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DEVELOPMENT OF THE KŁADKOWE BAGNO PEAT-BOG IN THE LATE GLACIAL AND HOLOCENE: DIVERSIFIED HISTORY OF TWO DEPOSIT BASINS STUDIED WITH USE OF MACROFOSSIL REMAINS ANALYSIS

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Abstract

This paper presents results of investigation on peat and lacustrine sediments from the Kładkowe Bagno peat-bog located in the Puszcza Knyszyńska Forest. Using analysis of plant remains from sediment samples, vegetative and generative finds were identified which allowed describing peat units. Basing on these results, reconstruction of subfossil vegetation and palaeoenvironmental changes in the mire was made. Altogether 4 subassociations of *Sphagnetum magellanici* were described, which delivered information about humidity of the mire surface during peat forming processes. Stages of deposit development were dated by radiocarbon method. Accumulation of the oldest sediments in the southern basin took place in the Late Glacial. Peat of the northern basin started to accumulate in the Atlantic period. The both parts of the mire aggregated probably 400 years ago.

Key words: Late Glacial, Holocene, Puszcza Knyszyńska Forest, peat, analysis of plant remains, subfossil vegetation

INTRODUCTION

The Puszcza Knyszyńska Forest is located in Northeastern Poland (Fig. 1), in the area of old-glacial plains, which genesis is connected with the Warta glaciation. During the Vistula glaciation, the area was situated in an immediate neighbourhood of the ice-sheet. More than 20% of the Puszcza Knyszyńska Forest is now occupied by paludal habitats, therein mires. Degree of peat-cover reaches 10%, which is one of the highest value in Poland (Okruszko 1995).

In 1999 palaeobotanical studies started on sediments of the Kładkowe Bagno peat-bog. Radiocarbon analysis of the bottom sediments dated the beginning of the mire development back to the Late Glacial. The main goal of the present study was to describe process of peat-bog development, with a special attention to the vegetation history.

CHARACTERISTIC OF THE KŁADKOWE BAGNO PEAT-BOG

The Kładkowe Bagno peat-bog is located in the northern part of the Puszcza Knyszyńska Forest (Fig. 1). It covers 40 ha and consists of two depressions connected by a distinct isthmus with shallow peat of ca. 0.3 m. The mire is surrounded by numerous kames. Both depressions are overgrown by *Vaccinio uliginosi-Pinetum* in the final phase of succession (Czerwiński, pers. comm.). Kładkowe Bagno, as a peat-bog, receives water from the atmosphere. According to Żarska (1993) the areas surrounding the mire are overgrown by *Tilio-Carpinetum*, *Melitti-Carpinetum*, *Serratulo-Piceetum*, and *Myceli-Piceetum*.

MATERIALS AND METHODS

Altogether 11 cores of sediments were collected using a Russian sampler of 5 cm diameter. The spots of drillings formed long and cross transects (Fig. 2). The southern depression of the Kładkowe Bagno peat-bog is ca. 5 m deep and the northern depression ca. 2.15 m deep. In total 149 samples of sediments have been prepared for analyses. Peat samples (140) were rinsed with distilled water with an addition of 10% KOH. The aim of that was full dispersion of peat lumps. Next the suspensions were boiled, then washed out on 0.2 mm sieve and peat was placed in Petri dishes. At first, generative finds (fruits, seeds, fruit scales) from every peat sample and from gyttja samples (9, not boiled) were picked out and placed in another dishes with glycerine-thymol mixture (Tobolski 2000). These finds were identified under a stereoscopic binocular. Vegetative plant remains were identified only in peat, with a light microscope. Different kinds of macrofossils were recognized: roots, periderm, epiderm, leaves, stems, wood. For each sample, a proportion of every taxon tissues in the total tissue mass was estimated.

After these analyses peat was classified according to Tołpa *et al.* (1967). Delimitation of subfossil syntaxa was

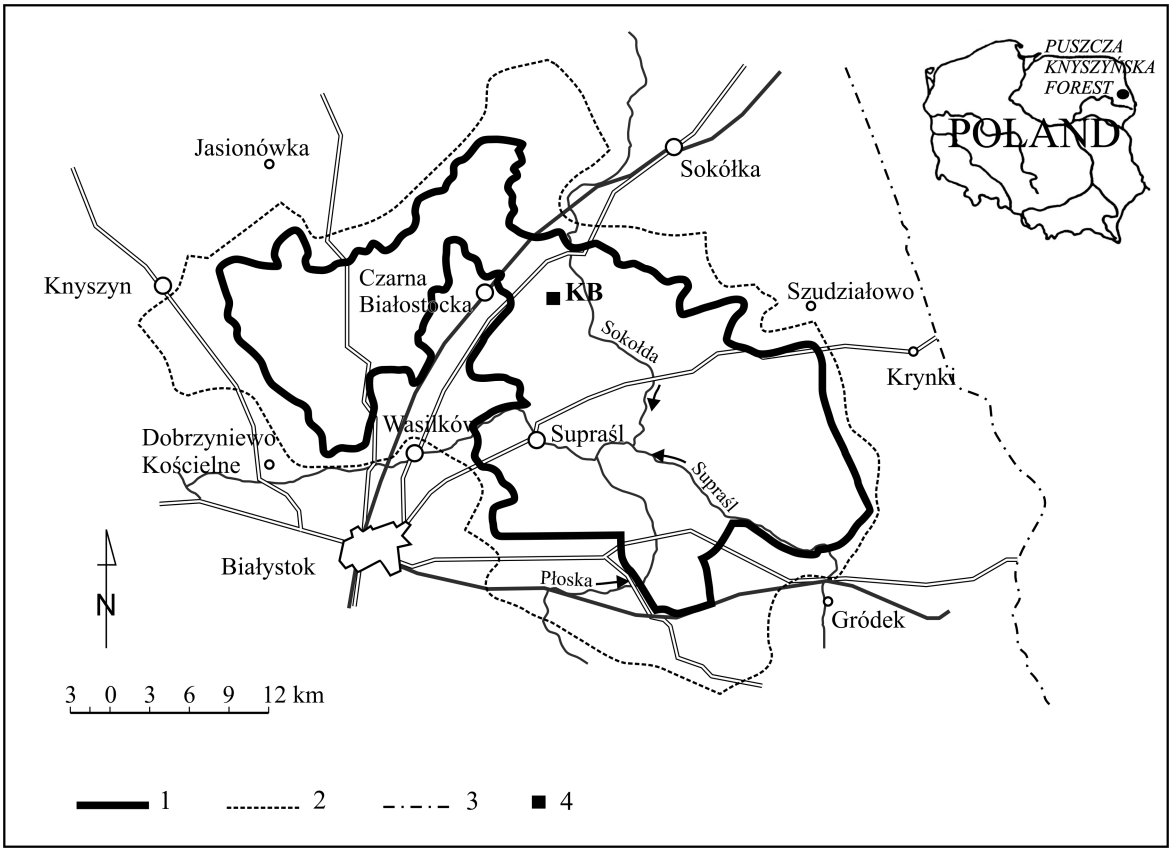

Fig. 1. Territory of the Puszcza Knyszyńska Forest. *1* – border of the landscape park, *2* – border of the buffer zone, *3* – state border, *4* – peat bog under study (KB – Kładkowe Bagno).

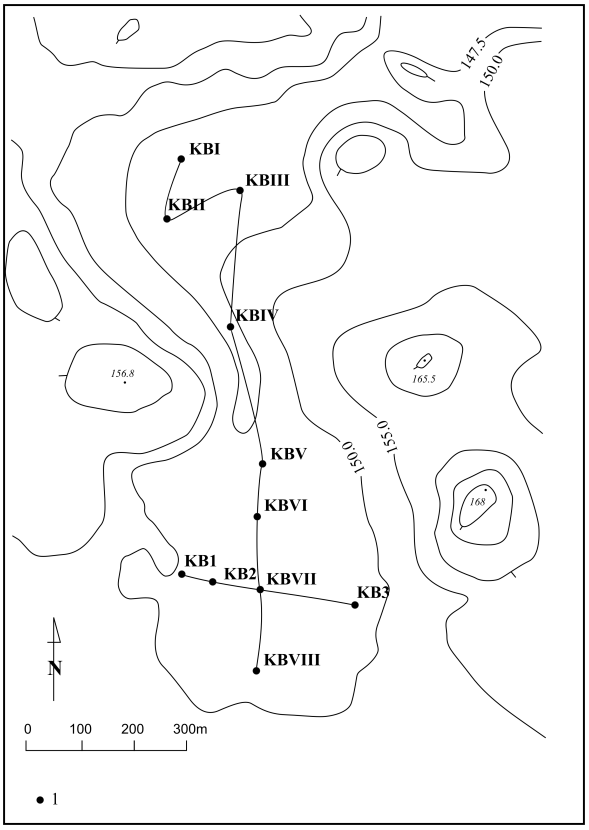

Fig. 2. Kładkowe Bagno peat bog. *1* – location of drillings.

based on the combination of plant remains. Criteria established for contemporary plant phytocoenology were adapted (Oświt 1973, Pałczyński 1975).

Several samples of peat were dated by the radiocarbon method. Chronology of peat profiles was presented in form of chronozones according to Mangerud *et al.* (1974).

RESULTS AND DISCUSSION

Plant remains, peat units and subfossil plant communities

Remains of 52 different plant taxa (species, genus, family) were identified in the investigated sediments. Quantitative representation of major plant types is as follows: trees and shrubs (7 taxa), dwarf shrubs (4), herbs (14), pteridophytes (2), peat-mosses (13), brown mosses (9), and algae (3). Some of the identified taxa are characteristic of six vegetation classes: *Scheuchzerio-Caricetea nigrae* (11 taxa), *Oxycocco-Sphagnetea* (10), *Phragmitetea* (5), *Alnetea glutinosae* (3), *Vaccinio-Piceetea* (2), *Charetea* (1).

Four of the recognized taxa are not found in the Puszcza Knyszyńska Forest region today:

a) peat-mosses: *Sphagnum platyphyllum, Sphagnum centrale*, and *Sphagnum angustifoilum*

b) brown moss: *Warnstorfia fluitans*

In total 13 peat units and two kinds of gyttja were recognized in the studied deposit (Fig. 3, 4). All peat units (humo-

peat therein), beside sphagnum-sedge peat, are present in the classification of Tołpa *et al.* (1967).

Only two subfossil plant associations (*Sphagnetum magellanici* and *Caricetum rostratae*) were reconstructed. However each of them occurred as several subassociations:

a) *Sphagnetum magellanici*: *S. m. typicum*, *S. m. eriophoretosum*, *S. m. pinetosum*, and *S. m. sphagnetosum fallacis*

b) *Caricetum rostrate*: *C. r. sphagnetosum fallacis*, and *C. r. calliergonosum*

The peat units and subfossil communities of the Kładkowe Bagno peat-bog were described in detail by Drzymulska (2005, 2006a).

Development of mire

Late Glacial

Initiation of peat-forming process in Kładkowe Bagno took place in the Late Glacial, in Younger Dryas (Kupryjanowicz 2004). It was a consequence of climate warming in Allerød, which caused melting of ground ice filling land depressions, and deposition of mineral material. The first subfossil community – subassociation *Sphagnetum magellanici eriophoretosum* occurred on mineral substratum in the area of the southern basin, next to the KBVII drilling site. Thin layer of *Eriophoro-Sphagneti* peat was formed there (Fig. 3, 4). Deposition of cotton-grass-sphagnum peat in the bottom of KBVII core implies extreme nutrient-deficient habitat. Trophy indicator for *Eriophorum vaginatum* achieves 1–2 in 5-degree scale (Zarzycki *et al.* 2002). In the half of Younger Dryas (10460 ± 40 ^{14}C BP) (Poz-2881), intense melting processes caused flooding of this little peat-bog and gyttja started to accumulate then. In the water body of Kładkowe Bagno, vegetation of the *Charetea* and *Potametea* classes occurred. Remains of Characeae, fruits and endocarps of *Potamogeton natans,* seeds, fragments of leaves and idioblasts of *Nymphaea alba* were recognized. Aggregates of *Pediastrum,* like *Pediastrum integrum*, were numerous. Their presence is an evidence of cold and clear water (Jankovská, Komárek 2000).

The presence of peat layer under lacustrine sediment in Poland was noted, e.g. in the Biebrza valley (Oświt 1973, Oświt, Żurek 1981, Balwierz, Żurek 1987), in Pomerania (Marek 1991), in the Masurian Lakeland (Kloss 1993), and in the Puszcza Knyszyńska Forest – Machnacz (Żurek 1992), and Stare Biele (Żurek 2000). Fen and transitional peat was dominant there but in the bottom of the Kuwasy I profile in the Biebrza valley (Oświt, Żurek 1981), highmoor peat was described, like in the KBVII profile studied here. Its appearance was connected with regional watershed.

The Late Glacial initiation of the Kładkowe Bagno lake, makes it similar to another water bodies functioning in the past in this region, like Machnacz (Żurek 1992), Stare Biele (Żurek 2000), Taboły (Drzymulska 2005, 2006b), and Rabinówka (Gródek-Michałowo Depression) (Drzymulska 2004a).

Early and middle Holocene (10000–5000 ^{14}C BP)

In Preboreal period, at the spot of the KBVII drilling, water body still functioned, because the age of the middle sample of lacustrine sediment is 9570 ± 40 ^{14}C BP (Poz-2879) (Fig. 3, 4). Anyway fall of water level, starting from the beginning of the Holocene took place, which was evidenced by the occurrence of *Potamogeton natans* (cf. Tobolski 1998). According to Żurek (1995) the reasons of low water level in lakes at the beginning of the Holocene were rapid forest development, low precipitation and high evaporation. Numerous remains of *Nympaea alba* were contained in gyttja. Waterlilies are important in process of overgrowing of lakes, uplift substratum preservation (Podbielkowski, Tomaszewicz 1982).

Transformation of water body into mire took place at the decline of Boreal period (8120 ± 40 ^{14}C BP, Poz-2878 – the age of the oldest peat sample) (Fig. 3, 4). The subassociation *Caricetum rostratae calliergonosum* was an initiator of that process. Disappearance of lake could be connected with a fall of water level noted in lakes and mires in the territory of Northern Poland from the second half of Preboreal period until the beginning of the Atlantic (Ralska-Jasiewiczowa, Starkel 1988). After overgrowing of lake by floating sedge-brown moss matt, the subassociation *Caricetum rostratae sphagnetosum fallacis* developed. It functioned in the vicinity of neighbouring KB2 drilling still in Preboreal period (9635 ± 50 ^{14}C BP, Poz-6426) (Fig. 4). In both cores this phytocoenosis was a parent community of *Cariceto-Bryaleti* peat.

According to palinological age determination (Kupryjanowicz 2004) radical changes in the mire started at the beginning of Atlantic period. In the vicinity of the KBVII (Fig. 3, 4) the mire transformed into raised bog, which is evidenced by occurrence of the subassociation *Sphagnetum magellanici typicum*. Slightly decomposed *Sphagnum magellanicum*-peat and *Eusphagneti* peat were accumulated. The mire lost contact with ground waters and ombrogenous phase started, with typical vegetation of the class *Oxycocco-Sphagnetea*. It could be connected with the phenomenon of notable fall of water level noted in lakes and mires in Northern Poland just in Atlantic period (Ralska-Jasiewiczowa, Starkel 1988, 1999). In the second half of this period the subassociation *Sphagnetum magellanici eriophoretosum* predominated in the peat-bog. The layer of *Eriophoro-Sphagneti* peat was then formed.

Thus, succession of plant communities after disappearance of lake carried on from phytocoenoses of eutrophic habitats (with brown mosses), through by sphagnum-sedge communities of mesotrophic habitats, to the stage of typical peat-bog.

Accumulation of highmoor peat in Atlantic period was also noted by Pacowski (1967) in Western Pomerania (Wieliszewo) and by Kloss (1993) in Masurian Lakeland. In Western Carpathians, the age of ombrogenous phase peat was about 8300 ^{14}C BP (Obidowicz 1990). In Machnacz (Kupryjanowicz 1994), *Ledo-Spagnetum*-type community occurred at the decline of the Preboreal.

In the second half of the Atlantic peat-forming process started in shallower northern basin of mire in the vicinity of the KBIII drilling (Fig. 2, 3). Its initiation dates back to 6280 ± 40 ^{14}C BP (Poz-2956). It could be connected with humid climate. The subassociation *Caricetum rostratae sphagnetosum fallacis* appeared there in mineral substratum.

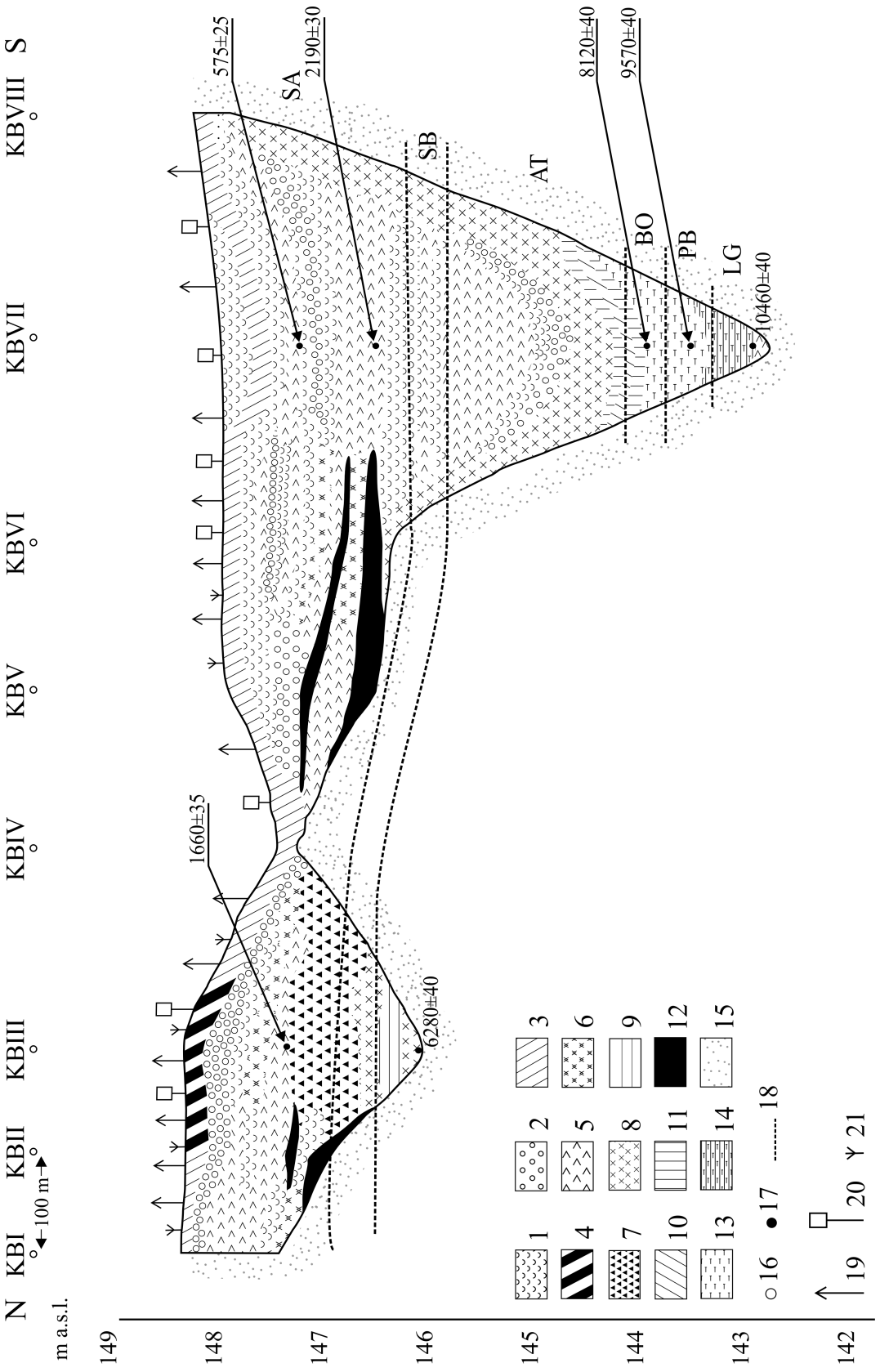

Fig. 3. Long section of the Kładkowe Bagno peat bog. Typology and age of sediments. *1 – Eusphagneti* peat, *2 – Sphagnum magellanicum*-peat, *3 – Cuspidato-Sphagneti* peat, *4 – Sphagnum fallax*-peat, *5 – Eriophoro-Sphagneti* peat, *6 – Pino-Sphagneti* peat, *7 – Pino-Betuleti* peat, *8* – sphagnum-sedge peat, *9 – Cariceto-Phragmiteti* peat, *10 – Bryaleti* peat, *11 – Cariceto-Bryaleti* peat, *12* – humopeat, *13* – medium-detritus gyttja, *14* – detritus-calcareous gyttja, *15* – sand, *16* – spot of drilling, *17* – ^{14}C dating BP, *18* – border of chronozones, *19* – pine, *20* – birch, *21* – willow, SA – Subatlantic period, SB – Subboreal period, AT – Atlantic period, BO – Boreal period, PB – Preboreal period, LG – Late Glacial.

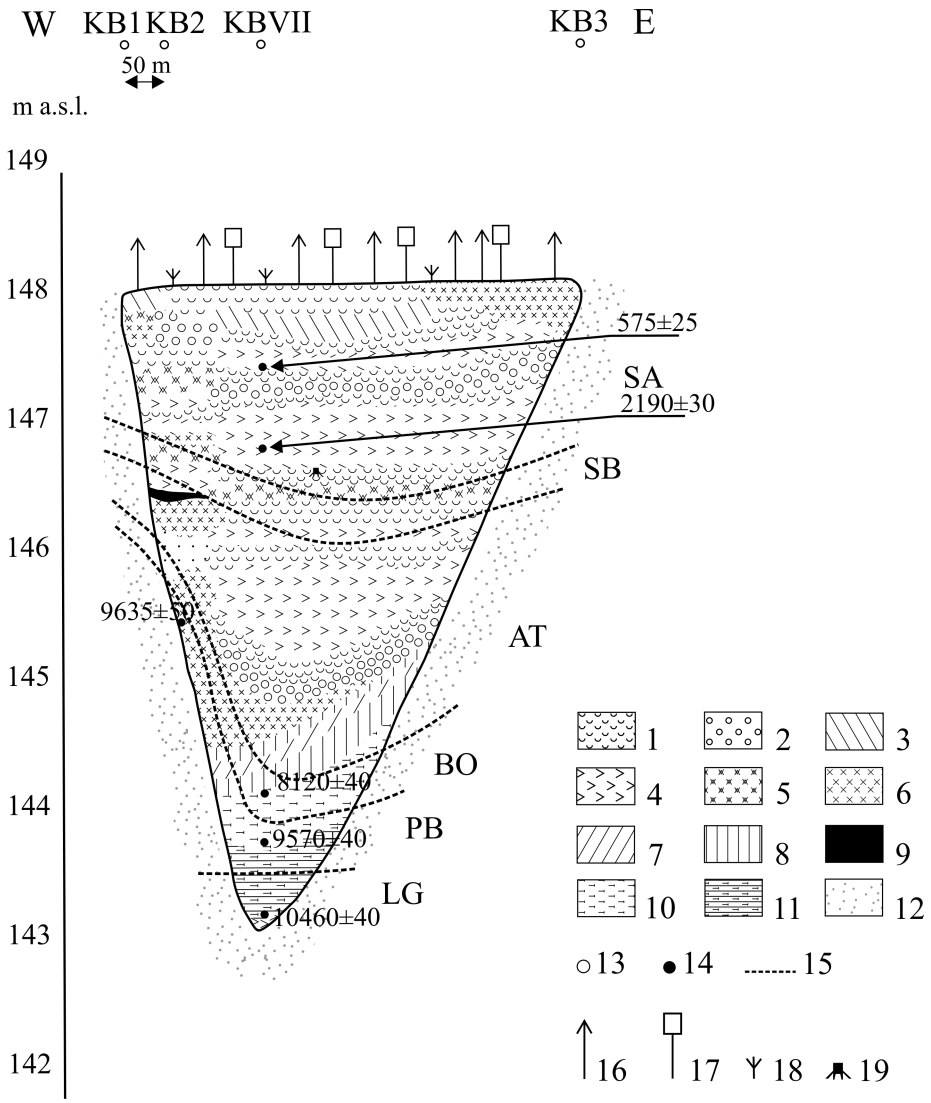

Fig. 4. Cross-section of the Kładkowe Bagno southern basin. Typology and age of sediments. *1* – *Euspahgneti* peat, *2* – *Sphagnum magellanicum*-peat, *3* – *Cuspidato-Sphagneti* peat, *4* – *Eriophoro-Sphagneti* peat, *5* – *Pino-Sphagneti* peat, *6* – sphagnum-sedge peat, *7* – *Bryaleti* peat, *8* – *Cariceto-Bryaleti* peat, *9* – humopeat, *10* – medium-detritus gyttja, *11* – detritus-calcareous gyttja, *12* – sand, *13* – spot of drilling, *14* – ^{14}C dates BP, *15* – border of chronozones, *16* – pine, *17* – birch, *18* – willow, *19* – coniferous stem, SA – Subatlantic period, SB – Subboreal period, AT – Atlantic period, BO – Boreal period, PB – Preboreal period, LG – Late Glacial.

Sphagnum-sedge peat and sedge-read peat were then deposited. However appearance of ombrotrophic peatmosses in these sediments indicates declining role of flowing waters in formation of the deposit.

Late Holocene (5000–0 ^{14}C BP)

In Subboreal period, in southern basin of Kładkowe Bagno, accumulation of peat still took place only in the vicinity of the KB2 and KBVII drillings (Fig. 2). Three species of highmoor peat were deposited there by subassociations of the *Sphagnetum magellanici*: *Eriophoro-Sphagneti* peat, *Pino-Sphagneti* peat and *Eusphagneti* peat (Fig. 3, 4). In Subatlantic period accumulation of peat started at the spot of several drillings: KBV, KBVI, KBVIII, KB1 and KB3 (Fig. 2, 4). Again (see above) *Caricetum rostratae sphagnetosum fallacis* was an initiator of peat-forming process (besides KBV). This community formed sphagnum-sedge peat. Appearance of the association *Sphagnetum magellanici* caused unification of type of the whole southern basin. In total two dates from the KBVII core are Subatlantic: 2190 ± 30 ^{14}C BP (Poz-2876), and 575 ± 25 ^{14}C BP (Poz-2875). The last one is connected with cotton-grass withdrawal, and appearance of peatmosses from *Cuspidata* (*Sphagnum fallax*) and *Palustria* sections. Just these peatmosses predominated in the southern basin of Kładkowe Bagno in the last phase of the Subatlantic. Therefore *Sphagnetum magellanici sphagnetosum fallacis* and *Sphagnetum magellanici typicum* subassociations functioned in the mire. The first one formed layers of *Cuspidato-Sphagneti* peat and the second one – *Eusphagneti* peat and *Sphagnum magellanicum*-peat (Fig. 3, 4).

In the northern basin (KBIII region, Fig. 2, 3), in Subboreal period, *Sphagnetum betulo-pinosum eriophoreto fruticuletosum* was recognized. It was a parent community of

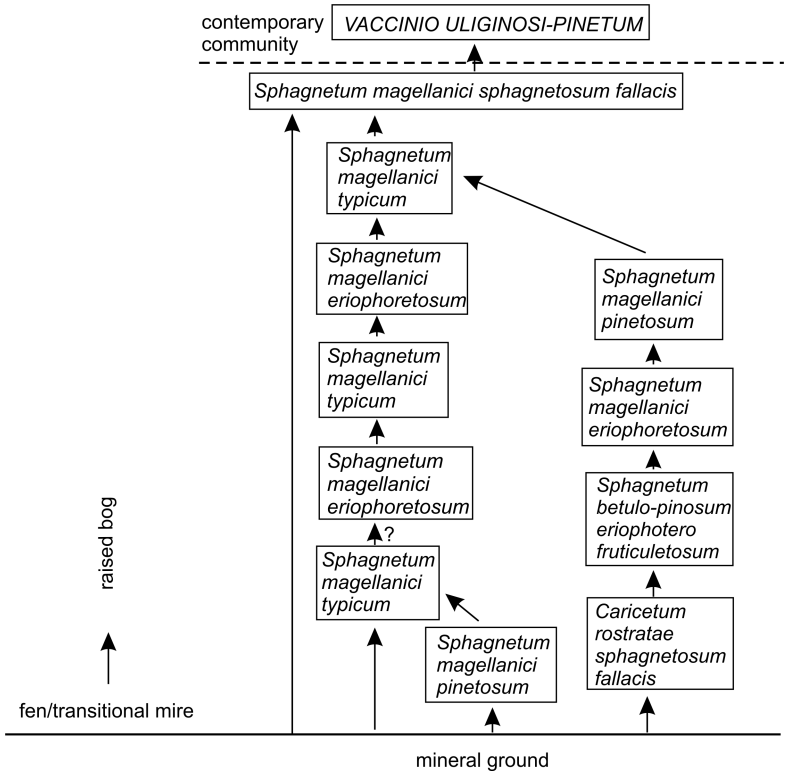

Fig. 5. Scheme of subfossil plant communities succession in the northern basin and isthmus of the Kładkowe Bagno peat bog.

Table 1

Frequency (%) of phytocoenoses occurrence in particular kinds of habitats

Phytocoenosis		Humidity of habitat			
		middle humid	humid	wet	very wet
Sphagnetum magellanici	*sphagnetosum fallacis*	–	100	–	–
	typicum	28.5	71.5	–	–
	eriophoretosum	71.5	28.5	–	–
	pinetosum	100	–	–	–

the *Pino-Betuleti* peat. Appearance of this syntaxon, discussed by Drzymulska (2006a), could be a result of groundwater level lowering in mires and lakes of Northern Poland territory at the middle of Subboreal period (Ralska-Jasiewiczowa, Starkel 1988). It was replaced in Subatlantic period by the subassociation *Sphagnetum magellanici eriophoretosum* (1660 ± 35 ^{14}C BP, Poz-6425) (Fig. 3). In this period peat accumulation started also in the vicinity of the KBI and KBII drillings (Fig. 2, 3). The northern basin of Kładkowe Bagno lost contact with groundwater, and ombrogenous phase started then. Several units of highmoor peat were formed: *Pino-Sphagneti* peat, *Eriophoro-Sphagneti* peat, *Cuspidato-Sphagneti* and *Sphagnum fallax*-peat (Fig. 3).

Table 2

KBIII profile – values of humidity index (HI) and humid conditions of habitats

Depth (cm)	Subfossil comunity	Humidity index (HI)	Habitat feature
0–10	*Sphagnetum magellanici sphagnetosum fallacis*	6.7	humid
10–40	*Sphagnetum magellanici typicum*	6.0	humid
40–50		6.0	humid
50–60	*Sphagnetum magellanici pinetosum*	5.5	middle humid
60–75		5.8	middle humid
75–85	*Sphagnetum magellanici eriophoretosum*	5.7	middle humid
85–97		6.0	humid
97–155	*Sphagnetum betulo-pinosum eriophoreto fruticuletosum*	6.4	humid
155–215	*Caricetum rostratae sphagnetosum fallacis*	7.1	wet
		7.9	wet
		8.2	very wet

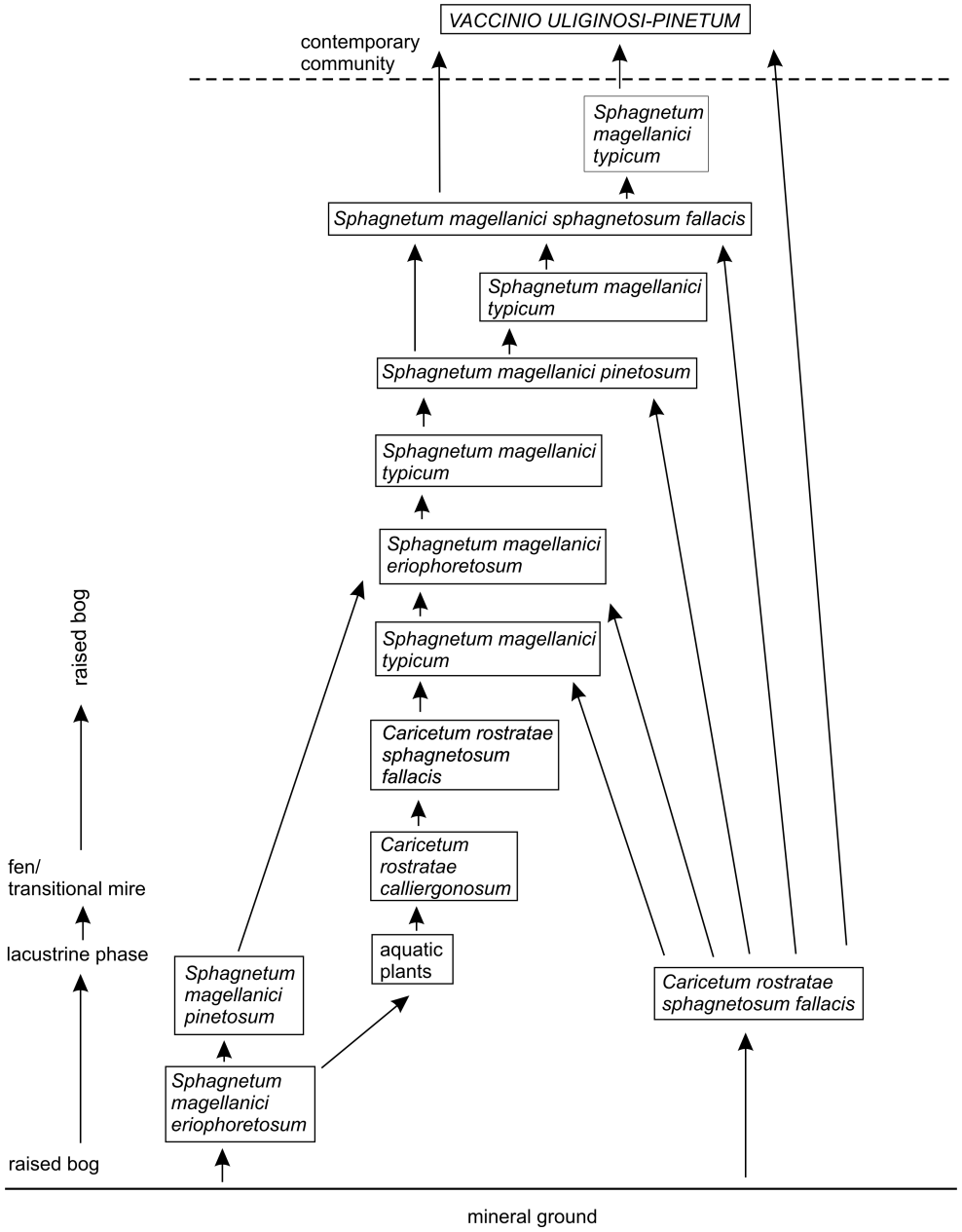

Fig. 6. Scheme of subfossil plant communities succession in the southern basin of the Kładkowe Bagno peat bog.

The both basins of the Kładkowe Bagno peat bog were aggregated probably several hundred years ago. The shallow isthmus in between is filled by 0.3 m layer of the *Cuspidato-Sphagneti* peat (Fig. 3). *Sphagnetum magellanici sphagnetosum fallacis*, appearing in mineral substratum, was its parent community. In the latest phase of the Holocene, the rate of highmoor peat deposition was 0.4–1.2 mm·year^{-1} (Drzymulska 2005). Basing on mean value (0.68 mm·year^{-1}) one can assess that the both basins joined about 400 years ago.

Peat of roof layers was slightly decomposed and it accumulated very fast, achieving 1.2 mm·year^{1}. Decomposition degree could be connected with high precipitation noted in the latest phase of the Holocene (cf. Ralska-Jasiewiczowa, Starkel 1988).

Succession of subfossil communities in Kładkowe Bagno was presented in Fig. 5, 6. Several subassociations of the association *Sphagnetum magellanici* functioned there. According to bibliographic data there is relationship between humidity of mire surface and occurrence of each subassociation (Pacowski 1967, Kloss 1993). *Sphagnetum magellanici pinetosum* and *Sphagnetum magellanici eriophoretosum* seem to be connected with the least humid habitats, *Sphagnetum magellanici typicum* and *Sphagnetum magellanici fuscae* (not present in Kładkowe Bagno) – with mid humid habitats, and *Sphagnetum magellanici sphagnetosum fallacis* occurs in more humid areas. That last subassociation was dominant in the final stage of deposit development in Kładkowe Bagno, because in the decline of Subatlantic period precipitation increased (cf. Ralska-Jasiewiczowa, Starkel 1988). Kloss (1993) observed such relationships in Nowe Sady VIII and Łuknajno VII (both in Masurian Lakeland). Many of British researchers also pointed importance of sub-

Table 3

KBVII profile – values of humidity index (HI) and humid conditions of habitats

Depth (cm)	Subfossil community	Humidity index (HI)	Habitat feature
0–15	*Sphagnetum magellanici typicum*	6.3	humid
15–30		6.2	humid
30–50	*Sphagnetum magellanici sphagnetosum fallacis*	6.6	humid
50–65	*Sphagnetum magellanici typicum*	6.4	humid
65–75	*Sphagnetum magellanici eriophoretosum*	5.8	middle humid
75–85	*Sphagnetum magellanici typicum*	6.2	humid
85–100		6.2	humid
100–110		6.2	humid
110–160	*Sphagnetum magellanici eriophoretosum*	5.9	middle humid
160–170	*Sphagnetum magellanici typicum*	6.4	humid
170–180	*Sphagnetum magellanici pinetosum*	5.3	middle humid
180–190	*Sphagnetum magellanici typicum*	6.1	humid
190–200	*Sphagnetum magellanici eriophoretosum*	6.0	middle humid
200–215	*Sphagnetum magellanici typicum*	5.7	middle humid
215–290	*Sphagnetum magellanici eriophoretosum*	5.9	middle humid
290–300	*Sphagnetum magellanici typicum*	5.7	middle humid
300–312		5.3	middle humid
312–325		5.8	middle humid
325–360	*Caricetum rostratae sphagnetosum fallacis*	6.8	humid
360–370	*Caricetum rostratae calliergonosum*	7.9	wet
370–380		7.9	wet
380–400		7.9	wet
400–490	aquatic plants	–	water
490–505	*Sphagnetum magellanici eriophoretosum*	6.3	humid

fossil plant remains analysis in recognizing mire surface humidity (Barber 1981, Blackford 2000, Chiverrell 2001).

To observe occurrence of each *Sphagnetum magellanici* subassociations in different humidity conditions in Kładkowe Bagno, humidity index (HI) of these subfossil communities was estimated (Drzymulska 2004b, 2005). This parameter was counted basing on humidity preferences of peat-forming plants (Yelina, Yurkovskaya 1992). The HI values let to define humidity of habitat according to Oświt 1992 (Drzymulska 2005). Data presented in Table 1 confirm connections of subassociations with less (*Sphagnetum magellanici eriophoretosum* and *Sphagnetum magellanici pinetosum*) or more humid (*Sphagnetum magellanici sphagnetosum fallacis* and *Sphagnetum magellanici typicum*) substratum, what Kloss (1993) implied.

The HI values and descriptions of habitat humidities along two complete cores (KBIII – northern basin and KBVII – southern basin) were listed in Tabs 2, 3.

The both basins of Kładkowe Bagno, despite different genesis and age, ultimately become similar. The other situation was noted by Obidowicz (1975) in Toporowy Staw Wyżni (Tatra Mountains). This deposit developed also in two peat-forming centres but past and present character of both basins are quite different. Unfortunately there are no other known examples of such kind of mires history, so any generalisations referring relationship: geographical location – development of mire, are not possible.

At present the whole surface of Kładkowe Bagno is overgrown by *Vaccinio uliginosi-Pinetum*. It seems to be result of drainage and stagnation in deposition of sediments (cf. Żurek 1993).

CONCLUSIONS

Both basins of the studied peat bog in Kładkowe Bagno characterize diversified history. The thickness of deposits, age and kind of peat-forming process in the two basins are different. Despite that, they ultimately aggregated, probably 400 years ago, and they form uniform mire at present.

In the history of the two basins, the following directions of development could be noted:

1. Northern basin – fen/transitional mire raised bog,
2. Southern basin – raised bog lacustrine phase fen/transitional mire raised bog.

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