (Lindner, 1977a). The lower (IV) glaciofluvial level (14–8 m relative altitude, Fig. 2) developed due to erosional incision by proglacial meltwater released during a retreat of the ice sheet in this glaciation. Levels of fluvial accumulation in a periglacial environment correspond to these levels in the extraglacial zone with regard to age and elevation.

Two fluvial terraces (III and II with relative altitude at 8–5 m and 4–2 m, respectively) were formed subsequently during the maximum of the main stadial of the Vistulian Glaciation and in the Late Glacial of this glaciation. The terrace I (floodplain) with relative altitude at 2–0.5 m was formed in the Holocene during several phases of fluvial activity (Krupa, 2013, 2015; Kalicki *et al.*, 2019).

MATERIAL AND METHODS

The analysis was based mostly on the authors' data collected over many years of studying geology of the Holy Cross Mountain area (Hakenberg and Lindner, 1971, 1973; Lindner and Braun, 1974; Lindner and Kowalski, 1974; Lindner, 1977a, 1984; Lindner and Mastella, 2002; Lindner and Dzierżek, 2013). The data embrace geological and geomorphological mapping, outcrops and boreholes interpretations, thermoluminescence and radiocarbon dating of

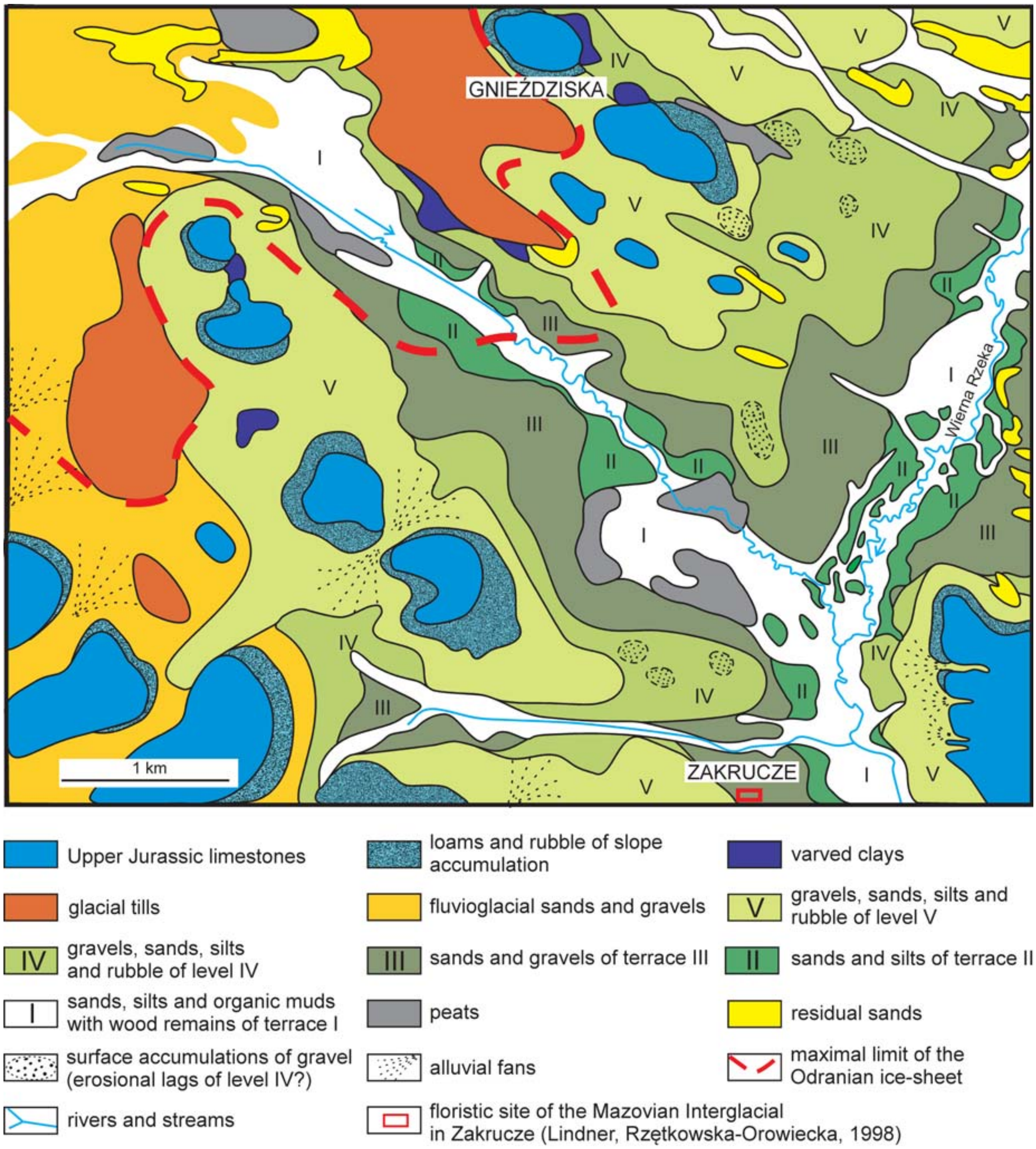

Fig. 2. Geological map of the western part of the Wierna Rzeka catchment between Gnieździska and Zakrucze (after L. Lindner, unpublished data).

fluvial, lake and slope deposits (Lindner, 1977b; Lindner and Rzętkowska-Orowiecka, 1998; Krupa, 2013, 2015). The analysis of the described material led to elaboration of a map of the current spreading of the valley deposits in the western part of the Holy Cross Mountains (Fig. 2). A new palaeogeomorphological sketch-map of the forefield of the ice sheet was also prepared (Fig, 3). A composition of the higher valley levels (nos. IV and V) in selected sites are presented (Fig. 4). A synthesis of the research is represented by a geochronological scheme of the analyzed deposits in the context of the glacial levels in the western part of the Holy Cross Mountains (Fig. 5).

VALLEY LEVELS

Level V (18−14 m above river level)

Advance of the Odranian ice sheet towards the western part of the Holy Cross Mountains was influenced by a river valley system, open to the west, existing since the Mazovian Interglacial, among others with organic deposits at Zakrucze near Małogoszcz (Lindner and Rzętkowska-Orowiecka, 1998), and fluvial runoff was dammed by the ice sheet. This process favoured ice-dam deposition in the Wierna Rzeka and Biała Nida catchments (Lindner, 1977a;

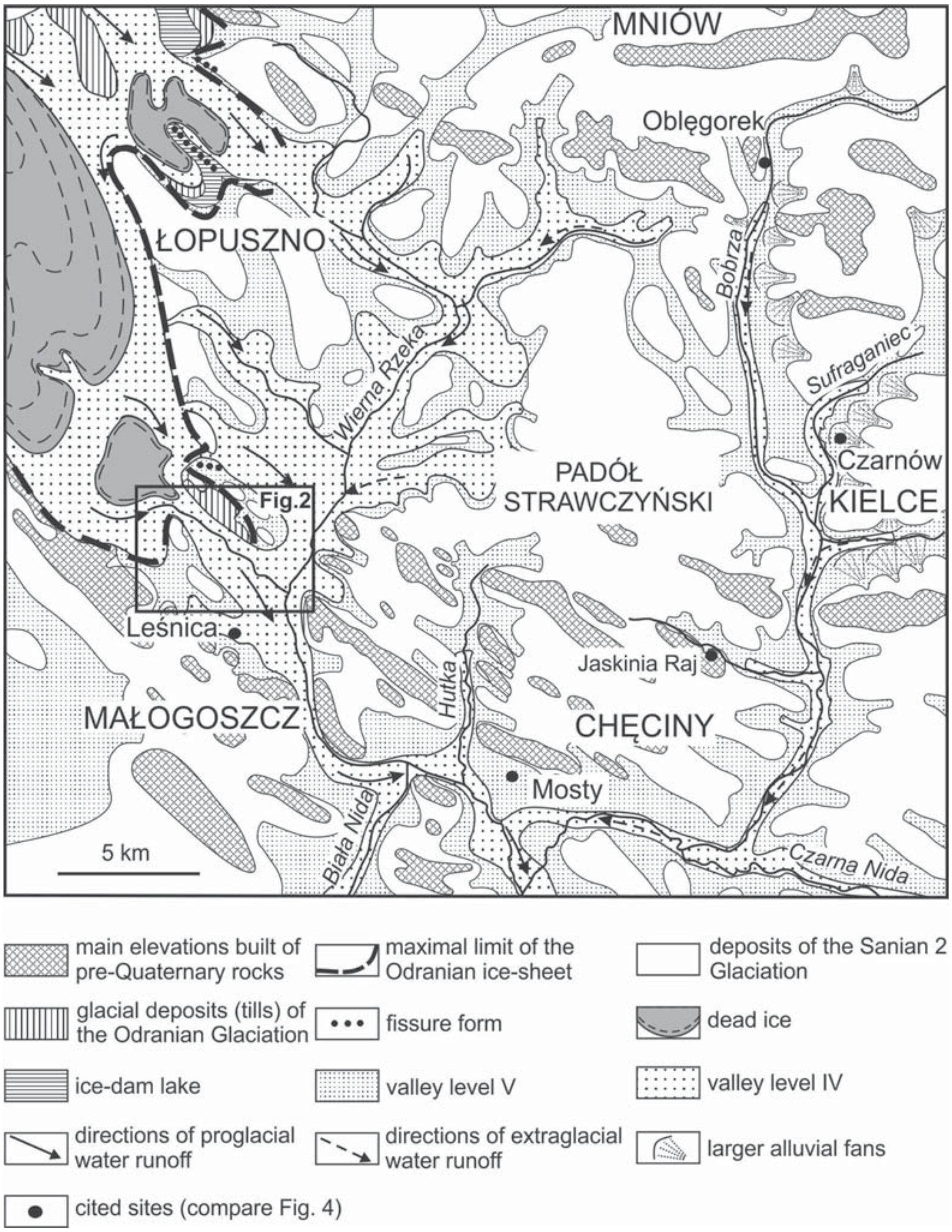

Fig. 3. Palaeogeomorphological sketch-map of the western part of the Holy Cross Mountains during the Odranian Glaciation with regard to the modern river network (modified after Lindner, 1977a).

Lindner and Mastella, 2002) and is recorded by sand, silt and varved clay more than 20 m thick, and occurring in the lower part of the level V. They are partly enriched with debris flow deposits composed of pre-Quaternary rocks, commonly with Scandinavian material of older glaciations (Sanian 1 and Sanian 2) (Lindner, 1977a). The upper part of the level V is represented mainly by glaciofluvial sand and gravel of the Odranian ice sheet. These deposits are also intercalated with or covered by debris flow deposits of pre-Quaternary sediments (Cabalski *et al.*, 2018b, as well as by residual material of older glaciations.

The level V (Fig. 3) in the Wierna Rzeka catchment occurs from 285–280 m a.s.l. to about 260 m a.s.l. In the western part of Padół Strawczyński, the contemporary proglacial waters that formed the level V were connected with extraglacial meltwaters at 250 m a.s.l. Ice-dam sand and silt of this level occur on glacial tills from older glaciations or on exposed pre-Quaternary rocks. In the southern part of Padół Strawczyński the level V occurs at 250–248 m a.s.l.

In the Wierna Rzeka gorge near Bocheniec, sediments of the level V reach the elevation of 250–246 m a.s.l. and are represented by sand and silt with admixture of fine

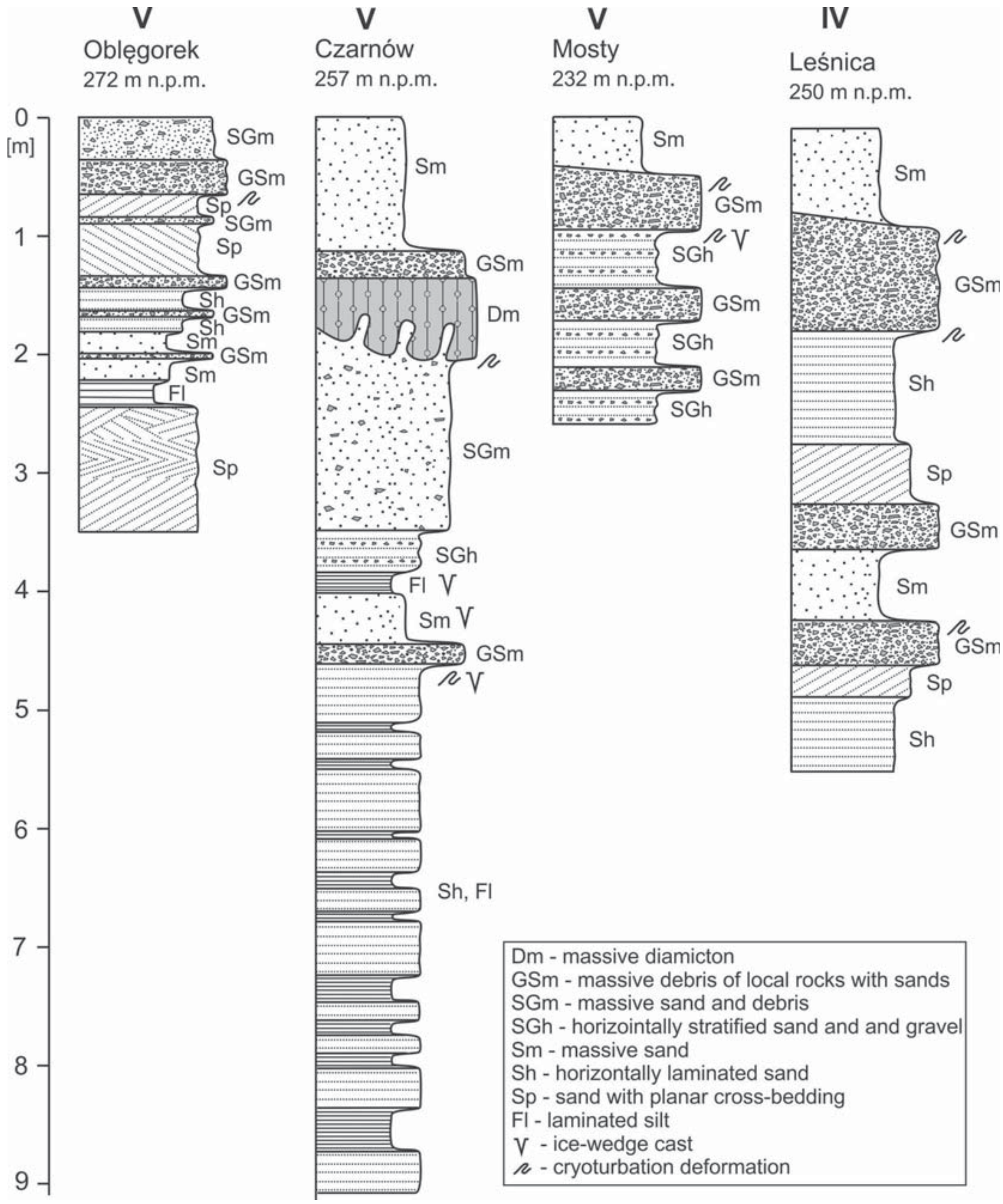

Fig. 4. Lithological columns of deposits of valley level V (Oblęgorek, Czarnów, Mosty) and valley level IV (Leśnica), after Giżejewski and Lindner (1977a, modified), Lindner (1977a, modified) and Cabalski *et al.* (2018a, modified). Symbols of lithofacies after Zieliński (1995).

gravel and deposits of debris flows composed of sharp-edged limestone rubble. They represent proglacial and extraglacial flows, directed towards the south for the first time during the maximum extent of the Odranian ice sheet (Lindner, 1977a; Lindner and Mastella, 2002). Further to the south and south-east, sediments of the level V were recorded in the Biała Nida Valley in localities to the south of the Korzeczkowskie Range, where they are extremely well exposed near Mosty (Fig. 3). According to Cabalski *et al.* (2018b), horizontally-bedded sand intercalated with debris flow deposits of the level V is sheared by deluvial limestone debris, occurring at several levels in the upper part of a gravel pit (Fig. 4). Debris flows developed during several stages of mass wasting in permafrost conditions, as indicated not only by enlarged debris concentrations, but also cryoturbation structures and ice-wedge pseudomorphs.

In the Czarna Nida, Hutka and Bobrza catchments, valley accumulation during the maximum limit of the Odranian ice sheet led to formation of the level V in the extraglacial zone, without any influence of proglacial water. In the Hutka catchment, sand of this level is located from 255–245 m a.s.l. in the northern part of the catchment (Lindner and Kowalski, 1974) to 250–245 m a.s.l. in its southern part. In the Czarna Nida catchment fragments of the level V are preserved at 242–250 m a.s.l. and at 255–248 m a.s.l. Sediments of this level are represented mainly by vari-grained sand with significant admixture of gravel. They were known to Filonowicz (1972) and based on their lateral transfer into slope deposits connected with the Odranian and Vistulian glaciations. Łyczewska (1971) assumed a possible contribution of proglacial waters of the older glaciations in development of the highest valley levels in the Czarna Nida catchment as a result of water transfer from the Wilków Valley (northern slopes of the Holy Cross Mountains) to the south along the Lubrzanka gorge (*cf.* Kowalski, 2002)

In the northern part of the Bobrza catchment the surface of the level V is located at 285–270 m a.s.l. Near Oblęgorek (Figs. 3 and 4), sediments of this level are represented by a sandy-silty complex covered with loam-rubble debris flow deposits composed of local rocks, enriched with Scandinavian material of older glaciations and overlying sand with rubble of local rocks. In the western part of the Upper Bobrza Valley, sediments of the level V are locally covered by loess of the last glaciation (Lindner, 1971).

In the central part of the Bobrza catchment, the level V dips slightly from 270–260 m a.s.l. to 255–252 m a.s.l. At Czarnów in the Sufraganiec Valley (left tributary of Bobrza), sediments of the level V represent a typical fluvio-periglacial accumulation (Fig. 4; Giżejewski and Lindner, 1977). They are developed as 9-m thick complex (Fig. 4) and its lower part is composed of sand interbedded with silt (Sh, Fl). They represent deposition in low-energy water conditions and very good sorting of material, most probably during the Liviecian Glaciation (Fig. 5). This material, accumulated above a fluvial series of the Mazovian Interglacial (Lindner and Giżejewski, 1977) is derived from older covers of sand and loess(?) od the Sanian 1 and Sanian 2 glaciations. During the anaglacial phase of the Liviecian Glaciation, this material moved to valleys by sheet flows and numerous floods.

Dimensions of the ice-wedge pseudomorphs occurring in the upper part of these sediments (Fig. 4) point to shrinkage of reservoir and permafrost conditions in the Odranian sand and silt, favouring soil freezing to several metres depth. The following warming, probably during the Zbójnian Interglacial (Fig. 5), is indicated by shearing of sand and silt surface by a gravel-sandy series (GSm, Sm in fig. 4), evidently representing flow conditions. Lack of washing out of earlier wedge structures indicates that the flow must have been active on a frozen substrate. Younger sand and silt accumulation (Fl in fig. 4) and permafrost conditions indicated by the above mentioned frost wedges, 0.5 m deep, suggest shallower freezing than in the previous case, most probably during the Krznanian Glaciation (Fig. 5).

The overlying sand with gravel (SGh) are remains after a water flow during the Lublinian Interglacial (Fig. 5). They are overlain by sand and gravel that created the alluvial fan formed by the Sufraganiec Stream at its mouth

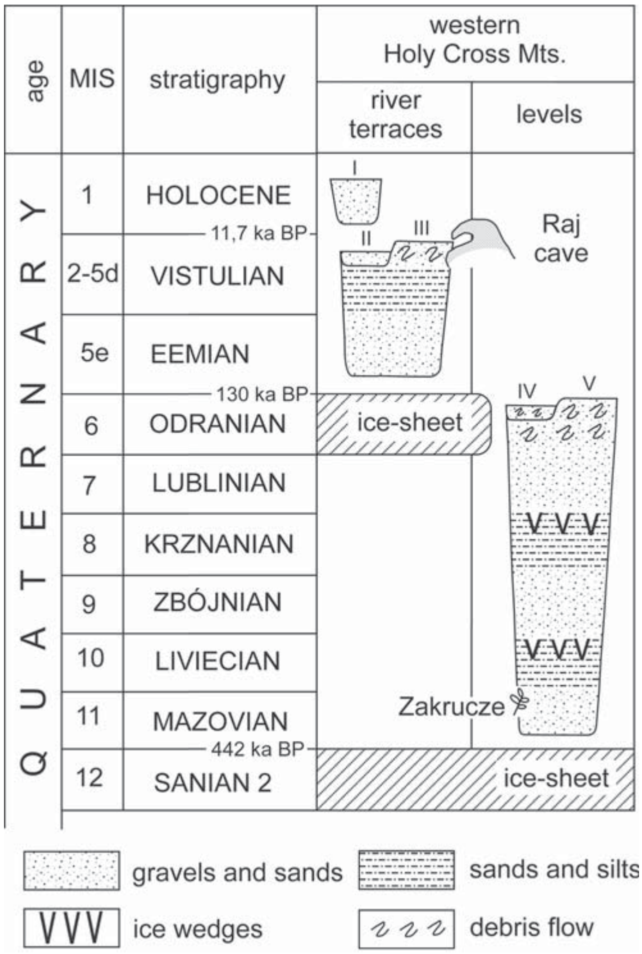

Fig. 5. Geochronology of the analysed deposits of valley levels and river terraces in the western part of the Holy Cross Mountains.

to the Bobrza Valley. The fan forms a sub-surface part of the level V, temporarily linked with the maximum limit and possibly also the retreat of the Odranian ice sheet (Giżejewski and Lindner, 1977; Lindner, 1977a). Such rapid and enormous alluvial fan accumulation was caused probably by fast melting of multi-annual snow and could have been deposited in extraglacial conditions on slopes and passes of the Holy Cross Mountains.

Warming that preceded the alluvial fan accumulation led probably to gradual increase of the active layer thickness in a frozen ground which, following significant altitude differences, resulted in formation of congelifluxion flows. In the Czarnów sequence (Fig. 4), deposits of this flow include loam and sand, which deform the underlying deposits. It corresponds to the melted and displaced upper part of diamicton from the older glaciations (Sanian 2), *in situ* exposures of which occur about 150 m apart from this sequence. Traces of deformation such as involutions and diapirs in a contact zone between the loam-sandy complex and the underlying deposits developed as strongly saturated sand, are most probably the deformations characteristic of unstable density stratification (Dżułyński, 1966).

The highest part of the Czarnów succession is a residual lag (GSm) developed on top of the loam-sandy complex and overlain by sand with rare cobbles (Sm), which are a parent rock of the modern soil. This lag evidences washing out of flow deposits, whereas the overlying sand represents terminal accumulation of the level V in the Middle Bobrza catchment, corresponding probably to the retreat of the Odranian ice sheet (Fig. 5).

In the lower part of the Bobrza catchment, sediments of the level V occur at 250–238 m a.s.l. In the middle Nida Valley, proglacial and extraglacial waters of the level V became connected at 245–235 m a.s.l. Due to youger erosion and accumulation (development of the level IV and river terraces), sediments of the level V are preserved on the slopes of this only and do not form a distinctly flat valley bottom (Hakenberg and Lindner, 1971).

Level IV (14–8 m a.r.l.)

The formation of the level IV is linked to the first stage of the Odranian ice sheet retreat (Lindner 1977a). In the western part of the Holy Cross Mountains, this stage was characterised by an extremely increased water runoff in the valleys, related to melting of the marginal part of the ice sheet and the multi-annual snow in the extraglacial area.

In the Wierna Rzeka catchment (Fig. 3), a runoff of proglacial waters occurred from the Łopuszno area to the south-east and it became connected with extraglacial waters in the Padół Strawczyński area to form the erosional level IV at 251–246 m a.s.l. A characteristic feature of the level IV is a small accumulation series (2 m thick), represented by sand and gravel located on an erosional plinth, usually eroded within ice-dam deposits of the level V from the maximum of the Odranian Glaciation. In the southern part of the Wierna Rzeka catchment, the surface of the level IV is located at 250–237 m a.s.l. Near Gnieździska (Figs. 2 and 3), sediments of the level IV infill a depression incising a glacial till from the maximum range of the Odranian ice sheet or deposits from the level V. Thanks to numerous excavations for water-sewage collectors of the Małogoszcz cement plant, sand of this level near Zakrucze is characterised by distinct cross-bedding, presence of wave ripples and silt-clay interbeds, in places disturbed due to unstable density stratification.

In the southern part of the Wierna Rzeka Valley, the surface of the level IV is located at 249–238 m a.s.l. and at 238–234 m a.s.l. within the gorge near Bocheniec. At Leśnica near Małogoszcz, sediments of this level were accumulated in the extraglacial zone and are represented (Fig. 4) by poorly sorted sand with interbeds of debris flow deposits composed of Jurassic limestones, covered by several dozen centimetres thick debris with traces of chemical weathering of a limestone rubble and overlying sand. In the Biała Nida Valley and at its junction with the Wierna Rzeka and Hutka valleys, the surface of the level IV is located at 235–226 m a.s.l. In the Biała Nida Valley in the southern part of this area, the surface of the level IV is preserved at 230–223 m a.s.l. Sediments of this level are represented also by sand with debris flow deposits composed of pre-Quaternary rocks. These flows, often represented as loam-rubble colluvia within sand of level the IV, indicate that similarly as the underlying level they were mdeveloped mostly by active slope processes, particularly intensive in fluvio-periglacial settings (fluvial and slope accumulation).

In the Czarna Nida and Bobrza catchments, erosion-denudation processes connected with the initial retreat of the Odranian ice sheet were not as distinct as in the Wierna Rzeka catchment. Lowering of the erosion-accumulation base level in this area was marked only as a trend to river incision into the surface of the level V and cutting of the overlying extraglacial alluvial fans near Czarnów.

Slope sediments formed in periglacial conditions of the Odranian Glaciation, preserved within the accumulation series of both valley levels described above (V and IV) were identified probably also in the central part of the Holy Cross Mountains, where glacial deposits correlated with MIS 6 are documented (Ludwikowska-Kędzia *et al.*, 2015; Ludwikowska-Kędzia and Pawelec, 2011, 2014).

FLUVIAL TERRACES

Terrace III (8–5 m a.r.l.)

The surfaces of the V and IV levels were incised by deep rivers probably during Eemian Interglacial. In the optimum phase of this interglacial, valley depths reached 30–40 m in relation to the surface of the level V and did not exceed 20 m only in the case of side valleys (Hakenberg and Lindner, 1971; Lindner, 1977a).

Gradual deterioration of climate conditions in the post-optimal part of the interglacial favoured infilling of the valleys during four gravel-sandy accumulation cycles, the youngest of which builds the terrace III (Figs. 2 and 3). In most cases sediments of this terrace are represented by sandy-rubble series up to 15 m thick. In many cases they are interbedded with debris flow loams and interbeds of silty sand, and in the marginal zone they contain ancient flows and slides of slope material, indicating valley widening due to lateral erosion. Accumulation of sediments of this terrace took place in typical fluvial-slope conditions (fluvio-periglacial according to Łyczewska, 1968, 1971).

In the case of the Bobrzyczka Valley (right tributary of Bobrza), sediments of the terrace III are represented mainly by medium- and vari-grained sand with interbeds of loessy silt, debris loam and deposits of slope flows composed of glacial till (Lindner and Braun, 1974). A characteristic element of this terrace is a cover of sharp-edged rubble of local rocks, several dozen centimetres or even 1 m thick, which allows to designate it as a rubble terrace (compare Lindner, 1972). Lack of a loessy cover on the terrace III in the zone with loess on slopes

(Lindner, 1971) allows to conclude that their accumulation must have preceded the interval during which the terrace was formed. Traces of this terrace, as well as interfingering of the upper part of alluvial deposits (silts with sand lenses) with deposition on the surface of the terrace III (Madeyska, 1974) can be observed at the entrance to the Raj Cave (Fig. 4).

Slope deposits incorporated within the older accumulation series of the terrace III in the western part of the Holy Cross Mountains correspond probably to silty and silty-sandy loam (debrites) on the slopes of the Bielińskie Range (central part of the Holy Cross Mountains), TL-dated at 70.0 ka BP and 48.0–29.8 ka BP, and referred to the middle and younger part of the Vistulian Glaciation (Ludwikowska-Kędzia and Olszak, 2009; Pawelec and Ludwikowska-Kędzia, 2016).

Terrace II (4–2 m a.r.l.)

A milder climate in the terminal part of the Vistulian Glaciation favoured erosion, incising surface of the terrace III in river valleys of the area (Figs. 2 and 5). A maximum of this erosion took placed during the Alleröd and infilling of valleys occurred mainly in the Younger Dryas when climate conditions promoted activity of braided rivers of the terrace II (Hakenberg and Lindner, 1971; Lindner, 1984; Ludwikowska-Kędzia and Olszak, 2000; Kalicki *et al.*, 2019).

Deposits of the terrace II, up to 3–5 m thick, are represented by vari-grained sand with rubble of local rocks and fine gravel, and with interbeds of fine sand and alluvial mud. Dune-like forms are preserved on surface of this terrace in the Wierna Rzeka and Bobrza catchments. Following ice-dams and related floods in the Late Holocene, the terrace II was locally covered with alluvial mud in valleys of larger rivers (Biała Nida and Czarna Nida) (Krupa, 2013; Kalicki *et al.,* 2019).

Terrace I (2–0.5 m a.r.l.)

The youngest alluvial series in river valleys of the western part of the Holy Cross Mountains (Fig. 2) is represented by sediments of the terrace I (floodplain). In the lower part of the valleys, particularly of Biała Nida and Czarna Nida, four distinct cascades (at 2.0 m, 1.2 m, 0.8 m and 0.5 m above a river level) can be observed on a floodplain (*cf.* Krupa, 2013, 2015, Kalicki *et al.*, 2019). Field observations and analysis of aerial photographs (Hakenberg and Lindner, 1973) indicate that three higher cascades belong to subsequent stages of meander development in the floodplain, whereas the lowermost cascade is represented by modern point bars.

Analysis of drillings made for hydrotechnical need, numerous probes and observations prove that the floodplain is composed of vari-grained sand with gravel, with interbeddings of peat and accumulation of black tree trunks, as well as fluvial mud and other fluvial deposits. These sediments occur in erosional incisions of higher fluvial terraces (in the lower parts of the valleys) and also in incisions of valley infillings in higher geomorphological settings.

Numerous probes and exposures in marginal zones of the terrace I indicate that almost its entire succession contains considerable admixture of organic material. It is expressed in most cases by a humus-related dark colour of sand and dispersed plant shred in alluvial mud, but interbeddings of peat or accumulations of branches and black tree trunks are also be present. Presence of tree trunks distinguishes the highest cascade from the lower ones. When it is undercut by a river, as in the case of Czarna Nida, the tree trunks are exposed within the modern river channel slightly below a water level. Radiocarbon age of tree trunks from this level is 1190 ± 120 years BP (Lindner, 1977b). Deposition of tree trunks forms a sort of a plinth for channel deposits, thus hampering deeper reworking of alluvia. Similar accumulations of tree trunks are preserved inter alia at a margin of the Lubrzanka River channel near Cedzyna (central part of the Holy Cross Mountains), where their radiocarbon age is 2810 ± 50 years BP (Kowalski, 2002).

CONCLUSIONS

The valley levels and river terraces distinguished in the western part of the Holy Cross Mountains are presented with respect to their geology and age (Fig, 5). Distribution of high valley levels (V and IV) presented for the western part of the Holy Cross Mountains, their geology and sediment age range from the Mazovian Interglacial to the maximum limit and first stages of the Odranian ice sheet retreat as well as coupling of sedimentation with contemporary periglacial conditions supplies with detailed palaeogeographic characteristics of this area in the younger part of the middle Pleistocene. According to the collected data, the main factors responsible for such vast distribution of sand accumulation above the modern valley bottoms were contemporary fluvial, glaciofluvial and fluvioperiglacial processes. These processes, particularly the latter ones, led to degradation of the older series (sand, loess and glacial diamicton) accumulated during the older glaciations (Sanian 1 and Sanian 2). Their significance was enhanced by common slope processes, characteristic of periglacial conditions.

These conditions contributed also to accumulation of the uppermost river terrace (III), formation of which took place during the maximum part of the Vistulian Glaciation (Fig. 5). A formation of the lower river terrace (II) is also indirectly related with climate deterioration in a terminal part of this glaciation (Younger Dryas). The four-cascade floodplain (I) should be generally linked with deformations of the longitudinal profile of rivers, caused by human activity related to deforestation and acquisition of new farming areas.

Acknowledgements

We would like to thank the anonymous reviewers for valuable comments on the manuscript. Special thanks to Dr Małgorzata Ludwikowska-Kędzia for careful analysis of the paper and precious suggestions.

REFERENCES

Cabalski, K., Dzierżek, J., Kowalczyk, S., 2018a. Subsurface deposits at the foot of the Grzywy Korzeczkowskie Range in the site Mosty, Holy Cross Mts. (Osady przypowierzchniowe u podnóży Grzyw Korzeczkowskich w Mostach (Góry Świętokrzyskie) w obrazie GPR). In: Lejzerowicz, A. (Ed.), Materiały III Ogólnopolskiego Sympozjum Geointerdyscyplinarnych Metod Badawczych ECEG, Chęciny, 11–13 kwietnia 2018, 29 (in Polish).

Cabalski, K., Dzierżek, J., Kowalczyk, S., 2018b. Pleistocene periglacial structures in the Mosty site, near Chęciny (The Holy Cross Mountains). In: Ludwikowska-Kędzia, M., Wiatrak, M. (Eds), Mat. XXV Konferencji Stratygrafia Plejstocenu Polski "Plejstocen Gór Świętokrzyskich", 78–80, Huta Szklana, 3–7 września 20018, Politechnika Świętokrzyska, Uniwersytet Jana Kochanowskiego, Kielce (in Polish with English summary).

Czarnocki, J., 1931. Dyluwium Gór Świętokrzyskich. Rocznik Polskiego Towarzystwa Geologicznego 7, 82–105 (in Polish with German summary).

Czarnocki, J., 1938. Ogólna mapa geologiczna Polski w skali 1:100 000, ark. 4, Kielce. Instytut Geologiczny, Warszawa (in Polish).

Dżułyński, S., 1966. Sedimentary structures resulting from convection-like pattern of motion. Rocznik Polskiego Towarzystwa Geologicznego 36 (1), 3–21.

Filonowicz, P., 1972. Pleistocene deposits in the SW part of Holy Cross Mts. Rocznik Polskiego Towarzystwa Geologicznego 42 (1), 105–116 (in Polish with English summary).

Filonowicz, P., Lindner, L., 1986. Szczegółowa mapa geologiczna Polski w skali 1:50 000, ark. Piekoszów. Wydawnictwa Geologiczne, Warszawa (in Polish).

Giżejewski, J., Lindner, L., 1977. Czarnów – deposition of fluvioperiglacial sediments in the Sufraganiec Valley and their stratigraphic position (in Polish with English summary). In: Lindner, L., Michalska, Z. (Eds), Przewodnik Sympozjum Terenowego „Czwartorzęd zachodniej części regionu świętokrzyskiego", 7–13, Warszawa-Kielce, 6–10 czerwca 1977, Wydawnictwa Geologiczne.

Hakenberg, M., 1973. Mapa geologiczna Polski w skali 1:50 000, ark. Chęciny. Inst. Geol. Warszawa (in Polish).

Hakenberg, M., Lindner, L., 1971. Quaternary deposits of the middle Nida Valley. Acta Geologica Polonica 21 (2), 241–264 (in Polish with English summary).

Hakenberg, M., Lindner, L., 1973. Holocene history of the middle Nida Valley. Acta Geologica Polonica 23(2), 435–444 (in Polish with English summary).

Kalicki, T., Frączek, M., Przepióra, P., Kusztal, E., Kłusakiewicz, E., Malęga, E., 2019. Late Quaternary geomorphology and geoarchaeology in the rivers of the Holy Cross Mountains region, central Europe. Quaternary Research 91, 584–599.

Klatka, T., 1965. Geomorfologia Gór Świętokrzyskich. Roczniki Gleboznawcze 15, 129–162 (in Polish with English summary).

Konon, A., 2008. Tectonic subdivision of Poland: Holy Cross Mountains and adjacent areas. Przegląd Geologiczny 56(10), 921–926 (in Polish with English summary).

Kowalski, B. J., 2002. Origin and age of the flooded and above flooded (high) terrace of the middle part of the Lubrzanka Valley in the Holy Cross Mts. In: Jaśkowski, B. (Ed.), Periglacial issues of Poland and areas of neighbourhood. Prace Instytutu Geografii Akademii Świętokrzyskiej w Kielcach 8, 151–215 (in Polish with English summary).

Krupa, J., 2013. Naturalne i antropogeniczne procesy kształtujące dno doliny Czarnej Nidy w późnym vistulianie i holocenie. Folia Quaternaria 81 (1), 5–174 (in Polish with English summary).

Krupa, J., 2015. Natural and anthropogenic channel pattern changes in the mid-mountain Valley during the Late Glacial and Holocene, Polish Uplands. Quaternary International 370, 55–65.

Lindner, L., 1971. Loess deposits at Oblęgorek near Kielce (Holy Cross Mts.). Acta Geologica Polonica 21(2), 265–278 (in Polish with English summary).

Lindner, L., 1972. Pleistocene stratigraphy and palaeogeomorphology of the north-western margin of the Holy Cross Mountains, Poland Studia Geologica Polonica 35, 1–113 (in Polish with English summary).

Lindner, L., 1977a. Pleistocene glaciations in the western part of the Holy Cross Mountains (central Poland). Studia Geologica Polonica 53, 1–143 (in Polish with English summary).

Lindner, L., 1977b. The age of river flood-terraces from the Góry Świętokrzyskie in the light of ^{14}C datings of the "black oak" levels Kwartalnik Geologiczny 21(2), 325–334 (in Polish with English summary).

Lindner, L., 1984. The Holy Cross Mts. Region (Region Świętokrzyski). In: Sokołowski, S., Mojski, J.E. (Ed.), Budowa geologiczna Polski, t. 1, Stratygrafia, część 3b, Kenozoik – czwartorzęd, 33–35, 65–73, 113–145, 255–286, 326–330. Wydawnictwa Geologiczne.

Lindner, L., Braun, J.J., 1974. Stratigraphie du Quaternaire et développement morphologique de la vallée de la Bobrzyczka aux environs de la grotte de Raj. In: Rubinowski, Z. (Ed.), Badania i udostępnienie jaskini Raj, 131–141, Wydawnictwa Geologiczne (in Polish with French summary).

Lindner, L., Dzierżek, J., 2013. Pleistocene glaciations and interglacials in the Holy Cross Mts. Region – a new approache. In: Bąbel, M., Dzierżek, J., Olszewska-Nejbert, D. (Eds), Od Czarnohory po Góry Świętokrzyskie – geologiczne peregrynacje, Polsko-Ukraińska Sesja Naukowa, Warszawa-Bocheniec, 15–19 października 2013, 39–44, Instytut Geologii Podstawowej Wydziału Geologii Uniwersytetu Warszawskiego (in Polish).

Lindner, L., Dzierżek, J., 2019. Pleistocene deposits in the western part of the Holy Cross Mountains. Studia Quaternaria 36 (2), 75–85.

Lindner, L., Kowalski, W.R., 1974. Quaternary cover around Mt. Miedzianka in the Holy Cross Mts. Acta Geologica Polonica 24 (2), 415–424 (in Polish with English summary).

Lindner, L., Mastella, L., 2002. Origin and age of the Wierna Rzeka (Łososina) gorge in the vicinity of Bocheniec, SW Mesozoic margin of the Holy Cross Mts. In: Jaśkowski, B. (Ed.), Geomorphological issues of the mountains and uplands in Poland. Prace Instytutu Geografii Akademii Świętokrzyskiej w Kielcach 6, 21–46 (in Polish with English summary).

Lindner, L., Rzętkowska-Orowiecka, A., 1998. New data on interglacial sediments at Zakrucze near Małogoszcz, the Holy Cross Region. Geological Quarterly 42 (2), 201–207.

Ludwikowska-Kędzia, M., Olszak, L., 2000. Terasa wysoka doliny Belnianki w rejonie Słopca Szlacheckiego – budowa i wiek osadów. Materiały konferencyjne „Geomorfologia gór i wyżyn w Polsce, kontrowersje i nowe spojrzenia", Wólka Milanowska, 16–19.05. 2000. IG WSP, Kielce, 76–78 (in Polish).

Ludwikowska-Kędzia, M., Olszak I., 2009. Lithology and stratigraphy of periglacial slope sediments of the Bielińskie Range near Huta Stare Koszary. In: Ludwikowska-Kędzia, M., Wiatrak, M. (Eds), Known data – new interpretations in the field of geology and geomorphology of the Holy Cross Mountains. Instytut Geografii Uniwersytetu Jana Kochanowskiego w Kielcach, 75–89 (in Polish with English summary).

Ludwikowska-Kędzia, M., Pawelec, H., 2011. Osady glacigeniczne w rejonie Mąchocic Kapitulnych. In: Ludwikowska-Kędzia, M, Wiatrak, M. (Eds), Geologia i geomorfologia Regionu Świętokrzyskiego. Instytut Geografii UJK, Kielce, 71–87 (in Polish).

Ludwikowska-Kędzia, M., Pawelec, H., 2014. Depositional environment of the glacigenic deposits from the Holy Cross Mountains (Poland) – interpretation based on macro- and microstructure analyses Geological Quarterly 58 (4), 807–826.

Ludwikowska-Kędzia, M., Pawelec, H., Adamiec, G., 2015. Sedminetological interpretation and stratigraphical position of glaciogenic deposits in the Napęków area (Holy Cross Mountains, Poland). Geologos 21 (4), 261–284.

Łyczewska, J., 1968. L'accumulation fluvio-périglaciaire dans la partie central du Bassin de la Nida, Pologne Centrale. Biuletyn Peryglacjalny 17, 125–147.

Łyczewska, J., 1971. The Quaternary of the Góry Świętokrzyskie Region. Prace Instytutu Geologicznego 64, 5–108 (in Polish with English summary).

Madeyska, T., 1974. Litologie et stratigraphie des sédiments dans la grotte de Raj. In: Rubinowski, Z. (Ed.), Badania i udostepnienie jaskini Raj, 61–91, Wydawnictwa Geologiczne (in Polish with French summary).

Marks, L., Dzierżek, J., Janiszewski, R., Kaczorowski, J., Lindner, L., Majecka, A., Makos, M., Szymanek, M., Tołoczko-Pasek, A., Woronko, B., 2016. Quaternary stratigraphy and palaeogeography of Poland. Acta Geologica Polonica 66 (3), 403–427.

Pawelec, H., Ludwikowska-Kędzia, M., 2016. Macro- and micromorphologic interpretation of relic periglacial slope deposits from the Holy Cross Mountains, Poland. Permarfost and Periglacial Processes 27 (2), 227–247.

Zieliński, T. 1995. Kod litofacjalny i litogenetyczny – konstrukcja i zastosowanie. In: Mycielska-Dowgiałło, E., Rutkowski, J. (Eds), Badania osadów czwartorzędowych. Wybrane metody i interpretacja wyników, Uniwersytet Warszawski, 220–235 (in Polish with English summary).