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GEOLOGY OF SUB-QUATERNARY BASEMENT AND STRATIGRAPHY OF QUATERNARY SEDIMENTS IN THE MIDDLE NOTEĆ RIVER VALLEY, WESTERN POLAND

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Abstract: A model of geological structure, including detailed stratigraphy of Quaternary sediments in the Middle Noteć River valley region, is presented. More than 950 boreholes and 64 geological sections have been analysed. The sub-Tertiary basement includes the Pomorze–Kujawy (Pomeranian–Kuyavian) Swell and the Szczecin–Mogilno Trough, built up of Cretaceous and Jurassic rocks. The Tertiary sediments are up to 260 m thick. Fourteen till beds, representing 7 glaciations: Narevian, Nidanian, Sanian I, Sanian II, Odranian, Wartanian, and Vistulian, have been distinguished, ranging from a few to 220 m in thickness. Fluvial and lacustrine sediments separating individual tills represent the Podlasian, Malopolanian, Ferdynandovian, Mazovian, Lubavian and Eemian interglacials.

Abstrakt: Przedstawiono model budowy geologicznej rejonu Doliny Środkowej Noteci wraz ze szczegółową stratygrafią osadów czwartorzędowych, uzyskany z analizy ponad 950 wierceń i 64 przekrojów. W podłożu trzeciorzędu występują tu głównie skaly jury i kredy, wchodzące w skład walu pomorsko-kujawskiego i niecki szczecińsko-mogileńskiej. Ukształtowanie podłoża osadów trzeciorzędowych wykazuje zgodność z budową struktur tektonicznych. Osady trzeciorzędu w rejonie Doliny Środkowej Noteci mają miąższość od kilkunastu do 265 m. W bezpośrednim podłożu osadów czwartorzędowych występują osady miocenu i pliocenu. Wśród osadów czwartorzędowych mających tu miąższość od kilku do 220 m wyróżniono 14 warstw glin lodowcowych reprezentujących 7 zlodowaceń: Narwi, Nidy, Sanu I i II, Odry, Warty i Wisly. Wyróżniono także osady rzeczne i jeziorne interglacjałów: podlaskiego, małopolskiego, ferdynandowskiego, mazowieckiego, lubawskiego i eemskiego.

Key words: sub-Quaternary basement, Quaternary stratigraphy, Noteć River valley, western Poland.

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INTRODUCTION

The aim of this paper is to present Quaternary stratigraphy and palaeogeography of the Middle Noteć River valley on the background of geological structure of that region.

The principal method applied in this study, consisting in an analysis of borehole data, has a number of drawbacks that result from the quality, quantity, spatial distribution and reliability of the data, as well as from subjective interpretation procedures. Some of presented conclusions would, therefore, require further verification.

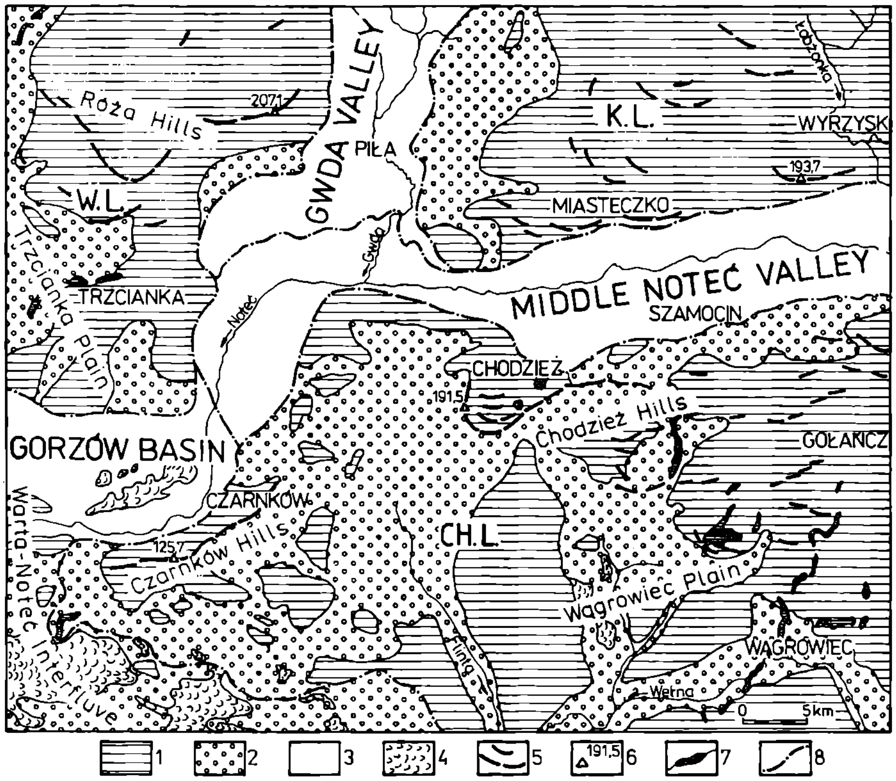
STATE OF RESEARCH

Geological and geomorphological problems of the study area have been dealt with in numerous papers which can be subdivided into three groups:

1. papers related to geological structure of the Mesozoic substratum: Pożaryski (1956, 1979), Dadlez & Dembowska (1963, 1965), Dadlez (1973, 1974, 1980), Cieśliński & Jaskowiak (1973), Dadlez & Marek (1974), Jóźwiak & Młynarski (1984);

2. papers discussing Tertiary sediments: Ciuk (1955, 1970), Gadomska (1957), Ciuk & Pożaryska (1982), Dyjor & Sadowska (1986), Piwocki & Olchowicz-Paprocka (1987), Dyjor (1992), Piwocki (1992); and

3. papers dealing with geomorphology and Quaternary geology. The earliest studies focused mainly on the origin of the Toruń–Eberswalde ice-marginal valley, as well as on the origin and age of morainic ridges (Maas, 1904; Keilhack, 1904; Korn, 1916; Lencewicz, 1926; Galon, 1929, 1961a, b, 1968a, b, 1969; Woldstedt, 1932). One cannot exceed the importance of Krygowski's (1952, 1953, 1956a, b, 1961a, b, 1962, 1972, 1975) work, who was frequently discussing the area in question when describing the morphology and geo-



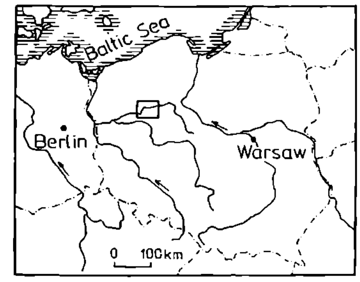


Fig. 1. Geomorphological sketch of the study area (based on Krygowski, 1956a; Kozarski, 1962a; Listkowska & Maksiak, 1977; Uniejewska & Włodek, 1978; Kondracki, 1978). *1* – morainic plateaus, *2* – outwash plains, *3* – valley bottoms, *4* – dune fields, *5* – end moraines, *6* – elevation points, *7* – rivers and lakes, *8* – boundaries of physiographic units; W.L. – Wałcz Lake District, K.L. – Krajna Lake District, CH.L. – Chodzież Lake District

logical structure of the Wielkopolska Lowland. From among numerous papers by Kozarski (1959, 1962a, b, 1965, 1980, 1981, 1988, 1991, 1992, 1993, 1995) and his team (Kozarski & Rotnicki, 1978; Kozarski *et al.*, 1980; Kasprzak & Kozarski, 1989; Kasprzak, 1985, 1991, 1992; Kasp-rzak & Kozarski, 1992a, b, c; Kozarski & Kasprzak, 1992), the following conclusions can be drawn:

– the area of Wielkopolska Lowland does not bear evidence in favour of the presence of an icesheet before the Vistulian maximum stadial;

– the Leszno Phase (20,000 yrs BP) left only one bed of lodgement till, several metres thick;

– the till hitherto associated with the transgression of the Poznań Phase icesheet (18,800 yrs BP) is, in fact, an ablation cover deposited during the recession of the maximum phase of the glaciation;

– a short-term advance during the Chodzież sub-phase (17,700 yrs BP) left, apart from frontal morainic ridges, a separate lodgement till bed; and

– the Noteć–Warta ice-marginal valley was active between the Chodzież sub-phase and the Gardno Phase (14,500 yrs BP), when the feeding by melting waters from the north was terminated.

Some of the above conclusions have been fully confirmed in this paper.

GEOMORPHIC SETTING

The study area is covered by 4 sheets of 1:100,000 topographic maps: Piła, Wyrzysk, Czarnków and Wągrowiec, attaining 3,600 sq. km. From the physiographic point of view, the area in question includes, apart from the Middle Noteć River valley (Fig. 1) and the eastern part of the Gorzów Basin, belonging to the Toruń–Eberswalde (Noteć–Warta) ice-marginal valley, the fragments of Wałcz Lake District, Gwda River valley, Krajna Lake District (on the north) and Chodzież Lake District (on the south).

The Middle Noteć River valley is the lowest-elevated area, being characterised by high and very steep valley sides and flat, broad bottom, up to 10 km wide. Within the valley, a number of erosion-accumulational terraces and a floodplain, built up mostly of peat (Galon, 1961a, b), can be distinguished. The Warta–Noteć interfluve shows classical aeolian landscape features (Stankowski, 1963; Kozarski, 1962b; Klimko, 1973).

The NW part of the study area comprises the Wałcz Lake District, also called the Wałcz Plateau, which can be subdivided into the Róża Hills and Trzcianka Plain (Krygowski, 1956a). The Róża Hills is a typical moraine plateau, composed chiefly of tills (Listkowska & Maksiak, 1977; Listkowska *et al.*, 1978), overtopped by hills up to 207.1 m a.s.l. which are separated by ice-melt kettles. The lower-situated Trzcianka Plain (up to 96 m a.s.l.) is less strongly dissected and composed mostly of last glacial fluvioglacial sediments (Fig. 1). This plain reveals small thicknesses of Quaternary sediments, underlain by shallowly subcropping Tertiary deposits (Listkowska *et al.*, 1978).

The Gwda River valley is a distinct depression formed during the recession of the Pomeranian Phase of the Vistulian Glaciation. Close to its mouth to the Noteć River, the valley becomes broader and forms the Ujście Basin.

The Krajna Lake District within the area studied is a plateau that bears numerous morainic ridges, like Dębowa

Góra (193.7 m a.s.l.), Rzadkowo (186.7 m), Wolsko (161.2 m), Góry Wysokie (155.8 m), and Brzozowa Góra (139.4 m), which originated during the recession of the Poznań Phase of the last glaciation, interrupted by several oscillations (Szupryczyński, 1958, 1961; Galon, 1961a, b; Kozarski, 1962a).

The highest-elevated part of the Chodzież Lake District, *i.e.* Chodzież Hills (Gontyniec 191.5 m a.s.l.) and Czarnków Hills (125.7 m a.s.l.), represents a zone of frontal morainic ridges that extends along the southern margin of the ice-marginal valley. To the south, a monotonous Wągrowiec Plain (70–90 m a.s.l.) occurs, being covered in large part by outwash sediments deposited during the recession of the Poznań Phase of the Vistulian. Its surface is dominated by numerous finger lakes.

METHODS

This study is based on an analysis of more than 950 drill cores collected in the Archives of Boreholes and Geological Documentation, Polish Geological Institute in Warsaw (*ca.* 60%), as well as those stored in archives of the Geological Enterprise (Przedsiębiorstwo Geologiczne) in Poznań, Voivodship Council (Urząd Wojewódzki) in Piła, Quaternary sand pit in Ujście (together *ca.* 5%), and those derived from the Borehole Documentation Archive, sheets Poznań (Krygowski, 1953) and Bydgoszcz (Adamiec-Chodkiewiczowa, 1962) of the Detailed Geological Map of Poland, 1:50,000.

The distribution of boreholes drilled in the study area is unequal (Fig. 2); most of them have been drilled in the western part (brown coal deposits at Trzcianka) and within large cities (Piła, Chodzież, Czarnków, Wągrowiec, Rogoźno, Wyrzysk). Difficulties in geological interpretation may result not only from the lack of sufficient number of boreholes, but also from their excessive concentration in some areas. In poorly documented areas the inferred geological models appear to be simple, whereas in densely drilled regions – much more complicated.

Basing on borehole logs, 64 geological cross sections of different length have been constructed (Fig. 2). When choosing cross section lines, both the number of boreholes and the orientation of linear morphological elements and sub-Quaternary structures have been taken into account (Figs. 1, 3). Original cross sections have been prepared on the 1:25,000 horizontal and 1:1,000 vertical scales. The choice of scale was important in areas of high borehole concentration, making it possible to present even several tens of centimetres thick beds. Relatively small vertical exaggeration of 25:1 prevents artificial denivelations of beds that would result in erroneous estimation of tectonic processes.

Lithological properties enabled the subdivision of a borehole log into individual beds of groups of beds. Special attention has been paid to stratigraphic boundaries, particularly that between the Tertiary and Quaternary. Logs of neighbouring boreholes have then been correlated with each other on the basis of lithological similarities (grain size, mineral and petrographic composition, $CaCO_3$ content, presence of clasts of Scandinavian provenance, occurrences of micas, glauconite and coal silt, colour, degree of compactness, etc.) and hypsometric position. The quality of borehole log descriptions is variable; the best ones refer to boreholes drilled for groundwater and brown coal prospection, since they include the whole section of Quaternary sediments and are usually fairly detailed. Deep boreholes (several hundred metres) bear abundant documentation, although the description of Quaternary and Tertiary sediments is usually simplified.

In case of drastic differences in the description of neighbouring logs, reinterpretation of lithological characteristics was necessary. Interpretation of logs of originally homogeneous sediments (usually tills) consisted in identification of erosion-denudational surfaces found in neighbouring sections.

Interpretation of geological cross sections made it possible to construct maps of the top of Mesozoic and the base of Quaternary deposits, as well as maps of thicknesses of Paleogene, Miocene and Pliocene strata. Extrapolated isolines have been corrected for topography by applying closely-spaced isohypses to high-gradient areas (deep erosional dissections) or drawing semi-circular isohypses in areas affected by glaciotectonic disturbances. These maps were the basis for subsequent palaeogeomorphological analysis.

Local stratigraphy of Quaternary sediments, most important in interpretation of geological cross sections, has

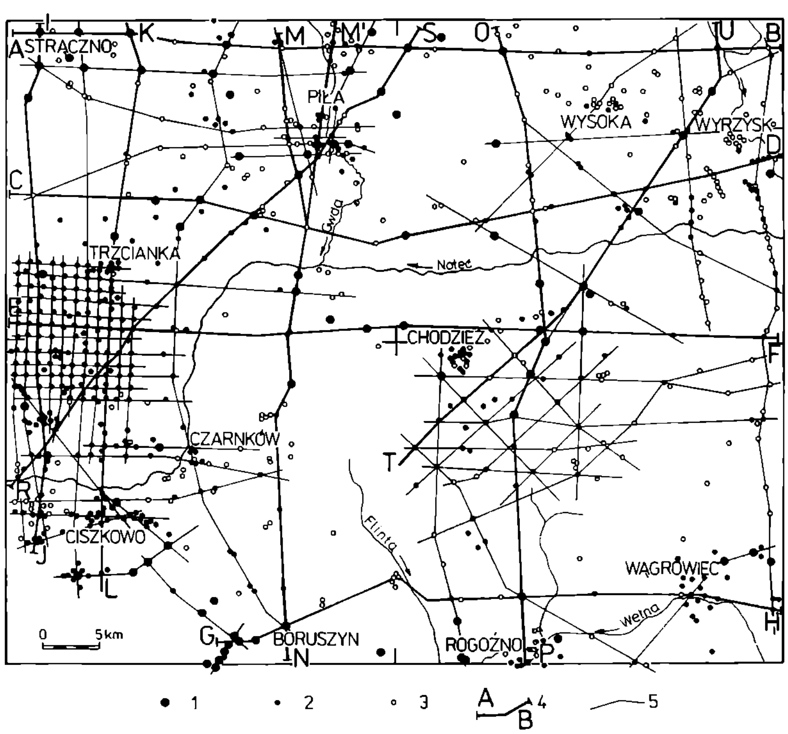


Fig. 2. Location of boreholes and geological cross-sections. *1* – boreholes that drilled Tertiary strata, *2* – boreholes that drilled Quaternary sediments, *3* – boreholes that did not reach the sub-Quaternary surface, *4* – geological cross-sections discussed in the text, *5* – other geological cross sections

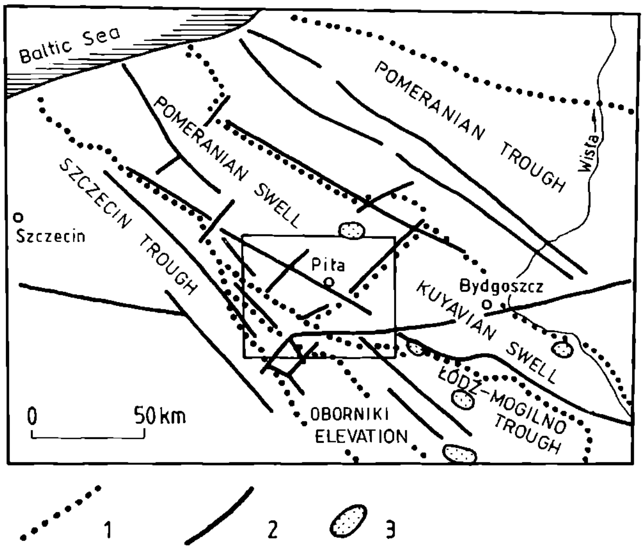


Fig. 3. Location of the study area against principal geological structures (based on Dadlez & Marek, 1974; Pożaryski, 1979; Jóźwiak & Młynarski, 1984). *1* – boundaries of structural units, *2* – principal faults, *3* – salt tectonic structures

been established according to the following rules:

1. correlated till beds should form continuous horizons of relatively smoothed base, except glaciotectonically-disturbed areas;
2. the ranking of individual till beds should be based on properties of intervening interglacial sediments and occurrences of distinct erosion-denudational surfaces;
3. the deepest boreholes (Boruszyn area), documenting the complete record of Quaternary events, and those having palaeobotanic documentation of interglacial stages (Piła region) are of key importance for reconstruction of the number of glaciations in the study area;
4. tills exposed at the groundsurface are older than those of the Pomeranian Phase of the last glacial stage;
5. thermoluminescence datings of sediments exposed in valley sides are only supplementary source of information, as far as stratigraphy of young strata is concerned; and
6. the proposed scheme of local Quaternary stratigraphy is confronted with those of neighbouring regions, as well as with schemes of the Quaternary stratigraphy of Poland by Lindner (1991a, b, 1992) and Baraniecka (1990).

GEOLOGICAL SETTING AND SUB-TERTIARY MORPHOLOGY

The Middle Noteć River valley is situated at the boundary of two large Mesozoic structures (Fig. 3; *cf.* Pożaryski, 1956): the Pomeranian–Kuyavian Swell (anticlinorium) and Szczecin–Łódź–Miechów Trough (synclinorium). These structures trend NW–SE, their boundary being placed along the intersection of the base of Upper Cretaceous strata (Dadlez, 1980; Fig. 3). In the study area only some elements of these two structures occur. The Piła and Nakło anticlines and the Skórka syncline, belonging to the Pomeranian–Kuyavian Swell (Fig. 4), appear in the northern and central parts of the area. The remaining parts cover fragments of the Szczecin–Łódź (Mogilno) Trough, including the Czarnków graben and Łęgów syncline that are separated by the Oborniki elevation, comprising the Rogoźno and Szamotuły–Oborniki brachyanticlines (Dadlez & Dembowska, 1963; Dadlez, 1973; Pożaryski, 1979).

The thickness of the Zechstein–Mesozoic complex in that part of the anticlinorium, drilled at Kotuń, SW of Piła, attains 4,195 m. The sub-Tertiary substratum is composed of the Lower–Middle Jurassic, rarely Upper Jurassic rocks (Fig. 4). The strata building the Pomeranian–Kuyavian Swell show insignificant dip values (Dadlez & Dembowska, 1963).

Geological structure of the Pomeranian–Kuyavian Swell is characterised as well by faults that strike both parallel (NW–SE) and perpendicular to the structural grain of this region. From the latter ones, the most important is the Czarnków–Tuchola (Brodnica) fault, separating the structure into the Pomeranian and Kuyavian Swells (Dadlez & Marek, 1974; Dadlez, 1980; Jóźwiak & Młynarski, 1984; Stupnicka, 1989). Salt tectonic features are also ubiquitous, like those described from Wałcz, Piła, Trzcianka, Chodzież or Wapno areas, situated immediately east of the study area (Dadlez, 1974).

The thickness of the Permo–Mesozoic complex in the Szczecin Trough exceeds 7,000 m (Pożaryski, 1956), that of Cretaceous strata being *ca.* 2,000 m in the western part of the trough. The thickness of Cretaceous rocks in the Mogilno Trough increases from the Oborniki elevation towards SE, where the Upper Cretaceous strata alone are more than 3,000 m thick (Dadlez, 1974). These structures were finally shaped during the Laramian movements, although reduced thicknesses of individual Mesozoic lithostratigraphic members indicate a step-like, synsedimentary uplift of the whole block.

The Oborniki elevation originated due to halotectonic processes of variable intensity that were active since the Triassic through Cretaceous times. The elevation is uplifted and cut by numerous faults (Stupnicka, 1989).

In the Middle Noteć River valley region, the top of Mesozoic rocks is documented by 80 borehole logs (Fig. 4).

The Triassic (Rhaetian) strata, represented by grey claystones bearing coalified plant detritus, have been found in only one borehole in the Oborniki elevation, south of Czarnków.

The Lower Jurassic rocks are documented by 21 boreholes, mostly in axial parts of the Nakło and Piła anticlines (Fig. 4). These are grey, fine-grained, coal silt-bearing sandstones of clayey cement. In places, coarse-grained, poorly lithified sandstones passing into sands and dark-brown, siderite-bearing mudstones, can also be found.

The Middle Jurassic subcrops on the sub-Tertiary surface are documented by 12 boreholes, localised in a narrow belt on the limbs of the Nakło and Piła anticlines (Fig. 4). These rocks represent grey mudstones and claystones with siderite, as well as fossiliferous sandstones.

The Upper Jurassic rocks have been drilled by 23 boreholes in a broad zone on the SW limb of the Nakło anticline and in the Skórka syncline, as well as in the axial part of the Piła anticline and the Oborniki elevation. These are usually grey, chalky, sandy or silty, fauna-bearing marls; rarely grey mudstones, claystones, clays and limestones.

The Lower Cretaceous strata build the sub-Tertiary surface in the Oborniki elevation (3 boreholes) and in a narrow zone in the outer basin belt. These are fossiliferous, dark-grey marls and clayey marls, accompanied by dark, sometimes sand-bearing, clays.

The Upper Cretaceous strata have been documented by 20 boreholes in the southern part of the area studied. These are mostly grey and dark-grey, sandy, poorly lithified marls that frequently comprise glauconite. There also occur dark-grey mudstones and marly sandstones.

According to Dadlez (1974), the present-day extent of Mesozoic rocks is of purely erosional character due to syn-and postdepositional uplift of individual parts of the Pomeranian–Kuyavian Swell.

The base of Tertiary strata shows good concordance with geological structures described above (Fig. 4). This surface rises within anticlines and lowers in synclines (basins). The sub-Tertiary surface plunges towards the SE, similarly as the Piła anticline axis, and following the slope of the anticline's limbs.

The highest part of the Piła anticline is situated at the continuation of the Wielkopolska Swell, uplifted in Jurassic times, and occurring SE of the study area (Dadlez, 1974). This part of the Pomeranian–Kuyavian Swell was particularly liable to uplift coeval with and postdating the Mesozoic sedimentation. Between the Piła anticline and a fragment of the Nakło anticline, the base of the Tertiary forms a vast depression oriented NW–SE, coinciding with the Skórka syncline (Fig. 4). This depression lowers towards the SE, from 90 m b.s.l. close to Wyrzysk to <200 m b.s.l. near Gołańcz. Along the Chodzież–Boruszyn line, the sub-Tertiary surface is dissected by the Chodzież depression, whose base dips towards SW from 100 m b.s.l. to 322 m b.s.l. It is the Boruszyn area where the Chodzież depression merges with another depression, oriented NW–SE, following the axis of the Czarnków syncline. Taking into account the depth of this structure (256 m b.s.l. near Czarnków), high gradients and height of its sides, as well as a certain coincidence with the strike of faults, it has been named the Czarnków graben. Its bottom dips south-eastwards.

SE of Czarnków, Krygowski (1952, 1961a) described a lowering in the sub-Tertiary surface (150 m b.s.l.), called the Ciszkowo depression. This depression appears to represent a shallow lowering in the northern part of the Oborniki elevation.

The Szamotuły–Oborniki anticline shows highly differentiated sub-Tertiary substratum (Fig. 4).

Lithological differentiation of rocks comprising the base of Tertiary strata did not influence its morphology, as shown by the same elevation of the top of different rock exposures. High relief energy of this surface, attainig 270 m, has been induced by tectonic movements (Krygowski, 1961b). Tectonic control on morphology of the sub-Tertiary surface is particularly well evidenced by the coincidence between fault zones and basement depressions. The deep Chodzież depression originated in the Czarnków–Tuchola fault zone, along which the surface of the Kuyavian Swell lowers in respect to that of the Pomeranian Swell (Stupnicka, 1989). Moreover, depressions occurring in the NW part of the study area appear to follow fault zones that are perpendicular to the Swell's axis (Fig. 3). The Czarnków graben originated probably due to differentiated uplift of individual blocks of the Szamotuły–Oborniki and Piła anticlines.

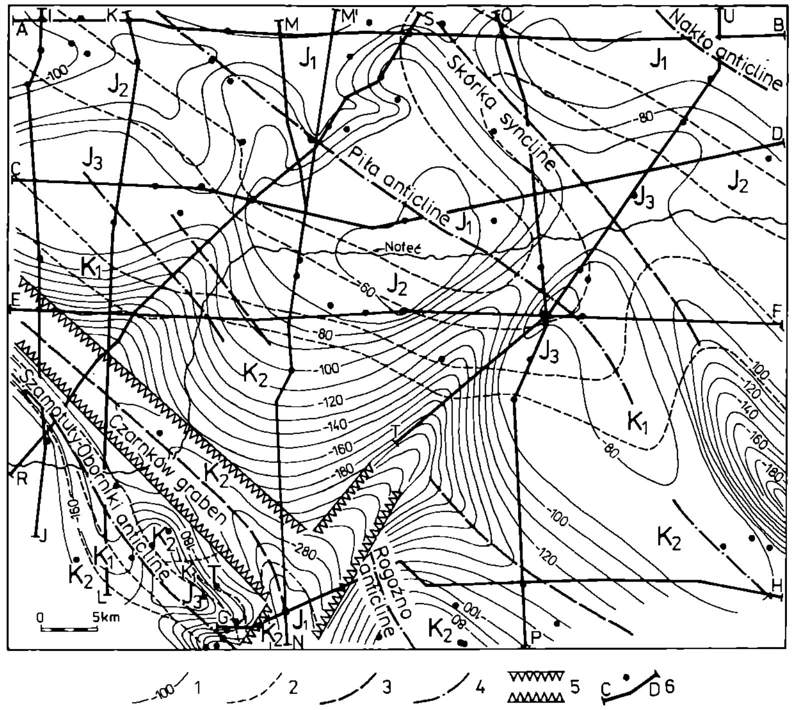


Fig. 4. Sub-Tertiary substratum in the Middle Noteć River valley region. *1* – contour lines, *2* – geological boundaries: T – Triassic, J_1 – Lower Jurassic, J_2 – Middle Jurassic, J_3 – Upper Jurassic, K_1 – Lower Cretaceous, K_2 – Upper Cretaceous, *3* – axes of synclines, *4* – axes of anticlines, *5* – tectonic grabens, *6* – location of boreholes and cross-section lines

The area of such a complicated geological structure could bear evidence of differentiated tectonic movements of diversified amplitudes (Dadlez & Marek, 1974; Dadlez, 1980). It is generally accepted that the Piła, Szamotuły–Oborniki and Rogoźno anticlines were being uplifted during and after the Mesozoic sedimentation, whereas synclinal areas, including the Czarnków graben and Chodzież depression, witnessed relative subsidence.

DISTRIBUTION AND PROPERTIES OF TERTIARY STRATA

In the Middle Noteć River valley Tertiary sediments are ubiquitous, unconformably overlying Mesozoic rocks (Listkowska *et al.*, 1978; Uniejewska *et al.*, 1979). Their distribution is documented by nearly 500 boreholes, 80 of which drilled Tertiary deposits down to their base. The smallest thickness (15 m) has been found in the Noteć River valley NE of Chodzież, the largest (*ca.* 265 m) – near Boruszyn. The distribution of Tertiary sediments reveals a certain regularity. In areas where the top of Mesozoic rocks is high, the thickness of Tertiary sediments ranges from a few dozen to *ca.* 150 m, whereas depressions are filled by 200 m thick Tertiary strata (Fig. 5). The base of Quaternary sediments clearly shows that 50 m a.s.l. contour encircles vast, flat surfaces (elevations). Taking this level as approximating the top of Tertiary sediments (Gadomska, 1957; Kowalska, 1960; Krygowski, 1961a), one should accept the Czarnków graben infill being 372 m thick. An increase in thickness of individual Tertiary stages (Figs. 5–8) within depressions of the sub-Tertiary surface (basins) and their decrease upon culminations of the Swell point to relative uplift of the anticlines during the Tertiary sedimentation. This idea is additionally supported by very small thicknesses or the lack of younger Tertiary stages upon uplifted regions (Figs. 7, 8).

The stratigraphy of Tertiary strata in the western part of the Polish Lowland, including the Middle Noteć River valley region, has been dealt with by Ciuk (1970), Dyjor & Sadowska (1986), Dyjor (1992) and Piwocki (1991). New

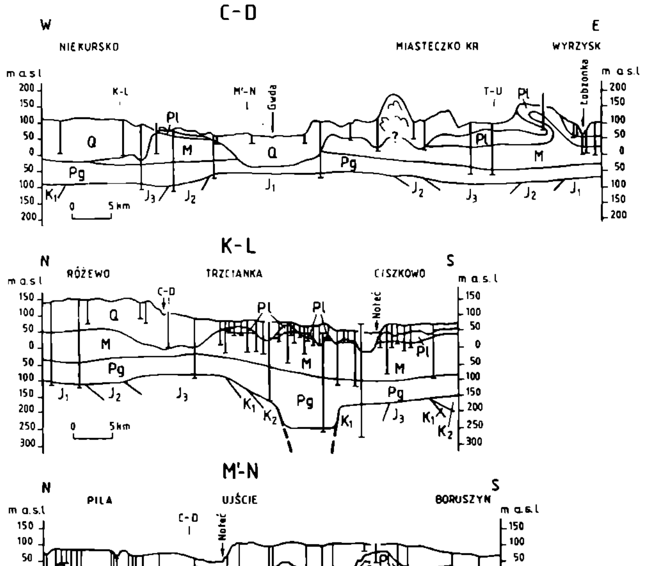


Fig. 5. Distribution and thickness of Tertiary and Quaternary sediments shown on selected cross-sections (*cf.* Fig. 2). J_1 – Lower Jurassic, J_2 – Middle Jurassic, J_3 – Upper Jurassic, K_1 – Lower Cretaceous, K_2 – Upper Cretaceous, Pg – Paleogene, M – Miocene, Pl – Pliocene, Q – Quaternary

investigations enable one to correct the position of some of Tertiary lithostratigraphic members in respect to the schemes applied in borehole descriptions. However, the traditional subdivision has to be kept, since there is little possibility of verification of every sigle description, particularly as the Miocene/Pliocene boundary is concerned.

The Tertiary strata in question belong to three series: Oligocene, Miocene and Pliocene. Since only few boreholes drilled Eocene and Palaeocene strata, they will be subsequently discussed together with more widespread Oligocene strata, and treated as Paleogene sediments.

The Paleogene sediments (mostly Oligocene) include sands, silts and clays, as well as mudstones and sandstones containing phosphoritic concretions, sulphur, and plant detritus. These are mostly shallow-marine sediments (Ciuk & Pożaryska, 1982; Piwocki & Olkowicz-Paprocka, 1987). The smallest thicknesses of Paleogene sediments (20 to 40 m) have been encountered in the axial part of the Piła anticline (Figs. 4, 6), the highest ones are confined to sub-Tertiary basement depressions, like 192 m close to Boruszyn and 154 m near Czarnków (Listkowska *et al.*, 1978). Deviations from this regularity are observed in the Szamotuły–Oborniki anticline, where tectonically-induced reduction in the thickness of Oligocene sediments (0–6 m) is visible. Paleogene sediments immediately underlying Quaternary strata have been documented by 16 boreholes, located upon large depressions within the sub-Quaternary surface, e.g. close to Piła and in the Noteć River valley (Fig. 5).

Miocene sediments have been drilled by most of the boreholes studied and are usually represented by fine-grained, quartzose sands intercalated by silty-clayey sediments, passing into thin layers of claystones and mudstones. Brown coal measures are represented by several metres thick layers (Trzcianka deposit). The cyclicity of sediments (sands – silts – clays – coal), as well as the presence of plant detritus, irregular intercalations of coal-bearing clays, or highly dispersed coal silt testify to periodically changing sedimentary conditions within lacustrine and – sometimes – brackish-marine basins (Listkowska *et al.*, 1978; Ciuk & Pożaryska, 1982; Dyjor & Sadowska, 1986; Piwocki, 1991). Miocene sediments are usually grey-brown due to the presence of coal silt, whereas quartzose sands are, as a rule, light-grey. The thickness of Miocene sediments changes from 0 to 183 m (Fig. 7), ranging between 40 and 80 m in the Pomeranian–Kuyavian Swell. Only tectonically-controlled depressions within the Swell do reveal a marked increase in the thickness of Miocene strata. The Szczecin–Mogilno Trough bears Miocene sediments 100 m thick, indicating a tendency to tectonic subsidence of this trough in respect to the Pomeranian–Kuyavian Swell (Kowalska, 1960). The relief of the top of Miocene sediments is considerably less differentiated as compared to the older surfaces.

A transition from Miocene to Pliocene sedimentation within the same terrestrial, gradually shrinking basin, was continuous (Uniejewska *et al.*, 1979; Ciuk & Pożaryska, 1982; Piwocki, 1991; Dyjor, 1992). The Pliocene strata are represented by clays, silts with fine-grained sands, and variegated clays. The lower parts of some logs of Pliocene sediments do also contain thin interlayers of brown coal or coalified plant detritus. Pliocene sediments do not occur

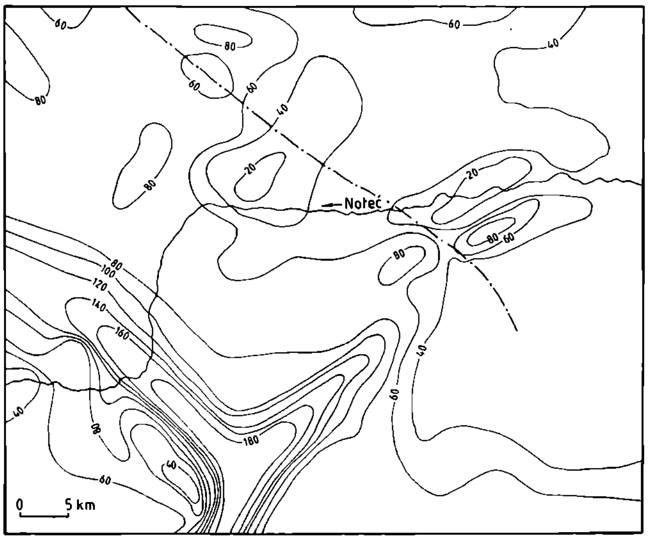


Fig. 6. Thickness of Paleogene strata (*dashed line* marks the axis of the Piła anticline)

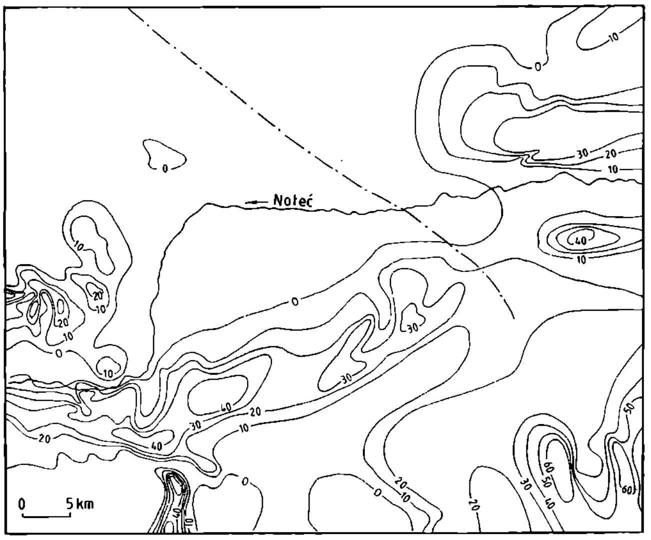


Fig. 8. Thickness of Pliocene strata (*dashed line* marks the axis of the Piła anticline)

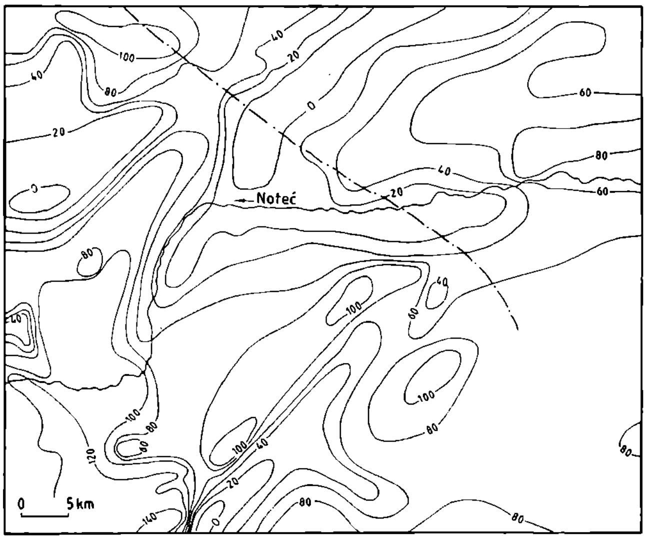


Fig. 7. Thickness of Miocene strata (*dashed line* marks the axis of the Piła anticline)

throughout most of the Pomeranian Swell (Piła anticline) and the Noteć River valley; in other areas their thickness ranges from a few to 30 m and, on some anticline limbs, even to 67 m (Fig. 8). Such a pattern results primarily from glaciotectonic processes (Ciuk, 1955; Kowalska, 1960; Krygowski, 1952, 1961a, b, 1962; Dyjor, 1992).

MORPHOLOGY AND ORIGIN OF SUB-QUATERNARY BASEMENT

The principal topographic elements of the sub-Quaternary surface are represented by elevations and intervening large and deep depressions. These are, from the north to the south, the Skrzatusz, Głupczyn, Białośliwie, Trzcianka, Szamocin, Jędrzejewo, Podanin, Gołańcz and Ludomy elevations (Fig. 9), whose height ranges from 40 to 60 m a.s.l., approximating the top of Tertiary sediments (Kowalska, 1960; Maksiak & Mróz, 1978; Gogołek, 1992). Locally, the elevations are overtopped by minor culminations, like those upon the Trzcianka (90 m a.s.l.) or Gołańcz and Jędrzejewo elevations (80 m a.s.l.; *cf.* Fig. 9). The Gołańcz, Szamocin, Białośliwie and Głupczyn elevations are probably a continuation of the so-called Gniezno–Turek Swell, whereas the Jędrzejewo and Ludomy elevations represent a continuation of the Poznań Swell; all of them distinguished by Krygowski (1961b). In the northern part of the study area the elevations are composed mostly of Miocene strata, those in the southern part being built up from Pliocene sediments (Figs. 7–9).

The elevations are accompanied by deep depressions of variable orientation (Fig. 9). The most extensive one is the Noteć depression, following the Noteć River valley. Its bottom attains 84 m b.s.l. NE of Chodzież, rising to the east and west up to 20 m b.s.l. The Noteć depression is 1 to 8 km wide, its sides being steep and high, up to 115 m SE of Chodzież. In the middle reach of the Noteć River valley, the so-called Noteć furrow has been found, representing a lowering of the sub-Quaternary surface, encircled by the 0 m a.s.l. contour (Kowalska, 1960; Krygowski, 1961a). Geological map 1:200,000 without Quaternary deposits (Listkowska *et al.*, 1977; Uniejewska & Nosek, 1978) shows deeper structures of slightly different shape.

The Noteć depression merges on the north with the Gwda depression, whose orientation follows in part the present-day course of the Noteć River valley (Fig. 9). Another well-documented depression, representing a continuation of the Gwda depression, occurs north of the study area (Maksiak & Mróz, 1978). In the deepest part, south of Piła, the sub-Quaternary surface plunges to 40 m b.s.l. The bottom of the Gwda depression is uneven and tilted to the south. This depresion is joined near Piła by the Róża Wielka depression on the west, separating the Skrzatusz and Trzcianka elevations, and by the Skórka depression on the east, separating the Głupczyn and Białośliwie elevations. The bottoms of these subparallel depressions occur at 10 m a.s.l. to 30 m b.s.l.

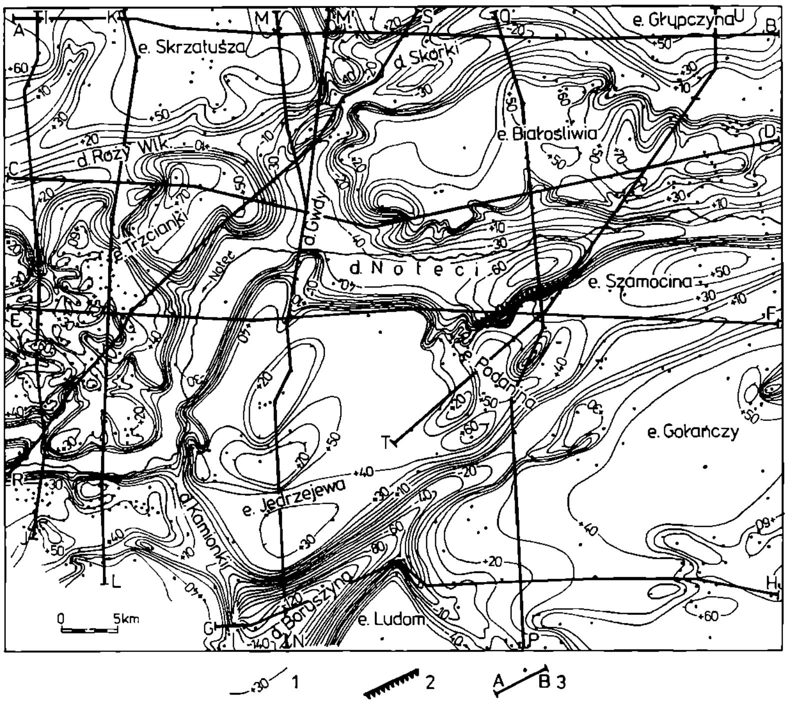


Fig. 9. Sub-Quaternary surface in the Middle Noteć River valley region. *1* – contour lines, *2* – cliffs, *3* – location of boreholes and geological cross-sections; e – elevation, d – depression

In the southern part of the study area, between Szamocin (NE) and Boruszyn (SW), another important depression of the sub-Quaternary surface occurs, being called Boruszyn depression (Fig. 9). In the NE part its bottom is narrow and relatively shallow, encircled by 0 m a.s.l. contour, whereas to the SW its size increases rapidly. Close to Boruszyn, the top of the Tertiary (Oligocene) sediments occurs at 147–110 m b.s.l., which gives 150–180 m height difference in respect to the surrounding elevations. The depression is here 5 km wide (Baraniecka *et al.*, 1986). A southern continuation of the Boruszyn depression is marked by a buried valley that follows the Tertiary Szamotuły graben, described by Gogołek (1991a, b).

The Boruszyn depression is joined by poorly developed Kamionka depression, oriented NW–SE. Its NW continuation could be represented by several narrow valleys that dissect the Trzcianka elevation (Fig. 9).

Apart from mutually merging, longitudinal depressions, the sub-Quaternary surface reveals as well a number of semi-circular depressions without outlet, like that in the deepest part of the Noteć depression near Chodzież (<80 m b.s.l.). Other landforms of this type occur within the Trzcianka (below sea level), Jędrzejewo (20 m a.s.l.) and Gołańcz (below sea level) elevations. These landforms are accompanied by ellipsoidal highs that represent the previously mentioned culminations (Fig. 9).

The recent studies do not confirm the presence of a sub-Quaternary valley which, according to Kowalska (1960), would represent joined meridional segments of the present-day Warta and Gwda River valleys. A dubious trace of such a joint could be found within a depression near Rogoźno.

The above review confirms the presence of the hitherto described relief elements, slightly modifying their outline and extent. The sub-Quaternary surface (Fig. 9) represents a picture generally similar to that shown on the 1:200,000 geological map stripped of Quaternary sediments (Listkowska *et al.*, 1977; Uniejewska & Nosek, 1978). The most important changes, in respect to previous studies, are as follows:

(1) the outline of the Noteć depression approaches that of the recent river valley, particularly in its southern segment;

(2) the Boruszyn depression is aligned NE–SW;

(3) the Róża Wielka depression has another character, as compared to that described by Kowalska (1960), who interpreted it as a joint of the Noteć furrow and Obra–Płonia depression; and

(4) the detailed identification and nomenclature of the sub-Quaternary elevations and depressions are introduced for the first time.

The sub-Quaternary surface in the Middle Noteć River valley region has a poligenetic character due to: glacial erosion and glaciotectonic processes, fluvial erosion, and the structure of solid basement (Krygowski, 1952, 1961b, 1962, 1975; Ciuk, 1955; Kowalska, 1960; Baraniecka, 1975, 1980; Maksiak & Mróz, 1978; Listkowska *et al.*, 1978; Uniejewska *et al.*, 1979; Gogołek, 1991a, b). Relief-forming processes, recorded in the shape of the sub-Quaternary surface, have been repeating throughout the Quaternary; therefore, the morphogenetic complexity of the surface in question affects not only the character of individual processes, but also their age.

Glacial erosion had decisive influence upon the final shape of the sub-Quaternary surface. Individual ice-sheets removed material from some elevations, whose surfaces were additionally denuded during interglacial stages. Local culminations overtopping flat elevation crests (*cf.* Jędrzejewo, southern Gołańcz, and SW Trzcianka elevations) originated due to pushing up basement material by advancing ice-sheet. Such a process was being repeated during subsequent glacial stages, as evidenced by the fact that flat elevation crests are composed of Miocene sediments (Skrzatusz, Głupczyn, NE Trzcianka elevations), whereas the culminations comprise mostly Pliocene clays of large thicknesses (Figs. 8, 9). Glacial erosion resulted as well in shaping of numerous depressions in the sub-Quaternary surface, due to the activity of both large glacial lobes (Boruszyn, Gwda, Kamionka, Róża Wielka depressions) and small glacial tongues (Białośliwie, Trzcianka, Jędrzejewo elevations). Similar processes have frequently been described from other areas (Krygowski, 1952, 1961a, b, 1975; Ciuk, 1955; Lamparski, 1972, 1983, 1991; Maksiak & Mróz, 1978; Baraniecka, 1980; Kasprzak, 1988; Kozarski & Kasprzak, 1992).

Another important relief-forming process that shaped the sub-Quaternary surface in the study area was fluvial erosion that produced or modified the pre-existing, elongated depressions (Noteć, NE Boruszyn, northern Gwda and other depressions). Erosion confined to individual interglacials affected the pre-existing glaciotectonic depressions.

The influence of geological structure and morphology of the base of Tertiary sediments upon processes shaping the sub-Quaternary surface close to the contact of large Mesozoic structures (Pomeranian–Kuyavian Swell, Szczecin–Mogilno Trough) has already been described by Lewiński & Samsonowicz (1918), Lencewicz (1926), Galon (1961a, b), Roszko (1968), Kopczyńska-Żandarska (1970), Baraniecka (1975, 1980) and Niewiarowski (1983). I would only like to focus on mutual relationships between morphological elements of the sub-Quaternary surface and endogenic processes. Systematic exaration of those elevations which developed upon anticlines of the Pomeranian–Kuyavian Swell led to removal of Pliocene and Lower Quaternary sediments and could indicate a persisting tendency to tectonic uplift. Principal linear elements of the sub-Quaternary surface are roughly coincident with landforms and structures of the sub-Tertiary basement. In both cases NE–SW and NW–SE trends dominate. The Boruszyn and Kamionka depressions, as well as a part of the Noteć depression are located exactly upon troughs within the sub-Tertiary surface (Figs. 4, 9). Considering the fact that glacial and fluvial erosion proceeded along the same linear zones throughout different Quaternary stages, one can conclude about fault activity in this area (Fig. 3).

STRATIGRAPHY AND LITHOLOGY OF QUATERNARY SEDIMENTS

Oldest (Narevian) Glaciation

The oldest Quaternary sediments in the study area are probably represented by two till beds, separated by a thin silt layer, found in the Boruszyn depression (Figs. 10, 11). The lower, grey-green and sandy till, containing clasts and intercalations of brown clays and brown coal, has been found by two boreholes. In both cases the till is underlain by dark-brown, silty Paleogene sediments. The base of the till lies at 147 and 125 m b.s.l., its thickness attaining 6 m. The upper till, also found in two boreholes, is dark-grey, sandy, and contains cobbles and interlayers of silts and coal-bearing clays. Its base is situated 115 m b.s.l., and its thickness ranges from 3.5 to 5 m.

Up to now, the tills occurring in a deep glaciotectonic depression close to Boruszyn have been associated with the till found at Ryczywół, despite height differences up to 80 m, and treated as the older level of the South-Polish Glaciations (Listkowska *et al.*, 1978; Baraniecka *et al.*, 1986). Similarly, tills occurring within deep exaration depressions (300 m b.s.l.) in eastern Germany (Čepek, 1967) used to be linked with the Elsterian I glacial stage. On the other hand, the sequence described from the Middle Noteć River valley correlates well with two till beds separated by fluvioglacial series, distinguished in the Myślibórz Lake District by Kozłowska (1974, 1979), and ascribed to the oldest glaciation. Kopczyńska-Lamparska (1979) also postulates the presence of the oldest glaciation near Szczecin. In turn, two tills (8 and 5 m thick) found in the Western Pomerania, of bases situated 130 and 110 m b.s.l., respectively, and considered as slides of the South Polish tills within valleys shaped during the Great Interglacial (Kopczyńska-Żandarska, 1970), could have been reinterpreted as being equivalent to the oldest glacial stage. Bipartition of tills of the oldest (Narevian) Glaciation has been described from other regions of Poland (Różycki, 1967; Straszewska, 1968; Lamparski, 1983). One can suppose, therefore, that the lowest-situated glacial sediments in the study area originated during the Narevian Glaciation. Their assignment to the South-Polish Glaciation (Listkowska *et al.*, 1978; Baraniecka *et al.*, 1986) does not explain remarkable height differences of the till base in a relatively small area: from 147 m b.s.l. at Boruszyn to 13 m b.s.l. at Piła.

It appears that the development of the oldest glaciation was largely influenced by morphology of the solid basement, despite the thick cover of overlying Tertiary sediments (Figs. 4, 6–8). The extent of this glaciation in Western Poland approaches that of the Szczecin Trough in the basement. Its central, most rapidly subsiding part comprises several tens of metres thick tills of the oldest glaciation (Kozłowska, 1974, 1979; Kopczyńska-Lamparska, 1979). The marginal part of the Szczecin Trough, close to the Szamotuły–Oborniki anticline in SW part of the study area, reveals the oldest glacial tills of much more smaller thicknesses and forming two beds. We are confronted here, perhaps, with the maximum extent of the oldest (Narevian) Glaciation. The Pomeranian–Kuyavian Swell probably blocked further, north-eastward advance of this glaciation.

One should take notice of the importance of such a lobate transgression of the first glaciation in shaping the base of Quaternary sediments. In the Boruszyn depression, glaciotectonic activity of a glacial lobe during the Narevian advance was probably intensified by tectonic activity of this region, the traces of which can also be found in the Early Pleistocene (*cf.* Baraniecka *et al.*, 1986).

Podlasian Interglacial

This interglacial is represented by grey-yellowish, fine-grained sands with admixtures of coarse-grained sands and singular gravels that overlie the lower or upper tills of the oldest glaciation (Figs. 10, 11). Their thickness, determined by boreholes near Boruszyn, attains 40 m. Uneven base of these sediments and the lack in one borehole of the upper Narevian till testify to intensive erosion preceding deposition of this series. Petrographic composition of these deposits includes, apart from quartz and feldspars, granitoids and sandstones, probably derived from eroded pre-existing glacial sediments. Listkowska *et al.* (1978) consider this series as fluvioglacial sediments of the South-Polish Glaciation.

Nidanian Glaciation

Glacial deposits, documented by 4 boreholes near Boruszyn (Figs. 10, 11) and in the Noteć River valley close to Zacharzyn (Fig. 12), overlie sands and gravels. Near Boruszyn, glacial sediments of that age are represented by grey-blue or grey till, comprising clasts of crystalline rocks, sand-

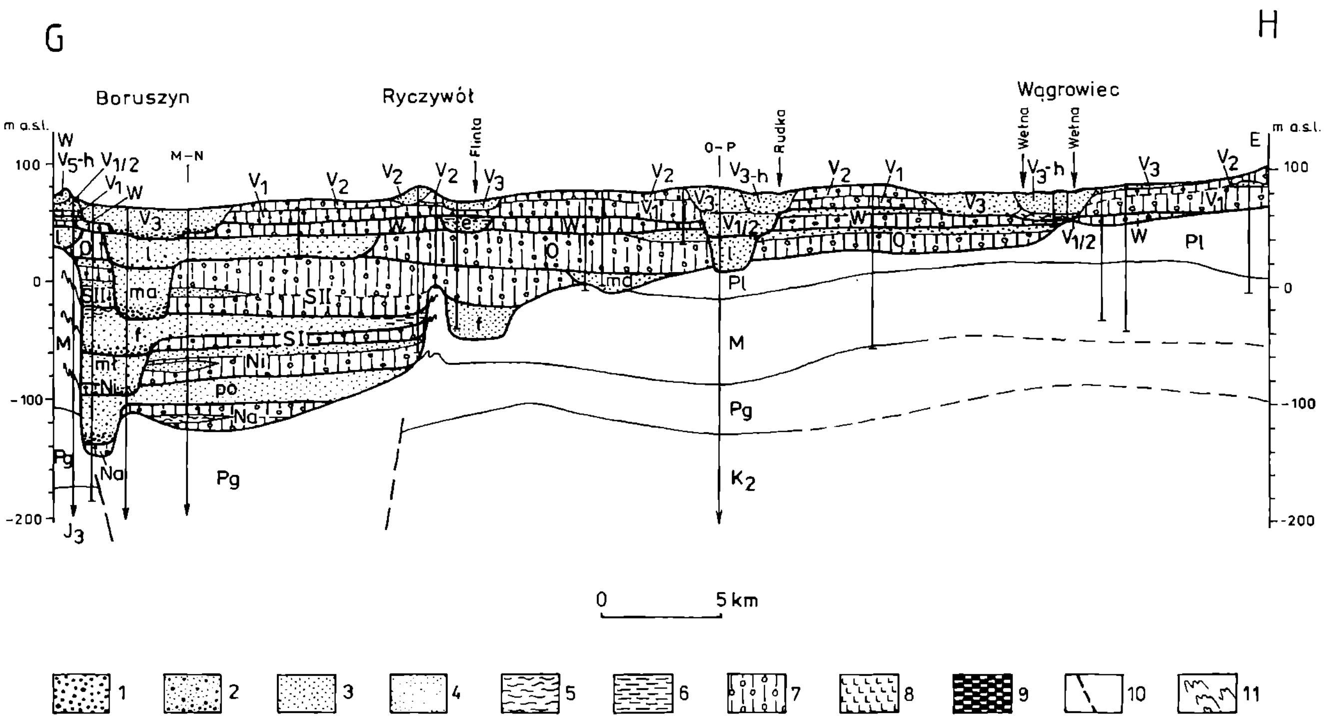


Fig. 10. Geological cross-section G–H (*cf.* Fig. 2). *1* – gravels and pebbles, *2* – vari-grained sands with gravels, *3* – medium-grained sands, *4* – fine-grained sands, *5* – silts, *6* – clays, *7* – tills, *8* – lacustrine marls, *9* – peat, *10* – faults inferred, *11* – glaciotectonic deformations; J_1 – Lower Jurassic, J_2 – Middle Jurassic, J_3 – Upper Jurassic, K_1 – Lower Cretaceous, K_2 – Upper Cretaceous, Pg – Paleogene, M – Miocene, Pl – Pliocene; Quaternary: Na – Narevian Glaciation, po – Podlasian Interglacial, Ni – Nidanian Glaciation, ml – Malopolanian Interglacial, S I – Sanian I Glaciation, f – Ferdynandovian Interglacial, S II – Sanian II Glaciation, ma – Mazovian Interglacial, O – Odranian Glaciation, l – Lubavian Interglacial, W – Wartanian Glaciation, e – Eemian Interglacial, V – Vistulian Glaciation: V_1 – V_5 – stadials (phases), $V_{1/2}$ – $V_{3/4}$ – interstadials (interphases), H – Holocene

stones and brown coal. The base of the till lies at 92 to 70 m b.s.l., its maximum thickness attaining 12 m. In the Zacharzyn area (Fig. 12), the Nidanian glacial deposits include gravels and cobbles cemented by clays and intercalated by fine-grained sands, of total thickness of *ca.* 8 m. The top of the underlying Paleogene mudstones occurs at 85 m b.s.l.

The recession of this glaciation left several metres thick layer of fluvioglacial sands and gravels that overlie the glacial till near Boruszyn (Figs. 10, 11).

Malopolanian Interglacial

This interglacial series is represented by sand-gravelly sediments, 40 m thick, overlying the Nidanian or Podlasian strata, and documented near Boruszyn and Zacharzyn (Figs. 10–12). The base of this series is situated at 90 to 60 m b.s.l. Large thickness of this series, well-preserved grading and the mode of occurrence, all indicate its fluvial origin. Erosional dissection of the sub-Quaternary basement close to Piła (Fig. 11), filled with sands and gravels, could also represent the Malopolanian Interglacial stage. Alternatively, one can relate its origin to subglacial tunnel valley accumulation during the Sanian I stage.

Reactivation of tectonic zones, induced by relaxation of individual basement blocks due to the recession of the Nidanian ice-sheet, favoured the development of river valleys in the Malopolanian Interglacial. The outflow was, at least partially, directed toward the south-west.

The identification and dating of South-Polish Glacial sediments in this region raises some difficulties due to the variable number of glacial beds distinguished and the lack of unequivocal key horizons. In Western Poland, one (Krygowski, 1961b, 1975; Maksiak & Mróz, 1978; Gogołek, 1991b; Jeziorski, 1991a–c), two (Kopczyńska-Żandarska, 1970; Listkowska *et al.*, 1978; Kozłowska, 1979; Uniejewska *et al*,. 1979; Dąbrowski, 1985) or even three (Krygowski, 1952; Kopczyńska-Lamparska, 1979; Gogołek, 1991a) South-Polish till beds have been distinguished. In Eastern Germany, the so-called Cromerian–Elsterian complex has been identified, including both cold (stadials, glacials) and warm (interstadials, interglacial) stages of different rank (Čepek, 1967, 1986; Lindner, 1988).

As far as the Middle Noteć River valley region is concerned, it appears that the Sanian II till is equivalent to the uppermost till from among South-Polish till beds hitherto-described, as well as to the lower part of the Middle-Polish till complex. The Sanian I till bed of previous stratigraphic schemes could be associated with the middle or upper South-Polish till, the Nidanian till being equivalent to the lowest or lower till from among this complex. The Sanian II till in the Middle Noteć River valley region could also be correlated with the upper part of the Elsterian (Elsterian II) complex, whereas the Sanian I till could be an equivalent of the Elsterian I, and the Nidanian till could be related to the Stadial B of the Cromerian complex, distinguished in Germany (Čepek, 1967, 1986; Wiegank, 1982; Lindner, 1988, 1991b).

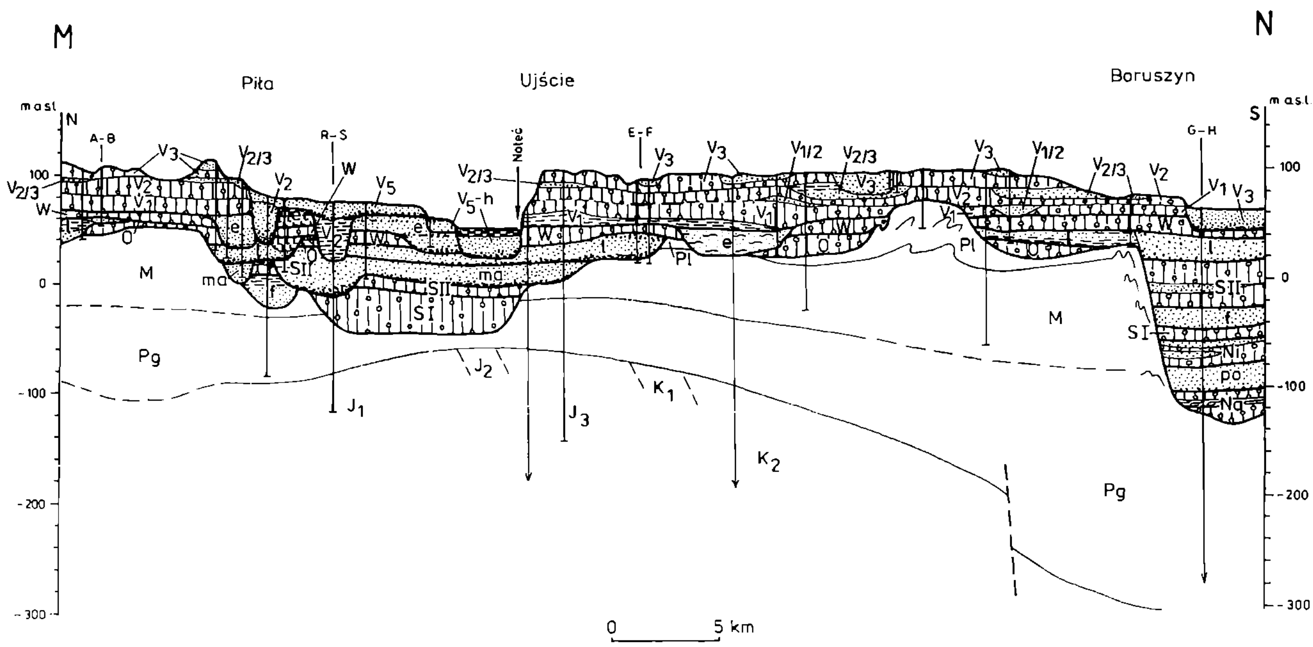


Fig. 11. Geological cross-section M–N (*cf.* Fig. 2). For explanations – see Fig. 10

Sanian I Glaciation

This glacial stage is represented by a glacial till bed (the third one in the Boruszyn area), whose base is situated at 60 to 20 m b.s.l. (*cf.* Čepek, 1967; Listkowska *et al.*, 1978; Uniejewska *et al.*, 1979). It is dark-grey, sometimes greenish (brown near Trzcianka), sandy till bearing gravels and cobbles, intercalated in places by blue clays. Its thickness ranges from a few to 25 m, averaging at a dozen or so metres (Figs. 10, 11, 13, 14).

Close to Chodzież, the remnants of this till are represented by a thin layer of lag, filling a depression in the sub-Quaternary basement (Fig. 13), whereas near Piła the Sanian I till fills the flat-bottom Gwda depression (Fig. 14). The recession of the Sanian I Glaciation left a few metres thick sands preserved near Piła (Fig. 14).

Strong glacial erosion during this stage modified the pre-existing glaciotectonic and erosional depressions near Chodzież (Fig. 13) and Piła (Fig. 14). Glaciotectonic depressions filled by tills deposited during the Sanian I glaciation occur S and NE of Piła (Fig. 11) and close to Runowo (Fig. 14).

Ferdynandovian Interglacial

This stage is represented by clastic sediments overlying the Sanian I till or Tertiary bedrock which, in turn, are covered by another till bed. Near Boruszyn, these sediments are composed of dark-grey, vari-grained sands with gravels in the bottom part and of grey-yellow, very fine-grained sands and silts in the upper part (Fig. 10). One can suppose, therefore, that they represent fluvial sediments. The total thickness of this series attains 40 m; its base being situated at 60–50 m b.s.l. near Skórka (Fig. 15), the Ferdynandovian Interglacial sediments are composed of coarse-grained sands and fine gravels, 23 m thick, whose bottom occurs at 30 m b.s.l. Near Chodzież (Fig. 13), in turn, this stage is represented by 30 m thick sands and gravels, drilled by two boreholes down to 60 m b.s.l. These sediments overlie washed-out sediments of the Sanian I Glaciation. According to Listkowska *et al.* (1978), these deposits are a fragment of the much more thicker (105 m) infill of a subglacial channel, formed during the Middle-Polish Glaciation. Similarly developed interglacial sediments have been found at Zacharzyn (Fig. 12).

East of Ryczywół (Fig. 10), 25 m thick fine-grained, probably lacustrine sands occur in the position of the Ferdynandovian Interglacial sediments. Analogous origin and age can be ascribed to fine-grained sands overlain by clays, that fill a sub-Quaternary depression near Piła (Fig. 11; *cf.* Dąbrowski *et al.*, 1987).

Sedimentary record of the Ferdynandovian Interglacial is not sufficient enough to reconstruct drainage pattern during this stage. One can only infer that river valleys in that time utilised pre-existing depressions and removed, to a large extent, previously deposited Sanian I sediments (Boruszyn depression; Figs. 10, 11), dissecting as well the sub-Quaternary bedrock (Skórka depression; Figs. 9, 15). A river in the Skórka depression flowed westwards, whereas valleys in the southern part of the study area followed the Boruszyn depression, characterised by the south-westerly outflow.

Sanian II Glaciation

The Sanian II (Wilga according to Mojski, 1982 and Baraniecka, 1990) Glaciation is represented by a till documented by a dozen or so boreholes; the fourth till bed in the Boruszyn area. It is a compact, grey or dark-grey till bearing cobbles and clasts of xylites or lignites. Few boreholes drilled only its traces, *i.e.* lag or isolated Scandinavian-derived clasts. The till is subdivided in places by a thin sand

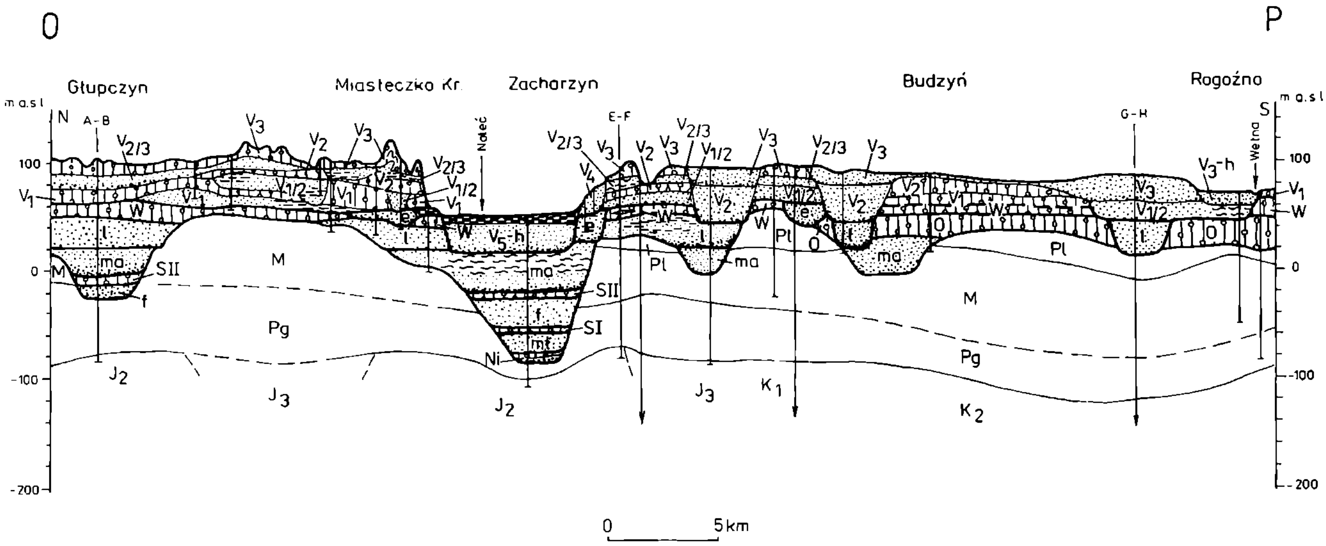


Fig. 12. Geological cross-section O–P (*cf.* Fig. 2). For explanations – see Fig. 10

layer. The Sanian II till is usually a dozen or so metres thick, attaining 40 m in thickness near Boruszyn and Ryczywół (Fig. 10). In those places where postdepositional erosion was more vigorous, the till thickness is reduced to even few tens of centimetres (near Skórka, Fig. 15 or Zacharzyn, Fig. 12). The base of the till varies from 25 m b.s.l. near Ryczywół (Fig. 10) and Boruszyn (Fig. 11) to 14 m a.s.l. close to Piła (Figs. 11, 14). High relief of the till base could be associated with differentiated rate and mode of basement reaction to unloading, induced by the Sanian II ice-sheet (Lamparski, 1983, 1991; Baraniecka, 1975, 1980). The till thickness increases with depth. Assuming that the till thickness is, *i.a.*, a function of the ice thickness, we can infer huge ice cover within pre-existing valleys and reduced ice thicknesses upon plateaus. On a local scale, this feature is shown in Fig. 10 where, near Ryczywół, the till drilled by the middle one of three boreholes located upon a basement high is thinner as compared to that found by nearby boreholes, located within depressions.

Apart from the bi-partite till, the Sanian II stage comprises as well ice-dammed sediments near Piła (Figs. 5, 11, 14) and a thin layer of fluvioglacial deposits near Boruszyn (Fig. 10) and Runowo (Fig. 14), both recording the recession of the ice-sheet in question.

Mazovian Interglacial

The Mazovian Interglacial sediments have been drilled by more than 30 boreholes. These are mostly medium- to fine-grained sands, as well as coarse-grained sands with gravels, occurring near Piła and Ujście (Fig. 11) and close to Skórka and Głupczyn (Fig. 15). Most of sedimentary logs reveal grading which, apart from the mode of occurrence, enables one to consider these sediments as fluvial ones. A surprising fact is the lack of policyclicity of valley development (*cf.* Różycki, 1967). Silty-clayey sediments that overlie the sandy series near Zacharzyn (Fig. 12) and Chodzież (Fig. 13) represent lacustrine deposits.

The thickness of Mazovian Interglacial sediments ranges from a few to 40 m, averaging at 25–30 m. Their base lies at 26 m b.s.l. to 22 m a.s.l., usually below the present sea level.

These data are not comparable to those obtained in the Central Wielkopolska Lowland, where sediments of that age

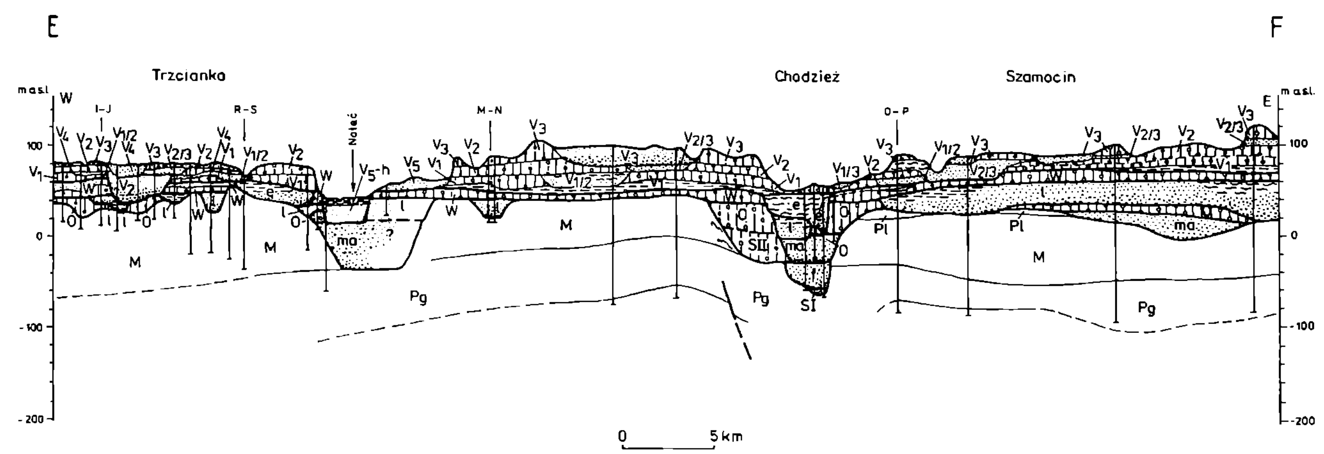


Fig. 13. Geological cross-section E–F (*cf.* Fig. 2). For explanations – see Fig. 10

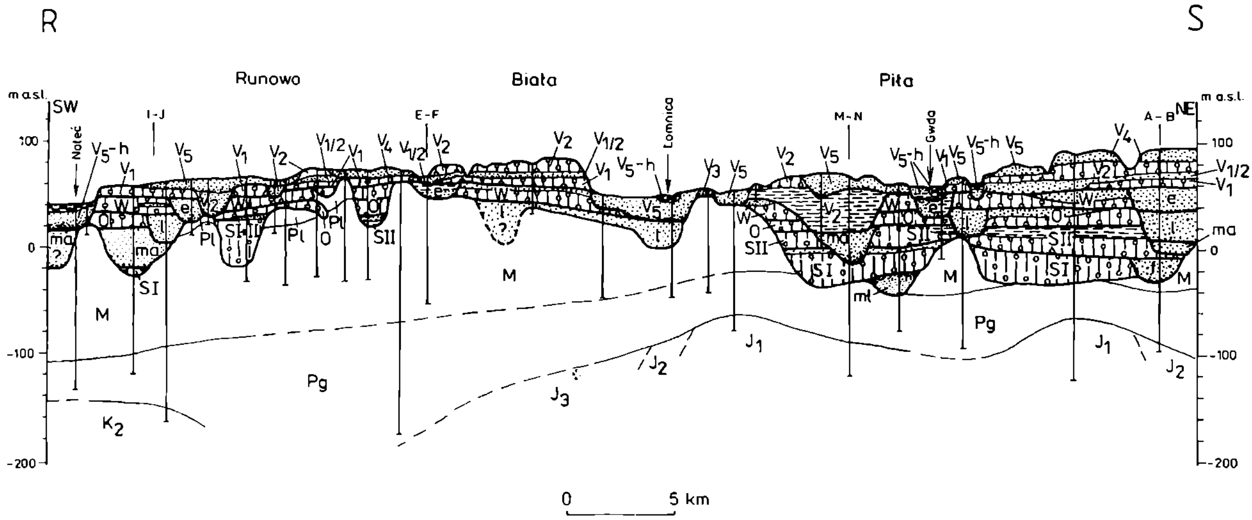


Fig. 14. Geological cross-section R–S (*cf.* Fig. 2). For explanations – see Fig. 10

infill a vast river valley, whose bottom in the eastern part (Powidz) occurs at 35 m a.s.l., and in the western part (Zbąszyń) is placed at the sea level (Dąbrowski & Szynalski, 1975; Dąbrowski, 1985; Lindner *et al.*, 1982). In the Middle Noteć River valley region such elevations are associated with buried valleys of the younger interglacial stage. According to Skompski (1982), the 20 m a.s.l. contour in Western Poland is the maximum possible elevation of the top of Mazovian Interglacial sediments. However, lacustrine sediments with *Paludina*-fauna occur at 0 m a.s.l. on either side of the Polish–German frontier (Skompski, 1980, 1982).

The Mazovian Interglacial drainage pattern (Fig. 16) followed the pre-existing depressions filled with older Quaternary sediments. Rivers of that age rarely dissected Tertiary strata. Reconstructed gradients of the Mazovian Interglacial valleys indicate that the outflow was directed towards the west and south-west. Valleys situated in the northern part of the study area originated on a former lake district swell, described by Maksiak & Mróz (1978) from the middle part of the Pomeranian Lake District. The pra-Gwda river valley is particularly well documented. Its bottom near Jastrowie, 20 km north of the study area, occurs at 20 m a.s.l. (Maksiak & Mróz, 1978), plunging to *ca.* 10 m b.s.l. near Piła. A meridional segment of the present-day Noteć River valley follows that fragment of this palaeovalley. Near Czarnków, the palaeovalley turns to the west, sloping to 24 m b.s.l. at Gulcz (Figs. 13, 14, 17).

In the Middle Noteć River valley region no traces of the Liwiec Glaciation have been found (*cf.* Lindner, 1984, 1987a, 1991a, 1992; Baraniecka, 1990). It is possible that one of fluvioglacial series separating the Sanian II and Odranian tills could be ascribed to this cooling. However, such a record of a glacial episode is not sufficient. Moreover, one should not forget that both the Odranian Glaciation and subsequent interglacials were characterised by strong erosion. On the other hand, the Fuhne cooling in Germany (Čepek, 1967; Erd, 1973; Wiegank, 1982), equivalent to the Liwiecian Glaciation stage, is well documented (*cf. also* Lindner, 1988, 1991b, c; Marks, 1991a).

The area studied bears no traces of the Zbójnian Inter-

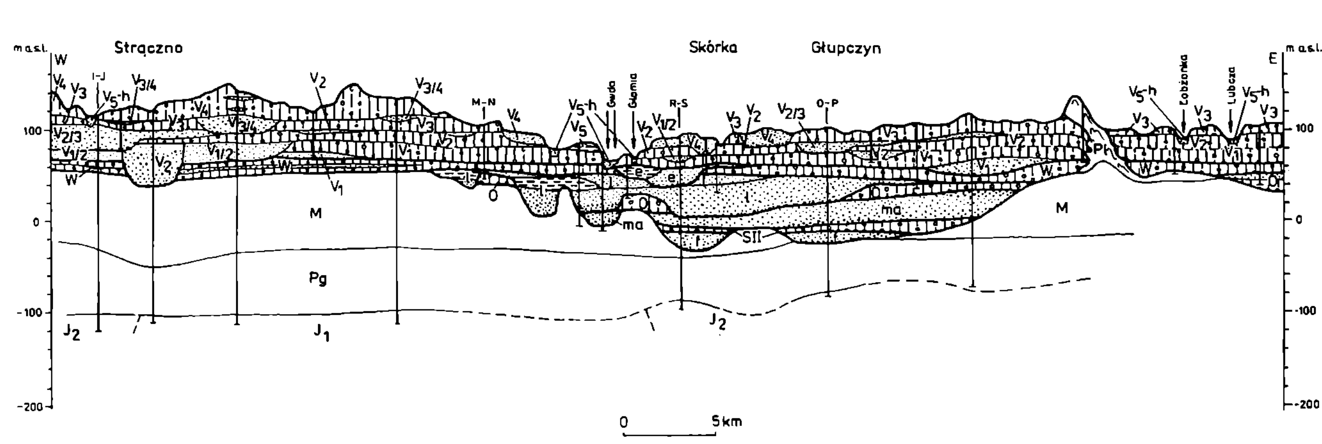


Fig. 15. Geological cross-section A–B (*cf.* Fig. 2). For explanations – see Fig. 10

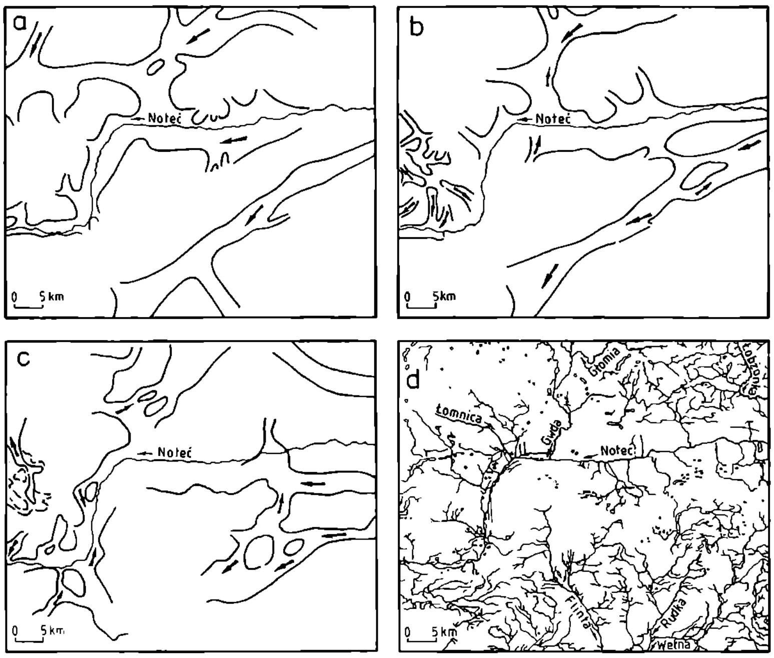


Fig. 16. Drainage pattern during: a – Mazovian Interglacial, **b** – Lubavian Interglacial, **c** – Eemian Interglacial, **d** – recent times

glacial, either (*cf.* Lindner & Brykczyńska, 1980; Lindner, 1984, 1987a, b, 1991a). Lacustrine fines separating the Sanian II and Odranian tills have been assigned to the Mazovian Interglacial stage.

Therefore, the Mazovian Interglacial silt-sandy-gravelly sediments, devoid of fauna and flora, occurring in the Middle Noteć River valley region between the Sanian II and Odranian till beds, should be treated as representing the Great Interglacial *sensu* Różycki (1967) and Baraniecka (1990), and correlated with the Holsteinian Interglacial *sensu lato* (Čepek, 1967; Čepek & Nowel, 1991).

Odranian Glaciation

The Odranian Glaciation in the study area is represented by a till bed, the fifth till of the Boruszyn region (Fig. 10). It is a grey or dark-grey sandy till, comprising in places numerous cobbles. Its thickness ranges from a few to 30 m near Ryczywół (Fig. 10) and Chodzież (Fig. 13). The Odranian till overlies not only pre-existing depressions, but also elevated Tertiary rocks. The base of the till occurs at 10 to 20 m a.s.l. within the depressions and 50 m a.s.l. upon elevations. South of the study area, the till has been found at *ca.* 20 m a.s.l. (Gogołek, 1991a, b, 1992). The Odranian till does also occur within small depressions or at the base of culminations of the sub-Quaternary surface, *i.a.* north of Boruszyn (Fig. 11) and near Straduń (Fig. 17). All these data point to morphogenetic importance of the Odranian Glaciation.

The Odranian till usually refers to the lower or middle part of the Middle-Polish Glacial sediments, distinguished in this area (Listkowska *et al.*, 1978; Uniejewska *et al.*, 1979). In eastern Germany two ubiquitous till beds of large thicknesses can be correlated with the Odranian till. These are the Saalian *sensu stricto* (Saalian I) and Flaeming (Saalian II = Drenthe) tills (Čepek, 1967; Wiegank, 1982; Lindner, 1988, 1991b; Čepek & Nowel, 1991; Urban, 1991; Urban *et al.*, 1991). Bi-partition of the Odranian tills is also a common feature in Poland. This stage is considered to be a stadial of the Middle-Polish Glaciation (Dąbrowski, 1985; Jeziorski, 1991a–c). However, such a two-fold division has not been documented in the area studied, which conforms to the results obtained by Maksiak & Mróz (1978) from the central part of the Pomeranian Lake District and by Gogołek (1991a, b) from the Buk area. The recession of the Odranian glaciation left thin fluvioglacial sediments near Wągrowiec (Fig. 10) and Piła (Fig. 14).

The Odranian ice-sheet was responsible for the final removal of older Quaternary sediments and, partly, Pliocene rocks from plateaus occurring in the northern part of the study area (Figs. 8, 9), as well as for smoothing out the sub-Quaternary surface. Most of the basement elevations have been shaped in that time.

Lubavian Interglacial

The Lubavian (Pilica according to Baraniecka, 1990) Interglacial stage in the study area is represented by two types of sediments. Apart from commonly occurring clastics, boreholes near Piła and Ostrówek (5 km south of Chodzież) drilled organogenic lacustrine sediments. At Piła (Fig. 11), organic muds and lacustrine marl of total thickness of 7.5 m (base at 33 m a.s.l.) are overlain by a till which, in turn, is covered by another organic series dated to the Eemian Interglacial (Dąbrowski *et al.*, 1987). Pollen spectra of the lower organic series at Piła are similar to those of the Lubavian Interglacial at Losy (Krupiński & Marks, 1986), being clearly different from those of older interglacial sediments (Dąbrowski *et al.*, 1987). According to Janczyk-Kopikowa (1991), pollen spectra from Losy and, hence, also from Piła, cannot document an interglacial. A similar opinion has recently been expressed by Krupiński (*personal communication*). Geological position of the sediments from Piła, however, requires their assignment to the Lubavian Interglacial stage.

In the majority of borehole logs, the Lubavian Interglacial is here represented by gravels, sands and silts of thicknesses ranging from 5 to 50 m, averaging at 20–40 m. The base of this series is placed between a few metres below sea level to 35 m a.s.l. Grain-size composition of these sediments makes it possible to subdivide them into three genetic series that reflect two erosion-accumulational cycles: the lower (oldest) – sandy-gravelly, fluvial series; middle – clayey-silty, lacustrine series, and upper – gravelly-sandy, fluvial series. These three series, however, seldom occur in superposition in one section (like near Straduń; Fig. 17). Sometimes, thick fine-grained, lacustrine series immediately overlies the Odranian tills. Deposition of the upper se-

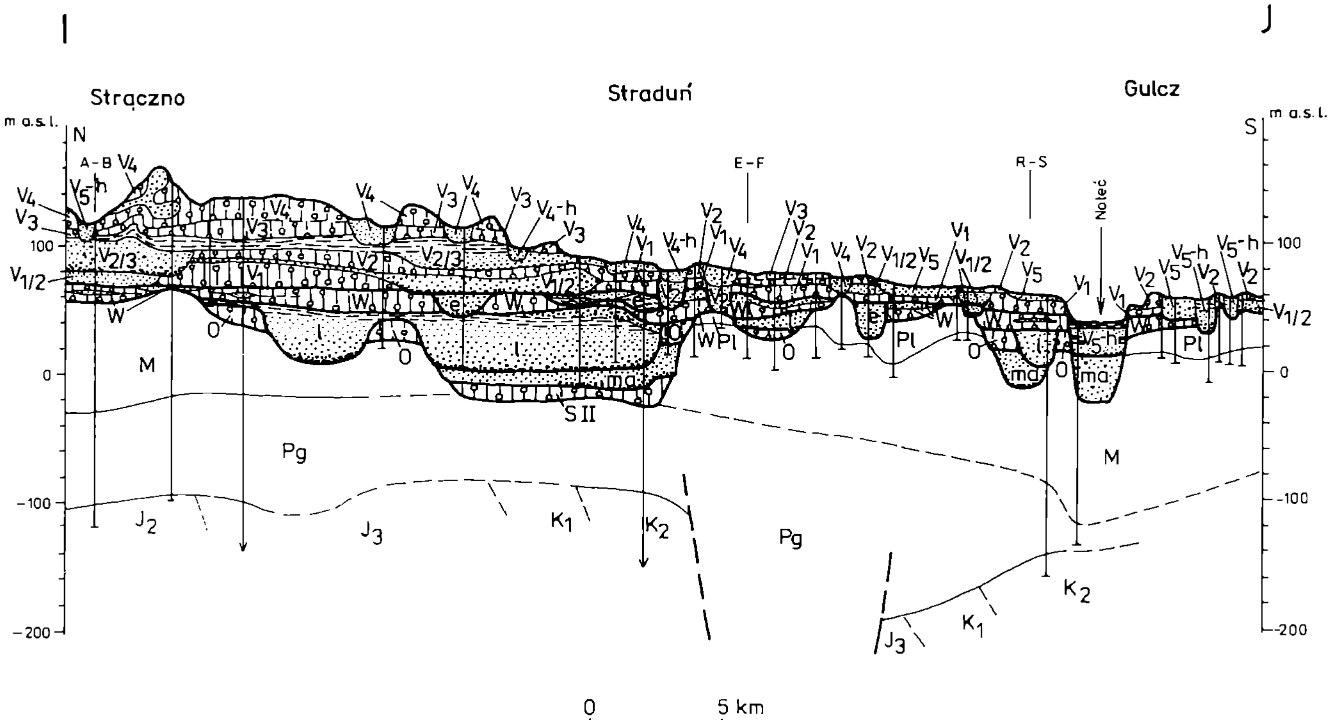


Fig. 17. Geological cross-section I–J (*cf.* Fig. 2). For explanations – see Fig. 10

ries was preceded by intensive erosion (e.g. near Boruszyn; Fig. 11). Such a cyclicity documents a relatively long interruption in glaciation of the Middle Noteć River valley region, irrespectively of the stratigraphic rank of this episode.

Well-developed valleys of the Lubavian Interglacial, filled with braided river alluvia, have also been found in the Inowrocław Plain (Jeziorski, 1991a–c).

The sediments described have hitherto been interpreted as the upper fluvioglacial horizon, separating tills of the Middle-Polish Glaciation (Listkowska *et al.*, 1978; Uniejewska *et al.*, 1979).

The Lubavian Interglacial drainage network (Fig. 16), despite considerable morphological changes induced by the Odranian ice-sheet, clearly follows the Mazovian Interglacial drainage pattern. New outflow directions have been formed as well, using glaciotectonic depressions left by ice lobes of the Odranian Glaciation, like that upon the Trzcianka elevation (Figs. 9, 13). Some of these buried valleys coincide with the course of the present-day Gwda and Noteć River valleys (Fig. 16). The Trzcianka elevation shows a radial, outward-directed pattern of drainage which could have resulted from a local uplift of this region at that time.

Wartanian Glaciation

The Wartanian Glacial stage is represented by a till, the sixth till bed near Boruszyn (Fig. 10). It is grey or dark-grey, sandy till with clasts, as well as till residua, represented by loamy clasts. In places (near Chodzież; Fig. 13 and close to Gulcz and Strączno; Figs. 15, 17), the Wartanian till builds two beds, similarly as in neighbouring areas (Maksiak & Mróz, 1978; Dąbrowski, 1985; Gogołek, 1991a, b; Jeziorski, 1991a–c), and can be correlated with the previously distinguished three stadials of the Middle-Polish Glaciation in Poland (Różycki, 1967; Baraniecka, 1984). The till thickness attains 30 m near Piła (Figs. 11, 14), usually ranging between 5 and 15 m. Its base occurs between 35 m a.s.l. near Biała and Piła (Fig. 14) and 60 m a.s.l. close to Strączno (Figs. 15, 17). In the eastern part of the study area, Włodek (1980) distinguished a Wartanian till situated at 60 m a.s.l., as has been confirmed by the recent study. Up to now, such a till has been assigned to the younger stadial of the Middle-Polish Glaciation (Gadomska, 1957; Listkowska *et al.*, 1978).

The Wartanian till does not occur at the groundsurface; it only crops out locally in the lowermost parts of the Noteć River valley side (Listkowska & Maksiak, 1977; Uniejewska & Włodek, 1977; Kozarski, 1991). In places, this till overlies Tertiary bedrock, like near Strączno (Figs. 15, 17), Miasteczko Krajeńskie (Fig. 12) or west of Chodzież (Fig. 13). More frequently, however, the till overlies either the Odranian till or Lubavian Interglacial sediments.

Fluvioglacial sediments overlying the Wartanian till near Piła, Biała (Fig. 14) and Trzcianka (Fig. 13) represent the recession of this glaciation.

Taking into account relatively poor inventory of the landforms and sediments preserved, one can conclude that the Wartanian Glaciation played minor role in shaping the structure and morphology of the study area. Small relief of the base of the tills and their uniform thickness, irrespectively of the basement morphology, could indicate still diminishing importance of tectonic movements upon ice-sheet development. Most probably, the loading of the Wartanian ice-sheet was too small to activate another phase of tectonic (isostatic) movements. Deposition of glacial tills under such conditions led to the final obliteration of pre-existing topography.

Eemian Interglacial

The Eeemian Interglacial succession is well documented by organogenic sediments, including lacustrine marls, gyttjas and peat-bearing muds (upper lacustrine series), drilled by a borehole at Piła (Fig. 11; *cf.* Dąbrowski *et al.*, 1987). The base of the organogenic series, overlying the Wartanian till, is situated at 45 m a.s.l. and its thickness attains *ca.* 20 m. Similar geological setting display Eemian organogenic sediments at Nakło, several tens of kilometres east of Piła (Karaszewski, 1973; Noryśkiewicz, 1979), although occurring at a slightly different elevation. On the other hand, the peat layer drilled by a borehole near Miasteczko Krajeńskie lies at the same elevation as the Nakło peat and is covered by a thin till bed. Interglacial peat at Śmielin near Nakło (Rühle, 1954; Środoń, 1954) does also occur within sediments which are hypsometrically equivalent to those at Piła, its thickness being considerably smaller. Despite the fact that the peat at Śmielin is overlain by a thick sedimentary cover including till, Włodek (1980) concludes that its position is uncertain and tries to associate the peat with an interstadial of the Vistulian Glaciation. A slightly higher elevation of the top of organogenic sediments (*ca.* 70 m a.s.l.) and their larger thickness at Piła, as compared to that at Nakło (*ca.* 60 m a.s.l.) and Miasteczko Krajeńskie (58 m a.s.l.), could be interpreted as resulting from stronger erosion in the Noteć River valley in respect to the Gwda valley during the Vistulian. Organogenic sediments ascribed to the Eemian Interglacial stage have been a subject to numerous detailed studies (Skompski, 1980; Tobolski, 1991).

An analysis of borehole logs, however, suggests that the Eemian Interglacial in the study area is represented, first of all, by mineral, mostly fluvial sediments. Near Trzcianka (Fig. 13) and Straduń (Fig. 17), traces of two erosion-accumulational cycles within fluvial sediments have been found. The cyclicity of valley development during the Eemian is not as dinctict as that during the Lubavian Interglacial stage.

Apart from lacustrine organogenic sediments, there also occur lacustrine mineral deposits represented by silts and silty sands (near Chodzież; Fig. 13), whereas ice-dammed silts and clays separating the Wartanian and Vistulian tills, although attaining similar hypsometric position, have been associated with the Vistulian (Włodek, 1980). The base of such a lithologically and genetically variable interglacial sequence lies at 6 to *ca.* 60 m a.s.l.

The Eemian drainage network (Fig. 16) does not bear evidence in favour of a link between the Chodzież depression and a valley near Gulcz, as it was the case during the Mazovian Interglacial. According to Listkowska *et al.* (1978), the principal Eemian outflow from that area was directed westwards. Rivers draining the North-Konin Plateau flowed to a bay of the Eemian sea that extended as far as Inowrocław (Rutkowski, 1967). Such a far south-reaching extent of the Eemian sea is questioned by Makowska (1980, 1986). Irrespectively of the distance to the Eemian sea, however, it appears that interglacial rivers in the study area preferred westward-directed trends of outflow. The eastern direction needs to be excluded due to either higher elevation or the lack of occurrence of Eemian sediments to the east of the area studied (Gadomska, 1957; Karaszewski, 1973; Włodek, 1980). Such a drainage pattern was probably controlled by the location of the divide along the axis of the Pomeranian–Kuyavian Swell, showing prolonged uplift tendencies (Baraniecka, 1980; Niewiarowski, 1983).

Vistulian Glaciation

The surface of the study area is nearly entirely covered by Vistulian sediments, whose stratigraphic subdivision has been established basing on borehole data. The results obtained should be treated not only as as a starting point for future detailed studies, but also as a base for critical analysis of the hitherto published views on the history of the last glaciation.

In the Middle Noteć River valley region 4 tills of Vistulian age have been distinguished and named, from the oldest upwards, V_1 through V_4. These tills are separated by thick silt-sandy-gravelly sediments. A characteristic feature of the till distribution is the reduction of their number from the north to the south. In the southern part of the study area only V_1 and V_2 till beds do occur, whereas the V_3 bed usually occurs upon plateaus situated north of the Noteć River valley, as well as in the Chodzież and Czarnków Hills. The extent of the youngest, V_4 bed is restricted to the Wałcz Plateau. Macroscopic properties of individual tills are very much alike. The V_1, V_2 and V_3 tills are grey and dark-grey, rarely grey-brown, whereas the V_4 till is usually yellow-brown. The near-surface parts of the tills, irrespectively of their age, are brown or yellow due to weathering (Krygowski, 1961b).

The V_1 till overlies either the Wartanian and Eemian strata or sands and varved clays deposited during the first trangression of the Vistulian, like near Ujście (Fig. 11), Miasteczko Krajeńskie (Fig. 12), Chodzież and Szamocin (Fig. 13). The base of this till occurs at 60 m a.s.l. near Chodzież (Fig. 13) to 80 m a.s.l. in the Wałcz Plateau (Fig. 15). Its thickness ranges from 5 to 25 m. The till crops out within cliffs of deep erosional dissections, being absent from the groundsurface.

The V_1 till is overlain by a layer ($V_{1/2}$) of sands and gravels, sometimes silts (Strączno; Figs. 15, 17) of fluvioglacial origin, whose thickness attains 40 m. Its base is situated at 38 to 60 m a.s.l.

The V_2 till ranges in thickness from 3–10 m in the Wałcz Plateau to a dozen or so metres in the Krajna Plateau. Its base can be traced from *ca.* 60 m a.s.l. in the western part of the area to 90 m a.s.l. in the northern part. On the south, the V_2 till occurs at the groundsurface (Fig. 10). Deep erosional furrows filled with sandy-gravelly or ice-dammed sediments, found at Budzyń (Fig. 12), Trzcianka (Fig. 13), Runowo and Piła (Fig. 14) and near Strączno (Fig. 15), are probably associated with subglacial channels of age coeval with the V_2 till.

This till is overlain by a series of gravels, sands and silts ($V_{2/3}$), up to 20 m thick. Bottoms of erosional dissections are filled with coarse-grained sediments, whereas fines occur either in upper parts of the log or directly overlie the V_2 till. These sediments are documented best in the Wałcz Lake District area, between Strączno and Straduń (Figs. 15, 17).

The base of the series is situated at 75–95 m a.s.l.

The V_3 till crops out at the groundsurface in the central and northern part of the study area and is incorporated into end moraines near Chodzież, Szamocin (Fig. 13) and Miasteczko Krajeńskie (Fig. 12). Its thickness ranges between 10 and 15 m and the base lies at 80–100 m a.s.l. (Figs. 11–13).

The V_3 till is covered by a series of fine-grained and silty sands, as well as vari-grained sands ($V_{3/4}$), 2 to 10 m thick. In the Wałcz Lake District this series is overlain, in turn, by another till bed (Fig. 15), whereas in the remaining part of the area it crops out at the groundsurface, forming extensive Flinta and Dymnica outwash plains, or filling up the Wełna valley (Figs. 10, 11, 14).

The V_4 till occurs only in the NW part of the area (Róża Hills; Figs. 15, 17). Its thickness attains 15 m, the base being situated at 110–115 m a.s.l. The till bears, in part, thin interlayers of sands. This till is probably associated with a fluvioglacial series, a dozen or so metres thick, which builds a discontinuous cover upon the V_4 till or older Vistulian sediments, filling as well deep erosional channels or forming higher terraces within principal river valleys (Figs. 12, 13, 17).

Proper correlation of the tills discussed is a very important problem for the stratigraphy of younger Pleistocene in the study area. This region is situated between end moraines of the maximum extent of the Vistulian Glaciation and the Pomeranian Phase (*cf.* Kozarski, 1962a; Galon & Roszko, 1967; Roszko, 1968; Galon, 1969). According to traditional views, one can expect here one or two tills, left by the Leszno, Poznań or Leszno–Poznań Phases of the last glaciation (Krygowski, 1952, 1961b, 1975; Gadomska, 1957; Kozarski, 1980, 1981; Włodek, 1980; Listkowska *et al.*, 1978; Uniejewska *et al*, 1979). Recent papers by Kozarski (1991, 1993) and Kozarski & Kasprzak (1992) upheld earlier opinions (Kozarski, 1962a, 1981) that the Poznań Phase did not leave any separate till bed (*cf.* Gogołek, 1992), whereas the Chodzież sub-phase is marked by a distinct bed of lodgement till (Kozarski, 1991, 1993, 1995). It appears, therefore, that we are confronted here with two tills of the last glaciation, although of different stratigraphic rank. It should be added that the Chodzież sub-phase was previously considered, basing on geomorphic criteria, as a recessional phase of high dynamics, similarly as the remaining phases and oscillations of the Vistulian (Kozarski, 1962a; Galon & Roszko, 1967). Recently, the Chodzież surge has been distinguished (Kozarski, 1995).

Boreholes drilled in the neighbouring areas, situated within the extent of the Pomeranian Phase, found more than 3 Vistulian till beds (Maksiak & Mróz, 1978; Kopczyńska-Lamparska, 1979; Kozłowska, 1979). Litho- and chronostratigraphic schemes established for Northern Poland include even 5 separate tills that postdate the Eemian Interglacial (Mojski, 1968, 1982; Makowska, 1980, 1986, 1991; Marks, 1988, 1991b; Baraniecka, 1990; Krzyszkowski, 1990). Few authors question the presence of an ice-sheet older than the Leszno–Poznań Phase in Northern Poland.

The Early and Middle Vistulian climatic record of the Wielkopolska Lowland is documented by a few localities (*i.a.*, Konin, Stare Kurowo) of mineral and organic sediments, as well as fossil periglacial structures (Kozarski *et al.*, 1980; Kozarski, 1991). However, no traces of an ice-sheet older than 20,000 yrs BP have been found so far (Krzyszkowski, 1990).

An analysis of borehole logs suggests the presence of an Early Vistulian ice-sheet. This opinion is based on identification of 4 well-developed and separated by sands and gravels till beds that overlie the Eemian Interglacial sediments (Fig. 17). It is also supported by the results of thermoluminescence datings of glacial and fluvioglacial sediments, sampled in cliffs of the Noteć River valley. All the age indicators are younger than 100 ka and range from 68 ±10 ka (Lub-2367) and 53 ±8 ka (Lub-2366) at Ujście, through 66 ±10 ka (Lub-2368) at Chodzież to 41 ±6 ka (Lub-2365) at Miasteczko Krajeńskie. More detailed data are supplied by the studies of sediments exposed at Wolsko on the Noteć River (Figs. 18, 19; *cf.* Dzierżek & Olszewska, 1993, 1996). Petrographic and textural properties of individual till beds at his exposure enabled one to distinguish 4 complexes. The lowermost complex I (layers 3–5 in Figs. 18 & 19) includes a melt-out till which marks the presence of an ice-sheet before the main stadial of the Vistulian. The complex II (layers 6 & 7 in Figs. 18 & 19) represents the maximum extent of the Vistulian ice-sheet, whereas complexes III and IV (layers 8–11) probably record both transgression and recession of the ice-sheet during the Chodzież sub-phase (Figs. 18, 19; Dzierżek & Olszewska, 1993, 1996). TL age indicators at Wolsko span a time interval between 80 to *ca.* 50 ka, only the uppermost layer being dated to 20 ka. It is interesting to compare these results to those obtained at Szamotuły (south of the study area), where dates from an interval 90–55 ka have been considered unreliable, and only those clustering around 20 ka have been chosen for interpretation (Gogołek, 1991b). On the other hand, ice-dammed sediments assigned to the Hrubieszów Interstadial have been distinguished unequivocally (Gogołek, 1990, 1992).

It is obvious that not every till bed distingusihed in an exposure or drilled by a borehole should refer to a separate glaciation or a stadial. However, one should take into account a possibility of assignment of some of till beds not only to individual glacial stages, but also to lower-rank units (phases, sub-phases, oscillations), as shown by the Chodzież sub-phase example (Kozarski, 1991, 1993, 1995; Kozarski & Kasprzak, 1992). It seems probable that the Strączno–Zawada oscillation (Kozarski, 1962a) left a separate till bed in the study area, since the youngest from among the tills distinguished occurs within the extent of this oscillation.

In the light of the above review, the stratighraphic position of tills distinguished in the Middle Noteć River valley region is as follows. The maximum phase of the Vistulian is represented by the V_2 till, whereas the V_3 till bed records the Chodzież sub-phase. The V_1 till testifies to an ice-sheet preceding the main stadial and could represent the Świecie stadial. Since the V_4 is restricted to the Róża Plateau, it could mark a minor glacial episode during the recession of the Chodzież sub-phase. These hypotheses should be verified by future detailed studies.

The Pomeranian phase (V_5) of the last glaciation is recorded in the study area within sands and gravels that build higher terraces of the principal river valleys (60–75 m a.s.l.; Figs. 11, 14). This phase is also responsible for the final

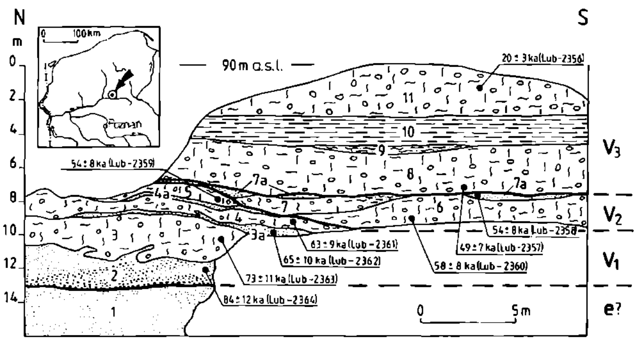


Fig. 18. Exposure of Vistulian sediments in the Noteć River valley side at Wolsko (based on Dzierżek & Olszewska, 1996). 1 – fine-grained sands, 2 – vari-grained sands and gravels, 3 – yellow-grey till, 3a – fine-grained sands with gravels, 4 – yellow-grey till, 4a – vari-grained sands, 5 – yellow-grey till, 6 – light-brown till, 7 – grey till and sandy silts, 7a – fine-grained sands, 8 – yellow-brown till, 9 – sandy silts, 10 – varved clays, 11 – yellow-grey till; *filled circle* marks sampling site and its TL age indicator with the laboratory number, V_1–V_3 as in Fig. 10

shaping of the Noteć ice-marginal valley (*cf.* Woldstedt, 1932; Galon, 1961b, 1968a, b; Kozarski, 1965).

Late Vistulian and Holocene

In Late Vistulian and Holocene times fluvial (Figs. 11–14, 17) and lacustrine (Wodziczko, 1948; Galon, 1961b, 1968a, b; Przybylski, 1961; Tobolski, 1962; Kozarski & Rotnicki, 1978; Klimko, 1973; Siliwończuk, 1977) deposition was ubiquitous. In this time-span several dune-forming episodes took place being recorded, among other areas, in dunes of the Warta–Noteć interfluve region (Pilarczyk, 1962; Rotnicki, 1970).

The topic of this paper does not include detailed discussion of landform development. Geomorphic analysis of the area is presented at large in papers by Majdanowski (1949, 1950), Krygowski (1952, 1961b, 1962, 1972), Rotnicki & Wasiłowska (1962), Szupryczyński (1958, 1961), Kozarski (1959, 1962a, 1965), Karczewski (1959, 1963, 1989), and many others.

Figure 20 summarizes lithological properties, origin and

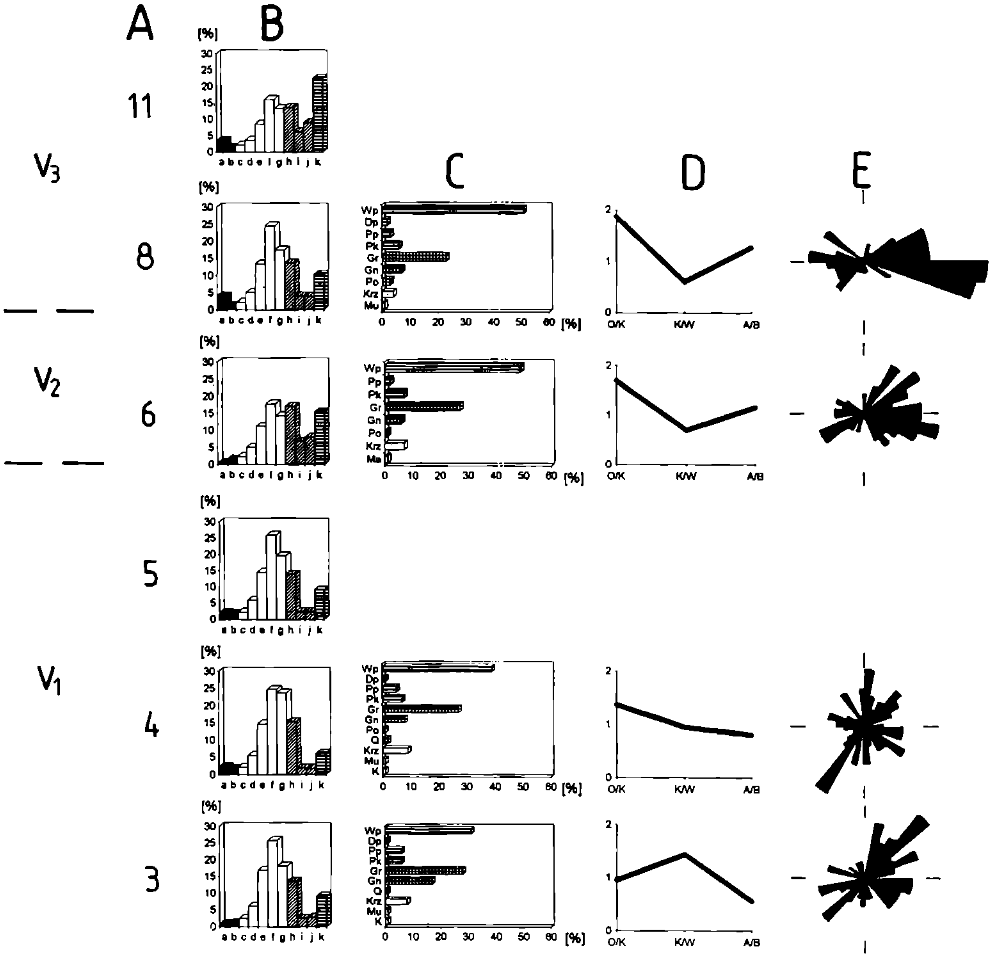


Fig. 19. Lithology of Vistulian sediments exposed in the Noteć River valley side at Wolsko (based on Dzierżek & Olszewska, 1996). **A** – layer numbering (as in Figs. 10, 18), **B** – grain-size histograms: a – 4 mm, b – 4–2 mm, c – 2–1 mm, d – 1–0.5 mm, e – 0.5–0.25 mm, f – 0.25–0.125 mm, g – 0.125–0.06 mm, h – 0.06–0.01 mm, i – 0.01–0.005 mm, j – 0.005–0.002 mm, k – >0.002 mm, **C** – petrographic composition of clasts – Scandinavian sedimentary rocks: Wp – limestones, Dp – dolomites, Pp – sandstones, Pk – quartzose sandstones and quartzites; Scandinavian crystalline rocks: Gr – granitoids, Gn – gneisses, Po – porphyres, Q – quartz; local rocks: Krz – flints, Mu –mudstones, Ma – marls; **D** – plots of petrographic indices: O – total of sedimentary rocks, K – total of crystalline rocks, W – total of limestones, A – total of poorly resistant rocks, B – total of resistant rocks; **E** – till fabric plots

stratigraphy of Quaternary sediments of the Middle Noteć River valley region. 14 till beds shown on geological cross-sections have been linked into 7 local glacial stages, confronted with stratigraphic schemes by Baraniecka (1990) and Lindner (1991a, 1992).

CONCLUSIONS

1. The sub-Tertiary bedrock is composed mostly of Jurassic and Cretaceous rocks that build large Mesozoic structures of the Pomeranian–Kuyavian Swell, Szczecin Trough, Oborniki Elevation and Mogilno Trough. The relief of sub-Tertiary surface attains 270 m (from 322 to 51 m b.s.l.). The topography of this surface is conformable to geological structure in that culminations relate to axial parts of anticlines and depressions are associated with synclines. Lithological control is poorly visible.

2. Tectonic activity in Tertiary and Quaternary times affected geological processes leading, *i.a.* to the formation of the Czarnków graben and the Chodzież depression. The Pomeranian–Kuyavian Swell was relatively uplifted during Tertiary and, partly, Quaternary sedimentation, as evidenced by reduced Tertiary thicknesses upon the Swell and increased sediment infill within the depressions, as well as by the lack of Pliocene and Lower Quaternary sediments in uplifted areas. Quaternary tectonic activity constrained reactivation of interglacial river valleys and location of subglacial furrows along fault zones.

3. The sub-Quaternary substratum is composed by Miocene strata in the northern part, and Miocene and Pliocene strata in the southern part of the study area. Tertiary rocks crop out in places at the groundsurface. The topography of sub-Quaternary surface is of poligenetic character. Among morphogenetic processes that shaped this surface, the most important was glaciotectonic activity during individual glacial stages that modelled glaciotectonic depressions, up to 180 m deep.

4. In the Middle Noteć River valley region 14 till beds, representing 7 glacial stages (Narevian, Nidanian, Sanian I, Sanian II, Odranian, Wartanian and Vistulian), have been distinguished.

5. The Narevian Glaciation is represented by two till beds preserved within a glaciotectonic depression near Boruszyn, formed during the transgression of this ice-sheet; whereas the Nidanian till occurs in the Boruszyn and Noteć depressions.

6. The Sanian I and Sanian II (Wilga) Glaciations played an important role in shaping the area studied. The related ice-sheets formed both depressions and highs in the substratum, and deposited thick beds of glacial sediments, smoothing out the pre-existing topography.

7. The Odranian Glaciation was the first one which left its deposits not only within depressions but also upon Tertiary elevations. Deposition of the till was preceded by intensive exaration that led to final removal of older glacial sediments and Pliocene clays. Highly dynamic ice-sheet tongues remodelled elevation sides and pushed up basement deposits.

8. The Wartanian Glaciation, partly bi-partite, left a till bed up to 30 m thick. Its morphogenetic influence was, however, negligible.

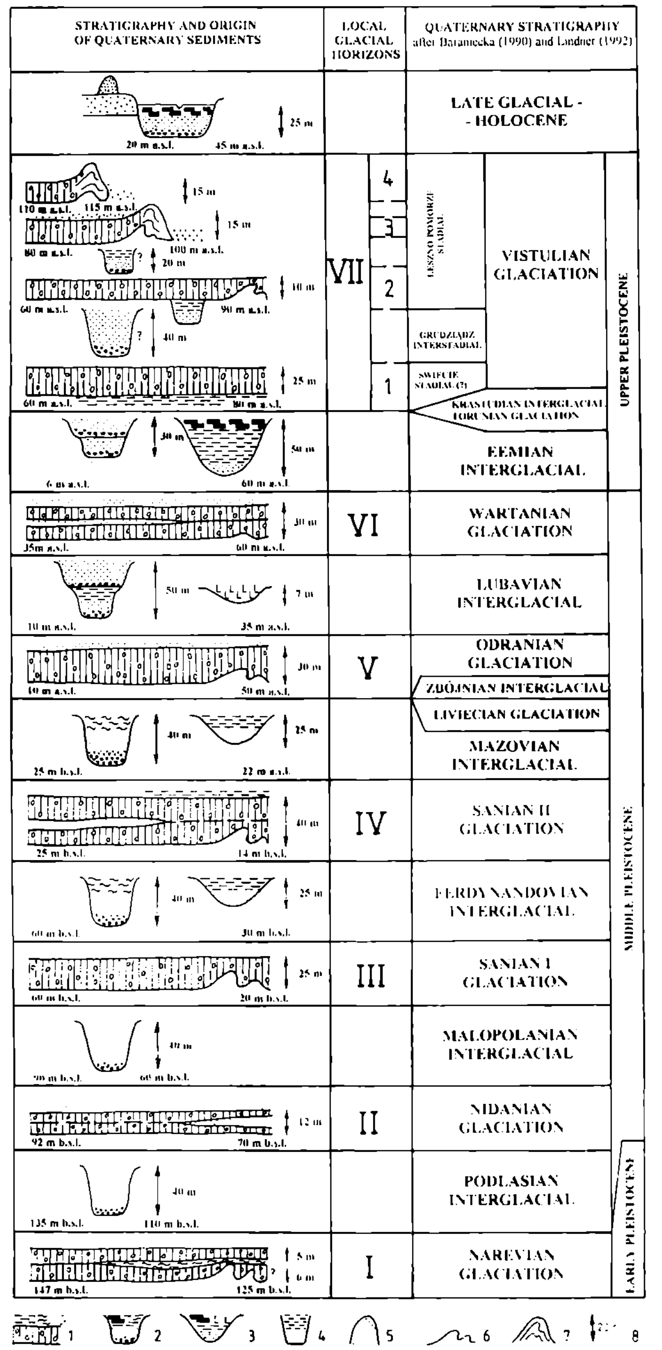


Fig. 20. Sequence of sediments and geological processes in the Middle Noteć River valley region versus Pleistocene stratigraphy of Poland. *1* – tills, ice-dammed clays and silts, and fluvioglacial sands and gravels, *2* – fluvial gravels, sands, silts, clays and peat, *3* – lacustrine sands, clays, gyttjas and marls, *4* – sands and clays of glacial channels, *5* – dune sands, *6* – glaciotectonic deformations, *7* – push moraines, *8* – maximum bed thicknesses; I–VII – local glacial horizons; VII (1–4) – Vistulian till beds; 25 m b.s.l. – 22 m a.s.l. – elevation of bases of individual series

9. The Vistulian Glaciation played a decisive role in shaping the present-day topography and sedimentary sequence of the Middle Noteć River valley region. This stage

is represented by 4 separate till beds, separated by sands, gravels and ice-dammed fines. The lowermost till probably represents an episode preceding the main stadial of the Vistulian, *i.e.* the Świecie stadial. The second till was left by the Leszno–Poznań Phase, the third – by the Chodzież sub-phase (surge), whereas the fourth till bed is most probably associated with a short-term transgression during the recession of the ice-sheet from the maximum extent of the Chodzież sub-phase. The Pomeranian Phase left mainly outwash sediments that compose the higher terraces in large river valleys.

10. Sediments separating deposits of the 7 glacial stages are of fluvial or lacustrine origin and represent the Podlasian, Malopolanian, Ferdynandovian, Mazovian, Lubavian and Eemian Interglacials, the three last ones being documented best.

11. The Mazovian *sensu lato* Interglacial was characterised by intensive fluvial erosion that affected the base of Quaternary strata and exhumed the pre-existing erosional and exarational depressions. However, neither the size of erosional downcutting nor the thickness of fluvial sediments of that age are comparable to those of neighbouring areas.

12. The Lubavian Interglacial drainage pattern developed during two erosion-accumulational cycles. Some segments of the buried valleys of that age dissected the top of Tertiary sediments. Apart from fluvial sands and gravels, this stage is represented by lacustrine clays, silts and organogenic sediments.

13. The Eemian Interglacial is the best documented warming in the area studied. Fluvial and lacustrine sediments, including organogenic series, occur at elevations that do not exceed 60 m a.s.l., and can easily be correlated with their counterparts in the neighbouring areas.

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Streszczenie

BUDOWA PODŁOŻA PODCZWARTORZĘDOWEGO I STRATYGRAFIA OSADÓW CZWARTORZĘDOWYCH REJONU DOLINY ŚRODKOWEJ NOTECI, ZACHODNIA POLSKA

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W pracy przedstawiono model budowy geologicznej wraz ze szczegółową stratygrafią osadów czwartorzędowych rejonu Doliny Środkowej Noteci (Fig. 1), leżącego pomiędzy Pomorzem a Wielkopolską, na granicy wielkich struktur geologicznych: wału pomorsko-kujawskiego i niecki szczecińsko-mogileńskiej. Podstawową metodą zastosowaną w pracy była analiza ponad 950 profilów wierceń oraz interpretacja 64 przekrojów geologicznych, wykonanych na podstawie tej analizy (Fig. 2). Linie przekrojów dobierano w taki sposób, aby przecinały zarówno elementy rzeźby współczesnej jak i osie struktur wgłębnych.

Omawiany rejon obejmuje oprócz Doliny Środkowej Noteci, stanowiącej wraz z Kotliną Gorzowską, fragment Pradoliny Toruńsko-Eberdswaldzkiej również obszary wysoczyznowe. Na N są to: Pojezierze Krajeńskie i Wałeckie, rozdzielone doliną Gwdy. Rzeźbę wysoczyzn polodowcowych urozmaicają kulminacje moren czołowych, z których największe mają wysokość ponad 200 m n.p.m. Na S od doliny Noteci występuje Pojezierze Chodzieskie, o równinnej powierzchni. Kulminacje występują jedynie w wąskiej strefie przydolinej w okolicach Czarnkowa i Chodzieży (Fig. 1).

W podłożu trzeciorzędu na omawianym terenie występują głównie skały jury i kredy, budujące wał pomorsko-kujawski i nieckę szczecińsko-mogileńską (Fig. 3). Podłoże osadów trzeciorzędu ma duże dniwelacje (od 322 do 51 m p.p.m.) i wykazuje zgodność z budową struktur tektonicznych (Fig. 4). Wyraża się to w występowaniu kulminacji tej powierzchni w osiowych częściach antyklin, a obniżeń w osiowych częściach synklin. Stwierdzono przejawy trzeciorzędowej i staroczwartorzędowej aktywności tektonicznej – podnoszenie się struktury wału względem sąsiedniej niecki oraz aktywność uskoków na granicy poszczególnych bloków podłoża mezozoicznego, prowadzącą do powstania obniżeń i rowów tektonicznych, takich jak rów Czarnkowa i obniżenie Noteci.

Osady trzeciorzędu w rejonie Doliny Środkowej Noteci mają miąższość od kilkunastu do 265 m (Fig. 5–8). W bezpośrednim podłożu osadów czwartorzędowych w części północnej terenu występują osady miocenu (drobnoziarniste piaski kwarcowe, z domieszką ziarn grubszych, przewarstwione osadami mułkowo-ilastymi z węglem brunatnym), natomiast w poludniowej – osady pliocenu (iły, iły pstre, mułki z domieszką frakcji drobnopiaszczystej). Miejscami skały trzeciorzędowe odsłaniają się na powierzchni terenu. W podłożu czwartorzędu (Fig. 9) wyróżniono szereg elewacji oraz obniżeń, z których największe, w rejonie Boruszyna, ma głębokość 180 m. Urozmaicona rzeźba podłoża czwartorzędu ma charakter poligenetyczny. Na jej ukształtowanie miały wpływ trzy grupy czynników: erozja lodowcowa i glacitektonika, erozja rzeczna oraz budowa geologiczna podłoża (w tym tektonika) i rzeźba „twardego" podłoża. Decydujący wpływ na ostateczny kształt powierzchni podczwartorzędowej miały szeroko rozumiane, powtarzające się w ciągu czwartorzędu procesy erozji lodowcowej.

Wśród osadów czwartorzędowych, mających w rejonie Doliny Środkowej Noteci miąższość od kilku do 220 m, wydzielono 14 warstw glin lodowcowych, reprezentujących 7 zlodowaceń.

Najstarsze osady czwartorzędowe (dwie warstwy gliny lodowcowej) pochodzą ze zlodowacenia Narwi i zachowane są

jedynie w dnie najgłębszego obniżenia w okolicy Boryszyna (Fig. 10–12). W podobnej sytuacji występują osady interglacjału podlaskiego, zlodowacenia Nidy i interglacjału małopolskiego (Fig. 10–14). Lądolody zlodowaceń Sanu I i Sanu II były odpowiedzialne za powstanie szeregu form w powierzchni podczwartorzędowej, a z drugiej strony zostawiły miąższe gliny lodowcowe, przyczyniając się do znacznego zniwelowania powierzchni terenu. Pomiędzy glinami tych zlodowaceń występują rzeczne lub rzadziej jeziorne osady interglacjału ferdynandowskiego, o miąższości do 40 m (Fig. 10–16).

Interglacjał mazowiecki (*sensu lato*) zaznaczył się erozją rzeczną, prowadzącą do odpreparowania starszych obniżeń i akumulacją mułków, piasków i żwirów o miąższości dochodzącej do 40 m (Fig. 11–17).

Lądolód zlodowacenia Odry był pierwszym na tym terenie, którego osady zachowały się na powierzchniach elewacji trzeciorzędowych (Fig. 10–12, 14). Akumulacja gliny poprzedzona była etapem intensywnej egzaracji lodowcowej, prowadzącej do usunięcia starszych osadów czwartorzędowych i plioceńskich z powierzchni części elewacji. Sieć rzeczna interglacjału lubawskiego rozwijała się w dwóch cyklach erozyjno-akumulacyjnych, a oprócz powszechnych do tej pory osadów mineralnych z tego okresu zachowały się miejscami jeziorne osady organogeniczne (Fig. 11, 12, 17, 18). Zlodowacenie Warty zostawiło miejscami dwudzielną warstwę gliny lodowcowej, ale jego rola morfotwórcza była znikoma (Fig. 10–14, 16, 18).

Z interglacjału eemskiego pochodzą osady rzeczne, wykazujące miejscami dwa cykle sedymentacji, oraz opracowane paleoflorystycznie i paleontologicznie organogeniczne osady jeziorne (Fig. 11, 12, 17).

Z okresu zlodowacenia Wisły pochodzi większość współczesnych form rzeźby i osadów na powierzchni omawianego terenu. Z najmłodszym zlodowaceniem należy wiązać 4 warstwy glin lodowcowych, rozdzielonych osadami piaszczysto-żwirowymi lub zastoiskowymi (Fig. 11–16). Odsłonięte w krawędzi doliny Noteci gliny lodowcowe różnią się składem mechanicznym, mineralno-petrograficznym, kierunkami transportu, genezą i wskaźnikami wieku TL (Fig. 19, 20). Najniższa z glin zlodowacenia Wisły reprezentuje prawdopodobnie stadiał przedmaksymalny Świecia, druga z kolei – fazę leszczyńsko-poznańską stadiału głównego, trzecia i czwarta pochodzą z fazy (subfazy) chodzieskiej.

W czasie recesji ostatniego zlodowacenia uformował się ostatecznie układ sieci dolinnej, w tym dolina środkowej Noteci, nawiązujący w wielu miejscach do dolin z poprzednich interglacjałów i do niektórych elementów rzeźby i geologii starszego podłoża.