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Geological, hydrological and phytosociological conditions of spring mire development in the Parsęta River catchment, Western Pomerania, Poland

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The geological and hydrological context of the occurrence of a rare group of spring mires (soligenous fens) in the young glacial area of Western Pomerania (Parsęta River catchment, Northern Poland) has been analysed. Spring mires are located mainly in the contact zones of units with different geological structure, which creates favourable conditions for the occurrence of large outflows of groundwater rich in calcium carbonate leached from glacigenic sediments. In selected objects (Ogartowo, Bobolice and Głodzino sites), which differ in terms of morphology and hydrology, the biogenic-carbonate sedimentation / sedentation styles were recognised, the supply conditions of spring mires were determined, and the habitat conditions and vegetation structure are described in detail.

Key words: spring mires, peats, calcareous tufa, spring vegetation, Holocene, the Parsęta River catchment, Western Pomerania

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INTRODUCTION

Spring mires belong to a rare group of geoecosystems that are supplied with groundwater (soligenous fens). They often cover small areas restricted to the zones of groundwater outflows; the supply may be both descending (= hanging spring mires) and ascending (= cupola spring mires). Apart from the specific botanic composition (=spring hygrophyte communities), they are characterised by a specific type of lithological development, i. e. peats alternating with calcerous tufas (Succov, 1988).

Sites of spring mires occur in many areas of Europe and Asia which have different environmental conditions (Kovanda, 1971; Jasnowski, 1975; Succov, 1988; Tobolski, 2000; Ilnicki, 2002; Wołejko, 2000; 2001; Hajek et al., 2006). In the majority of cases, they have been objects of study as regards peat, flora and phytosociological issues and considerably less often strictly geological and / or hydrological issues (Dobrowolski, 1994; 1998; Mazurek, Dobrowolski, 2006). Whereas, in the context of the great usefulness of tufa and peat series from such objects for palaeoclimatic and palaeohydrological reconstructions, which have been emphasized in the recent years (Alexandrowicz et al., 1994; Dobrowolski et al., 1999; 2002; 2005), definition of the geological and hydrological conditions of their functioning seems to be the key to further palaeoenvironmental interpretations.

The aim of the research presented in this article was to comprehensively recognise the geological, morphological, and hydrological conditions for the presence of spring mires in the Parsęta River catchment (Western Pomerania, Poland) – an area with a recognized inventory of these objects in terms of phytosociological issues (*vide* Osadowski, Fudali, 2001; Osadowski, 2002). The obtained results provide a basis for: (1) further detailed interdisciplinary studies on the evolution of this type of mires in the Holocene, and (2) palaeoenvironmental reconstructions on a regional scale.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTINGS

Regionally, the Parsęta River catchment (area 3150.9 km^2, Fig. 1) is located within the two hypsometrically and morphogenetically diverse macroregions of northern Poland: the West Pomeranian Lake District and the Koszalin Coast (Kondracki, 2000). The diversity of the geological structure of the region is reflected in loose Pleistocene and Holocene deposits the thickness of which reaches over 200 metres. Series of these formations include tills (five, six beds in some areas), glaciofluvial and fluvial sandy-gravelly deposits, as well as ice-marginal lake silts and sands from successive glaciations and their stadials. The southern and south-eastern part of the examined area within the West Pomeranian Lake District is located within the reach of the marginal zone of the Pomeranian phase of the Vistulian glaciation (Kostrzewski et al., 2008). A small southern fragment of the catchment is situated in the foreland of the maximum extent of the Pomeranian phase, in the proximal parts of the outwashes composed of sands and gravels accumulated by proglacial waters on the ice and between the blocks of dead ice (Fig. 2). Morainic uplands, which form a number of levels descending in the direction of the Baltic coast, stretch out to the north of the wide marginal zone encompassing end moraine hills with culminations of over 200 m a. s. l. (Karczewski, 1985). The West Pomeranian Lake District is dominated by an undulating and hilly morainic upland with relative heights reaching 20–30 m, and the biggest – central and northern – part of the study area within the Koszalin Coast is covered by a flat and undulating morainic upland with a low-energy relief of relative heights from 5 m and inclinations up to 5° (Kostrzewski et al., 2008). Melt-out tills with the thickness reaching several metres, with a great amount of boulders, can be found on the surface of a morainic plateaux. In some places, tills are replaced by glacial silty-gravelly sands which also lie in smaller patches on tills of the Pomeranian phase. To the north, in the lower plateau levels, tills are enriched with clay material. End moraines and dead-ice moraines, as well as kames and kame terraces diversify the relief of the morainic plateaux. These culminations are composed of melt-out material: dead-moraine sands and gravels, silty sands, kame sands and gravels, and fluvioglacial sands and gravels. The melt-out depressions which accompany these forms are often occupied by lakes of a different stage of development and filled with sands, silts, carbonate and organic deposits: lacustrine chalk, gyttja and peat. The plateau levels are cut by longitudinally oriented river valleys using the ways of meltwater outflow (of subglacial origin). In the transition zones between the plateau levels, numerous erosional cuts and denudation-erosional valleys were formed. Meltwater erosion-accumulation plains, over which erosion remnants indicating the former surface of the morainic plateau rise, are situated in the central and northern part of the study area. Fine-grained sands prevail in their structure, and gravel interbedding is found in some places. The part of the Pomeranian Pradolina whose latitudinal sections are used by the Parsęta and Radew rivers is located within the boundaries of the catchment. Late glacial higher terraces composed of 20-metre thick, layered fine-grained sands with fine-grained gravel formed in the valleys of the biggest rivers of the catchment (the Parsęta, Dębnica, Chociel, Radew, among others). The bottoms of the valleys are filled with gravels, sands, alluvia and peats of the Holocene floodplain. Small areas in the catchment are covered with aeolian deposits, ice-marginal lake silts and sands, as well as deluvial sediments overlying alluvia of the bottoms of the small valleys and erosional cuts.

HYDROGEOLOGICAL SETTING

Water circulation in the Parsęta River catchment is of diverse type (Dynowska, 1991) characterized by a considerable spatial variability of effective infiltration, rare occurrence of surface flow and medium and large groundwater resources. In the study area, the Quaternary multiaquifer formation contains a few aquifers: near-surface, inter-morainic, sub-till and valley, which differ in terms of occurrence depth, range

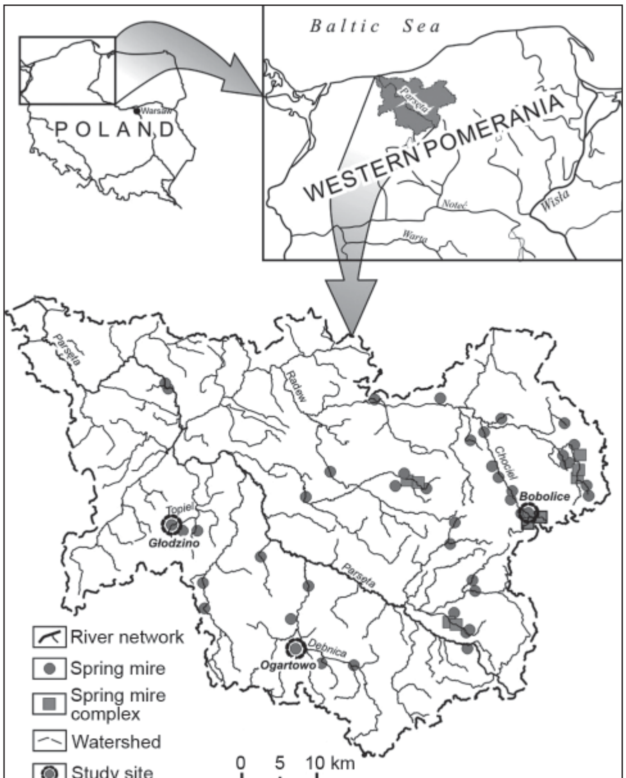

Fig. 1. Locations of spring mires and research sites in the Parsęta River catchment

1 pav. Šaltinių klampynės ir tirtos vietovės Parsetos upės baseine

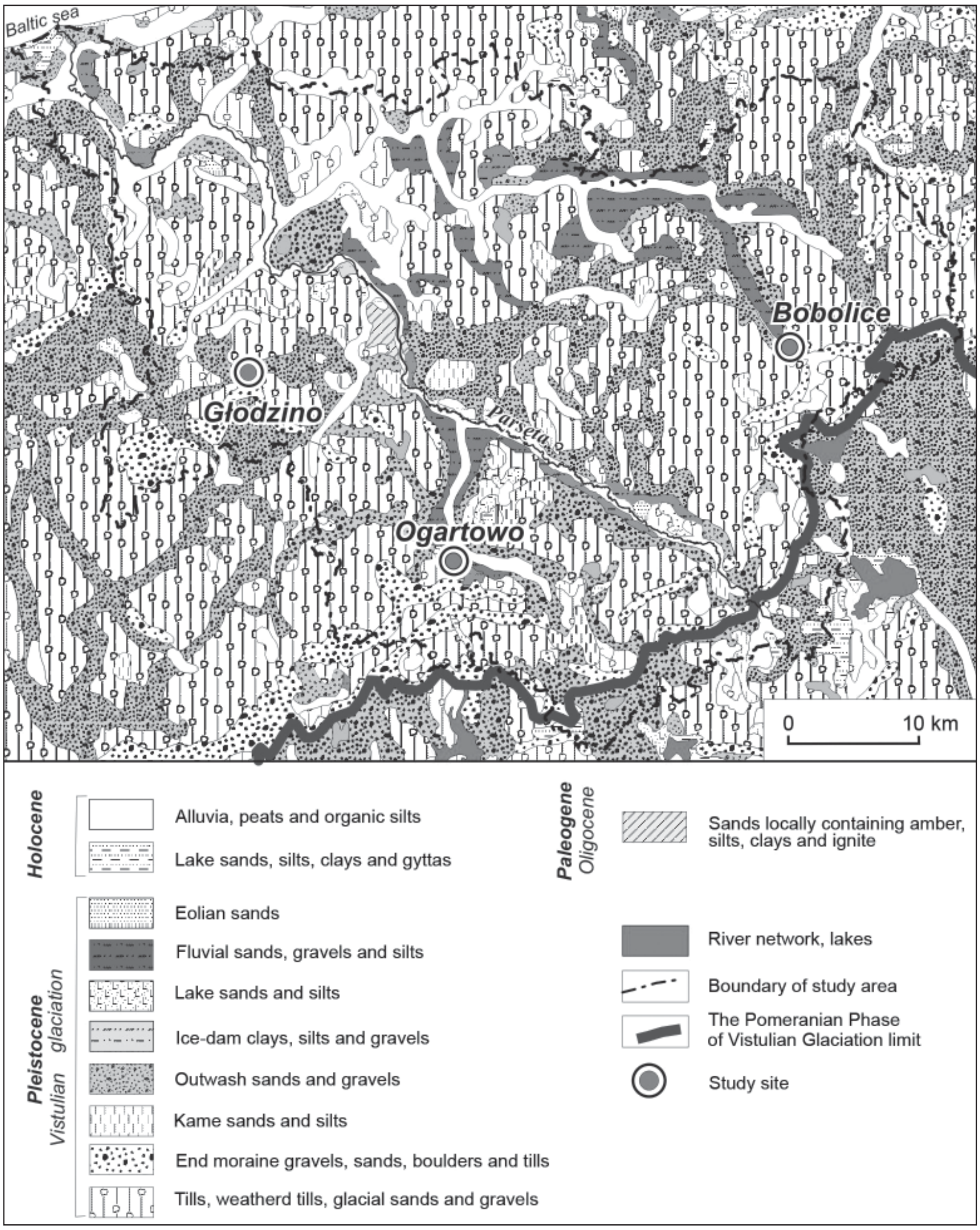

Fig. 2. Geological sketch map of the Parsęta River catchment (surface deposits) after Geological Map of Poland, 1 : 500 000, PGI, Warsaw 2006. Marks L., Ber A., Gogołek W., Piotrowska K. (eds.), modified. Online: http://www.pgi.gov.pl/mapy/mgp500/MGP500_main.html

2 pav. Parsetos upės baseino geologinio žemėlapio fragmentas

and groundwater resurces (Paczyński, Sadurski, 2007). Due to glacitectonic disturbances, the sub-till aquifer is still in hydraulic contact with the upper aquifers, as well as with the Neogene and Paleogene formations. The varied relief and lithology in the Parsęta River catchment influenced the formation of a number of separate local flows in the aquifer system, apart from a transitory and regional circulation subsystem. The main alimentation area of aquifers is the watershed zone of the Parsęta River catchment within the range of morainic plateaux, as well as areas of kame-melt-out relief and fluvioglacial plains. The supply takes place through a direct infiltration of rainwater and seepage through morainic tills. The local flow includes shallow groundwater found in the Vistulian deposits. In some places, part of groundwater from intermorainic aquifers with transitional flow leaks into the local system. The Parsęta and Radew river valleys and tributary valleys make up the drainage area. Groundwater outflows and the spring mires connected with them are supplied with water from the local near-surface aquifer and transitional intermorainic aquifers. Groundwater outflows are concentrated in the Parsęta River catchment in scarps of the morainic plateaux, on the slopes of kames and on the slopes of fluvioglacial outflow valleys and melt-out depressions. Whereas, in the morainic plateaux of the low-undulating relief composed of 40–100 m thick till beds of successive glaciations there are hardly any groundwater outflows.

MATERIALS AND METHODS

The research works were of interdisciplinary nature and were conducted in 2007–2008. From 53 spring mires in the Parsęta River catchment, which had been already inventoried (*vide* Osadowski, Wołejko, 1997; Osadowski, Fudali, 2001; Osadowski, 2002; 2008; Wołejko, 2001), three objects were chosen for a detailed study (sites: Bobolice, Ogartowo and Głodzino) representing different morphological types (cupola and hanging spring mires), geological contexts, types of supply (ascending and descending) and plant composition (location as in Fig. 1). The scope of the studies in each of the chosen areas included: (a) detailed geological (sedimentological) recognition of the peat bed, (b) determining the conditions of supply and drainage, and (c) physicochemical characteristics of groundwaters in the areas of their outflow to the surface, (d) phytosociological survey, and (e) determining the species composition of peat-forming vegetation.

Study sites

Ogartowo site (53º45.93'N; 16º07.92'E) is a complex of spring mires, which includes both a cupola spring mire (ascending supply) and a vast hanging spring mire (descending supply). It is situated at the hinterland of an undulating morainic plateau composed of tills and varigrained glacial sands of the Pomeranian phase of the Vistulian glaciation (Fig. 2). The plateau is deeply cut through with subglacial troughs and melt-water valleys used by the contemporary river network. The Ogartowo spring mire was formed at the foot of the morainic plateau egde in the contact zone with the Dębnica River valley. The river flows in this stretch through a melt-water valley filled with sandy deposits from the period of ice-sheet recession of the Pomeranian phase, and the narrow higher terrace is composed of Late Glacial fluvial sands. The cut of the Dębnica River valley in the plateau level and the high hydraulic gradients on the scarp of the plateau provide good drainage conditions for inter-morainic pressure waters supplying several efficient slope-foot springs.

Bobolice site (53°56.35'N, 16°37.01'E) represents a vast complex of spring mires. It is situated at the valley bottom of the Chociel River using a deep subglacial channel clearly marked in the relief and cutting through the undulating morainic plateau. The level of the plateau, reaching over 150 metres a. s. l., is more varied thanks to numerous melt-out depressions and kames. This zone, which is composed of glacial sands locally overlying tills, constitutes a supply area of Quaternary aquifers drained in the Chociel River valley. The Chociel trough with the river flow to NW meets, through the latitudinal trough, with another trough stretch of NW–SE orientation, with the river flow to SE (outside the Parsęta River catchment). During the period of ice-sheet recession of the Pomeranian phase, the Chociel trough was transformed by glacifluvial waters. Now, the Chociel River valley is filled with fluvioglacial sands from the period of ice-sheet recession, Late Glacial fluvial sands of higher terraces (Fig. 2), and Holocene biogenic sediments. Groundwater outflows within the Chociel River valley of subglacial origin are supplied with pressure waters from inter-morainic sand deposits.

Głodzino site (53°54.70'N, 16°51.76'E) represents a hanging spring mire. It is located on the left slope of the Topiel River valley, in its upper – spring – stretch. The Topiel River, flowing down from a hilly morainic plateau, changes its course from longitudinal to latitudinal, using a fluvioglacial-water valley in this stretch of its course. The highest level of the morainic plateau composed of tills and glacial sands, which is found in this area, passes with a steep scarp into the valley filled with a series of fluvioglacial sands and gravels. At the bottom of the valley, which originated due to the activity of glacifluvial water, numerous efficient slope-foot springs are found; they are supplied from near-surface and inter-morainic aquifers. The bottom of the valley is filled with a mire complex including, apart from spring mire, also percolating mires. Analysis of the flow volume in the upper course of the Topiel River (25.7 l/s) and in the section closing the mire complex (81.1 l/s) has shown that this stretch of the valley, 1.5 km in length, is characterized by an intensive underground supply (about 55.4 l/s).

Sedimentological methods

The sedimentological recognition of the beds of the examined spring mires was based on a detailed grid of geologic drillings (using a hand-auger with an Instorf sampler 0.5 m in length and 5 cm in diameter) made at intervals of 5–25 m along the geodetically determined transects. A macroscopic lithofacial analysis of the cores was made. The Troels–Smith method was used to describe the deposits.

Hydrological methods

The efficiency of the graoundwater outflows and / or the flow in the stream draining the mires, as well as the temperature, pH and specific electrical conductivity were measured. The ionic macrocomposition was determined in the collected samples of water after filtration. Analytical methods compliant with the Polish standards were used to determine the chemical composition of the water. The accuracy of the determined ionic concentrations was checked in terms of measured specific electrical conductivity (EMEP, 2007) and on the basis of the ionic balance of the water.

Phytosociological methods

Vegetation mapping within the spring mires was conducted along the transects (the same which were used for the detailed sedimentological recognition of the mire bed). The vegetation was studied by the Braun–Blanquet method (Matuszkiewicz, 2005). A phytosociological survey, which was used for the further analysis of the succession of the actual vegetation, was made within the objects. The nomenclature and classification of the spring communities were based on the concept of Hinterlang (1992) and Zechmeister and Mucina (1994), independent bryophytic communities according to Hübschmann (1986). The nomenclature of mire, rush, meadow and forest communities was adopted after Dierssen (1982), Matuszkiewicz (2005), Succow (1988) and Wołejko (2000). The names of recorded vascular plant species follow Mirek et al. (2001) and Ochyra et al. (2003).

RESULTS

Sedimentological features

The deposits building the beds of the analysed spring mires demonstrate a high internal lithofacial variability with a simultaneous similarity of sediment succession in separate objects. They are formed by fen peats (sedge, reed, and sedge-reed), mineralized peats, calcareous tufas and mineral-organic muds. The thickness of spring series in the mires studied ranges from 1 m to 8 m (Fig. 3). Strongly decomposed sedge peats (*Cariceti*), sedge-reed peats (*Carici-Phragmiteti*) and / or mineralized peats of a massive structure were registered at the bottom of all the objects. To the top, they pass into calcareous tufa with a visibly varied grain-size distribution from silty to coarse-grained (often with big lumps with sharp edges). Silt tufa – contaminated with plant detritus – was reg-

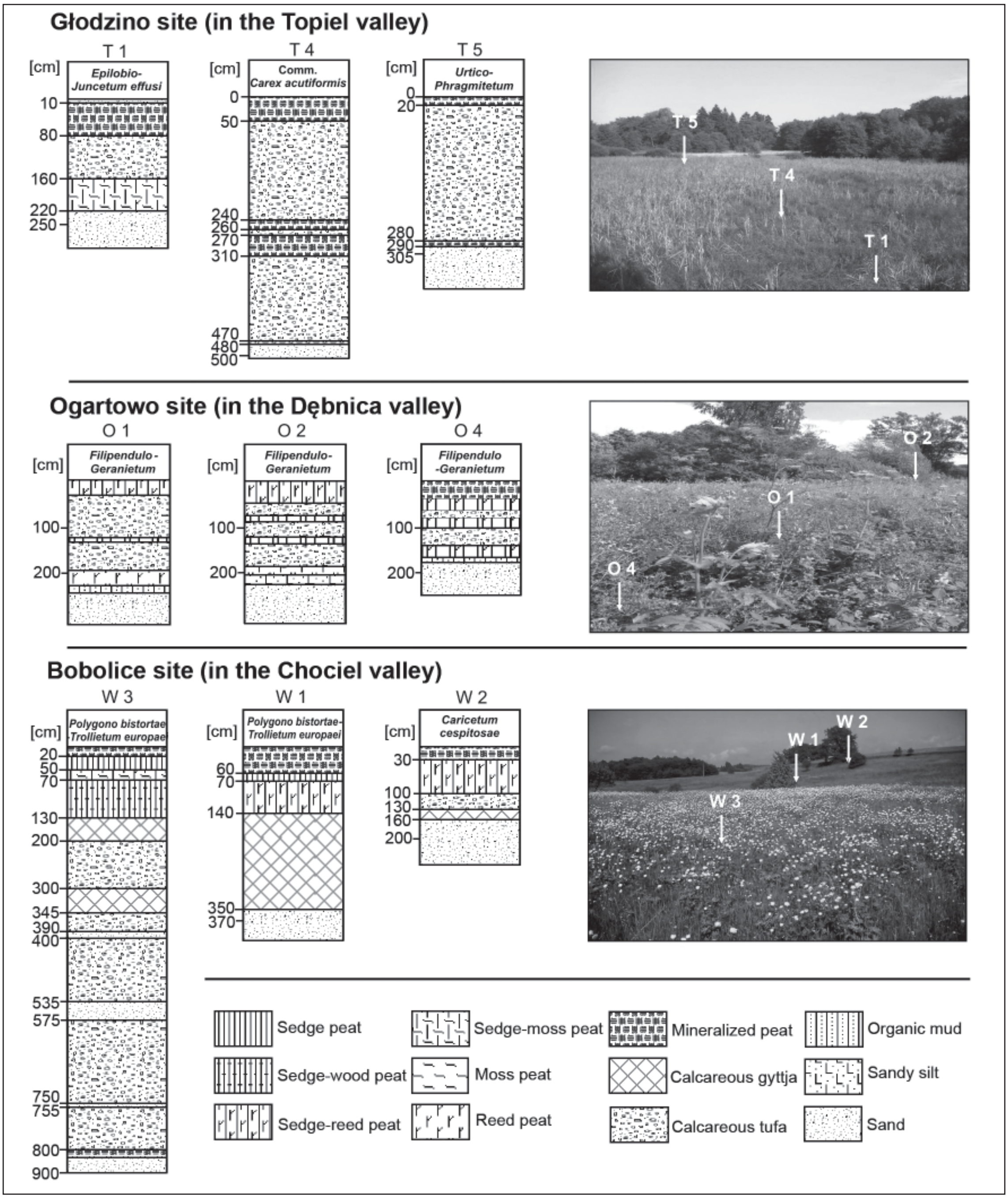

Fig. 3. Examples of lithological profiles of spring mires from the Parsęta River catchment (research sites)

3 pav. Parsetos upės baseino šaltinių klampynių litologiniai pjūviai (tirti plotai) istered mainly in the lower parts of the profiles of the hanging spring mire (*vide* the Głodzino site), whereas medium- and coarse-grained – with clear ferruginous streaks – in its higher-lying layers. Coarse-grained tufas with clearly marked layering dominate in the cupola spring mires (*vide* Bobolice and Ogartowo sites); in the top they turn into well decomposed sedge *Cariceti*) or moss-sedge (*Carici-Bryaleti*) peats contaminated with amorphous calcium carbonate (Fig. 3).

Hydrological conditions

In the Parsęta River catchment, depending on the nature of the drained aquifers, groundwater outflow efficiency varies greatly but with the dominance of very small and small outflows <1 l/s (Mazurek, 2006). Studies conducted on the spring mires show that they are situated in the areas of outflows of high efficiency scatter (from <1 l/s to >50 l/s). The total discharge from the area of the Ogartowo spring mire amounts to about 10.5 l/s (2006) and from the Głodzino mire 19 l/s (2007). The discharge in the stream draining the Bobolice mire amounts to about 46 l/s (2000). In the case of the objects, the deep cutting of the morainic plateau by the valley network created good conditions for drainage of inter-morainic pressure waters, and an intensive inflow of water results from a considerable alimentation area, high thickness of sediments (up to several dozen metres) and favourable filtration conditions (Fuszara, 1998; Kreczko, Prussak, 2004).

The groundwaters in the Chociel River valley (= Bobolice site), Dębnica River valley (= Ogartowo site) and Topiel River valley (= Głodzino site) are distinguished by a low and medium mineralization (specific electrical conductivity in the range 300–450 μS/cm) and a slightly alkaline pH. Cations of calcium (70 mg/dm^3 on average) and anions of bicarbonate (180 mg/dm^3 on average) prevail in the ionic composition. The examined outflows supplying the spring mires are of bicarbonate-calcium hydrochemical type; according to the ecological classification (Succow, 1988), these spring mires should be classified as eutrophic-calcareous and mesotrophic-calcareous.

Phytosociological assemblages

The flora of spring complexes of the Parsęta River catchment includes 525 species of plants, of them 447 species of vascular plans, 69 species of mosses and 9 species of liverworts (Osadowski, Fudali, 2001; Osadowski, 2002). According to the phytosociological classification, the flora of the complexes studied encompasses 60 associations and communities representing 7 vegetation classes. These are spring communities of the *Montio–Cardaminetea* and *Fontinaletea antipyreticae* classes (12 associations), rush and sedge of the *Phragmitetea* class (12), mire of the *Scheuchzerio-Caricetea fuscae* class (9), meadow and herb of the *Molinio–Arrhenatheretea* class (19) and forest and shrub communities of the *Alnetea glutinosae* and *Querco-Fagetea* classes (8). Their more detailed list and characteristics were presented by Osadowski (2008).

The flora of the examined spring complexes (Bobolice, Ogartowo and Głodzino sites) included 435 species, of them 386 species of vascular plants, 42 species of mosses and 7 species of liverworts. The phytosociological analysis showed 35 types of plant communities. The flora of the examined objects is dominated by meadow and herb communities of the *Molinio–Arrhenatheretea* class, which represent different succession stages after agricultural use was abandoned. The most important communities are those of wet meadows *Angelico–Cirsetum oleracei, Caricetum cespitosae, Filipendulo-Geranietum, Polygono bistortae – Trollietum europami* and meadow forms of communities with *Carex acutiformis* and eutrophic communities similar to *Urtico–Phragmitetum* rushes. The forest vegetation is dominated by marsh alder forests and willow bushes of the *Alnetea glutinosae* class. The forest association, which covers the largest areas, is the spring alder carr *Cardamino-Alnetum glutinosae*.

CONCLUSIONS

The distribution and nature of the supply of spring mires in young glacial areas is strictly connected with the local morphological situation and the lithological conditions of the cover deposits. In the Parsęta River catchment, these mires are concentrated in the contact zones of geomorphological units of different geological structure and in the areas of considerable hypsometric gradients. Such areas are: (1) morainic plateau scarps (exposing series of lithologically diversified glacial deposits), (2) fluvioglacial outflow valleys on outwash plains (with predominant weakly-permeable fine-grained deposits separated by gravel-sandy facies), (3) valleys of subglacial origin (with lithogenetically very variable deposits), and (4) slopes of melt-out depressions on morainic plateaux (exposing fine-grained facies of melt-out deposits).

The increased hydraulic gradient on the slopes of post-glacial and fluvial forms creates favourable conditions for groundwater drainage in the form of ascending springs and surface leakings. The formation of spring mires and their size are also connected with the manner in which they are supplied (descending or ascending outflows) and the groundwater resources of drained local and transitory aquifer systems. Waters with a free water table, supplying the layer springs around which the hanging spring mires were formed (with the dominating spring alder carr *Cardamino-Alnetum glutinosae*), are drained on the slopes of the valleys. In slope-foot locations with good conditions for drainage of inter-morainic pressure waters supplying efficient ascending springs, cupola spring mires were formed (with dominating communities of *Carex acutiformis* and rushes *Urtico-Phragmitetum*). It is possible for mire complexes including various types of polygenetic mires (dominated by diverse communities of the *Phragmitetea*, *Scheuchzerio-Caricetea fuscae* and *Molinio–Arrhenatheretea* classes) to form in the drainage areas of a few aquifers. As a result, on the morainic plateaux, which are poor in groundwater outflows, no spring mires are found.

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ŠALTINIŲ KLAMPYNIŲ GEOLOGINĖS, HIDROGEOLOGINĖS IR FITOSOCIOLOGINĖS SĄLYGOS PARSETOS UPĖS BASEINE, LENKIJOS VAKARINIAME PAJŪRYJE

S a n t r a u k a

Straipsnyje analizuojamas retos soligninių šaltinių klampynės, esančios jauniausio apledėjimo srityje Vakarų Pomeranijoje, geologinis ir hidrogeologinis kontekstas. Nustatyta, kad šios klampynės yra skirtingų geologinių struktūrų kontaktinėse zonose, kuriose yra sąlygos ištek4ti koncentruotam požeminiam vandeniui, turtingam kalcio karbonato ir išplautam iš moreninių darinių. Tirti skirtingi objektai atskleidė nevienodas sedimentacijos / sedentacijos sąlygas ir skirtingą šaltinių klampynių papildymą. Detaliai aprašytos floros asociacijos.

Raktažodžiai: šaltinių klampynės, Parsetos upės baseinas, Vakarų Pomeranija