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Differentiation of fen bedrock in the Elk Lakeland (NE Poland) in relation to late Pleistocene terrain morphogenesis

Abstract: The Elk Lakeland (NE Poland) with the area of 263 100 ha was formed during Vistulian glaciation. More than 66% of this region was shaped during the Leszno phase, 15% during the Poznań phase, and 19% during the Pomeranian phase. There are 1854 fens which cover the area of 7.3 % of the Elk Lakeland mesoregion. Fens have an area of 10.3 ha on average. About 82.5% of the studied fens is located on gyttja deposits, which suggests post-lacustrine origin of the wetlands. Primary the lakes had covered 11% of the Elk Lakeland, and 6.3% was transformed into fens. Most of them (60%) was formed on organic gyttja, 16% on calcareous gyttja, and 6% on clay gyttja. About 17.5% of fens was formed as a result of paludification. The types of bedrock underlying peats differ depending on the phases of glaciation.

Key words: fens, gyttja, disappearance of lakes, the Elk Lakeland

INTRODUCTION

The development of fens in young glacial areas depends on geomorphological conditions (particularly on the number and character of the original lakes occurring in negative landforms) and on the development of a river network. The land-forming intensity of lakes in the Masurian Lakeland (northern Poland) differed both in mesoregions, and in morphogenetic zones formed by the glacier of the Vistulian (Weichselian) glaciation. To date, half of the lakes of the Masurian Lakeland have been transformed into peatlands (Piaścik and Lemkowska 2004), with the zonation of this process being clearly depicted. The zonation is related to the latitudinal belts originated during the retreat of the Vistulian glaciation towards the north in the late Pleistocene (Marks 2005). These belts formed during the Leszno (Brandenburg), the Poznań (Frankfurt), and the Pomeranian phase (arranged here from the oldest to the youngest one). In the Masurian Lakeland, over 65% of the former lakes in the area formed in the Leszno phase were later transformed into peatlands, 30% – in the area formed in the Poznań phase, and 50% – in the area formed in the Pomeranian phase (Lemkowska and Piaścik 2006). In the Elk Lakeland, the original lakes covered about 11% of the area. The disappearance of lakes was assessed to be about 58%, of which 56.5% were transformed into fens (Piaścik and Lemkowska 2004). The land formation in the area of former

lakes, depending to a large extent on their size and depth, has determined the quantitative and qualitative differentiation of peatlands. The peat cover of particular morphogenetic zones of the Masurian Lakeland is at the level of 8.1% for the Leszno phase (L), 5.6% for the Poznań phase (POZ) and 7.0% for the Pomeranian phase (POM) (Lemkowska and Piaścik 2006). The mean area is 20 ha for peatlands of the Leszno phase, 13 ha for peatlands of the Poznań phase, and 10 ha for peatlands of the Pomeranian phase. About 80% of peatlands located in the area of the Leszno phase (L) and 90% in the areas of younger phases (POZ, POM) are of post-lake origin (Lemkowska and Piaścik 2006). In this paper an attempt was made to examine the spatial differentiation of the fen bedrocks in the Elk Lakeland (one of the mesoregions in the Masurian Lakeland, NE Poland) considering the morphogenesis of the area.

MATERIALS AND METHODS

The study was performed based on: geological documentation of the peatlands, database of peatlands of the NE region of Poland, and a map of distribution of peatlands of Poland prepared by the Institute for Land Reclamation and Grassland Farming (IMUZ) on a 1:100,000 scale. The extent of the phases of the Vistulian glaciation were determined according to Kondracki (1972). The areas formed in the particular phases were determined, and datasets of fens located

within these areas were created. The peatlands were separated into lacustrine peatlands underlain with: mineral gyttja (Gm), organic gyttja (Go) and calcareous gyttja (Gca), as well as peatlands formed as a result of paludification of mineral soils (M). The dominant genetic types of peat on the particular bedrock were determined. The data were compiled by size of peatlands and the thickness of the deposits was analysed. Spatial differentiation of peatlands was analysed based on the topographic maps on a 1:100,000 scale.

The Elk Lakeland mesoregion, called Upland Masuria (in Polish: Mazury Garbate), occupies the eastern part of the Masurian Lakeland macroregion, and is distinguished by very diverse relief (Kondracki 1972). Richling (1985) distinguishes here 7 microregions with 5 different types of relief, bedrock, and percentage of the area covered by lakes and forests. The Elk Lakeland is characterised by zonal hypsometric differentiation. Its northern part, formed during the Pomeranian and the Poznań phases of the Vistulian glaciation, is more elevated (>200 m above sea level) and hilly, in comparison with its southern part formed in the Leszno phase. The landscape is dominated by loamy-sandy hills and hillocks surrounding lakes (4.5% of the Lakeland area) using numerous concave landforms (Lossow 1996). The Elk Lakeland is drained by tributaries of the Biebrza River, i.e. the Elk and the Lega Rivers (Kondracki 1972). A large number of shallow and small lakes favoured the formation of wetlands which were created following prior shallowing by sediments (Churski 1988).

RESULTS AND DISCUSSION

The Elk Lakeland mesoregion, with an area of 263 100 ha, constitutes 20% of the Masurian Lakeland macroregion (Table). Around 66% of the mesoregion's area was formed in the Leszno phase, 15% in the Poznań phase and 19% in the Pomeranian phase of the Vistulian glaciation. There are 1,854 fens in the Elk Lakeland which cover 7.3% of region area (Table). Within the Leszno phase zone (L), 1,084 peatlands were found (13,917 ha), in the zone of the Poznań phase – 387 (2,786 ha), and within the Pomeranian phase – 383 (2,468 ha). In reference to the areas of the zones in which they are located, this accounts for about 8% of peat cover for the Leszno phase, 7% for the Poznań phase, and 5% for the Pomeranian phase.

Peatlands with an area of less than 10 ha predominate in the Elk Lakeland constituting 83% of total number of peatlands. The mean size of these wetlands

TABLE. Wetlands in the Elk Lakeland

Specifications	Mesoregion PE	Macroregion PM
Area (ha)	263 100	1 318 400
Part of PM area (%)	20.0	100
Number of fens	1854	7346
Area of fens (ha)	19 175	93 741
Part of postlake fens (%)	82.5	85.8
Average size of fens (ha)	10.3	12.8
Area of gyttjals (ha)	358	5588
% of region area:		
Fens	7.3	7.1
Gyttjals	0.14	0.42
Postlake fens	6.02	6.09
Current lakes area*	4.50	6.41
Primary lakes area	10.66	12.92
Overgrown lakes (%)	56.5	47.1
Lakes that disappeared (%)	57.8	51.4

PE – the Elk Lakeland mesoregion, PM – the Masurian Lakeland macroregion, *According to Lossow (1996).

is only 10.3 ha (for the Leszno phase (L) it is 12.8 ha, for the Poznań phase (POZ) it is 7.2 ha, and for the Pomeranian phase (POM) it is 6.4 ha). Fens of all the zones of glaciation in the Elk Lakeland are over 1.6 times smaller than in the analogous zones of the Masurian Lakeland (Lemkowska and Piaścik 2006).

The presence of gyttja (Go, Gm, Gca) in the bedrock of 83% of peatlands in the Elk Lakeland indicates their lacustrine genesis. Taking into account the current area of the lakes, limnic peatlands, and gyttja lands, the author calculated that the percentage of the area originally covered by lakes was 11% of the Elk Lakeland area. Over 60% of the fens were formed on organic gyttja, which ranks the Elk Lakeland first compared to other mesoregions of the Masurian Lakeland (Piaścik and Lemkowska 2004). Organic gyttja predominates in the bedrock of all of the fens, regardless of their size (Fig. 1), and most often alder-wood peats are deposited on this gyttja (Fig. 2). It should be noted that in the zone of the Leszno phase (L), the proportion of organic gyttja (61%) is 3.5-fold higher, compared to the neighbouring Masurian Plain (17%) formed entirely in the Leszno phase (L) (Piaścik and Lemkowska 2004), and it was 12-fold higher than in the zone of the Leszno phase (L) of the Great Masurian Lakes Region (5%) (Lemkowska et al. 2013). Organic gyttja accumulated in highly trophic lakes, and its presence is characteristic for water bodies where there is no flow (Uggla 1969 and 1971, Stasiak 1971). In the bedrock of the studied fens in the Elk Lakeland, organic gyttja reaches a thickness of 9 m. Its location in a hilly landscape promoted migration and fertilisation of waters, increasing the trophicity of the wetlands. Organic gyttja also indicates later land-formation of lakes,

FIGURE 1. Bedrock of fens in relation to size of objects (in ha) and terrain morphogenesis: PE – the whole Elk Lakeland; L – area of the Leszno phase; POZ – area of the Poznań phase; POM – area of the Pomeranian phase; M – mineral bed, Go – organic gyttja; Gm – mineral gyttja; Gca – calcareous gyttja; SUM – summary of fens

which is connected with climate cooling and with inhibition of calcium carbonate precipitation at the lake bottoms (Stasiak 1963), as a result of the inverse relation of coexistence of organic matter and calcium carbonate in lake sediments (Dean and Fouch 1983, Dean 1999, Punning et al. 2008).

Calcareous gyttja (Gca) is deposited in the bedrock of 16.4% of fens in the Elk Lakeland (Fig. 1) which most often have a thickness of about 1.7 m, up to a maximum of 7 m. The frequency of occurrence of Gca, compared to the Olsztyn Lakeland, the Mrągowo Lakeland, and the Masurian Plain, is 2-fold lower, and in comparison with the Great Masurian Lakes Region it is 3-fold lower (Piaścik and Lemkowska 2004), which indicates a much smaller amount of calcium carbonate washed out from post-glacial formations and deposited in former lakes. In the Elk Lakeland, Gca most often occurs in the zone of the Leszno phase (L) (Fig. 1), and is characteristic for large fens, with tall-sedge and alder-wood peats (Fig. 2). The increased frequency of the occurrence of calcareous gyttja in the bedrock of fens of the Leszno phase (L) may be connected with the degree of washing out of calcium carbonate, which is more easily washed out from coarse-grained fluvio-glacial sediments than from glacial tills (Rzepecki 1985, Petelski and Sadurski 1987, Bukowska-Jania 2003). Taking into account that fluvioglacial formations contained about 15% calcium carbonate at the end of the last glaciation, (Bukowska-Jania and Pulina 1999), and comparing this with the current content of CaCO_3 in soils (Kern 1985), one can state that up to the depth of 1.5 m CaCO_3 has been entirely washed out. This illustrates the level of chemical denudation and explains the localisation of the deposited calcareous gyttjas as a product of catchment erosion. It is thought that water flowing through sand-gravel formations with a carbonate content of 12% becomes saturated to degree comparable to waters migrating in calcareous rocks (Rzepecki 1985). The direction of water discharge from north towards south resulted in the possibility of an

additional amount of carbonates being supplied to lakes of the Leszno phase from the zones of the younger phases, i.e. the Poznań and the Pomeranian phases (Bukowska-Jania 2003).

Since the solubility of CaCO_3 decreases with increasing temperature, calcareous gyttja was accumulated in warm periods, when lowering the water level resulted in the shallowing of lakes and, as a consequence, in stronger heating and in the release of CO_2 to the atmosphere, intensified by the rippling of water. According to Stasiak (1963), the maximum of this phenomenon in the Masurian Lakeland falls in the second half of the Atlantic period (8000–5000 BP). The formation of limnic calcareous sediments occurs as a result of biochemical and physical precipitation of CaCO_3 in shallow basins. In deep water bodies, the CO_2 content increases, which results in dissolution of CaCO_3 (Więckowski 2009, Gierłowski-Kordesch 2010). Calcareous gyttja was accumulated in basins acting as sedimentation tanks for rivers (Więckowski 1993) and also in undrained depressions conserved by dead-ice (Goździk and Konecka-Betley 1992).

Mineral gyttja occurs only in 6.0% of fens in the Elk Lakeland, which is similar to the Olsztyn Lakeland, but twice less frequently than the Mrągowo Lakeland (Piaścik and Lemkowska 2004). The proportion of mineral gyttja is the greatest in the zone of the Pomeranian phase (POM), and in the zone of the Poznań phase (POZ) the gyttja occurs sporadically in the bedrock of smaller fens (Fig. 1).

About 17.5% of fens in the Elk Lakeland are not genetically linked with lakes, and they were formed directly on the mineral bedrock (M) (Fig. 1). Fens with such bedrock are twice more numerous than in the Mrągowo Lakeland and the Olsztyn Lakeland (Piaścik and Lemkowska 2004). This paludification index is the highest in the zone of the Poznań phase (POZ) (25%), which would indicate specific hydrological conditions enabling the direct transformation of the land in mid-moraine depressions into peatlands. The favourable terrain configuration (Uggla et al.

FIGURE 2. Kinds of peat in the Elk Lakeland in relation to fen bedrock and terrain morphogenesis (separately for different sizes of fens from <10 to >100 ha). Abbreviations were explained in Fig. 1

1967), the complex structure of the moraines and the soligenous and fluviogenous types of hydrological feeding have all contributed to this (Okruszek 1983). This is confirmed by the relatively small sizes of these fens, with which they could function when fed only with water flowing down from neighbouring hills (Stepa et al. 1995). The fertility of waters feeding wetlands is correlated with geomorphological factors. During the flow of water, it becomes enriched in nutrients, and their amount depends on the soil types the water is passing through (Żurek 1990). The effect of the catchment in this process was emphasised by Ugla (1964).

Peat deposits of the studied wetlands in the Elk Lakeland are mostly classified (68.5%) as deep deposits with thickness more than 130 cm (Fig. 3).

Their proportion is 13% greater in comparison with the mean for the whole Masurian Lakeland (Lemkowska and Piaścik 2006). In the zone of the Leszno phase (L) deep peat deposits constitute 63%, in the Poznań phase (POZ) 88%, and in the Pomeranian phase (POM) 77%. The peat deposits in the Elk Lakeland on average have a thickness of 1.6 m to a maximum of 6.2 m. In the zone of the Leszno phase (L), with milder relief, deposits are noticeably shallower than in the younger phases (Fig. 3). There are twice as many shallow peatlands (<80 cm) than in the zones of the Poznań phase (POZ) and of the Pomeranian phase (POM). These peatlands are usually of small size, and alder-wood peats dominate in the deposit. The thickness of the deposits reflects the differentiation of concave forms and of hydrological conditions in

FIGURE 3. Thickness of peat in fens for each phase of Vistulian glaciation (L, POZ, POM), for the whole Elk Lakeland (PE), and for different fens sizes (from <10 to >100 ha). Abbreviations were explained in Fig. 1

the areas formed during particular phases of the Vistulian glaciation. The dominance of organic gyttja in the bedrock of peatlands contributed to maintaining a high water level, ensuring favourable conditions for the accumulation of peat and for the formation of deposits of great thickness.

Studies completed to date have shown that wetlands are an integral part of the natural environment, they combine various landscapes and enrich them ecologically. Their formation is connected with the geological, geomorphological, and hydrological conditions of a particular area (Żurek 1969 and 1990, Dembek 2000, Lemkowska and Piaścik 2006). The distribution and specificity of these biotopes exhibit regional differentiation referring to the physical-geographical division and morphogenesis of the area. Interest in wetlands is growing due to the important role which they play in carbon turnover. The sparse knowledge of carbonate sediments and the need for more studies are also emphasised. Scientists are becoming increasingly aware that these areas are unrecognised reservoirs of knowledge concerning climate, geochemical, and hydrological processes (Alonso-Zarza and Wright 2010) and can help to forecast environmental changes.

CONCLUSIONS

1. Two-thirds of the Elk Lakeland area was formed in the Leszno phase of the Vistulian glaciation, and one-third was formed in the younger Poznań and Pomeranian phases.
2. The morphogenetic conditions of the Elk Lakeland related to phases of the Vistulian glaciation influenced the spatial, quantitative, and qualitative differentiation of fens. Fen formation in the zones formed in particular phases of the Vistulian

FIGURE 4. Distribution of fens in the Elk Lakeland

glaciation is connected with the number and size of the original lakes, and with the degree of their transformation into land. It decreases toward the north with increasing terrain elevation and increasing terrain relief.

3. Majority of the studied fens in the area of Elk Lakeland was located on gyttja deposits, which suggests post-lacustrine origin of the wetlands. The proportion of organic gyttja in bedrock increases towards the south. Most of paludification peatlands were formed in the Poznań phase.
4. The smaller proportion of calcareous gyttja in the bedrock of fens of the Elk Lakeland, compared to the neighbouring regions (the Great Masurian Lakes Region and the Masurian Plain) indicates post-glacial deposits were poorer in CaCO_3 in the Elk Lakeland. It also indicates a weaker degree of chemical denudation and less favourable conditions of calcium carbonate re-deposition.

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Zróżnicowanie podłoża torfowisk niskich Pojezierza Elckiego na tle późnoplejstoczeńskiej morfogenezy terenu

Streszczenie: Pojezierze Elckie o powierzchni 263 100 ha zostało ukształtowane podczas zlodowacenia Wisły. Około 66% terenu Pojezierza uformował lądolód w fazie leszczyńskiej, 15% – w fazie poznańskiej, a 19% w fazie pomorskiej. Występują tu 1854 torfowiska niskie, które zajmują 7,3% powierzchni mezoregionu. Średnia ich wielkość wynosi 10,3 ha. W podłożu większości torfowisk (82,5%) dominuje gytia, co świadczy o ich pojeziernej genezie. Pierwotnie jeziora zajmowały 11% powierzchni mezoregionu, z czego 6,3% przekształciła się w torfowiska niskie. Większość torfowisk niskich (60%) rozwinęło się na gytii organicznej, ponad 16% na gytii wapiennej, a 6% na gytii ilastej. W wyniku paludyfikacji powstało 17,5% torfowisk niskich. Stwierdzono zróżnicowanie w utworach podtorfowych pomiędzy torfowiskami usytuowanymi w różnych strefach zlodowacenia.

Słowa kluczowe: torfowiska niskie, gytia, zanik jezior, Pojezierze Elckie