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EVOLUTION OF THE LATE NEOGENE AND EOPLEISTOCENE FLUVIAL SYSTEM IN THE FORELAND OF THE SUDETES MOUNTAINS, SW POLAND

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Abstract: The oldest Cainozoic fluvial deposits in Lower Silesia date from the Oligocene. During the Middle and Late Miocene times, the fluvial system of this region was only slightly modified, especially in the foreland of the West and Middle Sudetes Mts. River lengths changed, following the migration of the North Sea shorelines. A rapid rebuilding of the fluvial system took place in the foreland of the East Sudetes Mts. either in the Late or Middle Miocene. Till that time, the main river valley of this region – the Nysa Kłodzka River, related to the Paczków and Kędzierzyn Grabens – used to flow towards the East, to a bay of the Paratethys sea. The new main river, pre-Odra, started to flow towards the North not before the Grodków Graben cut meridionally the Meta-Carpathian Swell. We are of the opinion that deposits of the Poznań Formation originated in an fluvial environment because no marine and/or limnic deposits have hitherto been discovered in the area of Lower Silesia above the uppermost of the Middle-Polish lignite seams (Henryk). The pre-Odra River drained the eastern part of Lower Silesia, and flowed towards the North, at least to the Poznań region. This main river captured such smaller rivers, as: the pre-Vistula, pre-Olza, pre-Ostravica, pre-Opava, pre-Nysa Kłodzka, and pre-Bystrzyca. Rivers draining the West Sudetes Mts. flowed first towards the North, to the region of the present-day Middle Odra River, and there turned to the West. It is conceivable that these rivers curved westwards just along the line of the present-day Wrocław – Magdeburg marginal stream valley ("Pradolina"). Since the Pliocene, the Sudetic rivers have started to transport coarser, sandy, and even gravelly material to a more distant foreland. Alluvial deposits of this phase occur exclusively on uplands. Coarse-grained sediments recognized in the bottom of deep erosional incisions were redeposited under subglacial conditions during the Mesopleistocene glaciations. The presented new interpretation of origin of the Poznań Formation basin and detailed recognition of Pliocene and Eopleistocene river system should initiate a new line of research into the Late Neogene and Eopleistocene sediments.

Key words: palaeogeography, fluvial sediments, Neogene, Eopleistocene, Lower Silesia, SW Poland.

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INTRODUCTION

This paper results from a project carried out by the Polish Geological Institute, supplementing the data gathered during geological mapping of Lower Silesia. The latter works have mainly been conducted in front of the East Sudetes Mts., up to the Odra River valley, where we have participated in the realisation of a dozen or so sheets of the *Detailed geological map of Poland, 1:50,0000*. We have also studied the other parts of Lower Silesia, and analysed data coming from type localities and cartographic boreholes.

In the first stage of research, we have concentrated on fluvial sediments assigned to the Gozdnica Formation (Fig. 1, Krzyszkowski *et al.*, 1998; Przybylski *et al.*, 1998; Badura & Przybylski, 1999a, b, 2000). These sediments are commonly named "pre-glacial" because of their deposition after accumulation of the Poznań Formation and before the first Scandinavian ice-sheet advance. Basing on sedimentological studies we conclude that the deposits of the Gozdnica Formation cover the older fluvial strata whose origin has been associated with the lacustrine-marine basin of the Poznań Formation. New views on the origin of the latter has led us to analyse a broader time interval, embracing the entire Miocene. These studies, supplemented by a critical review of the existing literature on Cainozoic strata in Western Poland, have enabled us to present a new palaeogeographic reconstruction of that area in Late Neogene and Eopleistocene times (Badura & Przybylski, 2001; Czapowski *et al.*, 2002; Badura, 2003).

DRAINAGE PATTERN IN LATE PALAEOGENE AND MIOCENE TIMES

The development of fluvial system in the northern foreland of the Sudetes proceeded through a few stages. The oldest stage, commencing together with the regression of the Late Cretaceous sea (Late Coniacian) and lasting until the Early Miocene, is poorly known. Basing on the reconstructed position of the Late Cretaceous shorelines and the extent of Palaeogene marine basins, one can infer that some of the Sudetic rivers must have been flowing towards the North, whereas the others probably flowed eastwards, following the retreating marine basin, and lengthening their courses. The Eocene and Oligocene marine littoral strata contain products of strongly weathered rocks of the crystalline basement, bearing abundant quartz and clay minerals, including kaolinite (Piwocki, 1975), as well as the Upper Cretaceous carbonates and sandstones.

Throughout the Early and Middle Miocene, accumulation of fluvial sediments was ubiquitous in the NW part of Lower Silesia. These sediments, however, are only known from boreholes. During the Early and Middle Miocene transgression of the then North Sea basin, the lower and middle courses of river valleys became inundated by brackish waters. Areas occupied by mires were the sites of future brown coal seams development.

Basing on indirect evidence, such as shorelines of the seas surrounding the Bohemian Massif, one can imply that rivers draining the Western Sudetes, i.e., starting from the present-day Nysa Łużycka until Kaczawa rivers, flowed to the North, whereas rivers draining the Central Sudetes must have been flowing northeastward, into a depression associated with the Szczecin-Mogilno-Łódź Syncline. The Eastern Sudetes, in turn, were drained by the Nysa Kłodzka river towards the East, and then southwestwards, into the Paratethys basin.

RIVER NETWORK IN THE LATE MIDDLE MIOCENE

Studies of petrographic and heavy minerals composition of the Middle Miocene alluvial sands and silts are infrequent. The palaeo-pattern of river network can only be inferred from palaeogeomorphological reconstructions, whose principal reference lines were marine shorelines and interfluves. The Lower Silesian region used to occupy a watershed position: the Central Sudetes together with the Meta-Carpathian Swell did form a European watershed separating the North Sea and Paratethys marine basins. As far as the present-day topography is concerned, a belt of sub-Quaternary bedrock outcrops between Opole and the Sowie Mts. in the Sudetes marks the axial part of the former Meta-Carpathian Swell.

The last Neogene marine transgression of the North Sea, during the Reinbeckian stage at the end of the Middle Miocene, left its traces in Ziemia Lubuska area (Standke *et al.*, 1992; Standke, 1996). This transgression was associated with accumulation of sands and silts of the Pawłowice (Mużaków) Formation (Ciuk, 1970; Piwocki, 1975; Dyjor, 1978). At that time, broad valley floors of the West- and Central Sudetic rivers became inundated due to an increase of the groundwater level. The resulting mires gradually turned into peatbogs and were later transformed into the Middle-Polish brown coal seams (Fig. 2). At the beginning of the Late Miocene, the extent of the then North Sea was similar to that of the present one (Vinken, 1988). After formation of the first, counting from the top, Middle-Polish (Henryk) coal seam, that part of Europe was free of more prominent marine transgressions, until the Holsteinian (Masovian) Interglacial (Ludwig & Schwab, 1995).

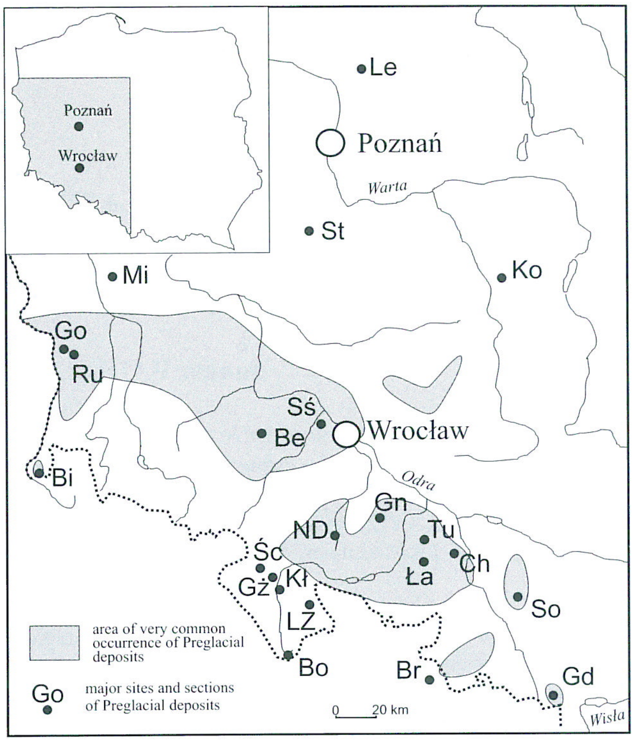

Fig. 1. Areas of common occurrence of preglacial deposits. Localities: Bi – Białopole, Be – Bielany, Bo – Boboszów, Br – Brantice, Ch – Chrząszczyce, Gd – Godów, Gn – Gnojna, Go – Gozdnica, Gż – Gożuchów, Ko – Korek, Kł – Kłodzko, Ła – Łambinowice, Le – Lechlin, Mi – Miodnica, Ru – Ruszów, Śc – Ścinawka, St – Stankowo, LZ – Lądek Zdrój, So – Sośnicowice, Sś – Sośnica, Tu – Tułowice

The south-eastern part of Lower Silesia belonged to the Paratethys drainage basin. Following the late Middle Badenian transgression, the Paratethys Sea definitely retreated from the Paczków and Kędzierzyn grabens; the youngest marine Grabowiec Formation strata (Alexandrowicz, 1997) have been found near Gliwice. At the same time, marine sediments at Nysa became covered by alluvial sands of the pre-Nysa Kłodzka River which marked the onset of the Kędzierzyn Formation. Near Głogówek, in turn, the alluvial fines contain rare Lower Mesozoic foraminifera, redeposited from the Western Carpathians (Ślączka, 1996). These facts point to infilling of the Kędzierzyn Graben by alluvia bearing material derived from both the Sudetes and Carpathians. Such a palaeotransport direction implies a reversal of the slope of the groundsurface, from that south-directed (towards the Paratethys), to a northward-directed one, towards

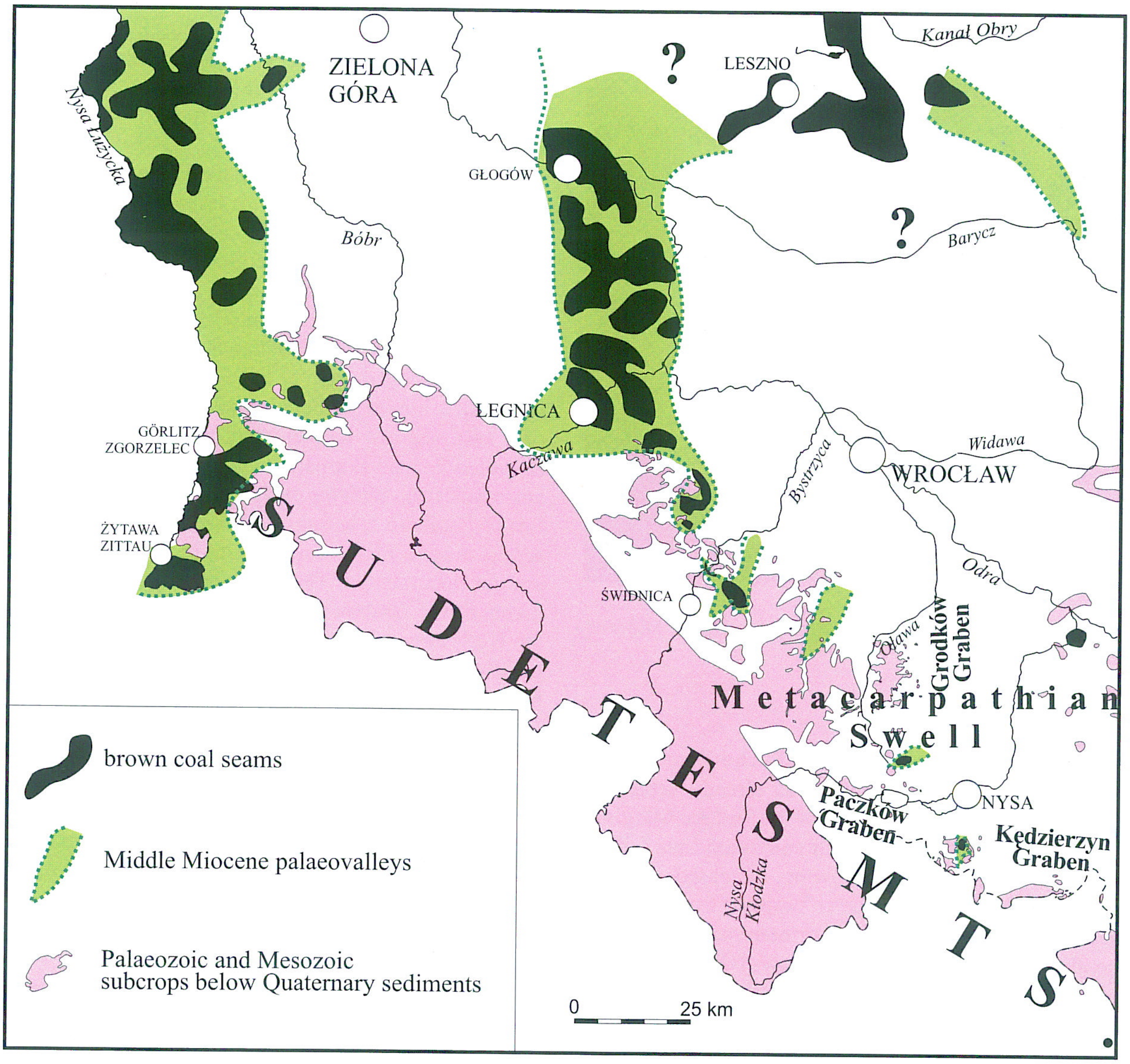

Fig. 2. Middle Miocene palaeovalleys marked by the biggest coal seams (coal seams after Piwocki, 1992, 1995)

the North-European Furrow, also called the Central European Subsidence Zone (Ludwig, 2001).

Regression of the Paratethys at the end of the Middle Miocene from the northern part of the Moravian Gate, and coeval uplift of the Western Carpathians and the Sudetes led to a complete reorganization of the landscape. A change in slope resulted in the formation of a new drainage pattern, directed northwards into the North Sea basin (Badura, 1999). Such an outflow became only possible after the Grodków Graben was formed, transversally truncating the Meta-Carpathian Swell (Fig. 3). At that time, the Silesian Lowland underwent strong subsidence, whose axis was parallel to the Middle Odra fault system. Most probably, following the northeastward shift of subsidence, a tectonic Grodków Graben between Strzelin and Opole was formed, whose deepest part occurs near Grodków. This depression became utilised by a new, pre-Odra, river.

The Grodków Graben was developing gradually and, probably, at the incipient stage, the river discharge was fairly high. Fluvial erosion partly removed marine Paratethyan deposits that infilled the Nysa bay, situated between the Sudetes, Fore-Sudetic Block, and Meta-Carpathian Swell. The eroded material was transported far to the West and North of the Nysa bay, as testified to by redeposited Mesozoic and Badenian foraminifers (Dyjor, 1968; Łuczkowska & Dyjor, 1971; Giel, 1979).

RIVER NETWORK IN LATE MIOCENE AND EARLY PLIOCENE TIMES

Analysis of many drillholes reveal that in the vicinity of the Sudetic Marginal Fault (SMF) accumulation of coarse-clastic deposits predominated (Badura *et al.*, in print). Coarse-clastic deposits in the SMF zone have been registered in Lower Miocene sediments. Such kind of deposition points to a rapid change of valleys floor slope and the existence of a morphological scarp as a border between the Sudetes and Fore-Sudetic Block. Hence, in Late Miocene times, the Sudetes formed a well-marked topographic high

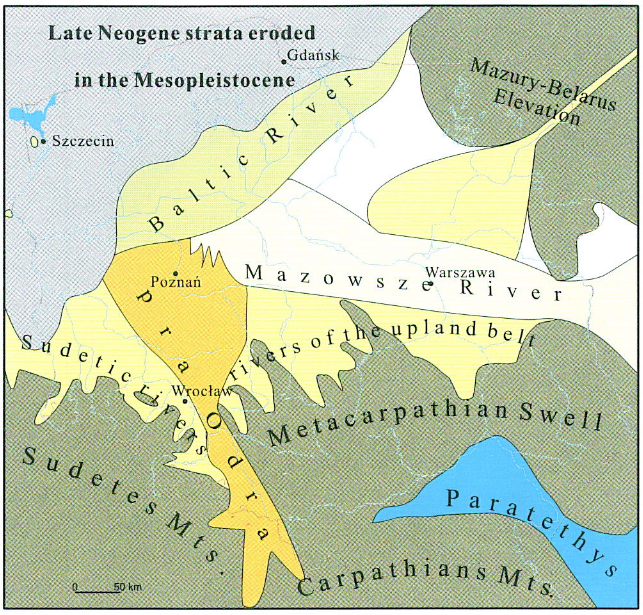

Fig. 3. Distribution of fluvial deposits of the Upper Miocene Poznań Formation

at the margin of the Bohemian Massif. The Fore-Sudetic Block, situated on the north-east, was already separated from the Sudetes by a distinct scarp of the Sudetic Marginal Fault. The hanging wall of this fault contained Late Oligocene–Early Miocene troughs showing increased rates of subsidence. These depressions were supplied by rivers that drained both the Sudetes and their northern margins, depositing mostly gravels and clays of mudflows (Oberc & Dyjor, 1969; Grocholski, 1977; Ciuk & Piwocki, 1979; Kural, 1979). Only large rivers did bypass both the troughs and their northern surroundings. At the boundary between the Sudetes and Lusatian Mts., strong subsidence occurred within the Zittau and Berzdorf-Radomierzyce troughs (Kasiński, 1991, 2000), bounded by faults orientated NNE–SSW. Uplift of the Strzegom Hills was not strong enough to block the north-directed outflow of the Bystrzyca and Strzegomka rivers. The eastern part of the Fore-Sudetic Block, forming a western continuation of the Meta-Carpathian Swell, underwent diversified vertical tectonic movements. In the Niemcza-Strzelin Hills, apart from the Grodków Graben, a few new grabens were formed which are now drained by the Oława, Mała Ślęza, and Ślęza rivers (Badura, 1999). The Meta-Carpathian Swell lost its position of the European watershed after these grabens were formed.

The terrestrial basin of the Poznań Formation (Badura, 2003), extending from southern Pomerania up to the Sudetes, represented a vast lowland area through which rivers flowing from Polesie and Podole in the East, and from Kraków-Częstochowa Upland, and the Western Carpathians and Sudetes, did pass (Fig. 3). The lowland was situated in the Central European Subsidence Zone that extended between the North Sea and the Kraków-Częstochowa Upland. The Sudetic rivers were then tributaries of the Baltic River, the largest river in Central-Northern Europe, which was flowing to the North Sea. Deposits of the Baltic River have been identified in Lusatia, Brandenburgia, and between the Sylt Island and NE part of Holland (Hucke, 1930; Ahrens & Lotsch, 1976; Kociszewska-Musiał & Kosmowska-Ceranowicz, 1969; Bijlsma, 1981; Krueger, 1994; Eissmann, 2002).

Variable rate of subsidence led to the formation of local depressions which, after floods, were becoming vast lakes or mires filled by silt-clayey sediments. The Poznań Formation has commonly been interpreted as a limnic one, showing periodical influence of marine ingressions (Dyjor, 1970, 1992). This inland basin should have been supplied by rivers that shed prograding deltas and/or alluvial fans. In the light of palaeogeographic, lithological, and sedimentological studies, however, there is little evidence for the presence of a vast, shallow lake existing within inland basin of the so-called Poznań Formation clays. This lake could not have any connection with the existing marine basins, either North Sea or Paratethys, as suggested by Różycki (1972). The inferred marine ingressions prograding from the Paratethys are not documented. The youngest Paratethys marine sediments of the Grabowiec Formation, in the southern part of the Kędzierzyn Graben, are overlain by terrestrial strata of the Kędzierzyn Formation (Alexandrowicz, 1997) which has been correlated by Dyjor (1987) with the Poznań Formation. The subsequent North Sea transgression following the Reinbeckian took place only in the Masovian (Holsteinian) Interglacial. In the Early Late Miocene, i.e., during the highest rate of deposition of the Poznań Formation sediments, the North Sea was situated some 800 km away from the Lower Silesian area, and the Paratethys basin was restricted to the Pannonian Basin and the eastern part of the Sandomierz Basin, situated 400 km to 800 km away (cf. Vinken, 1988; Hámor, 1989).

DRAINAGE PATTERN IN LATE PLIOCENE AND EOPLEISTOCENE TIMES

Global climatic cooling in the Pliocene, and Late Neogene tectonic mobility were suitable for the origin of a new formation of fluvial sediments, commonly called the Gozdnica Formation. The Pliocene and Eopleistocene rivers maintained drainage directions inherited from the Late Miocene (Fig. 4), although energetic regime of rivers changed: the rivers transported mostly sandy material, and in mountaineous areas also gravel- and boulder-size load, whereas starting from the Eopleistocene gravels became the predominant component.

The Gozdnica Formation comprises three lithosomes that show either different lithology or place of occurrence (Dyjor *et al.*, 1978; Dyjor, 1984, 1987). The dominating lithosome consists of sands with mud intercalations. Gravels and gravelly diamictons occur on watersheds and infill bottoms of deep erosional scours. This problem will be discussed in the next chapter.

The earliest-distinguished lithosome in front of the East Sudetes were gravels that build the so-called "white gravel series" (Zeuner, 1928; Behr *et al.*, 1931; Behr & Mühlen, 1933; Dyjor, 1966a, b; Wroński, 1975). In the 1960s, the

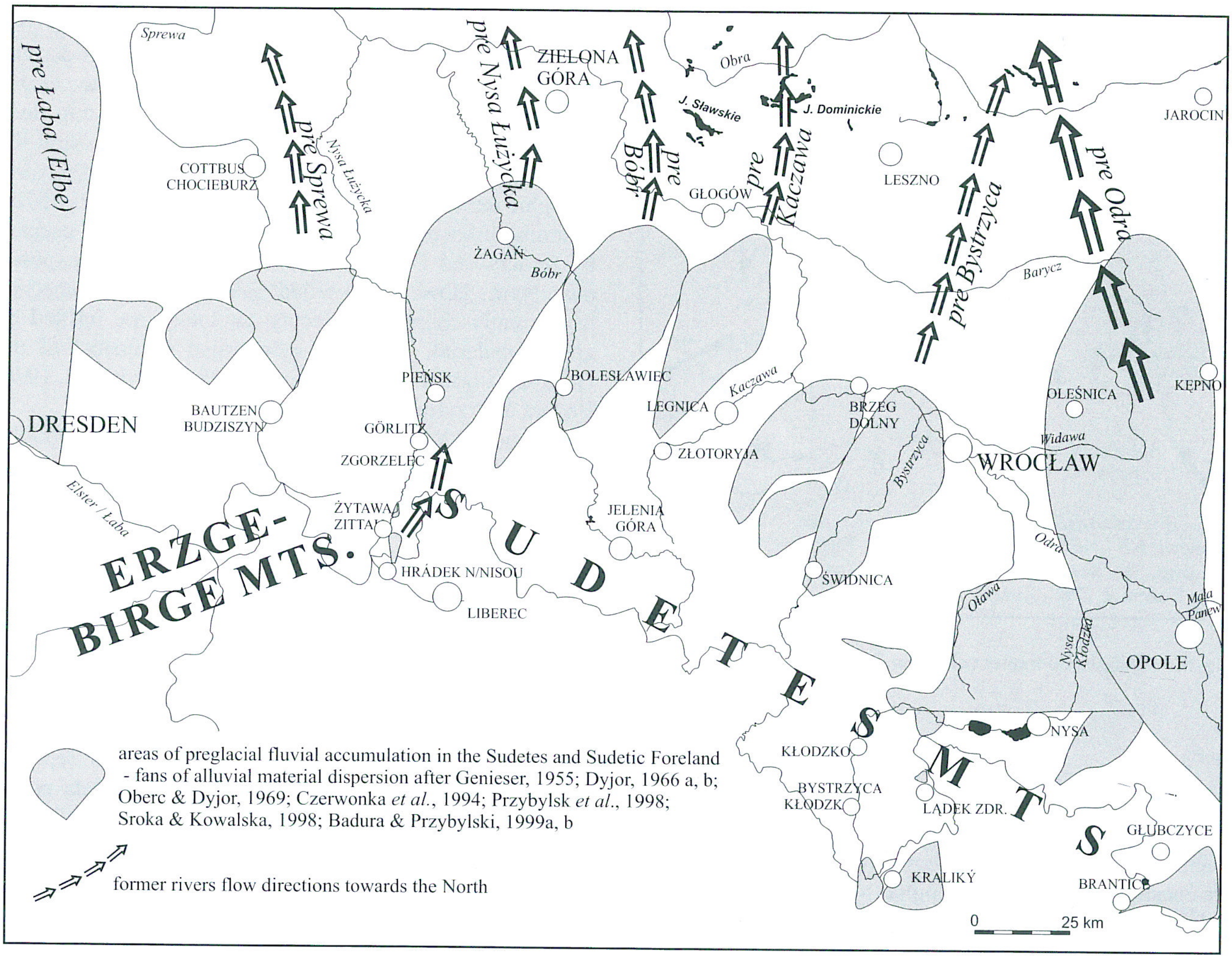

Fig. 4. Extent of Late Neogene and Eopleistocene alluvia in Lower Silesia

definition of this series was supplemented by sandy sediments exposed near Gozdnica and Ruszów, and called the Gozdnica Formation (Dyjor, 1970, 1984, 1995; Piwocki & Ziembińska-Tworzydło, 1997) or the Ziębice Group (Czerwonka & Krzyszkowski, 2001). The last cited paper is based on an assumption that individual formations within the group differ in heavy mineral composition. As far as age constraints are concerned, the deposits in question are commonly referred to as "preglacial" ones, i.e., postdating the Poznań Formation and predating the Elsterian (Sanian) Glacial sediments.

Young orogenic movements are considered to have been responsible for a change of fraction of the fluvial material in the youngest Neogene: from silty-clayey to sandy-gravel, and later on into gravel one (Dyjor, 1966a, 1995). Most of the authors, however, consider climatic changes to be a key factor in controlling fluvial accumulation. Of particular importance appear to be climatic cooling and its coeval drying, accompanied by episodic torrential rainfalls and related flash floods (cf. Różycki, 1972; Kosmowska-Ceranowicz, 1966; Rzechowski, 1987). These factors fostered an increase of transporting power of the rivers which carried coarse-clastic material from the mountains and deposited it even hundreds of kilometres away, in the lowland area. According to Wroński (1974, 1975), deposition of the so-called "white gravels" proceeded only in the Eopleistocene under cold climatic conditions. This is indicated by the presence of silt and clays packets with preserved lamination, embedded within the gravels. Such properties imply that the transport of fine material must have been proceeding in a frozen state (Ehlers *et al.*, 1984; Eissmann, 2002).

Topography of SW Poland in Late Pliocene and Eopleistocene times induced a northward-directed flow of the Sudetic rivers (Figs. 1, 4). The most distant occurrences of preglacial sediments bearing Sudetic material have hitherto been identified at: Oborniki Wielkopolskie (Skompski, 1994), Lechlin near Wągrowiec (Dobosz & Skawińska-Dobosz, 2003a), Stankowo near Leszno, Krzywin south of Poznań (Czerwonka *et al.*, 1994; Czerwonka & Krzyszkowski, 2001), and Korek near Kalisz (Dobosz & Skawińska-Dobosz, 2003b).

In the southern part of the Nysa Kłodzka Graben, between Boboszów, Lichkov, and Králiky in Bohemia, there occur fluvial sediments indicating that until the Late Pliocene the upper segment of the Nysa Kłodzka river belonged to the Danube drainage area (Figs. 1, 4). The drainage reversal to the North occurred only after the Králiky range became uplifted (Sroka & Kowalska, 1998).

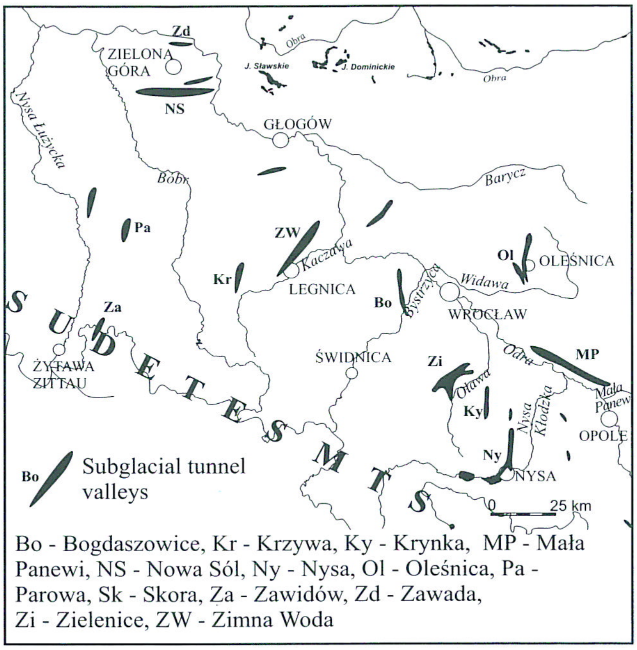

Fig. 5. Subglacial tunnel valleys in Lower Silesia

In the Głubczyce Plateau, on the Opava valley side at Brantice in Bohemia, and at Branice and Bliszczyce in Poland, quartz gravels of the Gozdnica Formation have been found at 50 m and 35–40 m above river beds. These gravels are considered by Czech geologists to represent Pleistocene sediments. According to Otava (1987), the higher terrace originated during the Donau glacial stage, and the lower one during the Günz stage. Gravels occurring at Branice are rounded, 2 to 12 cm in diameter, cemented by kaolin clay, and showing creamy or yellow-rusty colours. Their petrographic composition is dominated by quartz; quarzitic schists occurring rarely, and lidytes and other siliceous rocks being sporadic. At Bliszczyce, in turn, fluvial gravels rest on a strath cut into Lower Carboniferous rocks, and rising 40 m above the Opava river bed. The petrographic composition shows a few percent admixture of poorly rounded Culm siltstones and sandstones. Very strong weathering of Culm clasts fostered their disintegration; therefore, they cannot be found in the distal part of the alluvial fan at Branice. It is likely that such gravels originally composed a vast alluvial fan of the pre-Opava river that flowed from the mountains into a tectonic trough.

DEEP PLEISTOCENE EROSIONAL SCOURS

Near Kędzierzyn and Racibórz, the Gozdnica Formation is clearly bipartite (Dyjor *et al.*, 1978; Kotlicka, 1975, 1978). The sediments occur both on plateaus and within deep erosional scours. Within the fossil Ruda valley, Dyjor *et al.* (1978) have described gravels typical for the Gozdnica Formation, bearing a minor admixture of metamorphic rocks and granites, whose origin used to be associated with redeposition of older gravel series and exotic rocks derived from Lower Carboniferous conglomerates. Since the Gozdnica Formation occurs both on plateaus and within deep palaeovalleys, interpreted as being of Eopleistocene age, the latter series has been distinguished as a new lithostratigraphic unit, namely the Ruda Series (Dyjor *et al.*, 1978). A similar lithostratigraphic interpretation has been accepted by Badura and Przybylski (1994) for sediments exposed near Nysa. However, detailed palaeogeographic analysis has recently shown that deeply-cut scours are infilled by glacial material, including redeposited sediments of the Gozdnica Formation (Badura *et al.*, 1998; Przybylski, 1998; Badura & Przybylski, 1999b).

Regional analysis of the sub-Quaternary topography and lithological properties of fossil scour infills has revealed that the scours represent subglacial furrows, like: fossil valleys of the Odra river in the Moravian Gate, near Prądy and Oleśnica, Mała Panew, Zimna Woda near Legnica, Witka near Zawidów, and others (Fig. 5) (Krawczyk & Tkaczyk, 1997; Badura *et al.*, 1998; Badura & Przybylski, 1999b, 2000; Urbański, 1999; Kasiński *et al.*, 2003). It cannot be excluded that the fossil Ruda valley is also a subglacial furrow, as suggested by its uneven long profile. Similar processes of redeposition of preglacial sediments during the South-Polish (Elsterian) Glaciations have been reported from subglacial furrows in SW Germany (Kupetz *et al.*, 1989; Alexowsky, 1996; Stackenbrandt *et al.*, 2001; Eissmann, 2002).

LITHOLOGY OF MIOCENE FLUVIAL SEDIMENTS

The Middle Miocene transgression of the North Sea into Lusatia resulted in a rise of the groundwater level of the Sudetic river valleys. The valley bottoms became occupied by vast mires that later turned into brown coals of the so-called Middle-Polish (Henryk) seam. The extent of large brown coal deposits clearly mark fluvial palaeocourses (Fig. 2). Towards the North, the palaeovalleys lose their expressiveness crossing the dense network of numerous pools with thin layers of lignite (Piwocki, 1992). The subsequent marine regression terminated phytogenic accumulation and fostered intensive erosion upon higher-situated areas. Downstream-located valley segments became occupied by silts, fine-grained sands, and organic sediments. Dispersed organic matter is responsible for a characteristic grey colour of these sediments which build the so-called "Grey Clays" horizon within the Poznań Formation.

Late Miocene rivers were characterized by changeable discharge throughout their lengths. Close to the Sudetic mountain front and near island hills in the Fore-Sudetic area, sediments indicative of rapid, even catastrophic discharge, do occur. Rapid torrential flows accumulated mudflow sediments close to the mountain front (Ciuk & Piwocki, 1979; Osijuk & Piwocki, 1972; Kościówko, 1982). Proceeding downstream, the material was becoming segregated. Farther away from the mountains, silts and clays with intercalations and lenses of sand of variable thickness were deposited. Most frequently, these sediments are blue, grey-bluish or pale-greyish in colour, turning green when dried up or after exposure. Green colour is not related to the presence of glaucony, as has been frequently stated by several authors.

Numerous boreholes drilled in the Silesian Lowland pierced through a few centimetres thick clasts composed of clays or silts. Their presence points to great transporting power of streams undermining river banks. The clays and silts contain dispersed quartz grains, 1–2 mm in diameter, what indicates transport in suspension that could have proceeded, for instance, during inundation of the floodplains. Minor intercalations of sands resting within silts and clays could point to the presence of bars, point bars or crevasse splays. Small lenses of brown coals of the so-called Kędzierzyn and Oczkowice seams (Ciuk, 1970; Dyjor *et al.*, 1978) originated in drying up oxbow lakes or frequently inundated alluvial plains. Depending on highly changeable local conditions, well-sorted sands or angular clasts cemented by kaolin-smectite-illite clays, were deposited. In the western part of Lower Silesia, apart from predominating angular quartz grains, there also occur large feldspars. The latter are partly kaolinized, indicating that their weathering must have postdated deposition. In the Poznań Formation, large-scale angular clasts of the pre-Nysa Łużycka river occur in the Kożuchów Hills, more than 80 km away from the exposures of the Rumburg granites that bear characteristic bluish quartz grains. In the Gozdnica brickyard, these two types of sediments occur side by side, being assigned to the Gozdnica Formation.

In front of the East Sudetes, near Korfantów, the amount of sand within the Poznań Formation increases with the increasing distance from the mountains. According to Biernat (1964), such a feature can indicate that numerous small streams merged into one, large lowland river. Fluvial origin of the Poznań Formation is testified to by clasts, up to 10 cm in diameter, occurring in brickyards situated east of Niemodlin. There also occur layers of coarse-grained sands and gravels whose petrographic composition includes, apart from abundant quartz, black and brown siliceous rocks, as well as light-grey, faintly laminated quartzitic sandstones derived from the Western Carpathians.

The most intense fluvial accumulation of the Poznań Formation took place in the Sarmatian. These sediments are coeval with marine strata of the Machów Formation, described from the eastern part of the Carpathian Foredeep. Lithological differences between sediments shed from the Carpathians into the two basins clearly point to different sedimentary environments, marine and terrestrial ones, although developed under similar climatic conditions. A characteristic petrographic composition of clay minerals, transparent heavy minerals, coarse-grained sands, and gravels filling large Sudetic and Carpathian river valleys, clearly differentiates individual fluvial systems (Kosmowska-Ceranowicz, 1979; Brański, 2002). Differences in mineral composition are to be noticed throughout the Poznań Formation basin. Within limnic or marine environment, near-shore and bottom currents would led to differentiation of the minero-petrographic association, except for deltaic sediments. However, the Poznań basin sediments are devoid of deltaic, chemical or organodetritic deposits. Chemical composition of porous waters does not indicate any traces of relict marine waters (Szczepańska, 1982), either. Within the so-called "Green Clays" horizon of the Poznań Formation, no glauconite has been found, and the green colour probably results from the presence of ferric oxides precipitated on clay minerals due to pedogenic (gley) processes.

Results of biostratigraphic studies enable one to estimate the termination of deposition of the Poznań Formation sediments for the latest Late Miocene or Early Pliocene (Sadowska, 1987, 1995). It cannot be excluded, however, that either in Messinian or Early Pliocene times, decreased rates of subsidence combined with climatic changes could have led to a prolonged hiatus which, to our opinion, is coeval with the formation of a soil horizon, commonly called the "Flame Clays" horizon. We interpret the latter as the illuvial spodic horizon, developed upon clays and silts. Judging from the thickness of this illuvial horizon and its lateral extent one can infer that its development must have lasted for a long time, and that it reflects original topography, except for glaciotectonically disturbed regions. Since "flame horizons" had already been formed earlier upon watershed areas, we are not inclined to assign them any chrono- or lithostratigraphic value. Identification of the "Flame Clays" horizon as a separate depositional unit within the Poznań Formation is not justified, either.

Three sites of the "Pliocene" gravels in the Kłodzko Basin: Gorzuchów, Ustronie near Kłodzko, and Lądek Zdrój, have been described by Zeuner (1928), Berger (1931), and Krzyszkowski *et al.* (1998). At Gorzuchów and Kłodzko, gravel-boulder-loamy sediments accumulated during rapid torrential flows, have been found. Jahn *et al.* (1984) identified dark-blue and black silts and clays bearing pollen and macroscopic plant remains at the top of white gravels exposed at Kłodzko. White gravels of the Kłodzko and Gorzuchów sites differ from the other "preglacial" sediments by a high degree of weathering, kaolinization, and sandy-loamy infillings of intragranular pores. The petrographic composition is dominated by quartz; local porphyries and gneisses constituting a large admixture. Numerous gravels and boulders composed of amphibolites and gabbros are strongly weathered and form regolith clasts, whereas clasts of more resistant rocks have been either kaolinized or wrapped by clay minerals. These properties indicate that such strongly weathered material could not have been transported in highly-energetic environment, and that the clasts must have weathered later, under very warm, kaolinization- prone climate. That is why we interpret these sediments as deposited in Miocene, and not Late Pliocene (Jahn *et al.*, 1984) times. This hypothesis is supported in part by fluvial gravels exposed at Lądek Zdrój which are overlain by basaltoid lavas. The age of these gravels, composed of poorly weathered gneisses, mica schists, and quartz, has been determined for the Pliocene, and even Early Quaternary, whereas dates obtained from the basalts indicate that the gravels are probably of Late Messinian age (cf. Birkenmajer *et al.*, 2002).

LITHOLOGICAL AND SEDIMENTOLOGICAL PROPERTIES OF PLIOCENE FLUVIAL SEDIMENTS

The best recognised sites of Pliocene fluvial sediments have been described from the SW part of the Opole region and the eastern part of Lower Silesia (Fig. 6). These sediments cover there nearly entire area that extends between the Krynka valley in the West to the Odra river valley in the East, and between the Sudetes and the Odra river. Clays of the Poznań Formation are overlain by fine-grained sands, silty sands, and sandy silts, the grain/clast diameters increasing up the section. Detailed field studies and analyses of heavy minerals and petrographic composition of gravels have enabled us to distinguish fluvial series deposited by three rivers (Badura & Przybylski, 1999b, 2000; Badura *et al.*, 2001). Numerous boreholes (Biernat, 1964), including the cartographic Łambinowice borehole, pierced through a 50-m-thick complex of sands, silty sands, and silts. The number and thickness of sand layers increase upwards. Changes in heavy mineral composition in the Łambinowice log (Fig. 7) appear to indicate changes in the Pliocene river valley pattern. The lower, garnet-dominated, complex can be linked with the pre-Nysa Kłodzka river, the zircon-rutile-dominated middle complex – with the pre–Odra river, whereas the upper complex represents again the pre-Nysa Kłodzka river. In the last case, association of sediments with the pre-Nysa Kłodzka river is confirmed by the presence of material derived from the Intrasudetic Depression.

The sand pit at Tułowice exposes a 20-m-thick section of medium-grained sands bearing thin silt horizons, the 10 m of which are available to observations (Figs. 8, 9). The section is dominated by horizontally layered sands, locally showing medium to large-scale trough cross-bedding, and ripplemarks. The exposed sequence displays two main layers of silts and clayey silts, 0.1 to 0.6 m thick, which intercalate sands. At the base of one silty layer, alluvial fines with gravels have been found. The silty layers are composed in part of homogenised clay balls. Individual clay balls are also visible within sandy strata. Silty layers include as well imprints of leaves and branches, and infrequent seeds. Both the exposed and drilled sections are lithologically similar, the only differences being noticeable in the composition of heavy minerals. The upper part is dominated by resistant minerals, like: rutile, zircon, tourmaline and staurolith, amounting to 58% of all transparent minerals; whereas the lower part includes up to 53% of garnets. Petrographic composition of gravels occurring at the top points to the pre-Odra river as one which transported the resistant minerals-bearing sands.

Five fluvial complexes separated by erosional surfaces have been distinguished at Tułowice exposure (Fig. 8, 9). Each complex is composed of several assemblages showing a characteristic lithofacies succession (Badura *et al.*, 2001). The Tułowice series were mostly deposited by a low-energetic meandering river (complexes 1 through 4), showing positive balance of alluvium, as indicated by large thickness of the entire sandy series. This type of aggradation implies that the main factor controlling sediment accretion was subsidence of the Sudetic foreland. On the other hand, stable climatic conditions, and particularly dense vegetation cover stabilising river banks, limited the material supply and helped to maintain meandering character of the river.

Sediments of the 5-th complex represent a braided river (Figs. 8, 9). Changes in character of fluvial processes, registered in the complex 5, make it possible to hypothesize about termination of relatively stable climatic conditions of the Late Neogene, and first climatic oscillations of a new stage of development. The changes in depositional conditions could have been a result of climatic control, and related transformation of vegetational cover. Perhaps, it is a record of the first episode of transformation of the drainage pattern from meandering into braided one, at the incipient stage of cooling in the Northern Hemisphere. A marked change of the Atlantic Ocean circulation, following the closure of the Balboa Strait at around 2.5 Ma, seriously affected climatic conditions in the Northern Hemisphere. A roughly similar date can be accepted as the onset of changes in fluvial processes recorded at Tułowice. Close to Tułowice, the sandy series is overlain by a few meters thick complex of white gravels, clearly marking a rapid change of the climate.

"Preglacial" sands and gravels have also been found in the Twardogóra, Syców, and Ostrzeszów Hills (Winnicki, 1997; Czerwonka & Krzyszkowski, 2001). The gravels include single, kaolinized grains of Sudetic porphyries, as well as siliceous rocks, and banded quartzose sandstones. The petrographic composition indicates that the material must have been transported by the pre-Odra river. Most probably, the so-called quartzites of the Ostrzeszów Hills are also of Pliocene age. Their characteristic petrographic composition clearly points to the provenance of gravel material from the Sudetes and Carpathians, as has already been suggested by Gołąb (1951) and Połtowicz (1961). Despite petrographic inferences, indirectly indicating a Pliocene age, the sediments in question have been described as Miocene ones, and older than the Middle-Polish brown coal seam. The quoted authors did not take into account the fact that in Middle Miocene times rivers draining the East Sudetes flowed into a bay of the Paratethys, situated in the Kędzierzyn Graben area. Only in Sarmatian times, after the Grodków Graben was formed, transport of the Sudetic material to the North, into the Ostrzeszów Hills area, did become possible. The erroneous age interpretation of the Ostrzeszów Hills quartzites results from overturning of glaciotectonically-disturbed layers.

Pliocene sands are exposed at numerous localities in the Fore-Sudetic area, and at some places in the Wielkopolska region (Fig. 1). These sediments have commonly been subdivided into two complexes separated by erosional surfaces and showing sometimes minor mineralogical differences (August *et al.*, 1995; Wojewoda *et al.*, 1995; Czerwonka & Krzyszkowski, 2001).

The complexes have been assigned climatostratigraphic value, without taking into account sediment position within the valley or natural lateral channel migration. Basing on lithological similarities of sediments occurring in front of the Central and East Sudetes, one can conclude that they were formed under similar environmental conditions and at

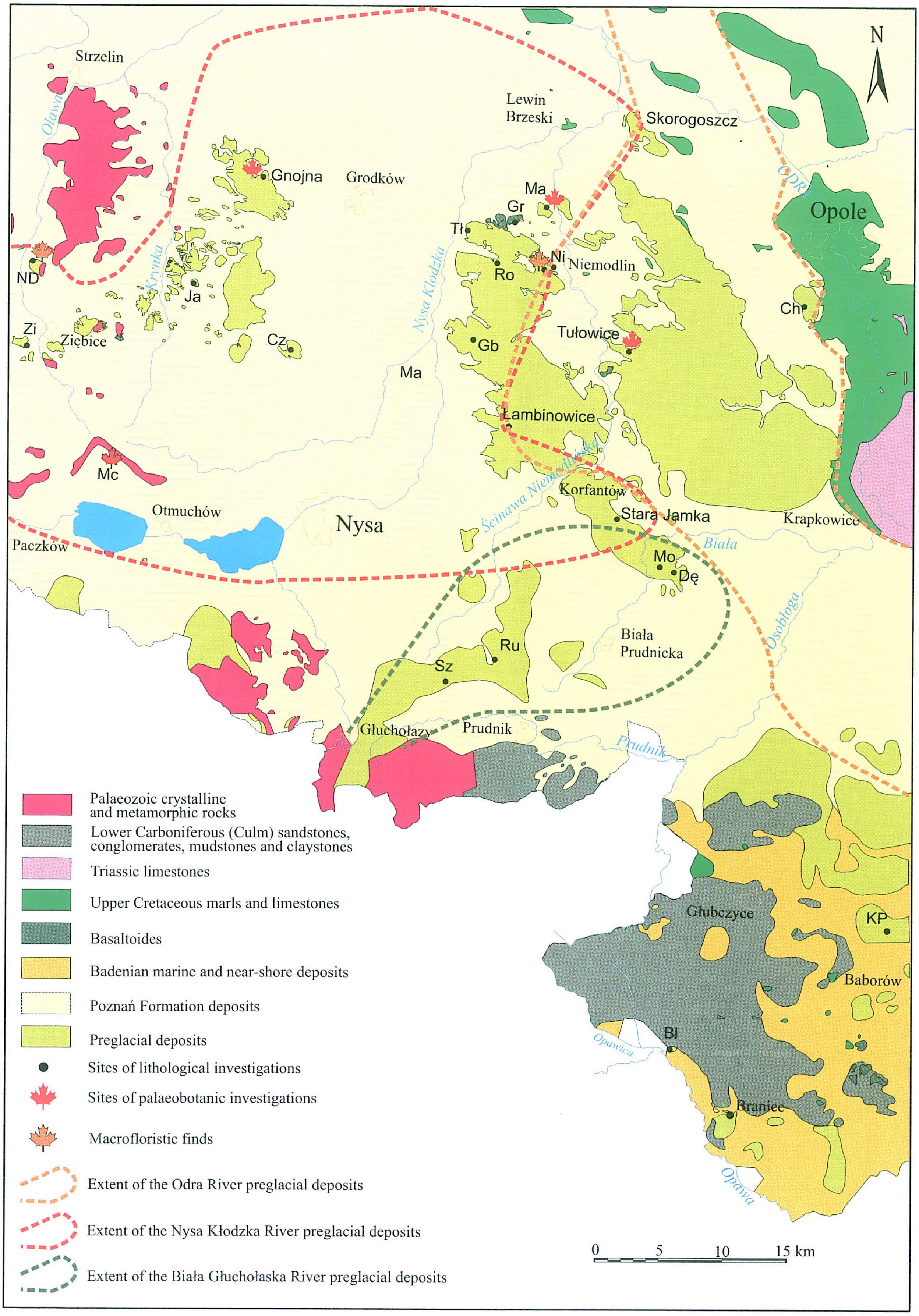

Fig. 6. Extent of preglacial deposits based on sub-Quaternary subcrops in the East Sudetic Foreland. Localities: Bl – Bliszczyce, Ch – Chrząszczyce, Cz – Czarnolas, Dę – Dębina, Gb – Grabin, Gr – Gracze, Ja – Jagielno, KP – Księżę Pole, Ma – Magnuszowiczki, Mc – Maciejowice, Mo – Mokra, ND – Nowy Dwór, Ni – Niemodlin, Ro – Roszkowice, SJ – Stara Jamka, Sz – Szybowice, Ru – Rudziczka, Tł – Tłustoręby, Zi – Ziębice

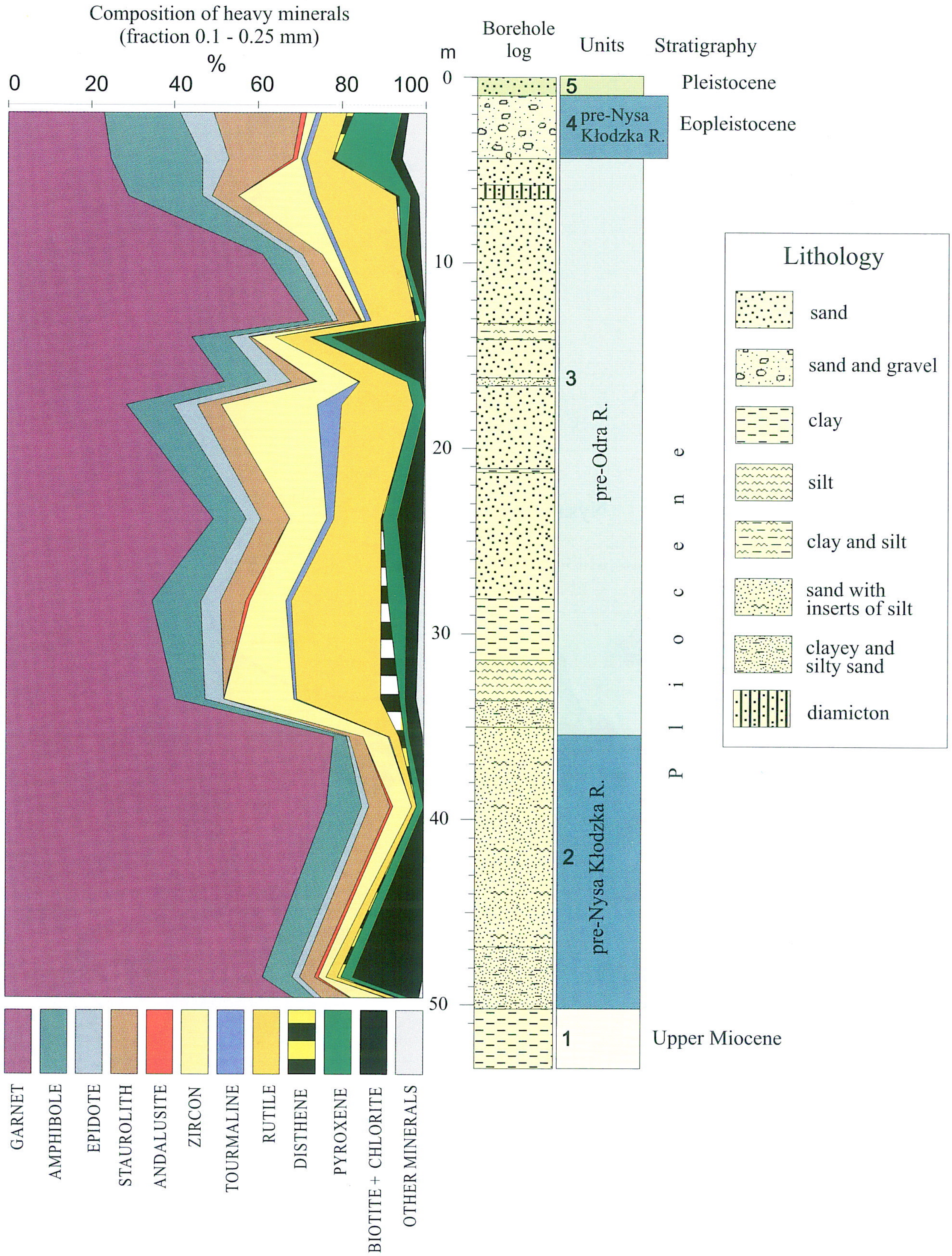

Fig. 7. Differentiation in petrographic composition and heavy minerals within fluvial deposits, exemplified by the Łambinowice borehole; for location see Figs. 1, 6

Fig. 8. Central part of exposure of Pliocene and/or Eopleistocene meandering river (pre-Odranian) sediments on the edge of the Niemodlin Swell near Tułowice

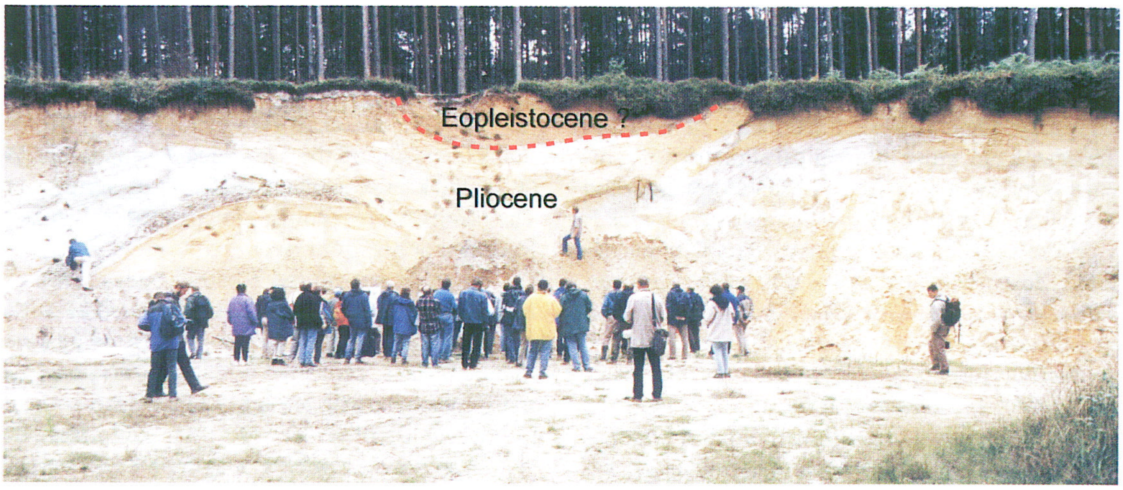

Fig. 9. General view of the Tułowice exposure

the same time as sediments exposed at Tułowice; the only difference consisting in the material brought by rivers draining different parts of the Sudetes.

Correlation of the above sediments with those of the Gozdnica Formation exposed at Gozdnica and Ruszów is not unequivocal. Sediments described from Gozdnica differ markedly from the other series by their grain-size, degree of weathering, and sedimentary structures. Principal sedimentary units are composed of: kaolin clays, rounded gravels, paraconglomerates with angular clasts including postsedimentary-weathered feldspars, as well as unweathered sands, silts, and clays. These sediments also show different sedimentological properties that are indicative of different sedimentary environments, principally associated with anastomosing rivers. Such a great lithofacies variablity implies that Neogene strata of different ages have been included into one lithostratigraphic complex. Unfortunately, solution to this problem is not possible without further detailed field studies. The above differences cannot be explained solely by lithological differentiation of the source areas, specific conditions of selective weathering, or differentiated fluvial regimes that were to occur on a relatively small area.

The Gozdnica Formation has been described from the western foreland of the Sudetes by Dyjor (1966a, b, 1970, 1985a, b, 1987), Stachurska *et al.* (1967, 1971), and Zastawniak *et al.*, 1992). At Gozdnica and Ruszów, Dyjor (1970) distinguished three members associated with variable types of sedimentation. The lower member is composed of kaolin clays bearing an admixture of sand and gravel, related to intense erosion of regoliths. The middle, sand-gravel member originated due to erosion of less disintegrated crystalline rocks. The material was still unsorted and poorly rounded, testifying to highly changeable discharge and rapid deposition. Feldspars occurring in these deposits have undergone postdepositional weathering. The upper member, in turn, is built up of sediments comprising unweathered feldspars, indicative of climatic cooling. The middle member, already showing traces of a cooling, has been assigned by Dyjor (1966b) to the Reuverian C, and the upper one – to the Eopleistocene.

The composition of gravel fraction and heavy minerals indicates that the material must have been supplied from the Izera gneisses and Karnonosze granite. Minor amount of siliceous rocks points to erosion of the Ještecký massif (Dyjor, 1985a). Occurrence of andalusite and zircons, derived from erosion of both Upper Cretaceous sandstones and metamorphic covers of the Karkonosze granite, provide indirect evidence that the sediment had been accumulated by the Nysa Łużycka river (Grodzicki, 1987).

According to Dyjor (1966a, b, 1992) and Zastawniak *et al.* (1992), accumulation of the Gozdnica Formation at Gozdnica started at the turn of the Middle and Late Miocene, when deposition of the so-called "Green Clays" of the Poznań Formation was still in progress. In the middle and eastern parts of Lower Silesia, in turn, the Gozdnica Formation sediments date back to the end of the Late Miocene (Stachurska *et al.*, 1967, 1971; Dyjor, 1987, Sadowska, 1987).

Diachronous character of this formation is difficult to explain in the context of Late Neogene climatic changes and tectonic movements that led to uneven uplift of the Sudetes. Inclusion in one formation of extremely differentiated deposits, like: poorly and well-rounded, weathered and unweathered, well-sorted and loamy, fine- and coarse-grained, indicates that they could represent sediments of different ages. On the other hand, close lithological similarity of sediments occurring at the top of the Poznań Formation and those of the bottom part of the Gozdnica Formation makes separation of the two formations impossible without detailed studies. Most frequently, the whole sand-silty complex has been assigned to the Gozdnica Formation, irrespectively of its position and other properties. Lithostratigraphic subdivision into two formations (Poznań and Gozdnica) is, therefore, strongly subjective and not justified by detailed petrographic, mineralogical or sedimentological studies. The lack of sedimentological analyses undermines the validity of conclusions drawn purely from palynological data. Some of biostratigraphic studies have been conducted upon sediments containing redeposited material, although this fact has not been taken into account in final interpretations.

LITHOLOGY OF EOPLEISTOCENE ALLUVIA

The Eopleistocene periodical coolings fostered erosional power of streams. Coarse-grained, well-rounded material was transported from the Sudetes, its petrographic composition being dominated by quartz (80–95%), and the other clasts being composed of either the most resistant rocks or less resistant ones, but situated close to their place of deposition. These gravels were transported first in a clayey-sandy matrix, and poorly marked layering points to high-energetic torrential flows. A characteristic feature is well-developed roundness that differentiates these gravels from those occurring in older series. There also occur local intercalations of silts and clayey silts that mark traces of abandoned channels and floodplains. For most of these sediments, kaolin matrix is a typical feature; sometimes there occur kaolin matrix-dominated paraconglomerates. Characteristic gravel and heavy mineral assemblages enable one to discriminate individual rivers (Przybylski *et al.*, 1998; Badura & Przybylski, 1999b, 2000; Czerwonka & Krzyszkowski, 2001).

The pre-Nysa Łużycka river transported characteristic, bluish quartz grains derived from Rumburg gneisses, large grey feldspars derived from Izera gneisses, as well as light-coloured schists, probably originated in the Ještecký massif in Bohemia. Gravels of such a petrographic composition have been identified in the Zittau Depression near Opolno Zdrój. Their occurrence in the SE part of the depression indicates that the pre-Nysa used to flow northeastwards, towards the present-day Smĕda-Witka valley, and then farther northwards.

According to Genieser (1955), however, the old Nysa river was to encircle the Działoszyn horst on the West. Gravels of fairly similar petrographic composition occur as well south of Nowogród Bobrzański. The occurrence of lydites indicates that the old Nysa Łużycka joined the pre-Kwisa river which transported material from the Kaczawa Mts. Heavy mineral composition of these sediments shows a high amount of andalusite derived from metamorphic cover of the Karkonosze granite. Eopleistocene sediments of the pre-Bóbr river have not been studied in detail, except for the Głogów area (Wagner, 1982). Medium-grained sandy deposits of the Gozdnica Formation at Polkowice, 60 m thick, also contain analusite of similar provenance. The sands were probably deposited by either the pre-Kaczawa or pre-Bóbr rivers.

At the base of the Central Sudetes, the Bystrzyca, Pełcznica, and Strzegomka rivers formed vast alluvial fans, 40–60 m thick. These are composed of unsorted, poorly rounded clasts, cemented by clayey-silty, brown-red material. A characteristic feature of these clasts is the occurrence of Permian rhyolites, derived from the Intrasudetic Depression. The gravel complex is underlain by alternating clays, silts, silty sands and sands, as well as loamy gravels that are lithostratigraphically correlated with the Poznań Formation (Badura *et al.*, in print).

Gravel series shed by rivers draining the Niemcza-Strzelin Hills have not been found so far. Most probably, predominance of poorly-resistant bedrock, represented by mica schists and amphibolites, as well as strong chemical weathering of rocks in that area were not suitable for abundant supply of identifiable material.

In an area comprised between the Strzelin Hills, Silesian Upland, and East Sudetes, gravel series shed by three large rivers (pre-Odra, Nysa Kłodzka, and Biała Głuchołaska) have been identified (Fig.1; cf. also: Przybylski, 1998; Przybylski *et al.*, 1998; Badura & Przybylski, 1999b; Badura *et al.*, 2001). The pre-Odra river transported material derived from both the Western Carpathians and East Sudetes. The West Carpathian flysch rocks are represented by banded quartzitic sandstones of the Lgota and Godula beds, and brown Menilite shales, as well as black siliceous rocks, whereas quartz grains and infrequent dark sandstones and brown-red siltstones originated in the Sudetes. In a few samples, high percentage of rutile and zircon has been found (Badura & Przybylski, 1999b), probably derived from denuded Upper Carboniferous Kyjevice beds (Otava, *pers. comm.*, 2002). A large amount of rutile has also been reported by Smoleńska (1975) from the Sośnicowice gravels in the Rybnik Plateau. These gravels probably mark the eastern margin of the Pliocene Odra valley, wherein both Carpathian material and Sudetic quartz were deposited.

The pre-Nysa Kłodzka sediments, in turn, are dominated by Sudetic rocks, such as: Permian rhyolites and tuffites of the Intrasudetic Depression, grey, creamy and pale-pink gneisses of the Śnieżnik Massif, Bystrzyckie Mts. and Doboszowice region near Paczków, as well as mudstones and lidytes of the Bardo Mts. The heavy mineral composition displays abundant garnets and amphiboles; zircon and staurolith occurring in smaller quantities.

The Biała Głuchołaska river sediments contain mostly quartz (>90% of the gravel fraction). Snow-white quartzites, schists, and gneisses occur sporadically. As far as heavy minerals are concerned, this catchment area, draining the Keprnik Massif in Bohemia, is dominated by a large proportion of staurolith.

The northernmost sites at which material of Sudetic provenance has been found occur at: Stankowo near Leszno, Krzywin south of Poznań, Kalisz, and NW of Wągrowiec. These sediments are a dozen or so metres thick, and contain: quartz, lydites, and flintstones. Predominance of staurolith within heavy minerals near Stankowo enabled Czerwonka *et al.* (1994) to conclude that the river must have been flowing from the East Sudetes. Fluvial gravels occurring at Wągrowiec comprise Carpathian quartzose sandstones and siliceous rocks similar to Menilite hornstones and shales. The largest quartz grains are 3.5 cm long; those of sandstones being 1.8 cm in diameter. The ccurrence of the pre-Odra river sediments near Wągrowiec, located some 350 km away from the river sources, as well as the size of gravel fraction indicate that it must have been a large river of periodically high transporting power.

A characteristic feature of preglacial rivers of the foreland of the East Sudetes were tectonically-controlled, frequent changes of the flow directions (Przybylski, 1998; Badura & Przybylski, 1999b). Due to lateral channel migration, fluvial deposition embraced vast areas that resemble broad alluvial fans (see also Mojski, 1984). The occurrence of Biała Głuchołaska sediments near Biała and Łącznik indicates that this river had never been flowing northwards in the Eopleistocene. On the other hand, the Nysa Kłodzka sediments build a vast distribution fan, extending between the Oława river valley in the NW to Łącznik in the SE.

The material is spread over a distance exceeding 60 km. The westernmost boundary of the pre-Odra river sediments, in turn, is shifted in respect to the present-day Odra valley by some 20 km westwards. In front of the East Sudetes, near Kędzierzyn, the width of the pre-Odra river valley exceeded 40 km, and in Wielkopolska region it attained even 80 km.

BIOSTRATIGRAPHY OF FLUVIAL SEDIMENTS

Palaeobotanically-dated biogenic sediments in SW Poland constrain the age of the Poznań and Gozdnica Formations. The onset of accumulation of the Poznań Formation is coeval with the age of the uppermost, Middle-Polish brown coal seam, commonly dated to the late Middle Miocene (Sadowska, 1987, 1995; Piwocki & Ziembińska-Tworzydło, 1997). The topmost part of the Poznań Formation, in turn, is constrained by the Sośnica and Gnojna sites (Stachurska *et al.*, 1971, 1973; Sadowska, 1987; Krajewska, 1997, 1998), associated with the Early Pliocene. Typical Pliocene palaeofloras, dating the Gozdnica Formation, have been reported from the Ruszów, Gnojna, Gorzuchów, Maciejowice, Niemodlin, Magnuszowiczki, and Tułowice localities (Jahn *et al.*, 1984; Stachurska *et al.*, 1967; Sadowska 1987; Badura *et al.*, 2001).

Another problem is posed by bio- and chronostratigraphic interpretation of the Gozdnica site, where, except for palynological studies, no sedimentological or petrographic investigations have been made. Detailed log descriptions have not been published either, except for a synthetic log summarizing data derived from different sites (Stachurska *et al.*, 1971). In the Gozdnica brickyard, sands and gravels infilling meandering river channels are exposed. These channels are situated at variable altitudes within the Poznań Formation deposits. Hence, it is difficult to interpret these infills as a separate formation cut-and-filled into older sediments, but as a pattern of channels and floodplains.

In the nearby "Stanisław" brickyard, Neogene sands rest on top of a 20-cm-thick brown coal layer, correlated with the Middle-Polish "Henryk" seam, although no palynological research has been made so far. These sands contain lenses of silts that bear both microfloristic remains, and redeposited pieces of wood and cones (Zastawniak *et al.*, 1992). The sands are overlain by Quaternary sands and gravels with numerous rounded quartz grains. The thickness of Neogene sands does not exceed 8 m, and the width of their exposure is up to 150 m. Judging from the size of exposure and prospective borehole logs, one can infer that it is a fragment of a large meander loop, cut into the Poznań Formation sediments. An analysis of sedimentary structures clearly indicates a dynamic fluvial depositional environment; hence, it is probable that much of floristic remains could have been redeposited. The occurrence of species typical both for the Miocene and Pliocene also points to redeposition of the floristic material, including macroremains (Zastawniak *et al.*, 1992). That is why it is so difficult to compare floristic assemblages found at Gozdnica with the other sites of Neogene flora in Poland. As compared to the nearby Ruszów site, the Gozdnica flora is clearly older. The stratotype of the Gozdnica Formation at Gozdnica probably represents the Upper Miocene Poznań Formation sediments, instead of Pliocene strata. Hence, the postulated shift of the lower boundary of the Gozdnica Formation to the late Middle Miocene appears to be erroneous and not justified in the light of other studies.

According to Stachurska *et al.* (1967), predominance of *Alnus* throughout the Ruszów section makes it possible to correlate the Ruszów log with the Late Pliocene Reuverian B stage, whereas Sadowska (1987) maintains that the sediments in question represent the Middle Pliocene.

An Early Pliocene age of the Gozdnica Formation in the eastern part of Lower Silesia is thought to be documented by a locality at Gnojna, in the Grodków Plain (Dyjor, 1985b, 1987; Sadowska, 1985, 1987). According to Sadowska (1987), pollen spectra of this locality are nearly identical with those found at Sośnica, the latter documenting the top of the Poznań Formation. The flora from Gnojna has been dated to the Pliocene, probably Early Pliocene, and compared to the Sośnica site near Wrocław (Stachurska *et al.*, 1973; Sadowska, 1985). The stratotype position of the Gozdnica Formation at Gnojna has been questioned by Badura *et al.* (1998) and Przybylski *et al.* (1998) who maintain that the position of organic sediments (Dyjor, 1984, 1985b, 1987) has been situated in a wrong place. These authors claim that the analysed sediments rest on top of the Poznań Clays exploited in the brickyard, and are not situated within sands and gravels of the Gozdnica Formation that cap the deposit.

At another Lower Silesian site, Kłodzko, typical Upper Pliocene organic sediments have been found by Jahn *et al.* (1984). These sediments, however, do not date the underlying gravels (as inferred by Jahn *et al.*, op. cit.), but are associated with another climatostratigraphic cycle. They were deposited within erosional scours truncated within preglacial white gravels. Pollen analyses of the rich floristic assemblage found within these strata is dominated by coniferous trees, mainly: *Pinus sylvestris* and *Picea*, and among deciduous trees – *Alnus*.

According to Sadowska (cf. Jahn *et al.*, 1984), the Kłodzko site is younger as compared to that of Ruszów because it documents a distinct climatic cooling. The share of typical Tertiary species is here reduced, and of special importance is high percentage of *Aesculus* which, according to Zagwijn (1960), is typical for Late Pliocene floras in The Netherlands. Intramontane position of the Kłodzko site does not enable one, however, for direct correlation with sites situated in lowland areas. Moreover, organic sediments make it only possible to determine the age of erosion of underlying gravels which, judging from the degree of their weathering, could be much older. Strong kaolinization of the gravels is typical for warm and wet, but not cold time intervals, as implied by the palaeoflora.

In the Upper Neogene and Lower Pleistocene fluvial sediments in the Niemodlin Plain, fossil leaf imprints have been found at four localities: Tułowice, Magnuszowiczki, Niemodlin, and Skarbiszowice. Leaf imprints found at Tułowice and Magnuszowiczki have been described by Krajewska (cf. Przybylski *et al.*, 1998) who claims that this flora shows a close resemblance to that of the Gnojna stratotype. Moreover, palynological studies of alluvial fines at Tułowice point to gradual climatic cooling (Badura *et al.*, 2001). According to Winter (*op. cit.*), the highest-situated samples contain *Hippophäe rhamnoides* pollen, already representing a Quaternary climatic element.

FINAL REMARKS

The oldest fluvial sediments in Lower Silesia originated in the Early Miocene. They are to be found within deep tectonic troughs situated at the margin of the Sudetes, as well as in the NW part of the Fore-Sudetic Block. The drainage pattern in the Sudetic area remained unchanged throughout the Middle Miocene, as shown by erosional valley landforms and correlative deposits deposited in front of the mountains. River valleys situated in the western part of Lower Silesia changed their lengths, following the changeable extent of the then North Sea shoreline. The extent of the last marine transgression in Middle Miocene times did not exceed the eastern Lusatia. It cannot be excluded that river valleys of that time were turning westwards along the present-day course of the Wrocław-Magdeburg marginal stream valley ("Pradolina"). During this transgression, sands and silts of the Pawłowice (Mużaków) Formation were deposited, and during the peak of transgression, the lower and middle courses of river valleys became inundated due to a rise of the ground water level. Hence, the valleys became filled with mires and peatbogs. Phytogenic sediments compose the youngest brown coal (Henryk) seam in Western Poland.

At the end of the Middle Miocene, a Paratethys marine bay existing in front of the East Sudetes disappeared. The rivers used to flow first along the Kędzierzyn Graben towards the East, then turned southeastwards. The uplift of the Carpathians and Sudetes led to a reversal of inclination of the groundsurface, so the rivers became to flow northwards. Strong subsidence of the Paczków and Kędzierzyn Grabens, as well as of the North-European Furrow fostered formation of the Grodków Graben which cuts the Meta-Carpathian Swell in its narrowest part. The graben was used by a new European river, the pre-Odra river, which flowed northwards and collected waters from rivers draining the West Carpathians and East Sudetes.

Following the North Sea regression and related lowering of the base level, erosional processes became intensified. The youngest silty and sandy deposits, and higher-situated peatbogs were being eroded. Sediments of the first phase of a new accumulational cycle compose the so-called "Grey Clays" horizon. Intense tectonic mobility at the turn of the Middle and Late Miocene was marked throughout Central Europe. Vigorous subsidence was compensated by increased rate of accumulation of sediments derived mostly from the eroded Carpathians, and – to a lesser extent – Sudetes. Clay minerals coming from the Carpathians occur in a meridional zone that extends from the Moravian Gate up to the middle Wielkopolska region. Rivers draining the West and Middle Sudetes reveal different compositions of clay and heavy minerals, pointing to different source areas. Textural, petrographic, and mineralogical properties of sediments indicate their fluvial origin. Sediments laid down by numerous rivers that used to flow through Silesia and Wielkopolska regions into the Baltic River build the Poznań Formation.

Tectonic mobility became less intense at the end of the Late Miocene or in Early Pliocene times. Pedogenic processes were developing at the surface of the so-called "Green Clays", leading to formation of the "Flame Clays".

Deposition of a younger fluvial series took place probably at the beginning of the Late Pliocene, following the first global cooling in the Northern Hemisphere. Big meandering rivers transported sandy material and, during floods, also clay balls. Oxbow lakes and slopes of point bars were the place of deposition of silts, frequently bearing leaf imprints.

The transporting power of streams was increasing with prograding cooling. High-energetic waters transported gravel material far into the mountain foreland, pointing to seasonally-controlled flows. Sandy clasts transported in a frozen state, found within these sediments, indicate flows proceeding during spring thaws. Such a type of accumulation persisted in Western Poland until the first great continental glaciation, i.e., the Elsterian Glaciation. Glacial advance changed drainage pattern in the European Lowland, whereas in the mountains it has remained unchanged since at least the Early Miocene.

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Streszczenie

EWOLUCJA SIECI RZECZNEJ NA PRZEDPOLU SUDETÓW W PÓŹNYM NEOGENIE I EOPLEJSTOCENIE

Janusz Badura & Bogusław Przybylski

Najstarsze osady rzeczne na Dolnym Śląsku znane są z miocenu wczesnego, ale należy założyć, że istniejąca tu obecnie sieć rzeczna zaczęła formować się już w okresie regresji epikontynentalnego morza późnokredowego. Powstałe wówczas zarysy zlewni głównych rzek stopniowo przekształciły się w obserwowaną obecnie sieć drenażu na obszarze Sudetów i ich przedpola. Na przedpolu Sudetów sieć rzeczna ulegała znacznie większym przemianom, zachowując jednak spływ ku północy (Fig. 1). Wzdłuż linii brzegowych paleogeńskich mórz w północno-zachodniej części Dolnego Śląska występują osady rzeczne wskazujące na dostawę materiału żwirowego z Sudetów, a na przedpolu Sudetów są obecne przemiennie występujące, a fragmentarycznie zachowane osady lądowe, rzeczne i bagienne (węgle brunatne). Dopiero we wczesnym miocenie w rowach i zapadliskach tektonicznych akumulowane były osady wskazujące na gwałtowne przepływy torencjalne.

Na przedpolu Sudetów Zachodnich najstarszy zarys traktów rzecznych późno-środkowomioceńskich odzwierciedlają duże złoża węgla brunatnego pokładu środkowopolskiego (Fig. 2). Na obszarze przedpola Sudetów Wschodnich nastąpiły w trzeciorzędzie największe zmiany układu sieci rzecznej. Przez cały paleogen i znaczną część miocenu odpływ rzeczny odbywał się tu ku SE rowem Kędzierzyna do Paratetydy. Na przełomie miocenu środkowego i późnego wypiętrzenie Karpat i Sudetów spowodowało zmianę nachylenia terenu ku północy. Ruchy tektoniczne zaznaczyły się także na obszarze Niżu Polskiego wzmożoną subsydencją oraz pionowymi przemieszczeniami w obrębie wału metakarpackiego. Wał ten pełnił rolę wododziału europejskiego, oddzielającego zlewnie Morza Północnego od Paratetydy, aż do późnego miocenu środkowego, kiedy to elewację tę przeciął poprzeczny rów tektoniczny Grodkowa, którym na północ popłynęła nowa rzeka, pra-Odra.

Ruchom tektonicznym i zmianom klimatu towarzyszyła wzmożona erozja. W jej wyniku rozmywane były między innymi węgle brunatne. Deponowane wówczas osady wyróżniane są litostratygraficznie jako poziom iłów szarych. Rzeki wynoszące głównie mułki, iły i piaski często przerzucały swoje koryta na rozległym obszarze. Każda z sudeckich i karpackich rzek charakteryzuje się swoistym zespołem minerałów ciężkich i proporcjami minerałów ilastych, a we frakcjach grubszych – składem petrograficznym. Na tej podstawie można wyznaczyć zasięg poszczególnych rzek na całym obszarze Niżu Polskiego (Fig. 3). Dzisiejsza dolina Odry, od granicy państwa na południu do Opola na północy, znajduje się we wschodniej części dawnego traktu rzecznego. Można jedynie przypuszczać, że mioceńska Odra już na terenie południowej Wielkopolski przechwytywała inne środkowosudeckie rzeki. Rzeki Sudetów Zachodnich nie tworzyły jeszcze wówczas wspólnego dorzecza z Odrą.

Basen iłów formacji poznańskiej należy zatem interpretować jako rozległą nizinę, po której płynęły rzeki sudeckie, karpackie oraz płynące ze wschodu. Wszystkie te rzeki łączyły się z rzeką bałtycką, która w neogenie i eoplejstocenie stanowiła główny trakt fluwialny w tej części Europy, płynąc od Fennoskandii ku Morzu Północnemu przez obszar dzisiejszego Bałtyku i zachodniego Pomorza (Fig. 3). Tylko dolny bieg tej rzeki przemieszczał się wraz z transgresjami i regresjami pra- Morza Północnego; generalne kierunki odpływów przetrwały jednak w niezmienionym układzie, aż do pierwszego kontynentalnego zlodowacenia niżowego w Europie.

W neogenie i wczesnym plejstocenie rzeki na przedpolu Sudetów migrowały tworząc szerokie powierzchnie sedymentacyjne (Fig. 4). W ciepłym klimacie późnego neogenu transportowane były głównie pyły i drobne piaski powstałe ze zniszczenia pokryw zwietrzelinowych, tworzących grubą warstwę na wychodniach skał sudeckich (Fig. 6, 7). Neogeńskim zmianom klimatycznym towarzyszyły zmiany w charakterze materiału rzecznego (Fig. 8, 9). Efektem tych zmian jest stopniowe przejście od sedymentacji mułków, piasków i lokalnie węgli brunatnych do piasków, a następnie żwirów. Dopiero pod koniec neogenu i w eoplejstocenie wraz z ochładzeniem klimatu rzeki zmieniły reżim i transportowały gruby materiał żwirowy (Fig. 8). Na przedpolu Sudetów Wschodnich szczegółowe analizy petrograficzne pozwoliły wyróżnić trzy główne rzeki: pra-Odrę, Nysę Kłodzką i Białą Głuchołaską (Fig. 6). Szerokość pasa rozrzutu materiału pra-Nysy Kłodzkiej wynosi około 60 km, a pra-Odry – 40 km.

Analiza materiału wiertniczego pozwoliła na zweryfikowanie hipotezy o powstaniu w eoplejstocenie sieci głębokich dolin z materiałem żwirowym występującym w ich dolnych partiach. Na podstawie szczegółowych analiz dostępnych materiałów stwierdzono, że formy erozyjne dotychczas interpretowane jako doliny to rynny subglacjalne powstałe w czasie zlodowaceń niżowych, a materiał neogeńsko-eoplejstoceński był redeponowany (Fig. 5).

W eoplejstocenie kontynuowane było wynoszenie materiału żwirowego na przedpole Sudetów. Materiał ten był transportowany w środowisku wysokoenergetycznych przepływów. Wskazuje to na okresowe, być może uzależnione od zmian pór roku, spływy. Znajdowane w osadach klasty piaszczyste transportowane w stanie zamarzniętym wskazują na spływ wód w czasie roztopów wiosennych. Akumulacja tego typu trwała w zachodniej Polsce aż do pierwszego kontynentalnego zlodowacenia półkuli północnej, w czasie piętra Sanu (Elstery). Transgresja lądolodu zmieniła układ dolin rzecznych niżowej części Dolnego Śląska, podczas gdy w górach pozostał on niezmieniony, co najmniej od miocenu wczesnego.