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TIME RECORD OF PALAEOHYDROLOGIC CHANGES IN THE DEVELOPMENT OF MIRES DURING THE LATE GLACIAL AND HOLOCENE, NORTH PODLASIE LOWLAND AND HOLY CROSS MTS

SŁAWOMIR ŻUREK[1], DANUTA J. MICHCZYŃSKA[2] and ANNA PAZDUR[2]

[1]*Institute of Geography, Świętokrzyski University, Świętokrzyska 15, PL-25-406 Kielce, Poland*
(e-mail: slavomir.zurek@pu.kielce.pl)
[2]*Department of Radioisotopes, Institute of Physics, Silesian University of Technology, Krzywoustego 2, PL-44-100 Gliwice, Poland*
(e-mail: danuta.michczynska@radiocarbon.gliwice.pl)

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Abstract: Radiocarbon dating of mire sediments is useful tool for reconstruction of time scale of wet and dry phases during the Late Glacial and Holocene. The method is applied here to determine palaeohydrological conditions of some Polish regions. On the basis of ^{14}C dating of sediment profiles from North Podlasie Lowland and southern piedmont of Holy Cross Mts., duration of wet (1100-1400, 2100-2600, 4700-5000, 7300-7500, 8000-8400, 8800-9200 and 10,500-10,850 BP) and dry (1700-2200, 2600-2800, 3400-3700, *ca* 4000 and 4500, 5100-5700, *ca* 6400, 6900-7100, 9200-9300, *ca* 10,100 and 10,900 BP) periods is suggested.

1. INTRODUCTION

The mire is composed of four parts: vegetation, water, acrotelm and peat deposit. Decomposition of plant remains in mire differs in the relation to above and underground parts of plants. In contrast to the complete decomposition and mineralization of the aboveground parts, resulting in the production of humus, decay processes of underground, submerged plant remains produce undecomposed peat fibre. Transformation of plant matter into peat takes place in the acrotelm layer, where aerobes, actinomycetales and fungi transform biomass into humus in periodical aerate conditions. Structural plant remains together with humus reach lower, highly hydrated deposit layer. Here, in anaerobic conditions, minor changes occur; peat is exposed to anaerobic bacteria activity that leads only to weak mineralization process, not to peat humification.

The ratio of undecomposed remains to humus in peat depends on different water conditions. In wide valley flooded by stagnating water for a long time medium and highly decomposed, plastic, often silt-covered reed fen peat is deposited. Under conditions of short-time flooding and constant inflow of ground water medium decomposed, rather fibrous tall sedge peat is accumulated. When shorter flooding with longer ground water presence occur, accumulation of highly decomposed, granulous-amorphous forest peat is observed as well. Regular and constant ground-water inflow, often ascending, and absence of flooding lead to accumulation of slightly decomposed sedge-moss peat with fibrous-spongy structure. Gradual reduction of ground-water flow creates transition bogs, and, when supplied with rainfall, raised bogs. Whole year's superiority of rainfall over evaporation, and its corollary - presence of ground water in the surface level of mires leads to sedimentation of slightly decomposed sphagnum peat, whereas its periodic subsidence results in accumulation of medium and highly decomposed cotton-grass peat material. Presence of wood and tree trunks in raised bog peat testifies to the reduction of water level and mire afforestation, what can result from climatical change (dry phase) or other, local changes (e.g. erosion of the dome and drainage of its slopes). As a consequence, cessation or considerable reduction of the raised bog peat production follows. When wetter period comes and ground-water table rises slightly humified raised bog grass peat is accumulated again. Persisting lowering of ground-water table in fen bogs causes high peat humification and its gradual mucking. Thus climate, through changes of humidity and temperature, controls development of valley fen bog, transition bog and raised bog in watershed zone. The control is realised by supplying of concave landforms i.e. various depressions and valleys, where the peat formation process is located, with water.

Initial stage of mire formation in the territory of Poland is dated back to the late Vistulian (Żurek 1990, 1993). During warm periods of the Late Glacial more than ten-centimetre strata of the moss-fenn were deposited in shallow depressions. Melting of dead or ground ice resulted in greater depth of hollows and in their flooding, what is reflected by the presence of gyttja superimposed over the peat. During the cold oscillations, dunes often encroached onto wetlands, and so blown sands covered the peat.

The dominant feature of the early Holocene landscape represented lakes, with moss fen mires on the shores. At first deep, these concave landforms were subjected to paludification because of the ground-water table was few metres beneath its present state; bottom of the depressions were often supplied by waters of head from deeper water-bearing horizon. In isolated depressions, moss fenn peat accumulated. Initial process of peat formation did not cease generally but was rather reduced to peat production in dry periods. While at the beginning of Mezoholocene water level raised, during the second half of the period it dropped. At that time a lot of shallower lakes that were subjected to the process of peat accumulation disappeared. On the other hand, rise of water level, resulting from permanently increasing accumulation, caused swamping of hitherto dry depressions and higher altitude areas within the local relief. A variety of mires characterised with a particular peat type appeared during the period: apart from moss fen mire, forest fen, reed fen and transitional bog are to be encountered. Further, intensification of mire development occurred at the beginning of Subboreal and Subatlantic periods. In valleys dominated supreme mires supplied with surface and ground water such as sedge fen and alder swamp; for watershed area transition and raised bogs are to be mentioned.

Reflection of human activity can be traced in the Polish peat deposits through the past thousand years. Various form and intensity of deforestation has contributed to transformation of forest communities into open moss-sedge mires and sedge fens, clearance of vegetation on slopes in valleys and depressions has triggered process of covering the valley mires by alluvial or deluvial silts. However, substantial cause of the mire development variations is still the natural water regime. The evidence of environmental humidity represent gyttja, chalk lake insertions in peat, decrease of peat decomposition degree, paludification of hitherto dry depressions, fen spring development, forest and shrubs retreat for the benefit of open associations like rushes, moss-sedge mires or rushes entering into transitional or moss-sedge mires. Conversely, increase of peat decomposition degree, afforestation of mires, lake terrestrialization, appearance of open communities with ferns, shrubs and sedge *Carex paradoxa* testify to dry climatic phase, drainage and lowering of ground-water level.

2. MATERIAL FOR ^{14}C ANALYSIS

Profiles of sediments from North Podlasie Lowland

The Białostocka Plateau that belongs to the North Podlasie Lowland (**Fig. 1**) is apparently distinguished from other early glacial marainic plateaux. Numerous outflow depressions with fossil lakes, narrowing and widening river valleys, lofty kame hills, morainic and outwash plains resemble the last glaciation landscape. It differs only in absence of lakes and outflowless depressions. Two of the kettle holes, covered by forest vegetation and protected within natural reservations "Stare Biele" and "Jesionowe Góry" with mire Machnacz, have been meticulously explored from the point of genesis of the peat deposits (Żurek, 1992, 1996a and 2000). Stare Biele mire is an outflow depression with numerous bays, of elliptic shape with 4 km and 1.5 km long axes. Position plan and cross section of the mire can be found in the article of S. Żurek and A. Pazdur (1999). Marginal zone of this carr mire includes fragments of transition and raised bogs. Sondage that was to bring the evidence on strata succession in few sections demonstrated that the thickness of peat, superimposed over thin gyttja layers, varied from 1.5 to 2 metres for most of the sampled spots (**Table 1**). Sedge-moss schwingmoore spread throughout the lakes, which, consequently, suffered from rapid afforestation with alder communities dominating for a long period. In places, within the upper part of the strata succession, alder peat is covered by sedge-moss fen peat. At the bottom of alder peat, in depth of some 1-1.3 m, occurs dark, highly humified, clammy layer indicating the period of the deposit's drainage. This layer was sampled for dating at three different places within the mire. Far away from the centre, in south-western bay, two highly humified layers were found in the peat that overlies a fossil upper terrace. Drilling (up to 10 m) in a deep kettle hole with a diameter little more than 10 m situated in northern bay showed that peat deposits, which are underlain with fine detrital gyttja (see **Table 1**) reach depth of 4.25 m.

Profiles of sediments from Białe Ługi, Holy Cross Mts.

Mire Białe Ługi, (southern piedmont of Holy Cross Mts., **Fig. 1**) occupies 1 km wide and few km long fossil valley between Belnianka (Nida tributary) and Czarna Staszowska (Vistula tributary). The valley is filled by raised peat over transitional and fen peat. There is also carr peat located on the both valley banks, where small rivers Trupień and Czarna are being formed. In 1994-1998, ten stratigraphical cross-sections of deposits were made and a macro-remain analysis of 18 bores was carried out (Żurek, 2001); the stratigraphical section and the geological profiles can be found in Żurek and Pazdur (1999). Roof part of the succession (up to 0.8-1.0 m depth) is built by slightly decomposed raised sphagnum peat over highly decomposed cotton-grass raised peat. Beneath the latter slightly and medium decomposed sedge-moss transition peat is present, and in the bottom part of the profile sedge-moss fen peat and brown-moss peat are encountered. In the sediments of the Białe Ługi mire two 5-15 cm thick strata of highly decomposed black peat were distinguished. The upper one occurs at the depth of 0.8 to 1-1.2 m, on the border between deposits of transition and raised peat. Within the black peat stratum, under it or over a dozen centimetres above fine 2-3 cm thick fire indicating layers of charcoal are incorporated. These represent probably an evidence of dry stage, when large fire may likely have occurred. The second, lower stratum of highly humified deposit, richer in wood remains, is located at the bottom part of the whole succession, on the border between transition bog and fen peat.

3. METHODS AND RESULTS OF ^{14}C DATING

Samples that were submitted for radiocarbon dating consisted of solely organic sediments. According to low portion of carbon in the samples, the pre-treatment of 4% HCl washing was chosen. After pre-treatment and carbonisation the samples were combusted, and CO_2 was purified by standard method used in Gliwice Radiocarbon Laboratory (Pazdur and Pazdur, 1986). Finally, ^{14}C activity measurements were carried out by gas proportional counting techniques (Pazdur *et al.,* 2000). Results of ^{14}C dating from Gliwice Radiocarbon Laboratory are listed in **Table 1**, marked with laboratory code Gd. Apart from these, determinations measured in other radiocarbon laboratories are to be found here, namely, dates with lab codes SRR-NERC (Scotland), Hv (Hannover, Germany), TA (Tartu, Estonia), Lod (Łódź, Poland) and those from Leningrad, now Petersburg, laboratory (Russia).

The values of ^{14}C age listed in **Table 1** represent conventional radiocarbon age determinations calculated according to the procedure of Stuiver and Polach (1977).

4. ^{14}C EVIDENCE OF PALAEOHYDROLOGIC EVENTS

Long-term hydrologic changes have specific consequences for the environment of mires. Climate desiccation causes lowering of ground-water table, what effect changes of physical and chemical properties of upper peat layer. At first, increase of the peat decomposition degree should be mentioned. Highly humified peat layers of dark colour (when fresh) thick from 5 up to 20-30 cm have been identified in course of stratigraphic studies of various fen and bog deposits (Żurek, 1995). Sometimes in higher decomposed peat (carr, reed fen, high-sedge fen, cotton-grass) black and clammy layers are observed. These testify to the dry period of longer duration, when peat production was drastically limited or stopped. Instead of organic matter accumulation, decomposition process and its mineralization began, proceeding from top towards the bottom levels. Nowadays, in artificially drained peatlands, this process, called mucking, leads to high decomposition and further to granulization of upper peat layers (Okruszko, 1960).

In the peat profiles from Biebrza basin or Białostocka Plateau, dated by ^{14}C, drainage led only to the increase of decomposition degree (to 60-80%) without indices of muck granules. Clamminess of highly decomposed peat

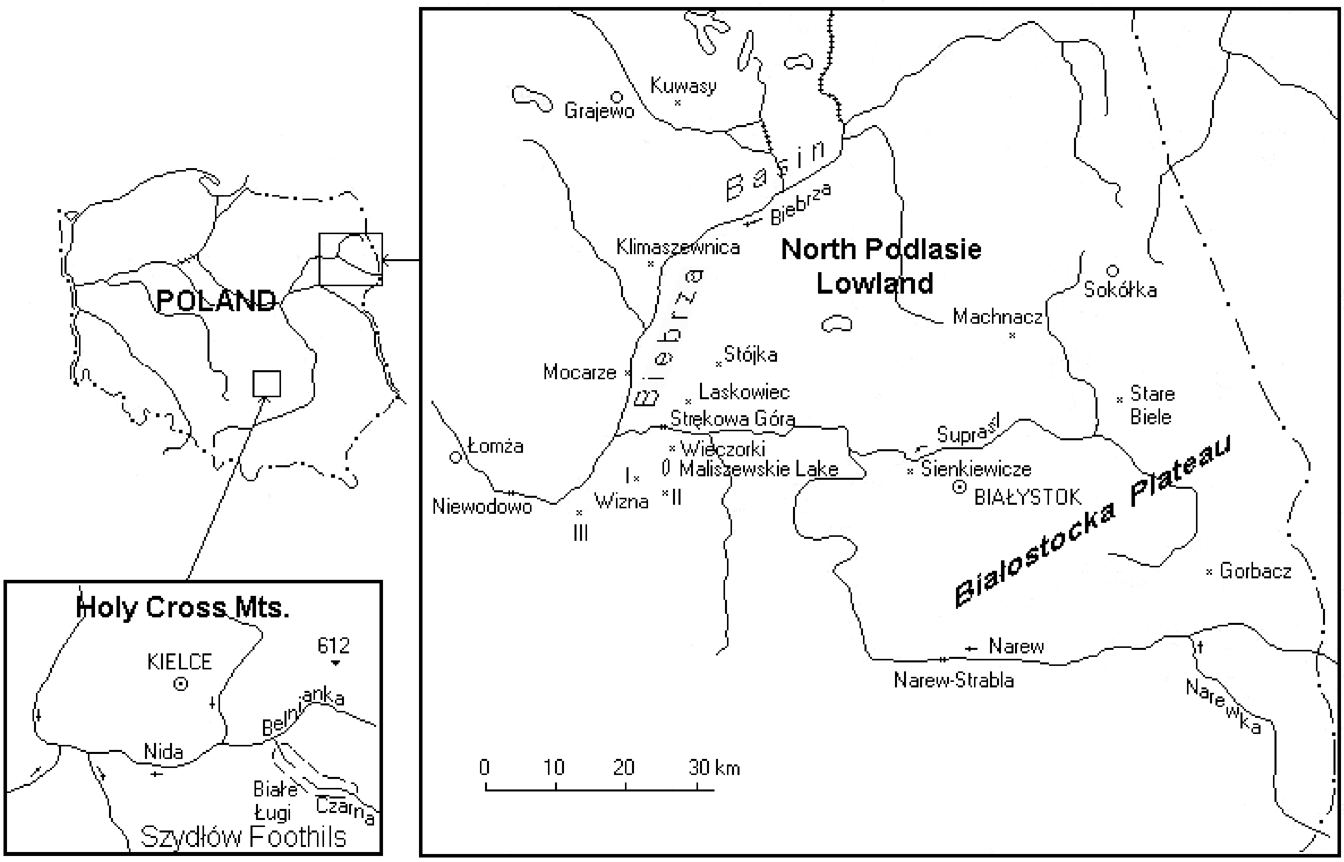

Fig. 1. Localization of investigated mires. Linear scale is the same for both window.

Table 1. *^{14}C dating results of peat samples from different sites of Poland. All dated samples came from NE Poland except Białe Ługi site (Central Poland). The symbols and numbers after slash in the column "Name of samples" indicate profile. Roman numbers (I, II, III)for Wizna mean different sites. Depth = conventional depth in profile.*

No.	Name of sample	Depth [cm]	Lab. no.	^{14}C Age [BP]	Material	Altitude [m asl]	References
1	Białe Ługi 1/13	315-320	Gd-9498	10880±250	sedge-moss fen p.	256,3	Żurek, Pazdur, 1999
2	Białe Ługi 2/21	95-100	Gd-11211	3480±80	cotton-grass p.	256,5	Żurek 1996b
3	Białe Ługi 3/21	175-185	Gd-10320	10170±120	sedge-sphag. p.	256,5	Żurek, Pazdur, 1999
4	Białe Ługi 4/14	405-408	Gd-9508	6940±750	humus with sand	256,3	Żurek, Pazdur, 1999
5	Białe Ługi 13/21	100-105	Gd-15137	2630±90	*Eriophorum p.*	256	not published
6	Białe Ługi 14/21	110-115	Gd-12266	6470±80	*Sphagnum-Carex p.*	256	not published
7	Białe Ługi 15/21	180-185	Gd-15135	8890±140	*Carex p.*	256	not published
8	Białe Ługi 16/21	190-195	Gd-15131	8750±150	*Carex p.*	256	not published
9	Białe Ługi 17/14	90-95	Gd-15129	1830±100	*Carex-Sphagnum p.*	256	not published
10	Białe Ługi 18/14	100-105	Gd-15127	2450±90	*Carex-Sphagnum p.*	256	not published
5	Biebrza Dolna 1/ Stójka (Ławki)	112-118	Gd-7825	2810±60	osier peat	104,1	Żurek, Pazdur, 1999
6	Biebrza Dolna 2/ Stójka (Ławki)	125-130	Gd-7826	5110±60	osier peat	104,1	Żurek, Pazdur, 1999
7	Biebrza Dolna 3/ Stójka (Ławki)	270-280	Gd-10491	8450±100	brown-moss peat	104,1	Żurek, Pazdur, 1999
8	Gorbacz 1	254-267	Gd-4487	8000±170	detrital gyttja		Wicik, 1989
9	Gorbacz 2	180-200	Gd-6172	1460±90	bog peat		Wicik, 1989
10	Klimaszewnica /27	145-152	Gd-10492	7150±80	reed-sedge peat	107,0	Żurek, Pazdur, 1999
11	Kuwasy 1/EO	95-100	Gd-7827	3650±50	alder peat	114,6	Żurek, Pazdur, 1999
12	Kuwasy 2/EO	186-191	Gd-10497	10850±150	brown-moss peat	114,6	Żurek, Pazdur, 1999
13	Laskowiec	18-23	Gd-2301	830±80	peaty formation	103,5	Żurek1987
14	Machnacz 1/ 6	405-415	Gd-5683	> 40800	sedge-moss peat	152,0	Żurek 1992
15	Machnacz 1/18	150-160	Gd-10494	7300±130	reed-sedge peat	150,5	Żurek, Pazdur, 1999
16	Machnacz 2/ 6	425-435	Gd-5864	> 43500	sedge-moss peat	152,0	Żurek 1992
17	Machnacz 2/18	372-382	Gd-10495	11690±150	brown-moss peat	150,5	Żurek, Pazdur, 1999
18	Machnacz 3/14	368-375	Gd-10499	29470±180	detrital gyttja	151,1	Żurek, Pazdur, 1999
19	Machnacz/ 14	138-148	SRR-3176	4040±50	cotton-grass p.	151,1	Haslam 1987
20	Machnacz/ 14	72-82	SRR-3175	1120±50	cotton-grass p.	151,1	Haslam 1987
21	Machnacz/ III 14	380-390	Gd-4959	11100±140	brown-moss peat	151,1	Kupryjan.1994
22	Machnacz/ III 14	330-340	Gd-6818	10370±100	detrital gyttja	151,1	Kupryjan.1994
23	Machnacz/ III 14	280-290	Gd-6819	8570±100	sedge-moss peat	151,1	Kupryjan.1994
24	Machnacz/ III 14	165-175	Gd-6824	7470±100	cotton-grass p.	151,1	Kupryjan.1994
25	Machnacz/ III 14	130-140	Gd-6820	3430±80	cotton-grass p.	151,1	Kupryjan.1994
26	Machnacz/ III 14	50-60	Gd-4966	1720±60	cotton-grass p.	151,1	Kupryjan.1994
27	Maliszewo I/Ia	477-481	Hv-5527	11460±210	peaty formation	104,1	Żurek 1978
28	Maliszewo II/Ib	186-191	TA-1077	5170±100	detrital gyttja	104,1	Żurek 1986
29	Maliszewo III/II	370-380	TA-1078	8940±120	sedge peat	104,5	Żurek 1986
30	Maliszewo IV/II	125-135	TA-1076	2350±100	reed peat	104,5	Żurek 1986
31	Maliszewo V/Ic	205-212	Gd-10490	5720±110	detrital gyttja	104,1	Żurek, Pazdur, 1999
32	Mocarze Ia	27-32	Gd-2302	1460±100	mud	102,5	Żurek1987
33	Narew/ Narew-Strabla	160-170	Leningrad	3800±70	wood of alder	121,5	Czeczuga1979
34	Narew/Narew-Strabla	50	Leningrad	1470±50	wood of oak	121,5	Czeczuga1979
35	Niewodowo	200-230	Lod-27	1420±130	oak trunk	98,0	Musiał, Strasz.,1988
36	Sienkiewicze 2	33-38	Gd-2306	940±100	muddy-alluvium f.	119,0	Żurek1987
37	Sienkiewicze 3	13-18	Gd-2303	670±90	peaty-muddy f.	119,0	Żurek1987
38	Stare Biele 1/I	115-120	Gd-9506	1700±210	alder swamp peat	143,0	Żurek, Pazdur, 1999
39	Stare Biele 2/I	180-190	Gd-11212	2690±70	alder peat	143,0	Żurek, Pazdur, 1999
40	Stare Biele 3/I	245-255	Gd-10321	4000±120	alder peat	143,0	Żurek, Pazdur, 1999
41	Stare Biele 4/I	995-1005	Gd-9503	13900±310	fine-detrital gyttja	143,0	Żurek, Pazdur, 1999
42	Stare Biele 5/II	94-100	Gd-9497	2190±130	alder peat	143,0	Żurek 1996b
43	Stare Biele 6/VII	120-130	Gd-10337	5310±100	alder peat	143,0	Żurek, Pazdur, 1999
44	Stare Biele 7/24	170-180	Gd-7748	6420±60	alder peat	146,0	Żurek, Pazdur, 1999
45	Stare Biele 8/29	110-118	Gd-10388	4480±130	alder peat	143,0	Żurek, Pazdur, 1999
46	Stare Biele 9/63	150-163	Gd-10493	9010±120	moss p. + wood	143,0	Żurek, Pazdur, 1999
47	Wieczorki	20-25	Gd-1820	1520±70	peaty formation	105,0	Żurek1987

48 Wizna 1/I	525-535	Gd-2017	12610±190	sedge-moss peat	104,5	Żurek 1986
49 Wizna 10/I	535-542	Gd-2084	12710±240	detr.-clayey g.	104,5	Żurek 1986
50 Wizna 11/85/ Maliszewo I	467-473	Gd-2562	11730±450	peaty formation	104,1	Balw.Żur.1989
51 Wizna 11/Góra Strękowa	145-155	Gd-1726	2210±70	sedge peat	101,5	Żurek1987
52 Wizna 12/Góra Strękowa	110-120	Gd-1727	1430±60	sedge peat	101,5	Żurek1987
53 Wizna 13/85/ Maliszewo I	362-367	Gd-2563	9400±500	calcareous gyttja	104,1	Balw.Żur.1989
54 Wizna 14/ Maliszewo I	240-245	Gd-2504	7960±180	calc. gyttja, wood.	104,1	Balw.Żur.1989
55 Wizna 15/ Maliszewo I	165-170	Gd-4020	3340±120	detrital g. + peat	104,1	Balw.Żur.1987
56 Wizna 16/ Maliszewo I	47-52	Gd-4021	1600±100	detr.-calc. gyttja	104,1	Balw.Żur.1989
57 Wizna 18/ Maliszewo I	140-145	Gd-4334	4820±100	detrital gyttja	104,1	Balwierz1986
58 Wizna 19/ Maliszewo I	70-78	Gd-4299	2770±90	calcareous gyttja	104,1	Balwierz1986
59 Wizna 2/I	425-435	Gd-2010	9270±120	sedge peat	104,5	Żurek 1986
60 Wizna 20/ Maliszewo I	35-40	Gd-2869	1770±100	detrital gyttja	104,1	Balwierz1986
61 Wizna 4/II	310-320	Gd-1530	9450±90	osier peat	106,0	Żurek 1986
62 Wizna 5/III	130-142	Gd-1534	4270±70	sedge peat	102,0	Żurek 1986
63 Wizna 6/II	65-75	Gd-1595	2050±40	alder-swamp peat	106,0	Żurek 1986
64 Wizna 7/III	50-60	Gd-1596	1150±40	reed-sedge peat	102,0	Żurek 1986
65 Wizna 8/ Maliszewo II	200-210	Gd-2086	7440±150	sedge peat	104,5	Żurek 1986
66 Wizna 9/I	518-525	Gd-2085	12430±170	sedge-moss peat	104,5	Żurek 1986

did not resulted from silting but from partly mineralization of organic matter, since the ash content in the discussed layers is little higher than in underlying and overlying strata. Hard granules found now and then are small fragments of charcoal coming from thin, black, fire-indicating layers. Highly decomposed layers (ca. 40-50 %) occur also within slightly humified sedge-moss fen peat. Besides sedge and brown-moss, remains of shrubs, ferns and some tall-sedge growing in mires with lowered water e.g. *Carex paradoxa* appear here as well.

Beginnings of biogenic accumulation

Postglacial accumulation of biogenic formation was initiated by climatic change. In warmer Lateglacial periods brown-moss peat or peaty formation were deposited, representing thus first stage of periglacial tundra paludification. Covering of biogenic deposits by gyttja testifies to the beginning of thermokarst process, which in Maliszewskie Lake (**Fig. 1**), as results of peaty formations dating (Gd-2562: 11,730±450 BP, Hv-5527: 11,460±210 BP) manifest it, took place during Alleröd (Żurek, 1978; Balwierz and Żurek, 1987 and 1989). Melting of permafrost in the Machnacz mire (Białostocka Plateau) began probably earlier, in Bölling (Kupryjanowicz, 1991) and was intensified in Alleröd, as backed by one date for brown-moss peat (Gd-10495: 11,690±150 BP). However, the opinion based on palynological analysis of brown-moss peat at the bottom of the Machnacz I profile about its Bölling origins has not found support in the radiocarbon dates. First result for the brown-moss peat brought value 11,100±170 BP (Gd-4959), second determination for sample from the bottom part of gyttja was as early as 29,470±170 BP (Gd-10499). The beginning of under-gyttja peat accumulation in mire Kuwasy was palynologically dated to the second part of Alleröd (Żurek, 1970), in Lower Biebrza basin (Stójka) to the Late Glacial (Oświt, 1973). These results are supplied with the radiocarbon dates from the Biebrza basin area, where was sampled a bottom of brown-moss peat, which developed in isolated depressions and was not covered by gyttja. The dates for the bottom layers of brown-moss peat in Kuwasy and Lower Biebrza are 10,850±150 BP (Gd-10497) and 8450±150 BP (Gd-10491), respectively; localisation of Kuwasy profile EO and the section was published by Żurek and Dzięczkowski (1971). It cannot be excluded that the beginning of peat accumulation in Lower Biebrza is not connected with ground ice melting in substratum but with rise of ground-water table or lake-water level in the neighbourhood, since in the nearby situated profile Stójka 14a (Oświt, 1973) Late Glacial brown-moss peat is covered by gyttja. Gyttja from the deep thermokarst depression of Stare Biele, dated to 13,900±310 BP (Gd-9503), is probably of later origin, since the pollen analysis (Kupryjanowicz 1998 and 2000) point to the Older Dryas period. Accordingly, the beginnings of mire formation in the North-East of Poland varied, and ranged from Bölling to Alleröd. It cannot be determined whether this initial stage of peat formation is connected only with the melting processes and when it came to an end. Current state of knowledge does not allow to choose any of alternatives (Nowaczyk, 1994) represented by the Late Glacial (Kozarski, 1963) and early Holocene periods (Stasiak, 1971; Seibutis, 1963).

Dry phases in mires

Approaching from the point of stratigraphy and changes of peat decomposition degree, humidity changes in Polish mires have not been dated in detail. Two recurrent surfaces in raised bog Bór nad Czerwonym (Podhale Basin) were observed in Subboreal Period (Obidowicz, 1978). One highly decomposed layer connected with Subboreal period was also found in a fen in the Biebrza basin (Oświt, 1973; Żurek, 1970). Recently, 2-3 highly decomposed layers situated one above the other have been identified in the mires Stare Biele (Knyszyńska Wilderness: Żurek, 1996a) and Białe Ługi in southern piedmont of the Holy Cross Mts (Żurek, 1996b). These enable to undertake a test dating of dry periods and humidity fluctuations recorded in peat.

In the shallow profile 21 in Białe Ługi mire (see **Table 1**) both of two highly decomposed layers were dated, resulting in the determinations 3480±80 BP (Gd-11211) for the upper (in the depth of 95-100 cm) and 10,170±120 BP (Gd-10320) for the lower (depth 175-185cm) one. In the profile 13, located some 100 m away from the former one, the bottom layer in the depth of 315-320 cm was dated to 10,880±250 BP (Gd-9498). Considering the situation in the profile 14, initially, the age of the lowermost part of the 4m deep succession could not be determined by the ^{14}C. The dating of organic layers (humus with sand) under the peat gave result 6940±750 BP (Gd-9508) and surprisingly, the age of the bottom part of peat over humus has been stated as 12,900±360 BP (Gd-14015). In the profile 6A (Żurek, 2001a, not included in **Table 1**) of this mire 2 cm thick organic layer from the depth of 212-214 cm, under the peat, was dated to 18,300±600 BP (Gd-14020). Hypsometric differences between position of bottom highly humified layers in the profiles 21 and 13 (ca. 1.5 m, **Table 1**) can be viewed as indicating subsidence of the central part of the deposit in a Younger Dryas as a consequence of the permafrost extinction.

The date 13,900±310 BP (Gd-9503, see **Table 1**) for the bottom sample of detrital gyttja from the kettle hole in northern bay of Stare Biele mire seems to be too early when compared to the palynological investigations setting the sample towards the end of Older Dryas (Kupryjanowicz, 2000). In the 4m deep succession of forest and sedge-moss peat deposit, three strata of highly humified peat (with the decomposition degree of 60-70%) were observed, the dating of which brought following results. The lower layer of highly humified dark forest peat from the depth of 170-180 cm located in north-western bay, representing the earliest Atlantic drainage period, was dated to 6420±60 BP (Gd-7748). The second drainage period, reflected by highly humified clammy alder peat in the central part of the mire (profile 7, **Table 1**), deposited 120-130 cm under present surface, is set to 5310±100 BP (Gd-10377); it is the period, when terrrestrialization of lakes and afforestation of the central part of the mire took place. Profile 29 situated in western bay brought the evidence of highly humified layer in the depth of 1.1-1.18 m, which was dated to 4480±130 BP (Gd-10388). In north-western bay, within a small area of transition bog (sedge moss coniferous forest *Carici chordorrhizae – Pinetum*) 10 m deep kettle hole was discovered. Here, where the accumulation rate was three times higher in comparison to alder swamp peat in the rest of the mire, three highly humified forest peat layers originated in Neoholocene were identified at 1.15-1.20, 1.8-1,9 and 2.45-2.55 m below present surface. According to ^{14}C dating, two earlier dry stages took place around 4000±120 BP (Gd-10321) and 2690±70 BP (Gd-11212), respectively; the latest is dated back to 1700±210 BP (Gd-9506). Regarding the palynological evidence, the earliest layer suffered from the lack of material and therefore it can be only stated that it is situated over Early Subboreal phase of *Pinus-Quercus* (Kupryjanowicz, 2000), the second dry period corresponds to *Pinus-Carpinus-Betula* phase; the BP date of the latest dry phase seems to be a bit younger than palynology would suggest. With the latest dry phase corresponds value Gd-9497: 2190±130 BP, measured on sample of highly decomposed deposit located in the depth of 0.94-1.00 m within the profile 2, situated in the distance of 130m from the kettle hole. Subatlantic period recorded within the mighty succession of the kettle hole probably began with moisten, sedge-moss fen associations supplanted alder carr. Dry conditions of the latest period opened the area for alder-birch forest.

In the cotton-grass bog peat of mire Machnacz an evidence of distinct dry period is represented by layer in the depth of 138-148 cm, dated to 4040±50 BP (SRR-3176, **Table 1**); in the layer hummock sphagnum and pine needles dominate (Haslam, 1987). Given the higher decomposition of peat and distinct increase of the humus content observed, Haslam showed that dry phases occur also at the levels of 136 cm, 107 cm and 96 cm under present surface.

In Biebrza basin, highly humified layers were dated at three sites. Profile Stójka 14a in the East of lower Biebrza Basin (not included in Table 1) incorporated, at the depth of 95-105 cm, a layer of osier peat that was connected with Subboreal period in the early seventies (Oświt, 1973). In the vicinity a profile with rather mighty, highly humified layer situated a little deeper (112-130 cm) has been sampled. Two radiocarbon dates, Gd-7826: 5110±60 BP and Gd-7825: 2810±60 BP, obtained for the bottom and the top of this layer show that in Subboreal period peat accumulation process was interrupted or was very slow indeed, and later, for the final phase of Subboreal, just decomposition is indicated.

Another evidence of dry phase represents highly humified dark layer, found in the depth of 150-160 cm, in deep sedge-moss fen peat of Klimaszewica. Entering of hummock sedge *Carex paradoxa* and reed communities to *Caricetum diandre* community attest to drainage. The dating of decomposed peat at 145-152 cm giving the result of 7150±80 BP (Gd-10492) brought evidence of the earliest Atlantic dry phase in this region.

Regarding situation of highly decomposed layer and its thickness, the Kuwasy profile is essentially the same as the profile 21 from Białe Ługi, what is shown also by date Gd-7827: 3650±50 BP, measured on sample coming from the bottom of forest peat at the level of 95-100 cm. While drainage in the Biebrza area caused afforestation with alder, in Białe Ługi it was cotton-grass raised bog community that entered into moss-sedge association of the transition bog.

As for the sample collection is concerned it should be stated that, unless highly decomposed layer was not thick some 5-10 cm, it was sampled as a whole and in this case an average age was received, without an opportunity of determining the length of period when peat formation was hibernated. Exceptionally, the discussed type of layer was outstandingly mighty, namely in sediments of Lower Biebrza mire, where 18 cm thick, highly humified stratum enabled to take samples from its top and the bottom;

radiocarbon dating of these samples showed that there had been a large hiatus of some 2300 years in the local peat accumulation. Furthermore, more detailed information on rate of peat accumulation processes were received when dates for peat under and over highly decomposed layer were determined. In the vicinity of the profile 21 in Białe Ługi mire, highly decomposed layers of which were dated to 3480±80 and 10,170±120 BP (see **Table 1**), respectively, almost no interruption occurred (8890±140 and 8750±150 BP), or, during later development, its duration could have been as long as 3840 years, from 6470±80 to 2630±90 BP. In the profile 14 representing the deepest spot of this mire, indices for some 620 BP-years long interruption were gathered (2450±90, 1830±100 BP). So long stagnation in the accumulation of peat as shown by dates for the profile 21 (approx. 6000 years) from the shore part of Białe Ługi mire is even more difficult to explain, when we consider that some 300 m away it lasted only some 600 years. It is possible, that Subboreal peat layer was burnt as a consequence of mire's fire.

Peat formation of Maliszewskie Lake

From the shore of Maliszewskie Lake (Wizna mire, see **Fig. 1**), a sample of detrital gyttja indicating a drainage phase and lowering of the water table (connected with the local peat formation; Żurek, 1978 and 1986) was submitted for dating. The first result of the gyttja dating (Gd-4020: 3340±120 BP) from this reference site of north-eastern Poland is questionable, because of probable contamination and rejuvenation of the deposit (Balwierz and Żurek, 1987). In the synthetic study on the palaeohydrology of Polish lakes and mires (Ralska-Jasiewiczowa and Latałowa, 1996) a hiatus spanned between 3500 and 7000 years BP was suggested for this profile. Dating of dark, detrital gyttja, located approximately 10 cm lower than in other profiles (205-212 cm), gave result 5720±110 BP (Gd-10490) connecting thus the local drainage period towards the end of Atlantic period, what has already been shown by measurement TA-10077: 5170±100 BP (Żurek, 1986). It seems that hiatus in so long period of time is absent - derital-calcareous gyttja from level 140-145 cm was dated to 4820±100 BP (Gd-4334). Temporary results of pollen analysis of the detrital gyttja sediment (205-212 cm) also point to the boundary of Atlantis and Subboreal periods (Balwierz, personal communication).

Wet phases in mires

Principal indicators of rise of the ground-water table are decrease of peat decomposition degree, retreat of trees and shrubs, increase of reeds and sedges populations, and finally, submerging of the peat deposit.

The latest phase of increase of moisture appeared in the vicinity of Góra Strękowa. Peat from the old riverbed exposed by lateral erosion of the channel was covered by sandy alluvial loam dated to 1430±60 BP (Gd-1727; Żurek, 1987). Climatic change leading to more humid conditions caused avulsion of the river channel. Oaks found in the river deposit of upper Narwia at Strabla (Czeczuga, 1969) and at Niewodów near Łomża (Musiał and Straszewska, 1988) were felled at this time (1470±50 and 1420±130 BP). In the channel zone of Moczarze area (Lower Biebrza basin), erosions and flows caused that around 1460±100 BP (Gd-2302) mud formations started to accumulate over sand-muddy sediments. Wet phase began little earlier, because from around 1520±70 BP (Gd-1820) peaty accumulations were formed in the shore zone of shallow raised bog in the environs of Wieczorki village (neighbourhood area of Maliszewskie Lake). Wet phase marked by increase of hollow sphagnums (*Sphagnum cuspidatum, Sphagnum recurvum*) at raised bog in Machnacz was dated to 1120±50 BP (SRR-3175; Haslam, 1987). Haslam's study (1987) that dealt with 18 sites of mires from western Ireland to north-eastern Poland allowed to establish the pattern of climatic change during Subboreal and Atlantic periods (Barber, 1993). From works on wet phases recorded abroad we would like to mention here article of Blackford and Chambers (1991) pointing to distinct decrease of peat decomposition degree in the blanket mires of Ireland and Great Britain in1400-1300 BP.

After 2810±60 BP (Gd-7825) the evidence of profile Stójka in Lower Biebrza region shows increasing amount of reed contemporarily with the birch decrease down to 25%, and peat decomposition degree going almost up to 50%. Similar situation was noted in the profile Stare Biele 1 (Żurek, 2000). Here, after 2690±70 BP alder forest retreated and bryales appeared, with birch and reed remains, i.e. sedge-moss shrub fen with constant and abundant water supply developed.

In the shore profile of Maliszewskie Lake, over dark detrital gyttja dated to 5170±110 BP (TA-1077; Żurek, 1986) grey-brown detrital-calcareous gyttja was accumulated, and in the upper whitish calcareous gyttja, indicating rapid rise of the lake water table, was present. Detrital-calcareous gyttja from the depth of 140-145 cm was dated to 4820±100 BP (Gd-4334), so wet phase began around 5000 BP and could have lasted until around 4700-4500 BP when in the profiles 1 and 29 of Stare Biele (see **Table 1**) dry phases occurred. Similarly to Stare Biele, in the kettle hole at Machnacz mire (Białostocka Plateau) after phase of moss-fen mire, with moss and low sedge, supplied with constant, moderate ground-water inflow, tall-sedge fen phase with dominating reed and tall sedge began to develop (Żurek, 1992). Surface water, connected with increased precipitation, and water inflow from little catchments supplied the mire. This moist phase lasted around 7300±130 BP (Gd-10494), what is in agreement with gyttja of Maliszewskie Lake, appearing over the sedge-moss fen peat dated to 7440±150 BP (Gd-2086).

The earlier wet period is related to the beginnings of Boreal period (Żurek, 1986). Planting mires of central Wizna with shrubs and lowering of water level were dated to 9270±120 BP (Gd-2100). Later rise of water level, decrease of peat decomposition degree and spread of low sedge *Carex lasiocarpa* resulted from abundant ground-water inflow. In the profile 9 of Stare Biele, the layer of gyttja covering the sedge-moss fen peat dated to 9010±120 BP (Gd-10493) testifies to increasing of water level as well. Uplift of water level during the initial

Younger Dryas can be reflected by presence of peat with gyttja over highly decomposed layer dated to 10,880±250 BP (Gd-9498) in the profile 13 of Białe Ługi mire and by accumulation of brown-moss peat in Kuwasy profile, which began around 10,850±250 BP (Gd-10497). It is to be added that the presence of peat with gyttja was stated only according to macroscopically observations and should be confirmed by the pollen analysis.

5. PALAEOHYDROLOGIC CHANGES IN NORTH PODLASIE LOWLAND AND THE HOLY CROSS MOUNTAINS IN LATE GLACIAL AND HOLOCENE

It seems that certain phenomena observed in the stratigraphy of mires, particularly changes of peat decomposition degree and botanical taxa spectrum, can be used to determine hydrologic conditions in the past and to reconstruct succession of dry and wet phases. As for chronology, radiocarbon dating of peat layers should be confirmed by pollen analysis. It may happen, however, that ^{14}C dates are in a strong disagreement with results of palynological investigation, being earlier or later than dating suggested by pollen spectra. Such case of major difference represent set of radiocarbon determinations for samples from profile Machnacz III (Kupryjanowicz, 1994). M. Kupryjanowicz suggested that the situation could be explained by contamination caused by using a small-diameter corer. According to him, sampling with a help of corer with bigger diameter decrease probability of contamination during sampling distinctively.

The radiocarbon dating of highly decomposed peat layers has enabled to state approximate duration of dry phases (**Fig. 2A**, after Żurek and Pazdur, 1999, changed), namely: in Subatlantic period 1700-2200 BP; in Subboreal

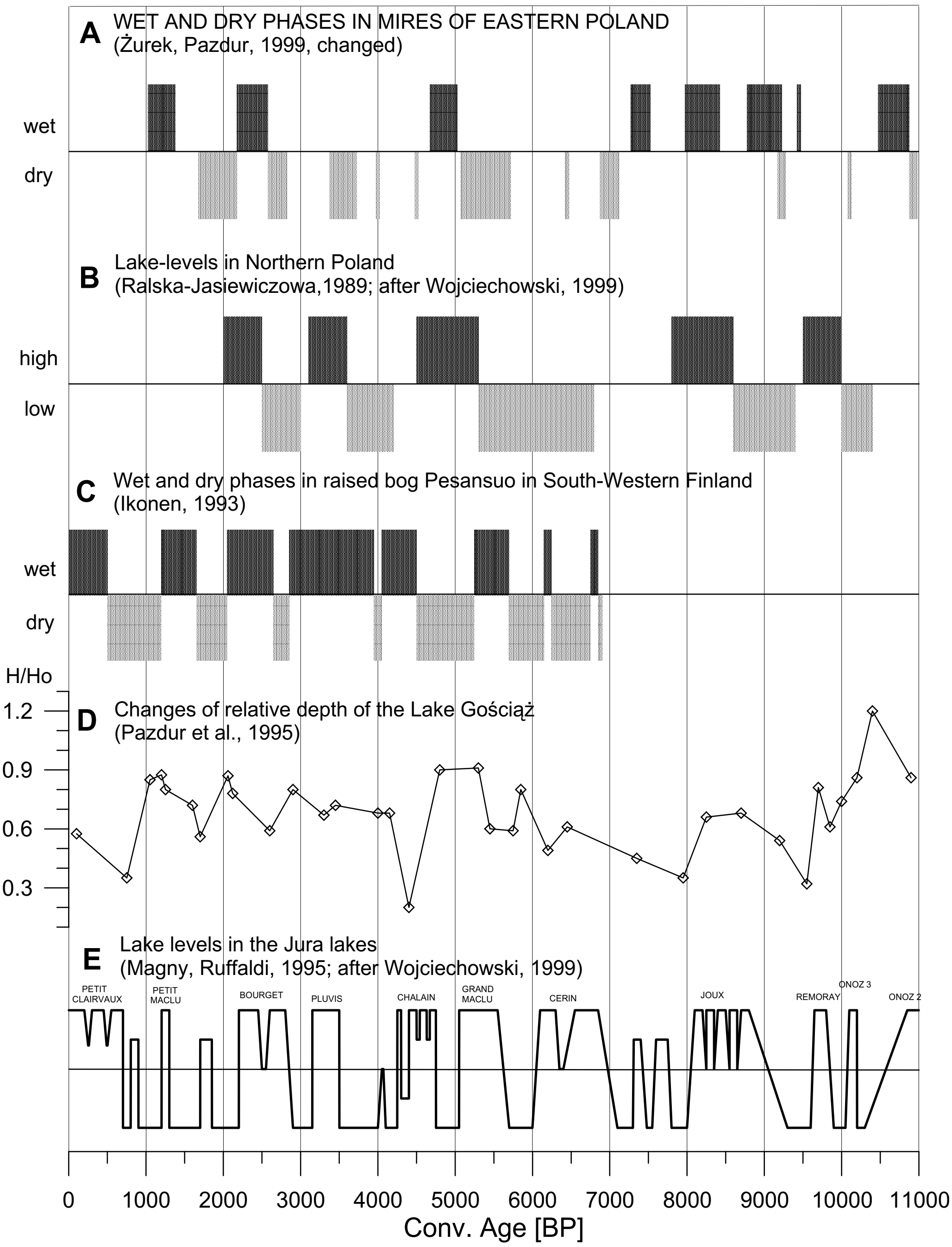

Fig. 2. Correlation between wet and dry phases in mires of Eastern Poland and other changes of climatic features during Late Glacial and Holocene in Poland, Finland and France.

period 2600-2800 BP, 3400-3700 BP, *ca.* 4000 BP and 4500 BP, in Atlantic period 5100-5700 BP, *ca.* 6400 BP and 6900-7100 BP; at the end of Preboreal 9200-9300 BP; at the beginning and at the end of Younger Dryas *ca.* 10,100 and 10,900 BP. On the other hand, wet phases can be approximately marked, according to the presented evidence, as follows: the middle (1100-1400 BP) and the beginning (2100-2600 BP) of Subatlantic period, the beginning of Subboreal period (4700-5000 BP), in Atlantic period 7300-7500 BP, the end (8000-8400 BP) and the beginning of Boreal period (8800-9200 BP). In Younger Dryas water table was raised during its earlier stage (10,500-10,850 BP).

Moisture changes plot for north-eastern Poland is in good agreement with the results for lakes and mires in Poland plotted in Figure 2B, elaborated by Ralska-Jasiewiczowa (1989; Starkel, 1990; Ralska-Jasiewiczowa and Latałowa, 1996).

Good agreement is apparent also for the moist phases up to 3 ka BP as recorded in the sites of north-eastern Poland and raised bog Pasänsuo (**Fig. 2C**) in south-western Finland (Ikonen, 1993). Dry and wet phases were distinguished here according to presence of rhizopod *Amphitrema flavium*, and 6 m long profile was dated by means of radiocarbon in the way that every 5 cm of succession was sampled (120 dates). The divergence refers periods 3400-3700 BP, 4700-5000 BP and 5200-5700 BP.

Similar agreement refers to high and low water level noted in Gościąż Lake (**Fig. 2D**; Pazdur *et al.*, 1994; Pazdur *et al.*, 1995), Biskupińskie Lake (Niewiarowski, 1995; Starkel *et al.*, 1996) and Kórnik-Zaniemyśl Lakes (Wojciechowski, 1999) sediments. High water levels in both regions are connected with the beginning of Subboreal and beginning of Subatlantic periods. Low water levels occurred at the end of Preboreal period, in the beginning and at the end of Atlantic period and in Subboreal period. Relatively good coincidence of high and low water-level stands with Polish and French Jura lakes (**Fig. 2E**; Magny and Ruffaldi, 1995) was shown in **Fig. 2**.

CONCLUSIONS

It should be noted that changes stated in mires sediments, especially changes in peat decomposition degree and botanical composition exploited to determine hydrologic changes in the past, especially to reconstruct of dry and moist phases in the Late Glacial and Holocene. Comparison of wet and dry phases reconstructed on basis of mires sediments from Eastern Poland are generally in good agreement with periods of high and low water level stands observed for Polish lakes, especially Gościąż Lake and lakes from Northern Poland. The disagreement between wet and dry periods pattern recorded in the Polish mires and the one reflected by the sediments of raised bog Pesänsuo in Finnland is observed for the time horizon prior 3 ka BP.

To conclude, authors' forthcoming research in the field of reconstruction of time scale for wet and dry periods pattern during the Holocene on the basis of radiocarbon dating is to be focused on exploiting of statistical methods for analysis of large sets of ^{14}C dates for peat and gyttja from various geographical regions.

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