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Evolution of the Mid- to Late Pleistocene river network in the southeastern part of the Holy Cross Mountains

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Geological and palaeogeographic maps, geological cross sections, and longitudinal river profiles are used to reconstruct the evolution of the Pleistocene river network in the southwestern Mesozoic margin of the Holy Cross Mountains. Particular attention is drawn on the formation of the Wierna Rzeka gorge in the vicinity of Bocheniec. The gorge is of tectonic origin, and was inherited following glacifluvial flow during the Odranian (Wartanian?) Glaciation maximum, when the ice-front reached the Bukowa–Gnieździska–Łopuszno line, and during early retreat.

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Key words: SW margin of the Holy Cross Mts., Mid- and Late Pleistocene, pre-Quaternary basement, ancient river valleys.

INTRODUCTION

The aim of the paper is to reconstruct the evolution of the Mid- to Late Pleistocene river network within the southwestern Mesozoic margin of the Holy Cross Mts. (Figs. 1 and 2). The study is based on abundant core data and electric logs from Quaternary deposits, as well as on the lithological and tectonic data from pre-Quaternary deposits. The latter were collected during the preparation of the Chęciny (Hakenberg, 1973, 1974) and Piekoszów charts (Filonowicz and Lindner, 1986, 1987) of the *Detailed Geological Map of Poland* at the 1:50 000 scale, as well as during investigations on the Quaternary in the area (Hakenberg and Lindner, 1971, 1973; Lindner, 1977, 1978, 1984, 1995; Lindner and Rzętkowska-Orowiecka, 1998).

It was suggested (Hakenberg and Lindner, 1971) that, during the Great Interglacial (Mazovian *sensu lato*), the proto-Nida in its southern section flowed northwards, opposite to the present-day direction. Later, Lindner (1977) showed that its present-day flow (from north to south) was inherited from glaciofluvial flow from the front of the Middle Polish Glaciation ice sheet, which reached the Bukowa–Gnieździska–Łopuszno line. Later investigations suggested flow of a proto-Czarna Nida towards the Włoszczowa basin through the valley system of the present-day Biała Nida during the Great Interglacial (Lindner, 1978). Then, the proto-Nida collected waters from all rivers of the southwestern part of the Holy Cross Mountains region, and the watershed separating the catchment area of these rivers was located in the present-day Wierna Rzeka gorge near Bocheniec. It was suggested therefore that the proto-Wierna Rzeka then carried its waters to the west, along the northern side of the Przedbórz-Małogoszcz Range (Lindner, 1978).

Evaluation of previously collected geological and geophysical data as well as analogous data obtained in the mid-seventies by the “Hydrogeo” company for the “Chęciny” reservoir, as well as field observations and palynological data from the Mazovian Interglacial *sensu stricto* site in Zakrucze near Małogoszcz (Lindner and Rzętkowska-Orowiecka, 1998) allow a new interpretation of the origin and age of the Wierna Rzeka gorge near Bocheniec.

GEOLOGICAL SETTING

The geological setting of the area analysed is presented with regard to the lithology and age of the Quaternary deposits,

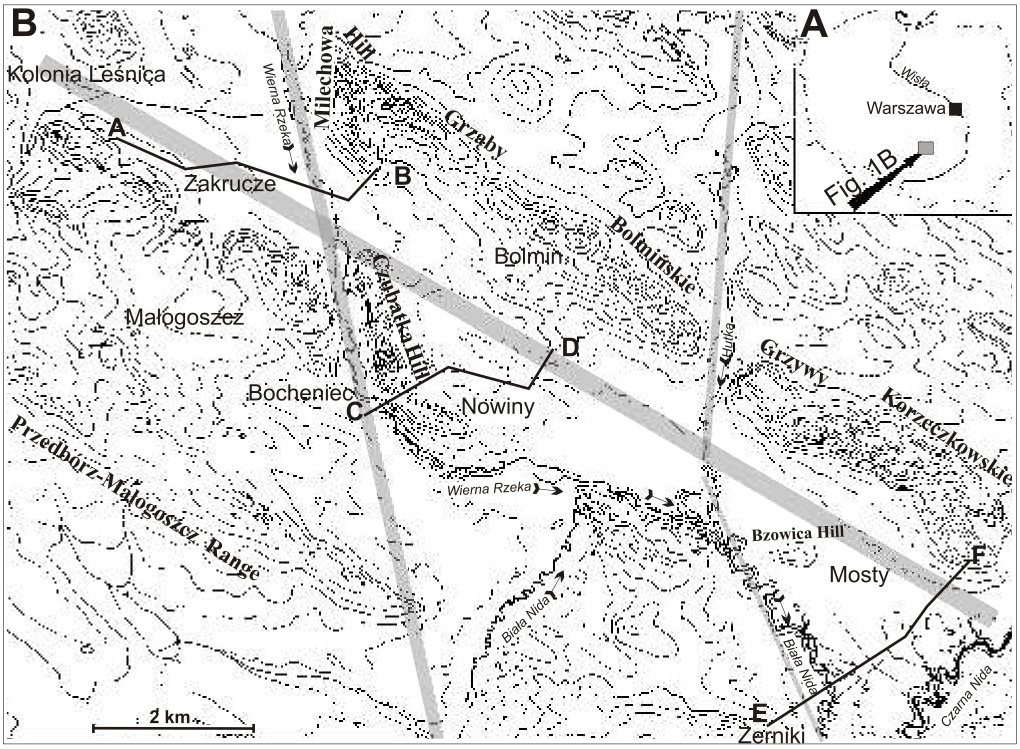

Fig. 1. Location (A) and morphological (B) sketch map of the area analysed with location of cross-sections (A–B, C–D, E–F from Fig. 4); the main fault zones are marked in grey

as well as to the lithology, tectonics and age of the pre-Quaternary basement.

PRE-QUATERNARY BASEMENT

The pre-Quaternary basement (the so-called older basement) comprises the western part of the Mesozoic margin of the Holy Cross Mts. (Czarnocki, 1938; Stupnicka, 1989, 1997), built here of Triassic to Upper Cretaceous deposits (Czarnocki, 1938; Hakenberg, 1971, 1974; Filonowicz and Lindner, 1986, 1987). In the area analysed it adjoins the Palaeozoic core of the mountains which lies to the south (Figs. 1 and 2).

Triassic deposits occur in the NE of the area analysed (Fig. 2). They comprise brownish-red sandstones, siltstones and claystones, with platy marly limestones at the top (Buntsandstein-Roetian). The upper part of the sequence comprises grey pelitic limestones with numerous bivalves and brachiopods, grey-yellowish marls and cellular limestones (Muschelkalk) as well as cherry-red claystones and siltstones, (Keuper) (Fig. 3).

Early Jurassic deposits are not present in the investigated area. The Jurassic succession begins with grey-yellowish gaizes of Callovian age (Mid-Jurassic). The pre-Quaternary basement is mainly composed of Late Jurassic deposits. They include nodular limestones, succeeded by pelitic limestones, platy limestones, spotted limestones with flints and massive limestones with sponges, of Oxfordian age (Fig. 3). These deposits build, among others, the eastern part of hills in the vicinity of Bocheniec and their continuation to the east, as well as hills to the south from Bocheniec and to the north from Grz¹by Bolmiñskie (Figs. 1B and 2B). Marly (chalky) limestones, transitional between the Oxfordian and Kimmeridgian, do not crop out in the area (Fig. 3). Oolitic, pelitic, light grey limestones and coquina beds occurring above are also of Kimmeridgian age. They build the western part of hills near Bocheniec, Milechowa Hill, Grz¹by Bolmiñskie and Grzywy Korzeczkowskie and they occur in a belt from ¯erniki (Figs. 1B and 2B). Marls and marly claystones prevail in the upper part of the succession.

The Early Cretaceous is represented by sandstones, conglomerates and gaizes (Albian), passing upwards into limy sandstones and glauconitic sandstones of Cenomanian age (Fig. 3). These deposits occur in a depression between hills in the vicinity of Bocheniec and Grz¹by Bolmiñskie, forming a small elevation, on which the Bolmin village is located (Figs. 1B and 2B). The upper part of the succession is a monotonous Late Cretaceous succession of marls and marly opokas with cherts and gaizes (Fig. 3).

The older basement is a fault-fold belt. The Bocheniec Anticline occurs in the southern part of the area (Stupnicka, 1971, 1972; Hakenberg, 1974). The central and northern part of the area, to the east of the Wierna Rzeka river, is occupied by the Bolmin Syncline, to the west of which the Małogoszcz Syncline occurs (*op. cit.*) (Fig. 2B). These are open folds with *ca.* 20° dipping limbs. Steep dips are observed only in the vicinity of faults. The axes are generally WNW-ESE. In the vicinity of Wierna Rzeka river, however, the Bolmin Syncline axis diverges to the NNW, whereas the axis of the Małogoszcz Syncline diverges to the SE (Fig. 2B). The divergence is linked

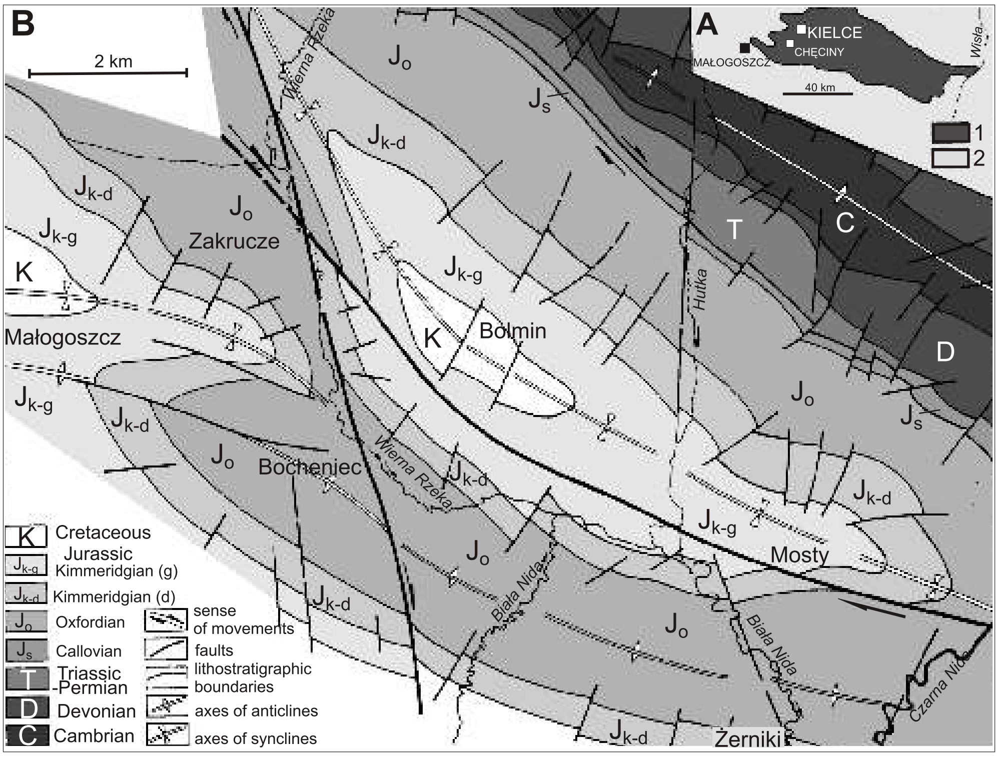

Fig. 2. **A** — location sketch-map of the area analysed in relation to the main geological structures of the Holy Cross Mts.: 1 — Mesozoic margin, 2 — Palaeozoic core; **B** — generalised tectonic sketch-map of the area analysed, based on Czarnocki (1938), Hakenberg (1973, 1974), Filonowicz and Lindner (1986, 1987), and individual investigations; other explanations see Figure 3

with a large fault along the Wierna Rzeka river in its southern part, separating the two synclines (Fig. 2B). The fault, of a dip-slip character with the western bloc downthrownk, was earlier a dextral strike-slip fault. Another parallel fault is located along the Hutka river (Fig. 2). Its character has not been determined. The large WNW-ESE fault, cutting the northern limb of the Bolmin Syncline south of Zaj¹czków and continuing towards Starochêciny (Fig. 2B) is, based on map analyses (Czarnocki, 1938; Hakenberg, 1971, 1974) clearly a dextral oblique-slip fault.

A large fault of the same trend cuts the Bolmin Syncline slightly to the south of its axis (Fig. 2B). The fault is shown on maps by Czarnocki (1938) and Hakenberg (1974). Analysis of these maps, as well as geological maps on a 1:10 000 scale (prepared during cartographic field courses of the Department of Geology, Warsaw University) and air photographs, including radar images, suggests a dextral strike-slip component of this fault (Fig. 2B). The strike-slip movement is indicated by the displacement of the Czubatka Hill ax is in relation to the Milechowa Hill ax is (Figs. 1B and 2). This fault has a wide fault zone (Fig. 1B), as is characteristic of strike-slip faults (Tchalenko and Ambraseys, 1970; Tan and He, 1982; Mandl, 1988, 2000; Mollema and Antonelli, 1999), also in the Holy Cross Mountains area (Jaroszewski, 1972). Within this zone the rocks are less resistant to erosion, and so this fault is well marked in the morphology of the area. It is most distinct in the western part of the area, where a 1 km wide depression between the Czubatka and Milechowa Hills occurs above the fault zone (Figs. 1B and 2B). Eastwards, in the vicinity of Nowiny, the fault zone passes into a valley, periodically discharging water to the Biała Nida near the Hutka river outlet (Fig. 1B). East of Hutka, the fault zone separates Grzywy Korzeczkowskie from the Bzowica Hill and continues in a depression in the Mosty village (Figs. 1B and 2B), passing eastwards into the Czarna Nida valley. The section of the fault zone analysed between the Wierna Rzeka river and the Czarna Nida is over 15 km long and is expressed as a 1.5 km wide depression (Fig. 1B).

QUATERNARY

The distribution, lithology and age of the Quaternary deposits in the area investigated is discussed in relation to earlier studies by Hakenberg and Lindner (1971, 1972); Lindner (1977, 1978, 1984, 1995) and Lindner and Rzêtkowska-Orowiecka (1998) and shown as three geological cross-sections (Figs. 1 and 4). All geological data were used in constructing the cross-sections.

Kolonia Leśnica-Zakrucze-Wierna Rzeka river valley cross-section. The cross-section (A–B) (Figs. 1B and 4) runs from Kolonia Leœnica to the west to the Wierna Rzeka river valley and the Milechowa Hill slope. The thickness of Quaternary deposits within the cross-section varies from several metres on the slopes of Milechowa Hill and 20–40 m in the vicinity of Kolonia Leœnica and Zakrucze, up to almost 90–100 m in the Wierna Rzeka river valley zone, where their basement was determined at 133–132 m a.s.l.

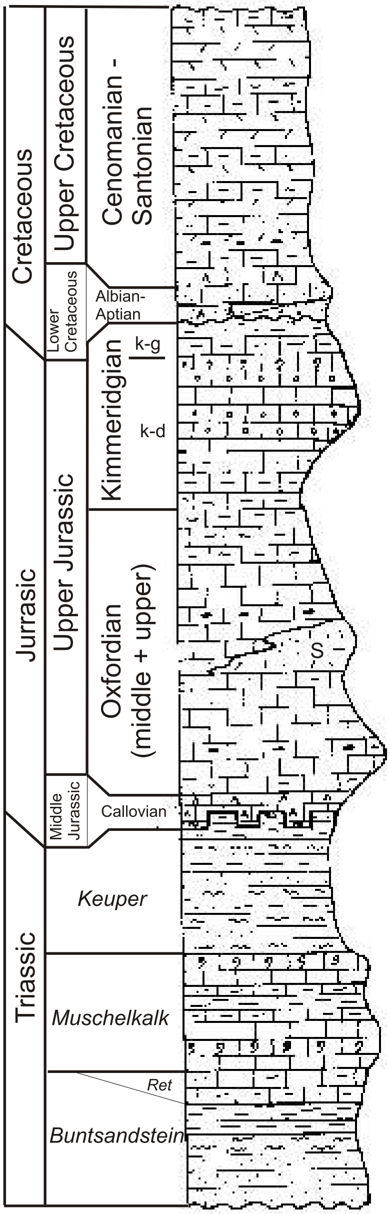

Fig. 3. Schematic lithostratigraphic column of the pre-Quaternary deposits from the SW Mesozoic margin of the Holy Cross Mts., after Hakenberg (1973, 1974) and Filonowicz and Lindner (1986, 1987); lithofacial units are written in italics; S — Oxfordian massive limestones; Kimmeridgian lithological members cropping out on elevations (k–d) and in depressions (k–g); for other explanations see text

The oldest determined Quaternary deposits include limestone debris and residual clays of the South Polish Glaciations (Fig. 4, bed 1) and debris and residual clays (Fig. 4, bed 2), probably formed in periglacial conditions of the Nidanian Glaciation or in the initial part of the Sanian 1 Glaciation. They are overlain by grey-yellowish silts (bed 3) and till (bed 4), representing also the Sanian 1 Glaciation and are linked with ice-dam accumulation and subsequent covering of the area investigated by the Scandinavian ice sheet during this glaciation (Lindner, 1995). To the west from Zakrucze and east from the Wierna Rzeka river valley, these deposits are covered by poorly sorted, locally clayey sands with gravel of local and Scandinavian rocks (bed 5). These represent glacifluvial accumulation in front of the advancing ice sheet of the Sanian 2 Glaciation. The presence of the later glaciation is proved by its till (bed 6).

The till and all underlying Quaternary deposits, as well as pre-Quaternary rocks occurring below, were subsequently eroded by rivers. Erosion events likely started during the retreat of the Sanian 2 (youngest South Polish Glaciations) ice sheet, and continued mainly in the initial part of the Great Interglacial (Mazovian *sensu lato*). Fluvial deposits of this interglacial include poorly sorted sands with gravel of local and Scandinavian rocks (bed 7), poorly sorted sands (bed 8), as well as bituminous shales and peats (bed 9), documenting climatic conditions typical of the optimum and post-optimal part of the Mazovian Interglacial *sensu lato* (Lindner and Rzêtkowska-Orowiecka, 1998). Karst processes initiating in this interval caused partial collapse of these deposits into a sink (Fig. 4).

In the entire area investigated, particularly within the contemporary river valleys, these interglacial deposits were subsequently covered by grey-yellowish silts (Fig. 4, bed 11). The silts as well as the younger medium- to coarse-grained sands with gravel of local and Scandinavian origin (bed 12) of the V terrace represent the advance and maximal range of the Scandinavian ice sheet during the Odranian (Wartanian?) Glaciation. It its maximum the ice sheet reached Bukowa, Gnieździska and Łopuszno, whereas its retreat produced voluminous melt-out water. Water favoured the cutting of terrace V and glacifluvial flow was a requisite of the formation of terrace IV, built mainly of fine- to coarse-grained sands with gravel (bed 12).

The later development of geological and geomorphological processes in the area included mainly the erosion of these glacifluvial terraces and the formation of fluvial deposits represented by sands with gravel (bed 14), included in the Eemian Interglacial, and by fine-grained and silty sands as well as by sandy silts (bed 18) building the surface of terrace III. Formation of this surface and the filling of many small side valleys is probably linked with the middle part of the Vistulian Glaciation. Its terminal part (late glacial) is marked by the formation of terrace II, built of medium-grained sands with gravel and silty intercalations (bed 20). The Holocene is represented by terrace I deposits in form of sands with intercalations of silts and gravels (bed 22) and in form of peats and organic muds (bed 23).

Bocheniec-Czubatka Hill-Nowiny-Bolmin geological cross-section. The C–D cross-section (Figs. 1B and 4) in the west passes through the gorge of the Wierna Rzeka river valley, south from Bocheniec, and after crossing Czubatka Hill reaches Nowiny and the vicinity of Bolmin in the east (Fig. 1B). In the area analysed the thickness of Quaternary deposits varies from several metres to *ca.* 20 m within the present valley, probably reaching 90–100 m between Nowiny and Bolmin, where the pre-Quaternary basement was determined at 136–137 m a.s.l.

The oldest Quaternary deposits are represented by limestone debris and residual clays (Fig. 4, bed 1), formed in periglacial conditions of the Nidanian and/or younger South Polish Glaciations (Sanian 1 and Sanian 2). Higher in the section poorly sorted sands with silt intercalations occur with re-

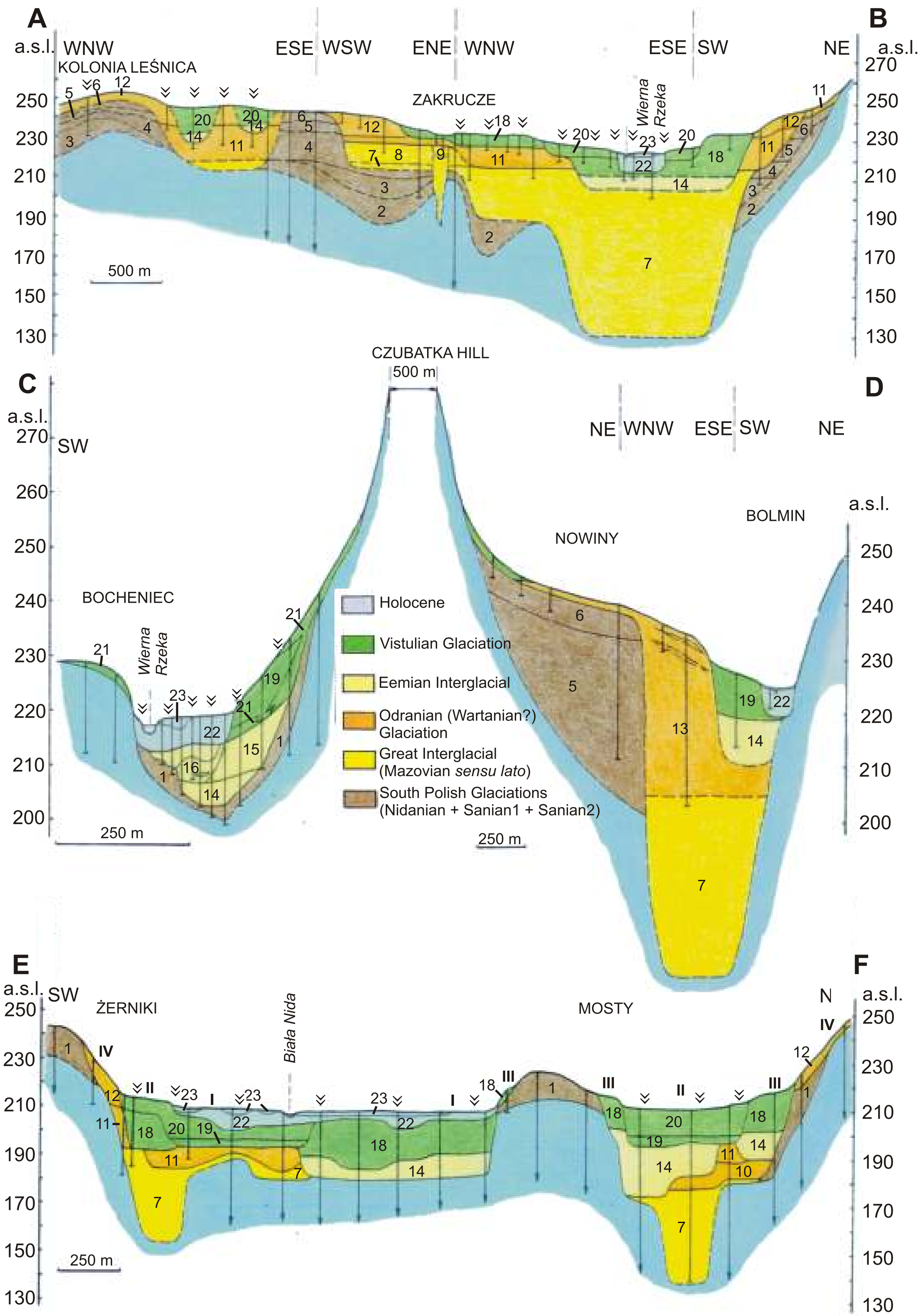

Fig. 4. Geological cross-sections through Quaternary deposits: A–B between Kolonia Leśnica, Zakrucze and Wierna Rzeka river valley (after Lindner, 1977, modified); C–D between Bocheniec, Czubatka Hill, Nowiny and Bolmin (after Lindner, 1977, modified); E–F between Żerniki, Biała Nida valley and Mosty

Pre-Quaternary basement is marked blue; vertical lines refer to boreholes, arrows above the cross-section refer to location of electric logs; **South Polish Glaciations**: (Nidanian + Sanian 1 + Sanian 2): 1 — debris and residual clays; (Nidanian + Sanian 1): 2 — debris and residual clays; (Sanian 1): 3 — grey-yellow silts, 4 — till; (Sanian 2): 5 — poorly sorted sand and gravel of local and Scandinavian material, locally clayey with intercalations of silts and clay , 6 — till; **Great Interglacial**: 7 — gravels and sand and poorly sorted sands with gravel of local and Scandinavian material, locally clayey, 8 — poorly sorted sands, 9 — bituminous shales and peats; **Odranian (Wartanian?) Glaciation**: 10 — sands and silts, 11 — grey-yellowish silts, 12 — poorly sorted sands with gravel, 13 — poorly sorted sands with intercalations of residual clays and tills ; **Eemian Interglacial**: 14 — gravels and sands with local and Scandinavian material, 15 — poorly sorted sands with gravel, 16 — sands and silts with intercalations of organic muds, 17 — medium-sorted sands with gravel; **Vistulian Glaciation**: 18 — fine-grained and silty sands and sandy silts, 19 — medium-grained and poorly sorted sands, locally with intercalations of gravel and silt, 20 — sands and silts, 21 — periglacial clays and limestone debris; **Holocene**: 22 — sands with intercalations of silts and gravels, 23 — peats and organic muds; location of cross-section of Fig. 1B; for other explanations see text

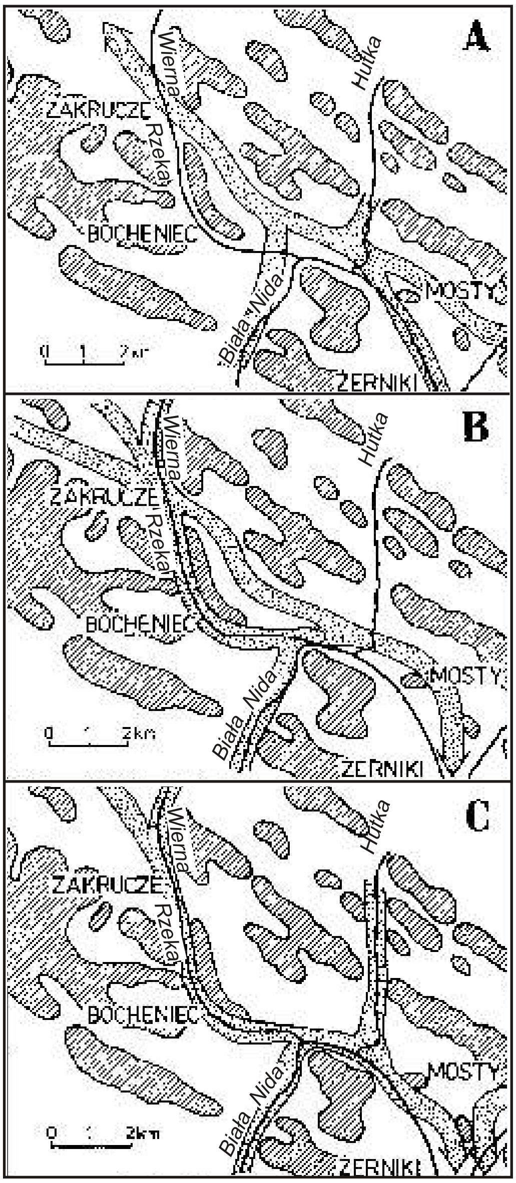

Fig. 5. Palaeogeographic sketch-maps of the Mid- and Late Pleistocene surface water runoff systems (dots) in relation to the main elevation built of pre-Quaternary rocks (diagonal lines) and the present-day river network within the SW Mesozoic margin of the Holy Cross Mts.; **A** — river valley pattern during the Great Interglacial; **B** — pattern of the glacifluvial runoff system during the Odranian (Wartanian?) Glaciation; **C** — pattern of river valleys during the Eemian Interglacial

sidual clays (bed 5), corresponding to the pre-maximal part of the Sanian 2 Glaciation. In the vicinity of Nowiny they are overlain by till (bed 6) documenting the Sanian 2 Glaciation (Lindner, 1995).

The till was eroded by river activity, documented by sands and gravels with local and Scandinavian material (bed 7), the uppermost part of which was drilled in the vicinity of Bolmin. In light of the existing data on the Quaternary of the area (Łyczewska, 1971; Lindner, 1977, 1984, 1995), the deposits may represent ancient alluvia from the Great Interglacial (Mazovian *sensu lato*). Between Nowiny and Bolmin they are covered by a thick sequence of poorly sorted sands with intercalations of residual clay and till (bed 13), which, judging from cartographic and geological data (Hakenberg, 1973; Filonowicz and Lindner, 1986), may be linked with the development of terrace V beyond the maximum range of the Odranian (Wartanian?) ice sheet.

Within the cross-section analysed, deposits of terrace V were cut by younger river activity, depositing gravels and sands with local and Scandinavian material (Fig. 4, bed 14), considered as an equivalent of the Eemian Interglacial (Hakenberg and Lindner, 1971). Analogous gravels and sands (bed 14), as well as the overlying poorly sorted sands with gravel of Eemian age (bed 15), sands and silts with intercalation of organic muds (bed 16) and medium-grained sands with gravel (bed 17) were recognised in the Wierna Rzeka river valley near Bocheniec (Lindner, 1977).

In this valley these deposits are covered by periglacial clays (bed 21), followed by poorly sorted sands (bed 18) representing, as in the vicinity of Bolmin, alluvial deposits of terrace III from the maximum of the Vistulian Glaciation. In the western slope of Czubatka Hill, deposits of this terrace are locally covered by periglacial clays and limestone debris (bed 21), also representing this interval. The youngest Quaternary deposits preserved within the cross-section are Holocene deposits of terrace I in the form of sands with intercalations of clays and gravels (bed 22) and the overlying peats and organic muds (bed 23).

Żerniki-Biała Nida valley-Mosty geological cross-section. The E–F cross-section (Figs. 1B and 4) from Żerniki in the west, the cross-section passes through the Biała Nida valley, crossing an elevation of the pre-Quaternary basement near Mosty as well as a fragment of the Czarna Nida valley, reaching the southernmost slopes of Grzywy Korzeczkowskie (Fig. 1B). Within the area analysed the thickness of Quaternary deposits varies from several to *ca*. 10 m on the slopes of these valleys up to 30–90 m in some parts. The largest values were determined east of Mosty, where the pre-Quaternary basement lies below 140 m a.s.l., and in the vicinity of Żerniki, where the thickness of Quaternary deposits probably reaches 60 m, and their basement may occur at 155–157 m a.s.l.

Within this cross-section no glacial deposits were recognised. The oldest Quaternary deposits represent debris and residual clays (Fig. 4, bed 1), probably formed during the South Polish Glaciations. These deposits, along with the pre-Quaternary deposits, are cut here by river valleys filled with ancient alluvial deposits represented by gravels and gravels with sands with local and Scandinavian material (bed 7) from the Eemian Interglacial (Hakenberg and Lindner, 1971; Lindner, 1977). Locally they are covered by sands and silts (bed 10) as well as by grey-yellowish silts (bed 11), representing ice-dammed deposits formed in extra-glacial conditions of the Odranian (Wartanian?) Glaciation. Within the valley slopes observed on the cross-section, the silts are covered by sands (bed 12), representing a glacifluvial flow from the maximum extent of this glaciation. During the retreat of the ice sheet of this glaciation, they were eroded, forming the shelves of terrace IV.

To the east and west of Mosty, these deposits are fragmentarily preserved due to younger valley processes leading initially to erosion, followed by the accumulation of gravels and sands with local and Scandinavian material (bed 14) repre-

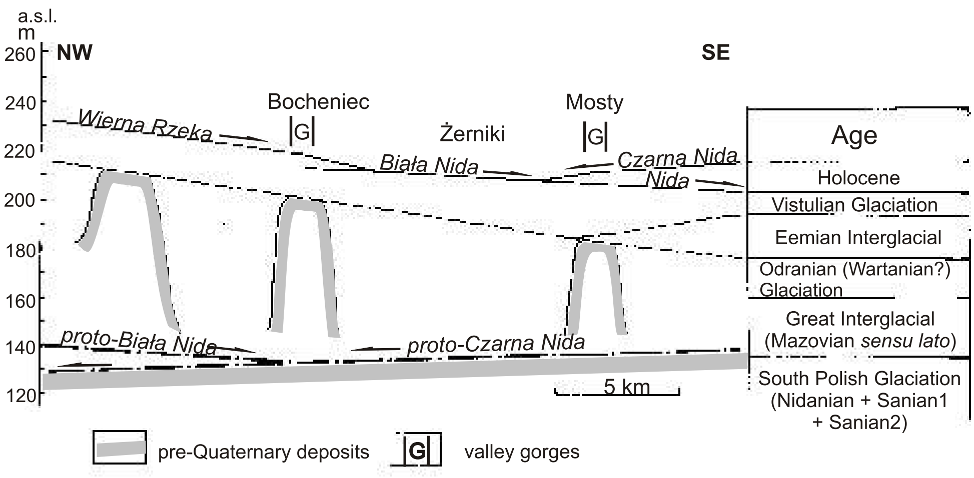

Fig. 6. Longitudinal profiles of river valley bottoms from the SW part of the Holy Cross Mountains region

senting the alluvial deposits of the Eemian Interglacial (Hakenberg and Lindner, 1971; Lindner, 1977). These deposits are overlain by thick sands (bed 18), suggesting intense covering of the valleys until the formation of terrace II during the maximal Vistulian Glaciation. The terminal part (late glacial) of this glaciation is characterised by the accumulation of sands with gravel (bed 19) as well as by sands and silts (bed 20) forming the surface of terrace I (Hakenberg and Lindner, 1973) built of sands, gravels and silts (bed 22), covered with peats and organic muds (bed 23).

PALAEOGEOGRAPHY

This description of the lithology and tectonics of the pre-Quaternary basement (the "older basement") between Małogoszcz and Chêciny (Fig. 2A), as well as the characteristics of the Quaternary deposits preserved in the central part of this area (Fig. 4) indicate a close relation of the occurrence of ancient and present-day river valleys with the lithology and tectonics of pre-Quaternary rocks.

Deposits most susceptible to erosion and denudation are the Jurassic marly (chalky) limestones of Oxfordian/Kimmeridgian age (Fig. 3). In effect, initial morphological WNW-ESE depressions were formed on their outcrops, in the marginal parts of the Bolmin Syncline and Bocheniec Anticline (Fig. 2B). Similarly trending depressions extend from the present-day Wierna Rzeka river valley, north from the Bocheniec gorge, to the Czarna Nida valley east of Mosty (Fig. 1B). Their formation is linked with easy erodibility of these deposits within the wide fault zone cutting the southern limb of the Bolmin Syncline (Fig. 2B). Therefore the location of the Neogene valley is obvious, the surface waters of which flowed to the SE (see Lindner, 1977) towards the Miocene marine bays in the vicinity of Chomêtów and Korytnica (Radwañski, 1969).

Later, following rejuvenation of the parallel fault system caused by loading of the area by ice sheets of the two younger (Sanian 1 and Sanian 2) South Polish Glaciations, the flow within the valley system was reversed (Lindner, 1977). During the Great Interglacial (Mazovian *sensu lato*), the proto-Czarna Nida flowing from Mosty in the east, through the region south from Bolmin, to the vicinity of Zakrucze in the NW (Fig. 5A) became the main valley of the area analysed. The bottom of this valley (the rock-cut bench of proto-Czarna Nida) should be located in the vicinity of Mosty *ca.* 132–137 m a.s.l., in the vicinity of Nowiny *ca.* 132–133 m a.s.l. and in the zone of the present-day Wierna Rzeka river valley between Zakrucze and Mielechowa Hill *ca.* 130 m a.s.l. (Fig. 6).

During the Odranian (Wartanian?) Glaciation, when the Scandinavian ice sheet had its maximum extent north from the Przedbórz-Małogoszcz range to the Bukowa–Gnieździska–Łopuszno line, its loading firstly caused the rejuvenation of the N-S fault in the zone of the present-day Wierna Rzeka river valley (west of the Mielechowa and Czubatka Hills). In this interval, along with the previously functioning valley system (from the Great Interglacial), the zone became the location of flow of proglacial waters from the contemporary ice sheet and their drainage to the Nida valley southwards from Mosty (Fig. 5B).

Increased activity of this N-S fault caused, near Bocheniec, the accumulation of glacial and extraglacial waters from the northern and eastern part of the Wierna Rzeka river drainage basin during the retreat of the Odranian (Wartanian?) ice sheet, contributing to the formation of a gorge, already in the Eemian Interglacial (Fig. 5C). During the Eemian Interglacial the valley bottom (Fig. 6) was situated from *ca.* 206 m a.s.l. in the vicinity of Zakrucze to *ca.* 203 m a.s.l. in the gorge zone near Bocheniec, and *ca.* 195 m a.s.l. (as the Biała Nida valley) in the vicinity of ¯erniki. This direction of bottom inclination was retained during the last glaciation until the present-day (Fig. 6).

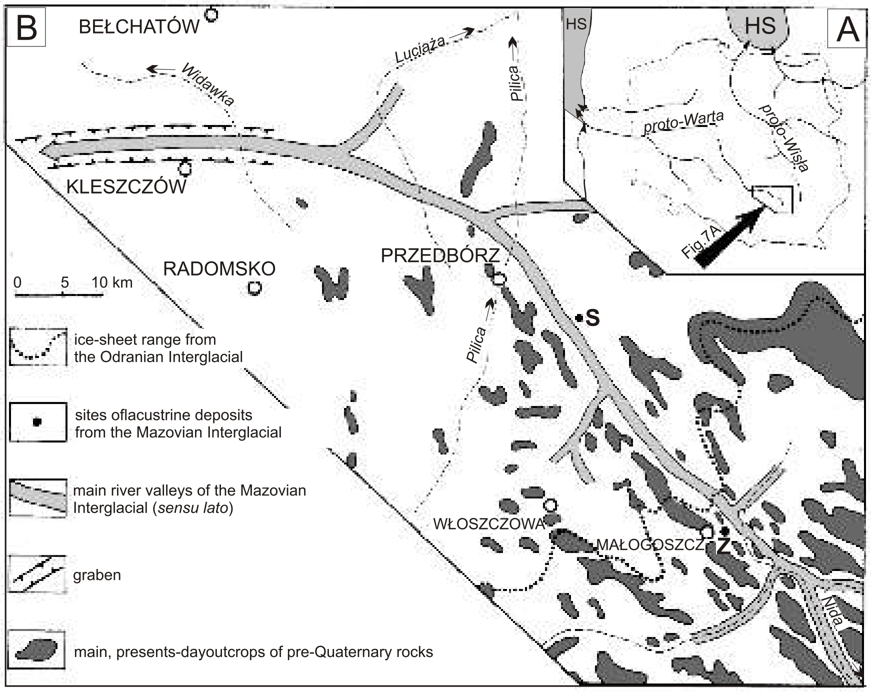

Fig. 7. **A** — location of the area analysed in relation to the river valleys of the Mazovian Interglacial in Poland and the contemporary bays of the Holstein sea (HS), **B** — probable pattern of the main river valleys from the Mazovian Interglacial in the western part of the Holy Cross Mountains region and the southern part of the Bełchatów region; 1 — range of the Odranian (Wartanian?) ice sheet, 2 — sites of lake deposits from the Mazovian Interglacial: S — Sewerynów, Z — Zakrucze; 3 — main river valleys of the Mazovian Interglacial, 4 — Kleszczów graben, 5 — main present-day outcrops of pre-Quaternary deposits

FINAL REMARKS

This data and discussion on the palaeogeographic development of river valleys in the SW Mesozoic margin of the Holy Cross Mts. indicate that the location and development of these valleys depended on the lithology and tectonics of pre-Quaternary rocks as well as on the flow directions of proglacial and extraglacial waters during the Pleistocene glaciations.

During the Great Interglacial (Mazovian *sensu lato*) the area analysed of the proto-Czarna Nida river valley represented the upper section of one of the largest and best recognised contemporary valleys in Poland (Lindner *et al*., 1982). This was probably proto-Warta, which at that time drained the present-day Widawka basin, and the traces of which are fluvial deposits of the ancient Ruszczyn valley (see Baraniecka and Sarnacka, 1971), located within the tectonic Kleszczów graben (Fig. 7). According to Baraniecka and Sarnacka (1971), the Ruszczyn valley was parallel to this, and its bottom was situated at 100 to 117 m a.s.l. Two sedimentological cycles can be recognised within the alluvial deposits. The older is represented by gravel-sandy deposits, 20–25 m thick, and the younger cycle is characterised by analogous deposits with silt intercalations up to 15–20 m thick. Between Małogoszcz and Przedbórz, waters of the proto-Warta-proto-Czarna Nida section analysed are documented by the deposits of the Mazovian Interglacial preserved in its drainage basin in Sewerynów (Jurkiewicz and Mamakowa, 1960) and Zakrucze (Lindner and Rzêtkowska-Orowiecka, 1998) (Fig. 7).

North-westwards, in Wielkopolska, the valley analysed represented a form which originated during the initial phases of the retreat of the Sanian 2 Glaciation (youngest of the South Polish Glaciations). Its development was determined mainly by the contemporary formation of a parallel proglacial streamway system, and to a lesser degree, by the influence of neotectonic processes. The valley, along with the joining proto-Odra valley, collected waters from the whole of western Poland, and the ensuing river, flowing to the west, reached the Holstein bay located NW of Berlin (Fig. 7).

The Mazovian Interglacial river valley course presented, that is a valley formed by a river with sources in the SW part of the Holy Cross Mts. region, in its upper and middle section distinctly follows zones of tectonic dislocations and is linked with the lithological variety of Mesozoic deposits. In the upper section the relations were worked out by field observations, whereas in the middle section the course of the valley follows the pattern of tectonic lineaments recognised on air photos (Ostaficzuk, 1981).

During the Middle Polish Glaciations this valley system was largely covered by deposits of several advances of the Scandinavian ice sheet. In its highest part only, SE of Małogoszcz (Fig. 7), the proto-Czarna Nida valley was located beyond the range of the oldest of these ice sheets (of the Odranian Glaciation), with the runoff inherited after glacifluvial flow. The flow collected proglacial and extraglacial waters, initially producing the surface of terrace V, and later of terrace IV in the interpretation of Lindner (1977) and Lindner and Mastella (2001). Such valley flow initiated the later Eemian and present-day river network pattern.

REFERENCES

BARANIECKA M. D. and SARNACKA Z. (1971) — The stratigraphy of the Qaternary, and paleogeography drainage basin of the Widawka (in Polish with English summary). Biul. Inst. Geol., **254** (13): 157–269

CZARNOCKI J. (1938) — Ogólna mapa geologiczna Polski w skali 1:100 000, sheet 4, Kielce. Inst. Geol. Warszawa.

FILONOWICZ P. and LINDNER L. (1986) — Szczegółowa Mapa Geologiczna Polski w skali 1:50 000, sheet Piekoszów. Wyd. Geol. Warszawa.

FILONOWICZ P. and LINDNER L. (1987) — Objaœnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000, sheet Piekoszów. Wyd. Geol. Warszawa.

HAKENBERG M. (1973) — Szczegółowa Mapa Geologiczna Polski w skali 1:50 000, sheet Chêciny. Inst. Geol. Warszawa.

HAKENBERG M. (1974) — Objaœnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000, sheet Chêciny. Wyd. Geol. Warszawa.

HAKENBERG M. and LINDNER L. (1971) — Quaternary deposits of the middle Nida valley (in Polish with English summary). Acta Geol. Pol., **21** (2): 241–264.

HAKENBERG M. and LINDNER L. (1973) — Holocene history of the middle Nida valley (in Polish with English summary). Acta Geol. Pol., **23** (2): 435–444.

JAROSZEWSKI W. (1972) — Mesoscopic structural criteria of tectonics of non-orogenic areas: an example from the north-eastern Mesozoic margin of the „wiêtokrzyskie Mountains (in Polish with English summary). Stud. Geol. Pol., **38**.

JURKIEWICZOWA I. and MAMAKOWA K. (1960) — The interglacial at Sewerynów near Przedbórz (in Polish with English summary). Biul. Inst. Geol., **150** (9): 71–104.

LINDNER L. (1977) — Pleistocene glaciations in the western part of the Holy Cross Mts. (Central Poland) (in Polish with English summary). Stud. Geol. Pol., **53**: 1–143.

LINDNER L. (1978) — Palaeogeomorphologic evolution of the western part of the Holy Cross region in Pleistocene (in Polish with English summary). Rocz. Pol. Tow. Geol., **48** (3–4): 479–508.

LINDNER L. (1984) — Region œwiêtokrzyski. In: Budowa geologiczna Polski, **1**, Stratygrafia, part 3b, Kenozoik, Czwartorzêd (ed. J. E. Mojski): 34–35, 65–73, 113–145, 255–286, 326–330. Wyd. Geol. Warszawa.

LINDNER L. (1995) — Till sequences and local morains in the Holy Cross Mountains area in Central Poland. In: Glacial Deposits in North-East Europe (eds. J. Ehlers, S. Kozarski and Ph. Gibbard): 329–337. A. A. Balkema. Rotterdam

LINDNER L., LAMPARSKI Z. and D¥BROWSKI S. (1982) — River valley at the Mazovian Interglacial in eastern Central Europe. Acta Geol. Pol., **32** (3–4): 179–190.

LINDNER L. and MASTELLA L. (2001) — Origin and age of the Wierna Rzeka (Łososina) gorge in the vicinity of Bocheniec, SW Mesozoic margin of the Holly Cross Mts. (in Polish with English summary). Prace Akad. Pedagog. Kielce, **5**.

LINDNER L. and RZÊTKOWSKA-OROWIECKA A. (1998) — New data on interglacial sediments at Zakrucze near Małogoszcz, the Holy Cross Region. Geol. Quart., **42** (2): 201–207.

ŁYCZEWSKA J. (1971) — The Quaternary of the Góry „wiêtokrzyskie (in Polish with English summary). Prace Inst. Geol., **64**: 5–108.

MANDL G. (1988) — Mechanics of Tectonic Faulting: Model and Basic Concepts. Elsevier. Amsterdam

MANDL G. (2000) — Faulting in Brittle Rocks. Springer. Berlin

MOLLEMA P. N. and ANTONELLI M. (1999) — Development of strike-slip faults in the dolomites of Sella Group, Northern Italy. J. Structur. Geol., **21**: 273–292

OSTAFICZUK S. (1981) — Megalineaments as evidence of some global tectonic phenomena. Bull. Acad. Polon., Sc. Ser. Terre, **29** (2): 143–155.

RADWAŃSKI A. (1969) — Lower Tortonian transgression onto the southern slopes of the Holy Cross Mts. (in Polish with English summary). Acta Geol. Pol., **19** (1).

STUPNICKA E. (1971) — Tektonika utworów mezozoicznych południowego obrze¿enia Gór „wiêtokrzyskich. Ann. Soc. Geol. Pol., **40** (3–4): 393–409.

STUPNICKA E. (1972) — Tectonic of the SW margins of the Holy Cross Mts. (in Polish with English summary). Biul. Geol. Wydz. Geol. UW, **14**: 21–114.

STUPNICKA E. (1997) — Geologia regionalna Polski. Wyd. Uniw. Warszawskiego

TAN T. K. and HE T. T. (1982) — A physico-rheological model for the large Thangshan earthquake. Tectonophysics, **85**: 123–148.

TCHALENKO J. S. and AMBRASEYS N. N. (1970) — Structural analysis of the Dasht-e-Bayaz (Iran) earthquake fractures. Geol. Soc. Am. Bull., **81**: 41–60.