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Geomorphological diversity of peatland basins in the Łódź region and its significance for the accumulation of biogenic sediments

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Abstract. An investigation was carried out on peatlands in the Łódź region. Geological and geomorphological studies focused on 31 sites. The peatland basins are located in moraine plateau and valleys. The diversity of basins in these areas was affected by geomorphological processes: glacial, fluvioglacial, slope, aeolian, thermokarst and fluvial. Peatlands in the region formed in different groups of basins: basins in the moraine area, basins of aeolian origin, basins in valleys (with a distinction between active and inactive valleys). Paleoecological analyses of biogenic deposits show that the peatlands developed from the Late Weichselian to the Subatlantic Period. The schemes of creation and development of the peatlands presented in this study prove a strong influence of geological and geomorphological factors.

Key words
geomorphology,
peatland,
biogenic sediment,
Central Poland

Introduction

The Łódź region is situated between a lakeland area and a highland area. The geomorphologically varied lakeland district, formed as a result of the last glacial period, is characterized by numerous lakes and landlocked areas which foster the development of peatlands. Its upland areas are almost devoid of landlocked depressions, and peatlands make up for only a small part of their total area (Żurek 1987). The geomorphological features of peatlands have been tested in all morphological areas of the world (see: Succow, Joosten, eds. 2001; Charman 2002; Evans, Warburton 2011; Żurek 2012). This article analyses peatland located in an area with particular relief characteristics and paleogeography. Specifically, the landform features of Central Poland are the result of the transformation of glacial relief (Saalian Glaciation) by long-term fluvial, slope or aeolian processes in the changing climate conditions of the Weichselian and the Holocene. This has resulted not only in an uneven distribution of peatlands in this area, which today occupy between 2 and 4% of the surface area (Żurek 1987), but also in the diversity of their geological and geomorphological substrate. In the Łódź region, according to the most common ecological classification of peatlands, almost all of the examined mires should be classified as fens, which reflects the zonal peatland system of Europe (e.g. Żurek 1987), while transitional peatlands and raised peat bogs are extremely rare (Żurek 1987; Jasnowski et al. 1994).

The Łódź region has been well examined in terms of its surface geological structure and geomorphological features, as a result of considerable field research (cf. Turkowska 2006) and the work involved in preparing the Detailed Geological Map of Poland. The latter resulted in documentation of how peatland is distributed (Fig. 1). However, peatlands themselves have seldom been the object of detailed research. Geological and geomorphological analyses of mires intensified after 2000, but, before this study, the peatlands of the Łódź region had not been subjected to in-depth and extensive telmatological research. In contrast, relatively numerous sites have been the focus of botanical studies (see Forysiak 2012).

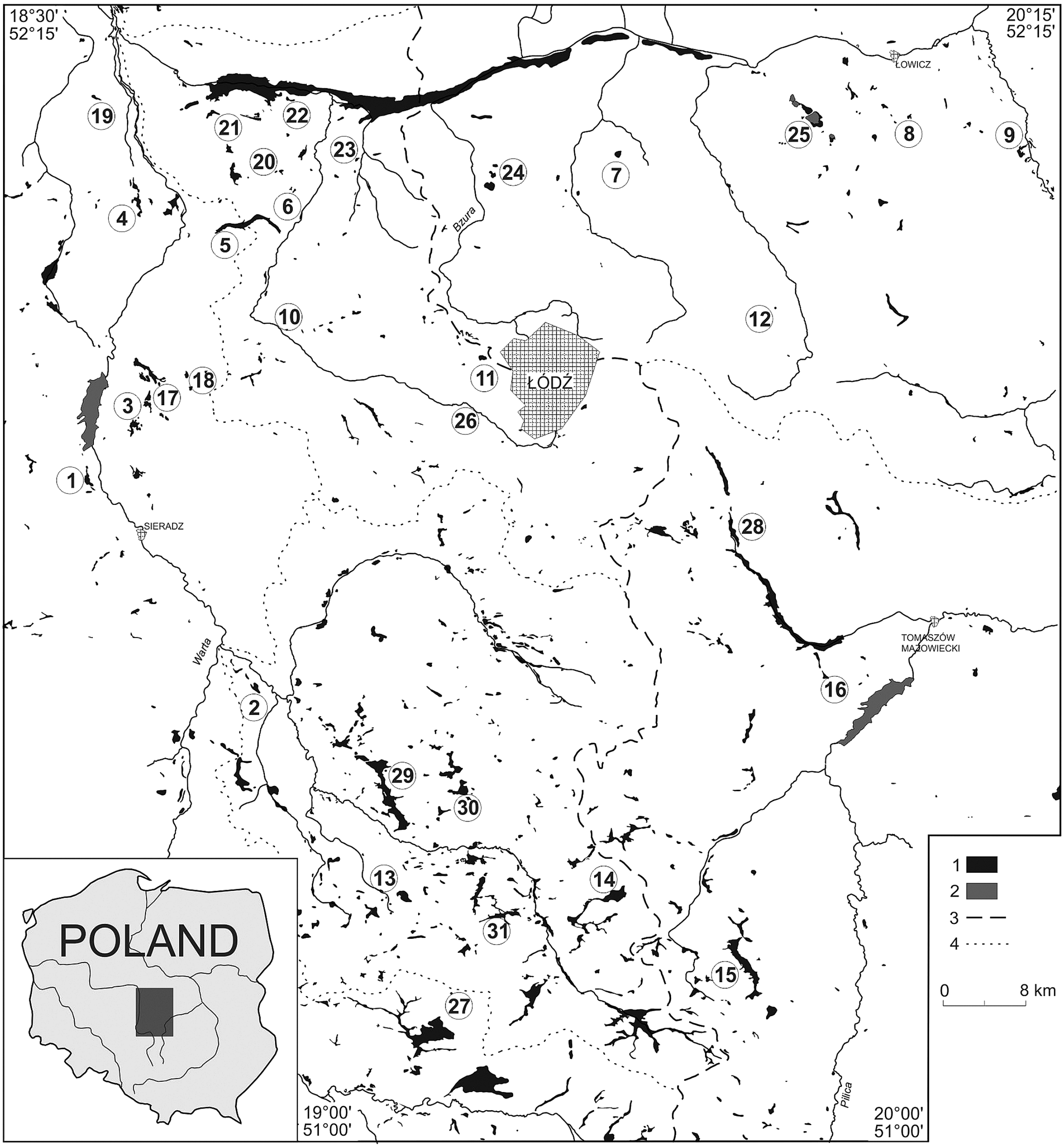

Fig. 1. Peatlands in the Łódź region (after Forysiak 2012, modified): 1 – peatlands, 2 – rivers and water reservoirs, 3 – watershed of the 1st order, 4 – watersheds of the 2nd order. Sites: 1 – Bartochów, 2 – Korzeń, 3 – Ługi, 4 – Czarny Las, 5 – Wilczków, 6 – Ner-Zawada, 7 – Witów-Silne Błoto, 8 – Polesie, 9 – Kopanicha, 10 – Mianów, 11 – Rąbień, 12 – Żabieniec, 13 – Chabielice i Parchliny, 14 – Napoleonów, 15 – Bęczkowice, 16 – Czarny Ług, 17 – Józefka, 18 – Niedźwiadne, 19 – Koźmin, 20 – Światonia, 21 – Świnice Warckie, 22 – Podgórze, 23 – Wierzbowa, 24 – Opalanki, 25 – Rogóźno, 26 – Kolonia Bechcice, 27 – Wolskie Bagno, 28 – Świątniki, 29 – Święte Łąki-Lubiec-Przerębiec, 30 – Podwódka, 31 – Dolina Świętojanki

Geological and paleoecological studies have focused on a total of 31 peatlands of the Łódź region (Fig. 1), but a comprehensive analysis of biogenic sediments (palynological analysis, analysis of plant macrofossils, diatoms, chironomid, and cladocera, and analysis of geochemistry and radiocarbon dates) has so far only been conducted for a few sites (see Forysiak 2012). These latter studies have covered the contemporary peatlands of the Łódź region within which peat-forming processes are currently active. The obtained material from the examined sites shows significant diversity in the geological and geomorphological structure of these peatland basins and significant diversity in the stratigraphical and lithological features of their biogenic deposits (Forysiak 2012).

Drilling and geological probing allowed the geological structure and configuration of the mineral substrate of mires, and the thickness and lithological variability of the biogenic deposits that fill their basins, to be examined. Analysis of the topography of the peatlands, their surrounding area and their substrate has led to identification of the geomorphological forms in which the peatlands exist, and has determined the nature of origin of their basins. The basins are located within various geomorphological forms, and are characterized by a diverse geological structure, as well as by a diverse lithology of biogenic deposits filling the basins.

Geomorphological Diversity of Peatland Basins in the Łódź Region

The collected documentary material revealed significant diversity in the geological and geomorphological structure of peatland basins in the Łódź region. There is a clear stratigraphic and lithological homogeneity to the documented deposits. In this paper, the analyzed objects were grouped according to their geomorphological location and the origin of the landform, i.e. peatlands located in moraine plateau and valleys. In doing so, the basic criterion used on the morphogenetic map (Dylik 1948) and the geomorphological map (Turkowska 2006) was adopted to represent the image of the landform of the Łódź region. Finally, moraine and fluvial zones were designated and a third group of peatlands, located in the vicinity of aeolian landforms, was distinguished.

The relief of the moraine plateaus area was shaped by glacial morphogenetic processes (Saalian Glaciation). The fluvial landforms were formed through the morphological processes occurring in a temperate and cold climate (post-glacial). The diversity of forms in these two areas was affected by geomorphological processes between the last glaciation and present day. The most important processes are: glacial, fluvioglacial, slope, aeolian, thermokarst and fluvial. These processes led to a great diversity and polygenicity of landforms in the Łódź region. It is, however, possible to indicate one process which determined the formation of the peatland basin, the results of which had not been considerably modified prior to the biogenic accumulation.

Peatland basins in river valleys

In the study area, peatlands located in river valleys prevail (Table 1). The largest group is formed by basins molded by fluvial processes. This is due to the degree of development of the fluvial network in this morphogenetic region and to the large number of depressions formed in the valleys. Peatlands are found in the active floor of river valleys, on the high accumulative terrace and in inactive river valleys, i.e. forms excluded from contemporary fluvial activity (usually as a result of changes in the river system, the cutting of valley bottoms and the formation of morphologic river terraces in the Late Weichselian). Peatlands in active river valleys tend to occupy fragments of cut-off river channels (oxbows) (e.g. in the locations of Korzeń, Polesie), floodplain basins (Bartochów, Czarny Las), or are sometimes found spread across the entire width of terrestrialised valley floors (Bęczkowice, Świątniki). Wetlands formed within fluvial forms which are excluded from river activity may occupy similar basins as those in active valleys; oxbow lakes, floodplain basins (Ługi, Józefka) and entire valley floors (Święte Łąki, Lubiec, Przerębiec). Age differences between forms shaped by fluvial processes are important, and result from forms in inactive parts of valleys being created in the Late Weichselian (since its beginning), and the forms in active valleys being formed from the turn of the Late Weichselian and Holocene up to the present day.

Table 1. Geomorphological differentiation of peatland basins in Łódź region

Location of peatland basin		Landform	Example
valley	active river valley	floodplain basin	Czarny Las Bartochów Kopanicha Chabielice Parchliny Mianów Koźmin Rogóźno
		oxbow	Polesie Korzeń Kolonia Bechcice
		valley floor	Bęczkowice Świątniki Wierzbowa
		thermokarst depression	Ner-Zawada Świętojanka
	inactive valley	river valley (floodplain basin, oxbow, floor)	Ługi Józefka Opalanki Święte Łąki-Lubiec-Przerębiec
		meltout basin	Podwódka
		floor of ice-marginal valley	Wilczków Świnice Warckie
		thermokarst depression	Napoleonów
moraine plateau		meltout depression (kettle hole)	Żabieniec Wolskie Bagno
surroundings of aeolian landforms (in moraine plateau and in valley)		closed basin (near dunes)	Rąbień Witów-Silne Błoto Czarny Ług Niedźwiadne Podgórze
		deflation basin	Światonia

Thermokarst processes (active in the Late Weichselian) were very important for the formation of contemporary peatland basins. They led to the formation of many drainless depressions and lower sections of extensive denudation valleys or low flow depressions. Depressions of thermokarst origin came into being as a result of melting of segregated ice and vein ice in the Late Weichselian. Those types of ice emerged during the Pleniweichselian and were gradually covered by mineral deposits (Goździk, Konecka-Betley 1992). The melting of ice in the Late Weichselian caused gradual subsidence of mineral sediments and the creation of basins. Some of these became drainless and their areas were covered with peats at the turn of the Oldest Dyras Period and Bölling (Goździk, Konecka-Betley 1992; Forysiak et al. 2010b). As they became even deeper, they may have become lake basins and occupied by peatland at the beginning of the Holocene. Thermokarst depressions may occur in both the high accumulative terrace of river valleys (e.g. Ner-Zawada) and the bottoms of inactive river valleys and vast valleys, nowadays dewatered by small watercourses, e.g.: Świętojanki valley (Goździk, Konecka-Betley 1992), Jeziorki valley – Napoleonów Peatland. The two forms of thermokarst genesis differ primarily in size (Table 1). Thermokarst kettles are small but relatively deep basins, created at the site of local accumulations of ice masses of considerable thickness. The second type are vast, basin-like, several-hundred-metre-long depressions, and relatively shallow with a varied configuration of their bottom.

Peatlands in glacigenic landforms

The basic features of the relief and superficial geological structure of the area were shaped by the glacigenic processes of the Saalian Glaciation. However, the glacial relief (with numerous hollows, in which biogenic sediments were deposited) was substantially modified by fluvial and slope processes, as well as the thermokarst and aeolian processes of the Weichselian, while still allowing biogenic accumulation in the transformed basin in the Late Weichselian and the Holocene.

Currently in the Łódź region, there are only a few peatlands located in forms shaped by glacial and fluvioglacial processes. These basins are located in moraine plateau and valley areas. A few peatlands are found within the dead-ice kettle in moraine plateau areas. The only well-documented site of this kind in the region is the Żabieniec Peatbog, which has a thick biogenic series (Lamentowicz et al. 2009).

Marginal valleys formed during the Saalian Glaciation were mostly incorporated into postglacial river systems. There are still, however, certain sections that were transformed by transverse processes during the Weichselian and filled with slope, aeolian and, (in the case of a periodic flow of water), fluvio-periglacial sediments. Nevertheless, parts of the depressions that were covered with peats in the Late Weichselian have remained. Contemporary peatland may also have been formed in the valleys of glacial origin which were not completely filled with slope sediments at the end of the Saalian Glaciation and the Weichselian. Therefore, the peatland basins were classified as forms shaped by glacial and fluvioglacial processes, even though their bottoms are covered with younger deposits. Nevertheless, the possibility of supplying and maintaining favorable water conditions is due to their original geomorphological and geological features.

Peatlands in the vicinity of aeolian landforms

Contemporary peatland basins formed as a result of aeolian processes are situated in moraine plateau and valley locations. Many of these forms were shaped by fluvial or denudation processes, but at that time they had open features. Their closure to the form of drainless depressions was the result of aeolian transportation of sand, and its accumulation as sand covers and dunes. Examples of relatively extensive, closed, peaty basins near dunes include the Rąbień and Silne Błoto peatlands, but there are also some small basins: Czarny Ług, Niedźwiadne and Podgórze. Basin closure by aeolian forms occurred (in most cases) during the dune formation phases of the Late Weichselian and during the Neoholocene. Landlocked depressions occupied by contemporary peatland and located near aeolian forms developed very rarely, mainly because of deflation. Of all the analyzed sites, only the Światonia peatbog was formed in this way, but the process of sand material deflation was directly caused by anthropogenic damage to the forest in the Neoholocene (Twardy 2008).

The inspiration for the scheme of geomorphological differentiation of peatland basins in the Łódź region has come from the classifications of Tamošaitis (1965) and Żurek (1990). Besides basins of glacigenic, fluvial or aeolian origin, the genetic classification of peatland basins proposed by Tamošaitis (1965) contains a wide range of types and subtypes of basins which do not occur in Central Poland (including sea genesis, karst genesis and some subtypes of glacial genesis basins). Based on studies of peatlands in the eastern Polish Lowland, Żurek (1990, 2012) emphasizes the relationships between the relief and the ways that water feeds peatlands to provide different types of biogenic deposits.

Stages of Peatland Development in the Łódź Region

The development of peatlands in a particular area is due to several factors, such as: climate, geological, geomorphological, hydrological and botanical factors. The diversity of climate conditions in the Łódź region is small. As a result, the potential conditions for the development of aquatic and wetland plants during the period under consideration are similar. However, there are clear differences in the shape of plant communities found in peatlands and, consequently, a diverse (on a regional scale) formation of accumulating biogenic sediments. This results from the differentiation of geomorphological and geological processes that occurred in the investigated area. Thus, it is not possible to generate a homogenous model of peatland development for the Łódź region. An example of a developmental model is provided in a diagram proposed by Żurek (1990) and based on the peatlands of the Biebrza ice-marginal valley. However, this model deals with an area marked by homogenous geomorphological features, and presupposes the existence of 7 development phases, defined mainly by means of hydroclimatic factors. However, the stages of peatland development in valleys surrounding Łódź are only partially consistent with the model of the Biebrza ice-marginal valley (Żurek 1990), but the model focused on time periods and on some of the trends in hydrological changes.

The above-described differentiation of peatland basins, based on their position (plateau or valley) and the processes that shape their basins (glacial, fluvioglacial, aeolian, fluvial, thermokarst), predominantly reflect the path of development of wetlands that were created in the forms included in these genetic groups. It is difficult to show peatlands with an identical course of paleographic and paleoecological development. Four broad patterns of peatland formation in the region were developed, representing 3 or 4 groups of basins:

1. Basins located in moraine plateau
2. Basins of aeolian origin
3. Basins located in valleys:
   a) in active river valleys
   b) in inactive valleys.

The development of peatland situated in the area of moraine plateau (in forms of glacial genesis) and aeolian landforms was quite similar, and was related to an endogenous reservoir development. Only a slight influence of slope or aeolian processes in the Late Weichselian and the Holocene was possible. The creation of separate schemes was influenced by differences in the time of depression formation. A separate issue relates to the period of direct human interference, described as the stage of anthropogenic transformations.

Geological and geomorphological research, as well as paleoecological analyses of peatlands located in valleys, shows variability and diversification of morphogenetic basins. It also indicates the age of their formation or a record of period features embedded in deposits filling the basins. The separation of basins located in valleys into two sub-groups is based essentially on their relation to modern fluvial networks and the possibility of the peatlands being fed (directly or indirectly) by river waters (from river channels at the height of the valley's water inflow level). The stages of valley fen development are connected with the impact of fluvial processes in the valleys in Central Poland. Therefore, they can be related to regional development tendencies in river valleys in the Late Weichselian and the Holocene. The variability of water conditions in valleys precludes the formation of ecological succession of plants (typical for mires with stable water conditions) on valley peatlands (Tobolski 2003). Thus, the scheme presented for valley peatlands is based on criteria other than the schemes for the two remaining groups.

Peatlands located in moraine plateau (in basins of glacial origin)

In the Łódź region, there are only rare occurrences of peatland in moraine plateau (in glacigenic basins). The basin of the Żabieniec peatbog, which is located in the deepest part of the postglacial depression, was studied. Żabieniec is the only documented modern reservoir of biogenic accumulation in Poland in which lake sediments older than the Late Weichselian have been found (Forysiak et al. 2010a). The development of the Żabieniec peatbog falls into a scheme of ecological succession – from lake to raised peatbog (Tobolski 2003, 2005). Five stages have been distinguished in this scheme (Fig. 2A).

Stage I (lake stage): the oligotrophic lake was filled mainly with silts and sand (with a small amount of biogenic substance and representatives of arctic species of water organisms). In the Late Weichselian, radical changes occurred in mesotrophic lakes. During the warming in the Late Weichselian, the status of autochthonous organic matter increased. In the Eo- and Mesoholocene, the reservoir was being filled with detrital gyttja with a mossy layer that showed a tendency to terrestrialisation as peatland.

Stage II (fen): permanent coverage of the reservoir surface took place 4,000 BP, along with the appearance of moss peats and sedges, probably across the whole surface of the water. This stage was the result of a tendency for lakes to become overgrown – typical and visible in peatlands in the temperate zone.

Stage III (transitional peatlands): after the permanent coverage of the reservoir by peat-forming plants, huddles of plants appeared in its centre. The remains of those plants were a series of sphagnum-bog and sedge-moss peats. This was the result of the increasing share of rainwater in the feeding of the habitat. This stage lasted for 2000 yrs (3,400––1,400 BP).

Stage IV (raised peatbog): this resulted from a forward reduction of water supply from the outside to its central part, and the central part being overcome with ombrotrophic greenery. It gave the basis for the moss peat. The stage began in the middle part of the Subatlantic Period (about 1350 yrs ago). In undisturbed floristic and hydrographic conditions it would probably have lasted to date. The process of peat accretion was stopped about 700 yrs ago.

Stage V (anthropogenic transformations): the natural development of peatbog was stopped by the founding of a village (the end of 14th century) and deforestation of the areas adjoining the hillside peatbogs (Balwierz et al. 2009; Lamentowicz et al. 2009; Kittel, Sygulski 2010). In the adjoining peatbogs there is a record of changes induced by economic activity from the end of 14th century up to now (together with periods of its weakening and symptoms of renaturization of the plant cover).

Peatlands in basins of aeolian origin

In this group of peatlands there were areas connected with natural aeolian processes of the Late

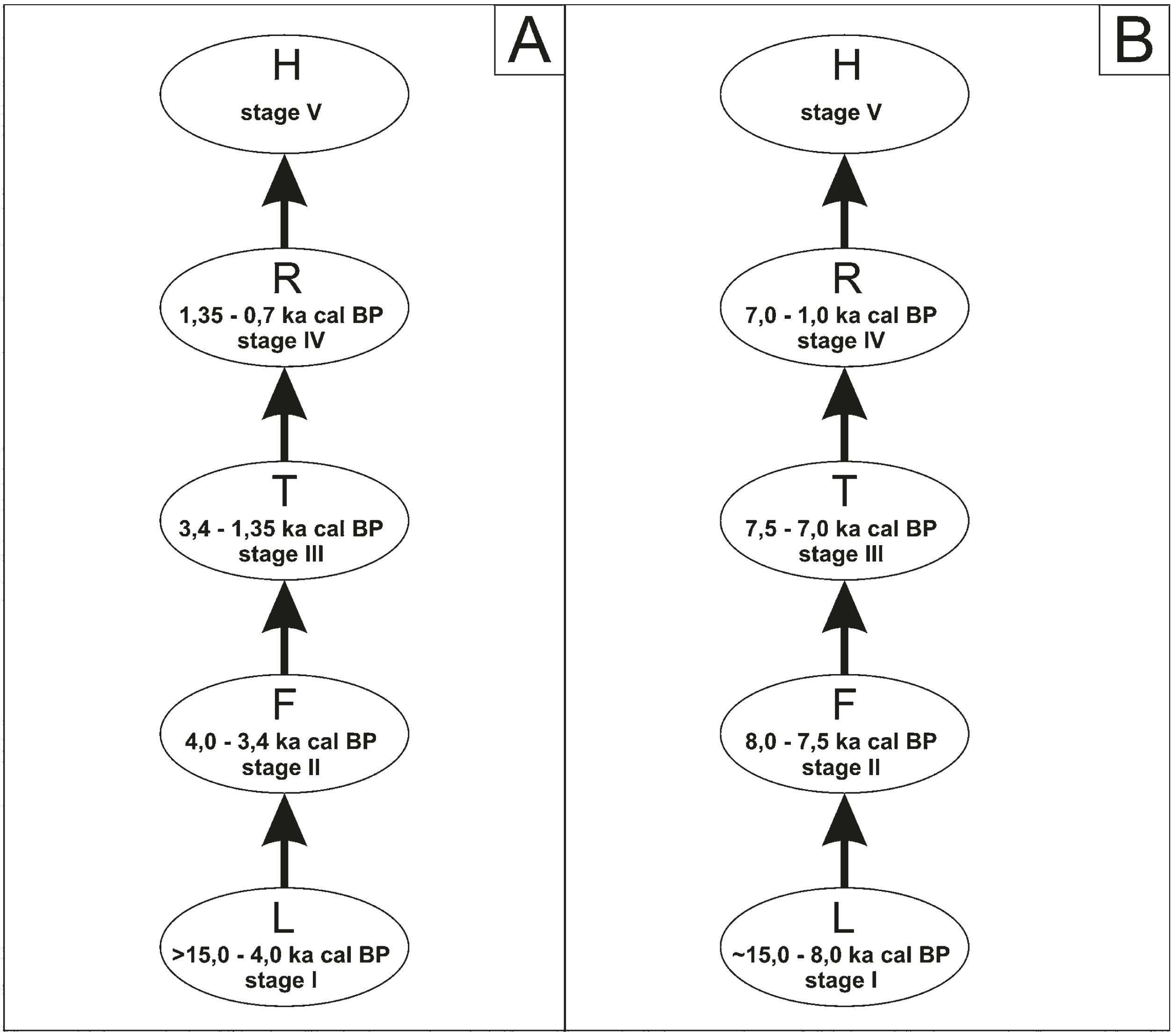

Fig. 2. Stages of succession in peatland basins: A – peatlands located in moraine plateau, in basins of glacial origin (based on Żabieniec Peatbog); B – peatlands in basins of aeolian origin (based on Rąbień); explanations: L – lake, F – fen, T – transitional peatland, R – raised peadbog, H – anthropogenic transformations

Weichselian, and human-induced processes in the Early Holocene. Five stages of development could be distinguished in the examined examples of peatlands (Fig. 2B), although these stages did not run synchronously in the areas of this type. This could result from the upland or valley location and from the local morphological conditions influencing the ways they were fed.

Stage I (lake stage): the formation of lake basins (as a result of the closure of the valley forms or other depressions with emerging or migrating patches of aeolian sands, and dunes) took place in the Oldest Dryas Period or in the Older Dryas Period (Fig. 2B). The morphometric features of basins were dependent on the morphology of their primeval form and on the lay of the dunes. They had an impact on the length of this stage and the process by which the basin filled with lake sediments (mainly detrital gyttja). In the marginal parts of lakes, peatlands already existed at this stage (e.g. Wasylikowa 1964, 1999; Marosik 2011).

Stage II (fen): peat-forming communities (usually of moss or sedge-moss) appear, due to the lake surface being covered by moor (Kloss 2005, 2007). In the case of the Rąbień peatland, this stage took place over a very short time in the middle of the Atlantic Period, and was mainly due to decreasing water levels and limitation on topogenic feeding, along with an increase in rain feeding (the last resulting from greater rainfall, cf. Rotnicki 1991; Starkel 2011). As far as the Witów-Silne Błoto is concerned, the ending of the lake stage and appearance of peatland took place earlier – in the final part of the Younger Dryas Period (Wasylikowa 2011). The part of the peatlands which was formed in the vicinity of aeolian forms did not have lake sediments in the substrate. The mineral surface of the basin underwent swamping, as in the example of Długie Bagno in Puszcza Kampinoska (Kloss 2007), situated in the depressions between dunes.

Stage III (transitional peatland): the increasing significance of rain waters and the impoverishment of the freshwater habitat led to an increased appearance of ombrophile species. This stage did not last for long on the Rąbień peatland – several hundred years in the middle of the Atlantic Period (Kloss 2005, 2007). The transitional peatland stage of the Długie Bagno took place concurrently (Kloss 2007).

Stage IV (raised peatbog): this stage occurred due to the end of topogenic and soligenic feeding in the internal parts of the peatbogs, which then led to minerotrophic flora extinction (Tobolski 2000; Kloss 2007). In the case of the investigated peatlands, this stage existed from the middle part of the Atlantic Period (Fig. 2B). The forming process of peatlands among aeolian forms and transformed by aeolian processes is closely connected to agricultural activity. Such processes were induced at the end of the Subboreal Period and the Subatlantic Period (Twardy 2008) by the deforestation of sandy areas which had previously been stabilised by forest. With favourable water conditions, raised peatland communities appeared in the previously originated depressions. This was the case with the Czarny Ług and Światonia peatlands.

Stage V (anthropogenic transformations): traces of direct human activity on the coastal parts of Rąbień and Silne Błoto and the adjacent dunes date to the Atlantic Period (Wasylikowa 1964, 1999). Nevertheless, they did not interfere with the peatlands' tendency for growth. It was not until the Middle Ages and Modern Times that colonial pressure led to the deforestation of the dunes surrounding water basins, initiating aeolian processes and changing the water relationships in the peatland basins. Anthropogenic transformations translated into flora alteration even in the central parts of the peatbogs (Kloss 2005, 2007).

Peatland located in valleys

a) inactive valleys

Unlike the case of the previously described patterns, it was not possible to devise a system based on habitat succession in peatlands occupying basins in inactive river valleys (and those in areas of high accumulative terraces, glaciogenic valleys and basins of thermokarst origin). These show a similar course of development to one another, even though they were placed in forms of a different origin. Biogenic accumulation processes began during the older part of the Late Weichselian. They developed without the interference of fluvial processes and river water feeding. Five of those development stages have been distinguished (Fig. 3A):

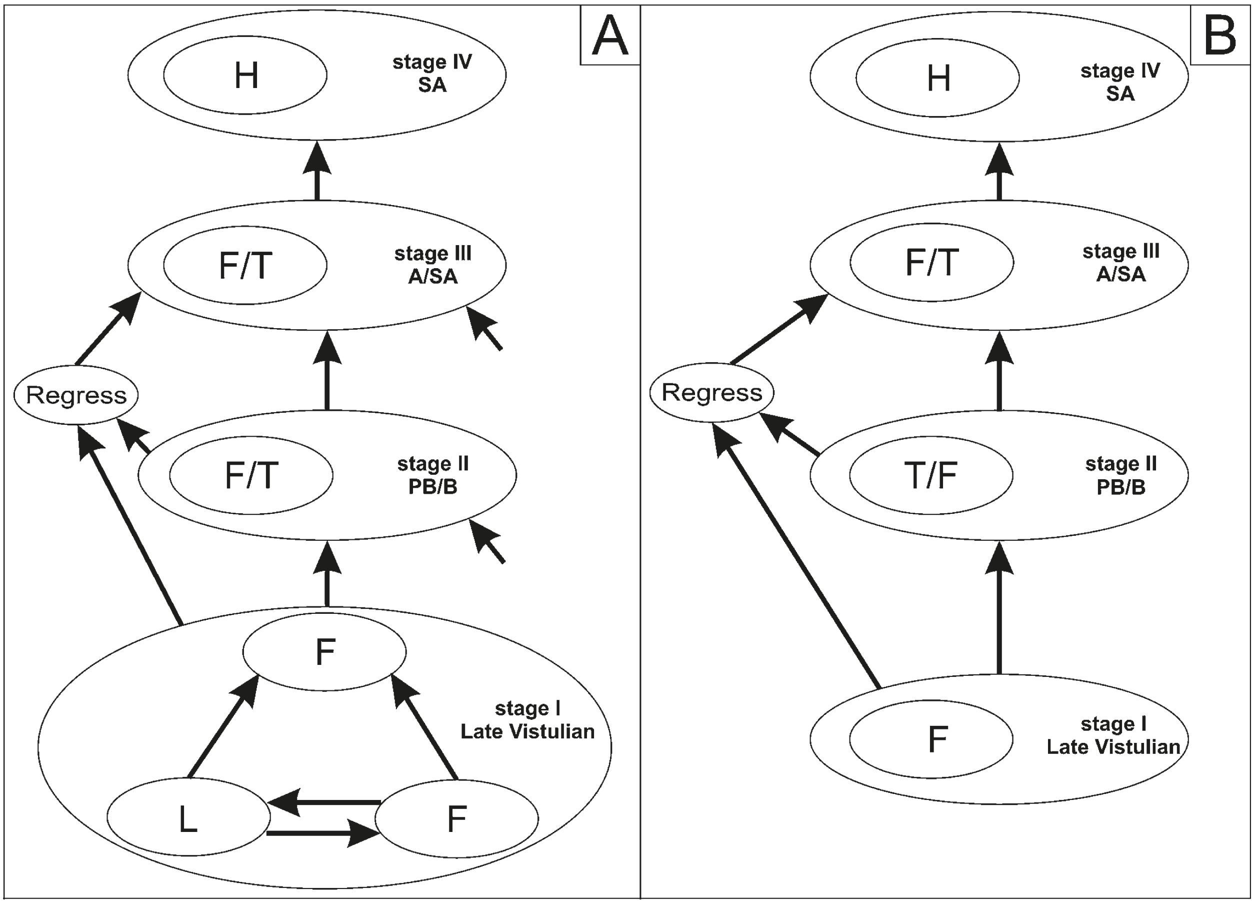

Fig. 3. Stages of succession in peatland basins located in valleys: A – peatlands located in inactive valleys; B – peatlands in active river valleys; explanations: L – lake, F – fen, T – transitional peatland, H – anthropogenic transformations, PB – Preboreal Period, B – Boreal Period, A – Atlantic Period, SB – Subboreal Period, SA – Subatlantic Period

Stage I (lake-peatland stage; the Late Weichselian): lakes formed in the basins or fens appeared at the mineral base. In the case of peatlands of thermokarst origin, the bottom series could have been laid in peatland (fen) – for example the Ner-Zawada site. Afterwards, with the melting of the ground ice, the bottom of the basin and the layer of the laid peat underwent some lowering. This was enough for a permanent lake reservoir to appear and it was later subjected to terrestrialisation of the fen (usually in the Younger Dryas Period). The basins of biogenic accumulation in ice-marginal valleys and abandoned river valleys started functioning as lakes at the beginning of the Late Weichselian (e.g. Ługi, Świnice Warckie) or in its younger period as fen (e.g. Wilczków).

Stage II (transitional peatlands and fens; the Eoholocene): at the end of the Young Dryas or at the beginning of the Preboreal Period, peatlands appeared in previously functioning lake reservoirs. At first they acted as fens, over time transforming into transition peatlands. This stage was mostly connected with the fact that ground water feeding decreased in favour of rain water. Lowering of the groundwater level led to a slowdown in peat mass growth and the extinction of peat creation processes (e.g. Ługi, Wilczków). This break lasted until the Neoholocene. At the same time, in the case of other sites, satisfactory ground feeding conditions were sustained and new peatlands appeared at the beginning of this stage (e.g. Wierzbowa).

Stage III (fen and transition peatlands; regress of peat formation): the Atlantic and the Subboreal Period were characterized by a break in the sedimentation processes of valley peatlands, as has frequently been observed in other basins of this type. Before the end of the Subboreal Period peat-forming plants appeared on part of the peatlands as a result of local groundwater rising in some valleys.

Stage IV (anthropogenic transformations of peatlands): the improvement of water conditions was partially connected with the increase in climatic humidity at the beginning of the Atlantic Period. The anthropogenic dilution of flora cover also affected the acceleration of the surface water flow. With the simultaneous aggradation of the bottoms of the valley river, this resulted in a rise in ground water level in valleys isolated from fluvial processes. The direct influence of agricultural activity in the form of peat exploitation and drainage for the planting of meadows took place around 200 yrs ago. Drainage was easier to carry out in these areas than in active river valleys. This was the reason for a considerably larger degradation level. In the last several hundred years there has been a secondary succession of peat-forming greenery in post-exploitation reservoirs.

b) active river valleys

In active river valleys, peatlands of different sizes were discovered. Regardless of the basin size or type, mire development was strongly connected with the development of the river valley and hydrological changes caused by fluvial processes in the Late Weichselian and the Holocene. Four stages of development have been distinguished (Fig. 3B):

Stage I (fen; the Late Weichselian): oxbow lakes or floodplain basins peripheral to river valley floors underwent swamping. In some cases covering with peats was preceded by the brief existence of open waters, e.g. directly after the basin formation (Korzeń, Bartochów, Bęczkowice). As much as the formation of the peatland basins was strictly dependent upon fluvial processes, their ongoing existence depended on feeding sources. Small peatlands near river channels (most often in oxbow lakes) were fed by fluvial waters and so depended on the river's developmental tendencies. Big peatlands which formed in floodplain basins or in oxbow lakes near valley slopes were most often fed by soligenic or topogenic water. Their development was largely connected with climate tendencies affecting the circulation of the groundwater and volume of surface water in the Late Weichselian.

Stage II (transitional peatlands and fens; the Early Holocene): at the turn of the Late Weichselian and the Holocene there was a phase of cutting through the contemporary river valley floors, as well as a lowering and concentration of the majority of river channels in the region. In the Boreal Period, when the fluvial processes were stabilized, there were already quite steadily functioning transition mires and fens in peripheral zones of valley floors or in subslope parts of low terraces. This change was due to lower water levels in the river channels, and resulted in a larger share of rain waters in the water balance of the mire. The lowering of the water level in the valleys also caused the disappearance of peat-forming plants in parts of the mire. In some sites, the process of peat sedentation was stopped and peat decomposition ensued.

Stage III (transitional peatlands and fens; the Atlantic Period and Subatlantic Period): in this stage, there were significant changes in the functioning of mires in river valleys. In the majority of those mires there was a hiatus, as documented in their sediments, resulting from the stoppage of peat growth and its mineralization, as described in the previous stage. However, in the investigated peatlands these changes did not take place at the same time, which resulted from the asynchronous nature of local fluvial processes and consequently from the course of hydrological changes in the valleys of that region. There were also mires where the process of intensive peat growth began in the third stage, as a result of which local groundwater supply conditions either improved, or the outflow of water into river channels was obstructed by sediment aggradation in the valley beds. In the case of mires which developed in oxbow lakes and floodplain basins of small river valleys, the peat growth decreased but the process did not stop, which may be the result of stabilization of hydrological factors in those valleys resulting from the groundwater content.

Stage IV (transitional peatlands and fens and their anthropogenic transformations; the end of the Subboreal Period and the Subatlantic Period): the fluvial processes from the third stage continued noticeably, leading to an aggradation of valley floors. There was a significant influence of human activity in the valleys, both direct (increasing supply of material into the river valleys, rising especially during the last hundreds of years) and indirect (hydraulic engineering works). A significant increase in the mineral material became apparent as it was transported into the mires, which influenced the fertility growth and eutrophication of habitats. More and more frequently, the wetlands were drained in order to create pasturages and to exploit the peat.

Conclusions

Geological and geomorphological works carried out in the selected peatland basins in the Łódź region, as well as the geological analysis of biogenic sediments accumulated inside them and the paleoecological research, enable several conclusions to be drawn.

Contemporary mires in the Łódź region are located in depressions of diverse genesis and geological construction.

This diversification made it possible to categorise peatlands by location (in plateau or valley mires) and the processes forming their basins (glacigenic, aeolian, fluvial or thermokarst); the vast majority of the mires are located in the valleys, while those existing on moraine plateau are extremely rare.

Peats are prevalent in the sediment structure of the analyzed peatland basins. Among them fens predominate, while the percentage of raised peatbogs is low. In parts of the analyzed objects there are lake sediments, which are usually the bottom layers of the biogenic sediment profiles.

The development of moraine plateau basins, and of valley basins of aeolian origin, is of endogenous character; it begins as a lake and then changes to fens, transitional peatland and, finally, raised peatbogs.

Biogenic accumulation basins located in river valleys do not provide constant sediment growth as they are dependent on the changeable dynamics of fluvial processes, which means that the registered growth of biogenic sediments is not synchronous in all valley peatlands of the region. The intensity of biogenic sediment growth can also be changeable in objects that are fed by groundwater and located in inactive valleys.

Some of the analyzed profiles contain lake sediments of the Holocene age (including those found outside the floors of river valleys), which is proof that lakes functioned in that period.

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