Landform Analysis, Vol. 14: 57–84

Evolution of the Toruń Basin in the Late Weichselian

Piotr Weckwerth

Nicolaus Copernicus University, Institute of Geography, Gagarina 9, PL-87-100 Toruń, Poland; pweck@umk.pl

Abstract: The Toruń Basin is the eastern fragment of the Noteć-Warta ice-marginal streamway. Genesis of the Toruń Basin firstly demonstrates processes of erosion and accumulation of meltwaters and the Vistula waters which occur on the background of changes in the height of erosion base and tectonic movements. In the formation of the Toruń Basin one cannot exclude its older, glacial and interglacial assumptions either, as through its location the form is related to the course of the fossil valleys.

The article presents functional stages and reorganizational mechanisms of water discharge directions in the Toruń Basin, stimulated by the tectonic activity of the older bed. In the Toruń Basin the following terrace sets can be distinguished: a) the outwash levels formed not so far away from the ice-sheet front, i.e. during the Wąbrzeźno Subphase, b) the distal sections of the outwash (XI, X), c) the Vistula ice-marginal streamway terraces (the transitional terrace and IX), d) the Vistula ice-marginal streamway terraces (VIII-VI) from the period of this river bifurcation at Fordon, and e) lower terraces of the Vistula valley. In the upper part of the Late Weichselian waters formed a system of sandbed braided rivers with changeable flow regime, which initially had higher energy, then reduced energy and high again. This resulted from the ice-sheet front retreat, intensity of its ablation and the inflow of the Vistula waters from the south.

Introduction

The Toruń Basin is the initial eastern fragment of the Noteć-Warta ice-marginal streamway, and belongs to its biggest widenings used by the valley of the lower Vistula, within the extent of the last glaciation (Galon 1934, 1953, Kozarski 1962, Niewiarowski 1968). The lower sections of the river valleys and meltwaters discharge tracks are concentrated within the valley. Hence, its genesis firstly demonstrates processes of erosion and accumulation of meltwaters and the Vistula waters which occur on the background of changes in the height of erosion base and tectonic movements of the older bed (Mojski 1980, Wiśniewski 1987, Starkel 2001, Weckwerth 2006, 2007c). In the formation of the Toruń Basin one cannot exclude its older, glacial and interglacial assumptions either, as through its location the form is related to the course of the late age fossil valleys (Weckwerth 2007c).

Investigations into the geomorphological development of the Toruń Basin were initialised by the works of German researchers who claimed the existence of an ice-dammed lake in the basin (Keilhack 1904, Jentzsch 1919, Sonntag 1916, 1919, Maas 1904, Woldsted 1932, Ost 1935). Its shallowing and the latter activity of the River Vistula were assumed to result in the development of terraces in the Toruń Basin. According to Lencewicz (1922, 1923), the ice-dammed lake was to be formed due to the breaking of a glacial lake near Włocławek. Its vanishing made it possible to join two basins in the line of the Vistula valley.

Samsonowicz (1924) and Galon (1929) rejected the idea of an ice-dammed lake in the Toruń Basin. They differentiated three terraces (upper, central and lower), though. The subsequent developments of opinions on the evolution of the basin relief were based upon the results of Galon (1929, 1934). Galon (1953) transferred the results of the investigations into the evolution of the valley and the Brda outwash onto the entire system of the Toruń-Eberswald ice-marginal streamway, defining the stages of the Late Weichselian hydrographic network of the Pol-

The article originates from Piotr Weckwerth Ph.d. thesis "Morphogenesis of the selected areas of the Toruń Basin and their part in hydrographic network during Upper Plenivistulian" defended in 2004 and awarded in the contest for the best doctoral thesis in geomorphology.

ish Lowland (Galon 1961, 1968). He distinguished eleven terraces in the basin out of which the oldest (terrace XI) was related to the discharge of waters during the Pomerania Phase (Galon 1968). Whereas, within the level of the terrace Vc (IX) the bifurcation of the Vistula waters started, i.e. some waters directed westwards through the Noteć-Warta ice-marginal streamway, and some waters ran northwards. According to Galon (1961, 1968), the above change of the Vistula flow into the northern direction at Fordon was initiated in the Oldest Dryas, and was to occur at the levels of the terraces from IX to VI. According to Galon, the direction of the Vistula exclusively northwards occurred as of the Alleröd, according to Roszko (1968) as of the Older Dryas, or as Augustowski claims (1982) as of the Bölling (on the grounds of the investigations conducted by Drozdowski 1974). Similarly, the incision of the Vistula waters into the level of the terrace VI is dated by Tomczak (1987) at the turn of the Oldest Dryas and Bölling. Niewiarowski (1987) claims this may have occurred 14,000 years ago. This author believes the timing problem of directing the Vistula waters to the north is still open and requires further research. Bifurcation of the Vistula in the vicinity of Fordon is questioned by Wiśniewski (1990). He claims the northward direction of the Vistula waters occurred in the level of the terrace VI. Weckwerth (2006) also referred to the issue of the Vistula bifurcation in the vicinity of Fordon, proving a shorter duration of this flow than was assumed by Galon (1961, 1968) due to the exclusion of the terrace IX.

The research into the evolution of the relief of the Toruń Basin was also conducted by Tomczak (1987), who distinguished five terraces within the Toruń Basin, and claimed the evolution of the terrace IX as a result of water surface wash on the frozen bed (permafrost). Moreover, Tomczak (1971, 1982, 1987) recognized the geological structure and the evolution of fluvial forms within the upper flood terraces and the Vistula flood plain. Problems of evolution and the age of forms and deposits of the Vistula flood plain in the Toruń Basin were dwelt upon in the works by, among others: Wiśniewski (1976, 1987), Niewiarowski & Noryśkiewicz (1983), Andrzejewski (1994, 1995), Kordowski (1997), and Szmańda (2000, 2002).

Main properties of the Toruń Basin relief

The activity of waters is responsible for the evolution of the present relief of the Toruń Basin. These waters formed a hydrologic node joining the valleys of the Vistula, Noteć, Drwęca and Brda with the Noteć-Warta ice-marginal streamway during the Weichselian ice sheet recession (Galon 1934, 1953, 1961, Niewiarowski 1968, 1969, Wiśniewski 1976, 1990). Hence, the basic relief forms of the Toruń Basin include outwash levels and terraces (Galon 1968). Moreover, some fragments of a morainic plateau are preserved in the Toruń Basin. The biggest of them, located in the central part of the basin, near Chrośna and Leszyce, reaches between 90 and 75 m a.s.l. Smaller morainic remnants are found in the vicinity of Nowe Dąbie (to the north of Łabiszyn) and near Aleksandrów Kujawski (Fig. 1).

Despite the dominance of fluvial forms, the Toruń Basin is characterised by a considerably diverse land relief. Its average altitude amounts to 67.93 m a.s.l., the areas located below 55 m a.s.l. (the Vistula valley, below the terrace VI) make up 30 % of its entire area, and the area located between 67 and 70 m a.s.l. take approximately 22% (terrace IX). Approximately 28% of the Toruń Basin is located above 70 m a.s.l. The Vistula flood plain is located lowest in the Toruń Basin, at 32–43 m a.s.l. At its contact points with morainic plateaux there are considerable denivelations, reaching up to 60 m. The highest elevations within the Toruń Basin constitute culminations of dunes located on the higher terrace levels. Their heights often exceed 100 m a.s.l. (Szwedzka Góra 115.9 m a.s.l., Dębie Góry 110–114 m a.s.l.), which makes up the maximum difference of height for the entire Toruń Basin of nearly 84 m. Height differences between the subsequent terraces of the Toruń Basin are minor, as they amount to 3–7 m. Considerably bigger denivelations, of approximately 27–38 m, occur only when, for instance the Vistula flood plain borders with the terraces located higher. Significant relative heights are found within the dunes located on the terraces of the Toruń Basin (10–25 m, maximum 40–45 m).

The outwash levels and terraces show considerable differences in the slope of their areas. These slopes are biggest for the outwash levels (0.217‰–0.36‰), and nearly three times as small for the terraces XI and X and for the transitional terrace (0.090‰–0.096‰). The gradient of the slopes of the terraces from IX to VI rise again, and amount to: the terrace IX – 0.120‰, the terrace VIII – 0.105‰, the terrace VII – 0.194‰, and the terrace VI – 0.115‰. With respect to the value of the inclinations of the terraces in the entire Noteć-Warta ice-marginal streamway quoted by Galon (1961), they are smaller by 50–70% for the terraces IX and X, and by 38% for the terrace IX, and by up to 84% for the terrace VIII. The terrace VII is characterised by a similar inclination both in the Toruń Basin and in the entire Noteć-Warta ice-marginal streamway. Perhaps this smaller gradient of the slope of the terraces in the Toruń Basin may be related to a bigger lateral activity of flowing waters here than in the Noteć-Warta ice-marginal streamway (Leopold et al. 1964, Schumm 1977, Knighton 1984).

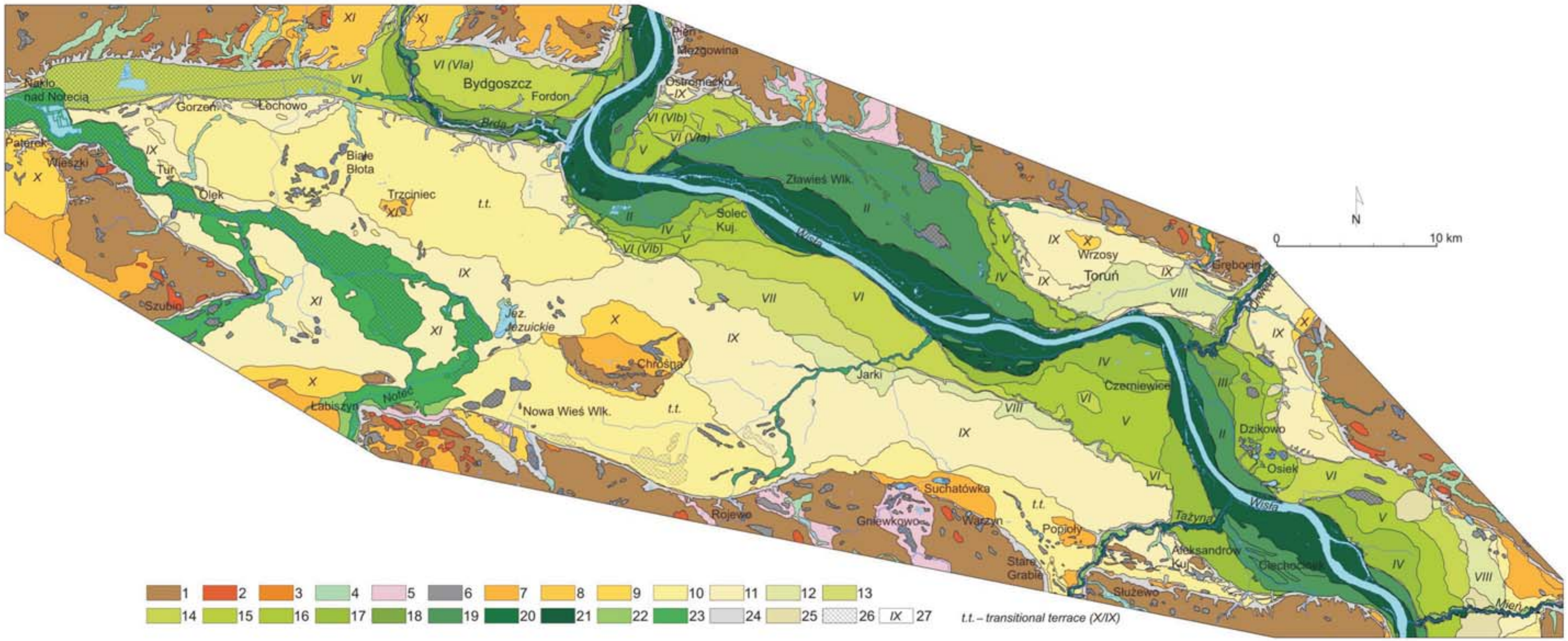

Fig. 1. Geomorphological map of the Toruń Basin
1 – morainic plateau, 2 – morainic hummocks and hills, 3 – kame, 4 – subglacial channels, 5 – meltwater erosional plain, 6 – kettles, 7 – outwash and outwash levels, 8 – terrace XI, 9 – terrace X, 10 – transitional terrace (X/IX), 11 – terrace IX, 12 – terrace VIII, 13 – terrace VII, 14 – terrace VI (VIa), 15 – terrace VI (lower level VIb), 16 – terrace V, 17 – terrace IV, 18 – terrace III, 19 – terrace II, 20 – terrace I (in the Brda valley), 21 – flood plains, 22 – terraces of other valleys, 23 – bottoms of small valleys, 24 – slopes and denudative forms, 25 – alluvial fans, 26 – biogenetic plains, 27 – terraces numbering after Galon (1953, 1968)

The hitherto prevailing investigations of the evolution of the Toruń Basin relief show that the terrace levels within the Toruń Basin formed at different times, starting from the deglaciation of this form. Initially, during the Krajna-Wąbrzeżno Subphase, the Toruń Basin was a track for meltwater discharge (Niewiarowski 1969). The rudimentary fragments of outwash levels located mainly in its southern part date from that period (Weckwerth 2005). The major evolution of the basin occurred with the start of the Pomerania Phase of the last glaciation. The basin was formed as an eastern extension of the Noteć-Warta ice-marginal streamway, as a result of the activity of meltwaters and waters from the extraglacial area (Galon 1961, Kozarski 1962, Niewiarowski 1968, 1969, Wiśniewski 1990, Weckwerth 2004, 2005). The flow of these waters at lower heights resulted in the formation of the terraces from XI to VI. Further evolution of the lowest group of the terraces was mainly related to the activity of the Vistula after its incision into the terrace VI and its change of flow direction to the north at Fordon (Galon 1953, 1961). According to Tomczak (1987) and Niewiarowski & Weckwerth (2006), the outwash levels found in the basin and related to the Krajna-Wąbrzeźno Subphase, developed at around 17 ka BP, whereas the terraces XI–IX at the end of the Weichselian from approximately 16 to 14–13.5 ka BP, the terraces VIII–III in the Oldest Dryas (from 14–13 ka BP to 12.4 ka BP) and in the Bölling (from 12.4 to 12.1 ka BP), and the terrace II in the Older Dryas (12.1–11.8 ka BP) and at the beginning of the Alleröd (11.8–11.5 ka BP), and the flood plain in the Holocene.

Geological structure of the Cenozoic bed

The formations of the Cenozoic bed of the Toruń Basin belong to major structural and tectonic units found in Poland (Fig. 2). These are: a marginal trough changing into a Precambrian platform (Eastern European platform) in the eastern part of the basin and the Central Polish Anticlinorium located in its central and western parts (Marek & Znosko 1972a, b). Their conventional border is determined by a zone of 2 to 7-kilometre width, which runs between the deposits of the Upper and Lower Cretaceous, in the line Fordon (Bydgoszcz)–Toruń–Czernikowo–Nieszawa–Włocławek (Marek & Znosko 1972a, Dadlez & Marek 1974, Marek & Znosko 1983).

A fragment of the marginal trough comprising the eastern part of the basin belongs to its Warsaw section (Płock section, Dadlez & Marek 1974). This marginal trough is a relatively young tectonic structure, as its southwest limit at the contact points with the Kujawy anticline formed during its uplift, between the end of the Cretaceous and the beginning of the Cenozoic (Dadlez & Marek 1983). The discussed eastern fragment of the Toruń Basin is located within the inclination of the Kujawy-Pomerania Anticlinorium and the northern part of the Płońsk section of the marginal trough (Dadlez & Marek 1983). Situated within the marginal trough, the Zechstein basin is a trough of WNW-ESE axis (Pożaryski et al. 1983). The top of the Cretaceous deposits bends northwards here (from 8 m b.s.l. to 20–23 m b.s.l.). Starting from southwest limits of the marginal trough, the bed of the Cenozoic deposits in the vicinity of Toruń make up the face of the bed from the Upper Albian and Cenomanian (inclination of the Kujawy Anticlinorium) to the Maastrichtian (Fig. 2). These are marine facies and lie relatively shallow along the Vistula valley, at the depth from 50 to 120 m, where they occur in the Quaternary bed to the south of Toruń (Fig. 3). They are mainly represented by marl, limestone, marly limestone, and marly gaizes (Cenomanian, Turonian, Coniacian and Santonian) and marls and marly gaizes belonging to the Maastrichtian with rich microfauna (Niewiarowski & Wilczyński 1979).

The central and western part of the Toruń Basin stays within the Middle-Polish Anticlinorium (Fig. 2), which is intersected with a dislocation zone in the Zechstein bed of a nearly parallel orientation (Łyczewska 1975, Dadlez 1980a, 1980b). As for its course, the zone relates to the Noteć valley and is considered a tectonic border between the Pomerania Anticlinorium in the north and the Kujawy Anticlinorium in the south (Dadlez & Dembowska 1965, Dadlez 1980a, Marek & Znosko 1972a). It also divides the Nakło region from the Gniewkowo region with a different degree of evolution of salt tectonics structures. These structures in the southern direction are significantly more visible, which is related to a considerable increase in the Zechstein thickness on the Kujawy swell as compared to the marginal trough (Marek & Znosko 1972a, Dadlez & Marek 1974). The swell, pillows and salt banks of the Gniewkowo region located within the basin occur in the vicinity of Ciechocinek and Nakło (Łobżenica/Więcbork), Chrośna, Toporzyska and Szubin (Fig. 2).

Relief of t the sub-Quaternary deposits

The relief of the sub-Quaternary surface within the Toruń Basin and its closest neighbourhood is characterised by a series of declines mainly related to the Quaternary processes of fluvial and glacial erosion (Fig. 3). The surface of the sub-Quaternary surface reaches the smallest height in Bydgoszcz (120.0 and 110.2 m b.s.l.), whereas its culminations are found in the vicinity of Toruń (65.5–66.8 m a.s.l.), and to the west of Łabiszyn (72 m a.s.l.), and in Bydgoszcz (67.6–70.0 m a.s.l.). Thus, the height difference in the sub-Quaternary surface reaches the value of 192 m (Fig. 2). The average height of the sub-Quaternary surface amounts to approximately 15 m a.s.l. Approximately 26% of its area is located below the sea level (from 0 to 120.0 m b.s.l.), 44% stays in the height range of 0–24 m a.s.l., whereas 30% is over 24 m a.s.l.

The culminations of the surface of the sub-Quaternary surface within the Toruń Basin consist of the Pliocene deposits, while alongside the increase in its depth in the depressions, the Miocene and Oligocene formations, as well as the Cretaceous and Jurassic formations are found (Fig. 3). The oldest Mesozoic deposits lying below the Quaternary formations of the Toruń Basin comprise deposits of the Lower Jurassic in the southwest limit of the basin, to the south of Szubin, and of the Upper Jurassic in the vicinity of Aleksandrów Kujawski and Ciechocinek, which, thus, belong to the Ciechocinek elevation (Łyczewska 1975, Niewiarowski & Wilczyński 1979). According to Kucharski (1966) and Łyczewska (1975), their high position is related to particularly intensive erosion processes at the end of the Pliocene. Moreover, the face of the Jurassic and Lower Cretaceous bed rocks are found further to the west towards the culmination of the Kujawy Anticlinorium, at the bottom of the fossil valley in the vicinity of Aleksandrów Kujawski and Nowa Wieś Wielka (Łyczewska 1975, Niewiarowski & Wilczyński 1979, Wrotek 1993, Jeziorski 1995a). The Lower Cretaceous deposits were also found in Bydgoszcz, at the bottom of exarational or tectonic troughs surrounded by a system of faults (Kozłowska & Kozłowski 1992).

Systems of valley forms, which run parallel and meridionally, play a major role in the diversified sub-Quaternary surface. The first system represented by a series of declines running accordingly to the axis of the Toruń Basin, along its southern slopes (Fig. 3). Their bottoms merge into a major wide valley form. They are located at 1–3 m b.s.l. and 14 m b.s.l. in the eastern part of the valley (in the vicinity of Toruń and Suchatówka) and 28–41.5 m b.s.l. in Nowa Wieś Wielka, where they reach the Cenozoic bed (Lower Cretaceous). Between Tur and Jarużyn it goes down to 41.4–58.0 m b.s.l., while in Nakło upon the Noteć down to 36.8 m b.s.l. (the Nakło tectonic trench). The mentioned main valley form developed in the Pleistocene bed in the eastern part of the Toruń Basin has a broadly concave character. It is located within the range of the Kujawy-Pomerania swell and lateral synclinorium and shows considerably smaller denivelations than those recorded father to the west. Within this area, to the east of Aleksandrów Kujawski and Suchatówka, the face of the Oligocene, at places the Miocene formations

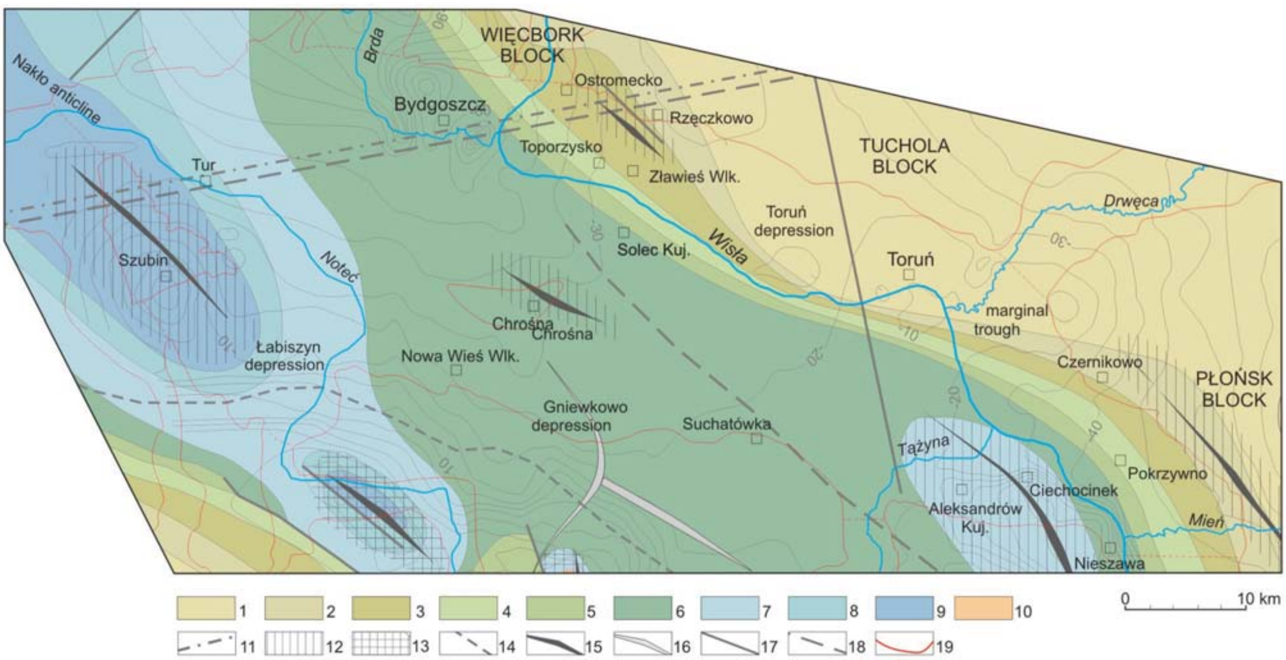

Fig. 2. Geological and structural map without Cainozoic formations (parly after: Marek & Znosko 1972, Dadlez & Marek 1974, Pożaryski 1974, Dadlez et al. 2000)

Upper Cretaceous: 1 – Maastrichtian, 2 – Campanian, 3 – Coniaciab and Santonian, 4 – Turonian, 5 – Upper Albian and Cenomanian, 6 – Lower Cretaceous, 7 – Upper Jurassic, 8 – Middle Jurassic, 9 – Lower Jurassic, 10 – Zechstein, 11 – border between the Kujawy antyclinorium and the Pomeranian antyclinorium, 12 – salt banks, pillows and swells, 13 – salt domes, 14 – border between zone of salt domes and salt banks, pillows and swells, 15 – antyclines axes, 16 – synclines axes, 17 – detected dislocations zones in the substratum of the Zechstain sediments, 18 – probable dislocations zones in the substratum of Zechstain sediments, 19 – morainic plateaux extent

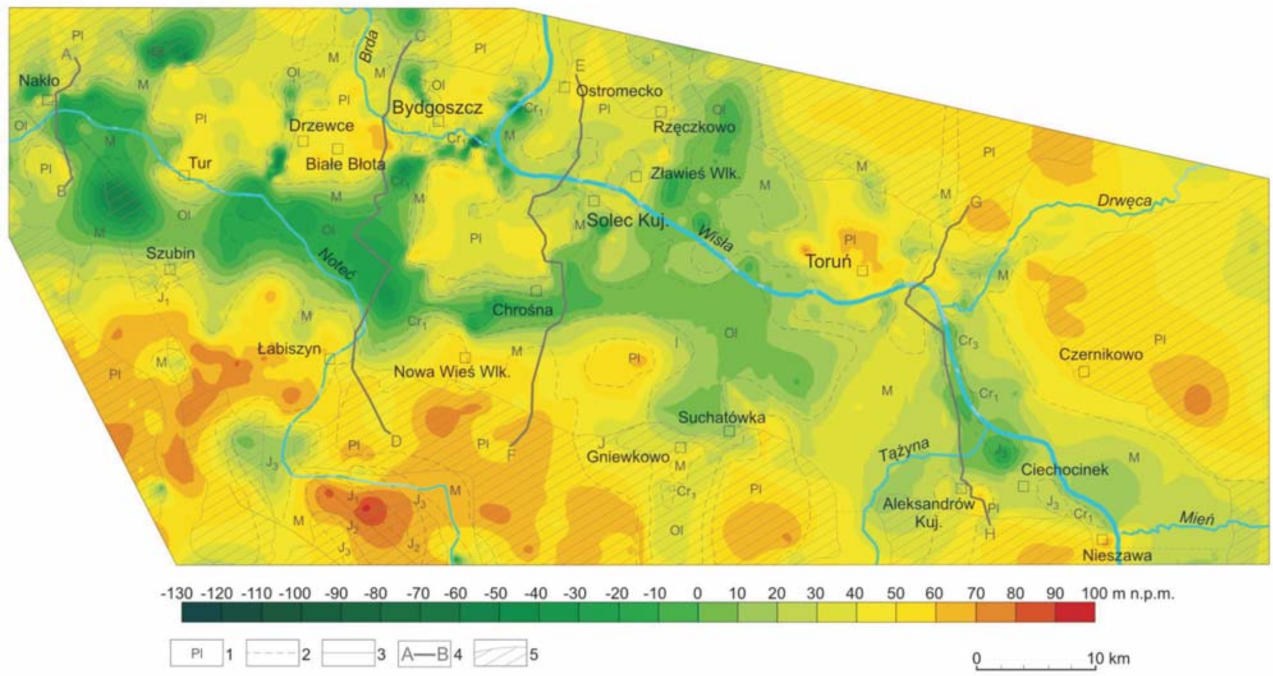

Fig. 3. Solid geological map of the sub-Quaternary surface
1 – stratigraphy (Pl – Pliocene, M – Miocene, Ol – Oligocene, Cr_3 – Upper Cretaceous, Cr_1 – Lower Cretaceous, J_3 – Upper Jurassic, J_2 – Middle Jurassic, J_1 – Lower Jurassic), 2 – geological borders, 3 – fault (after various authors), 4 – lines of geological sections, 5 – morainic plateaux extent

dominate at the bottom of the analysed depression. Whereas, in the deepenings below the sea level, there are the Jurassic and Cretaceous deposits which belong to the Mesozoic elevation of Ciechocinek

In the western direction the bottom of the parallel running major fossil valley to the south of Chrośna narrows down and deepens to 28–31 m b.s.l. It takes a character of a narrow section developed in the southern limit of the Chrośna anticline. This decline stretches farther to the west along tectonic depressions of the Kujawy Anticlinorium (the Gniewkowo and Łabiszyn depressions), and then changes into the Eopleistocene valley of the proto-Noteć (Dyjor 1987), and intersects the Nakło anticline in the northern limit of the Szubin structure (Figs 2 and 3). The slanting course of the described form as compared to the salt structures of the Middle-Polish Anticlinorium, and locally within their extent, resulted in complete erosion of the Paleogene and Neogene deposits. Hence, the bottom of the fossil valley in these places is made of the Cretaceous and Upper Jurassic deposits.

The predominant part of the above major fossil valley, located in the west and southwest part of the Toruń Basin evolved before the Great (Masovian) Interglacial (Figs 4, 5, 6). Within the area of the Toruń Basin an interglacial river running at that time flowed to the west along the Noteć valley (Niewiarowski & Wilczyński 1979, Uniejewska et al. 1979, Włodek 1980, Mojski 1984, Dyjor 1991, Brykczyński 1986 and others). Galon (1981), Włodek (1980), Brykczyński (1986) and Dyjor (1991) believed there had been an adjoining decline from the east, which had run parallel to the river in the southern part of the Toruń Basin. The analysis of the geological boreholes showed this form had been destroyed due to the activities of waters during the Eemian Interglacial. Its farther eastern extension can probably be found in the vicinity of Toruń, where the deposits of that dating occur in the fossil bottoms of the proto-Drwęca and the valley running in the line Lulkowo-Wrzosy-Stawki (Wilczyński 1973, Niewiarowski & Wilczyński 1979, Niewiarowski 1968). The discharge of waters within their area occurred from the northeast towards the southwest.

From the north and south other depressions contact with the large concaveness of the surface of the sub-Quaternary surface of the eastern part of the Toruń Basin. In the area located between Przyłubie, Chrośna, Suchatówka and Cierpice, the concaveness merges with a 10–15-kilometre wide fossil river valley from the Eemian Interglacial, whose deposits are found in the form of three cycles of sedimentation (Makowska 1979, 1980). Its limits, of a nearly meridional course, stretch onto the eastern environs of Solec Kujawski. The extent of this valley is determined by the sub-Quaternary surface datum of 20 m a.s.l. The considerable depth of this form with its bottom located at the altitude of 4.0–12.5 m b.s.l. proves significant intersection of the river which caused the elimination of the Pliocene and partially Miocene deposits. The erosion base of the Eemian river network used to be located close to the Baltic depression, which resulted in the reorganisation of the drainage system, which then began to look similarly to the present one (Fig. 3). The location of the Eemian fossil valley in the east and southeast part of the Toruń Basin almost matches the extent of the present valley of the River Vistula (Łyczewska 1975, Wiśniewski 1976, Niewiarowski & Wilczyński 1979). The major Eemian valley also comes into contact with more narrow fossil valleys located in the vicinity of Toruń and Gniewkowo (Fig. 6).

Another Eemian fossil side valley in the south part of the Toruń Basin is located to the southwest and west of Bydgoszcz (the environs of Łabiszyn and Nakło upon the Noteć). Its course in the western limit of the basin covers the fossil valley of the Great Interglacial (Fig. 6). The Eemian deposits do no exceed the datum of 50–60 m a.s.l., and lie lower with respect to the height of the layer of the lodgement till from the Central Polish Glaciations. Moreover, the Eemian valleys in the vicinity of Bydgoszcz probably run parallel to the present channel of the Vistula in Fordon and along the Vistula bend between Otorowo and Łęgnowo, and they relate to the present flood plain of the Vistula and the Brda valley.

Other forms of fossil valleys in the sub-Quaternary surface are located in the vicinity of Ślesin and Minikowo (to the east of Nakło) and in the line of the present Brda valley. The decline running along the line Brda-Noteć in the Toruń Basin stretches near the

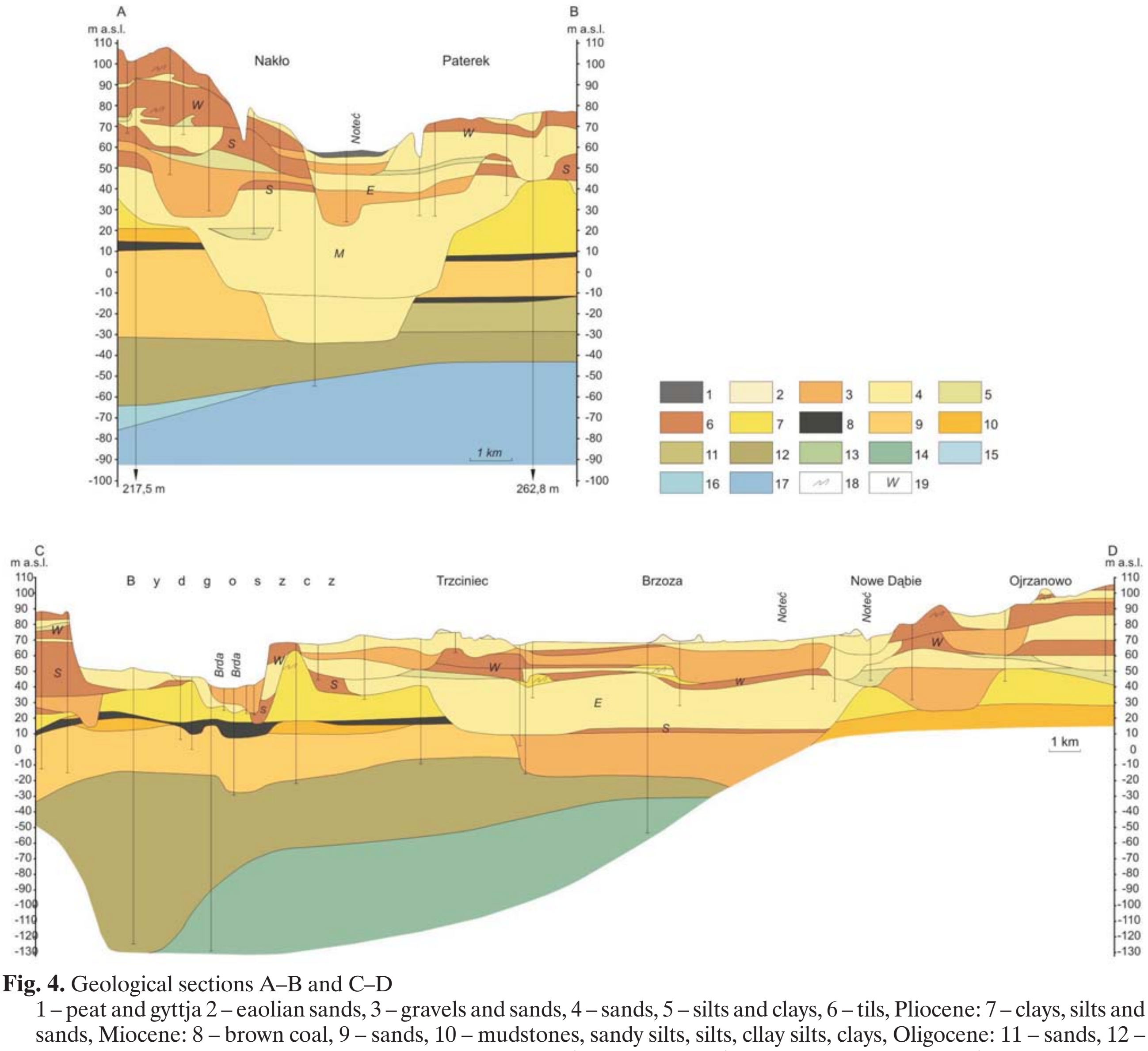

Fig. 4. Geological sections A–B and C–D

1 – peat and gyttja 2 – eaolian sands, 3 – gravels and sands, 4 – sands, 5 – silts and clays, 6 – tils, Pliocene: 7 – clays, silts and sands, Miocene: 8 – brown coal, 9 – sands, 10 – mudstones, sandy silts, silts, cllay silts, clays, Oligocene: 11 – sands, 12 – clays, claystones, clay silts, silts, 13 – Upper Cretaceous (marls and gaize), 14 – Lower Cretaceous (claystones, slates, sandy-clay slates, marly mudstones, marls, gaize, limestones,sandstones), 15 – Upper Jurassic (claystones, mudstones, slates, limestones, dolostones), 16 – Middle Jurassic (claystones, clay-sandy slates, marly mudstones, limestones, marls, sandstones), 17 – Lower Jurassic (mudstones, claystones, slates, clay-sandy slates, sandstones), 18 – glaciotectonic deformations, 19 – hypothetical age of the Pleistocene deposits: *W* – Weichselian, *E* – Eemian Interglacial, *S* – Middle-Polish glaciation, *M* – Masovian (Great) Interglacial, *P* – South-Polish glaciation

village of Drzewce and comes into contact with the valley running parallel in the vicinity of Kruszyn Krajeński. To the east of the Brda valley, in the northern part of Bydgoszcz, there is a depression described by Żurawski (1959). It is found in the bed of the Quaternary deposits with the bottom in the Miocene deposits at the height of 0–20 m b.s.l. The discussed system of fossil valleys in the western part of the Toruń Basin intersects the layer of the height of 30–40 m a.s.l., whose composition is dominated by the Pliocene silts and clays. Only in the area of Łochowo, Białe Błota and Myślęcinek do the culminations of this layer of the height of 50–55 m a.s.l. occur (Fig. 3).

The valley stretching from the environs of Łabiszyn towards Nowa Wieś Wielka belongs to the depressions in the sub-Quaternary surface located in the south part of the Toruń Basin. The valley bottom deepens to the north from approximately 0–10 m b.s.l. (1.5 m b.s.l. in Załachów) to below 30 m b.s.l., where it reaches the Jurassic deposits. A fossil valley located near Gniewkowo is another form (Fig. 3). Its bottom is cut into the Oligocene deposits (16 m b.s.l.) and is diversified with secondary deepenings with the face of Cretaceous bed (25.0 m b.s.l. and 54 m b.s.l.). In these places the fossil valley is deepest (72–79.8 m) as compared to the planar beds with the face of the Pliocene bed.

In the southeast part of the Toruń Basin, the almost planar sub-Quaternary surface with the face of bed of the Pliocene clays and silts is intersected by several deepenings directed from the south to the north. The deepest of these forms covers the present valley of the Tążyna. The bottom of this fossil valley was drilled at the level of 4 m b.s.l. (Fig. 3).

The relief of the sub-Quaternary surface in the vicinity of Bydgoszcz shows particularly interesting deep depressions of a tectonic character or related to glacial and fluvial erosion (Jankowski 1975, Kozłowska & Kozłowski 1992). They diversify this almost planar sub-Quaternary surface in this part of the basin, located at the height of 30–40 m a.s.l. and made of the Pliocene and Miocene deposits (Fig. 2). At their bottoms, ranging from 120.0 m b.s.l. do 16 m a.s.l. there are the Oligocene and Miocene deposits. The Cretaceous deposits are found at the depth of 105.0–120.0 m b.s.l. Some of these depressions are surrounded by a system of faults (Kozłowska & Kozłowski 1992). They may be genetically related to the dislocations of the Nakło anticline. The breccias of the Cretaceous rocks and the Miocene and Pliocene clays, recognised by Kozłowska & Kozłowski (1992), may indicate that these are fissures of a tectonic and karstic origin, developed in the line of profound dislocations (Baraniecka 1980).

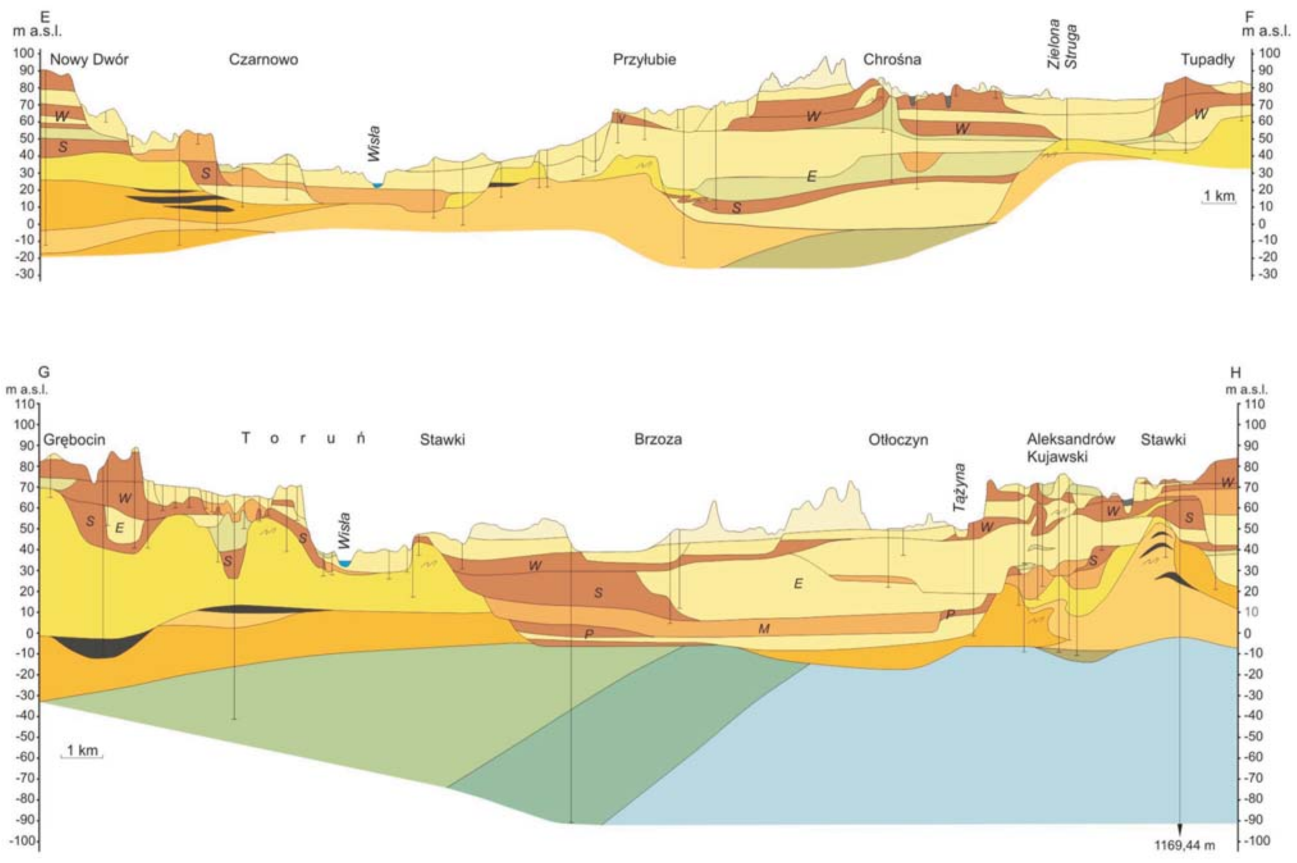

Fig. 5. Geological sections E–F and G–H explanations like in the Fig. 4

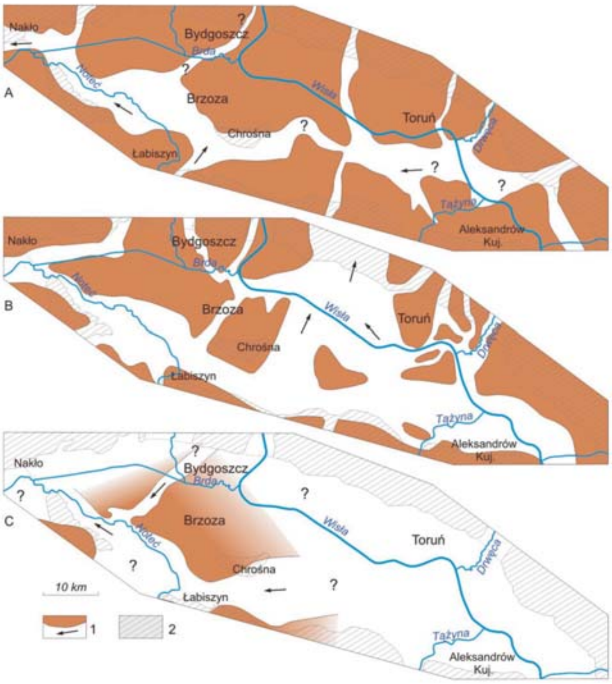

Fig. 6. Sketch of the main fossil valleys route in the Toruń Basin

A – from the Masovian (Great) interglacial, B – from the Eemian interglacial, C – before the Poznań phase of the last glaciation, 1 – bottoms of the fossil valleys and hypothetical direction of water flows, 2 – present-day morainic plateaux (A, B based upon the works by: Jankowski 1975, Makowska 1979, Uniejewska et al. 1979, Niewiarowski & Wilczyński 1979, Włodek 1980, Galon 1981, Brykczyński 1986, Jeziorski 1991, 1995a, 1995b, Mojski 1982, 1984a, 1984b, Kozłowska & Kozłowski 1992, Wrotek 1990, 1993, Uniejewska & Nosek 1992, Weckwerth 2007c, Wysota 2002)

Outwash levels – meltwater discharge phase

After deglaciation the Toruń Basin became a transit area for meltwaters, which created outwash levels within it. Their minor fragments are preserved at the contact place with the southern slope of the Toruń Basin (Fig. 1). They can be found to the west of the Tążyna valley (80–81 m a.s.l. and 79–78 m a.s.l.), in the vicinity of Łabiszyn (87–86 m a.s.l.), and near the village of Chrośna (80–81 m a.s.l.) in the central part of the basin. The Struga Toruńska outwash enters the basin at a similar height, to the north of Toruń (Niewiarowski & Tomczak 1969, Weckwerth 2004).

The evolution of the outwash levels in the southwest part of the Toruń Basin, in the vicinity of Łabiszyn, occurred in the line of a glacial depression. They formed at the back of the morainic forms transgressed by an ice sheet. They are currently located at the extent limit or within the present Toruń Basin (Weckwerth 2007b). The mentioned outwash levels are found to the west of Łabiszyn, at 86–87.5 m a.s.l. (Fig. 1). Their geological structure is dominated by lithofacies of poorly graded coarse sands with gravel of a planar cross-bedding (GSS = –0.33 phi). The thickness of their sets oscillates from 22 to 47 cm (Fig. 7). The secondary lithofacies include coarse sands with gravel of a trough cross-bedding. The association of the above lithofacies (SGp, SGt) was deposited in a sand-bed braided river of a changeable bed relief. The bed was dominated by sandy-gravely transverse bars (SGp), intersected at places by secondary interbar channels (SGt) due to the increase in the energy of depositional environment. They ran to the northwest (VM=309°), towards the northern limit of the Żnin channel. According to the results of the investigations conducted by Niewiarowski (1992, 1993), their discharge could not go farther to the south, along the Żnin channel or the Noteć valley (Fig. 1). These waters flowed along the River Gąsawka at 82–83 m a.s.l., towards the later Noteć-Warta ice-marginal streamway. They flowed through the depression with its bottom located at 80 m a.s.l. between Pińsko and Szczepice (to the south of Nakło). Kozarski (1962) determines the outwash track occurring here on the geomorphologic map but he does not characterise its structure or genesis. At the Wieszki site, located on the slope of the plateau to the south of Nakło, this level is composed of thicker, 3-metre, gravely-sandy deposits (Fig. 7). The lowest and the top of bed location are covered with gravely-sandy series (GSm, GSp, Gm). They are made of the lithofacies of poorly graded massive gravels of a compact grain matrix (the mean grain diameter from 0.28 to –1.40 phi). These sediments were deposited during high water regime, at the bottom of a gravel-bed braided river in the form of longitudinal bars. These bars gained distal growth (GSp) alongside the decreasing velocity of water discharge (GSK skewnig positively). Additionally, these forms were intersected with gravel sheet (Gm) which locally formed erosion surfaces. These are overlain by thin beds of medium grained sands with minor gravels (SGm), deposited during short-term falls of flow energy during the declining high water regime (Zieliński 1993, 1995).

The preserved sedimentation structures of the deposits at the Wieszki site indicate the northern direction of the palaeocurrent. It is related to the course of the slope of the morainic plateau, which together with the exposure location of approx. 350 m away from the ridge of the morainic plateau, excludes the possibility of deposition of these formations at the bed of the river which runs from the east to the west, and thus, from the Toruń Basin to the Noteć-Warta ice-marginal streamway. It may, therefore, be assumed that meltwaters, which flowed to the northwest of Łabiszyn at the level of 86–87.5 m a.s.l., turned farther to the north, towards Paterek and Nakło, causing the intersection of the northeast extent of the Gniezno Plateau (Fig. 14A). Hence, this flow connected to the ice sheet retreat from the line of north-Łabiszyn moraines was of a marginal character in the southwest part of the Toruń Basin.

Other outwash levels in the Toruń Basin are preserved to the west of Aleksandrów Kujawski, be-

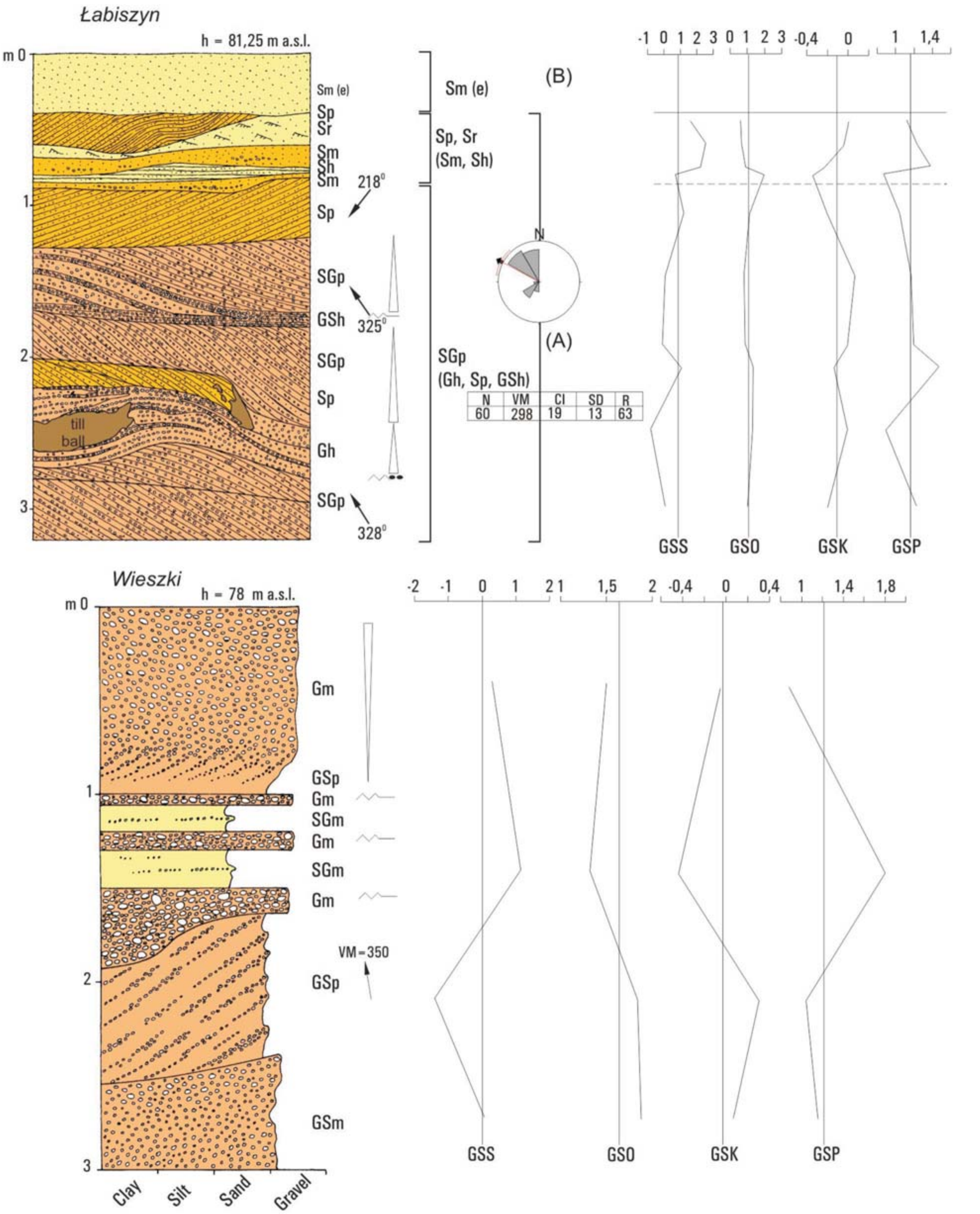

Fig. 7. Geological structure of outwash levels in the western part of the Toruń Basin
GSS – average grain diameter (Mean), GSO – standard deviation, GSK – skewness, GSP – kurtosis, explanations to the rose diagrams: N – population, VM – vector mean (°), CI – confidence interval, SD – standard deviation, R – clustered data ratio (%)

tween the Tążyna valley and Suchatówka (Fig. 1). They are found at 80–81 m a.s.l. in the vicinity of the villages Warzyn and Stare Grabie, and at 77.5–79 m a.s.l. near the villages of Popioły, Brzeczka and Grabie. Galon (1961, 1968) treated them as the terraces XI and X and claimed they were related to the flow of waters to the west. However, lithofacial examinations conducted there dismiss the above statements (Weckwerth 2005, 2007a). The outwash level of the height of 80–81 m a.s.l. (the Warzyn and Stare Grabie sites to the east of Suchatówka) is composed of lithofacial association St(Sh), deposited in a sand-bed braided river channel with folded megaripples of a stable dynamics of depositional environment (Fig. 8). The bed of the outwash series is made of glacial till (the Stare Grabie site), and the flow of waters went in the eastern direction (VM=101°). Furthermore, locally at the top of the outwash series there are sandy silts, silty sands and sands that constitute a lithofacial associotion Sh, Sr, SFh (Sp). It developed within a secondary, low-energy and shallow channel of the sand-bed braided river with a periodically vanishing flow in the edge part of the channel, at the contact place with the slope of the Toruń Basin. Its characteristic property is the cyclicity of the occurrence of small scale lithofacies Sp with lithofacies Sr, Sm and Sh. Water flow directed to the east (VM=71°). The above analysis of the geological structure and the southeast gradient of the slope of the outwash level of the height of 80–81 m a.s.l. both prove the flow of meltwaters in the southeast direction at this height, along the slope of the Toruń Basin (Fig. 14B). In the analysed exposures there have been no facts confirming Kostrzewa's opinions (1981) on the flow of waters in this level towards the west.

The fragments of the lower outwash level (78–79 m a.s.l.), located to the west of the Tążyna valley, slope towards the south. Minor differences with respect to the height between this surface and the above described upper outwash level (80–81 m a.s.l.) seem to indicate they evolved at a similar period of time, as water and glacial sediments in the Stare Grabie site were deposited by waters flowing slowly in the lateral part of the braided river channel.

The deposits making up an outwash level of the height of 78–79 m a.s.l. belong to the lithofacial association SGp, GSp, SGt (Sp, Sm, Gm) (the Popioły site, Fig. 8). In their lower part there are medium- and finely-grained sands of a planar cross-bedding (Sp), with built-on massive medium- and finely-grained sands (Sm). This is the deposit with a mean diameter of grains GSS ranging from 1.05 to 2.96 phi and poor and moderate graded. Sedimentation structures register the mean orientation of the palaeocurrent VM=121°. These are overlain by medium-scale lithofacies SGt, which consist of poorly graded medium- and coarsely-grained sands of a disturbed grain structure (GSS from –0.50 to –0.08 phi). The sedimentation structures of this deposit indicate the SWW flow of water (VM=109°). Deposition occurred in the channels with considerable velocity of water discharge and the bed covered with megaripples of folded ridges. Above the Popioły section, there are lithofacies SGp and GSp made of coarse-grained sands with gravel (gravely sands), of a planar cross-bedding (SGp). The thickness of these assotiations fluctuates from 25 to 60 cm. Further up they change to gravels with coarse-grained sands of a medium-scale tabular cross-bedding (GSp) and massive gravels with coarse-grained sand (GSm). They reach the thickness from 0.4 to 1.1 m. The deposits of the lithofacies SGp, GSp and GSm show a coarsening upward cycle, which indicates constantly increasing energetics of the depositional environment. At their bottoms there are massive coarse gravels with boulders (Gm). Initially, water discharge occurred to the southeast (VM=126°) and southwest (VM=203°), then to the south (VM=193°).

The southern direction of glaciofluvial flow (VM=211°) is confirmed by the lithofacies Sp which constitute a level in the village of Brzeczka at 77.5 m a.s.l. The sediments of fine sands and silts deposited by waters flowing to the south were found at a similar height, approximately 2 km farther to the south in the Grabie site (Fig. 8). Here, the outwash series is nearly 9 m thick. Two lithofacial associations were distinguished within: a low-energy channel of a sand-bed braided river Sp, SGp, Sr (Sm, Sh, SGm, Fm), and a secondary channel with a low water regime or proximal flood plain (Sp, Sr, Src (Sh, Sm, Sw, Fm, SGm). The river bed used to be dominated by ripples, although there was sporadic intensification of flow which concentrated in the channels of 1.6-metre depth and 10-metre width. This flow occurred in the southwest direction (VM=141°). The outwash series in the Grabie site shows considerably lower energetics of waters flowing southwards along the Tążyna valley than at the Popioły site. This may have been only a part of waters whose flow is registered by deposits in the Toruń Basin and others may have followed to the southeast, towards the present valley of the Vistula (Fig. 14B).

Until recently the above described outwash levels in the southeast part of the Toruń Basin, located at the contact place with the Parchanie valley, have been treated as terraces XI and X (Galon 1961 1968), which, due to their geological structure and direction of surface solpe, is now hard to accept (Weckwerth 2005, 2007a). The slope of the lower outwash levels equals 0.36‰. This inclination stays within the range of 0.16‰–1.34‰, which determines the gradient of water table transport in a channel for the deposits of the Popioły site, and is close to a gradient of the water table determined for the top part of the glaciofluvial series at this stand (the mean value J_{1t}=0,46‰). Taking into consideration the above values and the palaeocurrent direction, it may be assumed that this level and its corresponding bottom of the Parchanie valley were formed by the river before the Pomerania Phase, most probably during the Wąbrzeźno Subphase of the last glaciation.

The geological structure of the outwash levels in the southeast part of the Toruń Basin (80–81 and 77.5–79 m a.s.l.) running along its slopes, the southward inclination of the outwash level 77.5–79 m a.s.l., and the gradient of the water table determined on

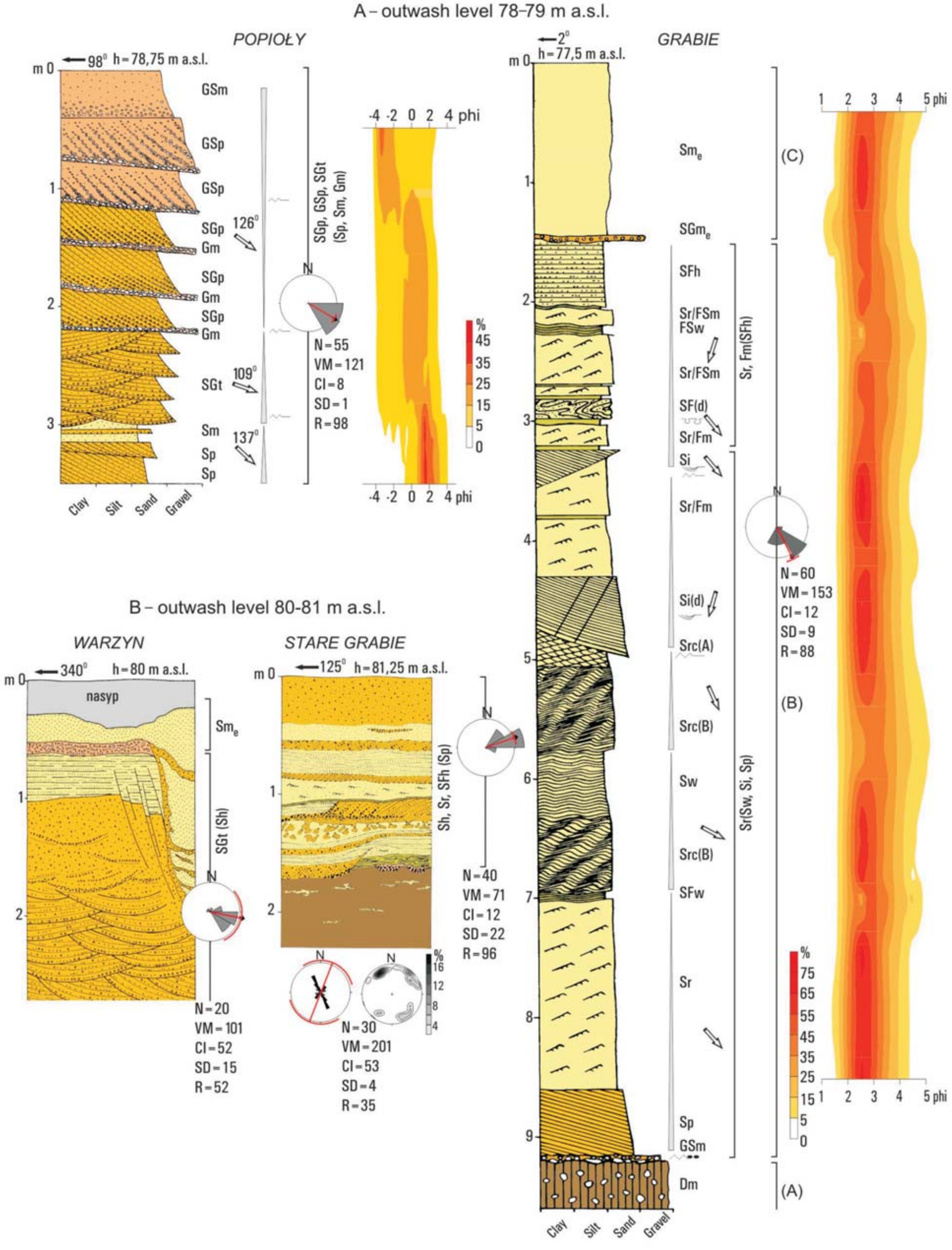

Fig. 8. Geological structure of outwash levels in the eastern part of the Toruń Basin (after Weckwerth, 2007a)

the grounds of the texture analysis of the deposits composing it, all indicate that these levels may have developed due to the activity of meltwaters flowing from the stagnating ice-sheet in the line of the south Wąbrzeźno moraines (Fig. 14B). The braided river flowing in the Toruń Basin at that time showed considerable discharge energy, so characteristic of the initial outwash sections. The discharge of waters in the vicinity of Toruń may have occurred at 84–85 m a.s.l. Perhaps, as a result of it, flattenings distinguished by Churska (1969) on the slope of the Dobrzyń Plateau near Obrowo and, located farther to the south in the Toruń Basin, the level of the Miena Valley at the mouth of the basin distinguished by Wiśniewski (1976) may have developed.

Distal sections of the outwash – the terraces XI and X of the ice-marginal streamway

Only the fragments of the terraces XI and X are still present among the highest ice-marginal streamway outwash terraces in the Toruń Basin. A small fragment of the terrace XI is located in the vicinity of Trzciniec to the south of Bydgoszcz (Fig. 1). This terrace is 76–77 m a.s.l. here. The thickness of its composing sandy-gravely deposits ranges from 7.5 m do 10.2 m. They overlie glacial till or sands with insertions of silts and clayey silts (Fig. 9).

The area of the terrace XI near Trzciniec is diversified with dunes whose relative heights increase from the west to the east, from 2 to 6.5 m (Fig. 1). This terrace is also composed of eolian cover sands which are 1–1.5 m thick. Underlying terrace sands form two lithofacial associations. The first lithofacial association Sp, St, Sr, Sh (Src, SFm) is dominated by Sp sets with the thickness from 50 cm to 75 cm. These are fairly well graded silty sands (GSS=2.87 phi, GSO=0.53 phi). Water discharge responsible for their deposition occurred in the northwest direction (VM=307°). The medium scale lithofacies St consist of medium-grained sands with laminated coarse-grained sands. This is a fairly well and well graded deposit with the mean grain diameter GSS from 1.70 to 2.59 phi. The analysed lithofacies were deposited by waters flowing to the northwest (VM from 322° to 343°) and to the west (VM=276°).

The lithofacies Sr, Sh (Src(A)) are composed of silty sands and sandy silts which were deposited from a homogenous and fractional suspension due to low flow energy of the palaeocurrent. The low water stages of the sand-bed braided river, in gradually left channels of water discharge in the northwest direction (VM from 300° to 334°), were accompanied by temporary disappearance of the water flow, the formation of a ripple, locally changing into a planar bed in shallow waters.

The other of the distinguished lithofacial associations is composed of the lithofacies FSm, Sr (Sh, S(d)). They consist of silts, sandy slits and silty sands. Their mean grain diameter GSS fluctuates from 3.23 to 4.87. The deposits are both fairly well and poorly graded. These deposits represent the sub-environment of the sand-bed braided river flood plain located at the limit of its proximal and distal parts,

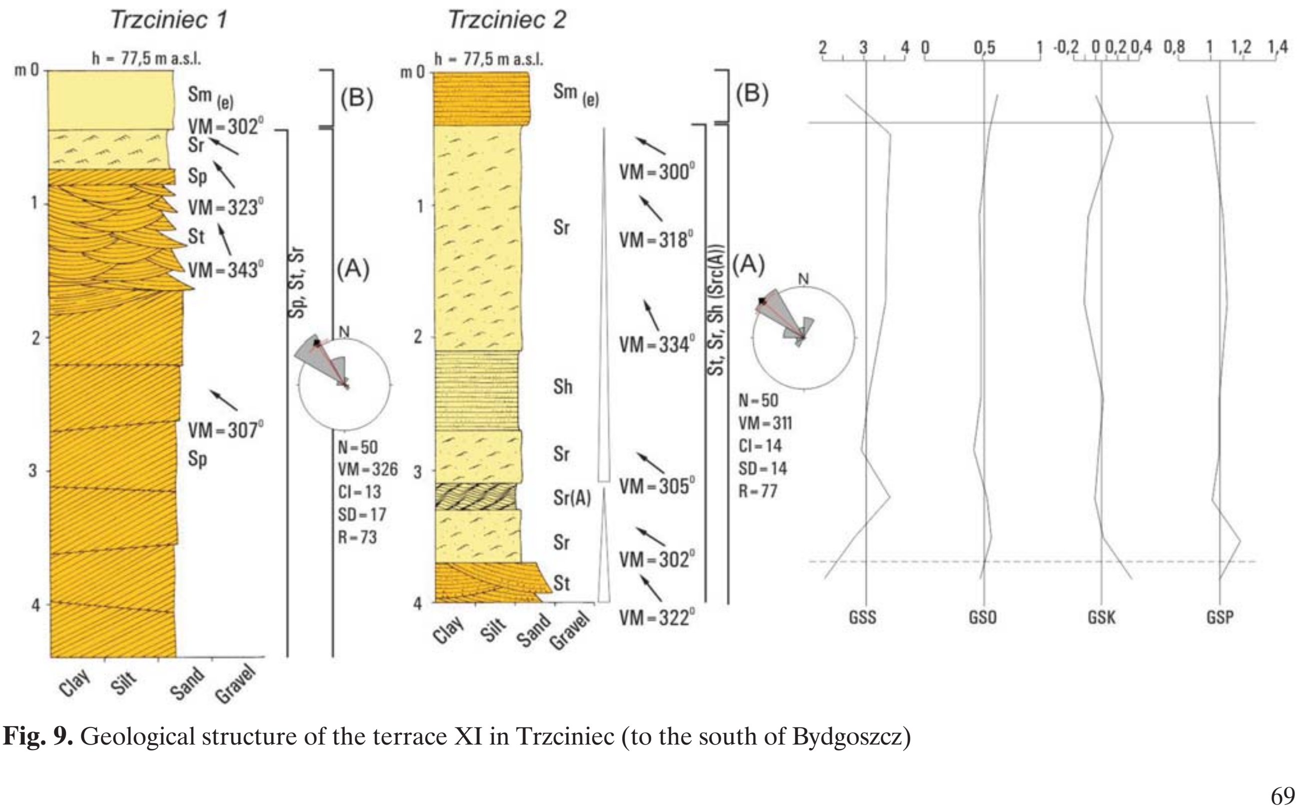

Fig. 9. Geological structure of the terrace XI in Trzciniec (to the south of Bydgoszcz)

where finely grained deposition was interrupted by the inflow of waters during a flood-wave culmination.

The sequence of the lithofacies Sp→St→Sr→FSm is a characteristic property of sandy and silty formations deposited by waters flowing in the level of the terrace XI. These lithofacies correspond to the sand-bed channel of the braided river with transverse bars separated by inter-bar channels. The disappearance of water discharge and low water stages in the channel were accompanied by the formation of transverse bars and shallow and low-energy flow in the lower part of the lower flow regime. Within the flood plain neighbouring the channel, water stagnation was interrupted by water inflow during flood-wave culminations.

The terrace X seems most probably to have been the last level of meltwater discharge in the Toruń Basin. Its narrow strips (up to 500 m wide) adjoin to the edges of the Chełmno Plateau in the northern part of Toruń (Niewiarowski & Tomczak 1969, Weckwerth 2004). They stretch from Lubicz to the west towards the district Grębocin-Bielawy. They can be found in the northern limits of the Papowo Forest and Łysomice Forest in the direction of Olek (Fig. 1). The geological structure of the terrace X strips is dominated by medium- and course-grained sands which are from 1.1 m do 3.5 m thick underlain by the layer of gravels deposited on the glacial till or ice-dammed lake clay (the depth of 1.6–3.4 m). Furthermore, the isolated fragment of the terrace X can be found in Toruń, where it is 76–77 m a.s.l. This terrace is composed of 11-metre thick sands, deposited on gravels or sands with gravels of up to 4 m thickness. Due to the lack of well-defined pavement it is difficult to state whether the entire series of deposits formed in the conditions of this terrace functioning. The bed of the above deposits includes glacial till or silts and sandy silts, as well as fine sands. Another fragment of the terrace X located to the west of Suchatówka consists of finely-grained sands changing into silts, which suggests its erosive and accumulative character.

The other fragments of the terrace X in the Toruń Basin are located in its central and southern parts. In the vicinity of Chrośna this terrace (75–76 m a.s.l.), intersects the surface of the morainic plateau remnant. The thickness of its medium- and finely-grained sands amounts to 1.5–2 m on average and up to 4 m maximum within the declines. Some of them are filled with peats and gytija of up to 4.7-metre maximum thickness. The erosive character of the terrace X in the vicinity of Chrośna can also be proven by the glacial till noticeable on its surface, and covered by a thicker (10–20 cm) layer of massive sands with gravel.

The narrow strips of the terrace X (approx. 350 m wide) adjoin the slope of the plateau located to the north of Godzięba and Dąbie (to the north of Gniewkowo) and in the vicinity of Rojewo (Fig. 1). The terrace deposits are covered with a layer of eolian massive silty sands that are 0.9 m thick. The glaciofluvial deposits of the terrace X mainly include finely-grained sands (7.5 m thick), which make up a lithofacial association Sp, Sr (FSh, Sh, Sm). The orientation of the structures of the lithofacies Sp indicates the direction of the palaeocurrent from NE to SW (VM from 205° to 210°). These formations were deposited in the conditions of the low-energy sand-bed braided river, away from major water discharge channels in the braided river forming an erosive terrace near Chrośna.

The analysis of the geological structure of the terrace X indicates that it was formed by meltwaters, which flowed through a multi-arm braided river of a bar sedimentation style, similarly to the terrace XI, characteristic of the distal parts of the outwash (Fig. 14C). The fragments of the terrace in the basin show considerable width of the flood plain of the then river, reaching up to 20 km.

In the levels of the terrace XI and X meltwaters inflowing into the Torun Basin joined the waters of the Noteć in the western part of the basin. This means that only in this fragment the northwest and west directed water discharge was of an ice-marginal streamway character.

Terraces of the ice-marginal streamway– the phase of the Vistula waters discharge

The terrace levels located below the terrace X developed as a result of the Vistula waters discharge. For the first time it occurred in the level of the transitional terrace located between the terraces X and IX (Weckwerth 2004). The surface of the transitional terrace declines from the east to the west, from 75–76 m a.s.l. near Aleksandrów Kujawski to 68–70 m a.s.l. to the southwest of Bydgoszcz, where its 2–3 metre slope divides it from the terrace IX and gradually disappears (Fig. 1). This terrace in the vicinity of Suchatówka was classified as the terrace X or XI (Mrózek 1958, Galon 1961, 1968). To the east of Suchatówka, the terrace is composed of sandy-gravely deposits of planar cross- and trough-cross bedding from 2 to 3 m thick (Fig. 10). They are represented by the lithofacial association SGt, SGm (Sp), which consists of coarse-grained sands with admixture of medium-grained sands. At the top they change to the llithofacies SGt of poorly graded coarse-grained sands with minor gravels. The described sediments were deposited in the form of sandy-gravely transverse bars (Sp) in the initial discharge phase of the Vistula waters. The traces of this discharge in the form of oriented and elongated depressions can be found on the surface of the transi-

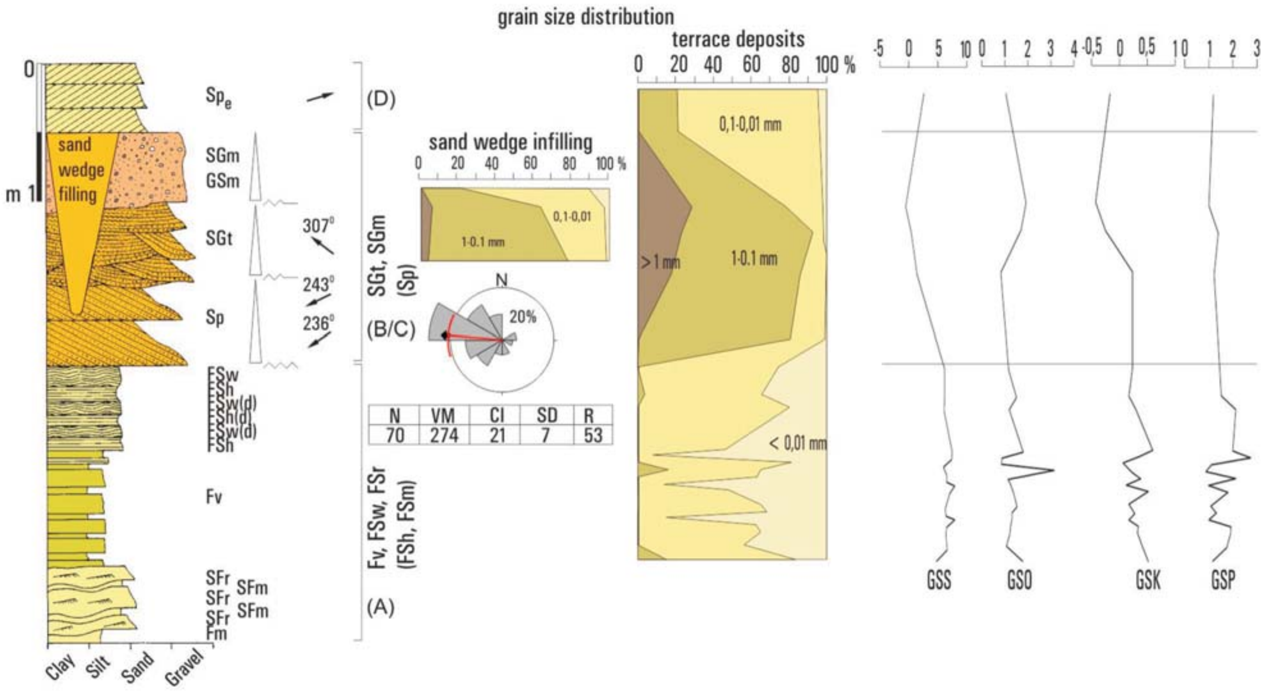

Fig. 10. Geological structure of the transsitional terrace in the south-eastern part of the Toruń Basin (Aleksandrów Kujawski site)

tional terrace in the vicinity of Aleksandrów Kujawski. However, more intensive discharge of waters in the sand-bed braided river took place through the interbar channels (SGt), which in the southeast part of the basin was accompanied by the change of water discharge direction to the NW. The sequence of the lithofacies Sp→SGt→GSm and the analysis of their graining indicators prove an increase in the dynamics of depositional environment in stages.

Due to the height of the transitional terrace in the Toruń Basin, near Suchatówka, i.e. 75–76 m a.s.l. and the registered palaeocurrent directions in its deposits, this terrace cannot be classified as the terrace IX. Neither can it be classified as the terrace X, which would have to be at least 78–79 m a.s.l. to the east of Suchatówka. Perhaps, the waters of late-glacial lakes patrticipated in the merging process of the Vistula waters discharge and meltwaters discharge, which resulted in the formation of the transitional terrace (75–76 m a.s.l.) in the Toruń Basin. These lakes were located in the mouth section of the Mienia valley and their waters may have run towards the Torun Basin. Andrzejewski (1994) distinguished two late-Weichselian evolution phases of these lakes in the mouth section of the Mienia valley at the contact with the Toruń Basin.

In the western part of the Toruń Basin the surface of the transitional terrace declines down to 68–71m a.s.l. In many places it is separated from the lower terrace IX by a distinctive slope, which is 2–3.5 m high. The geological structure of the transitional terrace IX is dominated by sands and gravels. The area located between Białe Błota and the village of Murowaniec and to the north of Tur is an exception as on the surface there are: glacial till, sands and gravels overlying glacial till and silts. Their occurrence is a result of organic accumulation of terrace deposits on older glacial and glaciofluvial deposits, which qualifies this section of the transitional terrace as an erosive terrace (Fig. 1). There are also kettles here, which contributed to a local decline of the terrace surface by 2.5–4 m and increasing denivelation of its surface up to 10 m. Moreover, this zone shows southern endings of the series of kettles oriented from the north towards the south, which may indicate the course of former subglacial channels. The biggest of these runs to the north of Białe Błota (Fig. 1). Presumably, the fossil channel found to the west of the above described channel, filled with sands and gravels of the total thickness of 22.5 m is also of the trough origin. In its southern extension on the surface of the transitional terrace to the west of Białe Błota there are meridionally running kettles filled with peat which are 0.5 m thick in the northern part and up to 3.0 m thick in the south.

The surface of the transitional terrace between Białe Błota and Murowaniec is composed of russet glacial till, which can be seen on the surface together with irregular kettle, where the thickness reaches 11.3 m. The geological structure of the surrounding and bed of the kettles where glacial till and loamy sands are may prove the relation of these deposits to the meltout of morainic material coming from buried blocks of dead ice over which discharge of waters occurred (Thomas et al. 1985, Olszewski & Weckwerth 1999).

In the western part of the Toruń Basin the transitional terrace consists of sands and gravels (GSt, SGt, (GSh)). Recognised in the Gorzeń site large-scale sets of a trough cross-bedded gravels of sandy matrix and gravely sands, separated by conspicuous gravely adjoining surfaces, were formed in the depositional environment of the sand-bed braided river of significant energy (Fig. 11). The analysed deposits formed in the deeper part of the channel of the sand-bed braided river. Gradual decline of depositional energetics, preceded by decreasing depth of outflow resulted in the development of smaller (lower) megaripples. The above interpretation is illustrated by the sequence of the lithofacies GSt→GSh→SGt.

Sands of up to 3–4 m thickness dominate in the composition of the deposits of the transitional terrace in the southern direction within the western fragment of the Toruń Basin (Fig. 11). The lithofacies Sp prevail at the Olek site near Tur. At the bottom they change into well and poorly graded sands of the lithofacies St, SGm (Sr) (GSS from 0.10 to 2.55 phi). The lithofacies SGm, whose bottom defines the course of an extensive erosive surface may be indentified with a gravely bed of the main discharge channel in the sand-bed braided river. The lithofacies St (Sr) developed as a result of megaripples migration at the channel bed of the sand-bed braided river. Locally, between large-scale sets of trough cross-beddings there are fine climbing ripple laminated sands, whose deposition may have been related to backflow eddy on the lee side of the megaripple.

The terrace XI is one of the best preserved levels of water discharge in the basin. Its large area declining westwards from 70–72 m a.s.l. in the vicinity of Toruń to 67–68 m a.s.l. to the west of Łochowo indicates that the flood plain of the braided river reached the width of 21 km at least. It was formed by the waters inflowing to the basin through the Brda valley from the north, through the Drwęca valley from the northeast, and by the waters of the Vistula and Noteć from the south.

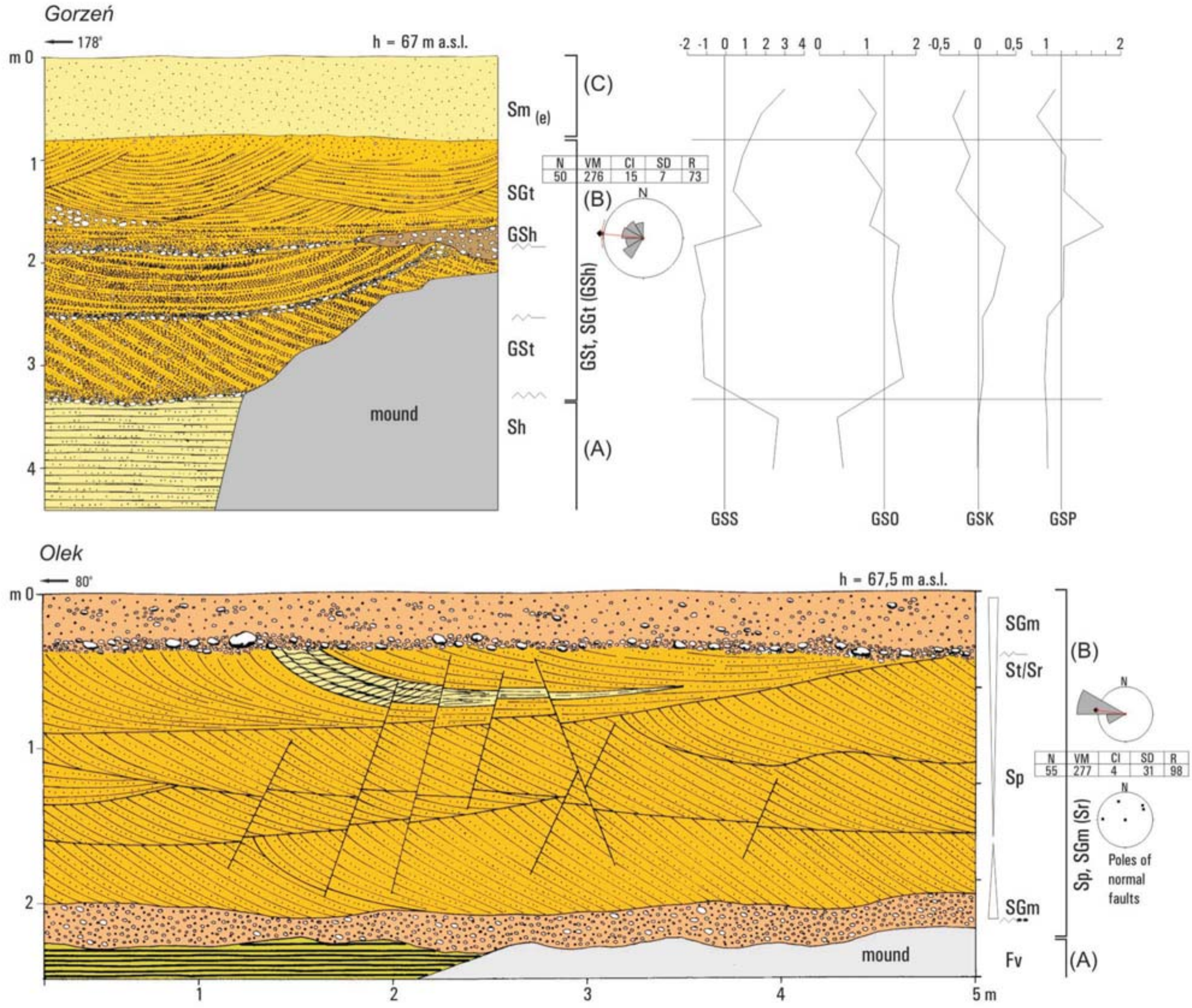

Fig. 11. Geological structure of the transsitional terrace in the western part of the Toruń Basin

To the west of Bydgoszcz the discharge of waters in the level of the terrace IX concentrated in the narrow (2.5–6 km) valley bottom, hence, its energy rose in this direction. The transitional terrace located higher is separated from the terrace IX by a noticeable slope that is 2.5–3 m high (Fig. 12). Its area near Łochowo is diversified with elongated parallel running depressions which are 1.5–2 m deep. The geological surface structure of the terrace IX is dominated by sands and gravels which overlie glacial till within the elevation (Fig. 12). This glacial till can also be found in the fragments located higher in the terrace. At the Łochowo site the deposits of the terrace IX overlie a series of finely-grained and silty sands of prevailing ripple and horizontal lamination, deposited by waters flowing towards north and northwest (VM=244°, VM=286°). Their mean grain diameter fluctuates from 2.71 to 3.04 phi. These formations (the lithofacial complex A), whose thickness ranges from 11.7 to 14 m, directly overlie the Neogene clays. These may be older than the main stadial of the Weichselian Glaciation (Uniejewska & Włodek 1977, Uniejewska et al. 1979, Włodek 1980, Wysota 2002).

At the Łochowo stand the lithofacial complex A comes into contact with a sandy-gravely terrace series at the top. This series fills a well-preserved fossil channel of water discharge of a recognised depth of approx. 4 m (Fig. 12). The channel bottom is varied due to 3–5-cm erosive scours. Above the erosive surface there is a layer of channel paving with boulders and till blocks (till balls). At places the gravely fractions form laminae, whose courses relate to the shapes of the clay blocks occurring there. The formation of these structures may be connected to water erosion products pushed on the river bed. After they got anchored, the structures of crescent mark and flute lasts formed around the till balls (Gradziński et al. 1986).

The biggest clayey blocks deposited in the layer of the channel paving were analysed petrographically with respect to gravely fraction (content of carbonates from 3.8% to 15.7%). The results of the analysis proved that the share of the Palaeozoic limestones was more dominant (57.1%, 58.6%, 48.4%) than crystallic rocks (31%, 29%, 35%). The content of northern sandstones equalled respectively: 7.7%, 8.2%, 8.2%. The percentage of local rocks reaches from 1.9% to 5.1%. The values of petrographic coefficients are O/K from 1.5 to 2.3, K/W from 0.5 to 0.8, and A/B from 1.1 to 1.6 (Fig. 12). The above results of the petrographic analysis coincide with the petrographic composition of the gravels of the Weichselian till analysed at the Tur and Samoklęski Małe sites.

Above the layer of the channel paving the fossil channel of water discharge is filled with medium- and finely-grained sands of planar cross-bedding, of an extremely large scale (Si). This lithofacies reaches the maximum thickness of 3.7 m in the axis of the fossil form (Fig. 12). Among the thickest layers of finely-grained sands there are sporadic reverse ripples. The mean grain diameter of the lithofacies Si filling the fossil channel changes towards the top from 2.64 to 1.22 phi (mean GSS=1.94 phi), which can be a result of increasing depositional energy in the sand-bed braided river. The orientation of the lithofacies Si laminae indicates the flow of waters in the west and southwest direction (VM from 216° to 262°). This direction can be identified with the orientation of the analysed fossil form. At the top of the lithofacies Si there is an increase in grains and improvement in deposit graded. The increasing energy of the depositional environment led to the deposition of a thicker (0.3 m) layer of massive sands with gravel (SGm), sands of trough cross-bedding and finely-grained sands of ripple lamination (Sr).

At the Łochowo site the sequence of the lithofacies SGm→Si→SGm→Sr→St→SGm within the terrace IX proves unstable conditions of water discharge and two major cycles in its development. Initially the discharge took place within and above the deep (approx. 4 m) channel of the sand-bed braided river. It was intersected in the glacial till deriving from the last glaciation and the sands underlying it. In the subsequent phase of the terrace IX formation in the vicinity of Łochowo, after the channel of water discharge had been filled with deposits, the sediments may have flowed by a shallower river with a wider channel, whose bed was covered with migrational megaripples. The flow of waters occurred in the northwest direction, thus accordingly to the orientation of the declines in the surface of the terrace IX, located near the analysed site. The fact that the filling phase of the fossil channel was related to the discharge of waters older than the terrace IX, ex. in the level of the transitional terrace or outwash terraces X or XI, cannot be neglected in the reconstruction of the development of the terrace IX near Łochowo

The results of the investigations conducted in the gap of the Vistula valley at Fordon allow stating that within its line the river discharged into the Toruń Basin in the level of the terrace IX (Weckwerth 2006). Earlier, during the ice-sheet retreat from the area of the Świecie Plateau, it flowed at the height of 83–86 m a.s.l., and led to the formation of the erosive level of meltwater discharge (Niewiarowski 1987). Below this level, on the slope of the Vistula valley near the village of Pień, there is a flattening at the height of 68–69.0 m a.s.l. that is lower by approx. 6–7 m (Fig. 1). It is composed of sands and gravels that are up to 2.8 m thick. These deposits overlie russet glacial till, whose continuous layer goes higher on the slope of the Vistula valley. The mentioned fluvial formations make up the lithofacies St, GSm (SGt, Sp, Sm, Sr),

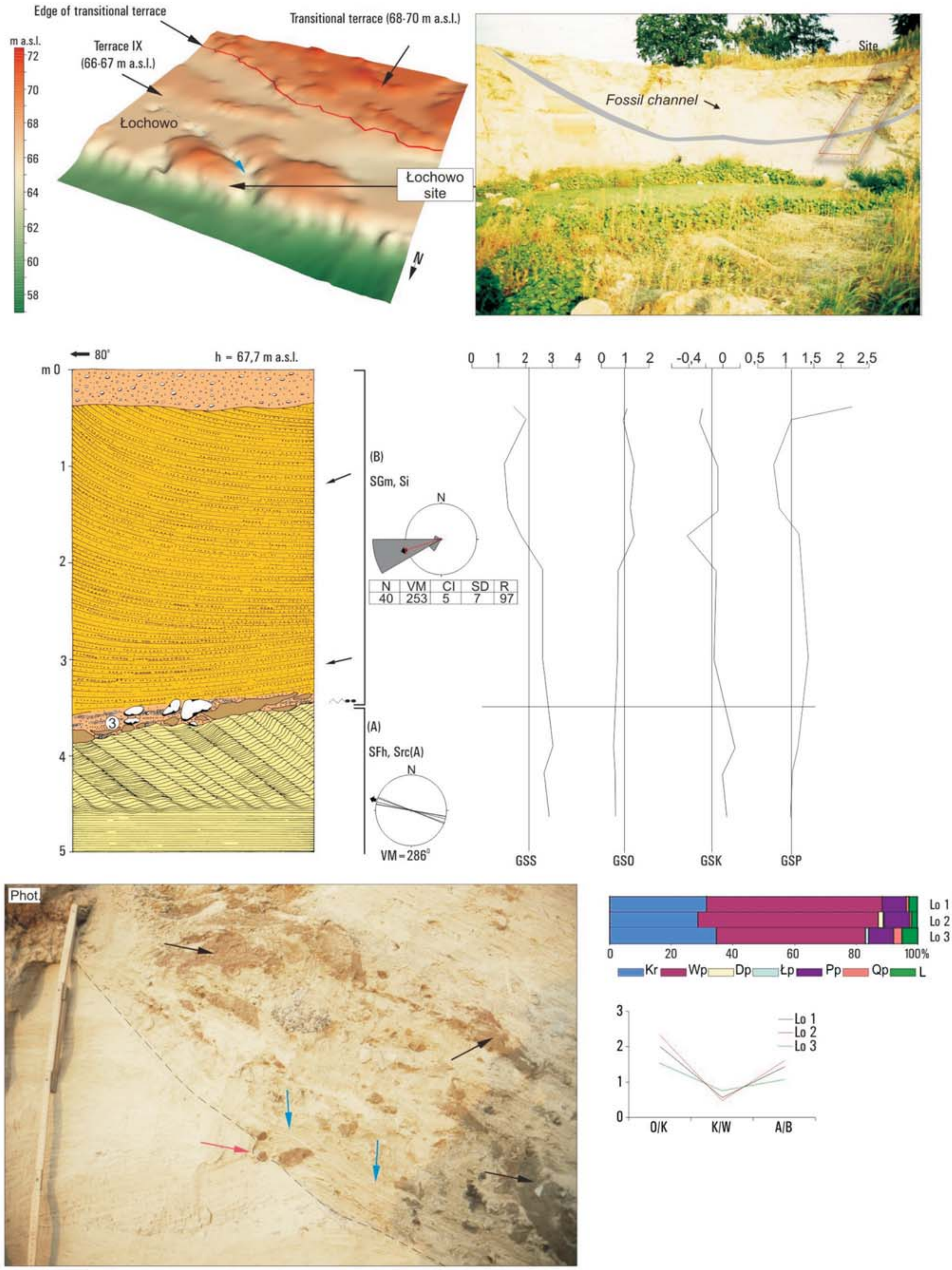

Fig. 12. Geological structure of the terrace IX in Łochowo (66–67 m a.s.l.), to the west of Bydgoszcz
black arrow – till ball, blue arrow – lamination around the till ball, red arrow – secondary erosive scour

whose mean diameter of grains equals 0.22–2.18 phi (Fig. 13). They are of worse graded towards the top. The analysis of graining indicates moderate and stable energy of depositional environment. Moreover, there are interbeddings of massive finely-grained sands and sands of planar cross-bedding and ripple lamination (Fig. 13). The dominating lithofacies (St, SGt) developed in the deeper part of the sandbed braided river channel. Initially, gravely bed covers formed in the channel (GSm), on which the lithofacies of sinuous megaripples (St, SGt) were deposited. Weakening dynamics of sedimentation environment was accompanied by the formation of individual transverse bars (Sp) during the descent of a high water stage. These bars formed during the moderate but unstable dynamics of depositional environment. The directions of the palaeocurrents of cross-bedding structures point to the southern direction of water discharge (VM=177°).

The structural and texture properties of the deposits constituting the described terrace strip on the Vistula gap at Fordon prove the existence of water discharge in the level of 68.0–69.0 m a.s.l. directed to the south, towards the Toruń Basin (Fig. 14D). These waters may have gone in the northern part of the basin, at the level of the terrace IX, which is approx. 67.5 m a.s.l. The results of the investigations appear to shorten the duration of bifurcation phase of the Vistula at Fordon as proposed by R. Galon (1961 1968), as they exclude the terrace IX. The subsequent redirection to the north in this place may be predisposed because of the waning of the dead ice buried in glacial deposits (Niewiarowski 1987) and because of the existence of the subglacial channel in the line of the Vistula valley, as indicated by Galon (1934) and Mojski (1980). The initial discharge of waters to the north in the Fordon gap can be seen in the narrow terrace strip, of the height of 58–60 m a.s.l. Such a direction of water discharge is illustrated by the preserved planar cross-beddings developed in sands which were deposited in the low-energy environment (Fig. 13B). The activity of other watercourses flowing from the neighbouring morainic plateau cannot be neglected in the formation process of this terrace. These watercourses may have been the Vistula's tributaries. Normal faults found in the deposits of the described terrace prove the existence of water discharge above the blocks of glacial dead ice, which were buried in the line of the present Vistula valley at Fordon (Weckwerth 2006).

The sudden increase in the amount of flowing waters in the Toruń Basin starting from the transitional terrace found its reflection in the thicker fraction of the terrace deposits, which indicates higher energy of the depositional environment. Only after the glacial till had been removed from the bed of the braided river channel did deep erosion mark itself clearly, which was noticeable starting from the terrace VIII to a greater degree. The change of hydrological conditions caused a faster reaction of the sedimentation in the channel of the braided river. The sandbed braided river, of dominantly bar-style sedimentation, changed into a higher-energy flow, in which the share of lithofacies of trough cross-bedding (St) rose. Deeper braided river channels dominated in which sinuous dunes migrated and formed sandy-gravely bed covers. Sandy transverse bars were rare. The material transport at the river bed occurred mainly on the traction way or developed from the fractional near-bed suspension. Higher energy water flow concentrated in the narrower bed zone of the valley, starting from the terrace IX, and particularly from the terrace VIII (Fig. 1). In the eastern part of the basin, this terrace reaches 65 m a.s.l., and in the central part 63 m a.s.l., and 62 m a.s.l. to the east of Bydgoszcz. The strips of the terrace VII occur sporadically in the Toruń Basin. Their minor fragments of 63–60 m a.s.l. can be distinguished at the mouth of the Drwęca and to the south of Toruń.

The terrace VI is the lowest level, in which flowing waters directed to the west through the Noteć–Warta ice-marginal streamway (Galon 1953, 1968, Kozarski 1962). This terrace is 57–60 m a.s.l. to the south of Toruń, 56 m a.s.l. near Cierpice, and 54 m a.s.l. in Bydgoszcz. In the vicinity of Ostromecko and Fordon it is developed in two levels (VIa and VIb) separated by a distinctive slope of 4–5-metre height (Fig. 1). The surface of the higher level of the terrace VI is composed of sands and gravels that are up to 2.2 m thick. They overlie medium- or finely-grained cover sands and sands of parabolic or rampart dunes. The terrace VIa reaches the height of 54–55 m a.s.l. in Bydgoszcz. Their deposits overlie the Neogene clays (Galon 1934, Weckwerth 2006). The bottom part of the terrace series is made of medium-grained sands with coarse-grained sands of a planar cross-bedding (Sp). Their accumulation occurred in the form of sandy transverse bars in the sand-bed braided river (Fig. 15A). The increase in the energy of the depositional environment contributed to the accumulation of trough cross-bedded sands (St), which formed due to migration of sinuous dunes in the deeper part of the channel. The discharge of waters occurred in the southwest direction, therefore, the terrace VI (VIa) developed still at the time of the Noteć-Warta ice-marginal streamway.

The top of the fluvial series of the lower level of the terrace VI (VIb) in Fordon is located at the depth of approximately 3–3.5 m. Under the bed of eolian cover sands (Fig. 15B) there is a real fossil terrace surface which is 50 m a.s.l. This height relates to the lower level of the terrace VIb to the south of Ostromecko (Fig. 1). To the west of Bydgoszcz, the height of the Noteć-Warta ice-marginal streamway bottom corresponds to the higher level of this ter-

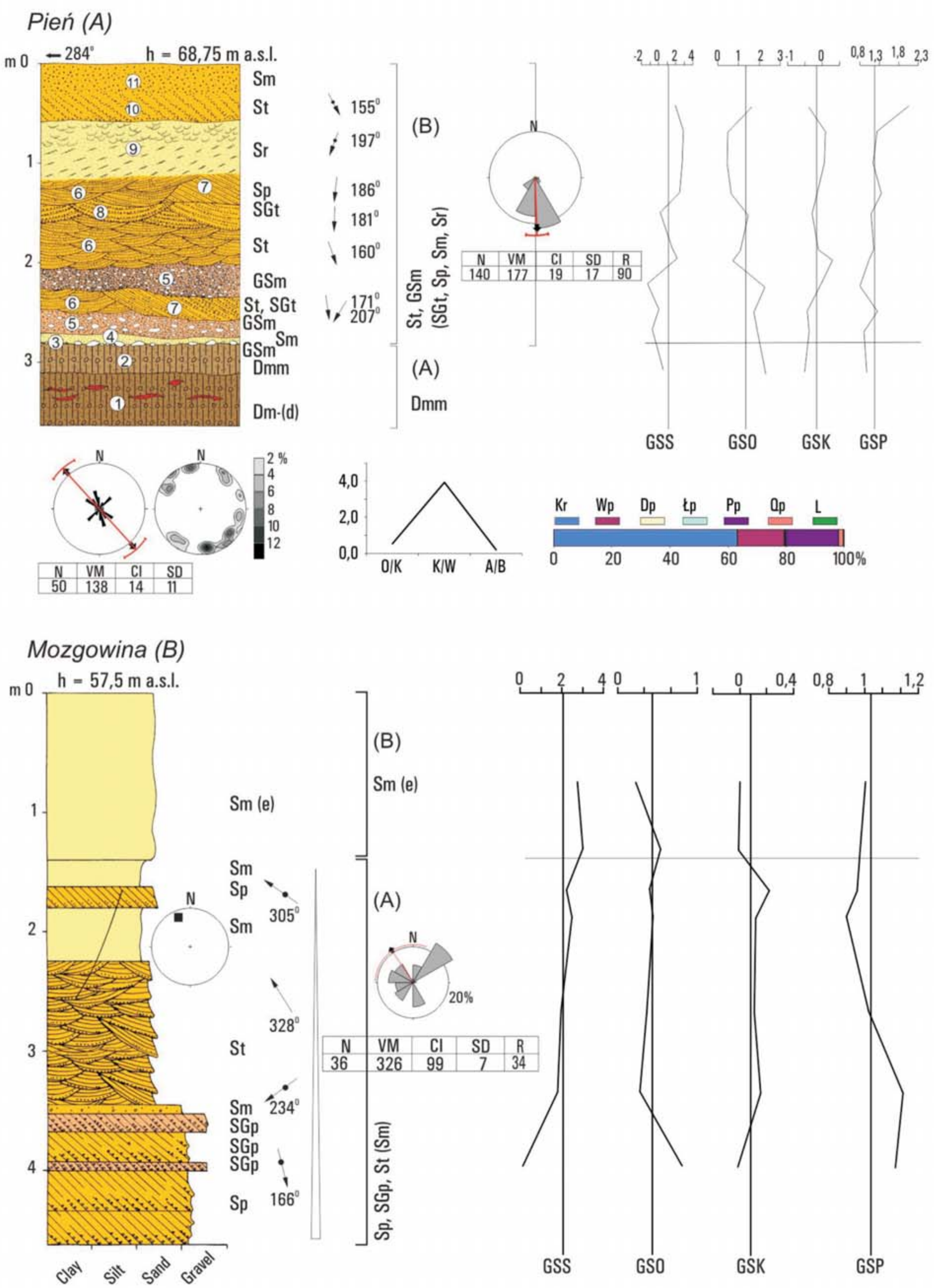

Fig. 13. Geological structure of the terraces in the northern part of of Vistula river gap at Fordon (after Weckwerth 2006)
A – terrace 68–69 m a.s.l. (Pień site), B – terrace 58–60 m a.s.l. (Mozgowina site)
1 – brown till with red layers, 2 – grey-brown till, 3 – boulders, 4 – massive fine-grained sand, 5 – gravel with boulder and coarse-grained sand, 6 – trough cross-bedded medium- and fine-grained sand, 7 – trough cross-bedded medium-grained sand with gravel, 8 – trough cross-bedded coarse-grained sand with gravel, 9 – ripple cross-laminated fine-grained sand, 10 – planar cross-bedded medium-grained sand, 11 – massive medium-grained sand

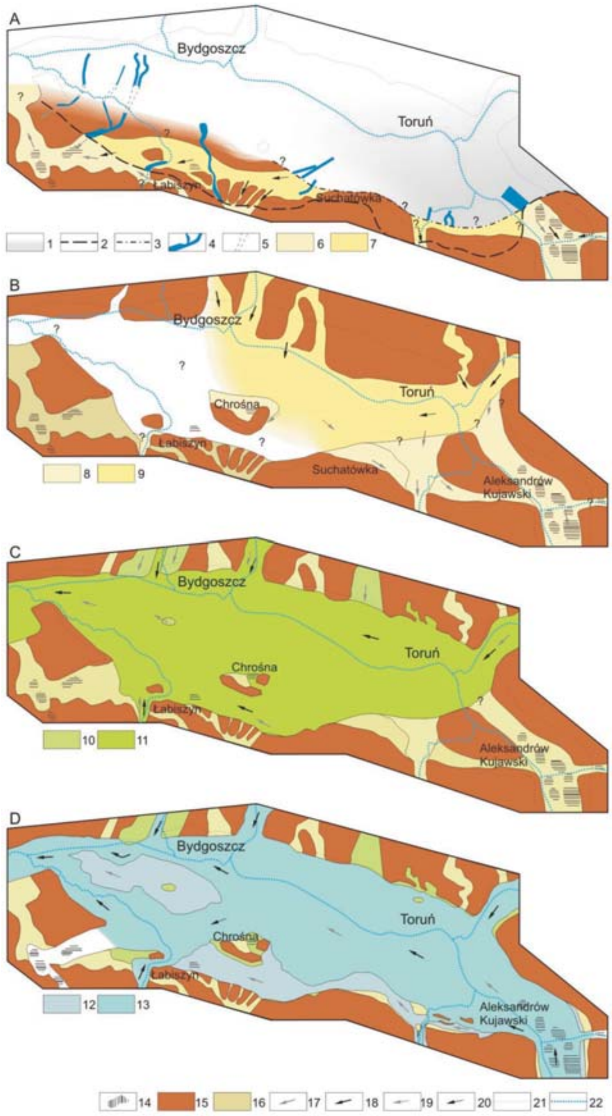

Fig. 14. Reconstruction of discharge directions of waters in the Toruń Basin up to the time of the Pomerania Phase of the last glaciation

A – meltwater discharge during the deglaciation of the Toruń Basin; B – meltwater discharge during the Wąbrzeźno Subphase; C–D – meltwater discharge during the Pomerania Phase

1 – ice sheet, 2 – the extent of the ice sheet front during its retreat in the Chodzież Subphase, 3 – hypothetical extent of the ice sheet front in the Toruń Basin, 4 – course of subglacial channels, 5 – probable course of subglacial channels, 6 – older outwash tracks; 7 – younger outwash courses of meltwater discharge; 8 – from the time of ice sheet stoppage in the line of the south-Wąbrzeźno moraines, 9 – from the time of ice sheet stoppage in the line of the central Wąbrzeźno moraines, 10 – in the level of the terrace XI, 11 – in the level of the terrace X, discharge of the Vistula ice-marginal streamway waters in the levels: 12 – of the transitional terrace, 13 – of the terrace IX, 14 – larger blocks (lobes) of the dead ice, 15 – morainic plateaux, 16 – inactive, older courses of water discharge, directions of water outflow: 17 – older, 18 – younger, probable directions of water discharge: 19 – older, 20 – younger, 21 – present extent of the Toruń Basin, 22 – present hydrographical network (an outline)

race. Therefore, the terrace VIb in Fordon with the surface covered with eolian cover sands is the level, where the Brda initially flowing to the south, began to run to the east towards the Vistula valley.

The deposits of the lower level of the terrace VI (VIb) in Bydgoszcz mainly include finely-and medium-grained sands (Fig. 15B). At the bottom they change into sands with gravel, and they directly overlie the Miocene clayey and silty deposits. The total thickness of the terrace deposits equals 1.6 m. The dominant lithofacies include trough cross-bedded sands (St). The size of the mean grain of this deposit is 1.93–1.96 phi. The secondary lithofacies contain the layer of channel paving, represented by massive sandy gravels with locally occurring boulders or gravels of a sandy matrix with individual boulders or fine sands and silts of horizontal lamination. The described sediments constituting the lower level of the terrace VI were deposited within the channel of the sandbed braided river, in which channel flows were marked with the formation of sandy foresets (Sp) during the fall of a high water stage. In the deeper part of the channel the more energetic discharge was related to the deposition of fast transported material in the inter-bar channels (St, SGt). The high energy character of this subenvironment is emphasised by numerous inserts of the blue-russet Neogenic clays which are found along the bordering sets of trough bedding (Weckwerth 2006). The analysis of the palaeocurrent directions showed the mean orientation of the mean vector VM=184°. Initially, waters flowed in the channel in the southeast direction (VM=129°), then the discharge went in the inter-bar channels to the southwest (VM=228°). The above changeability of palaeocurrent directions may have resulted from the attraction of the Brda waters in the terrace level VIb towards the gap section of the Vistula valley at Fordon.

Evolution of the fluvial relief with respect to the tectonic structures of the Cenozoic bed

The evolution of the river network in the Polish Lowland was closely related to the tectonic activity of the structures of the older bed. Changes in the valley network system near the Bydgoszcz-Toruń hydrographical node and the growth of the Toruń Basin in the northern direction due to the marginal erosion of the Vistula, as well as the reduction of the Quaternary formations within the flood plain and the modification of the surface relief of their bed, all may have been discussed in literature as the effects of these movements (Weckwerth 2006, 2007c).

The Toruń Basin is mainly located in the zone of banks, pillows and salt swells of the Cenozoic bed. There are noticeable relations between the location

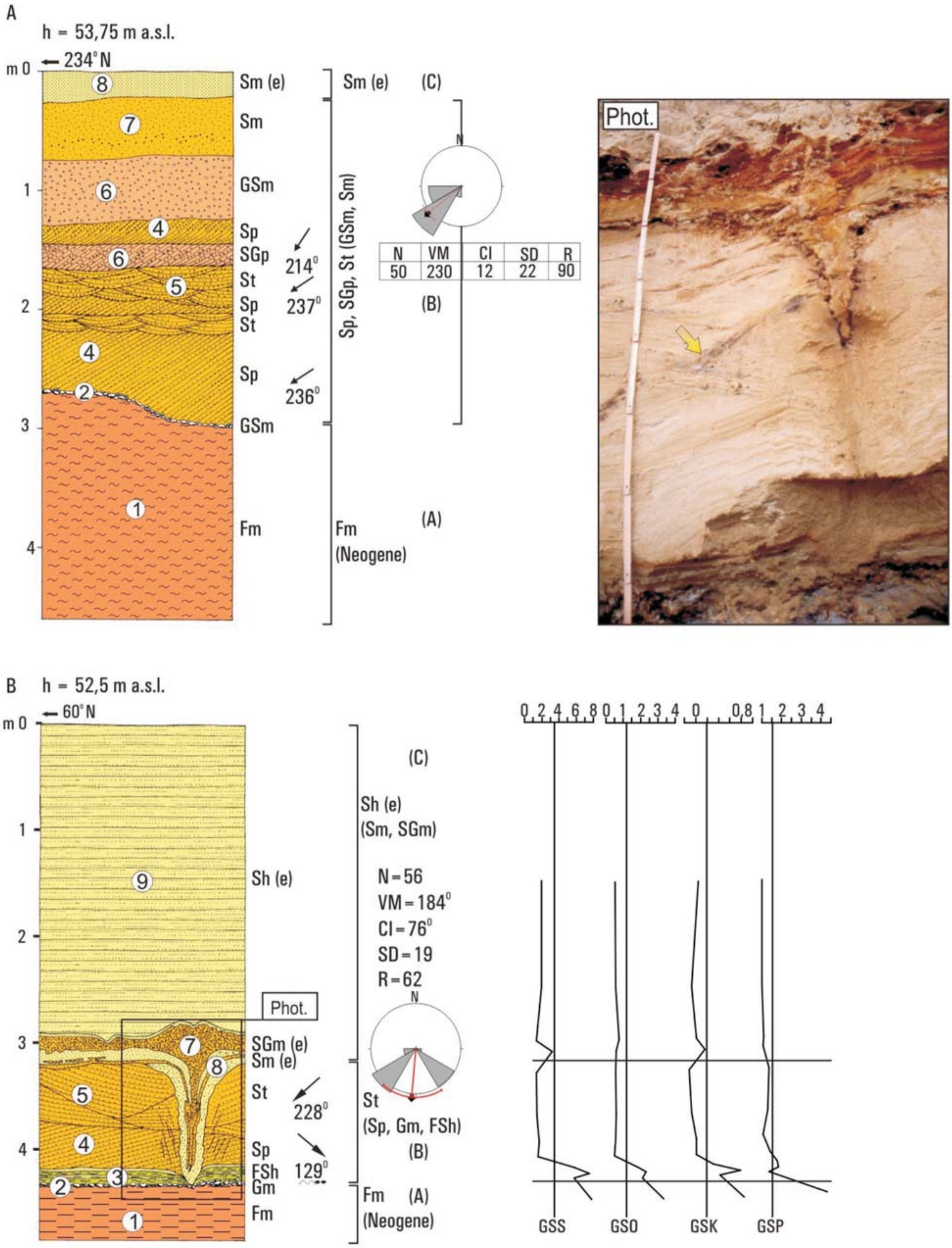

Fig. 15. Geological structure of the terrace VI in Bydgoszcz-Fordon (A – higher level VIa, B – lower level VIb, after Weckwerth 2006)

1 – clayed silt (Pliocene – outcrops A, Miocene – outcrops B), 2 – gravel with boulders, 3 – massive silt with fine-grained sand layers, 4 – medium-grained planar cross-bedded sand, 5 – trough cross-bedded medium-grained sand and sand with gravel, 6 – coarse-grained planar cross-bedded sand with gravel, 7 – massive medium- and coarse-grained sand, 8 – massive fine-grained sand, 9 – horizonatally bedded medium- and fine-grained sand (aeolian cover sands), arrow o the photograf indicates bedding surfaces of cross-bedded sand with a thin layers of Neogene clay

of these structures and the effects of the activity of the fluvial processes in the Pleistocene. A good illustration of these can be the similarities in the location of the elevations of the Quaternary surfaces to the Mesozoic elevations, particularly noticeable in the southern part of the Torun Basin. The bottom of the fossil valley incised into the Pleistocene bed to the south of Toruń relates to the Mesozoic Ciechocinek anticline (Fig. 2). Partially this area corresponds to the outwash levels and ice-marginal streamway terraces located high in the basin (Fig. 1). Another example is the location of the remnant of the morainic plateau in the central part of the Toruń Basin with the outwash levels adjoining it from the north. The remnant lies higher than the neighbouring ice-marginal streamway terraces and is located within the top culmination of the sub-Quaternary surface and the sub-Cenozoic Chrośna anticline. Similar relations may be found in the analysis of the location of the Zalesie anticline in the west and southwest extent and the surrounding of the Toruń Basin

The present evolution of the relief of the Toruń Basin may have been influenced by changeable load of the ice-sheet which triggered glacial and post-glacial isostatic movements (Liszkowski 1975, 1993, Piotrowski 1991). Moreover, activation of older dislocations and intensification of geothermal heat flow may have been of much importance (Petelski & Sadurski 1987, Dyjor 1991, Liszkowski 1993). These processes, in the final stage of relief evolution (ice-sheet retreat), may have resulted in the development of forms of glacial genesis, located within the activated salt structures. The examples of such forms may be: the morainic plateau in the vicinity of Szubin (within the Szubin anticline), the fragment of a morainic plateau in the central part of the Toruń Basin (the Chrośna anticline), the southeast part of the basin between Aleksandrów Kujawski and Suchatówka (the Ciechocinek anticline), and the glaciotectonically deformed morainic hummocks in the vicinity of Łabiszyn, which relate to the northern extent of the Zalesie anticline. In the cyclical evolution of the interglacial valleys in the area of the ice-marginal streamway, starting from the Eopleistocene, one cannot either exclude the ascent of deep "warm" waters squeezed from the Mesozoic formations in the lines of intersecting those tectonic dislocations (Petelski & Sadurski 1987).

The present location of the bottom of the Vistula valley in the east and northeast parts of the Toruń Basin has clear foundations in the fossil valleys of the Eemian Interglacial. Therefore, we cannot exclude the evolution of the river valley within the basin at the time of the retreat of the Warta ice-sheet. Alongside the ongoing deglaciation of the basin, the valley (ice-marginal streamway?) of a parallel orientation developed. It discharged meltwaters of the Vistula waters to the west accordingly to the valley layout of the Great Interglacial. In the later period a separate Eemian valley of the proto-Vistula evolved to the west of Toruń, and was directed towards the north to the Eemian Sea.

The analogical scheme of the river network development occurred at the end of the Weichselian Glaciation. After the deglaciation of the southwest part of the Torun Basin, meltwaters directed initially to the west, at the back of the Łabiszyn moraines (within the Toruń Basin), i.e. in the south and southwest surroundings of the Szubin anticline (Figs 1, 14, 16). These processes initiated incorporation of the Torun Basin to the Noteć-Warta ice-marginal streamway. The main development phase of the Noteć-Warta ice-marginal streamway, starting from the Pomerania phase of the last glaciation to the Late Glacial, marked itself by the formation of several terrace levels (Fig. 16). Waters directing to the west of Bydgoszcz created a significantly narrower valley of the width of 2.5–6 km in the vicinity of Nakło upon

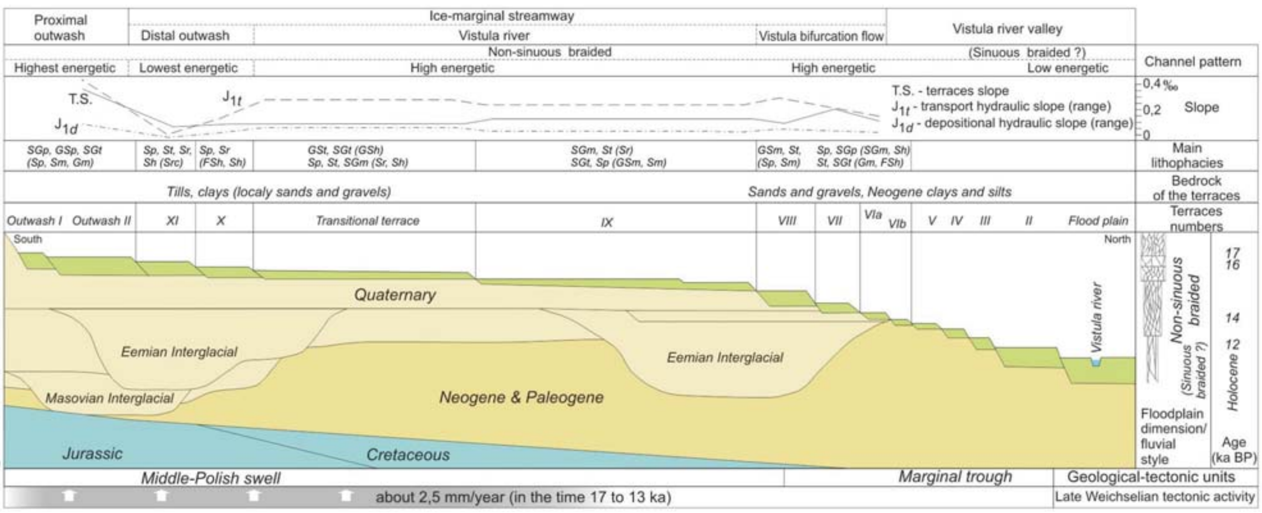

Fig. 16. Main development phases of the fluvial system of the Toruń Basin in the Late Weichselian (channel pattern and age of terraces in Late Glacial after Tomczak 1982, 1987)

the Noteć. This section is located in the northern limits of the Szubin anticline and with its course it corresponds to the Eopleistocene valley of the proto-Noteć and the fossil valleys of the Great and Eemian Interglacials (Figs 2, 3). The location of the described narrow fragment of the Noteć ice-marginal streamway to the north of the Szubin Mesozoic elevation makes it possible to classify it as a valley of the antecedent gap character (Weckwerth 2007c). Its development can be related to the relaxational uplifting movements of the Kujawy-Pomerania Anticlinorium (about 2,5 mm/year in time 17 to 13 ka, Weckwerth 2009) within the zone of banks and salt swells. The tectonic activation of the Szubin elevations may have also occurred after the glaciation periods and prior to the Weichselian Glaciation.

Another example of the influence of the tectonic movements of the Central Polish Anticlinorium upon the evolution of the fluvial relief in the Toruń Basin can be seen in the change of the Vistula channel to the northeast (Mojski 1980). As a result of this process, the discharge of waters through the ice-marginal streamway concentrated in the narrow belt of its bottom to the west of Bydgoszcz (the terraces VIII–VI), near the gap of the Vistula at Fordon (Figs 1, 16). This gap began to function most probably in the level of the terrace VIII or lower, and thus, the Vistula did not flow through the entire width of the Toruń Basin but only in its northern part. With respect to their course the southern limits of the terraces VIII–VI in the Toruń Basin relate to the northwest limit of the Kujawy-Pomerania Anticlinorium (Figs 1, 2, 16).

Conclusion

The development of the river network in the Toruń Basin was largely influenced by uplifting tectonic movements after the deglaciation period of the basin. Climatic changes were of high importance. Therefore, it may be assumed that the similar to the Late Weichselian Glaciation reorganizational mechanisms of water discharge directions, stimulated by the tectonic activity of the older bed together with possible bifurcation of rivers, may have taken place in the Toruń Basin at the start of the Eemian Interglacial.

At the end of the Weichselian Glaciation the Toruń Basin was a hydrographical node merging waters which flowed from various directions. With reference to Galon's investigations (1961, 1968) and the author's research we can distinguish the following terrace sets in the Toruń Basin: a) the outwash levels formed not so far away from the ice-sheet front, i.e. during the Wąbrzeźno Subphase; b) the distal sections of the outwash, i.e. the ice-marginal streamway terraces (XI, X); c) the Vistula ice-marginal streamway terraces (the transitional terrace and IX); d) the Vistula ice-marginal streamway terraces (VIII–VI) from the period of this river bifurcation at Fordon; and e) lower terraces of the Vistula valley (V–II). In the upper part of the Middle Weichselian waters flowing through the Toruń Basin formed a system of sandbed braided rivers whose changeable flow regime registered in the deposits of various outwash levels and terraces initially had higher energy, then reduced energy and high again (Fig. 16). This resulted from the ice-sheet front retreat, intensity of its ablation and the inflow of the Vistula waters from the south. The sudden increase in the transport power of flowing waters in the Toruń Basin occurred after the penetration of the Vistula from the Płock Basin into the Toruń Basin, and was related to the declining width of the river valley bottom starting from the discharge in the level of the terrace VIII. The limited amount of bar deposition was accompanied by a bigger share of deeper channel discharge of a bed formed predominantly by sandy megaripples. The magnitude of deep erosion of the Vistula, which lasted at the turn of the Middle Weichselian was conditioned by the energy and lithology of the channel bed. Deep erosion was obstructed by the glacial till of the main stadial of the Weichselian and clays.

The rising values of the hydraulic transport gradient of the water table distinguished for the deposits of the terraces younger than the outwash ones reflect the rising share of deep erosion. That may have been caused by tectonic uplifting (glaciostatic, Fig. 16). With respect to the present terrace slope, the bigger values of the transport gradient of the water table may prove a later neotectonic depression of their area in the eastern part of the Toruń Basin.

Acknowledgement

The article comprises main arguments and conclusions presented in the author's doctoral thesis. The thesis was written under the supervision of Prof. dr habil. E. Wiśniewski, whom I would like to thank for scientific guidance during my research. Some problems discussed in the article contain the results of the investigations conducted within the grant No. N N306 3538 33 obtained from the Ministry of Science and Higher Education.

References

Andrzejewski L., 1994. Ewolucja systemu fluwialnego doliny dolnej Wisły w późnym vistulianie i holocenie na podstawie wybranych dolin jej dopływów. Rozprawy UMK, Toruń: 113 pp.

Andrzejewski L., 1995. Genesis of the fluvial system of the Lower Vistula river based on the selected side valleys. In: Starkel L. (ed.) *Evolution of the Vistula river valey during the last 15 000 yers. 5* (8), IGiPZ PAN: 139–156.

Augustowski B., 1982. Charakterystyka geomorfologiczna. In: Augustowski B. (ed.) *Dolina dolnej Wisły*. Wydawnicwo PAN, Wrocław: 61–79.

Baraniecka M.D., 1980. Geneza elementów wklęsłych powierzchni podłoża czwartorzędu na obszarze wału kujawskiego i niecki warszawskiej. *Biul. Inst. Geol*., 322, *Z badań czwartorzędu w Polsce* 24: 31–64.

Brykczyński M., 1986. O głównych kierunkach rozwoju sieci rzecznej Niżu Polskiego w czwartorzędzie. *Przegl. Geogr*. 58 (3): 411–440.

Churska Z., 1969. Włocławek, Ciechocinek, Toruń. In: *Przewodnik XLI Zjazdu P. T. Geol., Konin, 21–23 września*: 191–193.

Dadlez R., 1980a. Fault pattern in Polish Lowlands and its bearing on the Permian-Mesozoic evolution of the area. *Przegl. Geol.* 5: 278–286.

Dadlez R., 1980b. Tektonika wału pomorskiego. *Kwartalnik Geol*. 24 (4): 741–767.

Dadlez R. & Marek S., 1974. Polska północno-zachodnia i środkowa. In: *Budowa geologiczna Polski*, IV, *Tektonika,* 1, Wyd. Geol., Warszawa: 239–255.

Dadlez R., Marek S. & Pokorski J. (eds.), 2000. *Mapa geologiczna Polski bez utworów kenozoiku 1:1 000 000*, PIG, Warszawa.

Dadlez R. & Marek S., 1983. Kompleks cechsztyńsko-mezozoiczny. In: Marek S. (ed.) Budowa geologiczna niecki warszawskiej (płockiej) i jej podłoża. *Prace Inst. Geol.* 103: 216–220.

Dadlez R. & Dembowska J., 1965. Budowa geologiczna parantyklinorium pomorskiego. *Prace Inst. Geol*. 40: 279 pp.

Dyjor S., 1987. Systemy kopalnych dolin Polski zachodniej i fazy ich rozwoju w młodszym neogenie i eoplejstocenie. In: Jahn A. & Dyjor S. (eds.) *Problemy młodszego neogenu i eoplejstocenu w Polsce*. Ossolineum, Wrocław: 85–101.

Dyjor S., 1991. Wpływ ewolucji paleogeograficznej na rozwój zlodowaceń w Polsce Zachodniej. In: Kostrzewski A. (ed.) *Geneza, litologia i stratygrafia utworów czwartorzędowych*, *Geografia* 50: 419–433.

Galon R., 1929. Kujawy „Białe" i „Czarne". *Bad. Geogr. Nad Polską Półn.-Zach.*. 4–5: 48–76.

Galon R., 1934. Dolina dolnej Wisły, jej kształt i rozwój na tle budowy dolnego Powiśla. *Bad. Geogr. nad Pol. Płn.-Zach.* 12–13: 111 pp.

Galon R. 1953. Morfologia doliny i zandru Brdy. *Stud. Soc. Sci. Torun*. 1 (6): 53 pp.

Galon R., 1961. Morphology of the Noteć-Warta (or Toruń-Eberswalde) ice marginal streamway. Pr. Geogr. IGiPZ PAN 29: 129 pp.

Galon R., 1968. New facts and problems pertaining to the origin of the Noteć Warta Pradolina and the valleys linked with it. *Prz. Geogr.* 40 (2): 307–315.

Galon R., 1981. Zagadnienie serii glacjalnej na przykładzie plejstocenu nad dolną Wisłą i dolną Drwęcą. *Biul. Inst. Geol.* 321, *Z badań czwartorzędu w Polsce* 23: 63–82.

Gradziński R., Kostecka A., Radomski A., Unrug R., 1986. *Zarys sedymentologii*. Wyd. Geol. Warszawa: 628 pp.

Jankowski A.T., 1975. Stosunki hydrograficzne bydgoskiego węzła wodnego i ich zmiany spowodowane działalnością człowieka. *Stud. Soc. Scient. Torun*., VII, PWN, Warszawa–Poznań–Toruń: 116 pp.

Jentzsch A., 1919. *Geologischer Führer durch die Umgegend Thorns*. Thorn: 56 pp.

Jeziorski J.W., 1991a. Kopalne osady aluwialne rzeki roztokowej z okresu interglacjału lubelskiego między Włocławkiem a Ciechocinkiem. *Przegl. Geol*. 39 (5–6): 284–292.

Jeziorski J. W., 1991b. Litostratygrafia osadów neoplejstocenu we wschodniej części Równiny Inowrocławskiej. In: Kostrzewski A. (ed.) *Geneza, litologia i stratygrafia utworów czwartorzędowych*, *Geografia* 50: 449–456.

Jeziorski J.W., 1995a. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000 ark. Aleksandrów Kujawski*. PIG, Warszawa: 33 pp.

Jeziorski J.W., 1995b. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000 ark. Gniewkowo*. PIG, Warszawa: 29 pp.

Keilhack K., 1904. Die grosse baltische Endmoräne und das Thorn- Eberswalder Haupttal. *Zeitschr. D. Deutsch. Geol. Gesll.*, Berlin: 132–141.

Knighton D., 1984. *Fluvial forms and Processes*. E. Arnold, London, New York, Melbourne, Auckland: 218 pp.

Kordowski J., 1997. *Morfologia i budowa geologiczna równiny zalewowej Wisły na odcinku Solec Kujawski-Strzelce Dolne*. IGiPZ PAN, Toruń: 27 pp.

Kostrzewa J., 1981. Morfogeneza doliny Tążyny. *Przegl. Geogr.* 53 (4): 803–818.

Kozarski S., 1962. Recesja ostatniego lądolodu z północnej części Wysoczyzny Gnieźnieńskiej a kształtowanie się pradoliny Noteci-Warty. *Prace Kom. Geogr.-Geol.*, II (3): 154 pp.

Kozłowska M. & Kozłowski, I., 1992. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000 ark. Bydgoszcz Wschód.* PIG, Warszawa: 38 pp.

Kucharski M., 1966. Geomorfologia i czwartorzęd doliny Wisły w okolicach Ciechocinka. *Zesz. Nauk. UMK, Geografia* 5: 37–59.

Lencewicz S., 1922. O wieku środkowego Powiśla. *Posiedz. Nauk. PIG* 3: 21–24.

Lencewicz S., 1923. O t. z. Zastoisku toruńskim. *Przegl. Geogr*. 4: 99–114.

Leopold L.B., Wolman M.G., Miller J.P., 1964. *Fluvial processes in geomorphology.* W. H. Freeman and Company, San Francisco and London: 522 pp.

Liszkowski J., 1975. Wpływ obciążenia lądolodem na plejstoceńską i współczesną dynamikę litosfery na obszarze Polski. In: *Współczesne i neotektoniczne ruchy skorupy ziemskiej w Polsce* 1: 256–277.

Liszkowski J., 1993. The effects of Pleistocene ice-sheets loading – deloading cycles on the bedrockstructureof Poland, Wybrane zagadnienia neotektoniki Polski. *Folia Quaternaria* 64: 7–23.

Łyczewska J., 1975. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000, ark. Ciechocinek.* PIG, Warszawa: 62 pp.

Maas G., 1904. Das Thorn-Eberswalder Haupttal und seine Endmoränen, Ein Schlusswort am Hernn K. Keilhack. *Zeitsch. D. Deutsch. Geol. Gesll.* 56, Brifl. Mitt: 159–164.

Makowska A., 1979. Interglacjał eemski w Dolinie Dolnej Wisły. *Studia Geolog. Polonica* LXIII: 90 pp.

Makowska A., 1980. Late Eemian with preglacial and glacial part of Vistulian Glaciation in Lower Vistula Region. *Quaternary Studies In Poland* 2 (1): 37–56.

Marek S. & Znosko J., 1972a. Tektonika Kujaw. *Kwartalnik Geol.* 16 (1): 1–18.

Marek S. & Znosko J., 1972b. Historia rozwoju geologicznego Kujaw. *Kwartalnik Geol.* 16 (2): 23–248.

Marek S. & Znosko J., 1983. Pozycja geotektoniczna i granice niecki warszawskiej (płockiej). In: Marek S. (ed.) Budowa geologiczna niecki warszawskiej (płockiej) i jej podłoża. *Prace Inst. Geol.* 103: 13–20.

Mojski J.E., 1980. Budowa geologiczna i tendencje rozwoju doliny Wisły. *Przegl. Geol.* 6: 332–334.

Mojski J.E., 1982. Geologiczne warunki powstania i rozwoju doliny dolnej Wisły. In: Augustowski B. (ed.) *Dolina dolnej Wisły*. Wydawnictwo PAN: 19–60.

Mojski J.E., 1984a. Niż Polski i wyżyny środkowopolskie. In: *Budowa geologiczna Polski, Czwartorzęd*, Wyd. Geol., Warszawa: 82–113.

Mojski J.E., 1984b. Zlodowacenie północnopolskie. In: *Budowa geologiczna Polski, Czwartorzęd*, Wyd. Geol., Warszawa: 218–255.

Mrózek W., 1958. Wydmy Kotliny Toruńsko-Bydgoskiej. In: *Wydmy śródlądowe Polski*. 2: 7–59.

Niewiarowski W., 1968. Morfologia i rozwój pradoliny i doliny dolnej Drwęcy. *Stud. Soc. Sci. Torun.* 6 (6): 132 pp.

Niewiarowski W., 1969. The relation of the Drwęca valley to the Noteć-Warta (Toruń-Eberswalde) Pradolina and its role in the glacial and lateglacial drainage system. *Geogr. Polonica* 17: 173–188.

Niewiarowski W., 1987. Evolution of the lower Vistula valley in the Unisław Basin and at the river gap to the north of Bydgoszcz-Fordon. In: Starkel L. (ed.) *Evolution of the Vistula river valey during the last 15 000 years*. part II, *Geographical Studies*, Special Issue 4, IGiPZ PAN: 233–252.

Niewiarowski W., 1992. Morphogenesis of the Żnin channel as an example of a subglacial channel of complex origin in the Polish Lowland. *Quaest. Geogr., Special Issue* 3: 131–142.

Niewiarowski W., 1993. Geneza i ewolucja rynny żnińskiej w okresie pełnego i późnego vistulianu. *Acta Univ. Nicolai Copernici*, *Geografia* 25: 3–30.

Niewiarowski W. & Noryśkiewicz B., 1983. Some problems concerning the development of the Vistula and Drwęca valley flors in the Toruń region. *Peterm. Mitteil. Ergänzungsheft* 282, Haack, Gotha: 144–154.

Niewiarowski W. & Tomczak A., 1969. Morfologia i rozwój rzeźby obszaru miasta Torunia i jego okolic. *Zesz. Nauk. UMK., Geografia* 6: s. 39–89.

Niewiarowski W. & Weckwerth P., 2006. Geneza i rozwój rzeźby terenu. In: Andrzejewski L., Weckwerth P., Burak Sz. (eds.) *Toruń i jego okolice, monografia przyrodnicza*. Wyd. UMK, Toruń: 65–98.

Niewiarowski W. & Wilczyński A., 1979. *Objaśnienia do Mapy Geologicznej Polski w skali 1:200 000, ark. Toruń.* Wyd. Geol. Warszawa.

Olszewski A. & Weckwerth P., 1999. The deformational structures of the deposits on the Höfdabrekkujökull forefield. *Landform Analysis* 2: 63–80.

Ost H.G., 1935. Neue Anschanungen zur Entwiclungsgechichte eines norddeutschen Urstromtales. *Zeit. F. Gletsch.* 22: 96–108.

Petelski K. & Sadurski A., 1987. Geneza pradoliny Redy-Łeby w świetle teorii transportu masy i ciepła. *Czasop. Geogr.* 58 (4): 439–456.

Piotrowski A., 1991. The influence of sub_Quaternary basemant on the development of Lower Odra Valley in Pleistocene and Holocene. *Kwart. Geol.* 35 (2): 221–234.

Pożaryski W., 1974. Podział obszaru Polski na jednostki tektoniczne. In: *Budowa geologiczna Polski*. *Tektonika* 1. Wyd. Geol. Warszawa: 24–34.

Pożaryski W., Tomczyk H. & Brochwicz-Lewiński W., 1983. Paleozoik przedpermski i jego podłoże. In: Marek S. (ed.) Budowa geologiczna niecki warszawskiej (płockiej) i jej podłoża. *Prace Inst. Geol.* 103: 206–215.

Raczyńska A., 1971. Zarys stratygrafii dolnej kredy w niecce mogileńskiej. *Kwart. Geol.* 15 (1): 106–121.

Roszko L., 1968. Z historii rozwoju doliny dolnej Wisły. *Folia Quater.* 29: 97–108.

Samsonowicz A., 1924. Zastoiska lodowcowe nad górna i środkową Wisłą (Lacs endigués glaciaressur la Haute et Moyenne Vistule). *Posiedz. Nauk. PIG* 1, Warszawa: 8–9.

Schumm S.A., 1977. *The fluvial system*. John Wiley & Sons, New York-London-Sydney-Toronto: 338 pp.

Sonntag P., 1916. Altes und Neues vom diluvialen Thorner Stausee. *Schriften Naturforschenden Gesellschaft in Danzig*, 14 (2): 66–86.

Sonntag P., 1919. *Geologie von Westpreuâen, Verlag von Gebrüder Borntraeger*: 240 pp.

Starkel L. 2001. Historia doliny Wisły od ostatniego zlodowacenia do dziś. *Monografie* 2, Wydawnictwo PAN, Warszawa: 263 pp.

Szmańda J.B., 2000. Litodynamiczny zapis powodzi w aluwiach pozakorytowych Wisły. In: Molewski P., Wysota W. (eds.) *Dawne i współczesne systemy morfogenetyczne środkowej części polski Północnej, Przewodnik wycieczek terenowych, V Zjazd Geomorfologów Polskich 11–14 września 2000, Toruń*: 221–231.

Szmańda J.B., 2002. Litofacjalny zapis powodzi w wybranych fragmentach równin zalewowych Wisły, Drwęcy i Tażyny, maszynopis rozprawy doktorskiej w Inst. Geogr. UMK Toruń.

Thomas G.S.P., Connaughton M. & Dackombe R.V., 1985. Facies variation in a Late pleistocene supraglacial outwash sandur from the Isle of Man. *Geolog. Journal* 20: 193–213.

Tomczak A., 1971. Kępa Bazarowa na Wiśle w Toruniu w świetle badań geomorfologicznych oraz archiwalnych materiałów kartograficznych. *Stud. Soc. Sci. Torun.* 7 (6): 111 pp.

Tomczak A., 1982. The evolution of the Vistula river valley between Toruń and Solec Kujawski during the Late Glacial and Holocene. In: Starkel L. (ed.) Evolution of the Vistula river valley during the last 15 000 years. part I, *Geographical Studies*, Special Issue 1, IGiPZ PAN: 109–130.

Tomczak A., 1987. Evolution of the Vistula valley in the Torun Basin in the Late Glacial and Holocene. In: Starkel L. (ed.) Evolution of the Vistula river valley during the last 15 000 years, part II, *Geographical Studies*, Special Issue 4, IGiPZ PAN: 207–232.

Uniejewska M. & Nosek M., 1992. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000 ark. Łabiszyn.* Wyd. Państw. Inst. Geol. Warszawa: 98 pp.

Uniejewska M., Nosek M. & Włodek M., 1979. *Objaśnienia do Mapy Geologicznej Polski w skali 1:200 000, ark. Nakło*. Wyd. Geol. Warszawa: 74 pp.

Uniejewska M. & Włodek M., 1977. Zagadnienia stratygrafii plejstocenu okolic Nakła. *Kwart. Geol.* 21 (4): 919–920.

Weckwerth P., Unpublished, Morfogeneza wybranych obszarów Kotliny Toruńskiej a problem jej roli w układzie hydrograficznym podczas górnego plenivistulianu. Ph.D. thesis, UMK, Toruń.

Weckwerth P., 2005. Poziomy sandrowe i ich rozwój w Kotlinie Toruńskiej w górnej części plenivistulianu. In: Kotarba A., Krzemień K. & Święchowicz J. (eds.) *VII Zjazd Geomorfologów Polskich, Kraków 19–22 września 2005, Współczesna ewolucja rzeźby Polski*: 507–512.

Weckwerth P., 2006. Problem bifurkacji Wisły pod Fordonem (Bydgoszcz) na tle ewolucji Kotliny Toruńskiej pod koniec plenivistulianu. *Przegl. Geogr.* 78 (1): 47–68.

Weckwerth P., 2007a. Kształtowanie się odpływu wód roztopowych w północnej części Kujaw w czasie recesji ostatniego lądolodu. In: Molewski, P., Wysota W. & Weckwerth P. (eds.) *Plejstocen Kujaw i dynamika lobu Wisły w czasie ostatniego zlodowacenia, XIV Konferencja Stratygrafia Plejstocenu Polski, Ciechocinek, 3–7 września 2007*. PIG, Warszawa: 163–169.

Weckwerth P., 2007b. Morfologia i mechanizm formowania moren łabiszyńskich. In: Molewski P., Wysota W. & Weckwerth P. (eds.) *Plejstocen Kujaw i dynamika lobu Wisły w czasie ostatniego zlodowacenia, XIV Konferencja Stratygrafia Plejstocenu Polski, Ciechocinek, 3–7 września 2007*. PIG, Warszawa: 147–155.

Weckwerth P., 2007c. Późnovistuliański rozwój sieci rzecznej w rejonie Kotliny Toruńskiej na tle struktur starszego podłoża. In: Florek W. (ed.) Morfotwórcza rola lodowców i lądolodów plejstoceńskich i współczesnych, *Słupskie Prace Geograficzne* 4, Akademia Pedagogiczna w Słupsku: 143–156.

Weckwerth P., 2009. Warunki depozycji osadów plenivistuliańskiej rzeki roztopowej w Kotlinie Toruńskiej. In: Żarski M., Lisicki S. (eds.) XVI Konferencja Stratygrafia Plejstocenu Polski, Strefa marginalna lądolodu zlodowacenia warty i pojezierza plejstoceńskie na południowym Podlasiu, Zimna Woda k. Łukowa, 31.08–4.09.2009: 135–138.

Wilczyński A., 1973. Budowa geologiczna okolic Torunia. *Acta UNC, Geografia* 10 (32): 13–39.

Wiśniewski E., 1976. Rozwój geomorfologiczny doliny Wisły pomiędzy Kotliną Płocką a Kotliną Toruńską. *Stud. Soc. Scient. Tor.* 8 (4–6): 124 pp.

Wiśniewski E., 1987. The evolution of the Vistula river valley between Warsaw and Płock Basins during the last 15 000 years. In: Starkel L. (ed.) Evolution of the Vistula river valey during the last 15 000 years, part II, *Geographical Studies*, Special Issue 4, IGiPZ PAN: 171–187.

Wiśniewski E., 1990. Evolution of the Vistula Valley. In: Starkel L. (ed.) Evolution of the Vistula river valley during the last 15 000 years, part III, *Geographical Studies*, Special Issue 5, IGiPZ PAN: 141–146.

Włodek M., 1980. Młodszy plejstocen w rejonie Nakła nad Notecią. *Przegl. Geol.* 8: 453–456.

Woldstedt, P., 1932. Über Randlagen der letzten Vereisung in Ostdeutschland und Polen und über die Herausbildung des Netzte-Warte Urstromtales. *Jb. Preuss. Geol. Landesanst*. 52.

Wrotek K., 1990. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000 ark. Ręczkowo*. Wyd. Państw. Inst. Geol., Warszawa: 66 pp.

Wrotek K., 1993. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000 ark. Złotniki Kujawskie*. Wyd. Państw. Inst. Geol., Warszawa: 33 pp.

Wysota W. 2002. *Stratygrafia i środowiska sedymentacji zlodowacenia wisły w południowej części dolnego Powiśla*. UMK, Toruń: 144 pp.

Zieliński T., 1993. Sandry Polski północno-wschodniej – osady i warunki sedymentacji. *Prace Nauk. Uniw. Śl.* 1398: 97 pp.

Zieliński T., 1995. Kod litofacjalny i litogenetyczny – konstrukcja i zastosowanie. In: E. Mycielska-Dowgiałło E. & Rutkowski J. (eds.) *Badania osadów czwartorzędowych, wybrane metody i interpretacja wyników*. Warszawa: 221–234.

Żurawski M., 1959. Dolina kopalna w rejonie Bydgoszczy. *Zeszyty Nauk. UAM, Geografia* 2: 131–132.