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PLEISTOCENE DEPOSITS IN THE WESTERN PART OF THE HOLY CROSS MOUNTAINS

Leszek Lindner, Jan Dzierżek*

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

** corresponding author*

Abstract:

The paper presents characteristics of the Pleistocene sediments in the western part of the Holy Cross Mountains. They are subdivided into four complexes and their stratigraphic setting is referred to the updated scheme for the Pleistocene of Poland. The Preglacial Complex includes fluvial sediments characteristic for its lack of Scandinavian material. Sediments of three main glaciations (Nidanian, Sanian 1 and Sanian 2) within the South Polish Complex, are referred also as the South Polish Glaciations. The oldest of these glaciations (Nidanian) is separated from the middle glaciation (Sanian 1) by sediments of the Podlasian Interglacial, represented by clay at the Kozi Grzbiet Cave that contains faunal remains and record of the Brunhes/Matuyama palaeomagnetic boundary. During the middle (Sanian 1) and youngest glaciation (Sanian 2), the Holy Cross Mountains were almost completely covered by the Scandinavian ice sheet, forming glacial deposits separated by fluvial series of the Ferdynandovian Interglacial. The Middle Polish Complex begins with sediments of the Mazovian Interglacial, represented by a pollen record from the Zakrucze site. They are followed by deposits of periglacial and fluvial origin of the Liwiecian Glaciation, Zbójnian Interglacial, Krznanian Glaciation and Lublinian Interglacial. The following glaciation (Odranian) is represented by the youngest glacial deposits that document presence of the Scandinavian ice-sheet in the westernmost part of the Holy Cross Mountains. The North Polish Complex is composed of a climatic warming (Eemian Interglacial) and cooling (Vistulian Glaciation), and is represented by valley and periglacial deposits. The last cooling of the Pleistocene is recorded in faunal remains in the Raj Cave.

Key words: Quaternary deposits, Holy Cross Mts., glacial palaeogeography, interglacial records

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INTRODUCTION

Recent detailed studies of the Pleistocene in the western part of the Holy Cross Mountains (Figs 1, 2) indicated that after the Early Pleistocene (Preglacial) there is a complete record of all Middle and Late Pleistocene Scandinavian ice-sheets (e.g. Czarnocki, 1931; Łyczewska, 1971; Lindner, 1977a, 1978, 1984, 1988a; Lindner *et al.*, 2013; Lindner and Dzierżek, 2013, 2018). Cold intervals are recorded by glacial deposits or traces of periglacial conditions prevailing beyond the maximum ice-sheet extent. Stratigraphic setting of glaciations is calibrated by cave deposits with Cromer-type fauna at the Kozi Grzbiet site near Chęciny and preservation of the boundary of Brunhes/Matuyama palaeomagnetic epochs (Głazek *et al.,* 1976, 1977). Equally important is presence of organic deposits of the Mazovian Interglacial at Zakrucze near Małogoszcz (Lindner and Rzętkowska-Orowiecka, 1998) and of cave deposits with faunal remains and Palaeolithic tools in the Raj Cave near Kielce (Kaczanowska, 1974; Madeyska, 1974). Particularly valuable are results of geological mapping for the Detailed Geological Map of Poland in scale 1:50 000, sheets Chęciny (Hakenberg, 1973) and Piekoszów (Filonowicz and Lindner, 1986). Additionally, stratigraphic reinterpretation of periglacial structures in sediments of the oldest (V) fluvioperiglacial horizon at Czarnów near Kielce (compare Giżejewski and Lindner, 1977; Dzierżek *et al.*, 2019) was also important.

MATERIAL AND METHODS

Analysed data were collected during long-term investigations in the study area including mapping, geomorphological analysis, and interpretation of borehole and outcrop sections, petrographic analyses of tills, palaeozoological and pollen analyses, and geophysical profiling. Besides, data from abundant publications were critically evaluated, with special consideration of the most important and well documented geological sites in the region.

Fig. 1. Location of the study area in the western part of the Holy Cross Mountains in relation to extents of the Sanian 1, Sanian 2, Odranian and Vistulian glaciations in Poland.

The main goal of research was to build a coherent and comprehensive model of the Quaternary deposits in the western part of the Holy Cross Mts, in strict reference to the current scheme of the Polish Quaternary stratigraphy. This model can be useful for regional correlation of Quaternary deposits, which is very important to order steadily increasing amount of geological data from the Holy Cross Mts.

PREGLACIAL COMPLEX

The Preglacial Complex (MIS 23-103) is represented by fluvial gravel, sand and silt characterised by a lack of Scandinavian material. They are preserved near Ruda Strawczyńska at 215–220 m a.s.l., set on a weathering cover of the pre-Quaternary rocks (Lindner, 1977a). They represent fluvial deposits (Fig. 2) of the ancient Wierna River, which at first flew to the south, then turned to the west on the northern side of the Małogoskie Range towards the Kleszczów Graben near Bełchatów (Lindner, 1978). In the Kozi Grzbiet succession, the Preglacial Complex is represented by fine-grained, cherry-red sand with clay interbeds, which probably represent disintegrated and washed out weathering covers of the Buntsandstein rocks (Głazek *et al.,* 1977).

SOUTH POLISH COMPLEX

Nidanian Glaciation (MIS 22)

The South Polish Complex begins with glaciofluvial sand and ice-dammed silt, and the overlying till of the Nidanian Glaciation. In Ruda Strawczyńska, this till is 3 m thick and occurs above fluvial deposits of the Kozienice Series (Fig. 2). Its continuation may be traced to the north to the pass in the western part of the Oblęgorskie Range, where it is bi- or even tripartite (Lindner, 1977a) and indicates a limit of a glacial lobe, was separated from the ice sheet that stagnated at culminations of the pre-Quaternary basement near Mniów.

Podlasian Interglacial (MIS 17–21)

Brownish cave clay preserved above the mentioned deposits in the Kozi Grzbiet Cave (Figs 2, 3) contains abundant bone fragments and gastropod shells, pieces of limestones and carbonate speleothems. Based on the collagen index of the analysed bone fragments (Głazek *et al.,* 1976, 1977), the clay may be subdivided into three horizons, with the middle one characteristic for a distinct cooling. This layer contains biotite, glauconite, pyroxenes and amphiboles, and its age was determined by co-occurrence of

Pliomys lenki, *Mimomys savini*, *Dicrostonyx simplicior*, *Ursus deningeri*, *Helicigona banatica* and *Pliobatrachus langhae*, which point out to the Late Cromerian faunal assemblage (Głazek *et al.,* 1976). A similar conclusion may be drawn from FCl/P absolute age determinations of the bones at 700–550 ka BP, which point out to the Cromerian II. This conclusion supplements a record of the Brunhes/Matuyama palaeomagnetic boundary, dated at 780 ka BP in the lower part of the cave clay (Głazek *et al.,* 1977).

Sanian 1 Glaciation (MIS 16)

This glaciation is well documented in almost entire study area by ice-dammed silt and glacial till, recognised in numerous drillings. The till is 5–8 m thick and is preserved e.g. at Leśnica Parcele, Ruda Strawczyńska and Skiby (Fig. 2). The till contains in the Bobrza and Hutka catchments many erratics of the Neogene (Lithothamnium limestone and Sarmatian marl) and the Palaeozoic (Devonian sandstone and limestone, and Cambrian quartzite), except for the Scandinavian material.

Ferdynandovian Interglacial (MIS 13–15)

It is represented by sand and gravel preserved above deposits of the older glaciation. They infill local depressions within a sedimentary cover of this glaciation or ancient fluvial series, preserved in incisions in the pre-Quaternary rocks.

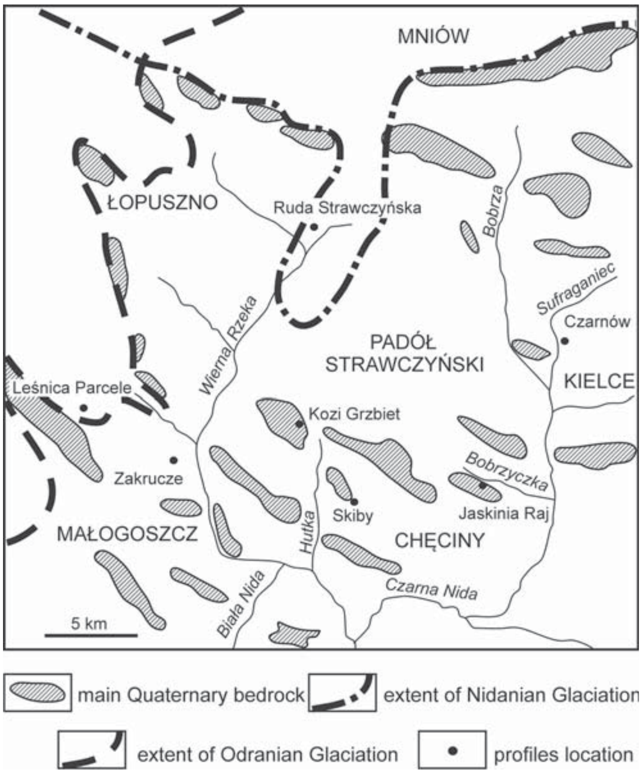

Fig. 2. Location of the cited sections in relation to the maximum extents of the Nidanian and Odranian glaciations in the western part of the Holy Cross Mountains.

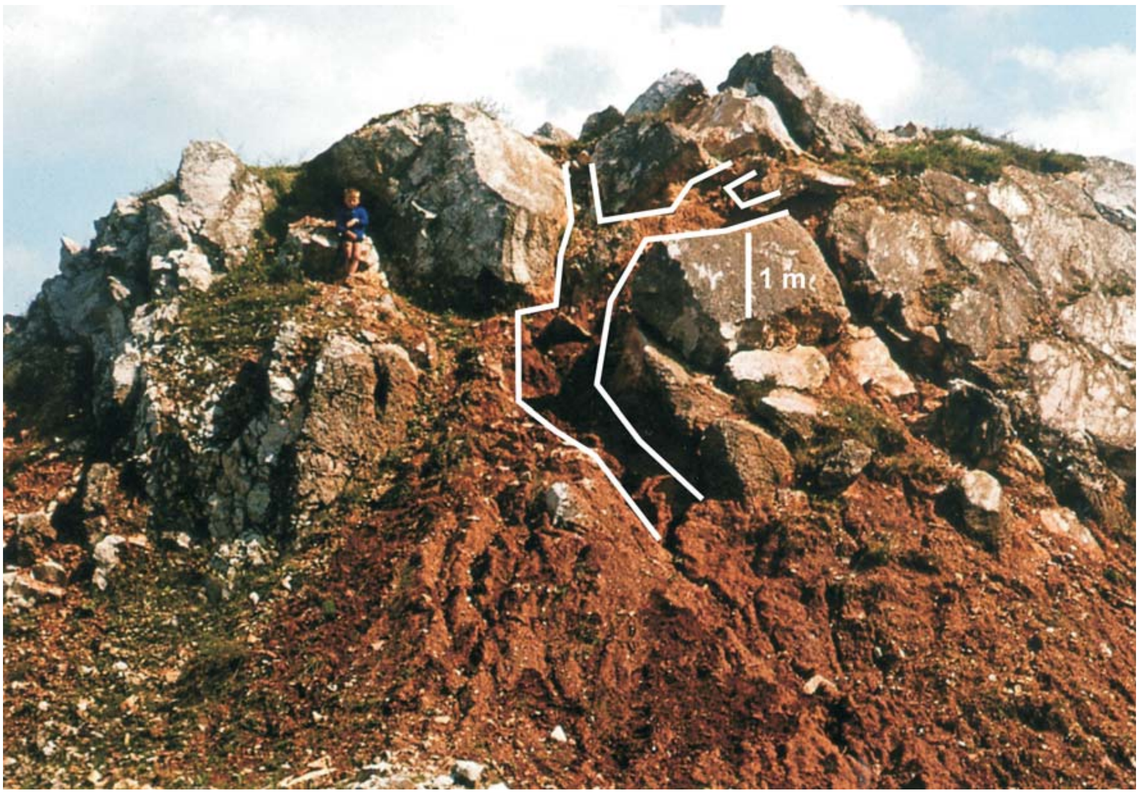

Fig. 3. Site Kozi Grzbiet with the Podlasie Interglacial deposits (phot. L. Lindner, 1972).

Fig. 4. Kame sands on the western slope of Miedzianka Hill (phot. L. Lindner, 1972).

Sanian 2 Glaciation (MIS 12)

This glaciation is documented by a younger, 3–8 m thick till preserved in the entire area and noted at numerous sites. It is underlain by ice-dammed silt, whereas accumulations of glaciofluvial sand and gravel occur commonly on its surface. They attain a form of kames or kame terraces at 350–400 m a.s.l. at Miedzianka (Fig. 4), accumulated within concave nunataks (ice-free oases) (Lindner and Kowalski, 1974). At 250–300 m a.s.l., these sediments form vast surfaces within the Padół Strawczyński basin. They build prominent kame terraces adjoining elevations composed of the pre-Quaternary rocks (Lindner, 1977b). They document contemporary deglacial conditions in the valleys, favouring development of fissure accumulation forms (Fig. 5; Radłowska and Mycielska-Dowgiałło, 1972).

MIDDLE POLISH COMPLEX

Mazovian Interglacial (MIS 11)

Intensive development of erosional-denudation processes is recorded by river valleys and gravel-sand accumulations. A valley system is a significant evidence of these processes, corresponding to the older network open to the west, towards the erosional base, most probably located in the Kleszczów Graben (Lindner and Mastella, 2002). Analysis of the borehole material from the western part of the Holy Cross Mountains and numerous geoelectrical surveys related with the formerly planned water reservoirs on Nida and Wierna rivers indicated that during the Mazovian Interglacial, the ancient Nida with its tributaries of Czarna Nida and Biała Nida flew towards the north and north-west. Passing across a depression between the high grounds of the Bocheńska Hill (Czubatka) and the Milechowska Hill, these rivers formed a valley system with the ancient Wierna River on the northern side of the Małogoskie Range. In the area with carbonate rocks, such deep fluvial erosion led to development of a valley system, 30–50 m deep. It favoured also a development of karst processes, resulting in creation of more or less distinct depressions. A relatively deep water-filled basin with organic accumulation was formed at the bottom of one of these depressions at Zakrucze near Małogoszcz. Pollen analysis of silt, bituminous shale and peat indicated climatic conditions typical of a climatic optimum of the Mazovian Interglacial, with domination of *Alnus*, *Quercus*, *Carpinus* and *Abies* (Lindner and Rzętkowska-Orowiecka, 1998).

Liwiecian Glaciation (MIS 10)

This glaciation was distinguished, based on reanalysis of deposits at Czarnów in the western part of the Holy Cross Mountains (Giżejewski and Lindner, 1977), at that

Fig. 5. Road cut across a fissure feature (esker) at Radkowice (phot. L. Lindner, 1972).

time located beyond the maximum extent of the ice-sheet (see Marks *et al*., 2016). Rhythmically bedded sand and silt, up to 4 m thick in the lower part of the sequence (Figs 2, 3), overlies the laterally exposed glacial till of the Sanian 2 Glaciation and is incised by an ice wedge, 2 m deep, that may be correlated with periglacial climatic conditions during the Liwiecian Interglacial. A cross-section of the Sufraganiec valley proves that these deposits are underlain by fluvial series of the Mazovian Interglacial (Giżejewski and Lindner, 1977). It may be assumed that these deposits represent fluvial accumulation in low-energy conditions and very good sorting (Dzierżek *et al*., 2019). Similar deposits were noted also in the lower catchment of the Wierna River, where they are about 20 m thick and overlie fluvial deposits of the Mazovian Interglacial (Lindner, 1977a). Further to the west, they were noted in the western margin of the Holy Cross Mountains, where they were TL-dated at 388 ka BP in the Czarna Sulejowska catchment (Lindner and Marciniak, 2008).

Zbójnian Interglacial (MIS 9)

This interglacial represents a subsequent climatic warming in the study area. It is indicated at Czarnów (Fig. 6) by shearing of the surface of older sand-silt deposits by a gravel-sand series, which may represent a remnant of fluvial deposits of the Sufraganiec River. This warming may be correlated with the Zbójnian Interglacial as evidenced by pollen data from the Zbójno section located in the Czarna Sulejowska catchment (Lindner and Brykczyńska, 1980). TL ages of this interglacial indicate the age >236 ka BP and these deposits are covered by a glacial till, TL-dated at 239–256 ka BP (Lindner and Marciniak, 2008) which corresponds to the Krznanian Glaciation.

Krznanian Glaciation (MIS 8)

Climatic conditions of this glaciation at Czarnów (Figs 2, 6) are documented by fine sand overlain by a thin cover of silt, cut by ice wedges to 0.5 m depth. The wedges indicate shallower freezing of the basement than in the case of the older wedge. New age interpretations of these sediments and of the incising wedges permit for their correlation with subsequent younger climatic cooling that may correspond to the Krznanian Glaciation (Dzierżek *et al*., 2019).

Lublinian Interglacial (MIS 7)

A subsequent climatic warming in the younger part of the Middle Pleistocene is marked by erosional shearing of silt with ice wedges and its covering by sand with gravel at Czarnów. This series evidences a flow that caused a formation of a huge Sufraganiec point bar or its alluvial

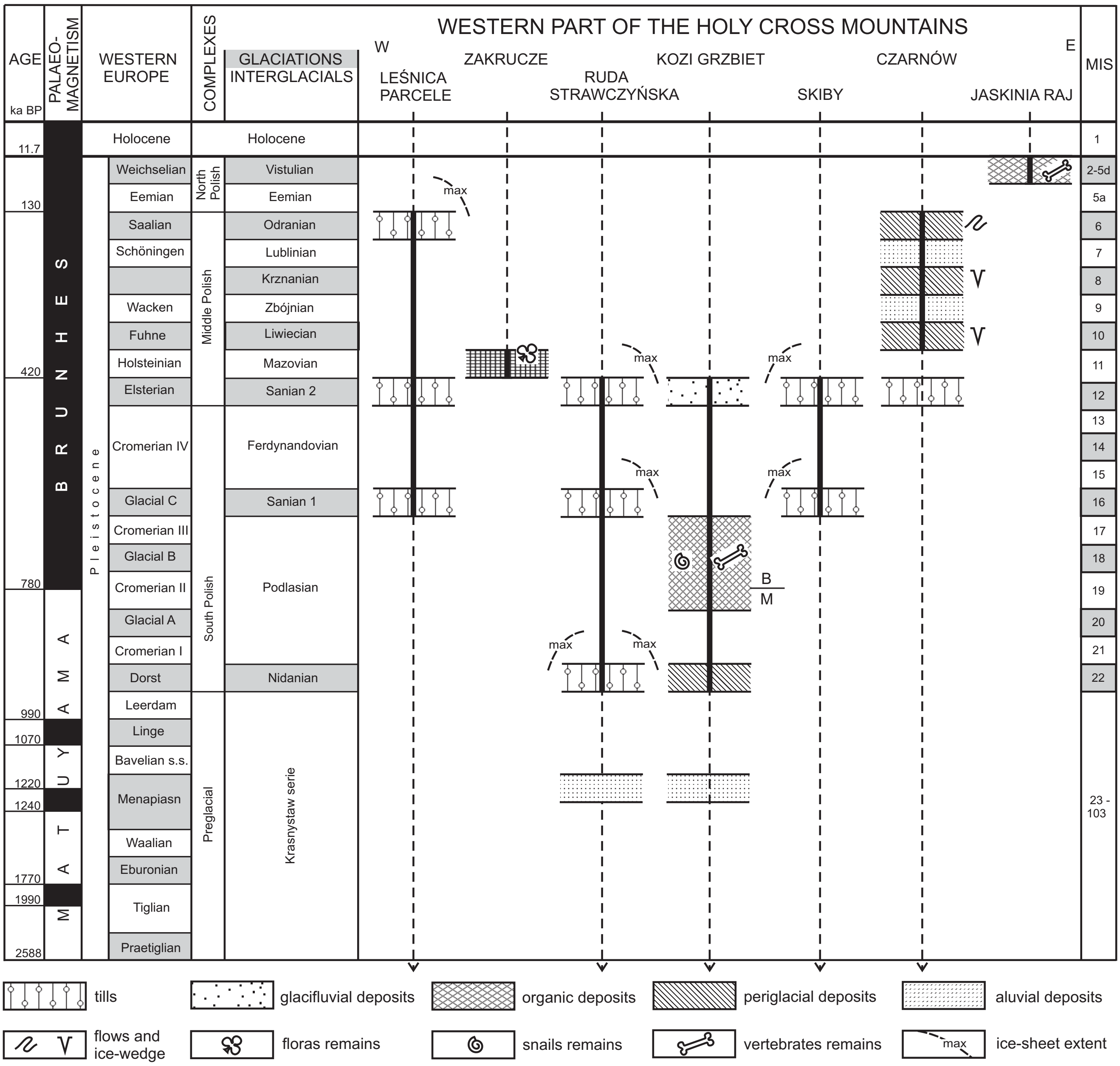

Fig. 6. Age of main types of the Pleistocene deposits in selected sections of the western part of the Holy Cross Mountains.

fan at the mouth of the Bobrza valley. A development of the alluvial fan was referred to a distinct warming, during which rapid accumulation of the Sufraganiec fluvial series caused a shift of Bobrza River towards the western slope of the valley and then forced a flow at the western side of Górki Szczukowskie. Such rapid and immense fluvial accumulation was most probably induced by fast melting of multi-annual snow, which could accumulate during the earlier glaciation on slopes and passes of higher ranges of the Holy Cross Mountains (Giżejewski and Lindner, 1977). According to the present knowledge, such significant climatic warming could take place during the Lublinian Interglacial (Dzierżek *et al.*, 2019). In the study area it is evidenced by the mid-loess Tomaszów-type interglacial soil at Tomaszów near Opatów (Jersak, 1969) and at Odonów in the Miechów Upland (Lindner, 1988b). According to palaeomagnetic data (Nawrocki and Siennicka-Chmielewska, 1996), the soil may represent a warming correlated with MIS 7, younger than the Chegan-Biva II palaeomagnetic episode (280–290 ka BP) and older than the Jamaica-Biva I palaeomagnetic episode (180–170 ka BP).

Odranian Glaciation (MIS 6)

It is indicated by rapid cooling and onset of periglacial conditions, marked at Czarnów by development of congelifluction flows that accompanied formation of the valley level V (Giżejewski and Lindner, 1977; Dzierżek *et al.*, 2019). In this section (Fig. 6), clay-sandy, 2 m thick deposits indicate such a flow that disturbs the underlying sediments. These deposits represent melted and displaced upper part of a glacial till of the Sanian 2 Glaciation, located 150 m to the north-east from Czarnów (Filonowicz and Lindner, 1986). The noted involutions and diapirs are probably characteristic for unstable density stratification (see Dżułyński, 1966).

A formation of the valley level V, located at 18–14 m above the river channel, represents fluvioperiglacial deposits *sensu* Łyczewska (1968) and it took place in Bobrza, Sufraganiec, Hutka and Czarna Nida catchments. In other valley systems of the western part of the Holy Cross Mountains (Wierna River and Biała Nida), the valley level V was formed by proglacial waters (Lindner 1977a; Dzierżek *et al.*, 2019). Release of these waters was evidently related to the Odranian Glaciation ice sheet, front of which reached during maximum the Leśnica Parcele-Gnieździska-Łopuszno line (Fig. 2) as indicated based on detailed geological mapping of glacial till, end moraines and fissure forms, as well as ice-dammed and sand-gravel sediments of the level V. Glacial till of that time is preserved at Leśnica Parcele, where it occurs above a glacial till of the Sanian 1 and Sanian 2 glaciations (Fig. 6). A geological context, particularly in relation to a setting of the Mazovian Interglacial deposits beyond the ice sheet extent at Zakrucze, is well documented by numerous drillings made for requirements of the Małogoszcz cement works.

Deposits of the level V contain commonly numerous flows of slope material that usually represent weathering covers of the pre-Quaternary rocks (Lindner, 1977a; Cabalski *et al.,* 2018). According to the present-day knowledge, the Odranian Glaciation with its retreat stadial of Wartanian is correlated to MIS 6 and the contemporary glacial tills are TL-dated at 181–147 ka BP (Lindner, 1992; Lindner *et al.*, 2013). Sediments of the valley level V in the axial part of the valleys (particularly of Wierna, Biała Nida and Nida rivers) were erosionally incised at the beginning of the Odranian ice sheet retreat and combined with immense release of a proglacial water. The valley level IV, located at 8–14 m above the river level, was formed at that time and it was an initial phase of development of the present Nida valley system, from this moment inheriting a flow to the south, towards the Vistula valley.

NORTH POLISH COMPLEX

Eemian Interglacial (MIS 5e)

This first interval starts the Late Pleistocene (Fig. 2) and is recorded in the study area by fluvial activity. Maximum erosion took place during the interglacial optimum. Drill-core data related to the water reservoirs on Nida, Biała Nida and Czarna Nida rivers and in the lower stretch of the Wierna River indicate that in most cases axes of contemporary rivers may be correlated with axes of older valleys (Lindner, 1977a). During the optimum of the Eemian Interglacial, the valley depth reached 30–40 m in relation to the surface of the buried valley from the maximum of the Odranian Glaciation, i.e. from the formation of the level V. In relation to the present valley floodplain, bottoms of these valleys are located at depths of 25–10 m. Such deep erosion was favoured by capture of slope material by vegetation and increased rainfall (*cf.* Marks *et al.*, 2019). Within the valleys and their tributaries, fluvial deposits of the Eemian Interglacial age are represented mainly by gravel with low admixture of medium and coarse sand. These sediments are 3–5 m thick and predominated by pebbles of local rocks (Hakenberg, 1973; Filonowicz and Lindner, 1986). The Bedlno site near Końskie is the closest floristic locality that documents contemporary vegetation (Środoń and Gołąbowa, 1956), with climatic optimum indicated by domination of *Corylus*, *Quercus* and *Tilia*.

Vistulian Glaciation (MIS 2–5d)

Gradual deterioration of climatic conditions by the end of the Eemian Interglacial (Marks *et al.,* 2018) led to prevalence of accumulation in the river valleys of the Holy Cross Mountains area at the beginning of the Vistulian Glaciation. This accumulation corresponded directly to a change in dynamic regime of contemporary rivers, supplied by slope processes with detritic material exceeding a river load. As evidenced by studies of contemporary fluvial deposits, burial of valley depressions was not continuous and included several cycles of gravel-sand accumulation, separated by valley widening caused by lateral erosion (Hakenberg and Lindner, 1971). Geological-geomorphological mapping indicated that sediments of the youngest cycle (up to 6–8 m thick) form the terrace III, a level of which rises to 8–5 m above the present-day river (Dzierżek *et al.*, 2019). Development of the terrace III took place during the maximum development of periglacial conditions of the Vistulian Glaciation (Hakenberg and Lindner, 1971), probably during the maximum extent of the ice sheet.

Debris-clay deposits in the Raj Cave (Fig. 6) show that numerous remains of small rodents, birds, fish, frogs and large mammals (Kaczanowska, 1974; Kowalski, 1974; Madeyska, 1977), and flint tools are accompanied by water accumulations of washed-out loess and sand of the terrace III of the Bobrzyczka River (Lindner and Braun, 1974). Analysis of these facts evidences that the age of the Raj Cave sediments may be related to the interglacial and the following main stadial of the Vistulian Glaciation, when a loess cover at Słowik and Oblęgorek (Lindner, 1971b) and the terrace III was formed. Flint tools preserved in the Raj Cave mark that the Palaeolithic man appeared in the western part of the Holy Cross Mountains at 54–40 ka BP.

The terminal part of the main stadial of the Vistulian Glaciation is marked by erosional incision of the terrace III, mainly during the Allerød warming, followed by filling of valleys by deposits of braided rivers and development of the terrace II (4–2 m high), corresponding to the Younger Dryas cooling (Hakenberg and Lindner, 1971).

The Holocene (MIS 1) is linked with accumulation of the terrace I in river valleys in the study area (Hakenberg and Lindner, 1973), formation of dunes and organic deposits in valleys karst cavities and depressions around dune forms.

DISCUSSION

Long-term studies of the Pleistocene in the western part of the Holy Cross Mountains allow for a complete geological interpretation of its deposits in terms of the modern stratigraphic scheme of the Polish Pleistocene.

The Preglacial Complex is represented by fluvial accumulation documented by sediments without the Scandinavian material. These sediments were deposited in valleys flowing to the west, towards the Kleszczów Graben. They may correspond to a younger part of the Preglacial series correlated with the Krasnystaw Series (comp. Mojski, 2006). The older part of the preglacial deposits correlated with the Kozienice Series may be recorded within the ancient Biała Nida and ancient Bobrza valleys, located at higher elevations and directed south-eastwards (compare Lindner, 1977a). Recent studies performed to the north of the parallel stretch of the Pilica valley indicated that most deposits of the Kozienice Series are of the Pliocene age (Bujak *et al.,* 2016; Marks *et al.,* 2016).

During this part of the Pleistocene that is represented by the South Polish Complex, the study area was occupied by three Scandinavian ice sheets. The oldest ice sheet (Nidanian Glaciation) reached the main mountain ranges in the northern part of the area, invaded the catchment of the present Wierna River (tributary of the Nida River) with a relatively narrow glacial lobe. In contemporary periglacial conditions beyond the maximum extent of this ice sheet, repeated freezing and melting caused 'brecciation' of cherry-red weathering clay above preglacial sand in the in the Kozi Grzbiet Cave.

During the Podlasian Interglacial cave deposits at Kozi Grzbiet were deposited, containing numerous fauna remains and record of the Brunhes/Matuyama palaeomagnetic boundary (780 ka BP). In the northern part of the Holy Cross Mountains, the older part of this interglacial is recorded in organic deposits at Ceteń on the Drzewiczka River (Borówko-Dłużakowa, 1977; Lindner *et al*., 2013).

In the middle and younger part of the Middle Pleistocene, the area was covered by ice sheets of the Sanian 1 and Sanian 2 glaciations, recorded by glacial tills and glaciofluvial sand and gravel. Petrographic characteristics of till erratics confirms earlier opinions of Czarnocki (1931) and Różycki (1972) on the Sanian 1 Glaciation ice sheet advance from the east and south-east, reaching the eastern and southern part of the Padół Strawczyński basin by numerous glacial lobes (Lindner, 1977a). The central part of this basin was probably devoid of ice and formed a nunatak (ice-free oasis) at that time, bounded from the west by glacial lobes of the ice sheet approaching from the west and depositing glacial till.

Organic deposits of the Ferdynandovian Interglacial have not been noted in the study area. In turn, they are preserved to the west near the Kleszczów Graben (Kuszell, 1991; Marciniak, 1991) and to the south of the parallel stretch of the Pilica River at Podgórze (Jurkiewiczowa *et al.,* 1973) and Białobrzegi (Janczyk-Kopikowa, 1991). To the south-east of the Holy Cross Mountains, this interglacial is probably documented by a palaeosol that separates glacial tills of the Sanian 1 and Sanian 2 glaciations at Wydymacz near Staszów (Walczowski, 1972; Lindner, 1988b).

Glacial till of the Sanian 2 Glaciation, similarly as that of the older glaciation, is characterised by erratics of local origin (Czarnocki, 1931). As evidenced by analysis of numerous boreholes, soundings and outcrops (Hakenberg, 1973; Filonowicz and Lindner, 1986), presence of these erratics, transported by the ice sheet from the east, exceeds the area of the Padół Strawczyński basin and reaches the upper catchment of the Wierna River. In this area, as well as at the culmination of the Oblęgorskie and Chęcińskie ranges, this ice sheet contacted with the main mass of the Scandinavian ice sheet advancing from the north-west (Lindner, 1977a). As a result, a specific ice 'suture' developed, favourable for development of kames during deglaciation. At Kozi Grzbiet, kame sand mantles the earlier functioning cave. TL age of the sand determined by M. Prószyński is equal to 440–400 ka BP (Lindner, 2009). On slopes of culminations composed of the pre-Quaternary rocks, particularly in the Oblęgorskie and Zgórskie ranges, glacial and glaciofluvial deposits interfinger with congelifluxion flows of clay-boulder weathering covers documenting periglacial conditions (Lindner and Bogucki, 2002).

During the Mazovian Interglacial, sediments of which begin the Middle Polish Complex, intensive development of fluvial processes took place and valleys were formed, open to the west, towards the Kleszczów Graben. This event is documented at Zakrucze, represented by shallow water reservoir developed within a karst depression. A middle part of this complex is recorded by periglacial and fluvial deposits, subsequently documenting a climate change (Liwiecian Glaciation, Zbójnian Interglacial, Krznanian Glaciation, Lublinian Interglacial) beyond the extent of the contemporary ice sheets. Ice sheets of the Liwiecian and Krznanian glaciations did not occupied the western part of the Holy Cross Mts. An extent of the Zbójnian ice sheet is located to the north of the Holy Cross Mountains and the Wieprz River exit to the Vistula, where it was TL-dated at 393–354 ka (Żarski, 1994). The ice sheet of the Krznanian Glaciation stagnated several dozen of kilometres to the north of the study area and it was treated previously (Lindner, 1971a; Jurkiewiczowa *et al.,* 1973) as an equivalent of the pre-maximum stadial of the Odranian Glaciation.

The younger part of the Middle Polish Complex is documented by glacial deposits of the Odranian Glaciation, during which the Scandinavian ice sheet reached the westernmost part of the area in the vicinity of Małogoszcz. Beyond its extent, the levels V and IV were formed, representing deposition of both proglacial and extraglacial waters, with numerous interbeddings of slope deposits composed mostly of redeposited weathering covers of local pre-Quaternary rocks.

The North Polish Complex represents deposits of the Eemian Interglacial and Vistulian Glaciation, including river terraces III and II, and accompanying slope covers. The clays in the Raj Cave contain faunal remains and flint tools that record the first appearance of the Palaeolithic man at 54–40 ka BP that is in the middle and younger part of the Vistulian Glaciation. Further fluvial activity led to development of the terrace I in the Holocene.

The presented occurrence of the Pleistocene deposits in the western part of the Holy Cross Mountains is very similar to deposits preserved in the central part of the area (compare Ludwikowska-Kędzia and Olszak, 2009; Ludwikowska-Kędzia, 2017). Main differences are related mainly to the assessment of their stratigraphic position, particularly age of tills of the South Polish glaciations, and genetic and stratigraphic characteristics of slope deposits (polygenetic complex), part of which may be considered as remains in situ of glacial deposits of the Odranian Glaciation (compare Ludwikowska-Kędzia, 2017).

CONCLUSIONS

The research allowed to complete geological interpretation of the Pleistocene deposits in the western part of the Holy Cross Mountains in reference to the current stratigraphic scheme of the Polish Pleistocene.

The oldest Pleistocene deposits in the western part of the Holy Cross Mountains belong to the Preglacial Complex and they are of fluvial origin. Deposits occurring within the ancient Biała Nida and ancient Bobrza valleys can be correlated with the older part of Preglacial Complex deposits (Kozienice Series), whereas fluvial deposits of the ancient Wierna River with the Krasnystaw Series.

There is an evidence for occurrence of ice sheets during Nidanian, Sanian 1, Sanian 2 and Odranian glaciations. Tills of Sanian 1 and Sanian 2 glaciations are well documented almost in the whole study area. The oldest ice sheet (Nidanian Glaciation) reached the northern part of the area (with a narrow glacial lobe in the catchment of present Wierna River). The ice sheet of the Odranian Glaciaton reached the westernmost part of the area in the vicinity of Małogoszcz. Depositional glacial complexes are completed by glaciofluvial sand and gravel, and by periglacial features. The main interglacial deposits in the western part of Holy Cross Mts are well documented at Kozi Grzbiet (Podlasian Interglacial) in cave deposits with numerous remains of fauna, and at Zakrucze (Mazovian Interglacial) in organic deposits. The North Polish Complex is represented by deposits of river terraces with accompanying slope covers, cave clays of the Raj Cave and loess.

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