OCCURRENCE OF THE NATURAL ISOLATION BARRIERS IN POLYGENETIC RIVER VALLEYS FROM THE EASTERN PART OF THE POLISH LOWLANDS

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Abstract
A lot of rivers in the eastern part of the Polish Lowlands are a polygenic form, which origin is linked closely with the Scandinavian ice-sheets activity. They consist of many glacial melt-out depressions, which were formed as a result of areal deglaciation and were taken by the lake system. During the origin of the outflow system, rivers for their flow adopted them. Due to areal deglaciation typical morphological forms were formed there. These include basin-like valley bottoms of lake origin, side valleys connecting postglacial smaller melt-outs on the plateau, glacigenic deformations on the marginal zones of the plateau and postglacial accumulation plains with a high-stand or ice-dammed sandy-silty cover. Lacustrine and then boggy sedimentation in valley bottoms induced forming wide cover, building of organic soils with small quantities of channel facies sediments. Peats and warps occurring there are characterized by very high sorption capacities. Their CEC achieves 150 meq/100 g of soil and they bond up to 95% Pb and Cd from input solutions with concentrations up to 50 mg/dm^3. They also represent non-permeable or semi-permeable sediments. Due to physic-chemical properties and occurring in form of thick, laterally continuous layers, they create natural, isolation barriers protecting groundwater against pollutants. Evaluation of size, thickness and durability of these barriers enable to non-conflict land development of this area, which is consistent with principle of “Sustainable Development”.

Introduction

The presented investigations aim at showing the connection between the presence of natural isolation barriers, protecting groundwater against pollutions and the geological setting and origin of postglacial areas based on river valleys in the eastern part of the Polish Lowlands (fig.1).

The eastern part of the Polish Lowlands is a typical postglacial area, on which clear traces of continental ice-sheet activity are observed in the river system. Most rivers have an “inherited” character (4), because several glacial melt-out depressions were adopted for their flow. The investigations indicated that most river valleys reveal extremely large dimensions - the width of the valley bottom is too large for the rivers necessity and erosional possibility. Besides, the valley bottoms are completely filled with lacustrine and marsh sediments. The origin of these organic sediments – peats and warps – can only be connected with a stagnant water environment.

These observations allow excluding the erosional origin of such types of river valleys. Their origin was linked mainly with the melt-out of the Scandinavian ice-sheet and thus only areal deglaciation was responsible for the formation of such specific morphology. Due to the dominant type of deglaciation, numerous melt-out depressions were formed, in which the sedimentation of lacustrine, followed by marsh sediments took place. The subsequent evolution of the morphology and creation of river systems did not cause a complete drainage of the areas, without run-off. At present, in river valleys, the melt-out depressions form wide sections infilled with organic sediments, whereas the alluvial zone, composed of sands, is very narrow. Such types of river valley stretches represent the period of dominance of the initial geomorphological conditions in the development of a river. The investigated rivers have not yet formed their own valley. According to Falkowski (4) these stretches can be recognized as type Ib that is of young rivers modeling the valley through sedimentation. In the areas of river valleys with economic mining, organic sediments form an effective isolation barrier reducing the possibility of contaminating the groundwater and underlying soils. For health and economic reasons it is a duty to identify such natural protecting barriers. The detailed and correct assessment of natural barriers is necessary for the location of investments, which are particularly hazardous for the environment. Such knowledge can also prevent the incorrect utilization of some areas. The essential condition for the correct identification of the presence, form and effectivity of natural isolation barriers is the recognition of structures and origin of geological units, on which they exist.

Methods

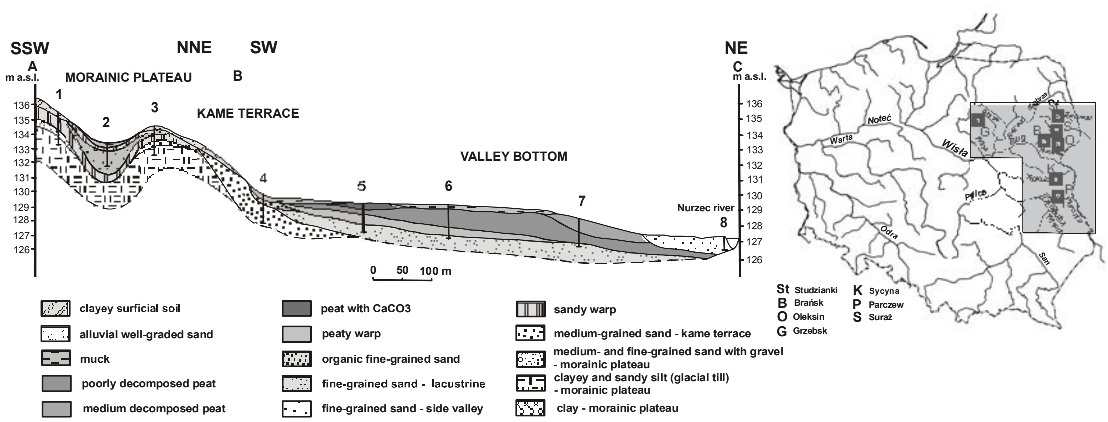
Geological research was carried out on selected, characteristic and representatives sections of polygenic melt-out river valleys of the Polish Lowlands. They were parts of valleys of Narew, Piwonia, Supraśl, Krzna, Orzyc, Toczna, Pisa, Tyśmienica, Nurzec and Orzyc (Fig.1) situated in the range of two glaciations: of Odra and Warta (8). 140 samples of soils building the selected geomorphological units from 7 chosen representative poligenic river valleys were collected (Fig 1) for laboratory tests. Potential to retain pollution was tested through analysis of the following parameters: type of sediments, CEC (cation exchange capacity - method prepared by Sapek (12, 13) in the Institute of Land Reclamation and Grasslands /Warszawa/, based on the measurement of copper sorption), sorption of Pb, Cd and Cu, sorption intensity of Pb, Cd, Cu, permeability of sediments (the Kamieński tube method, consolidometer method, calculated using the statistically elaborated "American formula"), mineral composition (thermal analysis and X-ray diffraction analysis), content of organic matter (roasting at temperatures of 550^0 C) and pH. Sorption of Cd^{2+}, Cu^{2+} and Pb^{2+} was conducted by means of the "BATCH" method using solutions of nitrates of these metals (9). This concentration was 5, 10, 20, 50, 100 mg Pb/dm^3, and in some cases also 500 mg/dm^3 in order to obtain a saturated condition. Sorption of ions of heavy metals (S) was calculated from the difference of concentrations of these elements in solutions before and after analysis (AAS method), that is from difference of input concentration and concentration in the equilibrium state. Experimental isotherms of heavy metals sorption for each sample were prepared using the Henry or Freundlich model (2). The retardation factor – R was also determined. Knowledge of the value of retardations calculated on the basis of the sorption isotherm parameters enables easy evaluation of hazard from the substance undergoing sorption and the sorption intensity, understood as the property of soil, can be classified based on calculated retardations (9). This classification was presented by Witczak (14). This author assigned 5 degrees of sorption intensity: low (R=1–2), medium (R=2-10) , high (R=10-100), very high (100-1000) and unlimited (R>1000).

Results

Origin and geological setting

The undertaken investigations proved that the geological setting of every analyzed stretches (Fig.1) of the river valleys is very similar, especially with respect to the sequence of lithological layers. Their origin is connected with the scheme of areal deglaciation, (3, 5, 6,11). An example of this type of a polygenic melt-out river valley, a stretch of the Nurzec river in the Oleksin area is shown on Fig.1 and 2. Due to climatic warming and decline of glacial ice alimentation (according to Różycki /11/), the deglaciation in the Polish Lowlands initiated the creation of a large zone covered with dead ice. On the stagnated glacier (ice-sheet), in a landscape of dead ices, the river system originated through the concentration of the flowing rainwater and melt-water (3). The rivers cut by fissures into the dense ice covering the valley. In general, they were characterized by high flow rate and braided sedimentation (1).

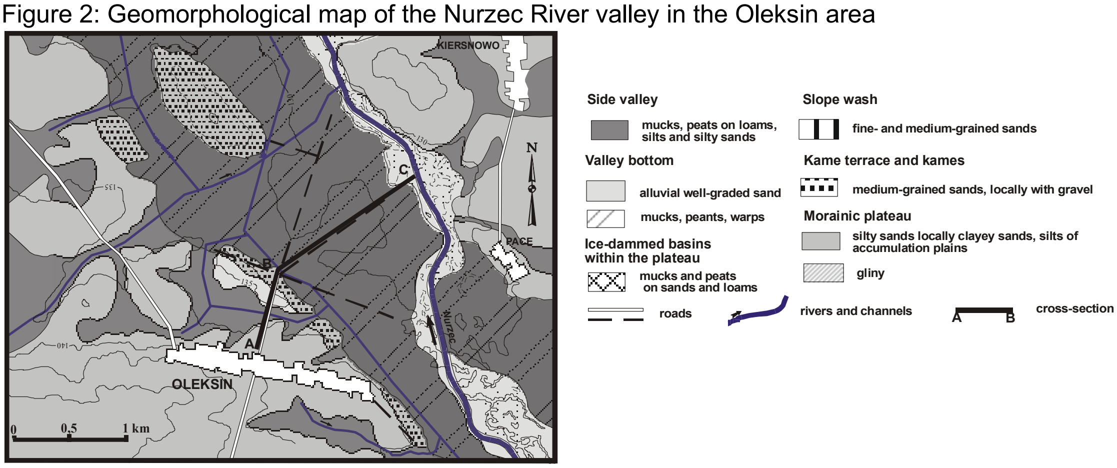
Figure 1: Lithological cross-section through the Nurzec River valley in the Oleksin area (3)



Incisions of rivers caused the formation of interfluves – glacial plateaux and water-divides on the ice sheet. The flow of glacial rivers induced widening of the fissures in the dead ice cover and the formation of kames. Kames are the oldest relief forms in this area and at present are situated on the highest elevations. In the next phase of deglaciation, the steps of accumulation plains were formed. They descend towards the present-day river valleys. Creation of the first river system in the dead-ice landscape determined the runoff direction of the present-day, melt-out river valley. Some modifications of this runoff system (initially formed on the ice) could be caused by the formation of melt zones in places with elevations in the basement of the glaciers. In effect, local sedimentation of terrigenous ice-dammed sediments, in some areas formed like varved clay, took place. During the final phase of areal deglaciation, the present-day river valleys were infilled only with thick dead-ice blocks, the area of which corresponded to the recent lake basins. These blocks remained the longest in melt-out depressions, which usually created series, and formed watersheds. The shape of the melt–out depressions was genetically conditioned by the preglacial morphology and type of glacier (ice-sheet) tongue advance during the transgression. The morphology of the exaration depressions was modified and underlined by deflection of the susceptible basement of the glacier ice-sheet as a consequence of displacement of flexible soils by the sinking ice blocks (Falkowski et al., 1988). Finally, after the entire glacier melted, the depressions were taken by the lake system. Sedimentation of terrigenous sediments, linked with the Vistulian Glaciation, took place, followed by the deposition of organic sediments – lacustrine and marsh. Deltaic sedimentation also took place in the beginning of alluvial channel and flood facies sedimentation.

As a result of areal deglaciation, geomorphological units, characteristic for this model of morphogenesis, came to exist in all of investigated areas (Fig. 1): valley bottoms consisting of many post-lake basins with traces of drainage, morainic plateau and fluvioglacial terraces on the plateau slopes, in some cases deformed, side valleys and ice-dammed basins within the plateau (3). The marginal zones of the morainic plateaux bear strong glacitectonic and glacistatic deformations, which were observed in most of the investigated river valleys (Krzna, Nurzec, Wkra, Nida, Narew, Orzyc Tyśmienica, Orzyc and others). In most stretches (Krzna, Nida, Wkra, Orzyc, Krzna, Toczna, Nurzec), ice-dammed basins and side valleys with melt-out origin occur within the adjacent morainic plateaux (Fig. 2). These forms originated as ice-dammed reservoirs, after the melting of dead ice blocks divided into smaller parts.. Fluvioglacial terraces adjoin the morainic plateaux and occur as kame shelves (Fig. 1). They were formed during glacial river flow in depressions between the created plateau and the edge of the melting dead-ice block. form valley bottoms of rivers. At present, occupying large areas, creating a system and infilled with organic sediments, depressions after ice-sheet melt-outs, which are characterized by the occurrence of a thick cover of organic soils, form bottoms of the present-day river valleys, i. e. the flood terrace.

Figure 2: Geomorphological map of the Nurzec River valley in the Oleksin area



The quantity of sediments of the channel facies in these river valleys is small in relation to their area. In some sections of the investigated river valleys (e.g. Nurzec) kames occur in the valley bottom (Fig. 2).. They were formed when dead-ice blocks lying in depressions melted.

Isolation potential (capacity) of sediments

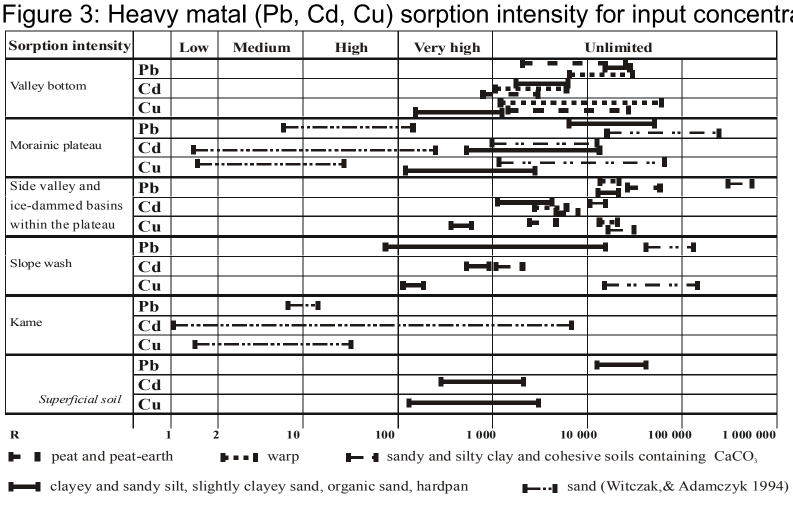
The presented scheme of the evolution of morphogenesis and lithogenesis in the analyzed areas explains the mechanism of the sediments origin, which can be considered as potential natural isolation barriers protecting groundwaters and underlying soils against anthropogenic contaminations. Peats and mucks reveal the best capacity to retain pollutants. In valley bottoms and in side valleys and ice-dammed basins within the plateau, they generally form a continuous cover. These sediments achieve particularly high CEC values, up to 156 meq/100 g of soils (Table 1). They also bond exceptionally high quantities of Cd, Pb and Cu, because sorption of these elements equals up to 99% (3). Sorption intensity of peats and mucks is unlimited (Fig. 3). Peats also are recognized as non-permeable or semi-permeable sediments, though their permeability coefficient varies between 10^{-4} and 10^{-6} m/s. This is a result of the specific properties of peats and organic matter (10). These sediments absorb water during wet periods and return it evaporating and drying during dry periods. Warps occurring in valley bottoms and in side valleys and ice-dammed basins within the plateaux are composed of 5 to 30 % of organic matter and are characterized by a slightly worse capacity to hold pollutions in comparison to peats. Nevertheless, these sediments must be considered as active, because their CEC achieves values up to 110 meq/100 g of soil (Table 1). The sorption intensity for warps is unlimited (R>1000 – Fig. 3). In valley bottoms, the most common sequences of sediments comprise peat-muck-warp. In this case, a perfect zone protecting against the expansion of toxic contaminations is formed. The large thickness of all organic sediments in this geomorphological unit is very advantageous for environmental protection. In the investigated stretches the thickness reaches an average of 1.5 m (max 7 m). Analysis of the presented data indicates that sediments building this layer are characterized by high, stable and anticipatable sorption as well as permeable capacities.

Table 1: Sorption and permeability capacities of sediments building polygenic, melt-out river valley

Geomopholo gic unit	Sediments **(content of organic matter [%])** *(content of clay fraction [%])*		Cation exchange capacity (CEC) [meq/100 g of soils]			Sorption of heavy metals at input solution of 50 mg/dm^3 [%]			Perme-ability coefficient [m/s]	pH
			min		max.	Pb	Cd	Cu		
Valley bottom	peats **(51.2-81.2)**		119	140	156	**99.7** *(99.5-99.9)*	**99.2** *(97.4-99.8)*	**99.4** *(98.6-99.9)*	10^{-6}	4.5-6.0
	warps **(5.3-26.0)**		35	60	105	**99.5** *(99.4-99.7)*	**98.0** *(96.4-99.5)*	**98.5** *(95.3-99.7)*	$10^{-6} – 10^{-8}$	5.0-7.2
	mineral-organic deposits	clays/ clayey sands	21	55	63	**99.1**	**86.7**	**76.0**	$10^{-6} – 10^{-9}$	6.2-7.2
		fine-, medium-grained sands	16	22	28	**98.6**	**96.5**	**96.4**	10^{-5}	
Side valleys	peats **(53.5-74.4)**		92	115	141	**-**	**-**	**-**	10^{-6}	4.6-6.0
	warps **(5.9-26.0)**		37	56	88	**99.5**	**98.1**	**99.5**	$10^{-6} – 10^{-8}$	6.5-7.1
	loams/clays *(11-54)*		38	75	157	**99.5** *(99.3-99.9)*	**92.2** *(84.4-96.3)*	**84.6** *(74.0-99.9)*	$10^{-6} – 10^{-9}$	7.1-8.0
Mora-inic plateau	clays *(30-57)*		55	80	152	**99.7-99.8**	**87.2-97.6**	**96.9-99.9**	< 10^{-9}	7.5-8.1
	slightly clayey sands/lomas *(4-30)*		24	50	148 $CaCO_3$	**99.1** *(97.2-99.7)*	**86.6** *(77.6-95.2)*	**86.1** *(44.8-99.9)*	$10^{-6} – 10^{-8}$	5.5-8.5
	hardpan - slightly clayey sands *(2-10)*			23		**96.4**	**77.6**	**80.4**	10^{-6}	5.7
Slope wash	fine-, medium-grained sands/silty sands/ slightly clayey sands/ silts/ loams *(1-30)*		18	45	149 $CaCO_3$	**99.6** *(89.2-94.3)*	**85.4** *(83.2-87.6)*	**88.6** *(66.4-99.9)*	$10^{-5} – 10^{-8}$	6.5-8.6
Kames	sands			15		**-**	**-**	**-**	> 10^{-5}	6.0-6.2
	Superficial soils **(on the average - 6)**		19	39	101	**99.7** *(91.5-99.8)*	**89.1** *(78.9-95.5)*	**86.6** *(68.8-96.4)*	10^{-5} - 10^{-6}	4.7-5.9

They also occur as a continuous layer. However, within the boundaries of protection zones occur areas where the groundwater quality is threatened. These are valley kames forming "windows of easier penetration" by contamination (3). Furthermore, as being composed of sands and gravels, these structures, located within weak carrying soils (like peats or warps), have the best conditions for foundation of engineering objects. This problem is linked also with kame terraces occurring in the marginal zones of the valley bottom, where the location of industrial objects is very probable. Very similar sequences of sediments as in the valley bottom were found in side valleys and ice-dammed basins within the plateau. The profiles are: warp-loam, peat-clay-loam and muck-peat-warp-clay. The sorption capacities of these sediments reach high values, which are very similar in comparison to those of soils occurring in valley bottoms. (Table 1). The potential to retain pollutants of sediments building this type of sediment sequences also causes the occurrence of an effective cover holding pollutants in these structures. The morainic plateau represents an area with the greatest differences of the granulometric content of sediments and mineral content of the clay fraction. Well-graded, fine- and medium-grained sands as well as cohesive soils containing clay minerals such as kaolinite, illite, beidelite and chlorite, occur there. Due to that, soils with very high as well as low sorption capacities were found there (Table 1). Clays represent very effective sediments to hold pollutants. Their CEC achieve values from 55 meq/100 g of soils (Table 1) to 157 meq/100 g of soils (for soil with 16% content of $CaCO_3$). They also bonded up to 99.8% Pb and up to 96.9% Cu and 97.6% Cd from the input solution with higher concentrations of this heavy metal (50 mg/dm^3). The sorption intensity of Pb, Cd and Cu is also unlimited (R>1000 – Fig.3). It is necessary to point out that the value of sorption, as well as the form of the curve describing its dynamics for cohesive deposits, depends on the content of clay fraction, on its mineral composition and the content of organic matter, oxides and hydroxides of iron and aluminium and on cadmium carbonate (7, 10). The permeability coefficient for these cohesive soils reaches 10^{-9} m/s. However, these sediments occur in a non-continuous layer because of strong glacigenic deformations. Mainly glacial tills as well as clayey sands, loams and sandy loams also build the morainic plateau. Though to a smaller degree than clays, these cohesive sediments sorb relatively high quantities of the investigated heavy metals (Table 1). A hardpan layer – sands with admixture of clay and silt, cemented with Al, Fe, Mn oxides and with SiO_2 occurs among sandy sediments of the plateau and kames. Soils building these illuvial horizons are characterized by higher sorption capacities and a smaller permeability coefficient than non-cohesive sediments (Table 1). As occurring in continuous layers, these horizons form a barrier against the migration of pollutants. Sorption capacities, especially to bond heavy metals, of the slope wash sediments are diverse depending on the granulometric and mineral composition. The composition is a result of a variable geological setting of the morainic plateaux, from which these sediments originate.

Figure 3: Heavy matal (Pb, Cd, Cu) sorption intensity for input concentration of 50 mg/dm^3



The poorest capacities to hold pollutions reveal sands of kames and kame terraces, however only in zones without hardpan horizons. Superficial soils reveal the lowest values of the CEC and the lowest sorption of heavy metals in comparison to peats, muds and warps (Table 1).

Discussion

In the case of threat to the groundwater and surface waters quality in inherited river valleys and adjacent areas and when there is a necessity to estimate the degree of their protection, it should be noted that there are two zones with a different geological setting and different protection capacities (3). The valley bottom, that is a wide area filled with thick lacustrine and marsh sediments (peats, mucks, warps, mineral-organic soils) forms the first zone. This zone is characterized by stabile and high protection capacities. These sediments form a lateraly, continuous cover. Valley kames are the only exception. The second zone is represented by the morainic plateau, slope wash and kame terraces. The sorption and permeability capacities of soils building these geomorphological units are not predictable as in the case of bottom sediments. Their protecting potential depends on their occurrence and type of deglaciation, which locally took place. It is very important if splitting of the ice-sheet into many parts or if a slow, gradual melting of the wide glacial interfluve took place, which in the latter case caused sandy and silty accumulation plains to form. The occurrence of sediments with very high capacities to hold pollutants (e.g. clays, loams) as well as soils protecting groundwaters to a smaller degree (e. g. sands, sand gravel-mix) takes place.

Conclusions

- The origin of most stretches of river valleys in the eastern part of the Polish Lowlands is melt-out and connected with areal deglaciation.
- Organic sediments: peats, mucks, warps and mineral-organic sediments dominate in polygenic river valleys in the eastern part of the Polish Lowlands.
- Organic sediments occurring in valley bottoms, side valleys and ice-dammed basins within the plateau are characterized by very high sorption capacities with relation to various pollutants. They form laterally continuous, thick layers. These features induce the formation of always effective, natural isolation barriers protecting groundwater against pollutants.
- The origin of valley areas in the eastern part of the Polish Lowlands determines sorption capacities of sediments, thus determining the occurrence of natural protection barriers.

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