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Regularities in the occurrence of protection zones in polygenetic river valleys from the eastern part of the Polish Lowlands

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ABSTRACT:

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The occurrence of organic soil cover in river valleys is typical of regions that were subject to areal deglaciation. This feature results from the adaptation of a series of linear depressions of glacial melt-out origin by rivers for their flow. Such a series of depressions, primarily composing overflow lakes, underwent subsequent infilling with mainly lake and marsh deposits. These very thick deposits, characterised by high sorption potential and developed in the form of continuous structures, can be considered as effective protection layers, isolating groundwater from contamination.

Key words: River valley, Areal deglaciation, Organic deposits, Sorption potential, Protecting barrier, Pollutants

INTRODUCTION

River valleys are of crucial economical value, but as zones of accumulated surface runoff of waters from the catchment area they are subject to pollution. It is therefore important to determine the degree to which they are susceptible to environmentally hazardous wastes.

The object of the present investigation was to determine the influence of the lithology and origin of various river valley sediments, and of those occurring in their direct vicinity, on their potential to retain pollutants. Sediments of the river valleys may be considered as a subsurface protection layer for groundwaters and the underlying sediments, sorbing compounds hazardous to the environment. The presence of such a protection layer and its efficiency influences the natural prevention of pollution, and provides for a safe and rational utilization of river valley bottoms. The determination of the origin and setting of the geomorphological units of river valleys enables the recognition of the presence, type of occurrence and degree of efficiency of a natural protection zone. Evaluation of the extent, thickness and stability of the protection zone allows prediction of the reactions of the natural environment to pollution hazards. It is therefore of great importance to determine the frequency and regularity of occurrence of those geomorphological units that are characterised by a geological setting ensuring the presence of protection zones.

This paper presents the geomorphological view of large areas connected with evaluation of the susceptibility of the covering soils to pollution in selected localities. Geomorphological investigations in the eastern part of the Polish Lowlands have proved the predominance of rivers with a polygenetic and an "inherited" character, that is rivers which have adapted a series of glacial melt-out depressions for their flow. Initially these depressions were covered with vast and shallow overflow lakes, as a result of which parts of valleys and, occasionally, also whole valleys, have a basin shape. With few exceptions (i.e. chain lakes), the lakes were completely infilled with lake and marsh deposits: lake clay, gyttja, organic mud and peat. The proportion of channel deposits in basin-like river valleys is rather small in relation to their area.

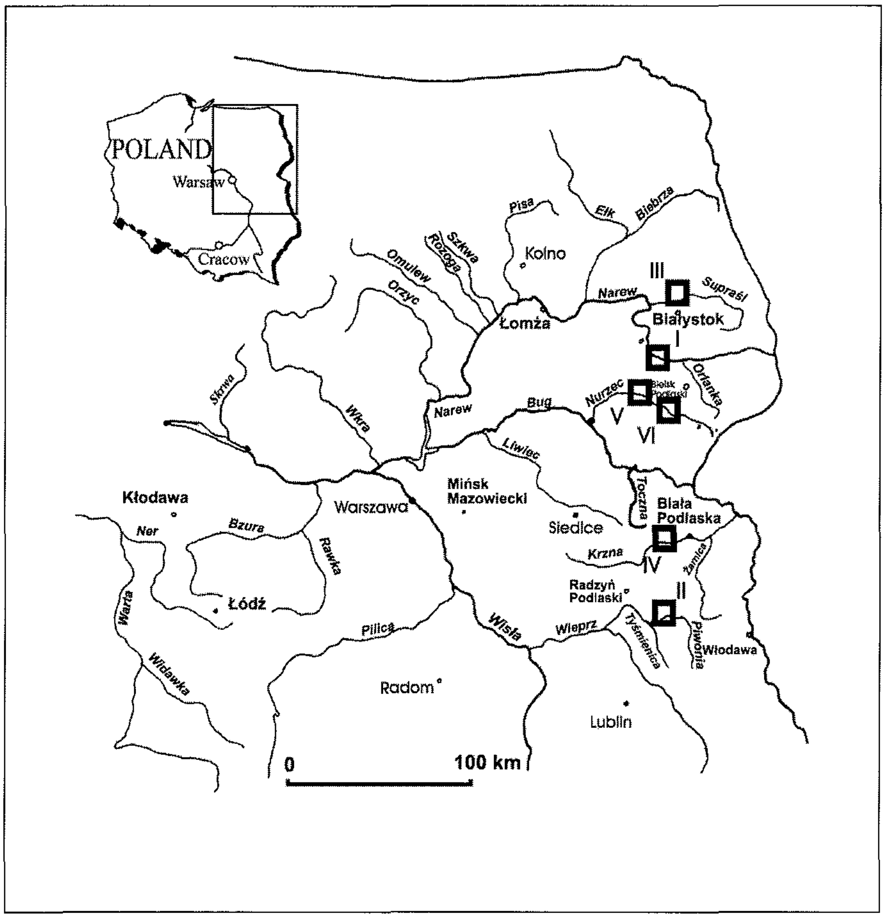

Fig. 1. Location of the study areas

I – Narew river valley in the Suraż area,
II – Piwonia river in the Parczew area,
III - Supraśl river valley in the Studzianki area,
IV - Krzna river valley in the Sycyna area,
V - Nurzec river valley in the Briańsk area,
VI - Nurzec river valley in the Oleksin area

Due to the presence of extensive covers of organic deposits, this melt-out model for the origin of river valleys explains the creation of natural, favourable conditions for the protection of river valleys and adjacent areas against pollution.

Investigation of the detailed geological setting of river valleys from the eastern part of the Polish Lowlands and analysis of the sorption characteristics of their deposits were carried out on several sections, selected on the basis of literature studies and field surveys in the valleys of the rivers Narew, Bug, Krzna, Wkra, Nida, Tyśmienica, Nurzec, Supraśl, Wieprz, Piwonia and Toczna, as well as in the catchment areas of some of their tributaries (Text-fig. 1). All of the rivers lie within the range of the Odranian and Wartanian glaciations (according to the scheme by LINDNER & MARKS 1995). Because areas lying in the direct neighbourhood of the catchment areas can influence the harmful concentration of pollutants in river channels due to stream recharge, slope zones and small parts of the adjacent plateau were also included in the investigation. In cases of an effective recharge system or the presence of soils absorbing pollutants, these areas can favour the preservation of water of good quality.

The lithological characteristics, filtration coefficients, cation exchange capacity (CEC), heavy metal sorption (Pb, Cd, Cu), heavy metal sorption intensity and retardation factor (R) were used as indicators of the potential of the deposits in inherited river valleys and adjacent areas to retain pollutants. Selected soil samples were also subject to indicative tests of the potential to intercept physical pollutants, i.e. organic and mineral particles using industrial waste and ashes (wastes from power plants).

The special protection potential of organic soils, particularly peats, have been noted and utilised in other countries. In the United States, sorbents obtained from peat oil are typically used in industry instead of clays or zeolites. Peats are also utilised in ecological catastrophes,

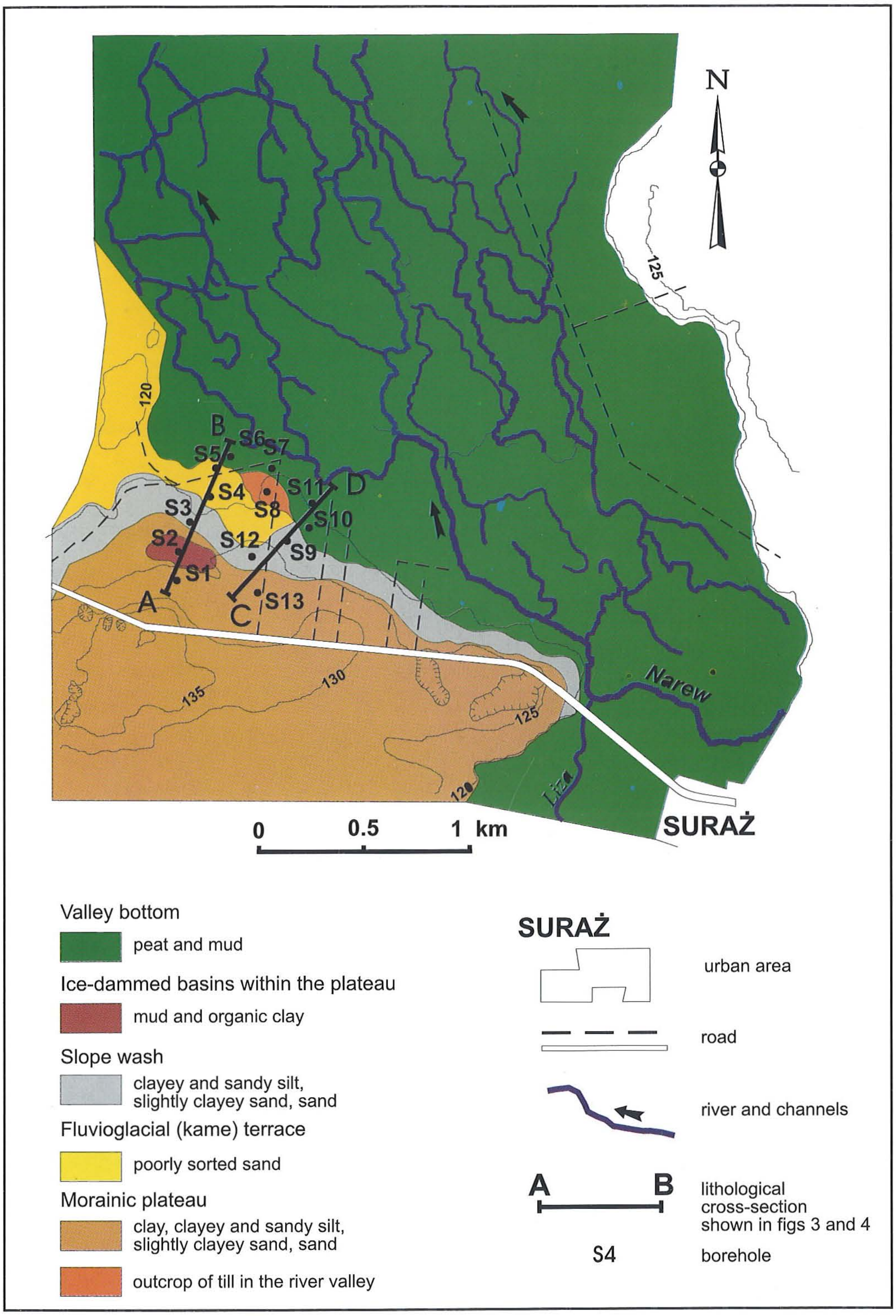

Fig. 2. Geomorphological map of the Narew river valley in the Suraż area

in cases of pollution with liquid toxins (OLKOWICZ-PAPROCKA & *al.*1994). They have also been tested as effective filtration agents for the removal of toxic pollutants from industrial and urban sewage as well as absorbents of pungent, unpleasant odours. Application of this type amount to 15% of the use of peat in the USA (OLKOWICZ-PAPROCKA & *al.* 1994). A similar use of peat is now commencing in Canada (IRVINE & BARSOTTI 1994; fide OLKOWICZ-PAPROCKA & *al.* 1994).

The names of deposits applied in the text are used in accordance with BS 1377, Part 1 (1990), excluding organic soils.

MORPHOGENESIS AND GEOLOGICAL SETTING OF THE INVESTIGATED SECTIONS

Six typical sections of inherited river valleys (Text-fig. 1), considered representative of the catchment area, were chosen for further detailed investigation:

Narew river valley near Suraż (I)
Piwonia river valley near Parczew (II)
Supraśl river valley near Studzianki (III)
Krzna river valley near Sycyna (IV)
Nurzec river valley near Brańsk (V)
Nurzec river valley near Oleksin (VI).

A similar geological setting of all of the analysed river valley sections indicates a similar origin. The analysed area originated as a result of areal deglaciation (RÓŻYCKI 1972), during which many characteristic features were formed – a postglacial river valley bottom, the present flood plain, glaciotectonically disturbed moraine plateaux and adjacent kame terraces. The width of the analysed areas (river valley bottoms) is too large for the stream and its erosional potential in cases of low initial gradients. All of the investigated valleys are generally infilled with marsh and lake deposits, hence by deposits that originated in a stagnant water environment. Additionally, glacial recession took place according to a determined, cyclic sequence of phenomena.

Climatic warming and decline of glacial ice alimentation caused deglaciation in the northwestern part of the Polish Lowlands, according to RÓŻYCKI (1972), along with the creation of a large zone covered with dead ice. Due to concentration of the flowing rainwater and meltwater, a river network originated on the stagnated glacier in the dead ice area (FALKOWSKI, T. 1988). The network cut into the tight ice cover by fissure-like valleys of seasonally rising rivers characterised generally by high flow rates and braided river sedimentation. Eventually, interfluves (glacial plateaux and water divides on the ice) were formed. Flow of glacial rivers caused widening of fissures in the dead ice cover and the formation of kames. These kames are the oldest relief forms in the area and at present are situated at the greatest elevation. Steps of accumulation plains, descending towards the present-day river valleys, were formed during the next phase of areal deglaciation. It is worth noting that formation of the first river network in the dead ice landscape determined the runoff directions of the present-day melt-out river valleys. Some modification of the network (initially formed on ice) could be caused by the appearance of thaw zones in dead ice above elevations in the glacier basement. In effect, a local sedimentation of ice-dammed deposits took place (e.g. the brickworks in Żółtki by Narew). In some areas, these were developed as varved clays (e.g. near the mouth of the river Supraśl). In the final phase of areal deglaciation the present-day valleys were infilled only by thick blocks of dead ice, the area of which corresponded to the recent lake basins. The dead-ice blocks remained the longest in exaration depressions, thus acting as watersheds. The presence of depressions, occurring in series, was determined by the preglacial morphology and the type of glacier tongue advance during its transgression (MOJSKI 1972a). The morphology of the exaration depressions was modified and emphasised (e.g. basin shape) by deflection of less susceptible basement through the sinking of dead ice blocks (FALKOWSKI & *al.* 1984-85, 1988). After the ice finally melted, the depressions were adopted by a lake system. Sedimentation of terrigenous deposits linked with the Vistulian Glaciation took place, followed by organic and deltaic deposits, representing initial alluvial forms of the channel and flood facies.

Glaciotectonically and glaciostatically strongly deformed escarpment zones of the moraine plateaux adjacent to the valleys were formed during areal deglaciation (dead ice moraines). The pressure of dead ice blocks within the exaration depressions caused squeezing out of plastic material towards areas devoid of ice cover and the formation of numerous depressions (JAROSZEWSKI 1991). Analysis of most of the river valley sections revealed the presence of ice-dammed plains and side valleys of melt-out origin within the adjacent plateaux. These forms originated as ice-dammed reservoirs after melting-out of glaciers into smaller dead ice blocks, typically due to the concentration of streams of ablation water. Only plateaux areas directly adjacent to river valleys were included in the present investigation.

Fluvioglacial terraces (kame terraces) border directly on plateaux. They occur as shelves originated during the flow of glacial rivers in depressions between the plateau and the escarpment of the melting glacial ice (on the lowest steps of the accumulation plains of FALKOWSKI & *al.* 1984-85, 1988). These shelves of kame terraces have been considered as traces of ice marginal valley (pradoline) occurrence by some authors (MOJSKI 1972b, BIENIASZEWSKA 1980). NOWICKI (1971) treated such forms occurring in the Supraśl river valley as of fluvial origin, formed during the Vistulian Glaciation.

The final phase of areal deglaciation is testified by the presence of vast basin-like depressions of dead ice melt-out origin, occurring in series and typically infilled with organic deposits. The depressions were filled with lakes, adopted later by rivers during formation of the runoff network which, in a later phase, also drained them. Sedimentation of lake deposits, followed by marsh deposits, took place simultaneously with sedimentation of the channel and flood facies. Formation of alluvial clay was marked by an increase in ash content (increase of mineral content) of the peats. The geomorphological units described above occur in all of the analysed river valley sections. Aerial photographs also revealed the lack of meandric displacement of the river channels. This proves that the valleys are very young and do not have the meandering character that is typical of mature, 'unconfined' rivers with thick alluvial fill within the meanders representing the channel and abandoned channel facies.

In inherited post-lacustrine valleys, the presence of alluvial deposits resting on the organic deposits is rather doubtful in most of the areas, whereas the supra-flood plain, referred to in the paper as the valley bottom, is composed mainly of organic lake and marsh deposits.

Narew valley near Suraż

The glacier was last present in the area during the Wartanian Glaciation (LINDNER & MARKS 1995). The area includes a vast, basin-like Narew river valley bottom in the vicinity of Suraż, connected to the wide valley of the river Liza, infilled with peats (Text-fig. 2). The adjacent plateau has high slopes with descending kame terrace shelves with local ice-dammed deposits. Strong

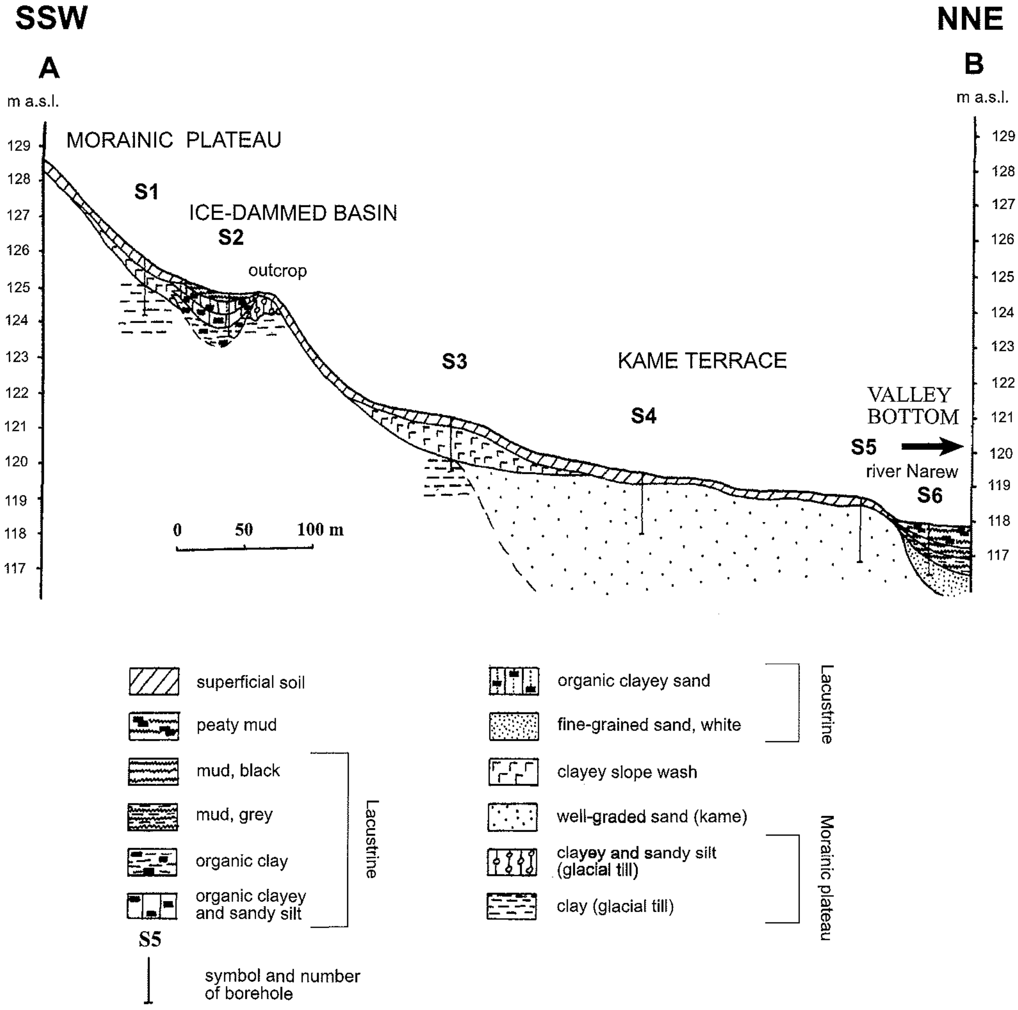

Fig. 3. Lithological cross-section through part of the Narew river valley in the Suraż area

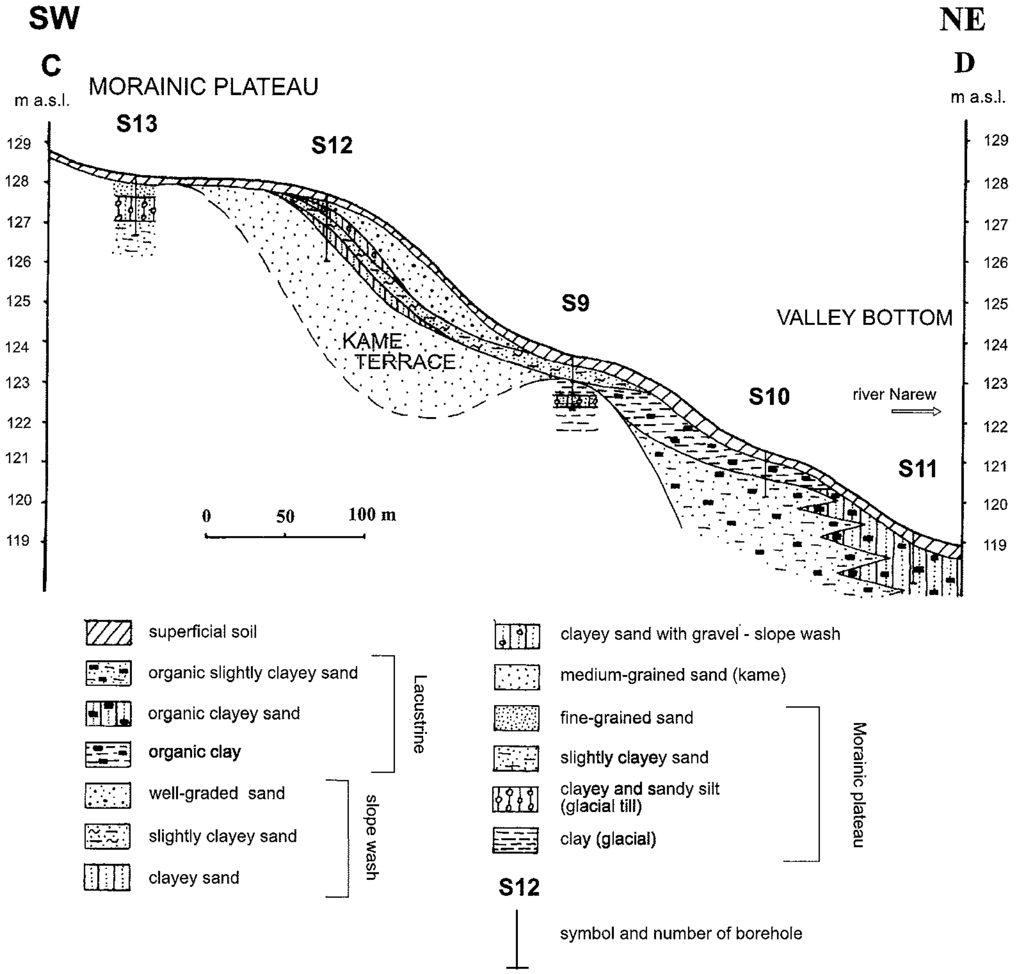

Fig. 4. Lithological cross-section through part of the Narew river valley in the Suraż area

glaciogenic disturbances, even overfolds, are observed within the plateau and on the slopes of the Narew valley. A wide valley bottom with traces of dunes in the eastern part of the area has also been noted. It was formed after infilling of the lake basins with organic deposits in the final phase of development of the surface water runoff system. The borders of units directly adjacent to the plateau are often masked by slope wash or, locally, by deposits of mudflows (Text-figs 3 and 4). The setting and shape of these geomorphological units, and particularly the basin form, width of valley bottom (average 5 km) and infilling with stagnant water deposits, proves that the origin of the Narew valley may be explained by the areal deglaciation model of Różycki (1972).

According to the present investigation, the vast deep depressions near Suraż, infilled with lake and marsh deposits (lake clay, gyttja, muds and peats; the peatbog within the small river Awisa – 7 km from Suraż – is about 7 m thick), as well as the type of valley slopes with small lobes of lake and ice-dammed deposits (Text-figs 3 and 4) unequivocally indicate that linear dead ice blocks marked the last phase of deglaciation, and therefore the first phase of the development of the present-day water runoff network. The inherited river valley is the youngest landscape element in the area.

The vast Narew valley bottom, actually post-lacustrine plains, is infilled mainly with organic lake and marsh deposits. The accretion of these deposits greatly exceeded the supply of terrigenous material. They include peat wood, strongly clayey, with a degree of decomposition between 45 and 50% (Oświt 1962), mucky in the topmost part. They form a lowland bog covering an area of 10.5 ha and with peats from 0.5 to 1.0 m thick. River alluvia form only a small percentage of the valley deposits and usually occur in the form of sandy dams within lake and marsh deposits (lake clay, alluvial clay and peats). The lake and fluvial sediments were deposited simultaneously until the disappearance of the overflow lake and the formation of the longitudinal channel profile of the present river Narew. Migration of the river channel through erosion entails the concentration of channel facies deposits (dam) – mainly medium sands - in new channels eroded into the organic deposits.

Infilling of the post-lacustrine plain, the present flood plain (valley bottom), with flood and marsh deposits in the form of muds and peats with a high ash content still takes place. The large admixture of terrigenous material in organic deposits within the valley is also influenced by the supply of aeolian deposits from dunes, as described by LASKOWSKI (1970).

Irregular glaciotectonic and glacistatic structures were noted within the plateau, in the form of large folds within the slope and as small folds and flakes in the area adjacent to the valley. The structures were observed in large (up to 20 m deep) gravel-pits situated on hills near the valley, along the Suraż – Łapy road. The folds are overturned towards the plateau, which suggests that the deformation force was directed away from the valley axis and was genetically linked to the active ice of the glacier transgression as well as to the dead ice. Various lithologies and facies of Pleistocene deposits underwent dislocation. These typically include cohesive soils varying from slightly clayey sands, clayey and sandy silt to clays, with intercalations of poorly sorted sands. FIREK (1970) and FALKOWSKI, E. (1971) described examples of glaciotectonic and glaciostatic disturbances in the area. The presence of many isolated complexes of disturbed beds in the slopes of the plateaux, particularly clayey, restricts the migration of groundwater and hence pollutants, towards the valley axis. They form natural barriers of low permeability, increasing the filtration time (FALKOWSKA 1997). Damming up of flowing (drained) groundwater is typically emphasised by the parallelism of the axis of glaciotectonically uplifted forms to the valley slopes. The morainic plateau is therefore a zone of strongly glaciotectonically deformed tills and fluvioglacial deposits as well as ice-dammed deposits. All of these deposits usually developed during the early glaciations and were subsequently uplifted by glacier ice tongues during their transgression as well as by the pressure of large blocks of dead ice in the terminal deglaciation phase. In the Suraż area the plateau is represented by elevated parts of the area with a variable relief, without traces of fluvial, postglacial erosion on their slopes (excluding local occurrences of kame terrace shelves), but with frequent traces of lacustrine sedimentation on slopes. The plateau slopes are characterised by a diversified relief, including small hills and basin like, flattened depressions containing lake sediments, situated higher above the valley bottom (Text-fig. 3). The depressions are infilled with clayey and sandy silt as well as with grey organic clay covered by organic mud. Their origin is often linked to the squeezing out of deposits of different plasticity by dead ice blocks, and with the creation of ice-dammed, water-filled basins within the plateau during block disintegration of the glacier (FALKOWSKA 1995b).

Their typical presence at higher elevations on the valley edge rather than within the plateau is linked with the squeezing out of the basement on the edges of ice blocks, which were situated within the valley.

In the Suraż area, fluvioglacial terraces lie adjacent to the glaciotectonically and glaciostatically deformed plateau. According to E. FALKOWSKI (1971) these deformations resulted from the pressure of dead ice. The terraces occur in the marginal zones of the melted-out depressions in the form of kame terrace shelves (Text-figs 3, 4). They consist of fine- and medium-grained sands. Lobes of varved clay, considered to be traces of small marginal lakes at the edges of dead ice blocks, locally replace the terraces.

An important element in the area is the presence of slope wash deposits occurring locally within the plateau slopes and the kame terrace (Text-figs 3, 4). They began to form during the Vistulian Glaciation and are linked to large-scale denivelations of the plateau slopes and their diverse lithologies. Loose (fine- and medium-grained yellow sands), and cohesive (slightly clayey sands, clayey sands and greyish yellow and yellow clayey and sandy silts) sediments have been recognised within the slope deposits.

According to KAZIMIERCZUK (1970) and DANIELEWSKA & KONDRATIUK (1996), the groundwaters of the Narew valley are strongly related to waters within the river channel. Within the flood plain the groundwater level lies several centimetres below the surface, or on it in periods of high precipitation. There are, however, areas within the valley where the groundwater level lies deeper, up to 1.0 –1.5 metres below the surface (KAZIMIERCZUK 1970). On the other hand, according to GAWIN (1971), there is no uniform groundwater level and no direct hydraulic connection between the plateau groundwaters and the Narew waters.

Observations of the Narew valley near Suraż indicate the predominance of organic soils in the form of peats and muds in the valley infilling. This also applies to the depressions adjacent to the Narew valley, where lake and marsh deposits are present.

Piwonia valley near Parczew

Genetic structures similar to the geomorphological units distinguished in the Narew valley, i.e. morainic plateau, slopes with kame terraces and valley bottoms inherited after melt-outs, have also been observed in the Piwonia valley (Odranian Glaciation – LINDNER & MARKS 1995) near Parczew (Text-fig. 5).

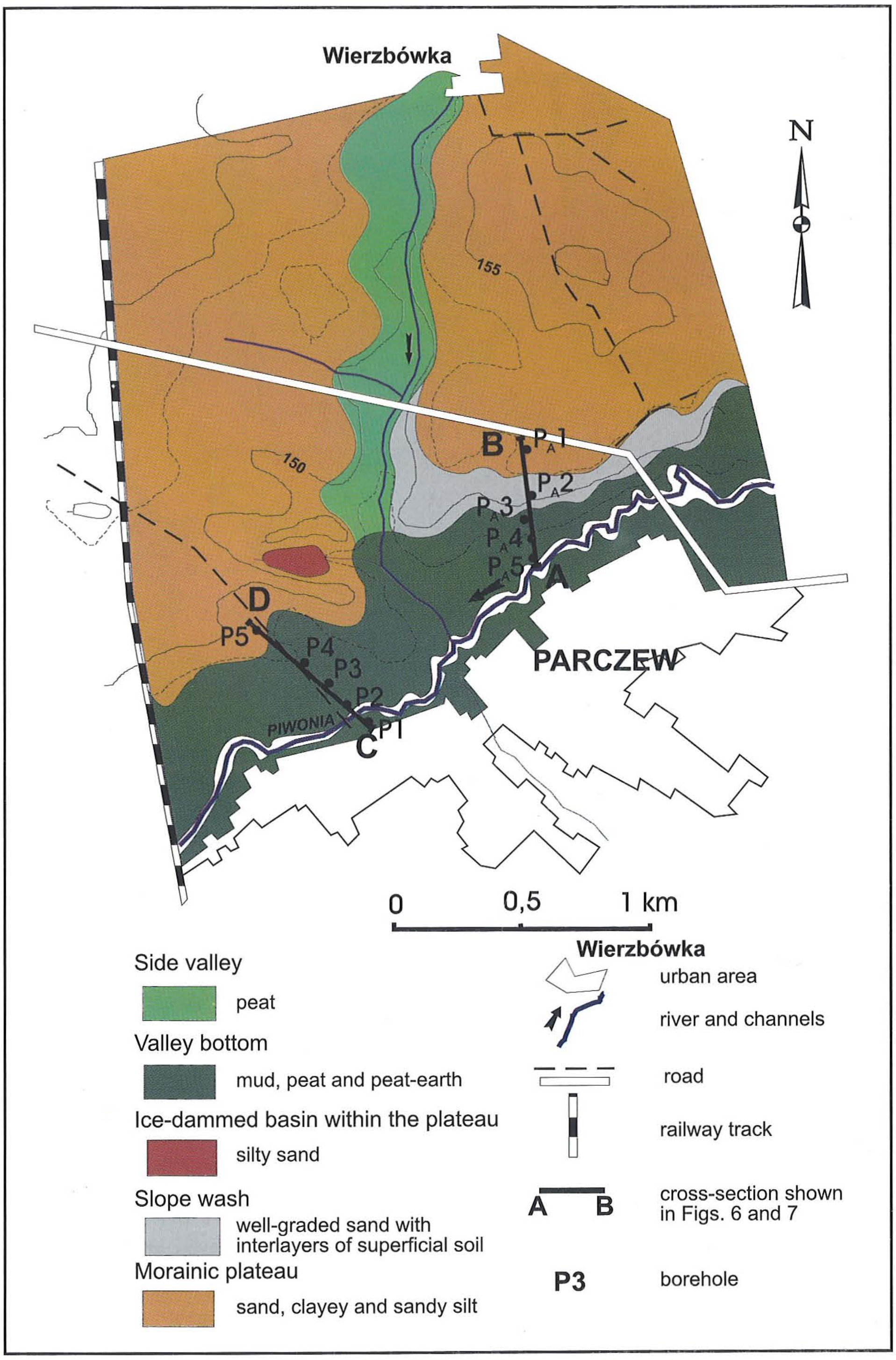

Fig. 5. Geomorphological map of the Piwonia river valley in the Parczew area

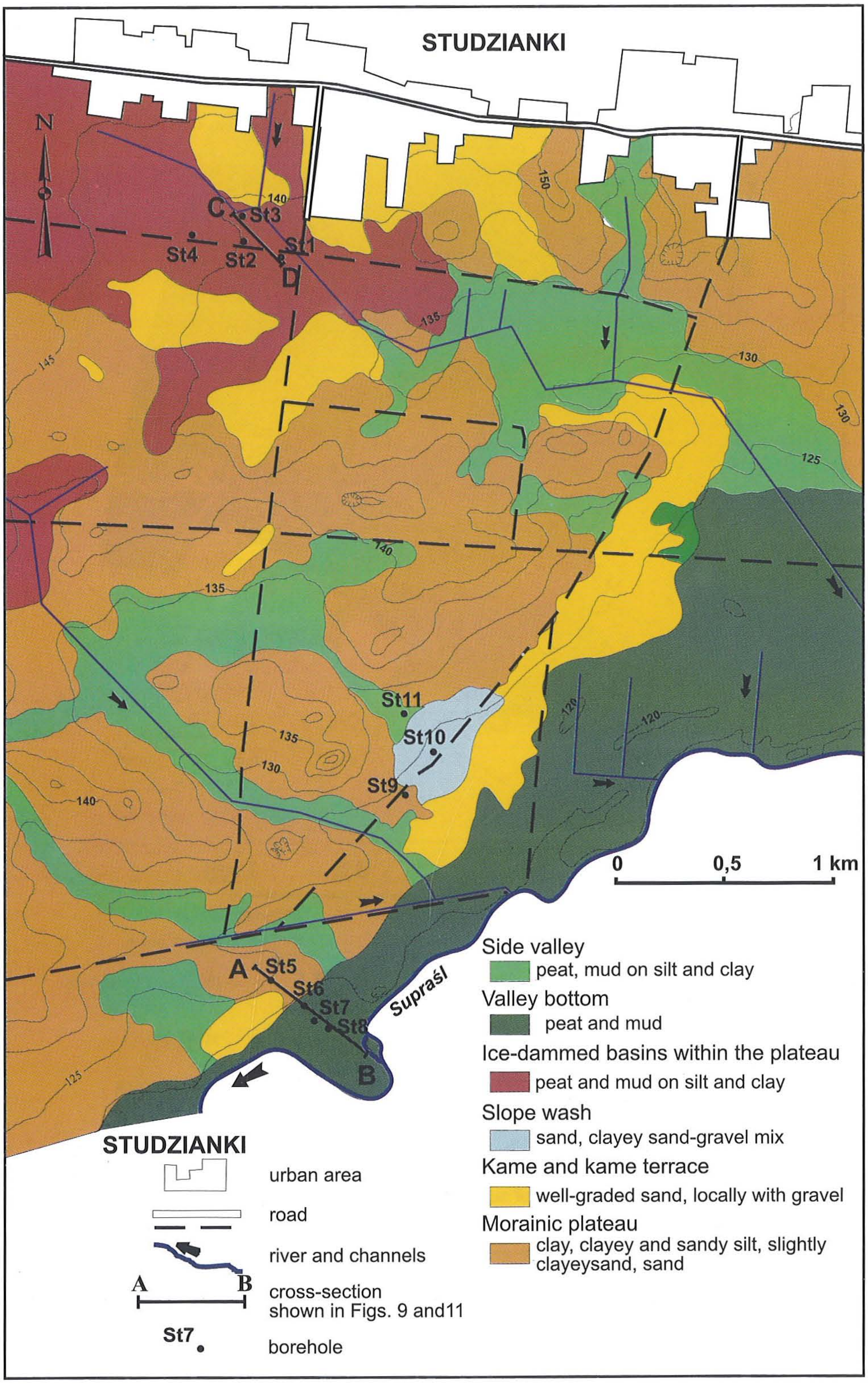

Fig. 8. Geomorphological map of the Supraśl river valley in the Studzianki area

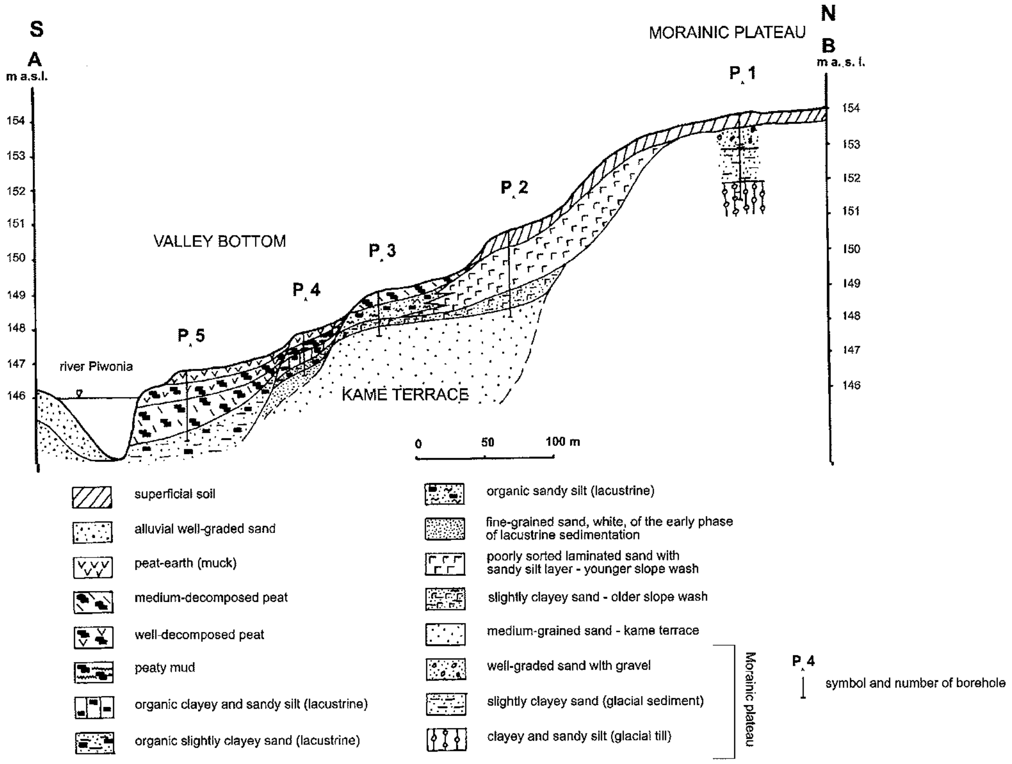

Fig. 6. Lithological cross-section through the Piwonia river valley in the Parczew area

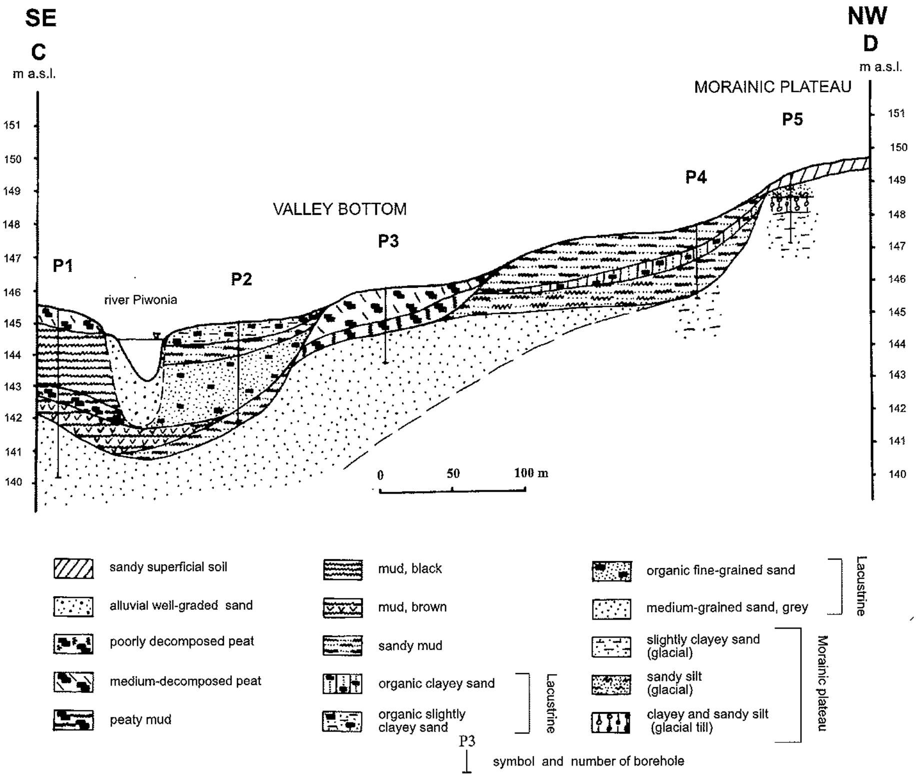

Fig. 7. Lithological cross-section through the Piwonia river valley in the Parczew area

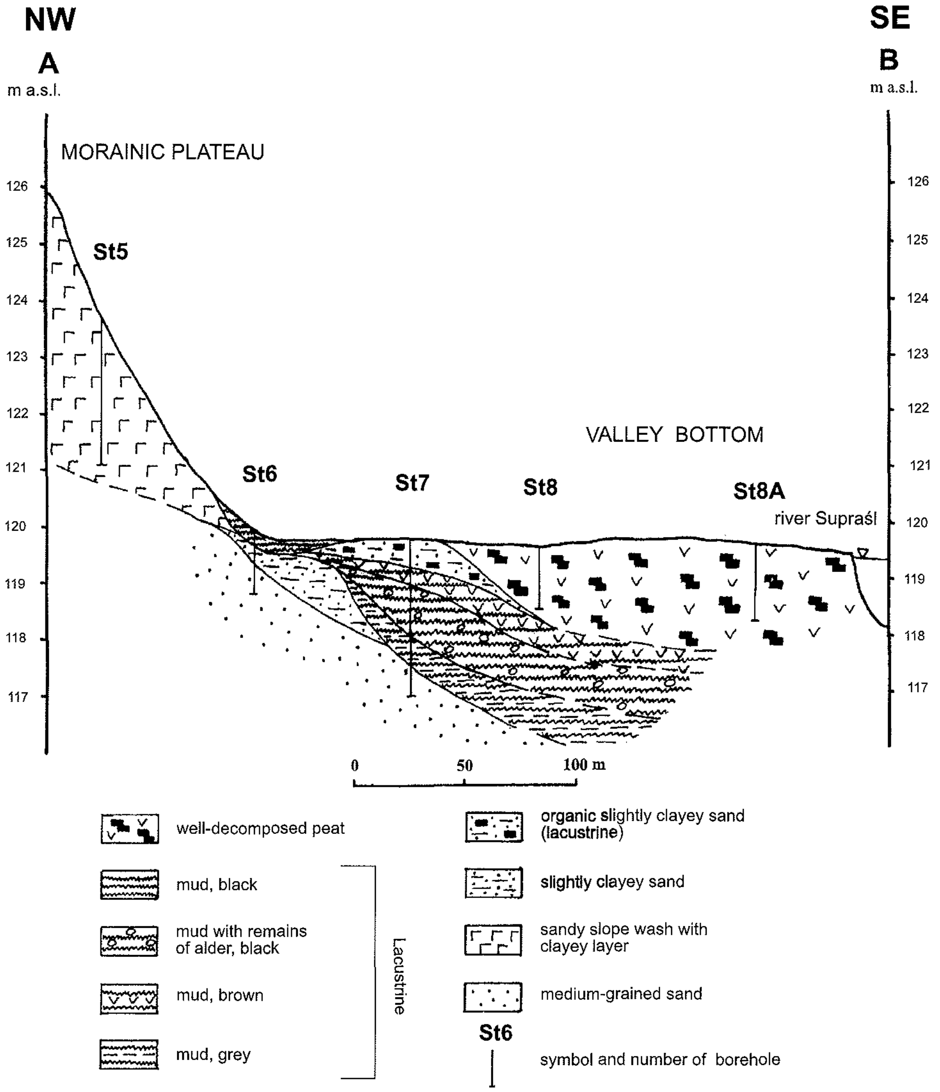

Fig. 9. Lithological cross-section through the Supraśl river valley in the Studzianki area

Although narrower than the Narew valley near Suraż, the Piwonia valley near Parczew is filled with lake and marsh deposits represented by peats and organic muds. Despite the fact that it encompasses one ancient lake basin, the area is characterised by two types of sedimentation (FALKOWSKA 1995a), as is shown by two cross-sections (Text-figs 6, 7), situated about 1 km apart (Text-fig. 5). The first type is dominated by peats and second type by organic muds. The origin of these muds was probably linked to the supply of terrigenous material from lake slopes, therefore with the formation of earlier slope wash. The peat in the area reaches a maximum thickness of 4.2 m (DZIAK 1975). Lithological diversity of peats was also observed near Suraż (smaller admixture of organic particles), where, however, it is linked to the development of aeolian forms in the Narew valley. The sandy alluvia in the valley bottom are present-day sediments and they fill the channel of the Piwonia to only a small extent. Shallow water lake deposits, including organic muds and sands, lie on kame terrace shelves covering the slopes of the plateau (Text-figs 6, 7). These form a system of terraces, linked to drainage phases of lakes created after the melting of dead ice (FALKOWSKA 1995a). The cross-section shows the "step-like" character of these deposits, whereas in the Narew valley the organic deposits on slopes occur as lobes forming "abraded" terraces.

The morainic plateau is formed by hills surrounding lake basins composed of medium- and coarse-grained sands and gravel to clayey sands and clayey and sandy silts. Strong glaciotectonic deformations, resulting from the squeezing out of Pleistocene deposits by melting blocks of thick dead ice, have been observed within the

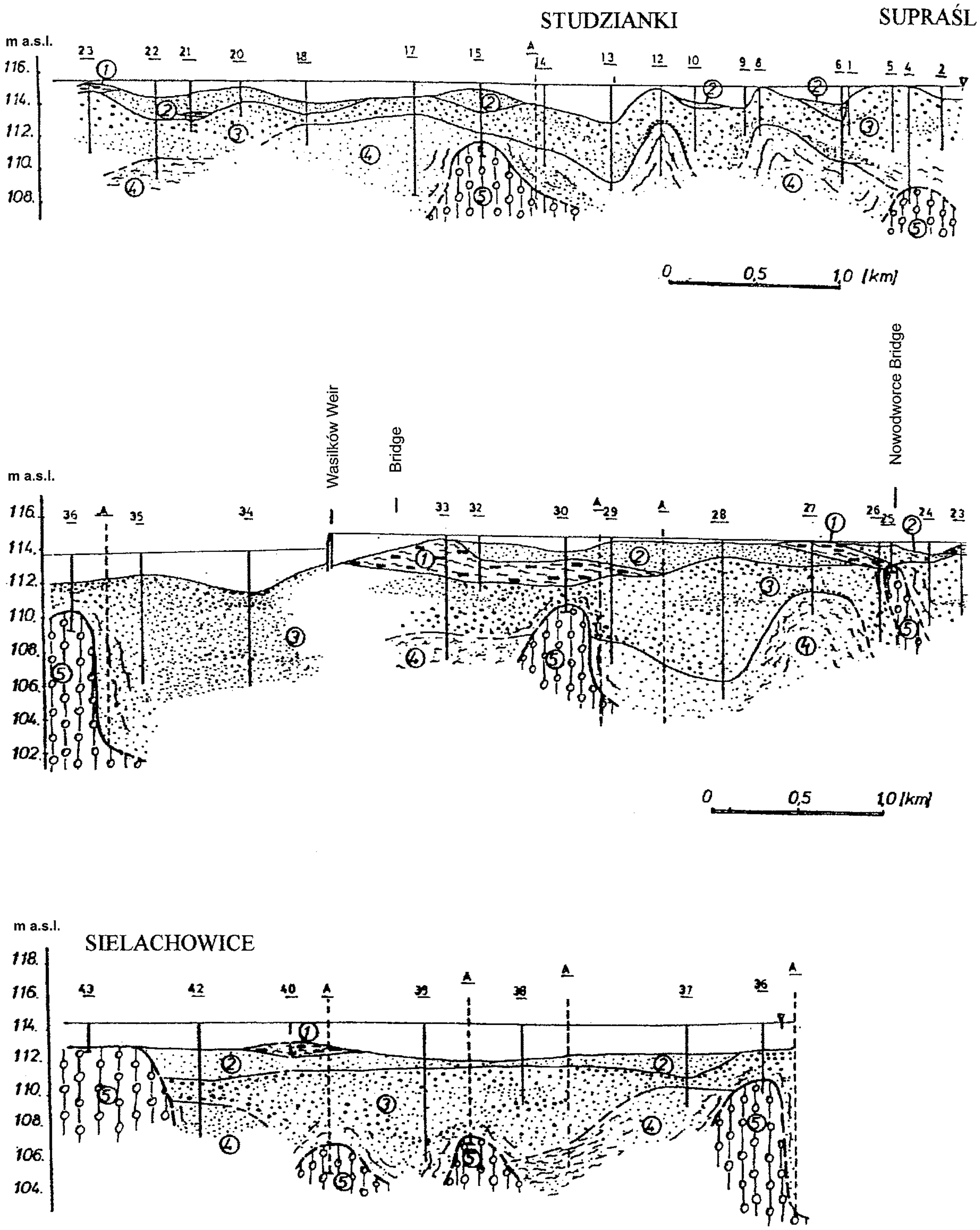

Fig. 10. Geological cross-section along the Supraśl river valley between Supraśl and Sielachowice (after: FALKOWSKI & al. 1992) 1 – mud, 2 – alluvial poorly sorted sand, locally with gravel, 3 – fluvioglacial deposits (sand with boulder, gravel), 4 – ice-dammed basins deposits (fine-grained sand, silty sand,, silt), 5 – glacial till, A – deep boreholes projected onto the line of the cross-section

plateau. A system of depressions and flat areas infilled with fine-grained (fine sand and silt) deposits, covered by mud and peat up to 1.7 m thick, developed between elevations within the plateau. They form the characteristic basin-like valleys of the tributaries of the Piwonia. Morphologically they are similar to the depressions and flat areas noted near Suraż. There, however, they occur some distance away from the valley, and the margin of the the valley is also much more distinct.

A vast kame terrace built of well-graded sand and gravel has been recognised near Parczew. It is overlain by slope and lake deposits (Text-fig. 6). About 4 km SW of the area presented on the geomorphological map (Text-fig. 5), the terrace crops out at the surface. Structures typical of this undisturbed geomorphological unit (cross stratification including sand, gravel and beds of sand mixed with gravel) are visible in the walls of a large gravel-pit. The kame terrace, however, is not continuous: it does not occur on the cross-section (Text-fig. 7) and does not have a hypsometric equivalent on the other side of the valley.

Slope wash deposits, which began to form in the Vistulian, are considered the most characteristic of the deposits in the Parczew area. They form a very thick cover (up to 2 m) in the form of sloping terraces supported by the organic soils of a dammed lake. They are composed of well-graded sand, silt and clayey silt. The material is strongly mixed. It contains horizons rich in organic matter, which represent the trace of a retreating lake basin.

According to Knyszyński (1980), Piwonia is a draining river, with outflow towards the NW, and with a fall of about 50 m. Due to the high content of peat and mud, as well as "fluvial-periglacial and lake-flooding" sediments in the subsurface part of the catchment area, infiltration of precipitation water is impeded (Knyszyński 1980). Peats are considered non-permeable, as the process of precipitation, water accumulation, and evaporation in dry periods takes place within them.

Supraśl river near Studzianki

The area is situated in the vicinity of the village of Studzianki near Białystok, within the range of the Wartanian Glaciation (Lindner & Marks 1995).

A narrow gorge zone between two large glacigenic lakes was observed there. After partial draining and infilling, the lakes were adopted for the river valley (Falkowska & Falkowski 1994, fig. 8). As in the Parczew area, a glaciotectonically and glacistatically deformed morainic plateau with varied morphology in the form of dead ice moraines, kame terraces as single shelves, side valleys of the Supraśl tributaries, as well as a basin-like valley bottom occur here. Marginal lakes of the plateau, which were not observed in the vicinity of Suraż and Parczew, are also present in the area (Text-fig. 8).

Fluvioglacial deposits – sands and gravels covered with muds and peats over 2 m thick (Text-fig. 9) and forming a lowland bog, 224 ha in area, occur within the valley bottom. The maximum thickness of peat in the area reaches 3.1 m, with a mean thickness of 1.4 m (Zimny 1957).

Recent sandy alluvial deposits of the river Supraśl represent a rather small part of the valley infilling. They include residual boulders and gravels, as well as small lobes of till. Strong glacigenic deformations were observed within the river channel (Text-fig. 10).

The plateau is characterised by a very complex geological setting as well as a varied morphology. Intense glaciotectonic and glacistatic processes initiated by the pressure of dead ice blocks generated during areal deglaciation, as near Suraż, caused extensive localised uplift and deformation. The contact forms of dead ice are built of gravel and sand, through silt, to clayey and sandy silt and clay. Xenoliths of chalk are also present (Zapiecek, Studzianki). Frequent depressions infilled with clays and silts, overlain by muds and peats occur between the elevations on the plateau. They represent ice-dammed basins originated after the melting of dead ice blocks. As a rule they have wide flat bottoms (Text-fig. 11). At present they are fragments of the "intermittent stream valleys – Supraśl tributaries" (Falkowska & Falkowski 1994). During the period of a non-drained postglacial lake system, ice-dammed forms such as ice-dammed terraces built of cohesive soils covered with peat were formed in the contact zones between the squeezed-out hills and the dead ice blocks.

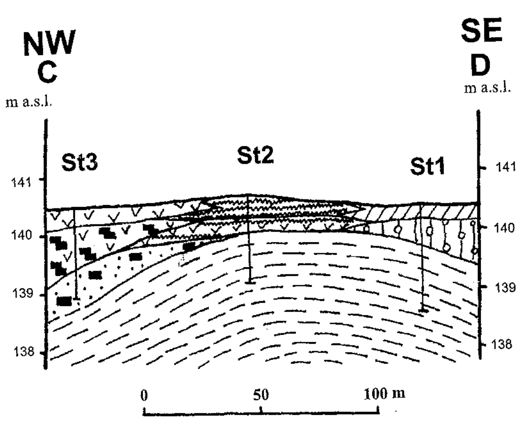

Fig. 11. Lithological cross-section through the ice-dammed basin within the plateau in the Studzianki area (explanation on Text-figs 3 and 9)

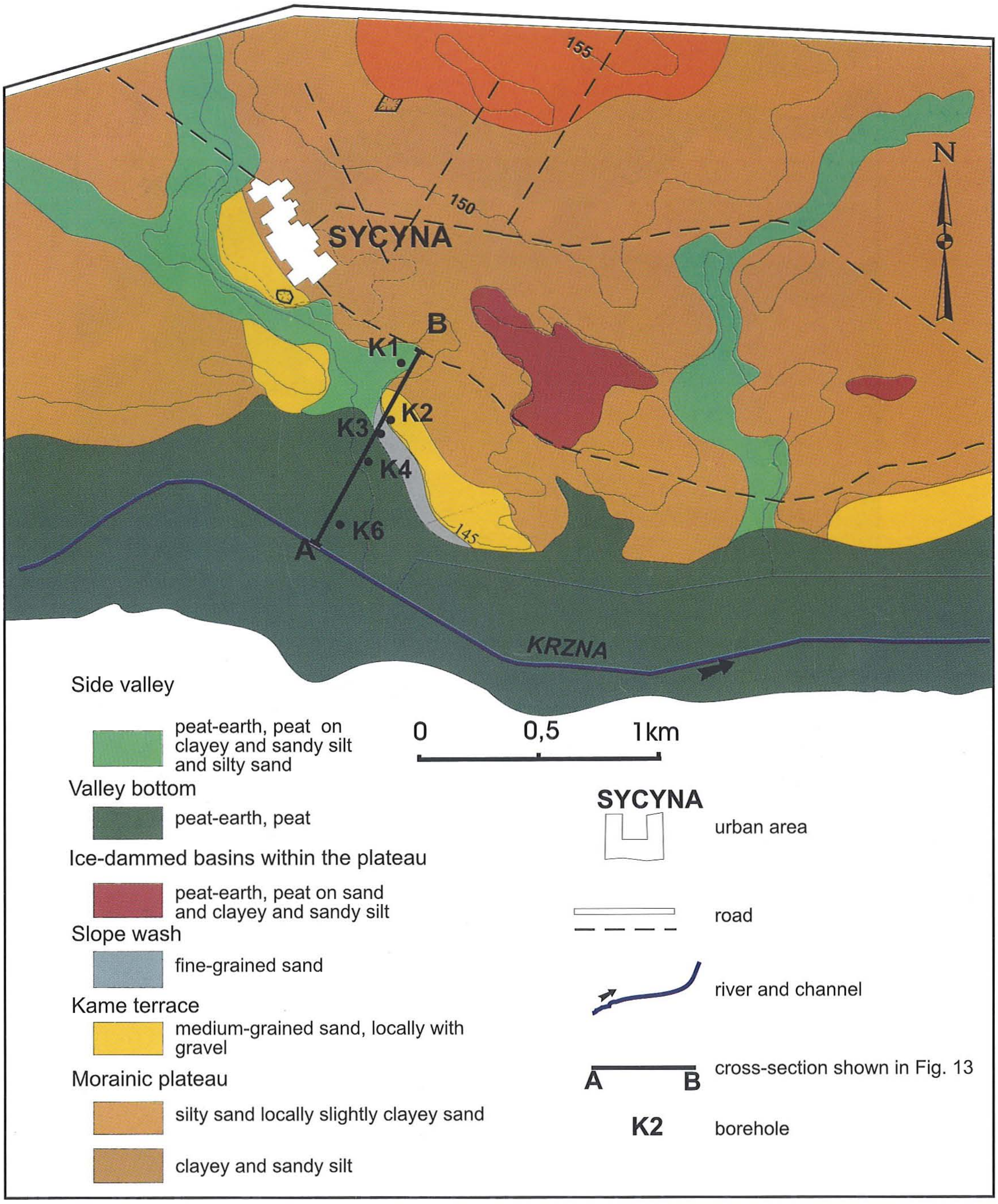

Fig. 12. Geomorphological map of the Krzna river valley in the Sycyna area

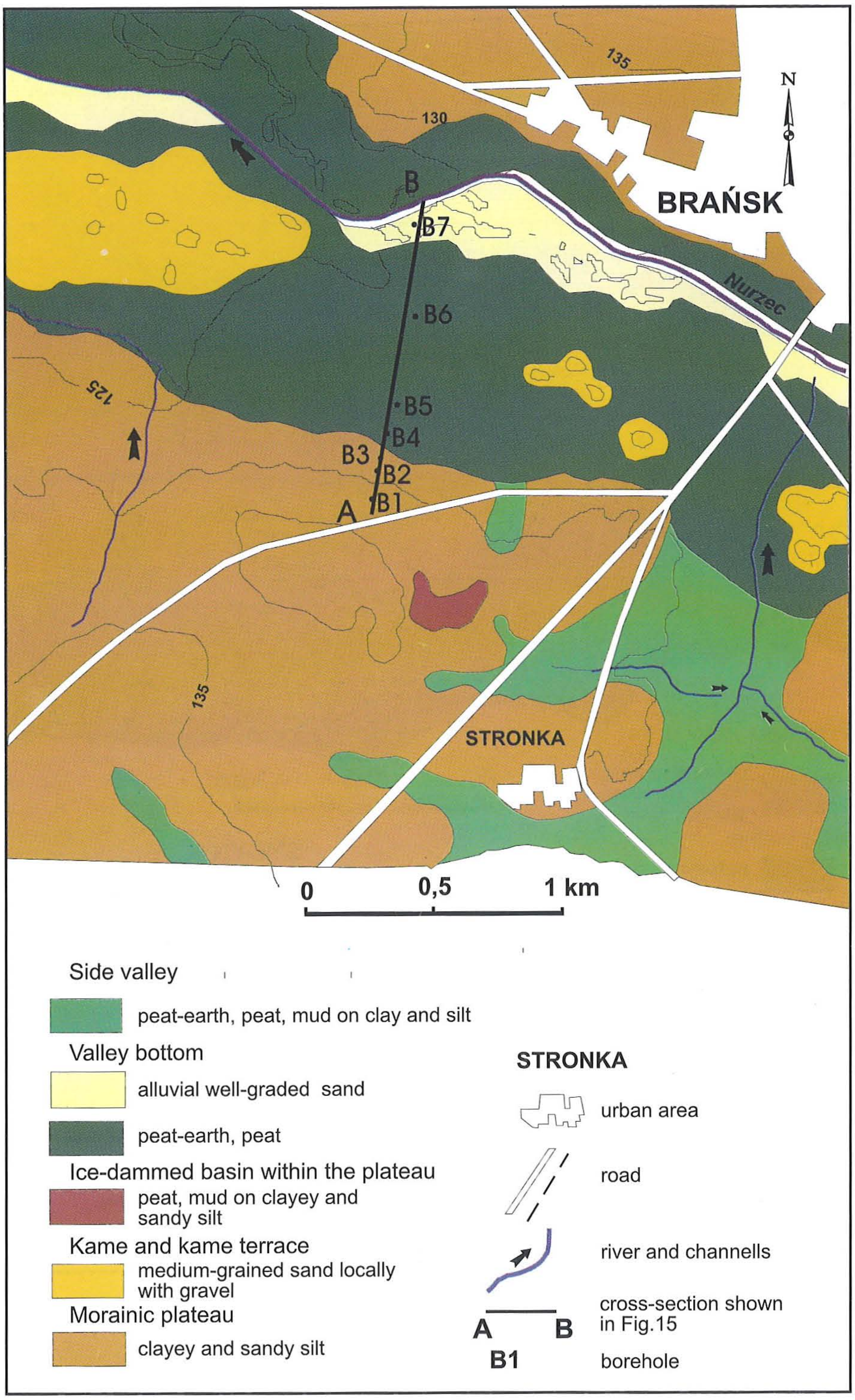

Fig. 14. Geomorphological map of the Nurzec river valley in the Brańsk area

Shelves of fluvioglacial terraces occur on the slopes of the plateau and do not have their hypsometric equivalents on the opposite side of the valley. Lithologically they include fine-, medium- and coarse-grained sands, commonly with gravels. Fluvioglacial deposits are typically covered by slope wash, represented by deposits with varying grain-size, depending on their origin, e.g. from flood deposits of glacial rivers.

Glaciotectonic deformations within the river valley (Text-fig. 10) and in the marginal zone of the valley complicate the hydrogeological conditions given for the main groundwater basin (MGB) by KLECZKOWSKI (1990). They can cause the formation of areas with a low groundwater flow rate and areas with a perched water table. According to FALKOWSKI (1994) the inflow of groundwater through the valley bottom in the Supraśl valley near Studzianki is rather difficult. MAŁECKI (1989), in turn, stated that deeper aquifers, isolated by till, connect directly with surface waters through zones of deep erosional cuts. According to him, the water table between moraines in the Supraśl valley is unconfined, whereas within the plateau the groundwater surface is confined.

Krzna river valley near Sycyna

The analysed area lies within the range of the Odranian Glaciation (LINDNER & MARKS 1995). It displays a similar geological setting and a similar origin to the area of Suraż, Parczew and Studzianki.

The extremely wide river bottom (flood plain), being an ancient basin formed after the melting of dead ice blocks, is infilled with a thick cover of organic deposits (Text-fig. 12). Their thickness reaches 2.5 – 3.0 m and increases towards the river channel (Text-fig. 13). They form a lowland bog with an area of 502 ha (ŁASZEK & DZIAK 1959). Fine white sands with undecomposed root fragments and, rarely, gyttja underlie the organic deposits. The sands are considered to be pre-Holocene, of Vistulian age. Sandy alluvial deposits of the present river Krzna lie within the lacustrine soils (FALKOWSKA 1998). However they are not clearly seen in the area, being masked by extensive improvements to the drainage carried out just before 1939. In turn, flood facies deposits influence the formation of peats with a lower organic matter content due to the increased mineral content.

The morainic plateau is composed of medium-grained sands, silty sands, clayey and sandy silt and clayey gravels. The varied depth at which gravels and clayey sand-gravels mix occur is particularly noteworthy. They were most probably deformed glacistatically, as in the case of the plateau, by sinking dead ice blocks. Silty sands, locally slightly clayey, as well as fine- and medium-grained sands predominate in the morainic plateau (Text-fig. 12). They form "accumulation" plains, flat, wide surfaces formed during the slow, stepwise disappearance of the ice-sheet (FALKOWSKI & *al.* 1988). During seasonal high water, waters flowing from the melting glacier caused floods and the sedimentation of fine-grained deposits. Continuous, illuvial hardpan horizons, about 10

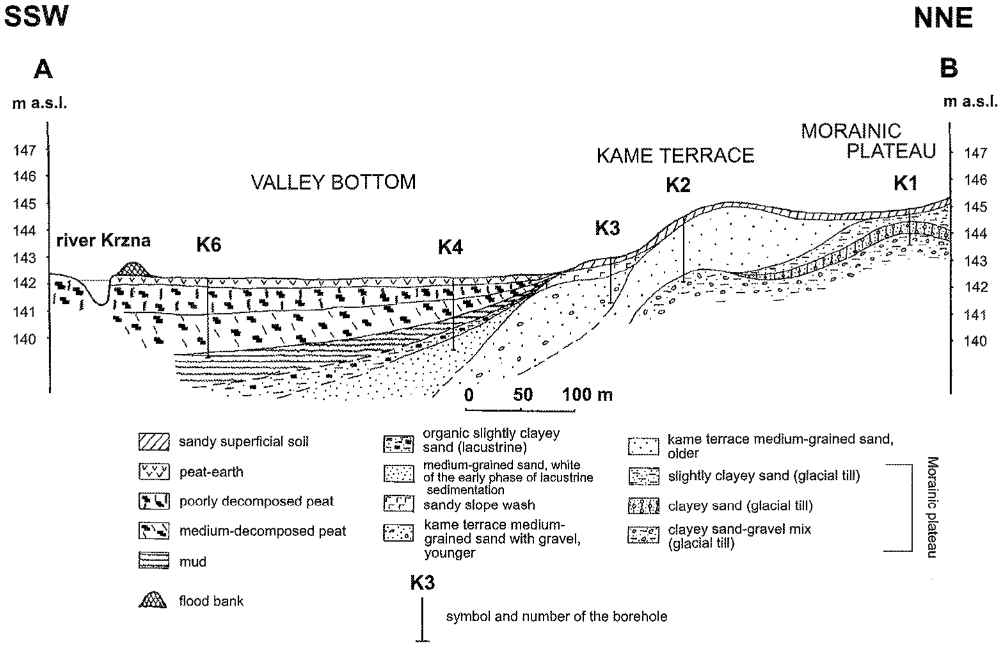

Fig. 13. Lithological cross-section through the Krzna river valley in the Studzianki area

cm thick on average, which can act as barriers against the migration of pollutants, were recognised within the sands. Hills composed of cohesive sediments (clayey and sandy silt, clayey sands and slightly clayey sands) also occur between the flat plains of the plateau. The morphology is additionally complicated by flat depressions infilled with clayey and sandy silt, silt and silty sand, overlain by organic deposits (mud, peat and peat earth). These can be linked genetically with structures on the plateau that formed after the melting of small dead ice blocks. A similar ice-dammed origin can be applied to deposits occurring in side valleys and represented by mud and peat, underlain by silt, clayey and sandy silt as well as silty sands. The side valleys are rather elongated and, at present, used by intermittent streams, tributaries of the Krzna (Text-fig. 12).

Kame terraces composed of medium-grained yellow and white sands, commonly with gravel, are present on the slopes of the plateau. They are not continuous (Text-fig. 12) and were formed in some marginal parts of the plateau. The two terrace shelves (Text-fig. 13) indicate a stepwise change in thickness of the dead ice block within the valley and a change in the flow rate of glacial rivers during deglaciation (FALKOWSKA 1998).

Organic soils play a crucial role in the geological setting of the investigated region. They cover a vast area and are usually very thick. KRAJEWSKI & *al.* (1985) noted that the Krzna has usually a draining character, although the drainage is impeded by the organic soil cover.

Nurzec river valley near Brańsk

In contrast to the area of Suraż, Sycyna, Parczew and Studzianki, the region of Brańsk, lying within the range of the Wartanian Glaciation (LINDNER & MARKS 1995), is characterised by the occurrence of valley kames. These originated during the splitting of dead ice blocks lying in future melt-out depressions. Short episodic streams of melt-water, carrying sandy material, used crevasses and thawings formed in ice blocks. The kames are typically composed of medium-grained sands, locally with interca-

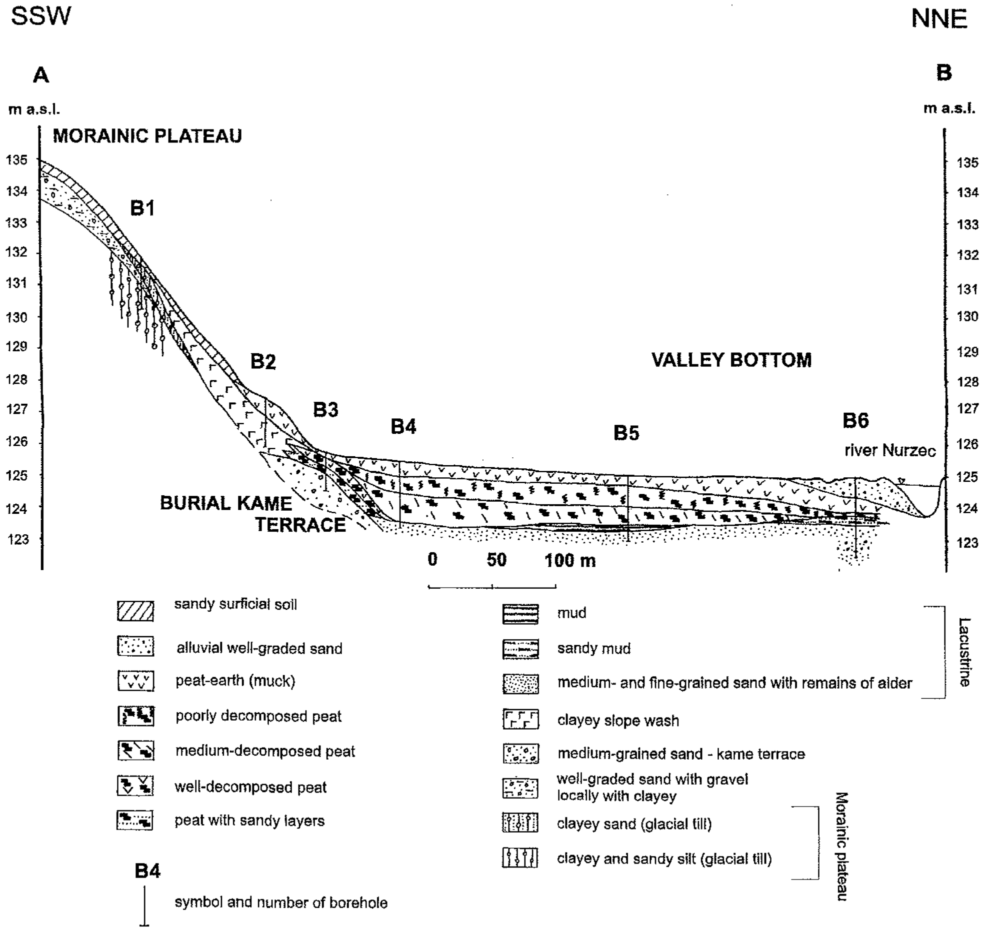

Fig. 15. Lithological cross-section through the Nurzec river valley in the Brańsk area

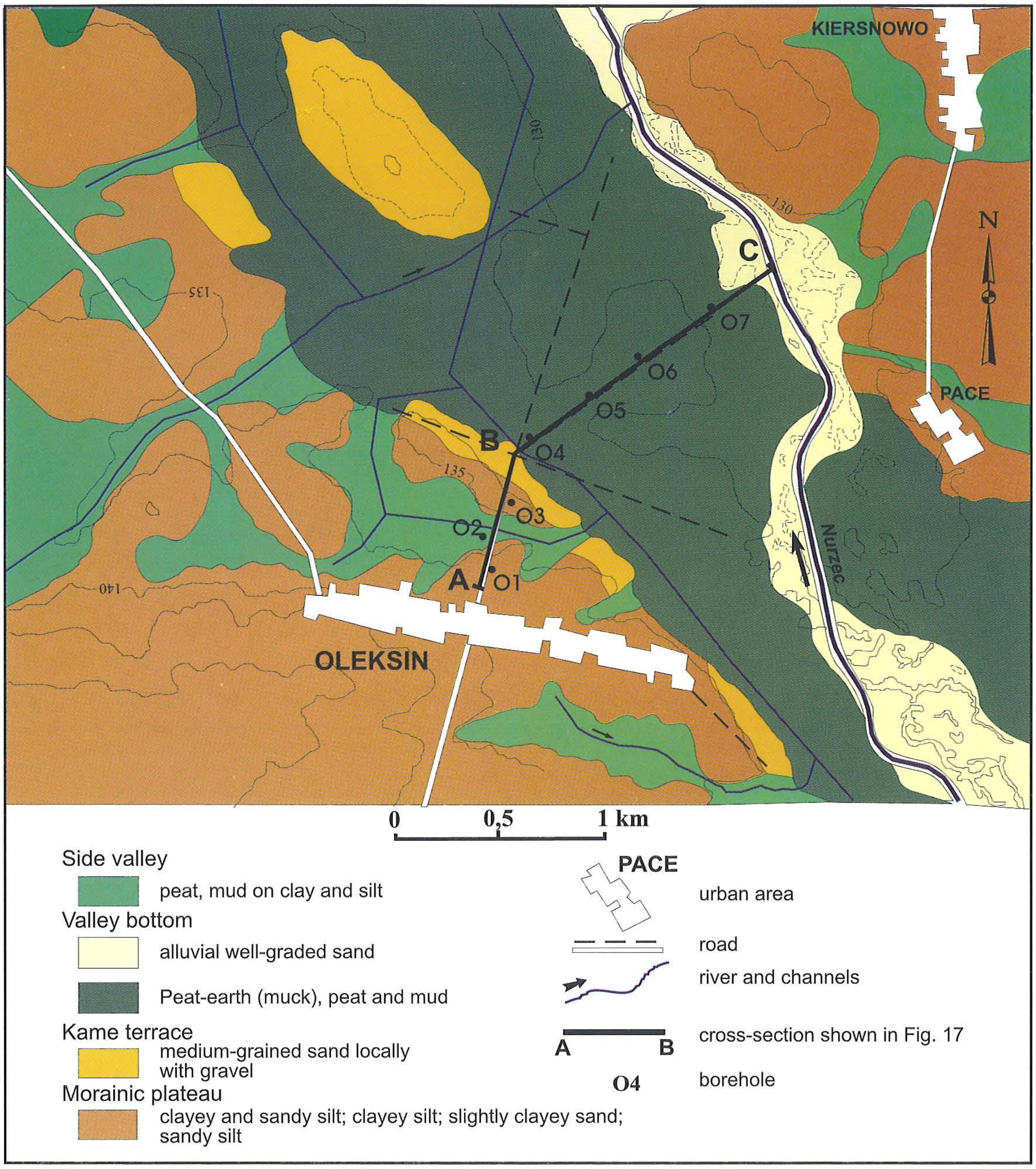

Fig. 16. Geomorphological map of the Nurzec river valley in the Oleksin area

lations of gravels and coarse-grained sands. The sands and gravels of the kames are locally exploited for aggregate.

The Nurzec valley bottom near Brańsk is infilled with lake and marsh deposits, forming recently a lowland bog with an area of 36 ha (ZAWADZKI 1957), improved between 1934 and 1939. The ancient melt-out basin is filled with peats with differing degrees of decomposition of the organic matter (ZAWADZKI 1957). At present the average thickness of the peats reaches 1.8 m, with a maximum measured value of 3.4 m (SIENKIEWICZ-DEMBEK & DEMBEK 1982). The upper part of the peat (up to 0.3 m) is usually changed into peat-earth. Muds and sandy muds occur locally below the peats (Text-fig. 15). The peats are underlain by fine and medium-grained sands with alder root fragments, deposited during the Vistulian Glaciation. Simultaneously with lacustrine sedimentation, deposition of poorly sorted alluvial sands took place. The rivers used a series of lake basins after dead ice blocks for their flow. Flood deposits caused an increase in the ash content of the peats.

The morainic plateau in the investigated area is composed of glaciotectonically strongly deformed clayey sands and cohesive clays. However, beyond the area shown on the geomorphological map, accumulation plains comprising silty sands, fine-grained sands and silts occur, as in the vicinity of Sycyna. Ice-dammed basins, representing traces of marginal lakes, containing clayey and sandy silts and silts overlain by peats and muds, have also been found in this geomorphological unit. They represent side valleys, covering large areas of the plateau, with an ice-dammed origin. As in the case of the previously described side valleys, they are used by intermittent streams, tributaries of the Nurzec.

In places shelves of kame terraces lie adjacent to the plateau slopes. They were drilled through by some boreholes in the line of the cross-section, as they are typically covered by lake deposits – organic soils and clayey deluvia. They reach up to 1.2 m on the plateau slopes (Text-fig. 15).

The Nurzec valley has a draining character throughout its course, while three aquifers occur in Quaternary deposits within its catchment area (FALKOWSKI, T. 1988).

Nurzec river valley near Oleksin

The Nurzec valley near Oleksin is situated within the range of the Wartanian Glaciation (LINDNER & MARKS 1995).

This area is characterised by a very wide valley with a bottom built of lake and marsh deposits (Text-fig. 16). The area is cut by a system of dewatering ditches, and, like the whole Nurzec valley, it was improved between 1934 and 1939. Peats were recognised in the melt-out basin. They form a vast lowland bog with an area of 2163 ha, in which the peat layer reaches a maximum thickness of 2.9 m, with an average thickness of 1.3 m (ZAWADZKI 1957). The peats lie on fine-grained white lacustrine sands (Text-fig. 17). Deposits probably representing

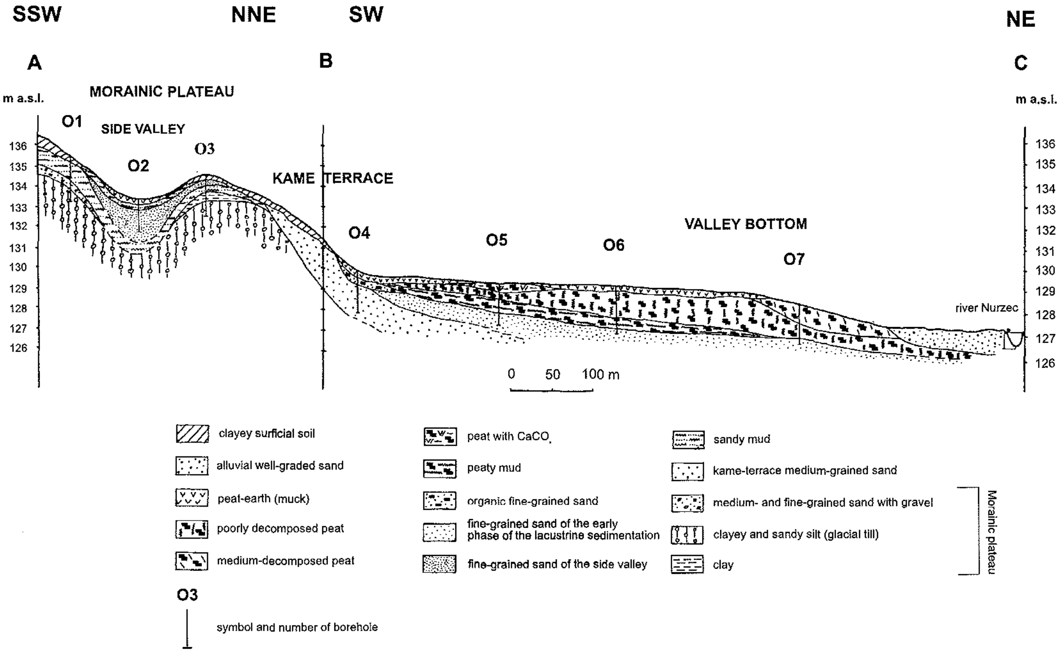

Fig. 17. Lithological cross-section through the Nurzec river valley in the Oleksin area

underwater slope wash, represented by muds and organic sands lying at the slope foot, accumulated in the shore zone of the ancient lake. Like the underlying sands, they are considered to be of Vistulian age. River alluvia form a dyke inserted into organic soils deposited in stagnant waters. Valley kames, similar to the ones described from the area of Brańsk, are also present within the valley bottom. Valley kames and kames occurring within morainic plateaux are very common in the whole area of Podlasie (MOJSKI 1972a).

The kame terrace bordering the plateau, as in the case of the one near Suraż, crops out only locally and is composed of well-graded sands. It originated during the flow of melt-waters in the zone between the ice block and the edge of the forming morainic plateau. It is often interpreted as the trace of an ice-marginal valley (pradoline) or as a river terrace formed during the Vistulian Glaciation. The ice in the valley caused squeezing out of the material towards areas already devoid of ice cover, and glacigenic deformations as described by KLATKOWA (1993) (Text-fig. 17). Traces of ice-dammed depressions, used by intermittent streams, have also been found within terrigenous deposits, as in the case of Parczew, Studzianki, Brańsk and Sycyna. Channel-like side valleys are infilled with clays, silts and fine-grained grey sand overlain by peats and muds.

As in the Brańsk area, the Nurzec valley has a draining character. Three aquifers within the Quaternary deposits are present here (FALKOWSKI, T. 1988). Due to the presence of cohesive soils, the inflow of waters from the plateau is impeded, particularly in the marginal parts.

LITHOLOGICAL FEATURES AND FILTRATION COEFFICIENT OF THE DEPOSITS

The investigations of the selected river valley sections have shown that the origin and lithology of their deposits, particularly in the valley bottom, are distinctly different from those of the hitherto commonly accepted models (Text-fig. 18).

The bottom of a melt-out river valley of postglacial origin is characterised by the following succession: peat (or peat earth) – mud – organic sand (medium-, fine-grained, clayey or sandy silt). Peat-earth (muck) and peat contain over 30% of organic matter[1], muds – 5 to 30% of organic matter, while organic sands contain 2 to 5% of organic matter. From the point of view of environment protection, organic deposits reaching an average thickness of 1.5 m, with a maximum of 5 to 7 m are very favourable. The clay fraction of cohesive soils consist mainly of beidelite and kaolinite. For sands the permeability coefficient exceeds 10^{-6} m/s, for peats it is below 10^{-6} m/s, while for muds the coefficient lies between 10^{-6} and 10^{-8} m/s.

The deposits of the plateau are characterised by the largest variation in grain-size and it has not proved possible to identify a typical lithologic succession. Sands as well as clays with a permeability coefficient lying between 10^{-4} and 10^{-12} m/s occur. The cohesive soils are additionally characterised by a varied clay fraction. Thermal and X-ray analysis showed the presence of beidelite, kaolinite, illite and chlorite admixtures, variably distributed regionally. Locally the deposits contain goethite and calcium carbonate. Cohesive soils also build marginal zones of the plateaux adjacent to the valley in Suraż, Brańsk and Oleksin, whereas in Studzianki, Parczew and Sycyna, non-cohesive soils (sands with a variable grain size) predominate.

Side valleys and ice-dammed basins within the plateau show a similar succession to the one described from the valley bottom, with cohesive soils representing the lower parts of the sequence. Typical successions include: mud – clayey and sandy silt; peat - clayey and sandy silt – clay; and peat-earth – peat – organic sand. The thicknesses of the organic deposits are much smaller that those of the organic deposits in the valley bottom. The permeability coefficient of the mineral deposits lies below 10^{-8} m/s for clayey and sandy silt and clay, and below 10^{-5} m/s for organic sand. The clay fraction includes kaolinite and beidelite. An admixture of calcium carbonate is a typical feature.

The lithology of deposits occurring on plateau slopes (slope wash deposits) is directly linked to the setting and lithology of the plateau. Slope wash deposits composed solely of cohesive soils occur near Brańsk. Genetically they are linked to mudflows, rather than to downwash processes. High water ice-dammed basins within the plateau or lake high water stages probably played a crucial role in their formation. As in the case of the plateau, a typical lithologic succession has not been recognised for the slope deposits. They comprise sands with a variable grain content to sandy and clayey silts with a clay fraction composed of beidelite, kaolinite and illite. Due to lithologic differentiation the permeability coefficient varies between 10^{-12} and 10^{-4} m/s. Organic beds are also present in the slope wash deposits.

The kames and kame terraces are composed of quartz-feldspar fine- and medium-grained yellow sands, with a medium permeability coefficient reaching 10^{-4} – 10^{-5} m/s. According to PAZDRO & KOZERSKI (1990) these deposits can be considered as soils with a medium permeability. They contain illuvial horizons that are very important for environmental protection. These horizons are cemented with Al, Fe and Mn oxides and with SiO_2 (hardpan) and form continuous covers, 7 cm thick on

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[1] organic matter content determined by the ignition loss method

Valley bottom	Side valley and ice-dammed basin within the plateau			Morainic plateau	Slope wash	Kame and kame terrace	Superficial soil
peat/peat-earth *(30 - 80%)** mud *(5 - 30%)* sand (fine-, medium-grained,slightly clayey sand, sandy silt) *(2-5%)* > 10^{-6} m/s	peat *(30-75)* clayey and sandy silt clay	peat-earth *(65 - 80%)* peat *(30 - 75%)* organic sand (2-5%) 10^{-5} m/s	mud *(5-30%)* clayey and sandy silt 10^{-8} - 10^{-10} m/s	clayey sand-gravel mix, fine-, medium-grained sand, silty sand, slightly clayey sand, silt, sandy silt, clayey and sandy silt, clayey sand, sandy and silty clay, sandy clay with silt, 10^{-4} - 10^{-12} m/s	fine-, medium-grained sand, sandy silt slightly clayey sand, clayey and sandy silt, clayey silt clayey sand sandy and silty clay, ⇒ organic laminae 10^{-4} - 10^{-12} m/s	sandy surficial soil 10^{-6} m/s sand > 10^{-5} m/s hardpan (slightly clayey sand) 10^{-6} m/s	sandy or clayey to 7% organic matter 10^{-5} m/s
beidelite kaolinite, $CaCO_3$	kaolinite, beidelite + $CaCO_3$			beidelite, kaolinite, illite chlorite admixture, gethite, $CaCO_3$	beidelite, kaolinite		

* - percentages

Fig. 18. Typical successions of the analysed geomorphological units

average. They form a barrier against the migration of pollutants because, as slightly clayey sands with a clayey-ferruginous cement, they decrease the horizontal flow of solutions through the soil, and are more chemically active. Their permeability coefficient reaches 10^{-6} m/s. Hardpan horizons are also present in accumulation plains of the plateaux, particularly in their upper, silty part.

An additional element isolating groundwater from pollution is superficial soil. It forms a generally compact cover with a mean thickness of 0.3 m. The soil covering kame terraces is only about 0.1 to 0.2 m thick. It contains up to 7% of organic matter, determined by the ignition loss method.

Superficial soil occurring in the regions under discussion is cohesive as well as sandy. It comprises fine- and medium-grained organic sands and slightly clayey sands and clayey sands with a clay fraction of 5 to 16% and a permeability coefficient reaching an average of 10^{-5} – 10^{-6} m/s. In a few cases superficial soils contain calcium carbonate, albeit in rather small amounts.

PROTECTION POTENTIAL OF DEPOSITS BUILDING THE INVESTIGATED RIVER VALLEYS AND ADJACENT ZONES

The potential of soils occurring in river valley bottoms and in adjacent zones to act as protection barriers against pollution largely depends upon their sorption properties. These properties include the potential of soils to retain pollutants, as well as the adsorption and absorption of various compounds hazardous to human health. They also include the retention durability of these pollutants by the sediment, that is their low liability to desorption.

Poorly permeable deposits, such as silty and clayey deposits, as well as peats and muds, form natural barriers to groundwater flow, playing a positive role in restricting the migration of pollutants to groundwater, a feature that was emphasised by Witczak & Adamczyk (1994). Pollution sorption by the aquifer material causes a delay in migration in relation to water flow, which can be roughly evaluated when the distribution coefficient K for the sorption isotherm is known (Buchter & *al.* 1989; Osmęda-Ernst & Witczak 1991a, b). The concept of retardation of migration (the retardation factor - R) is applied to determine the horizontal migration time in the aquifer as well as the vertical migration time through the aeration zone (Witczak & Adamczyk 1994).

The parameter that can be used as a measure or indicator of soil sorption potential, and of the potential of the deposits to retain various pollutants, is the cation exchange capacity (CEC). It determines the number of cations that can be adsorbed by the sediment with a simultaneous transfer of an equivalent number of cations to the solution. During the exchange reaction a dynamic equilibrium state is established between the number of cations in the sorption complex and the number of cations in the solution. Bache (1976) considers the CEC value as an equivalent of the negative charge of the sediment. This parameter is expressed as milliequivalents/100g of soil.

A test method, developed by Sapek (1979, 1986) in the Institute of Land Reclamation and Grasslands Farming at Falenty near Warszawa, and based on the measurement of copper sorption, was used to determine the cation exchange capacity of the investigated deposits. In the case of sands, this method gives slightly higher values than those obtained by other methods of determining the CEC. Additional, control determinations of the total of alkaline cations and hydrolithic acidity of kame sands revealed a difference in values not exceeding 4 meq/100 g of soil.

CEC determinations were carried out on 140 soil samples that had been previously selected for laboratory analysis. The determinations were repeated three times, and the difference between the obtained values did not exceed 5%. The values vary from 8 (for medium-grained sand) to 156 meq/100g of soil (for peat).

Cation exchange capacity (CEC) of investigated sediments

The above-mentioned analyses related to effective cation exchange capacity, i.e. occurring in natural pH environments. pH was therefore additionally determined for all of the sediments in question. For peats, pH varied between 4.8 and 7.3, and for mineral deposits between 5.8 and 8.6. This parameter determined the sorption potential of deposits.

Peats and peat-earth (muck) in valley bottoms, and in side valleys and ice-dammed basins within the plateau, show the best sorption potential (Text-fig. 19). They possess particularly high CEC values, reaching an average of 120 meq/100 g of soil (maximum > 150 meq/100g of soil). The CEC of peats increases linearly (correlation coefficient 0.87) with increasing content of organic matter (Text-fig.20). Muds in the valley bottoms are characterised by slightly lower CEC values than those of peats (Text-fig. 19). Nevertheless the values are favourable, as the CEC reaches an average of 62 meq/100 g of soil (max 110 meq/100 g of soil). Peats and muds are typically characterised by the ability to act as buffers, retaining a constant pH level despite the addition of acid or alkali. Within the valley bottom, only the fine- and medium-grained organic sands have rather small CEC values. They, however, form only the lowermost part of the succession. Thus, it may be concluded that the origin of deposits infilling inherited valley bottoms produces the effective protection cover with high and stable sorption potential.

Deposits in side valleys and ice-dammed basins within the plateau can be considered as an effective zone for capturing pollutants because of their sorption potential. The peats and muds occurring there have similar CEC values to those of the organic deposits of the valley bottom. The CEC of the peats reaches an average of 115 meq/100 g of soil, and that of the muds an average of 56 meq/100 g of soil (Text-fig. 19). Clayey and sandy silts and clays occurring in the lowermost part of

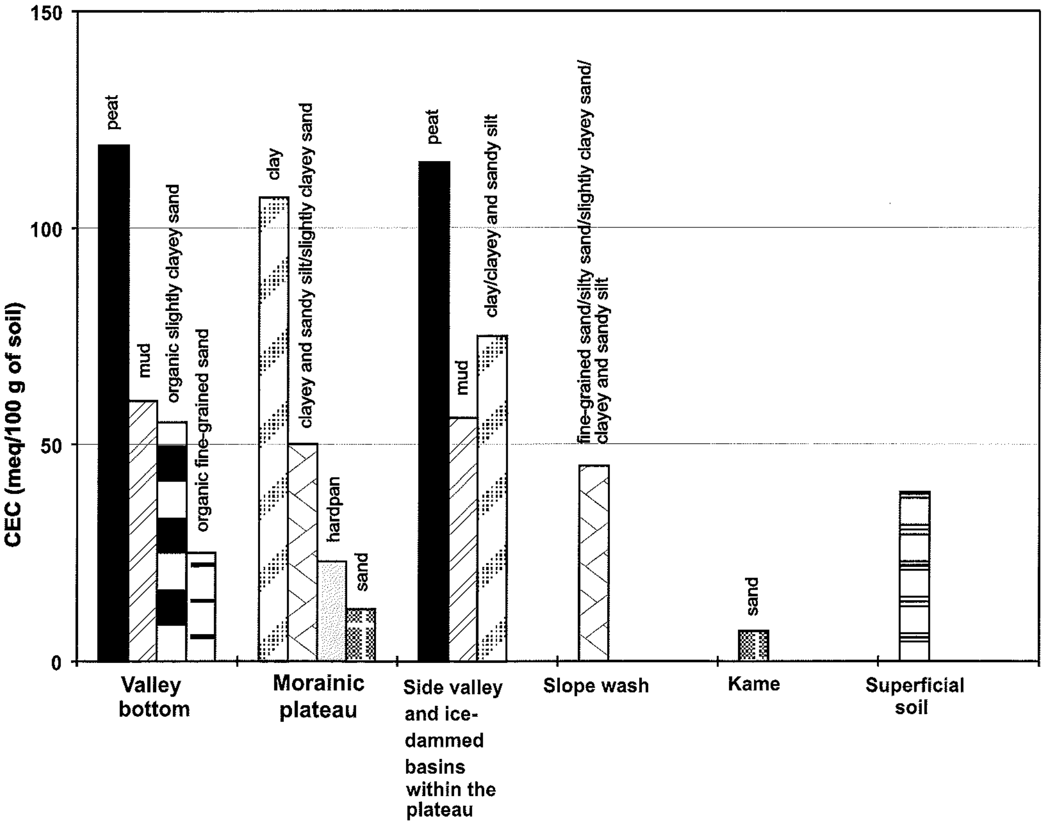

Fig. 19. Cation exchange capacity (CEC) mean values for deposits of the analyzed geomorphological units

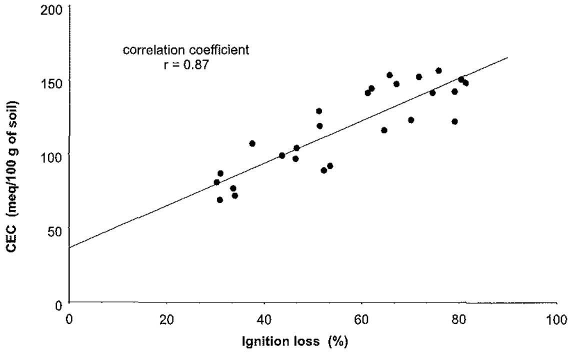

Fig. 20. Relationship between CEC and organic matter content

this geomorphological unit have higher CEC values of 38 to 157 meq/100 g of soil.

The plateau is an area with the largest lithologic variability, with soils characterised by both high and low CEC values (Text-fig. 19). Soils within the plateau with high CEC values include clays with CEC values between 80 and 153 meq/100g of soil as well as slightly clayey sands, clayey and sandy silts, clayey sands, mainly tills, reaching a CEC value of 50 meq/100 g of soil. These soils can therefore also play an important role in the protection of groundwater against pollutants. Sands building the plateau reach an average CEC value of about 8 meq/100 g of soil. The sand deposits of the plateau also contain hardpan horizons, which are similarly characterised by lower CEC values. As continuous layers within sandy soils, despite rather low sorption potential (23 meq/100 g of soil) they can counteract the lateral migration of pollutants.

The sorption potential of slope wash deposits depends upon their mineral content and grain-size. These are content is linked to the geological setting, particularly the lithology of the plateau, from which the slope deposits originated.

Sands of kames and kame terraces have the poorest potential to retain pollutants. Nevertheless these deposits are not completely chemically inert to all pollutants. Their CEC reaches values from 2 to as high as 15 meq/100 g of soil. Hardpan horizons are also present within them.

Superficial soils reach CEC values between 19 and up to 100 meq/100 g of soil. Because of their continuous cover they can play a crucial role in the protection of groundwater against pollution.

Sorption of lead, cadmium and copper

Binding of heavy metals in soils is a very complex event, involving ion exchange as well as chemical, physical, mechanical and biological sorption (PITTMAN & *al.* 1994, VELDE 1995, JACKSON 1998).

Heavy metals are retained in the sediment mainly by clay minerals, organic matter, calcium carbonate and oxides and hydroxides of iron and manganese, i.e. by sediment components influencing CEC values. The mechanism and degree of heavy metal binding by these components is variable (BOLT 1978, FIC & ISENBECK-SCHRÖTER 1989, PETTERSSON & *al.* 1993, SHINE & *al.* 1995).

Thirty-seven soil samples, representative of each geomorphological unit, were selected for detailed laboratory analysis of sorption.

Cadmium, lead and copper were selected for the determination of the sorption of heavy metals by soils forming an effective cover protecting groundwater. These metals are good indicators of the potential of sediments to retain particularly hazardous pollutants – toxic compounds.

Sorption of Cd^{2+}, Cu^{2+} and Pb^{2+} ions of selected soil samples was carried out by means of the "batch" method, applying solutions of nitrates of these metals with a variable input concentration – c_0. For lead, the applied concentrations were 5, 10, 20, 50, 100 mg Pb/dm^3 and, in some cases, in order to obtain a saturation concentration, also 500 mg Pb/dm^3. Cadmium was applied with 1, 5, 10, 20, 50 mg Cd/dm^3 solutions to soil samples, while sorption of copper was checked using solutions with concentrations of 50, 100, 200, 400, 600 and 1000 mg/dm^3 and, in some cases, also 800 mg/dm^3. A saturation concentration for copper was obtained for most soil samples.

To determine the sorption of ions of particular metals, 1 g of an air-dried soil sample was soaked for 24 hours in a water solution of Triton X-100 to improve its wettability. After removal of Triton X-100 with a water pump, 50 ml of the input solution of a particular concentration was applied. This suspension was then shaken for 4 hours. After 24 hours, when the equilibrium state was reached, the water solutions were separated in a centrifuge, followed by filtration using a medium filter. In the case of Pb and Cd, the equilibrium concentration was determined using the spectrophotometric and ASA method, while for Cu the potentiometric method was used. As a control, a few determinations of metal concentration were carried out using the ASA method. For most of the solutions the pH was also determined. Sorption of heavy metal ions (S) was calculated from the difference between their concentrations in solutions prior to and after the analyses, that is from the difference between the input concentrations and the equilibrium concentration. The sorption was expressed as % of absorbed heavy metal ($S_{\%}$).

The content of ions of Na, K, Ca and Mg dislodged by heavy metals was determined in selected samples in equilibrium solutions.

Analysis of the results of Pb, Cd and Cu sorption

Deposits forming the bottoms of river valleys, as well as side valleys and ice-dammed basins within the plateau, particularly peats, have the highest potential to bind heavy metals. Only slightly clayey organic sands bind smaller amounts of Cu, nevertheless, even in this case sorption exceeds 75%. Peats and muds retain > 99% of this metal (Text-fig. 21). Sorption in this case takes place mainly as a reaction of cation exchange of calcium, magnesium, potassium, sodium and hydrogen. Generally, the potential of retaining Cd, Pb and Cu in such a sequence of deposits occurring in valley bottoms and in side valleys as well as ice-dammed basins within the plateau are very high. As in the case of CEC, the potential of peats to bind particular heavy metals increases with an increasing content of organic matter (Text-fig. 22).

The deposits building the plateau are characterised, as in the case of the CEC, by a varied potential to absorb heavy metals (Text-fig. 21). Clays absorb > 99.8% of Pb from solutions with lower input concentrations, and similar amounts of Cd and Cu. Slightly clayey sands, clayey and sandy silts, clayey sands – mainly tills, can also intercept very large amounts of heavy metals, although to a smaller degree. Within clays, as well as within deposits with a smaller clay fraction, the environment pH can induce precipitation of hydroxides of Cd, Pb and Cu. The sandy deposits of the plateau bind heavy metals to a lower degree, particularly when solutions with higher input concentrations are applied.

The analysed heavy metals were bound least by the sands of kames and kame terraces, because in the case of Pb sorption exceeds 70% (Text-fig. 21). These deposits are not, however, inert against different pollutants. According to the investigations of Helios-Rybicka & Kyzioł (1991) and Kyzioł (1994), in lower concentrations, i.e. up to 1 mg/dm^3, ions of Cd, Pb as well as Cu are completely sorbed by sands. Differences in the degree of sorption of these heavy metals occur with higher concentrations. These deposits intercept lead and copper best. Values of sorption from a 20 mg/dm^3 solution, presented by Kyzioł (1994), reach 11.5 mg/100g of soil for Cd, 17.6 mg/100 g of soil for Cu, and 19.6 mg/100 g of soil for Pb. The presence of calcium carbonate and oxides of Fe, Al and Mn improves their sorption potential (Davis & *al.* 1987). Similarly, Pleczyński (1988) noted that with increasing depth in a sandy succession, the concentration of heavy metals decreases, while the surface layers of

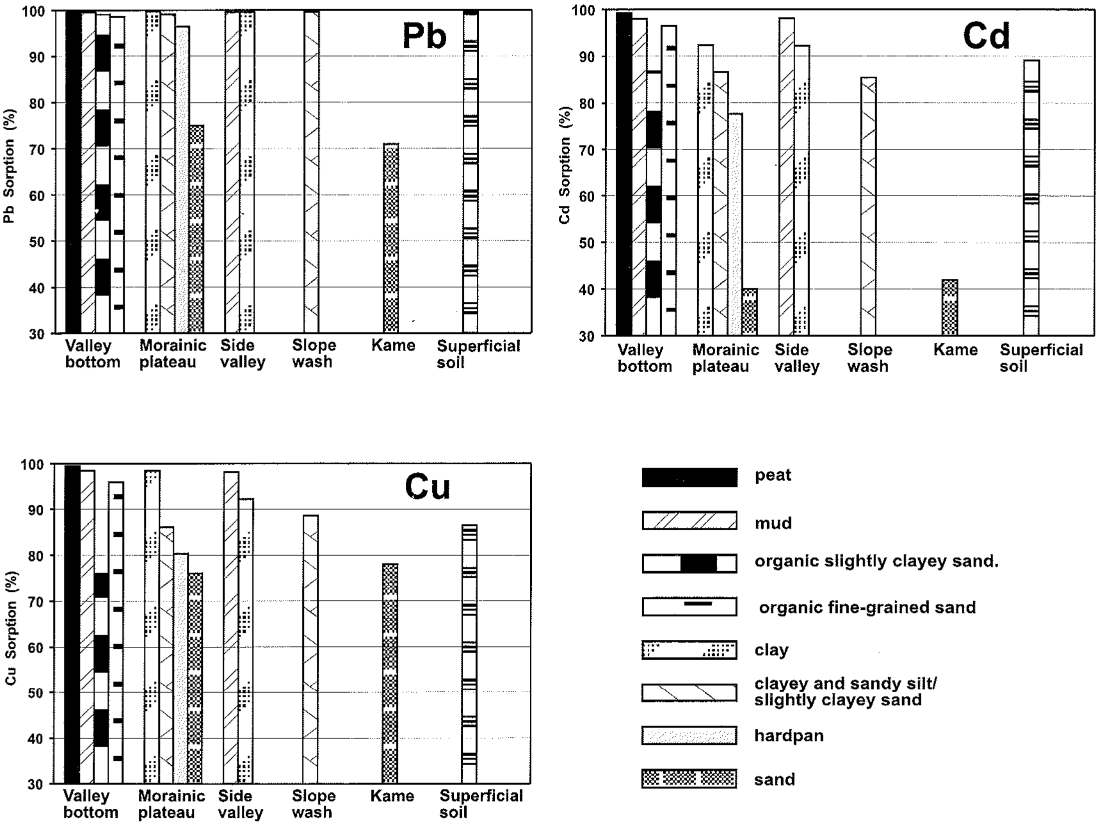

Fig. 21. Example of Lead (Pb), Cadmium (Cd) and Copper (Cu) sorption by the investigated deposits at an input solution of 50 mg/dm^3

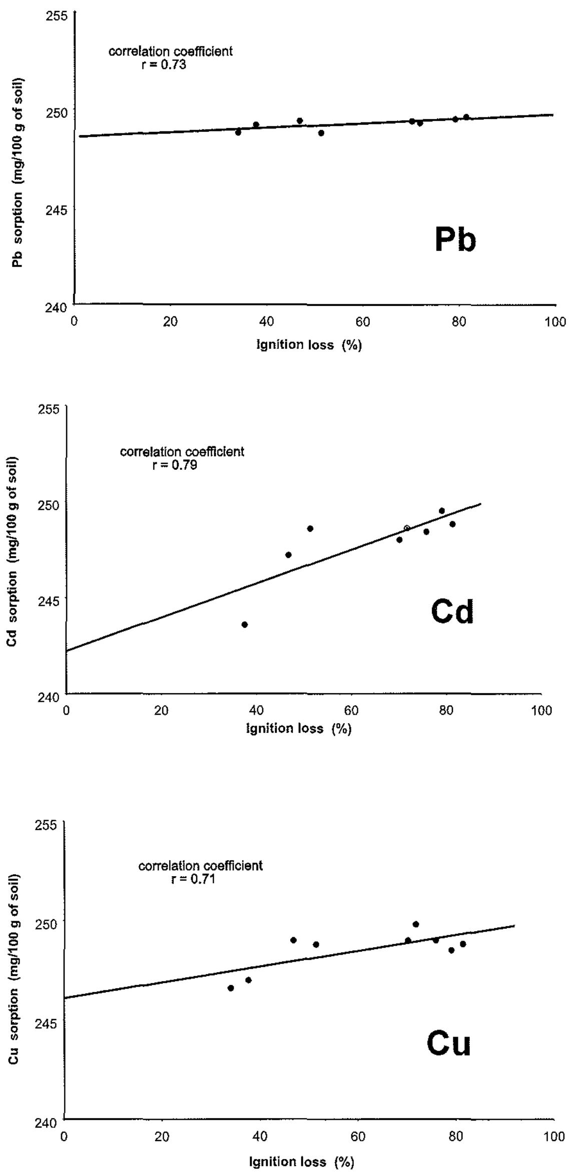

Fig. 22. Relationship between sorption of Pb, Cd, Cu and organic matter content

sand (from 0.1 to 0.15 m) sorb an average of 70 – 90% of these metals. The results of analysis of the sorption potential of kame terraces can be also applied to the sandy alluvial soils of the investigated valleys.

Superficial soils reveal much lower potential to absorb heavy metals in comparison to peats, muds and clayey and sandy silts, however the investigated samples absorbed over 99% Pb, 89% Cd and > 86% Cu (Text-fig. 21).

The sorption potential of alluvial and dune sediments were not analysed becouse these sediments are represented to only a small extent in the regions investigated. However, the investigations of KONECKA-BETLEY & *al.* (1994) indicate that the mineral horizons of soils developed from alluvial deposits are much richer in all components than those developed from aeolian deposits. The latter are characterised by an acidic reaction, low sorption capacity and a low degree of precipitation with alkali (KONECKA-BETLEY & *al.* 1994). In the humus horizon these characteristics are slightly higher: heavy metals therefore concentrate there, with their content decreasing with depth.

With an increase in the input concentration in each sample of each type of soil an increase in sorption S values is observed along with a decrease in the percentage of the sorbed metal. This is consistent with the observations of SAPEK (1980) for sorption of copper by peat-earth soils from the "meliorated peat areas" of Wizna and Kuwasy.

During the analyses, the content of Ca, Mg, Na and K ions dislodged from the sorption complex were additionally determined in selected equilibrium solutions after Pb sorption. The pH of these solutions was also tested. In the case of peats, the pH of equilibrium solutions exceeds the value beyond which precipitation of hydroxides of the particular metal takes place. For selected samples the pH reaches values from 8.39 to 8.04 and from 7.28 to 7.01. The presence of organic matter, which is a strong complexing agent, may counteract the formation of these compounds. With an increase in concentration of the input solution concentration, the pH of the equilibrium solution after sorption of peats decreases. This indicates an increasing number of dislodged hydrogen ions. As in the case of the H^+ ion, the concentration of Ca^{2+} and Mg^{2+} ions increases in the equilibrium solution, whereas the number of dislodged Na^+ and K^+ ions is stabilised and does not depend on the input concentration. As with the peats, during heavy metal sorption by muds the pH of the equilibrium solution decreases with an increase in input concentration, and the content of magnesium and calcium ions increases. The determined content of sodium and potassium ions remains relatively stable.

In equilibrium solutions after Pb sorption, a pH decreasing from 8.00 to 7.58 (for input concentration of $100mg/dm^3$) has been determined for a sample from the plateau, which points to an increase in H^+ content. An increasing concentration of Ca^{2+} ions, as well as Mg^{2+} ions was found, together with a slight increase in Na^+ and K^+ concentrations.

Migration retardation and Pb, Cd and Cu sorption intensity

Experimental heavy metal sorption isotherms were prepared for each sample during analysis of sorption for selected heavy metals by applying the HENRY or

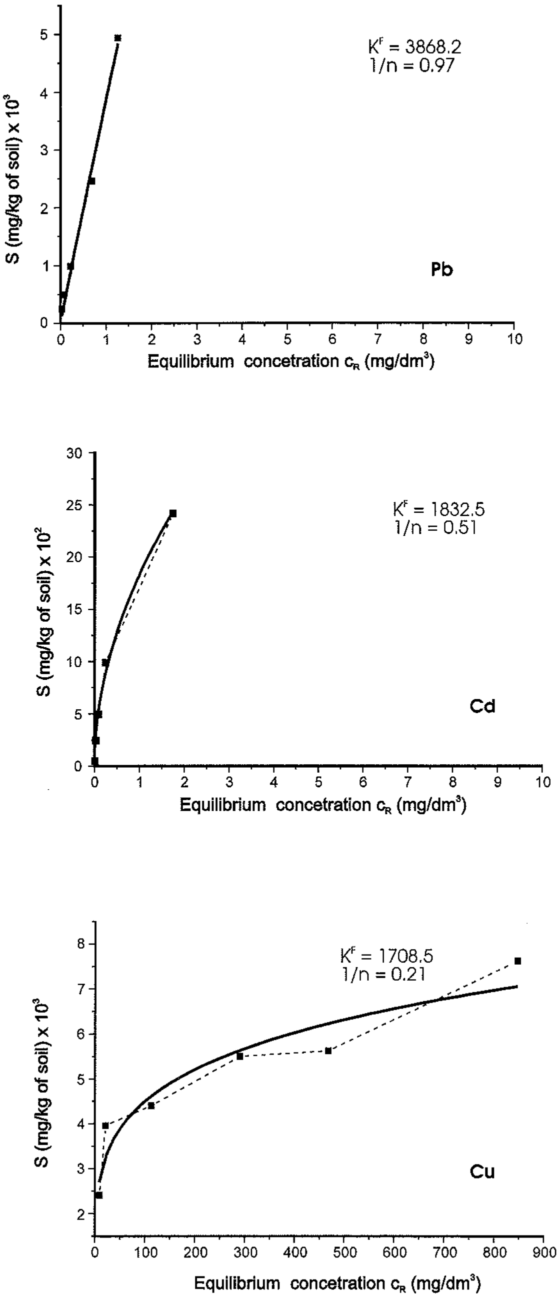

Fig. 23. Experimental and calculated sorption isotherms for organic fine-grained sand

Freundlich model, on the assumption that the concentration of the investigated heavy metals in equilibrium solutions in comparison to soil without heavy metals are low enough to be neglected (Bolt 1979; Osmęda-Ernst & Witczak 1991a, b; Appelo & Postma 1993).

The Freundlich isotherm equation is as follows:

$$N^X = K^F c_R^{\frac{1}{n}}$$

N^X - equilibrium solution of the sorbed element in soil (mg/kg)

c_R - equilibrium solution of the sorbed element in aqueous solution (mg/dm^3)

K^F - constant characterising sorbing area of soil (dm^3/kg)

n - constant characterising relationship between soil and sorbed element (non-dimensional)

The Henry isotherm equation is as follows:

$$N^X = K_d c_R$$

K_d - division coefficient (dm^3/kg)

Text-fig. 23 presents experimental and calculated sorption isotherms. In the case of peats occurring in the valley bottom and in side valleys and ice-dammed basins within the plateau, in spite of a very high input concentration, saturation with lead and very often with copper was not obtained. Singular samples were saturated with cadmium.

The effect of sorption on the migration of pollutants can be expressed by the retardation factor R. The rate of migration for the element undergoing sorption is R times slower in comparison to the natural groundwater flow rate (Osmęda-Ernst & Witczak 1991a, b). Its value depends on such parameters as porosity and bulk density of the soil skeleton. The following relationship occurs in the Henry model:

$$R = 1 + \frac{\rho_d}{n_0} K_d$$

ρ_d - dry density (Mg/m^3)

n_0 - active porosity of the medium (non-dimensional). Active porosity was not determined during analyses, in calculations using total porosity:

$$n = \frac{\rho_s - \rho_d}{\rho_s}$$

ρ_s - *particle density* (Mg/m^3)

The obtained retardation factor values are low, because porosity occurs in the denominator of the equation. However this does not significantly affect the calculation.

Estimation of the retardation factor R for the process described by the Freundlich isotherm is possible for a particular equilibrium concentration of the element undergoing sorption in the solution. In this case it is essential to determine a substitute division coefficient - K^F_d

$$K^F_d = K^F c_R^{1/n-1}$$

The retardation factor R is then calculated from the equation:

$$R = 1 + \frac{\rho_d}{n_0} K^F_d$$

The value of the retardation factor, calculated from parameters of the sorption isotherm, allows estimation of the degree of hazard from the substance undergoing sorption, while sorption intensity, treated as a soil characteristic, can be classified on the basis of calculated retardations (OSMĘDA-ERNST & WITCZAK 1991b). A classification of this type was presented by WITCZAK (1984) (Table 1).

The retardation factor R was calculated based on the determined sorption isotherms of cadmium, lead and copper for the analysed soils.

For sediments of the valley bottom, as well as of side valleys and ice-dammed basins within the plateau, the sorption intensity for the analysed heavy metals is unlimited, as R considerably exceeds 1000 (Table 2).

Retardation factor R	Sorption intensity
1 - 2	Low
2 - 10	Medium
10 - 100	High
100 - 1000	Very high
>1000	Unlimited

Tab. 1. Classification of sorption intensity on the basis of the retardation factor R (WITCZAK, 1984)

Only some mineral soils with a lower content of the clay fraction in the case of Cu sorption can be classified as sediments with very high sorption intensity (R between 100 and 1000).

The sediments of the plateau have varying sorption intensity. For cohesive soils the sorption intensity is unlimited, as for sands the parameter varies from small to very high values, particularly in the case of cadmium and copper sorption.

Similar results as those for the plateau have been obtained for slope wash deposits. Clayey and sandy silts, slightly clayey sands, organic sands and sands with hardpans have very high sorption intensity, whereas clays, sandy and silty clays and sediments with $CaCO_3$ have unlimited sorption intensity.

In the case of lead, superficial soils have unlimited sorption intensity (R exceeding 1000). For cadmium and copper, R lies between 100 and 1000, thus the sorption intensity of these metals by soils is very high or unlimited.

The sands of kames and kame terraces have small and occasionally high sorption intensities against all

Sorption intensity		**Low**	**Medium**	**High**	**Very high**	**Unlimited**		
Valley bottom	**Pb**					● ●● ● ▲●	●▲ ▲ ●●■▲▲■ ●▲ ●▲	
	Cd				●	▲▲●▲ ● ■ ▲●▲■▲ ● ▲ ●●●●		
	Cu				■	●● ● ■▲● ●▲ ● ▲ ●	● ●▲▲●● ▲ ▲	
Morainic plateau	**Pb**		xx	x	x	■■	■ ■○ ○ ○	○ ○
	Cd	xxx	x	x x xx	x x ■	○■ ■○ ○ ○	○ ■	
	Cu	xx	x x	x xx	■	■○■○ ■	○ ○○	
Side valley and ice-dammed basins within the plateau	**Pb**						■ ▲■▲ ●	○
	Cd					■ ▲■ ▲ ●	○	
	Cu				■	●	▲▲○	
Slope wash	**Pb**			■			■ ○	○
	Cd				■	○○		
	Cu				■		○	○
Kame	**Pb**		x	x				
	Cd	xx		xxx	x xxx	x x		
	Cu	x		xxx				
Superficial soil	**Pb**						■ ■■	
	Cd				■	■■		
	Cu				■	■ ■		

R **1** **2** **10** **100** **1 000** **10 000** **100 000** **1 000 000**

- ● peat and peat-earth ▲ mud ○ sandy and silty clay and cohesive soils containing $CaCO_3$
- ■ clayey and sandy silt, slightly clayey sand, organic sand, hardpan x sand (Witczak,& Adamczyk 1994)

Tab. 2. Heavy metal (Pb, Cd, Cu) sorption intensity for input concentration of 50 mg/dm^3

analysed heavy metals. Some sandy sediments, however, particularly those enriched in calcium carbonate, organic matter or oxides and hydroxides of Fe, Al and Mn, have a very high sorption intensity of Pb, Cd and Cu.

OSMĘDA-ERNST (1991) estimated the retardation factor for lead and cadmium in the sandy bottom sediments of the river Reda in Pieleszew. In the case of lead, R reached 1210 at 1 mg Pb/dm^3 input concentration, thus indicating unlimited sorption intensity. At 10 mg Pb/dm^3 input concentration, the migration delay decreased to 304, indicating a very high sorption intensity. In the case of cadmium, at 5 mg Cd/dm^3 input concentration, R reached 97, indicating a high and close to very high sorption intensity.

Desorption of lead, cadmium and copper

Desorption of lead and cadmium was carried out on selected soil samples with distilled water and ammonium ion using 1 n ammonium acetate (NH_4COOH) at pH 7. The use of NH_4^+ enabled estimation of the quantity of bound heavy metal in cation exchange positions (after HELIOS-RYBICKA & KYZIOŁ 1991).

A quantity not exceeding 0.76 mg/dm^3 was liberated using H_2O from samples enriched in lead. This metal is bound most strongly by peat-earth (Text-fig. 24), as only low concentrations of lead were determined in the solution. The largest quantity of the metal was liberated from clayey sand-gravel, however it did not exceed 1% of absorbed lead. A similar tendency can be observed in the case of cadmium. The highest desorption was obtained

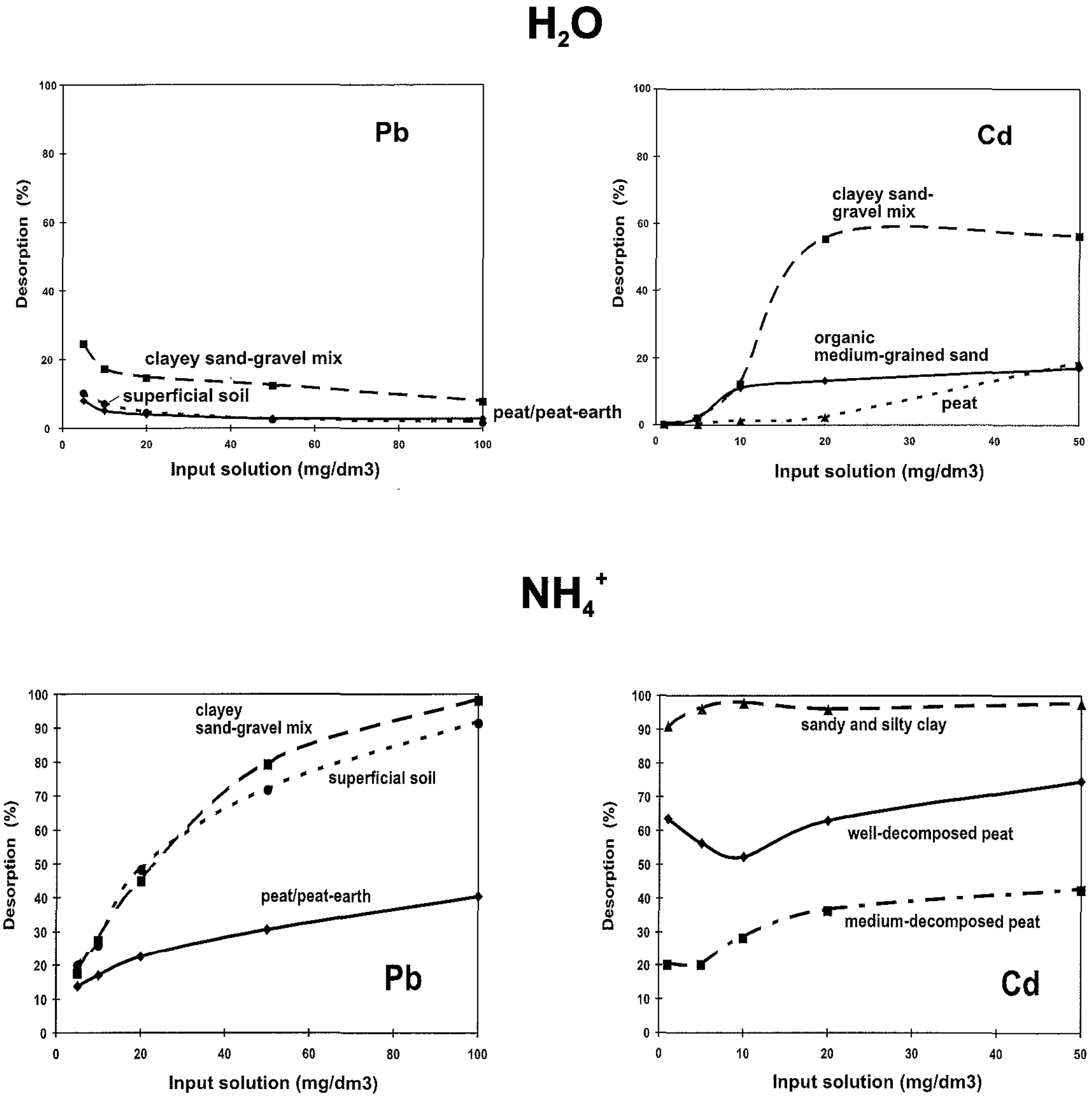

Fig. 24. Desorption of lead (Pb), cadmium (Cd) and copper (Cu) for analysed deposits

for clayey sand-gravel, where it reached 5% for the highest input concentration.

In desorption of lead from samples enriched in this metal, the ammonium ion removes Pb^{2+} most easily and in the largest quantities from a mineral deposit – clayey sand-gravel (Text-fig. 24). At 5 mg Pb/dm^3 input concentration desorption reaches 17%, and at 100 mg Pb/dm3 input concentration it reaches 98% of the previously bound metal. Similar results have been obtained for soil, though sorption was slightly lower for higher input concentrations, reaching 91%. The smallest quantities of lead were liberated from peat-earth (Text-fig. 24). Desorption of cadmium by the ammonium ion is particularly high for sandy and silty clay, representing a mineral sediment from the plateau. Cadmium is poorly removed from peats, and the process depends largely on the degree of decomposition of the organic matter. The results testify that cadmium is desorbed to a larger degree than lead by the analysed sediments.

During the desorption analysis many factors influencing its degree and dynamics were taken into account. The most important of these include: solid phase content, clay mineral structure, buffer abilities of soil, type of metal ions, oxidation and reduction potential, and the quantity of the sorbed element (after Helios-Rybicka & Kyzioł 1991, Kyzioł 1994). When sorption within the soil and input concentration are higher, the liberation of heavy metals takes place to a larger degree. According to Kyzioł (1994), a stronger bond of the metal with the solid phase occurs when precipitation and co-precipitation takes place along with sorption by ion-exchange reactions. The elements are thus less mobile, this occurring only with a pH change.

Lead is much more mobile but only at pH values lower than 5.0. Soils covering large areas in the river valleys and their vicinity, e.g. organic soils including lowland bogs with pH values typically exceeding 5.3, therefore have low desorption abilities, considerably lower than for mineral soils. This is a favourable factor in the protection of groundwater against pollution.

Retention of selected physical pollutants

Selected samples of organic soils infilling valley bottoms were subject to indicator analyses of their potential to retain physical pollutants. The degree of their retention of organic and mineral elements of liquid manure and power plant ashes was determined.

Most farming suspensions were partly purified after passing through soil layers, and the best results were obtained for peat and soil from the plateau as well as from kame terraces. Samples of these soils retained 50 to 79% of the organic elements from the input suspension (Table 3). In tests on the potential to retain mineral elements, peat with a low content of organic matter (37.5%) enriched the filtering solution with 42% of the elements. The remaining samples retained variable quantities of the mineral elements: soil retained 6% and peat (71.6% organic matter content) as much as 64%.

Sample number	Capture of organic components from pollution		Capture of mineral components from pollution	
	mg/dm^3	%	mg/dm^3	%
suspension	0.0627	-	0.0407	-
$P_A2/1$	0.0313	50	0.0384	6
St8/1	0.1300	79	0.0577	-42
O7/1	0.0244	61	0.0145	64

Tab. 3. Capture of physical pollutants by selected samples

When testing the permeability of peats using suspensions with ashes, the solution was observed to decrease the permeability rate significantly. After washing with a suspension containing ashes, samples St8/1 from Studzianki, K4/2 from Sycyna and O6/1 from Oleksin showed decreased permeability (Table 4).

Sample number	Coefficient of permeability for filtration of H_2O m/s	Coefficient of permeability for filtration of ash suspension m/s
St8/1	3.20×10^{-4}	5.81×10^{-6}
K4/2	1.72×10^{-4}	1.62×10^{-5}
O6/1	2.15×10^{-4}	1.15×10^{-5}

Tab. 4. Permeability coefficient using water and ash suspension

The results obtained are similar to those of Hoffmann & *al.* (1991) in testing the isolation abilities of peat near sites with wet ashes waste. According to those authors, this results from colmatation of peat layers by ash particles. thus causing decreased permeability potential of ashes.

DISCUSSION

The investigations confirmed a similar origin and geological setting of the selected river valleys, despite their occurrence within the range of two glaciations (Odranian and Wartanian). Similarities in the lithologies of the subsurface deposits have also been confirmed. The origin of the analysed river valley sections is postglacial, of an exaration (melt-out) type and is directly connected with the same scheme of areal deglaciation. As a result, a postglacial geomorphology of catchment areas in the eastern part of the Polish Lowlands was formed, in a similar manner to the region of the Biała Podlaska Voivodship presented by Falkowski & *al.* (1984-85, 1988), albeit with some modifications.

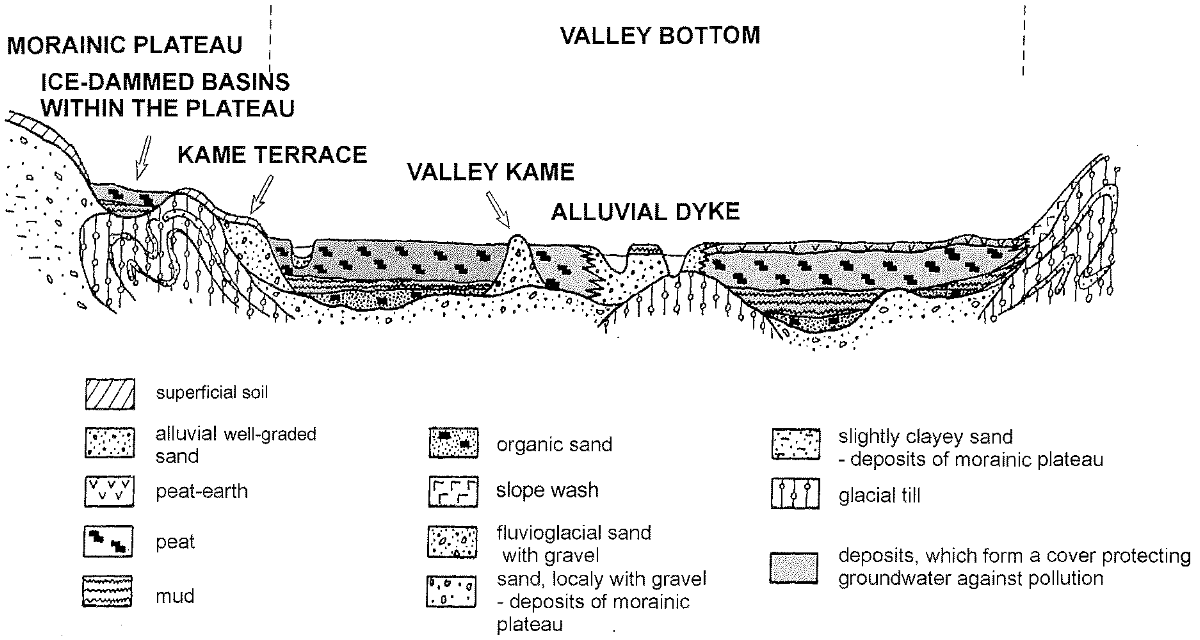

Fig. 25. Schematic cross-section through a postglacial melted-out river valley

The results enabled the presentation of a schematic cross-section through such a polygenetic ("inherited") river valley (Text-fig. 25). A polygenetic river valley is characterised by a valley bottom composed of several lake basins with distinct features of postglacial lake drainage, morainic plateaux with common glacigenic deformations, as well as numerous local kame terraces adjacent to the plateaux. Ice-dammed basins filled with peat and side valleys of a similar melt-out origin on the adjacent plateaux (Text-fig. 25) characterise most valley sections. The ice-dammed basins within the plateau formed as basins after melting-out of dead ice blocks of the stagnant glacier. There is a regularity in the form and extent of the melt-out basins infilled with marsh and lake deposits. In source areas there are clusters of many smaller melt-out basins (e.g. Mołoczki village – valley of an unnamed stream in the Nurzec drainage basin). The area covered by lobes of organic soils in these source areas is larger than that in the middle and lower parts of the river valleys. The occurrence of vast valley bottoms filled with organic soils, kame terraces on valley slopes and glacigenic deformations in marginal areas of plateaux testifies for a postglacial origin of the investigated river valleys.

The investigations show that subsurface deposits of the same origin have similar physical and chemical features regardless of the different ages and ranges of the glaciations involved.

The origin and lithology of the valley regions in question determines the sorption potential of the deposits occurring there, and therefore influences the presence and character of the protecting cover. This relationship facilitates evaluation of the potential of the natural groundwater protection cover in lowland areas characterised by a postglacial morphology.

The character of the sorbing complex, uniformity and continuity of the protection cover as well as its permeability determined the potential for deposits occurring in the selected valley sections to act as a protection against pollution. In the case of organic deposits, the organic matter content is a crucial feature in determining this potential, while the types of clay minerals present are less important. In mineral soils, on the other hand, it is the quantity and content of the clay fraction, the calcium carbonate and the admixture of oxides and hydroxides of Fe and Mn that are most critical.

Deposits from the analysed valley zones have been divided into five classes in respect of their potential to retain pollutants (Table 5). The classification is based on the type of occurrence of the deposits, particularly the presence of continuous layers and the position within the succession, as well as the cation exchange capacity (CEC), Pb, Cd and Cu sorption intensity, percentage sorption of these heavy metals, and the permeability.

Class I includes peats and peat-earths (mucks) with the highest potential to retain pollutants. They are characterised by very high sorption intensities (CEC, heavy metal sorption), and additionally form a continuous cover in valley bottoms, as well as in side valleys and ice-

Division criterion / Class of potential to retain pollutants	Lithological features of the deposits	Type of deposits occurrence	Cation exchange capacity CEC (meq/100 g of soil)	Sorption intensity Pb, Cd, Cu	Sorption of heavy metals at input solution of 50 mg/dm^3 S (%)			Permeability according to Z.PAZDRO, B.KOZERSKI (1990) permeability coefficient*
					Pb	Cd	Cu	
I (very high)	peat	continuous cover	72-156	unlimited (R*** > 1000)	99.5-99.9	97.4-99.8	98.6-99.9	semi-permeable $10^{-4}>k>10^{-6}$ m/s
II (good)	mud	intercalation in peat, deposits underlying peat	35-110	unlimited (R > 1000)	99.4-99.7	96.4-99.5	95.3-99.7	semi-permeable $10^{-6}>k>10^{-8}$ m/s
III (medium)	clay, sandy and silty clay, cohesive soil with $CaCO_3$	lack of continuous cover, glaciogenically deformed, with fissures [1)]	55-157	unlimited (R > 1000)	99.3-99.9	84.4-97.6	74.0-99.9	semi-permeable and non-permeable $k < 10^{-9}$ m/s**
IV (poor)	clayey and sandy silt, slightly clayey sand, organic sand, sand with hardpan	non-continuous cover, with frequent glaciogenic deformations	18-88	very high (100< R<1000)	96.4-99.7	77.6-95.2	44.8-99.9	poorly permeable $10^{-5}>k>10^{-6}$ m/s
V (very poor)	fine-, medium-grained sand, coarse sand	continuous cover (kame), intercalations in cohesive soils	2-15	low, medium, high (1 < R < 100)	-	-	-	well permeable $k > 10^{-5}$ m/s
superficial soil	medium-grained sand, clayey sand	continuous cover	19-101	unlimited, very high (R > 100)	99.7	78.9-95.5	68.8-96.4	poorly permeable $10^{-5}>k>10^{-6}$ m/s

*/ estimated on the basis of investigations and literature
**/ in the cases where no fissures are present
***/ R – retardation factor

[1)] in the cases when these deposits occur in a continuous layer, they should be classified under class II or even under class I

Tab. 5. Proposed classification of deposits building the analysed "inherited" river valleys from the eastern part of the Polish Lowlands (on the basis of their potential to retain pollutants)

dammed basins within the plateaux. They are also considered as poorly permeable or non-permeable soils, in spite of their permeability coefficient reaching values between 10^{-4} and 10^{-6} m/s.

Class II includes muds occurring in valley bottoms and in ice-dammed basins within plateaux and in side valleys. Their potential to retain pollutants is slightly poorer than that of peats. Nevertheless, due to high CEC values (reaching 110 meq/100 g of soil) and sorption of particularly high quantities of cadmium and lead, they are chemically active. Additionally, muds belong to the category of semi-permeable soils.

Class III includes clays, sandy and silty clays, and deposits containing calcium carbonate, characterised by very high sorption intensity and a low permeability coefficient (lower than 10^{-9} m/s). These soils are very efficient in retaining pollutants, however because of numerous glaciogenic deformations they do not form a continuous cover on the plateau.

Class IV includes slightly clayey sands, clayey sands (mainly tills) and sands with hardpan horizons - permeability coefficient 10^{-5} – 10^{-6} m/s. Despite much lower sorption intensity in comparison to clays, they also can be considered important in the protection of groundwater against pollution.

Class V includes sands of kames and kame terraces in zones without hardpan horizons. They show the poorest potential to retain pollutants and have high permeability coefficients.

Superficial soils are characterised by low cation exchange capacity values and poorer potential to bind heavy metals in comparison to peats, muds and clayey and sandy silts. Nevertheless, because they form a continuous cover, they play a crucial role in groundwater protection. Due to their specific character and lithologic variability, directly related to the underlying rock from which they have originated, as well as podzolization, the superficial soils were not classified into any of the proposed classes with regard to the retention of pollution.

The wide range of typically continuous organic deposits of post-lake origin occurring within valley bottoms is crucial for groundwater protection. Deposits formed in stagnant water environments – peats, peat-earths, muds and mineral-organic soils – are typical of the entire valleys of the Nurzec and Supraśl, constituting up to 50% of the deposits occurring in the source areas (Text-figs 26, 27). They are also present in interfluvial areas. The presence of vast areas covered with organic soils is therefore a characteristic regional feature of the eastern part of the Polish Lowlands.

In post-lacustrine parts of river valley bottoms the most typical sequence is peat-earth – peat – mud – organic sand (fine-, medium-grained, clayey, sandy silt). This sequence is particularly favourable for environmental protection. Very favourable conditions have been also observed in side valleys and ice-dammed basins within plateaux, characterised by the sequence of peat – clayey and sandy silt – clay, peat earth – peat – organic sand or

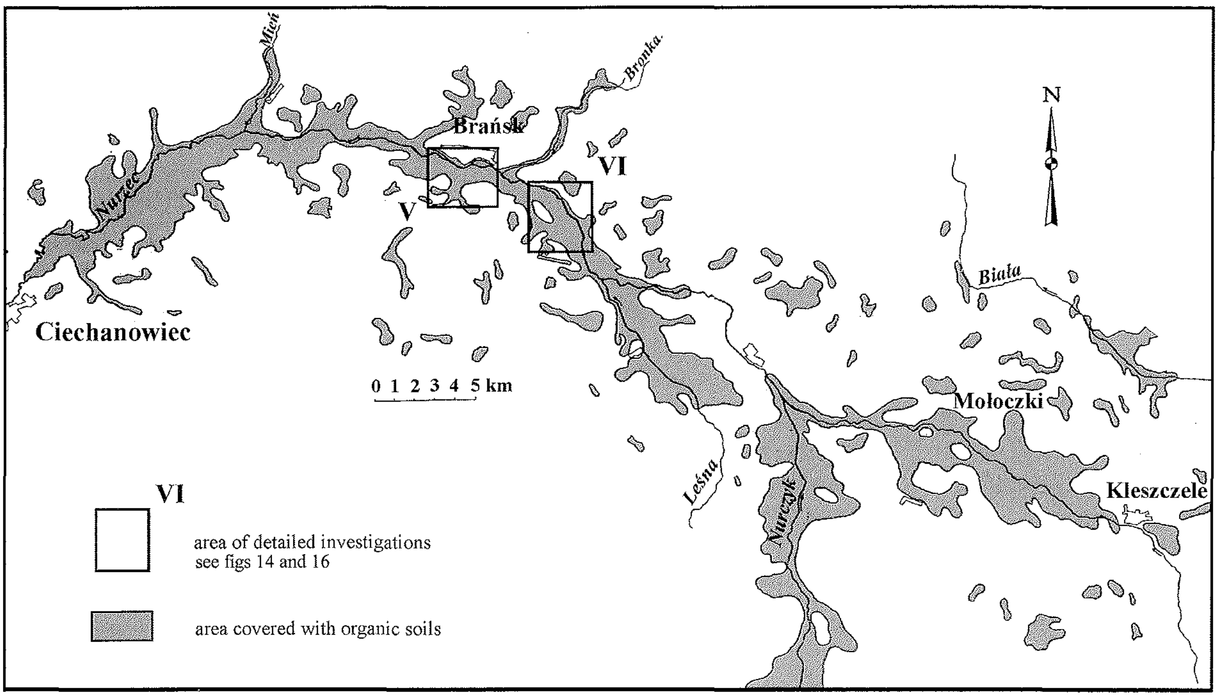

Fig. 26. Occurrence of organic deposits (peat-earth, peat, mud, mineral-organic soils) in the drainage of the Nurzec

mud – clayey and sandy silt. Side valleys play a crucial role in the process of purifying waters recharging the river, as they provide routes for runoff from the plateau, particularly during spring thaw. The plateau is characterised by the largest degree of variation in grain-size of the sediments (fine- and medium-grained sands, slightly clayey sands, clayey and sandy silts, sandy and silty clays, clays, sandy clays, silty clays and clayey sand-gravels) as well as by mineral variability of the clay fraction (kaolinite, illite, beidelite, chlorite). These sediments are covered by soils with particularly good sorption potential as well as by soils that are less capable of capturing pollutants. Therefore it

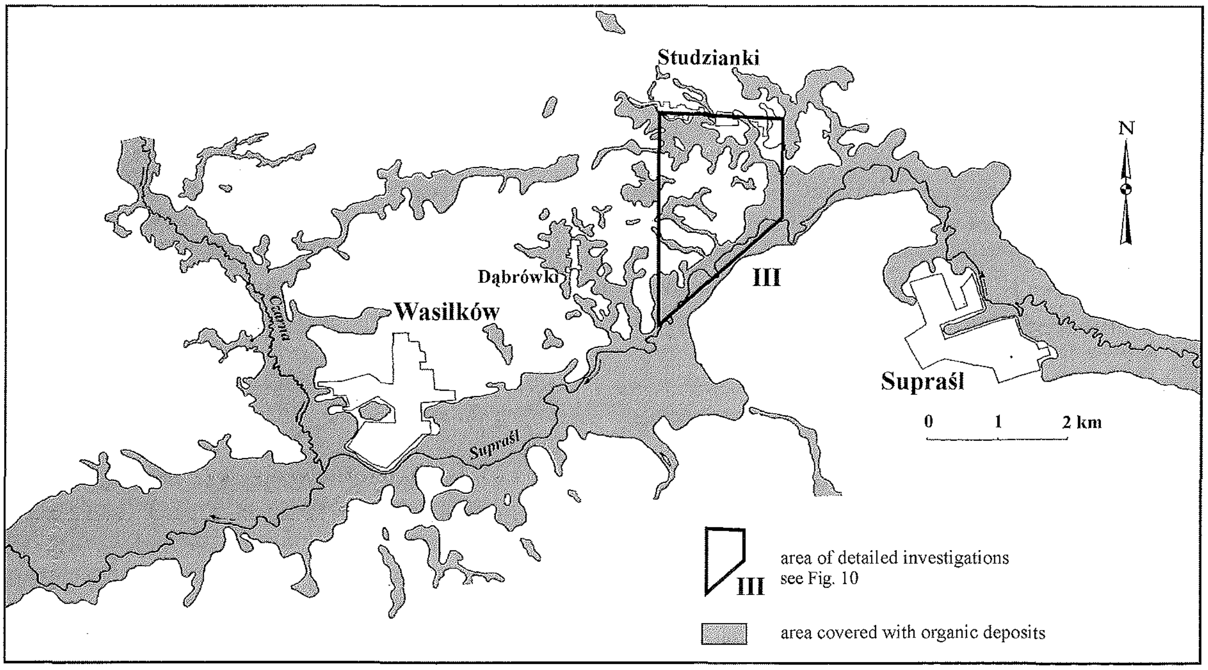

Fig. 27. Occurrence of organic deposits (peat-earth, peat, mud, mineral-organic soils) in the drainage of the Supraśl

is difficult to express their efficiency in pollutant retention. The occurrence of glaciotectonic and glaciostatic deformations in plateau slopes may considerably restrict the migration of pollutants. Many irregular, isolated structures were formed on plateau slopes, forming barriers with very low permeability, which lengthen the filtration route during plateau drainage. However strongly deformed deposits may also form structures favouring filtration, e.g. intercalation of well-graded sands within cohesive deposits or fissures in clayey and sandy silts. Sands with hardpan horizons provide important groundwater protection in the case of highly permeable deposits occurring in kames, kame terraces and on plateaux (particularly accumulation plains). In non-cohesive soils, hardpan horizons form continuous horizons with low permeability and much higher sorption potential, particularly in respect of the retention of heavy metals, in comparison to the surrounding deposits.

Kames and alluvial dams of stream flow routes, occurring within peats and muds form “windows of easier penetration” by pollutants in valley bottoms filled with organic deposits. This is emphasised by the fact that they provide the optimum conditions for engineering construction in areas of poor load-bearing soils such as peats. However, as possible construction sites, they can be prone to pollution hazards. This also applies to kame terraces on valley margins, which are often selected as construction sites.

The efficiency of a protection cover in the bottoms of the investigated river valley sections is provided by its continuity. Construction work that cut through the layer of peats and muds destroys the integrity of thus layer and endanger the environment.

Rapid flooding of the river valley by flood waters is a separate issue. This can cause dilution of pollutants and force a subsequent sorption of hazardous compounds over a large area, greatly exceeding the size of the channel. Part of the overbank water can return through deposits lining the river bottom. Additionally, valley retention is linked to the origin of basin-like river valleys, thus causing flattening of the overbank wave. Nevertheless, improper management within valley bottoms may lead to the possibility of washing out pollutants into the channel during flooding.

The predictability of origin and geological setting of the analysed valley sections and the importance of soils infilling them in pollution capture suggest the need for a wider investigation in the whole area of the Polish Lowlands. The issue is of particular economic significance.

Of the applied heavy metals, lead was best bound in most cases, presenting the greatest affinities to sorption centres of the analysed soils.

CONCLUSIONS

Polygenetic river valleys are typical of the eastern part of the Polish Lowlands. The origin of river valleys from this area includes the adaptation of a series of glacial melt-out depressions by rivers for their flow. Erosion was restricted to gorge zones.

River valleys of this region are characterised by a predominance of organic deposits (lake and marsh) in the form of vast covers. The non-cohesive (sandy) deposits of the channel facies are areally restricted.

Due to very high sorption potential, great thickness and lateral continuity, organic deposits form a natural layer protecting groundwater from pollution.

There is a close relationship between the occurrence of natural protection barriers and the morphogenesis and lithogenesis of the river catchment areas.

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