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The development and genesis of a small thaw lake filling the Skaliska Basin during the Late Glacial and Holocene

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ABSTRACT. The northern part of the Mazury Lake District is marked by the presence of a depression described as the Skaliska Basin. At the end of the Pleistocene, the Skaliska Basin was the site of functioning of a thaw lake, within series of laminated clayey sediments were formed. The surface of the clayey sediments was overlain by a sandy fan. Blocks of dead ice underlying the fan and the overlying surface of the clayey sediments were the origin of small isolated water basins. Since the Allerød they were filled with limnic sediments, passing into peats towards the upper part. In order to reconstruct the vegetational history of the Skaliska Basin and the conditions of sedimentation of the lacustrine gyttjas and peats, several sections were obtained from such basins and subjected to examination of plant macroremains, palaeolimnological analysis and AMS dating. Sedimentation of lacustrine sediments began with sands with an admixture of silt and peat. The beginning of sedimentation of lacustrine sands of aeolian origin falls within the Allerød, whereas the end of that process in ca the middle of the Preboreal. Sands are frequently overlain by a strongly decomposed lacustrine dy sediment. Subsequently a sequence of detritus gyttja accumulated. The complex of gyttjas is interbedded with occasional Scirpo-Typheti peats. Sedimentation of lacustrine sediments is followed by accumulation of peats formed within communities with tall sedges. These communities, according to their compoition, correspond to the associations of *Cicuto-Caricetum pseudocyperi* Boer. et Siss. and *Caricetum elatae* Koch. The upper part comprises peats resembling the present-day community of *Sphagnum centrale*, displaying features of a transition bog. Also the occurrence of *Eriophorum vaginatum* confirms changes towards ombrotrophic conditions. The uppermost part of the sections often comprises heavily decomposed peat with components no longer identifiable by macroscopic analysis.

KEYWORDS: macrofossil analysis, limnological analysis, palaeoecological reconstruction, Late Glacial, Holocene, Skaliska Basin, nort-eastern Poland.

INTRODUCTION

Studies of changes in the vegetation and environment of the East Baltic Lakeland during the Late Glacial of the Vistulian glaciation and the Holocene were launched at the end of 1920s and the beginning of 1930s. Particular progress in this field was provided by investigations conducted by H. Groß (1935, 1936, 1937a, b, 1938) and W. Ołtuszewski (1937). Examinations of the history of postglacial changes in vegetation were continued in the eastern part of the Mazury Lake District and at the site of Woryty (Pawlikowski et al. 1982, Ralska-Jasiewiczowa 1989), which has become a reference site for the western part of the Mazury Lake District.

From the beginning of the 1990s, there was a noticeable increase of interest in this poorly studied area of Poland. Subsequently palaeobotanical analyses have been carried out on lacustrine and peat sediments at various sites. e.g. Nietlice (Kupryjanowicz 2002), Dudka (Nalepka 1995, Gumiński 1995, 1999), Tłokowo (Żurek 2003), Oleczno (Filbrandt-Czaja 1999), Dgał Wielki (Filbrandt-Czaja 2000), Lake Miłkowskie (Czernik 2004, Wacnik 2009a, b), Wigry (Kupryjanowicz 2004, 2007) and Sejny (Szwarczewski & Kupryjanowicz 2008). At the present time several new sites are being investigated, including Szczepanki (Wacnik

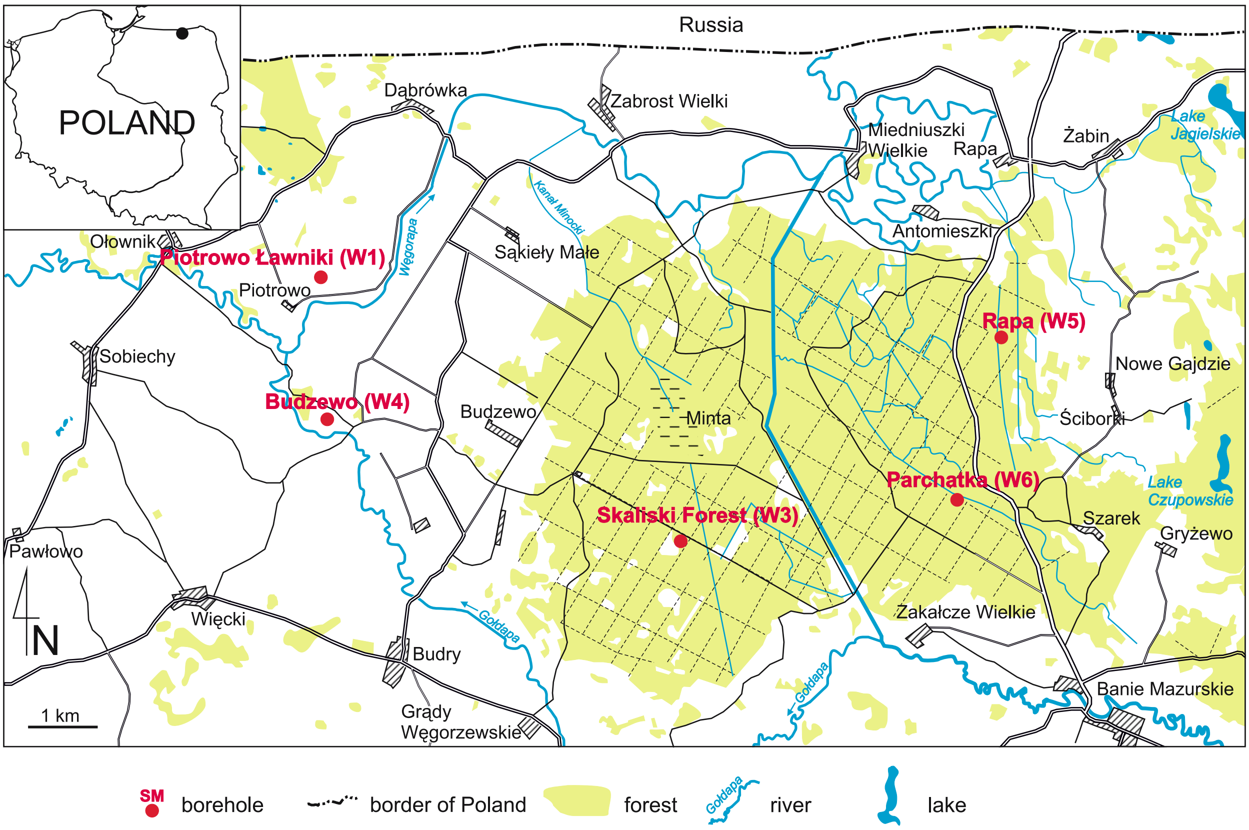

Fig. 1. Location of the study area

et al. 2010, 2012), Lake Staświńskie (Gumiński 2008, Wacnik & Ralska-Jasiewiczowa 2008), and the Bałupiany (Pochocka-Szwarc et al. 2006, Karpińska-Kołaczek et al. 2013).

When trying to correlate recorded changes in vegetation and palaeoenvironments, determine their causes or rates of change, the main problem is lack of radiocarbon dates. Most older studies are completely devoid of such dates, while recent analyses mostly include only a few dates. Two sites are particularly worth mentioning in this context: the Lake Wigry and the Lake Miłkowskie. The Lake Wigry was subjected to an investigation of the detailed chronology of the section (22 AMS ^{14}C dates), which has been already completed and the site has become a reference one for the Suwałki Region (Kupryjanowicz 2004). The Lake Miłkowskie is located within the Mazury Lake District and is marked by well-developed lamination of its sediments. The period of deposition of the material covers over 14 000 years and the detailed chronology is based on radiocarbon dating (48 AMS ^{14}C dates) and the number of varves.

Most studies lack analyses of macroscopic plant remains which document local changes in vegetation. Examination of the history of thaw basins in this region of Poland was initiated by J. Stasiak and her palynological analyses of sites in the surroundings of Giżycko, Mrągowo (Stasiak 1961, 1963, 1967), Pisz (Stasiak 1971) and Suwałki (Stasiak 1965, 1969). This was the time of development of a detailed study of bottom sediments of the Lake Mikołajki (Ralska-Jasiewiczowa 1966), of key importance in the reconstruction the local vegetation. Lacustrine and peat sediments are frequently have no or only very low amounts of material suitable for such analyses. However, an abundant but still unpublished flora of plant macroremains has been analysed, from the site of Woryty (Ralska-Jasiewiczowa unpublished). Similar investigations were also carried out on fragments of the section from the Miłkowskie Lake (Kloss, Wacnik, Czernik unpublished). Some papers are based on materials sampled from archaeological sites like Osinki (Kościk 1963), Pieczarki (Polcyn 2000), Paprotki Kolonia (Pirożnikow 2002, Karczewski 2011), and Tłokowo (Schild et al. 2003). The subfossil phytocenoses of the sites of Suche Bagno and Kołowin were analysed by Kloss (2005). Presently, the plant remains of the sites of Szczepanki (Wacnik et al. 2010) and Wigry (Żurek & Drzymulska 2005) are being investigated.

The great majority of sections bear a record of the history of vegetation that covers the close of the Late Glacial of the Last glaciation and the Holocene. Only infrequent ones provide information on processes and events that occurred in periods older than Allerød (Gałka & Sznel 2013).

GEOLOGY AND GEOMORPHOLOGY OF THE STUDY AREA

To the north-east of Węgorzewo, in the northern part of the Mazury Lake District, a depression is located, classified by Kondracki (2000) as a microregion of the Mazury Lakeland by the name of the Skaliska Basin. The northern part of the area is overlapped by the border with the Kaliningrad Region. From the east the basin is surrounded by morainic hills (the Kruckie and Klewińskie hills) while from the west and south – by a morainic upland and single kame hills (Piotrowo, Jurgucie, Kolonia Sobiechy). The ground surface of the basin ranges in altitude from 94–95 m a.s.l. in its western and northern part to 100–105 m a.s.l. in the area of the Skaliski Forest. The geology and palaeogeography of the area of the Skaliska Basin and its closest surroundings were thoroughly studied during geological-photographic surveys conducted for the Detailed Geological Map of Poland at a scale of 1: 50000.

At the end of the Pleistocene, the area of the Skaliska Basin was marked by the presence of a thaw end basin with glacilimnic sedimentation developing between blocks of dead ice. It resulted in the formation of a series of laminated clayey sediments, interbedded with silts of a massive structure. Their thickness ranges from 12.8 to 17.8 m (Pochocka-Szwarc & Lisicki 2001, Pochocka-Szwarc 2003, 2005, 2010). Above these laminated clays and silts an alluvial fan developed depositing sandy sediments as a result of changes in the direction of flow of meltwaters during the deglaciation of the ice sheet in the Pomeranian phase (Main Stadial of the Vistulian glaciation).

Above blocks of dead ice underlying the Skaliska Basin, small isolated water basins were formed, and were infilled after the Allerød with lacustrine sediments, passing upwards into peats (Kołaczek et al. 2013).

In order to reconstruct the history of vegetation and conditions of sedimentation of lacustrine gyttjas and peats in the Skaliska Basin, several boreholes were drilled with the use of the Wieckowski probe. The materials obtained were sampled for sedimentological, palynological, and diatomological studies, analyses of Cladocera, isotopes of carbon and oxygen, as well as for radiocarbon dating of 27 samples was carried out in the Poznań Radiocarbon Laboratory (Tab. 1).

METHODS

The cores investigated were obtained from 5 boreholes of lacustrine and peat sediments denoted as Piotrowo-Ławniki (W1), Skaliski Forest (W3), Budzewo (W4), Rapa (W5) and Parchatka (W6), located within the Skaliska Basin (Fig. 1).

Samples for analysis of macroscopic plant remains were taken in close correlation to samples meant for other studies.

Samples averaging 50–100 ml in volume were macerated in a 10% solution of KOH and detergents. After the sediment was boiled to a pulp, it was subjected to wet sieving using a sieve with a mesh diameter of Ø 0,2 mm. Plant remains: seeds, fruits, needles, and other vegetative parts, suitable for identification, were picked out and placed in a mixture of glycerine, water and ethyl alcohol, in the ratio of 1:1:1, with addition of thymol. The remains were identified with the use of keys, atlases, and other publications (Beijerinck 1947, Berggren 1969, Cappers et al. 2006, Kats et al. 1965, Nilsson & Hjelmquist 1967, Velichkevich & Zastawniak 2006, 2008), as well as with the use of the reference collection of modern seeds and fruits and the collection of fossil floras of the Palaeobotanical Museum of the W. Szafer Institute of Botany, Polish Academy of Sciences. Names of vascular plants follow mainly Mirek et al. (2002).

Results of identification are presented in diagrams plotted with the POLPAL software for Windows (Nalepka & Walanus 2003). Definition of the Local Macrofossil Assemblage Zones (L MAZ) was based on the occurrence of one or several taxa which were most abundant or characteristic, with regard to quantity or indicatory features.

Types of peat were determined following the genetic classification by Tołpa et al. (1967, 1971). For two types, willow peat and alder peat, no Latin name was used, as their botanical composition indicated a complete dominance of remains of *Salix* sp. or *Alnus glutinosa*, respectively, however, accompanied by several taxa not characteristic for the Saliceti or Alneti peat. Coarse-detritus gyttja was distinguished following the classification by Bülow (Tobolski 2000).

Table 1. Radiocarbon dates

No.	Samples (depth in cm)	Lab.code	Age ^{14}C	Remarks	Dated material
1	Piotrowo (W1) 30–40	Poz-41016	4265±35 BP		peat
2	Piotrowo W1 55–60	Poz-37991	5420±40 BP		*Carex* sp. fruits
3	Piotrowo (W1) 295–300	Poz-37992	1000±30 BP		*Betula* sect. *Albae*, *Schoenoplectus lacustris* fruits
4	Piotrowo (W1) 310–320			small, thymol	*Betula* sect. *Albae* fruits, *Cristatella mucedo*
5	Piotrowo (W1) 430–400	Poz-37993	6570±100 BP	very small 0.07mgC	*Betula humilis* fruits and plant tissues
6	Piotrowo (W1) 450–460	Poz-40013	9790±100 BP		plant detritus
7	Skalisko (W3) 43–46	Poz-41018	2190±30 BP		leaves
8	Skalisko (W3) 60–70	Poz-41019	2460±30 BP	thymol	*Menyanthes trifoliata Carex elata*, *Carex acuta* fruits
9	Skalisko (W3) 190–200	Poz-41020	4110±40 BP	thymol	*Betula* sect. *Albae* scales and fruits
10	Skalisko (W3) 220–230				fragments of wood
11	Skalisko (W3) 270–280	Poz-41022	5300±50 BP		fragments of wood
12	Budzewo (W4) 180–190			thymol	*Betula* sect. *Albae*, *Najas marina* fruits
13	Budzewo (W4) 240–245	Poz-37983	4770±40 BP		*Betula* sect. *Albae* fruits and plant tissues
14	Budzewo (W4) 345–350	Poz-37984	5560±50 BP	small, 0.4mgC	fragments of wood and plant tissues
15	Budzewo (W4) 450–460	Poz-41017	7020±80 BP	small, thymol	*Betula* sect. *Albae*, *Cicuta virosa*, *Stachys palustris fruits*, *Cristatella mucedo*
16	Budzewo (W4) 640–650+620–630	Poz-41012	7170±70 BP	thymol	Poaceae, *Cristatella mucedo*, *Typha* sp. *Juncus* sp. seeds *Cristatella mucedo* *Betula* sect. *Albae* scales
17	Budzewo (W4) 800–810	Poz-41008	6730±110 BP	small	Poaceae, *Betula* sect. *Albae* fruits
18	Budzewo (W4) 900–910				Musci, *Betula* sect. *Albae* fruits
19	Budzewo (W4) 970–975	Poz-37987	9660±60 BP		*Betula* sect. *Albae* fruits, *Schoenoplectus lacustris* fruits
20	Budzewo (W4) 980–990	Poz-38016	9570±60 BP		fragments of wood and plant tissues
21	Budzewo (W4) 980–990	Poz-38017	9540±50 BP	thymol	fragments of wood and plant tissues
22	Rapa (W5) 250–255	Poz-41023	7300±50 BP	small, thymol	*Betula* sect. *Albae* scales, *Schoenoplectus lacustris* fruits, *Solanum dulcamara* fruits
23	Rapa (W5) 360	Poz-33502	9000±60 BP	small, 0.5mgC	fragments of wood and plant tissues
24	Rapa (W5) 441	Poz-35684	11330±60 BP	too small	fragments of plant tissues
25	Parchatka (W6) 550–560	Poz-37988	8400±60 BP	small, 0.6mgC	*Schoenoplectus lacustris* fruits
26	Parchatka (W6) 610–620	Poz-38065	9410±60 BP		fragments of plant tissues
27	Parchatka (W6) 665–670	Poz-37989	8700±50 BP		*Schoenoplectus lacustris* fruits

STRATIGRAPHY OF MACROSCOPIC PLANT REMAINS

Within diagrams plotted for macroscopic plant remains, the Local Macrofossil Assemblage Zones were distinguished, numbered from the base to the top part and denoted as PŁ MAZ 1-4, SF MAZ 1-4, Bu MAZ 1-6, Ra MAZ 1-6, and Pa MAZ 1-8.

The criteria used in defining the zones were the occurrence of one or several most abundant or characteristic and diagnostic taxa within a given zone. The zone boundaries were defined on the basis of the appearance, disappearance, and increase or decrease in the abundance of taxa of a significant quantitative or indicative value. The zones are described in Tables 2–6.

PIOTROWO-ŁAWNIKI (W1)

The section of Piotrowo-Ławniki (54°18′7″N, 21°51′44″E) was drilled in a peat bog developed on the surface of a Pleistocene ice-dammed lake and directly overlying clayey sediments. The section was located ca 200 m to the north of the Węgorapa River, ca 1 km from the area in which the Węgorapa River flows into the Gołdapa River.

Lithology (depth in cm):

20–40 peaty humus
40–60 sedge-reed (Carici-Phragmiteti) peat
60–120 sedge (Cariceti) peat
120–150 detritus gyttja
150–170 Potamioni peat
170–210 coarse-detritus gyttja

210–350 dy (>80% humus)
350–460 minerogenic sediments, mainly sand with silty intercalations

The development of the basin was initiated at the close of the Late Glacial. According to palynological analysis (Kołaczek et al. 2013), the beginning of sedimentation falls within the Younger Dryas. The basal part (460–350 cm) consists of silt with an admixture of sand, nearly devoid of plant remains suitable for identification. The base of zone PŁ-1 (Figs 2 & 3, Tab. 2) comprises, apart from single fruits of *Betula humilis*, *B.* sect. *Albae*, and *Typha* sp., frequent non-determined eggs of insects. Infrequent statoblasts of the bryozoa, *Cristatella mucedo*, and mollusc shells suggest that the sediment was deposited in a shallow basin with waters of a high calcium carbonate content. Waters of lakes in their initial stage of development are frequently enriched with calcium carbonate originating from the surrounding postglacial sediments (Nowaczyk & Tobolski 1980, Borówka 1992). Identification of pollen grains of aquatic plants, i.e. *Potamogeton* subgen. *Eupotamogeton*, *Myriophyllum spicatum*, and *Lemna*-type, suggests relatively shallow and still waters. The nature of the sediment and the very poor composition of the macroflora indicate a rather infrequent sediment type, namely lacustrine sands. Sands are transported into lacustrine basins mainly as a result of aeolian activity. Sediments of this type and their origin were documented by Tobolski (1966), in the Prosna valley, and within the section of Jęzor-Jaworzno (Szczepanek & Stachowicz-Rybka 2004), where traces of aeolian sands were recorded since the Younger Dryas. The aeolian activity in the area was confirmed in studies by Woronko, who identified traces of aeolian processes in quartz grains found within the Skaliska Basin (Woronko & Pochocka-Szwarc 2013). In the zone between 210–350 cm, the sediments consist of a lacustrine dy, containing over 80% of humic matter. Typically in this sediment are found small amounts of remains of fruiting parts of tree birches, representing plants growing on the shore of the sedimentary basin, and, from the littoral zone and beyond, *Schoenoplectus lacustris* and *Potamogeton natans*. Eggs of insects and statoblasts of bryozoan, *Cristatella mucedo*, which inhabit the surface of lakes with moderately warm water and abundant in calcium carbonate, were particularly frequent.

Cristatella mucedo possesses a fragile structure and prefers sites with limited wave action (Økland & Økland 2000).

The type of sediment and occurrence of remains of plants from beyond the littoral zone indicates that from the close of the Boreal to the beginning of Atlantic the basin may have been filled with water attaining, at this site, a depth of 300–350 cm.

In zone PŁ-2, at the depth of 210 cm, the sedimentation type changed. The accumulation of coarse-detritus gyttja, is comprised of plant remains of allochthonous origin, and contained fine fragments of aquatic plant tissue, single fruits of *Mentha aquatica*, *Najas marina*, and *Ceratophyllum demersum*, idioblasts of

Table 2. Piotrowo-Ławniki (W1) – the description of the Local Macrofossil Assemblage Zones (L MAZ)

Local Macrofossil Assemblage Zones	Depth (cm)	Description
PŁ-1	210–460	Single occurrences of remains of *Betula* sect. *Albae*, *B. humilis*, *Juncus* sp., and Poaceae were recorded. Among swamp and aquatic plants, remains of *Typha* sp., *Schoenoplectus lacustris*, and *Potamogeton natans*, accompanied by statoblasts of bryozoan, *Cristatella mucedo*, were identified
PŁ-2	130–210	Single occurrences of remains of tree birches and horsetails were recorded. Aquatic plants are represented by *Najas marina* and *Ceratophyllum demersum.* Statoblasts of bryozoan, *Cristatella mucedo*, are relatively abundant
PŁ-3	90–130	The zone is dominated by remains of two species: *Najas marina*, representing aquatic plants, and statoblasts of bryozoan *Cristatella mucedo*. Remains of *Cenococcum geophilum* and mollusc shells are recorded only as single occurrences
PŁ-4	40–90	Zone marked by the most abundant and most diverse plant remains within the entire section. Associations of peat plants, particularly *Carex pseudocyperus*, *C. rostrata*, *C. nigra*, and *Eleocharis palustris*, are the dominants. Swamp and aquatic plants are well represented. The identified species include *Oenanthe aquatica*, *Alisma plantago-aquatica*, *Schoenoplectus lacustris*, *Nymphaea alba*, *Potamogeton natans*, and *Najas marina*
PŁ-5	20–40	No plant remains were found. Strongly decomposed peat is the dominant sediment

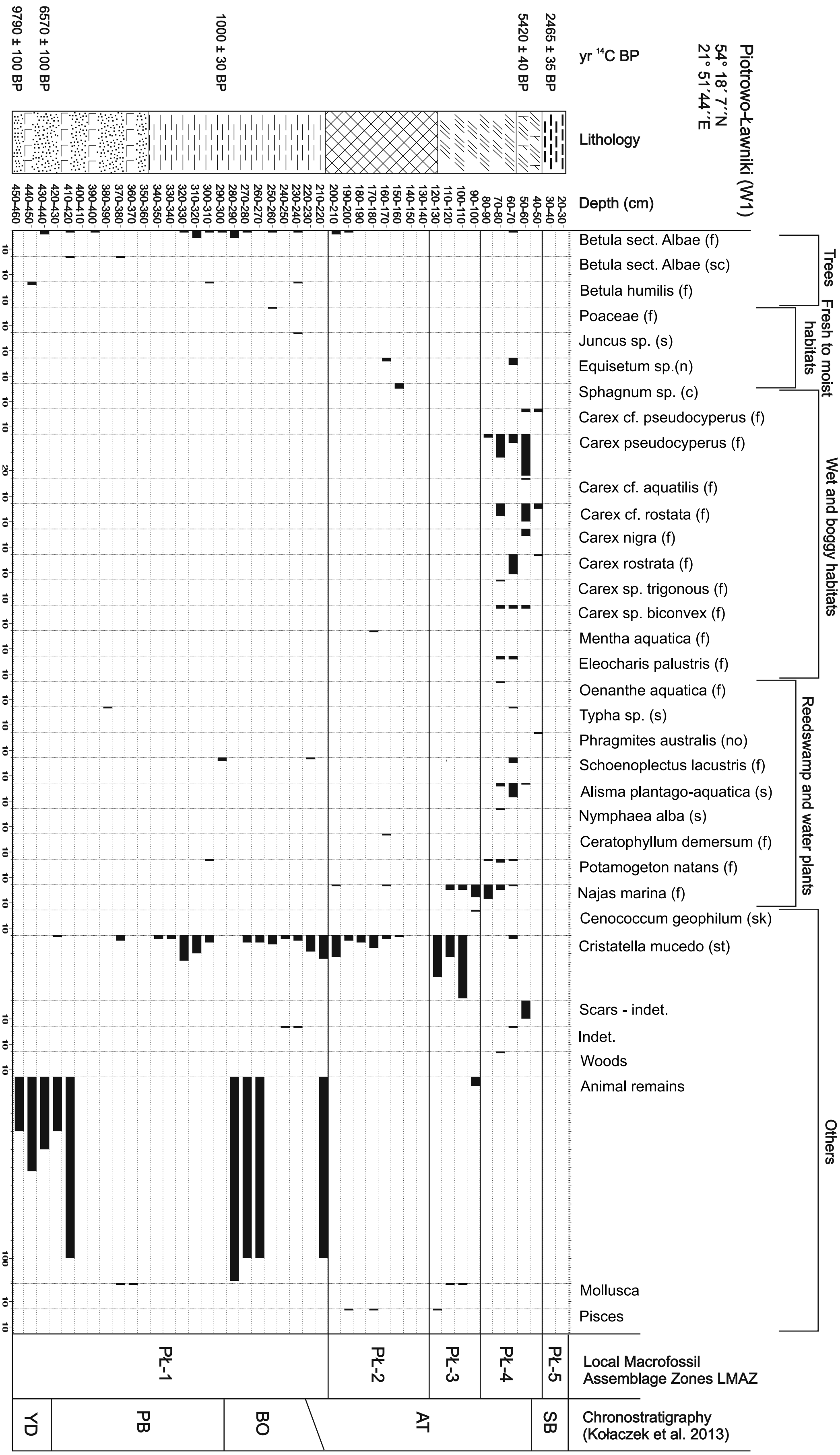

Fig. 2. Diagram of macrofossils from the Piotrowo-Ławniki site. Abbreviations: **s** – seed, **f** – fruit, **n** – needle, **t** – tegmen, **c** – capsule, **no** – node, **sc** – scales, **sk** – sclerotia, **st** – statoblast

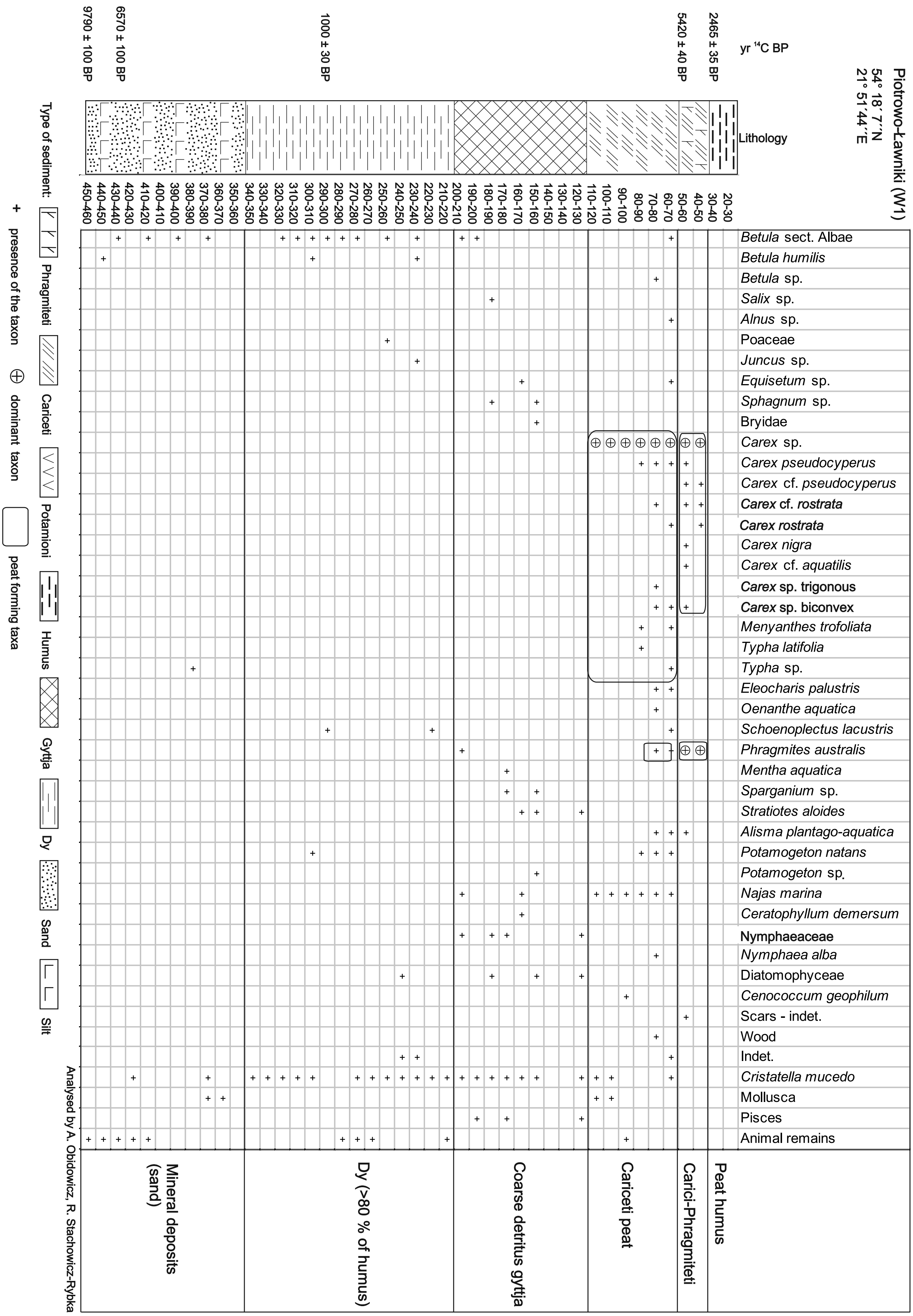

Fig. 3. Diagram of plant tissues in peat analysis and additional macrofossils from the Piotrowo-Ławniki site

Nymphaeaceae, and diatoms. The part of the basin that was sampled, though still beyond the littoral zone, was clearly becoming shallower due to accumulation of gyttja. Zone PŁ-3 is marked by an increase in the proportion of *Najas marina* and *Cristatella mucedo*, remains of *Carex* spp. appear as well.

As such basins become shallower, they are invaded by rooted vegetation and eventually accumulate sedge peat, but the initial zones are devoid of autochthonous sedge remains. However, from the onset of zone PŁ-4, at 90 cm, it may be deduced that sedge species were represented mainly by *Carex pseudocyperus* and *C. rostrata*, found within associations requiring highly eutrophic habitats. The basal part of the zone is marked by the occurrence of a shallow basin with vegetation typical of shallow, highly eutrophic waters, inhabited by *Nymphaea alba*, *Potamogeton natans*, and *Najas marina*, with a belt of swamp, including *Alisma plantago-aquatica*, *Schoenoplectus lacustris*, *Typha* sp., and *Phragmites australis.* Due to their presence, the basin eventually becomes filled with peat sediment.

The uppermost 40 cm of sediment comprises highly humified peat with constituents indistinguishable by means of macroscopic analysis. According to palynological analyses, the proportion of Cyperaceae is as high as in the preceding zone, therefore both zones bear sediments of the same origin. The nearly complete humification of plant material results most likely from the lowering of the water level during the deposition of peat, subjected to intensive fluctuations due to land drainage works carried out in this area for many years. Sediments of the Piotrowo-Ławniki section end with the beginning of the Subboreal.

SKALISKI FOREST (W3)

The section from the Skaliski Forest (54°16′09″N, 21°56′38″E) was located in a peat bog, which developed on sandy sediments of an alluvial fan, ca 1km to the south of the boundary of boggy forests known as the Minta (Fig. 1).

Lithology (depth in cm):

60–210	sedge (Cariceti) peat
210–220	willow (Saliceti) peat
220–245	sedge (Cariceti) peat
245–260	silt with an admixture of detritus
260–280	sedge (Cariceti) peat

The basal part of the section (zone SF-1 and base of zone SF-2, mainly the depth of 280–220 cm) consists of a sedge peat of uncertain origin (dominance of radicells of *Carex* sp.), interbedded (at the depth of 260–245 cm) with a thin clayey intercalation, in which abundant sclerotia of *Cenococcum geophilum* as well as fruits of *Schoenoplectus lacustris*, and nodes of *Phragmites australis* (Figs. 4, 5, Tab. 3) were identified. Statoblasts of *Cristatella mucedo* were also found, which is a species preferring still or slowly flowing waters, however, tolerating a broad range of trophic conditions. Colonies of *Cristatella mucedo* have been recorded in water bodies of various conditions, from oligotrophic to eutrophic (Okamura 1997, Økland & Økland 2000). Formation of a bed of clayey sediments, comprising remains of swamp and aquatic plants, is most likely a result of a rise in the water level and inwash of terrigenous material into the area of the already developed sedge peat bog. This event occurred within the Preboreal/Boreal (Kołaczek et al. 2013) and was the initial stage of development of the peat bog, ending with the appearance of *Salix* sp. As willow was present within a community usually alien to it, the thin stratum of peat comprising the tree (top of zone SF-2, mainly the depth of 220–210 cm) was described as willow peat. No fruiting remains of plants were recorded within this layer.

Zone SF-3, at the depth of 200 cm, begins with accumulated peats formed in communities of tall sedges. Initially the composition of the community was conformable with the association of *Cicuto-Caricetum pseudocyperi* Boer. & Siss., usually marginal to water bodies being overgrown by vegetation, or forming enclaves in wet mid-forest hollows. Presence of such a community is shown also by the prevalence of fruits of *Alnus glutinosa*, *Betula* sect. *Albae*, and *Urtica dioica*, as well as by the occurrence of scales of *Pinus sylvestris.* Subsequently, the area was invaded by communities with *Carex riparia* (zone SF-4) and communities with *Carex elata* (zone SF-5), composition of which resembles the present-day association of *Caricetum elatae* Koch., abundant in remains of *Menyanthes trifoliata* and *Comarum palustre*. Such communities, particularly *Caricetum elatae*, indicate waters with intensive vertical movements (Nowiński 1967). The uppermost part bears a record of the replacement of the peat-forming tall-sedge

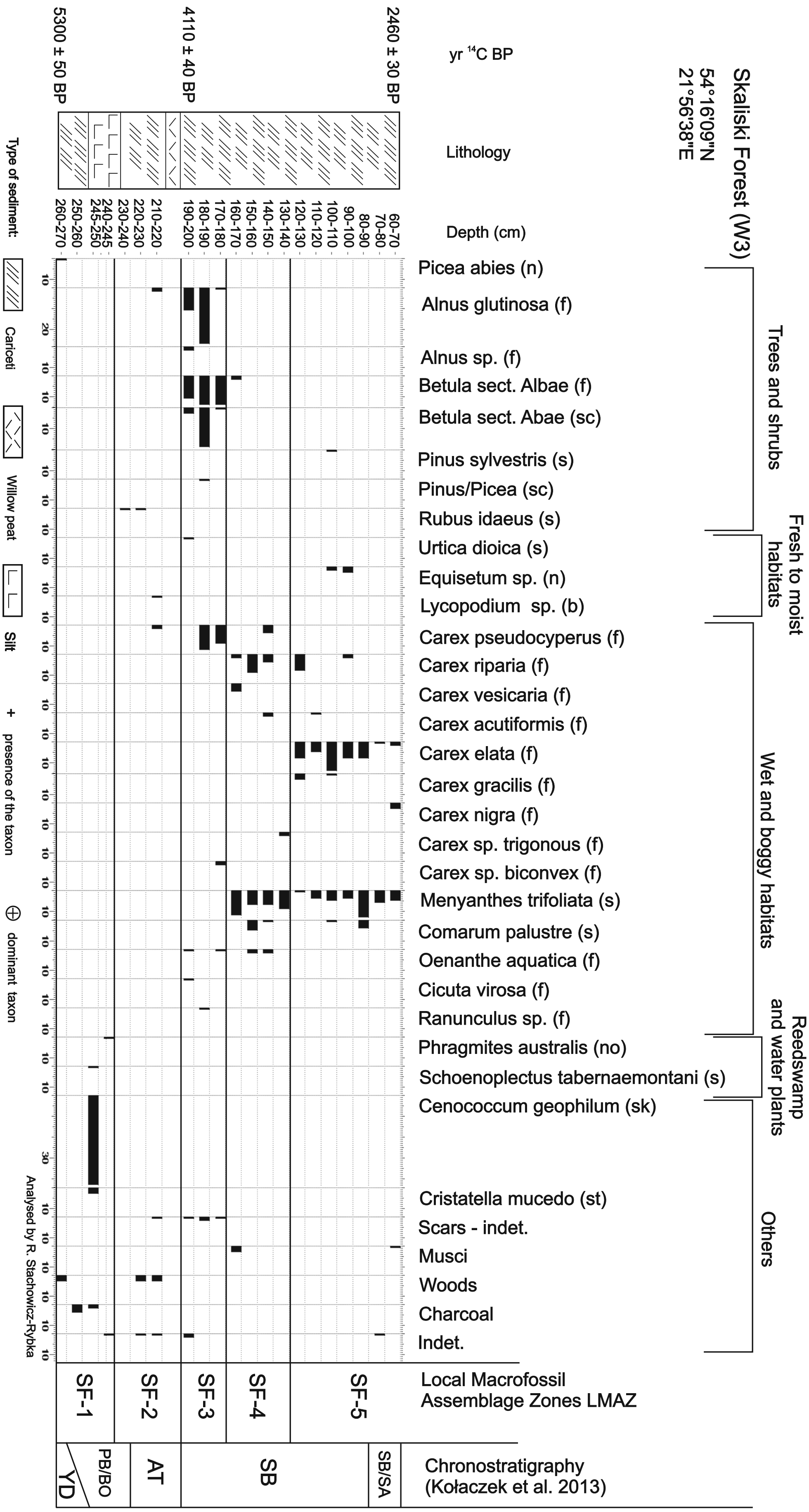

Fig. 4. Diagram of macrofossils from the Skaliski Forest site

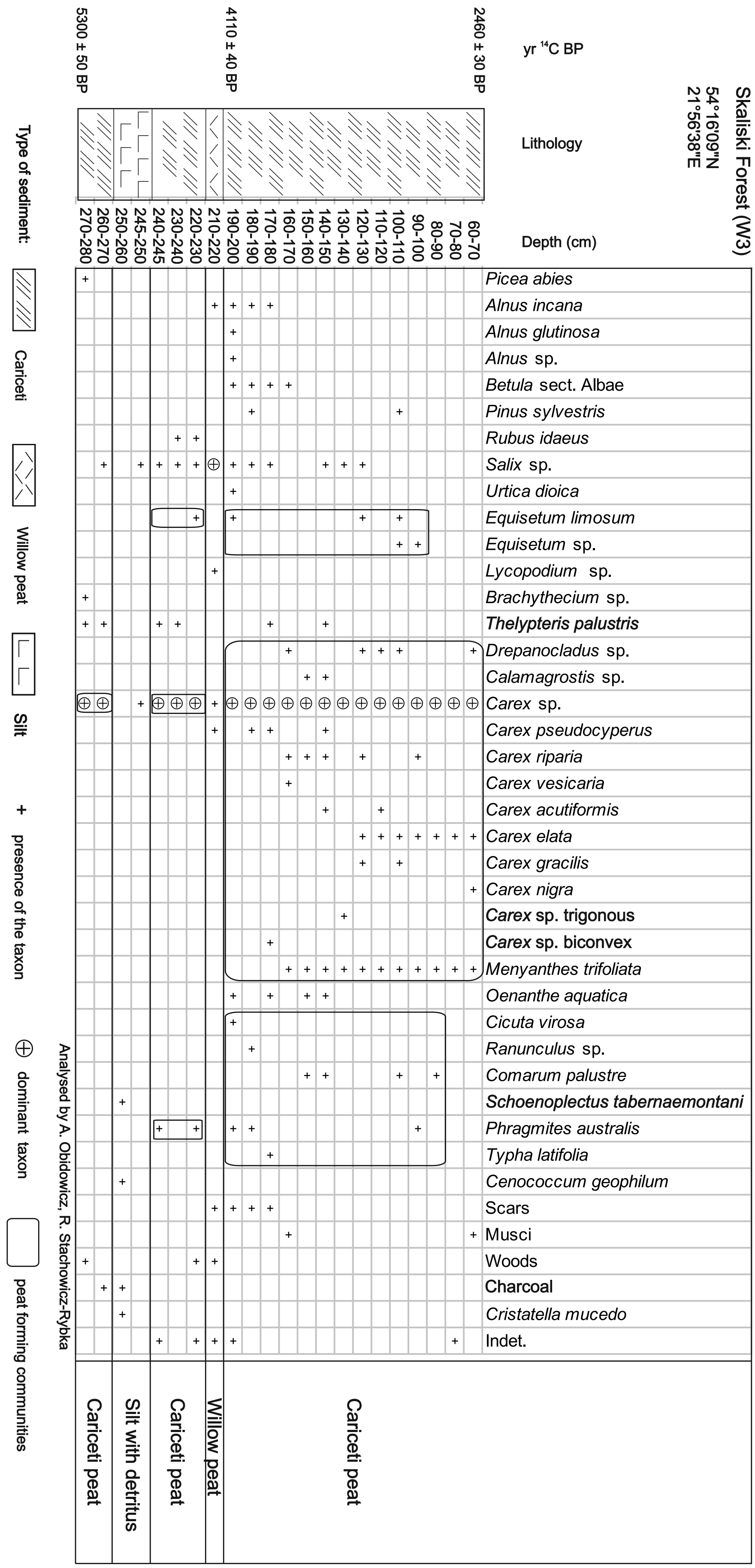

Fig. 5. Diagram of plant tissues in peat analysis and additional macrofossils from the Skaliski Forest site

Table 3. Skaliski Forest (W3) – the description of the Local Macrofossil Assemblage Zones (L MAZ)

Local Macrofossil Assemblage Zones	Depth (cm)	Description
SF-1	240–270	Zone with infrequent plant remains. *Cenococcum geophilum* is the dominant species, particularly in the sample from the depth of 245–250 cm. Among trees, remains of *Picea abies* are found, while among swamp and aquatic plants – of *Phragmites australis* and *Schoenoplectus tabernaemontani*. Woods and charcoal occur as well
SF-2	200–240	Remains of plants typical of humid habitats, including *Alnus glutinosa*, *Rubus idaeus*, and *Lycopodium* sp., are recorded only as single occurrences. Among peat plants, *Carex pseudocyperus* was identified
SF-3	170–200	In this zone, remains of *Alnus glutinosa* and *Betula* sect. *Albae* attain their highest frequency within the entire section. Among trees, remains of *Pinus/Picea* were also determined. Single occurrences of *Urtica dioica* are recorded. Among peat plants, *Carex pseudocyperus* is very numerous. Swamp vegetation and vegetation typical of humid habitats is represented by *Oenanthe aquatica* and *Cicuta virosa*
SF-4	130–170	Remains of tree birches are recorded as single occurrences. Peat plants, represented by *Carex pseudocyperus*, *C. riparia*, *C. vesicaria*, and *C. acutiformis*, make an abundant group in the zone. *Menyanthes trifoliata*, *Comarum palustre*, and *Oenanthe aquatica* were identified as well
SF-5	60–130	Remains of pine are found as single occurrences. Numerous remains of peat plants, such as *Carex elata*, *C. gracilis*, *C. nigra*, *C. riparia*, and *C. acutiformis* were determined. *Menyanthes trifoliata* and *Comarum palustre* were also identified

communities by a community representing the class of Scheuchzerio-Caricetea nigrae, including *Carex nigra*.

BUDZEWO (W4)

The section of Budzewo (54°17′06″N, 21°55′55″E) was drilled from a peat bog developed on the flat surface of a Pleistocene ice-dammed lake, ca 200 m to the east of the Gołdapa river (Fig. 1). It consists of lacustrine sediments underlain by sands of a low thickness.

Lithology (depth in cm):

20–150	edge-reed (Carici-Phragmitieti) peat
150–180	swamp (Limno-Phragmitieti) peat
180–230	Potamioni peat
230–270	swamp (Limno-Phragmiteti) peat
270–1010	detritus gyttja with dy

Accumulation of sediments of the basin was initiated at the beginning of the Holocene, in the Preboreal. The section attains a thickness of 10 m and includes a segment (1010–270 cm) formed of limnic sediments, the description of which is consistent with the definition of coarse-detritus gyttja (Figs 6, 7). The initial zone Bu-1 is typified by the dominance of *Cenococcum geophilum* sclerotia, indicating solifluction processes, and lack of dense plant cover around the basin (Ławrynowicz 1983, Wick et al. 2003, Tinner et al. 2008). Single remains of *Carex pseudocyperus* were also found (Tab. 4). The basal part of zone Bu-2 contains plant remains dated to 9570±60 BP, 9540±50 BP (Tab. 1). Examination of the vegetative parts of plants revealed the presence of small amounts of plant detritus, originating from communities surrounding the sedimentary basin, as well as of swamp and aquatic plants. Similar results were obtained in the analysis of plant macroremains. Open water existed in the basin from before 9570±60 BP to 4770±40 BP (Tab. 1). This was the time of deposition of gyttjas of a homogenous botanical composition. According to identification of plant remains, the surroundings of the basin were occupied by *Betula* sect. *Albae*, *Pinus sylvestris*, and *Alnus glutinosa*, boggy areas also supported *Rorippa palustris* and *Urtica dioica*, while drier habitats were occupied by Poaceae. The recorded remains of peat-forming plants, particularly in the lower part of the zone, suggest the occurrence of peaty sites around the basin, inhabited by tall-sedge swamp communities with *Cicuta virosa* and *Carex pseudocyperus* and by low peat bogs with *Carex elata*, *C. rostrata*, *C. riparia*, and *Menyanthes trifoliata*. The belt of reedswamp included *Phragmites australis*, *Lycopus europaeus*, *Mentha aquatica*, *Schoenoplectus lacustris*, and *Typha* sp. Aquatic vegetation was poorly represented by remains of *Nymphaea alba*, *Sparganium emersum*, and *Hippuris vulgaris*. Idioblasts of Nymphaeaceae, diatoms and remains of aquatic animals, particularly bryozoan, *Cristatella mucedo*, were observed as well. Statoblasts of *Cristatella mucedo* are notably the dominant items in the diagram, reflecting their abundance and continuous presence within sediments deposited in an aquatic environment. As was previously noted, their occurrence is an indicator of still and slow-flowing waters of a broad trophic spectrum (Okamura 1997, Økland & Økland 2000). As indicated by the species composition of aquatic plants, as well as by the results of analysis of diatoms (Sienkiewicz 2013) and Cladocera (Gąsiorowski 2013), in this period the basin included an open water surface. Both above mentioned analyses provide evidence for great fluctuations in water level, dated to the beginning of the Boreal and early Atlantic, however, not obviously confirmed by changes in aquatic and swamp vegetation, macroremains which were rather infrequent in the zone.

With the beginning of the Subboreal (Kołaczek et al. 2013), the basin became shallow as a result of progressive infill with limnic sediments. The basal part of zone Bu-3 is marked by early accumulation of peat of a Limno-Phragmitioni type, with *Phragmites australis*, *Typha* sp., and *Nuphar luteum*. This initial stage of peat bog development was interrupted by a rise in water level and the growth of an aquatic plant community, leading to the accumulation of Potamioni peat. The diverse flora of the community comprised among others. *Stratiotes aloides*, *Nymphaea alba*, *Najas marina*, and *Ceratophyllum demersum*. In zone Bu-4, the increase in abundance remains of *Phragmites australis* and *Typha latifolia*, indicating a renewed fall in the water level within the littoral zone, corresponds with a stratum of Limno-Phragmitioni peat. The final occurrence of bryozoan, *Cristatella mucedo*, is recorded as well, presaging the complete disappearance of open water. This process was accompanied by the disappearance of diatoms (Sienkiewicz 2013) and Cladocera (Gąsiorowski 2013). The increasing trophic status of the site is indicated by the increase in the amount of *Urtica dioica* fruits, followed by a stratum of Carici-Phragmiteti peat. Accumulation of peat in such communities, composed mainly of *Phragmites australis* and abundant sedges, particularly *Carex pseudocyperus* and *C. riparia*, resulted in the complete infilling of the basin. Both zones Bu-5 and Bu-6 are marked by an increase in the amount of charcoal, while zone Bu-6 is further characterized by a decrease in the number of tree remains and the appearance of *Rorippa*

Table 4. Budzewo (W4) – the description of the Local Macrofossil Assemblage Zones (L MAZ)

Local Macrofossil Assemblage Zones	Depth (cm)	Description
Bu-1	990–1010	*Cenococcum geophilum* is clearly the dominant species. Peat plants are represented by *Carex pseudocyperus*
Bu-2	250–990	The zone is marked by a high proportion of statoblasts of bryozoan, *Cristatella mucedo*. Remains of *Betula* sect. *Albae*, *Pinus/Picea*, *Alnus glutinosa*, and Poaceae are found frequently, particularly at the basal part. The group of peat plants, comprising *Cicuta virosa*, *Rorippa palustris*, *Carex pseudocyperus*, *C. elata*, *C.* cf. *elongata*, *Menyanthes trifoliata*, and *Stachys palustris*, is diverse, however, recorded in minor amounts. Swamp and aquatic plants are well represented and include species like *Typha* sp., *Schoenoplectus lacustris*, *Lycopus europaeus*, *Mentha aquatica*, *Rumex hydrolapathum*, *Stratiotes* sp., *Nymphaea alba*, *Hippuris vulgaris*, and *Sparganium emersum*
Bu-3	150–250	Among trees, *Betula* sect. *Albae* is most frequent. *Urtica dioica* and *Equisetum* sp. were identified as well. The zone is dominated by swamp and aquatic plants, represented by remains of *Phragmites australis*, *Stratiotes* sp., *Batrachium* sp., *Nymphaea alba*, *Ceratophyllum demersum*, *Najas marina*, *N. minor*, *Nuphar luteum*, *Potamogeton obtusifolius*, and numerous oospores of Characeae
Bu-4	120–150	The zone is characterized by a high proportion of remains of plants typical of humid and peat habitats. *Urtica dioica*, *Poaceae* sp., *Equisetum* sp., as well as *Carex pseudocyperus* and *Carex* sp. div. biconvex are found. Among swamp plants, *Phragmites australis*, *Typha* sp., and *Lycopus europaeus* are still abundant. Statoblasts of bryozoan, *Cristatella mucedo*, are still present
Bu-5	60–120	The zone is characterized by high amounts of *Betula* sect. *Albae*. Among trees, *Pinus/Picea* was determined as well. Remains of *Viola palustris* and *Equisetum* sp., as well as of peat plants: *Carex pseudocyperus*, *C. riparia*, and *Carex* sp. div. biconvex and trigonous, are recorded only as single occurrences. *Phragmites australis* is still abundant. The presence of *Cenococcum geophilum* is recorded. Charcoal and fragments of wood are found as well
Bu-6	20–60	Zone marked by infrequent remains of *Rorippa palustris*, Poaceae, and *Carex* sp. div. trigonous. Remains of *Phragmites australis*, sclerotia of *Cenococcum geophilum* and charcoal are found less frequently than in the preceding zone

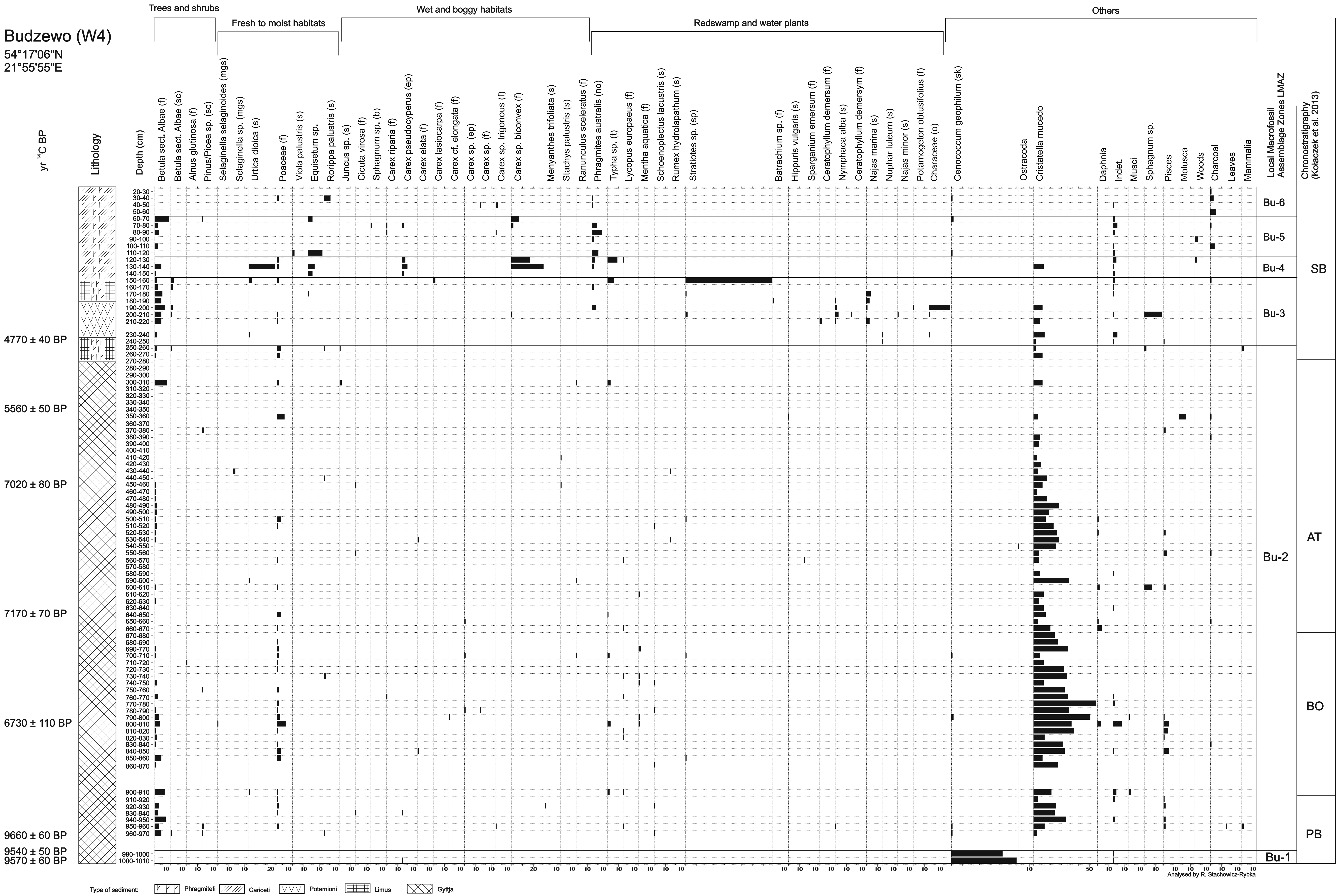

Fig. 6. Diagram of macrofossils from the Budzewo site

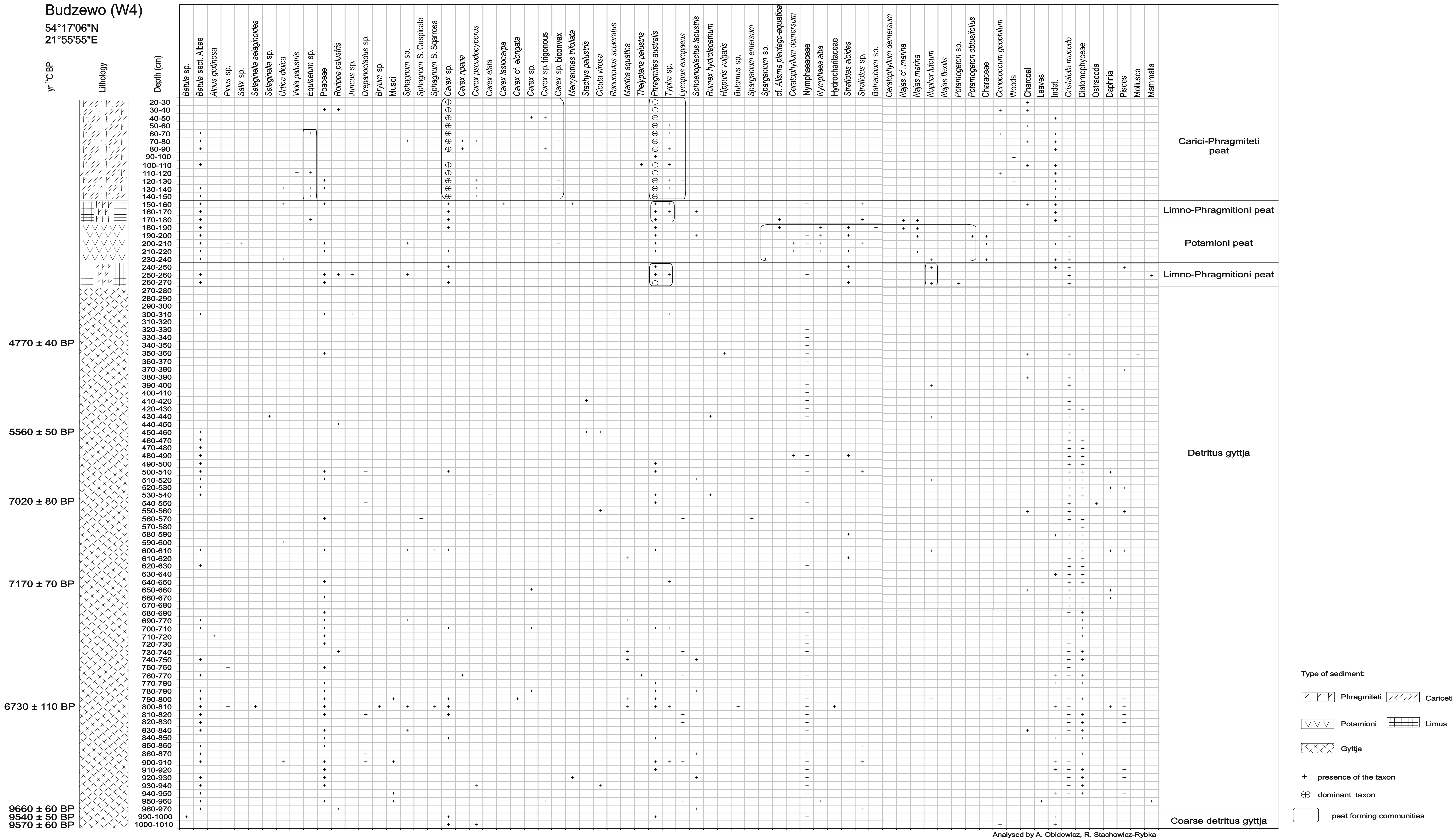

Fig. 7. Diagram of plant tissues in peat analysis and additional macrofossils from the Budzewo site

palustris, a heliophyte likely to indicate deforestation of the surroundings of the basin.

RAPA (W5)

The section of Rapa (54°17′47″N, 22°00′42″E) was obtained from a borehole drilled in a peat bog developed on the surface of the distal part of the alluvial fan, at the eastern end of the depression forming the Skaliska Basin (Fig. 1).

Lithology (depth in cm):

20–50 sedge (Cariceti) peat
50–70 alder swamp forest (Alneti) peat
70–90 reed (Phragmiteti) peat
90–150 swamp (Limno-Phragmitioni) peat
150–190 bulrush (Scirpo-Typheti) peat
190–230 alder swamp forest peat
230–240 bulrush (Scirpo-Typheti) peat
240–430 detritus gyttja
370–430 sand with an admixture of silt and peat

The record of sedimentation of lacustrine sediments in the Rapa section begins with sand with an admixture of silt and peat. The radiocarbon date of 11 330±60 BP and palynological studies (Kołaczek et al. 2013) indicate that the sedimentation of lacustrine sands of an aeolian origin was initiated within the period of Allerød and ended approximately in the middle of the Preboreal, as similarly in the section of Piotrowo-Ławniki. Zone Ra-1, covering this part of the profile, is marked by only infrequent plant macroremains. The top part is characterized by the appearance of remains of tree birches; capsules of *Sphagnum* sp. are relatively frequent. Among remains of animals, mollusc shells (Tab. 5), suggesting an abundance of calcium carbonate in the waters, are worthy of note.

Circa 9000±60 BP, when the plant cover in the area of the basin was dense enough to prevent the sedimentation of sands within the lake, a stratum of coarse-detritus gyttja was accumulated within the basal (430–370 cm) part of the bed of clay with an admixture of sand and humus. Fragments of tissues of vascular plants, growing on the lakeshore, are accompanied by fruits and fine fragments of tissues of macrophytes: *Stratiotes aloides*, *Nymphaea alba*, *Najas marina*, and *Najas* sp. (Fig. 8, zone Ra-2, Fig. 9). Occurrence of such taxa suggests that at that time the depth of the basin did not exceed 1.0–1.5 m. After the end of accumulation of gyttja, the increasingly shallow basin was invaded by swamp vegetation, represented mainly by *Typha* sp. and *Schoenoplectus lacustris*, which resulted in the deposition of the Scirpo-Typheti peat. This type of peat is not frequently described (Tobolski 2000), and within the study area it was recorded only in this section.

With the beginning of the Atlantic, the peat bog was colonized by *Alnus glutinosa*, and the dominance of its vegetative remains within the peat mass provides the basis for its definition as an alder peat. However, it cannot be described as an Alneti peat, as it is devoid of the species characteristic of the parent association of *Carici elongatae-Alnetum*. It cannot be

Table 5. Rapa (W5) – the description of the Local Macrofossil Assemblage Zones (L MAZ)

Local Macrofossil Assemblage Zones	Depth (cm)	Description
Ra-1	370–430	Single remains of tree birches and grasses are recorded. Statoblasts of bryozoan, *Cristatella mucedo*, remains of *Cenococcum geophilum* and charcoal were identified as well. Mollusc shells are very numerous
Ra-2	220–370	Remains of aquatic and swamp plants, such as *Najas marina*, *Potamogeton natans*, *P. perfoliatus*, *Nymphaea alba*, and *Schoenoplectus lacustris*, are the dominants. Remains of *Betula* sect. *Albae* are infrequent in this zone. The basal part contains statoblasts of C*ristatella mucedo* and fragments of fish skeletons
Ra-3	180–220	Zone characterized by infrequent remains of peat and swamp plants such as *Eleocharis palustris*, *Phragmites australis*, and *Schoenoplectus lacustris*
Ra-4	140–180	Remains of *Betula* sect. *Albae* and *Rubus idaeus* are the dominants. Among plants typical of nitrophilous habitats, *Urtica dioica* and *Polygonum* sp. were identified. *Carex* sp. div. biconvex, *Cicuta virosa*, *Mentha aquatica*, and *Phragmites australis* were found as well
Ra-5	70–140	Single remains of tree birches, *Solanum dulcamara*, *Equisetum* sp., *Carex* sp. div. biconvex, *Cicuta virosa*, and *Phragmites australis* were recorded in the zone
Ra-6	20–70	Renewed increase in the number of remains of *Betula* sect. *Albae*. *Equisetum* sp. *Carex* sp. div. trigonous and *Cenococcum geophilum* were also identified

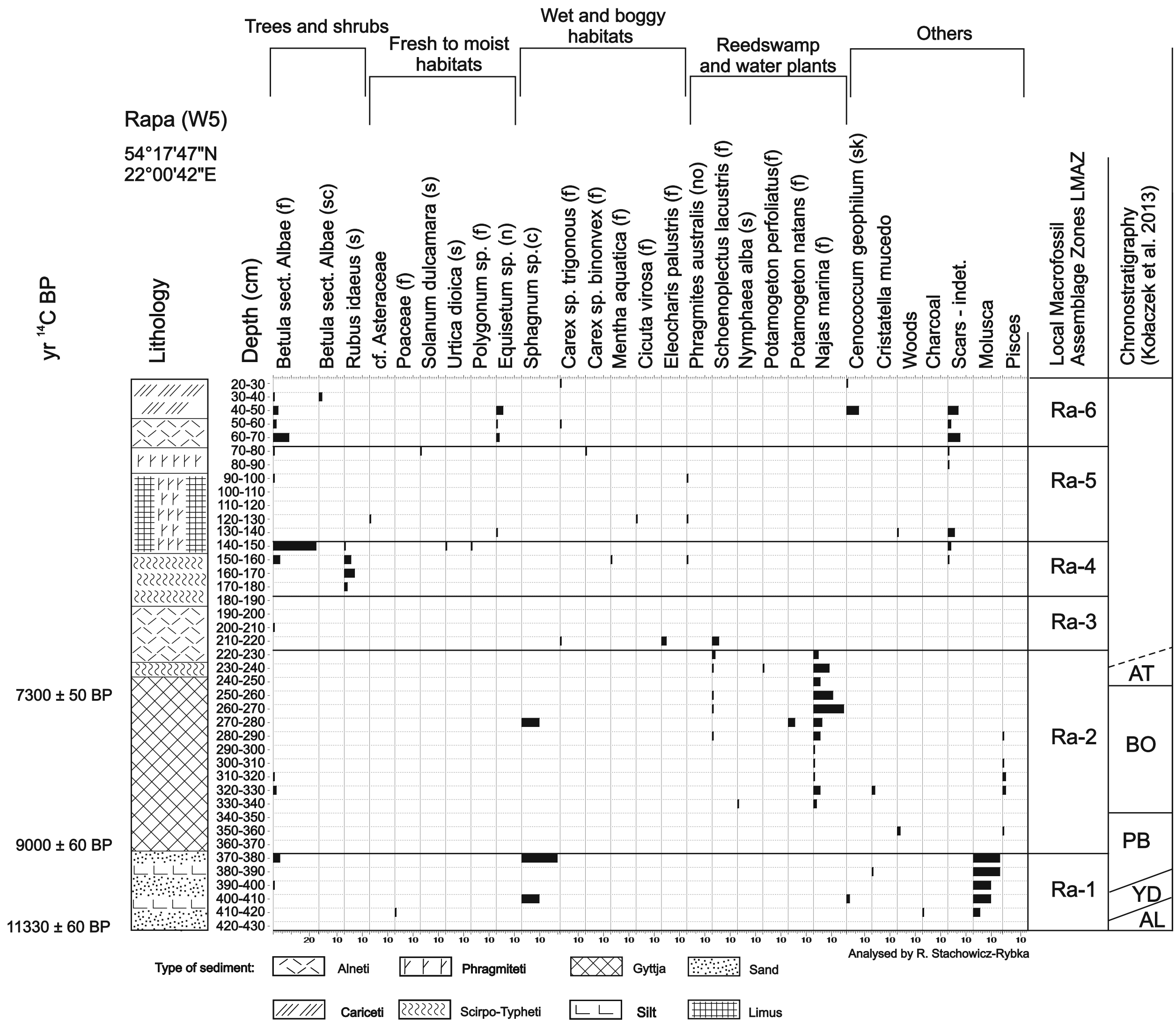

Fig. 8. Diagram of macrofossils from the Rapa site

excluded that the zone of swamp plants, previously forming the Scirpo-Typheti peat, was adjacent to a boggy alder forest, however, no additional drillings were performed in the surroundings of the section. The stratum of peat with *Alnus glutinosa* is overlain by a renewed accumulation of swamp peat, Scirpo-Typheti. Associations in which this kind of peat developed are found growing in deeper water within the littoral zone than other swamp communities. Therefore, the water level was limiting the growth of black alder. The previous suggestion of an adjacent zone of *Carici elongatae-Alnetum* is confirmed by the occurrence of infrequent vegetative remains of *Alnus glutinosa* and seeds of *Rubus idaeus*. The basin was still dominated by meso- or eutrophic conditions and the water level remained basically unchanged, however, the appearance of *Equisetum limosum* and an increase in the proportion of *Phragmites australis* justifies classifying the accumulated peat as Limno-Phragmitioni. The progressive terrestrialisation of the basin was promoted by development of a community dominated by *Phragmites australis*, beneath which Phragmiteti peat accumulated. The reoccurrence of *Alnus glutinosa*, this time with acompanied species of its association (*Solanum dulcamara* and *Helipterums palustris*), resulted in the deposition of the Alneti peat. The final stage of the development of peat bog is marked by the prevalence of sedge communities. Numerous radicells of *Carex* spp. were preserved but only small amounts of fruiting remains, so that the identification of the original communities was not possible.

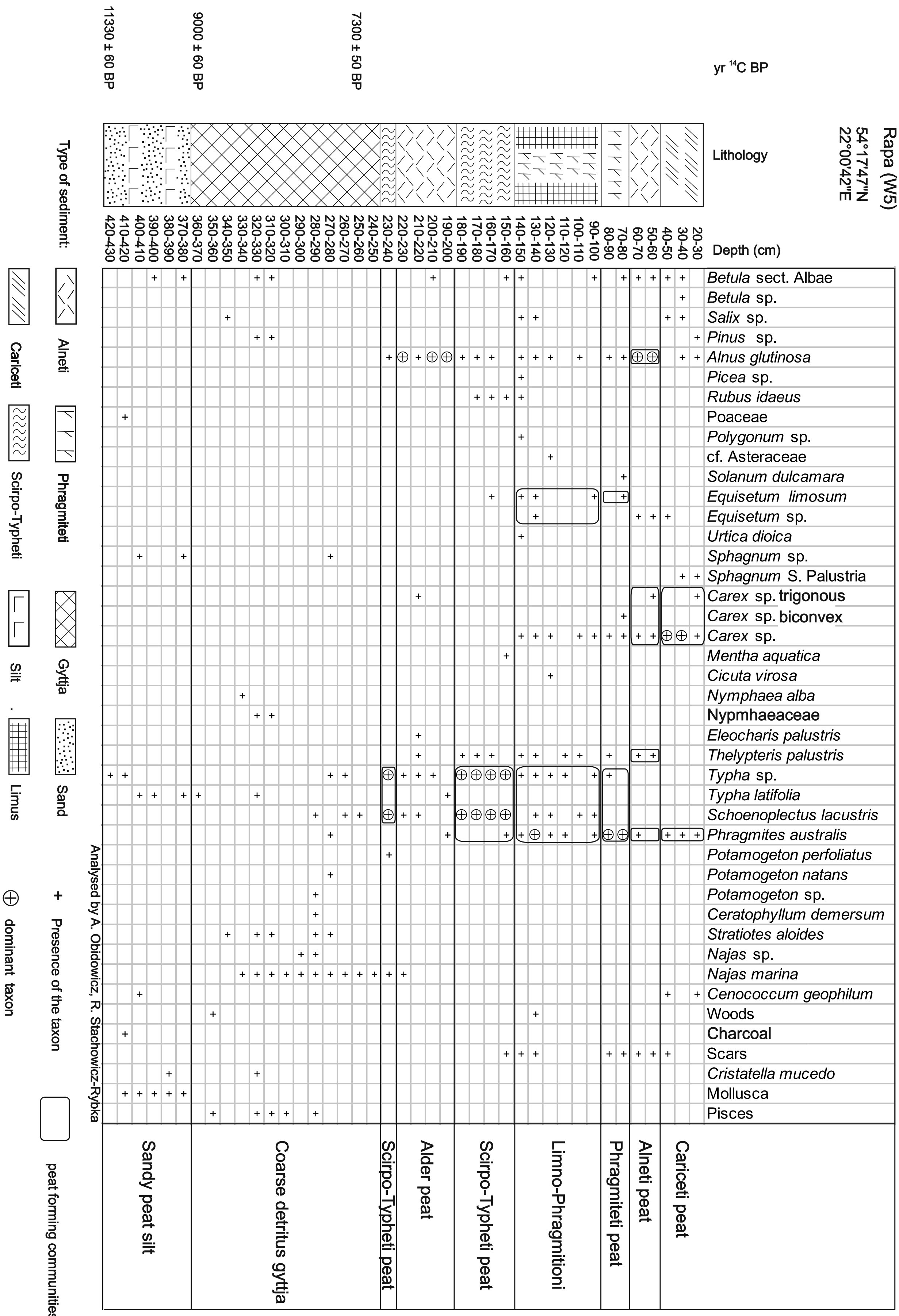

Fig. 9. Diagram of plant tissues and additional macrofossils from the Rapa site

PARCHATKA (W6)

The section of Parchatka (54°17′47″N, 22°00′42″E) was drilled in a peat bog, formed on the south-eastern part of the sandy fan, in the valley of a small watercourse, in the north-eastern part of the Skaliska Basin.

Lithology (depth in cm):

20–90	moss (*Sphagnum centrale*) peat
90–110	sedge (Cariceti) peat
110–150	sedge-moss (Bryalo-Parvocaricioni) peat
150–440	sedge (Cariceti) peat
440–520	coarse detritus gyttja
520–675	sandy detritus gyttja

Deposition of sediments within the Parchatka section was initiated in the Boreal, ca 8700±60 BP (Tab. 1). The first sediment deposited in this water basin was the sandy detritus gyttja, containing plant detritus of diverse origin and sand, washed or blown in from the surroundings. Therefore, it may be assumed that vegetation around the basin was of a low density. Minor amounts of remains of *Pinus sylvestris* indicate that this was the only tree found in the close surroundings of the basin. The classification of the sediment deposited at this stage as a coarse-detritus gyttja may be questionable, particularly if the definition by Bülow is applied, as the sediment is devoid of diatoms, idioblasts of Nymphaeaceae and carapaces of Cladocera. However, it comprises fruits and vegetative remains of *Cladium mariscus* and *Schoenoplectus lacustris*, providing evidence of a continuously high water level. From perturbations of pollen curves in the pollen diagrams, it may be concluded that the middle part of the zone of sandy detritus gyttja has been affected by sediment redeposition between 570–630 cm. This is supported by a radiocarbon date obtained from a depth of 620 cm, which gave a date older than the date obtained for the basal part of the section (9410±60 BP). This level with redeposition covers the base of zone Pa-2 (Figs 10, 11), nearly devoid of fruiting plant remains. With the progressive increase in density of tree stands surrounding the lake, the supply of sand was hindered, resulting in the accumulation of coarse-detritus gyttja.

Two zones are marked by the occurrence of trunks of *Alnus glutinosa*, most likely originating from the adjacent community. Additionally, in zone Pa-3, fruits of *Alnus glutinosa* were exceptionally abundant. The surroundings of the basin were also occupied by *Betula* sect. *Albae*, *Tilia cordata*, *Pinus sylvestris*, and *Salix* sp. Numerous occurrence of seeds and fruits of *Cladium mariscus*, *Schoenoplectus lacustris*, *S. tabernaemontani*, *Potamogeton natans*, and *Najas marina* (Tab. 6) suggests an increase in the trophic status of the basin and its gradual shallowing towards the upper part of the zone. Among remains of animals, the high proportion of mollusc shells indicates an environment abundant in calcium carbonate. From the depth of 440 cm, i.e. the top of zone Pa-3, accumulation of sedge peat is observed. As the abundance of sedge radicells was not accompanied by the presence of fruits or seeds, it was not possible to identify the associations that formed the peat. Zone Pa-4 (Fig. 10) bears a record of withdrawal of aquatic vegetation. The proportion of remains of trees is still high. Their composition is the same as in zone Pa-3 and indicates a fall in the water level. The subsequent zone, Pa-5, is marked by the occurrence of *Potamogeton natans* and *Ceratophyllum demersum*, implying a short-lasting rise in the water level. Above this zone, aquatic vegetation is not observed, therefore the zone records the end of lacustrine sedimentation. The subsequent stage of development of this depression was the deposition of sedge peat, as seen up to a depth of 150 cm, followed by a clear change in the composition of peat-forming communities. The surface of the peat bog became dominated by associations representing the class of *Scheuchzerio-Caricetea nigrae*, depositing a Bryalo-Parvocaricioni peat, then a 20-cm-thick stratum of sedge peat and finally developed into a short-sedge association in which *Sphagnum warnstorfii* occurred.

The uppermost 90 cm of the section is formed of peat with *Sphagnum centrale*, what demonstrates a significant change in the nature of the habitat. On the basis of 23 phytosociological surveys from peat bogs in the Bavarian Alps (Kaule 1973), the community of *Sphagnum centrale* was recorded, displaying features of a transition bog. Compared to this community, peat from the Parchatka section contains remains of the indicator species,

Carex spp. (the above mentioned alpine association includes *Carex elata* and *C. panicea*), and, occasionally, of *Menyanthes trifoliata*,

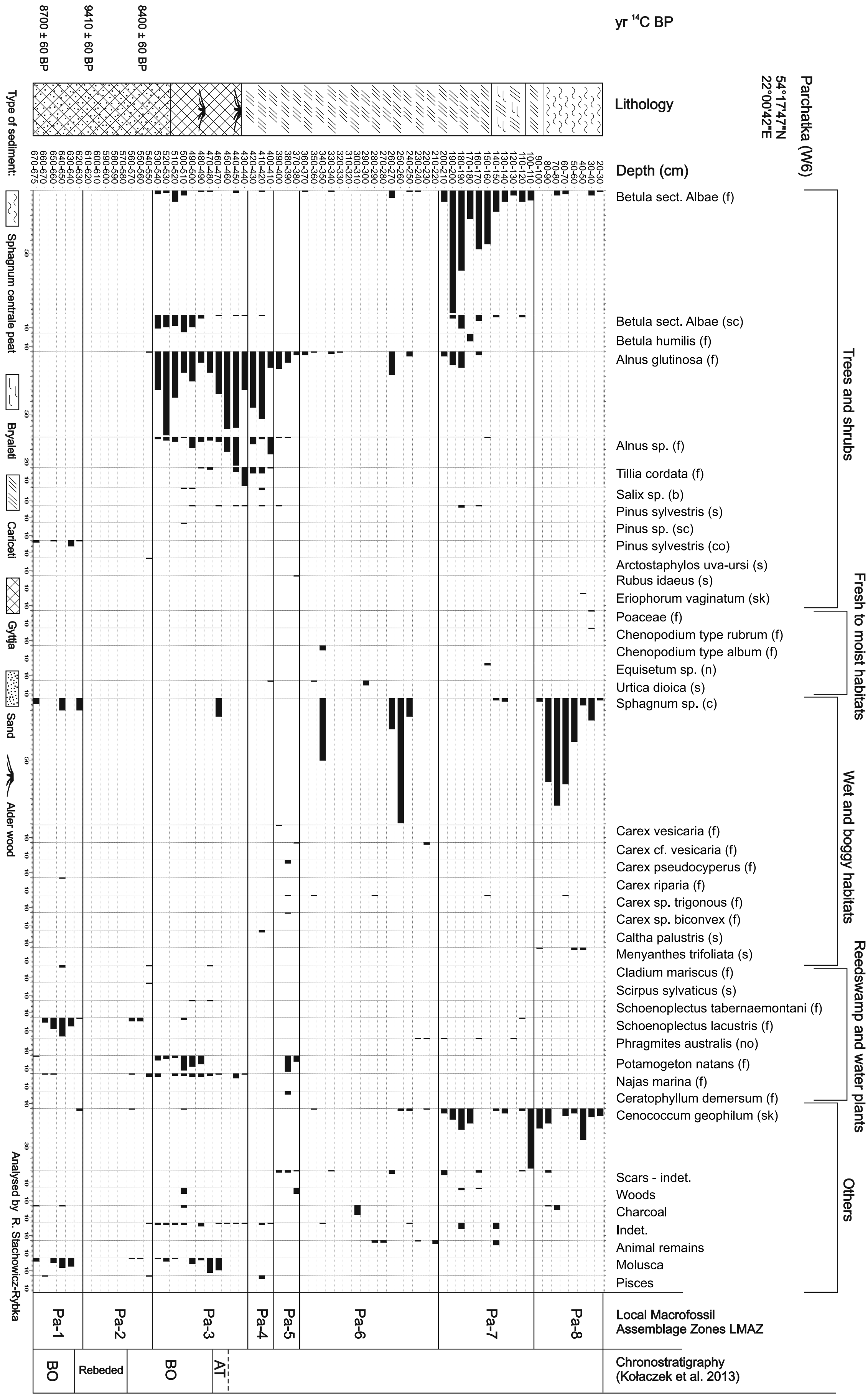

Fig. 10. Diagram of macrofossils from the Parchatka site

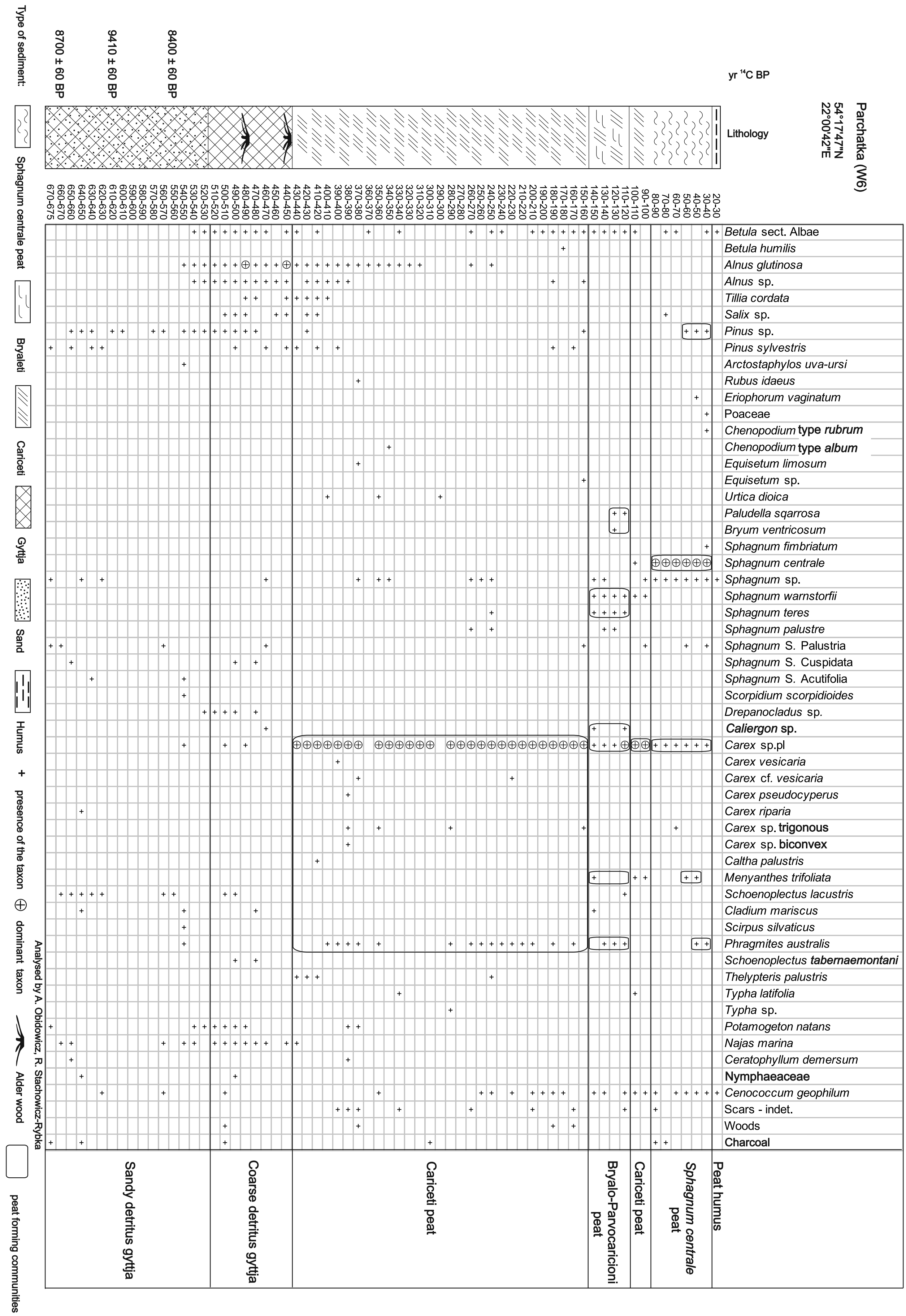

Fig. 11. Diagram of plant tissues and additifonal macrofossils from the Parchatka site

Table 6. Parchatka (W6) – the description of the Local Macrofossil Assemblage Zones (L MAZ)

Local Macrofossil Assemblage Zones	Depth (cm)	Description
Pa-1	600–675	Remains of swamp and aquatic plants, particularly of S*choenoplectus lacustris*, *Potamogeton natans*, *Najas marina*, and *Cladium mariscus*, are the dominants. Among trees, *Pinus sylvestris* was recorded. Mollusc shells are very numerous
Pa-2	540–620	No plant remains were found in the basal part of the zone. In the top part they are infrequent and marked by the dominance of swamp and aquatic plants such as S*choenoplectus lacustris*, *Scirpus sylvaticus*, and *Cladium mariscus*. *Alnus glutinosa* and the dwarf shrub *Arctostaphylos uva-ursi* were present
Pa-3	430–540	The lower boundary of the zone is marked by a clear increase in the amount of remains of *Betula* sect. *Albae* and *Alnus glutinosa.* The top of the zone contains also *Tilia cordata*, *Pinus sylvestris*, and *Salix* sp. Among aquatic plants, *Cladium mariscus*, S*choenoplectus tabernaemontani*, *S. lacustris*, *Potamogeton natans*, and *Najas marina* were determined. Mollusc shells were found abundantly
Pa-4	400–430	The zone is dominated by remains of trees and shrubs. *Alnus glutinosa*, *Tilia cordata*, *Betula* sect. *Albae*, *Pinus sylvestris*, and *Salix* sp. were identified. *Urtica dioica* and *Caltha palustris* were also present
Pa-5	370–400	Among trees and shrubs, *Alnus glutinosa* was still the dominant species. Remains of *Pinus sylvestris* and *Rubus idaeus* are also found. Peat plants, like *Carex vesicaria*, *C. pseudocyperus*, and *Carex* sp. div. biconvex & trigonous were recorded. Among aquatic plants, *Potamogeton natans* and *Ceratophyllum demersum* were identified
Pa-6	210–370	The lower boundary of the zone is marked by the last occurrence of aquatic plants. Among trees, remains of *Alnus glutinosa* and *Betula* sect. *Albae* were recorded. *Urtica dioica* and *Chenopodium album* were identified as well. Peat-forming plants included *Carex vesicaria*, *Carex* sp. div. trigonous, and bog mosses. Swamp plants were represented by *Phragmites australis*
Pa-7	100–210	Remains of trees such as *Betula* sect. *Albae*, *B. humilis*, and *Alnus glutinosa* are the dominants. *Pinus sylvestris* was found as well. Among peat plants, *Carex* sp. div. trigonous and bog mosses were recorded, while among swamp plants were *Phragmites australis* and *Schoenoplectus lacustris*. *Cenococcum geophilum* occurs abundantly in this zone
Pa-8	20–100	Amounts of *Betula* sect. *Albae* notably decrease. Remains of *Chenopodium rubrum*, *Eriophorum vaginatum*, and Poaceae were also determined. *Menyanthes trifoliata* appears in this zone. *Cenococcum geophilum* is still relatively abundant. In the basal part of the zone charcoal fragments were observed

Phragmites australis, and *Pinus* sp. Appearance of *Eriophorum vaginatum* confirms changes towards ombrotrophic conditions.

CONCLUSIONS

The macrofossil remains and plant tissues found in several sections from the Skaliska Basin (Fig. 12) area reflect the development history of local vegetation inhabiting small water basins. Despite numerous differences in the way of formation of particular basins, they also showed similarities. Their development was initiated in the Allerød, as in the Rapa section, and continued until the Subboreal, as in sections of Piotrowo-Ławniki, Skaliski Forest and Budzewo. These sections also represent the most complete successions. The Allerød (Rapa section) and Younger Dryas (Piotrowo-Ławniki section) were marked by sedimentation of lacustrine sands of an aeolian origin, proceeding up to ca the middle of the Preboreal.

Except for sections of Budzewo and Skaliski Forest, thaw basins were initially a site of deposition of sand with an admixture of silt and peat. In the Piotrowo-Ławniki section, sands are overlain by a sediment with strongly decomposed lacustrine dy, containing over 80% of humic matter, while in the Budzewo section – by detritus gyttja with an admixture of dy. Subsequently, sequences of detritus gyttja were accumulated, the thickness of which fluctuates between 720 cm and 95 cm. The complex of gyttjas is very occasionally interbedded with Scirpo-Typheti peats. Sedimentation of lacustrine sediments is followed by the accumulation of peats, formed by tall-sedge communities. These communities, considering their composition, correspond to the associations of *Cicuto-Caricetum pseudocyperi* Boer. & Siss. and *Caricetum elatae* Koch. Only in the section of Parchatka, however, are found uppermost deposits comprising of peats whose origins resemble the present-day community of *Sphagnum centrale*, displaying features of

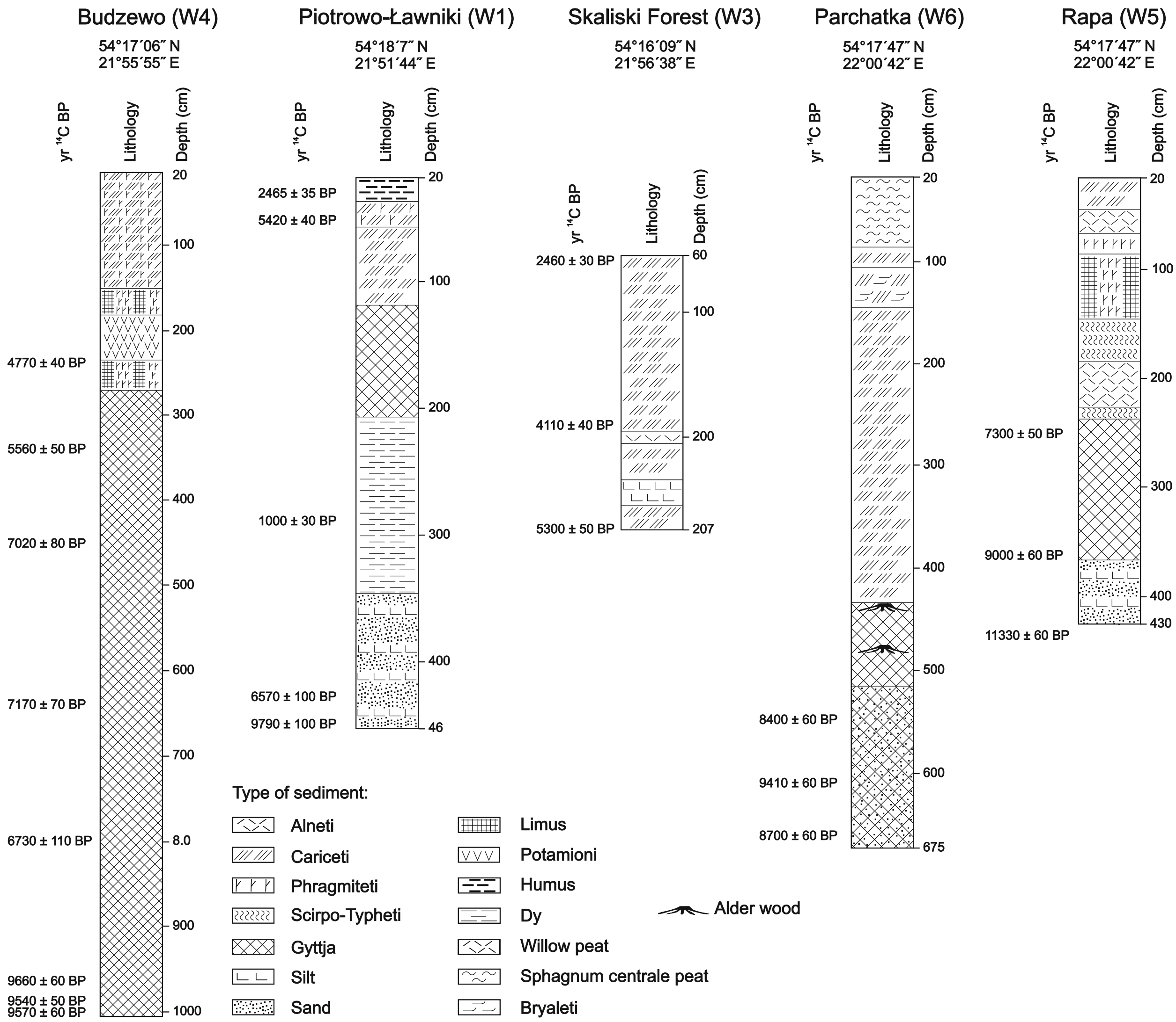

Fig. 12. Correlation diagram for the Skaliska Basin

a transition bog. The occurrence of *Eriophorum vaginatum* in this section also confirms changes towards ombrotrophic conditions. The uppermost part of the sections often consists of strongly decomposed peat, the origin of which must be associated with strong fluctuations in water level that accompanied peat development and with land improvement, conducted in the area for many years.

The investigated sites did not include taxa indicating human activity in the immediate surroundings of the basin. Exclusively, the two last zones of the section from Budzewo are characterized by an increase in the amount of charcoal, with zone Bu-6 by a decrease in the proportion of tree remains. However, the presence of the heliophyte *Rorippa palustris*, may indicate deforestation of the surroundings of the basin.

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