Bulletin of Geography. Physical Geography Series, No. 8 (2015): 81–93
http://dx.doi.org/10.1515/bgeo-2015-0007

Authigenic and allogenic organic remains as an indicator of geomorphological process activity within the floodplain environment: two case studies from Racibórz Basin, southern Poland

ISSN 2080-7686

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Abstract. Distinction between organic components accumulated *in situ* and those deposited by sedimentation is essential for the assessment of the intensity and extent of impact of geomorphological processes. Authigenic components include moss remains, fragments of the root systems of herbaceous plants and trees, the epidermis of rhizomes, and leaf sheaths, as well as a fungal mycelium. Among the allogenic components are aboveground parts of plants, including leaves of vascular plants, wood, epidermis and periderm, sporomorphs, sporangia, fruits and seeds, as well as zooclasts and protist remains. Microscopic grid analysis allows the share of individual morphological forms of organic matter to be determined in order to reconstruct the deposition conditions on the floodplain. This method makes it possible to detect episodes of activity of fluvial, aeolian and slope processes even when not accompanied by sedimentation of mineralogenic components.

Key words
biogeomorphology,
organic deposits,
macrofossil analysis,
Odra River basin

Introduction

Organic deposits are a valuable archive of the environmental change record. The composition and degree of decomposition of plant and animal remains reflect both habitat conditions at the time of their deposition and post-accumulation sediment changes. According to the Tauber model (1965), as modified by Brown (1996), organic remains deposited in the floodplain sediment may represent an authigenic component (generated where it is found) or an allogenic component (transported and deposited by geomorphological agencies such as gravity, water and wind). The latter may consist of local, regional and long-distance transport components. The local component (including the remains of components of herbaceous plants, canopy and trunks) is usually supplied gravitationally with the participation of wind. Also, regional and long-distance transport components (mainly pollen) are deposited by precipitation from the atmosphere. Flowing water may supply all of the aforementioned components, with the addition of organic matter eroded from soils. In research practice, it is not always possible to identify the alimentation zone for the material deposited. Fortunately, to solve most geomorphological issues it is sufficient to determine whether the matter is authigenic or allogenic in origin. Remains accumulated *in situ* may be treated as indicators of the periodic inhibition of transport and deposition processes on the floodplain. On the other hand, the sedimentation of organic detritus can be connected with episodes of intense erosion and sediment transportation.

Despite its signalled scientific potential, the issue of the genesis of organic remains has not so far attracted proper attention in paleoenvironmental studies. This is partly due to the lack of a generally-accepted research methodology to allow the variability of organic matter composition to be characterised. Sedimentological studies traditionally use the symbol [C] to describe all organic deposits, irrespective of their genetic variability: even the most general proposals for the division of these deposits into the organic sediments from suspension [O] (Brierley 1991) or peat [Cp] (Krzyszkowski 1996) have not been adopted. As a result, organic deposits are treated as an indicator of "depositional quiet" on the floodplain, even if the organic remains were delivered by flood or slope processes. This article aims to show the potential of studies on the genesis of organic remains in the reconstruction of fluvial, aeolian and denudation processes in river valleys. The study, carried out in the upper Odra River basin, aims to identify forms of organic matter in river valleys and correlate individual morphological forms of organic matter with the processes of accumulation *in situ* or sedimentation.

Study Area

The morphological and genetic diversity of organic matter accumulated in the floodplain environment of a meandering river will be presented with the example of two research sites in the upper Odra River basin.

The Sławięcice 1 site (50°22'37"N, 18°19'47"E), situated in the lower reach of the Kłodnica valley (Fig. 1), has a sedimentary record of geomorphological processes in the distal zone of the floodplain. These fragments of the valley floors were originally formed by a sinuous river from the Late Vistulian to the middle Holocene. As a result, what predominate in the distal zone of the Kłodnica and Osobłoga valleys are sand-bed meandering rivers, featuring lateral bars built of up to 3 m upward-fining (from gravelly sand to silty sand) alluvial series(Wójcicki 2006, 2010). In the second order, a large area within the distal floodplain is occupied by organic plains developed in former oxbow lakes. The oldest organic deposits in palaeochannel fills date to the turn of the Older Dryas and Allerød (11780 ± 120 ^{14}C BP) in the Osobłoga valley and to the turn of the Allerød and Younger Dryas (10850 ± 310 ^{14}C BP) in the Kłodnica valley (Wójcicki 2006). According to pollen analysis and ^{14}C dating, the biogenic accumulation at the Sławięcice 1 site began in the Preboreal phase of the Holocene (Nita, Wójcicki 2005). Generally, organic deposition dominated in the oxbow environment throughout the older phases of the Holocene. According to this model, the palaeomeander at the Sławięcice 1 site is filled with organic sediments with relatively little mineral admixture (Fig. 2). This suggests that, for about 10 000 years of its history, the site was situated outside the transportation and sedimentation zone. Alternatively, the inundation waters reaching this part of the valley floor were already devoid of mineral suspension load. Distinct evidences for the intensification of denudation processes in the studied floodplains come from the Subatlantic Phase. In this period, at the foot of the loess plateau in the Kłodnica valley (Fig. 1A), progradation of alluvial fan sediments (massive sandy silt) started. The oldest evidence of gully erosion is dated to more than 2240 ± 100 ^{14}C years BP at the Ujazd/ /Zandrzyny site (Fig. 1B), which corresponds to the decline of the Lusatian culture settlement (Klimek 2003). Additionally, at the foot of outwash plains and Pleistocene terraces, sandy deposits accumulated as a result of slopewash processes. The initiation of these processes was dated between 1340 ± 50 ^{14}C years BP at the Krapkowice 1 site in the Osobłoga valley (Fig. 3B), and 720 ± 60 ^{14}C years BP at the Las Czajka site (Fig. 1B) in the Kłodnica valley. At the Sławięcice 1 site, sedimentation of sandy deposits from the nearby slopes began in the early Medieval Ages (1305 ± 70 ^{14}C years BP). Through the late Holocene, the distal floodplains of the Kłodnica and Osobłoga Rivers were located outside the zone of overbank sedimentation due to the remoteness and incision of the active channel (Wójcicki 2006).

The Steblów 2 site (50°27'06"N, 17°57'32"E) is located within a small palaeomeander in the lower reach of the Osobłoga valley (Fig. 3). Its history documents the development of geomorphological processes within the proximal floodplain during the late Holocene. At that time, a system of inset terraces in the Kłodnica and Osobłoga valleys was formed. In the Subboreal, and especially in the Subatlantic period, there was an increase in activity of fluvial processes, including active channel incision and intensive sedimentation of vertical accretion deposits. As a result, the thickness of overbank facies may exceed 1 m locally. The flood sediments

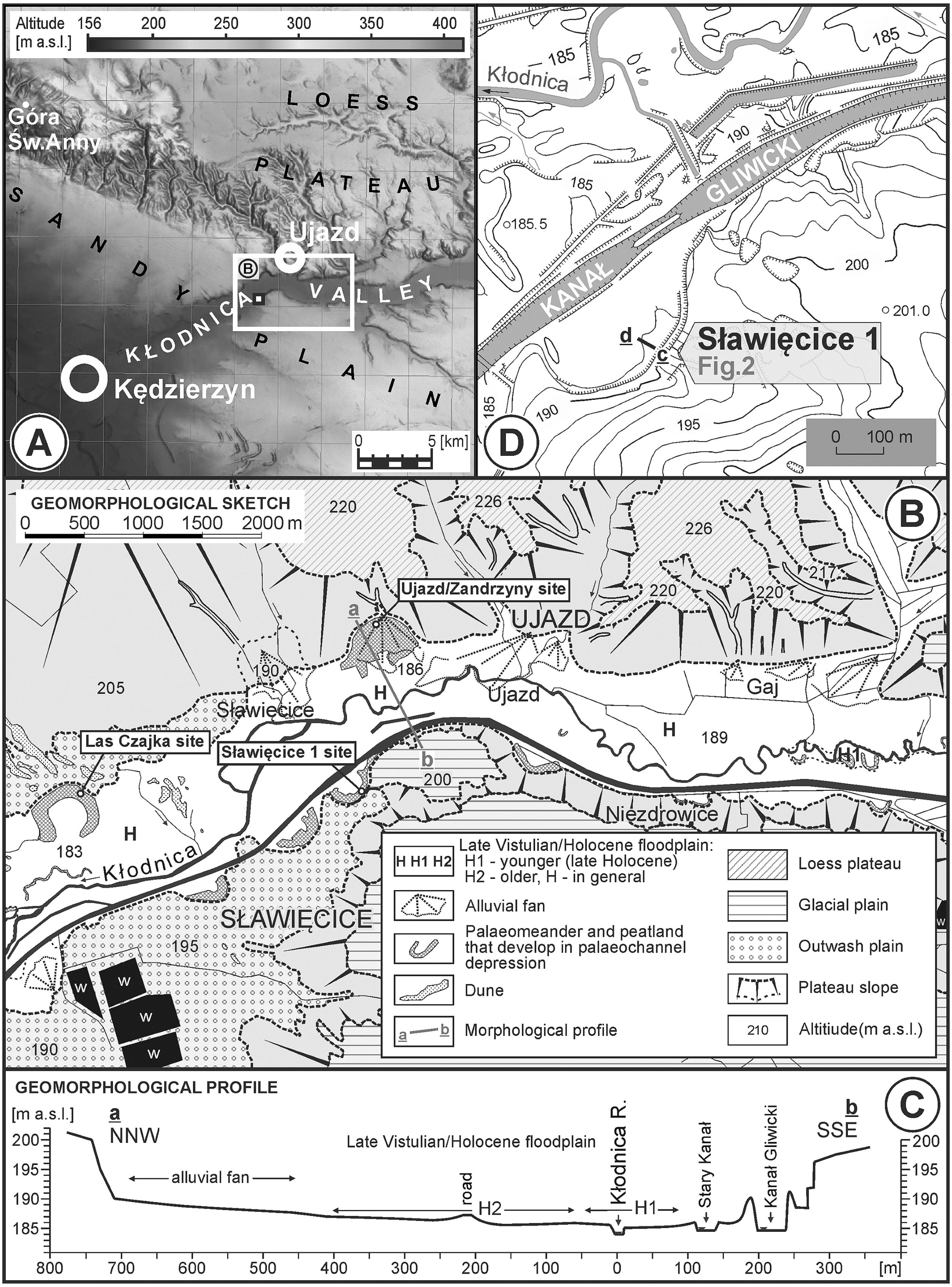

Fig. 1. Location of the Sławięcice 1 site: A – situation of the lower Kłodnica River valley; B – geomorphological sketch of the valley reach studied; C – cross-profile through the valley; D – topography of the site area

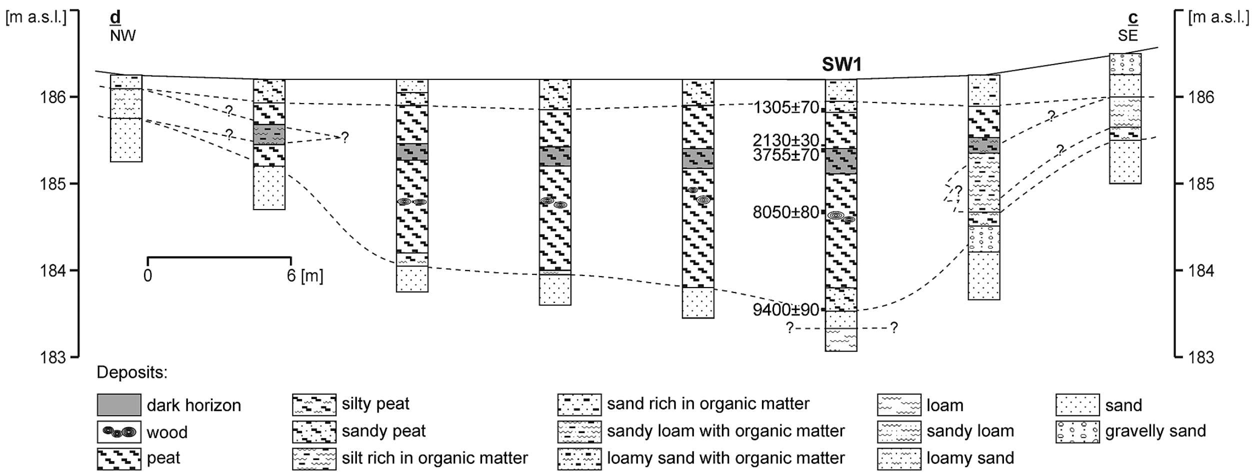

Fig. 2. The Sławięcice 1 site: geological cross-section

(fine sand to sandy mud) are usually poorly sorted, normally graded and massive or rhythmically stratified. They commonly consist of organic-rich layers with organic detritus and charcoal (Wójcicki 2006, 2010). According to this scheme, the oxbow at the Steblów 2 site is filled with mineral-organic sediments (Fig. 4) with relatively low organic matter content. The constant presence of mineralogenic components in the core indicates that the accompanying organic remains might have been deposited by flood waters. The results of ^{14}C dating show that the oxbow began filling up between 359 BC and AD 133 and the sedimentation of components of almost exclusively abiotic origin is recorded from the early Medieval Ages (Wójcicki 2013).

Methods

For both sites, geological cross-sections were prepared and material for laboratory analyses was collected in the thalweg zone of the paleomeanders. The relative content of organic matter to abiotic components was identified by the loss on ignition method. The key element to this publication was the application of the microscopic grid method to identify the forms of organic matter and the participation of various morphological groups in the total volume of the organic components. The sediment samples of 10–15 cm^3 were soaked in distilled water, crumbled and stirred until the different types of organic remains were evenly dispersed. The suspension was used to prepare a minimum of three samples, each of which was analysed in three selected, representative fields of view of an optical microscope (at magnifications of 40× to 400×). The first stage relied on a comprehensive analysis of the content of different types of organic components. The proportions of amorphous matter to preserved plant remains (phytoclasts), animal remains (zooclasts) and fragments of fungal thalli were determined. At this stage the percentage participation was estimated of only the smallest fractions, such as sporomorphs and the remains of protist organisms. The estimation of the contents of the above-mentioned groups of organic matter was carried out in a field of view of 4 mm^2 divided into a grid of 49 squares (Tobolski 2000). Finally, the samples were rinsed in water on a 0.2-mm mesh sieve to remove humic substances and fine-fraction components of both organic and mineral origin. In the case of the presence of larger carpological finds (e.g. strobili), their share was estimated in relation to the volume of the remaining organic matter at this stage. After washing the samples, the microscopic grid method was used again, this time to determine the share of individual types of phytoclasts, zooclasts and thallus fragments. When determining the origin of the organic remains, the author used the identification key, iconographic material and photographs found in publications such as the following: Kac et al. (1977), Schweingruber (1990), Tobolski (2000), Fairbairn (2001), Cappers et al. (2006), Mazei and Tsyganov (2006) and Szeroczyńska and Sarmaja-Korjonen (2007).

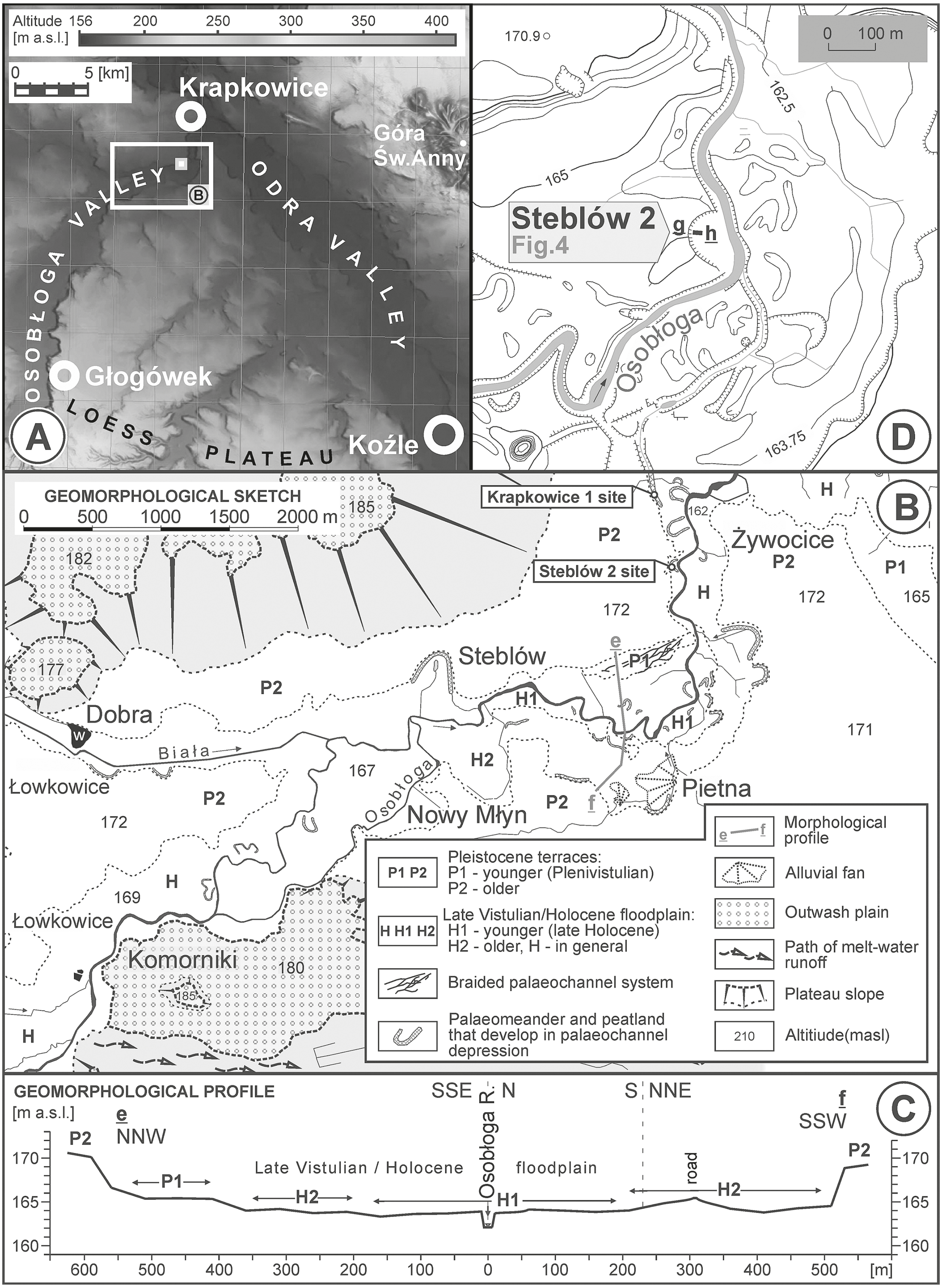

Fig. 3. Location of the Steblów 2 site: A – situation of the lower Osobłoga River valley; B – geomorphological sketch of the valley reach studied; C – cross-profile through the valley; D – topography of the site area

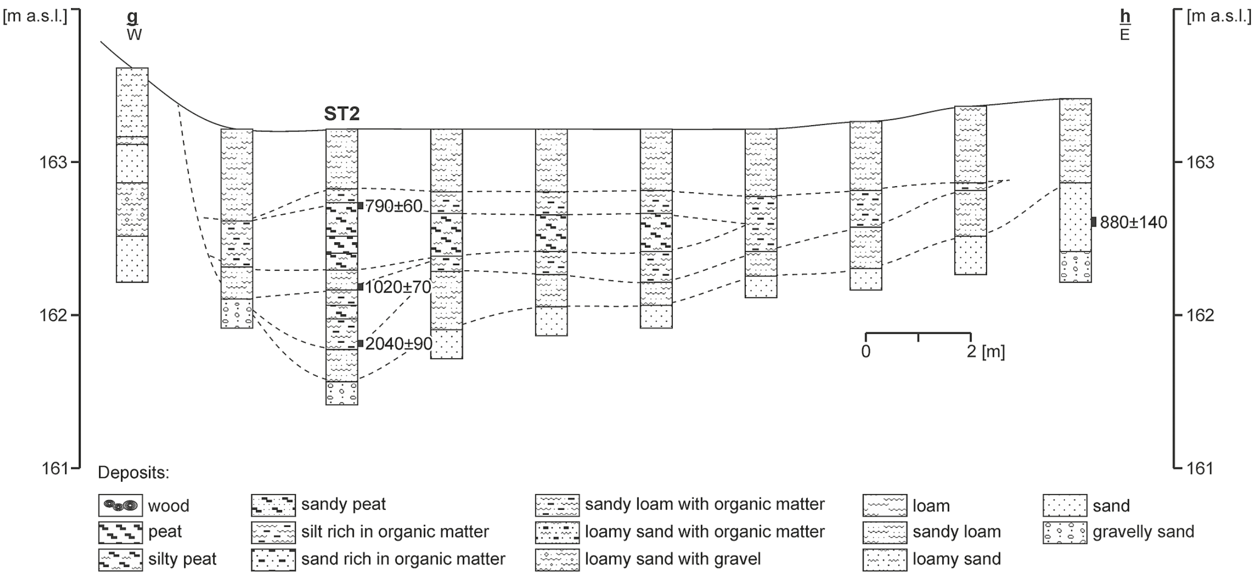

Fig. 4. The Steblów 2 site: geological cross-section

Results

By applying the microscopic grid method and with reference to the system of Troels-Smith (1955), the groups of biocomponents in peat and lake sediments (Tobolski 2000) and the classification used in the palynofacial analysis of the sediments from the valley of the Seine River (Sebag et al. 2006), the following forms of organic matter were recognized:

1. **Amorphous organic matter** (Fig. 5A)**:** crumbled amorphous material of vague outline and obliterated cellular structure. Thanks to its intense, dark colour the matter can be distinguished from grey or yellowish-grey components of mineral or mineral-organic origin.
2. **Phytoclasts:** plant organs or their parts with at least partially visible cell structure, which can be divided into:

2.1. Charred phytoclasts (Fig. 5B)**:** opaque, black forms, and (contrary to the amorphous substance) with clear outline and recognisable cellular structure.

2.2. Preserved phytoclasts: vegetative and generative plant organs at different stages of fragmentation and decomposition. The vegetative phytoclasts can be divided into moss (morphological group 2.2.1), herbaceous (morphological groups 2.2.2, 2.2.3 and 2.2.4) and wood components (morphological groups 2.2.5 and 2.2.6):

2.2.1. Leaves and stems of mosses (Fig. 5C, D)**:** leaves most often composed of a single layer of cells that can be differentiated into the chlorophyllose and hyaline cells (Sphagnopsida), without leaf veins but often with a costa or two costae (Bryopsida).

2.2.2. Large leaves of vascular plants (Fig. 5E)**:** usually larger than 5 mm in length, composed of two to several layers of cells with parallel venation (needles of conifers or leaves of submerged aquatic plants) or netted venation (leaves of floating aquatic plants or terrestrial plants).

2.2.3. Non-woody roots and rhizomes (Fig. 5F)**:** elongated, narrow, generally cylindrical forms, branched or without branching.

2.2.4. Epidermis (Fig. 5G, H)**:** flat pieces with a distinct cellular structure built of one to several layers of cells; transparent and uniformly coloured.

2.2.5. Periderm (Fig. 6A)**:** flat fragments with a distinct cellular structure composed of several layers of cells; at least partially opaque with unevenly coloured cells (periderm of trees, bushes and shrubs).

2.2.6. Wood (Fig. 6B)**:** jagged pieces, translucent at the edges, with characteristic rays in the radial and tangential sections.

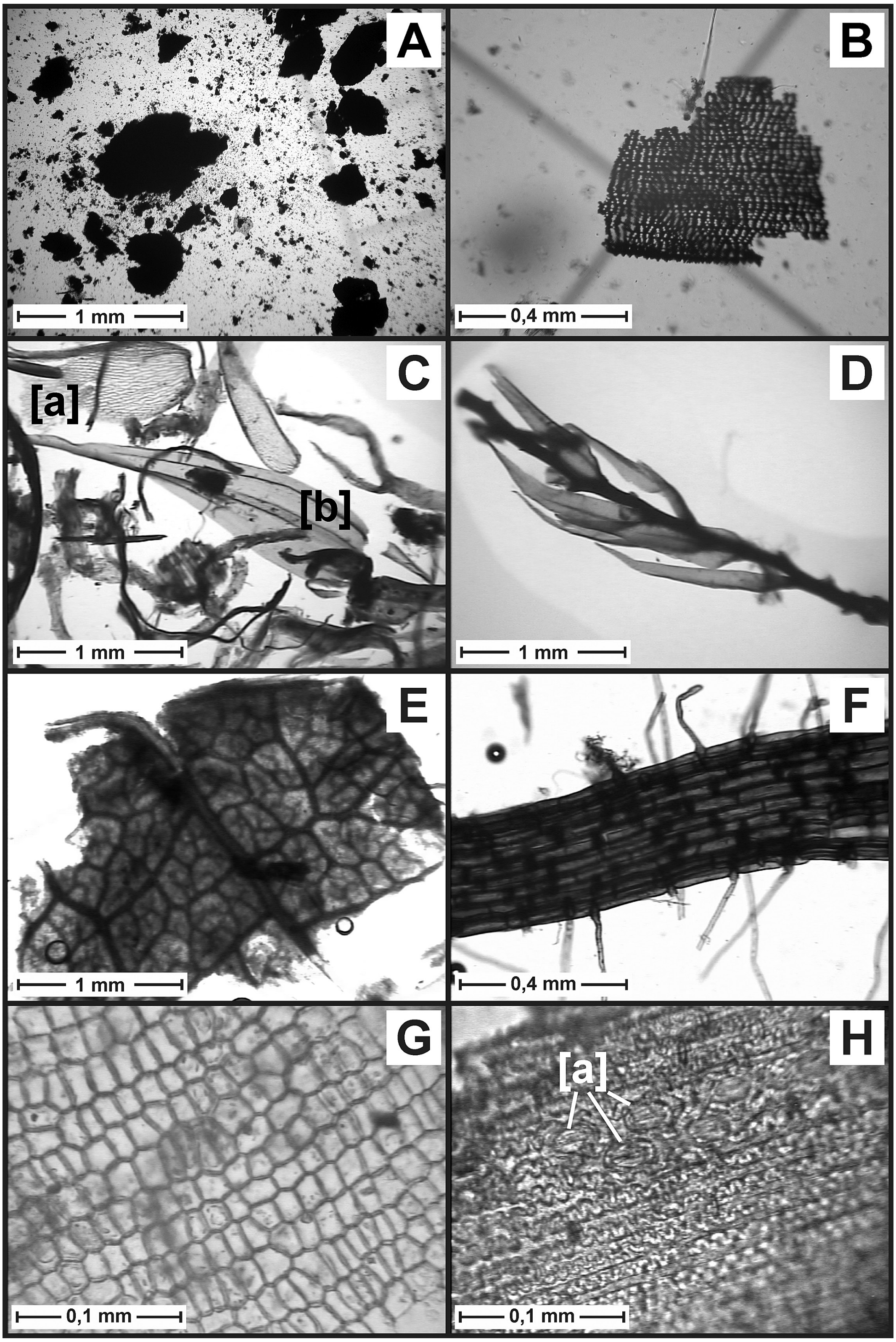

Fig. 5. Morphological forms of organic matter recognized in deposits of the Sławięcice 1 and Steblów 2 sites: A – amorphous organic matter – Sławięcice 1; B – charred phytoclasts (charcoal) – Sławięcice 1; C – mosses: a comparison of branch leaves of peat moss (*Sphagnum*) [a] and true moss (*Tomentypnum nitens*) [b] – Sławięcice 1; D – mosses: the leafy stem of *Drepanocladus sendtneri* – Steblów 2; E – a fragment of leaf (unidentified vascular plant) – Steblów 2; F – a little root of *Equisetum* – Sławięcice 1; G – epidermis (*Potamogeton*) – Steblów 2; H – epidermis with stomata [a] (cf. *Calamagrostis canescens*) – Sławięcice 1

2.2.7. Sporangia, fruits and seeds (Fig. 6C, D)**:** regular-shaped forms, usually with a distinct cellular structure.

2.2.8. Sporomorphs (Fig. 6E)**:** fossil pollen grains and spores.

3. Zooclasts: animal remains at different stages of fragmentation and decay, rather common in the sediments, albeit usually in small amounts. In the sediments of the analysed oxbow lakes the following fossils have been identified:

3.1. Chitinous exoskeletons and "survival pods" (Fig. 6F)**:** hyaline heads and carapace of arthropods (Cladocera, Chironomidae) as well as brown ephippia of Cladocera and bryozoan statoblasts.

4. Fungal thallus (Fig. 6G)**:** the most common findings of this type include the thread-like hyphae (mycelium) that are usually in the form of branching hyaline or brownish filaments, sometimes ending with a spherical sporangium.

5. Protist remains: according to the system of Whittaker (1969), this group includes the remains of eukaryotes, excluding organisms with monophyletic clades of animals, plants and fungi. In the deposits of one of the sites in the Osobłoga valley, the remains of siliceous organisms were identified in this group:

5.1. Silica shells (Fig. 6H)**:** diatom shells saturated with silica as well as coverings of testate amoeba built of quartz grains.

The use of the microscopic grid method allowed the observation of the varied proportions of components in the studied cores.

In the SW1 core the following series of deposits with an organic component were distinguished (Fig. 2, Table 1):

- 25–38 cm highly-decomposed sandy peat with roots and epidermis of herbaceous plants;
- 38–108 cm highly-decomposed peat with similar shares of tree remains (wood and periderm) and remnants of herbaceous plants (roots and epidermis);
- 108–138 cm poorly-decomposed peat with a high content of wood, roots and epidermis of herbaceous plants;
- 138–150 cm poorly-decomposed peat with a high proportion of vertically-oriented wood;
- 150–162 cm detritus sediment with horizontally-oriented wood;
- 162–200 cm moderately-decomposed peat with a predominance of roots and epidermis of herbaceous plants with the participation of wood;
- 200–240 cm moderately-decomposed peat with the dominance of herbaceous plant remains;
- 240–267 cm poorly-decomposed sandy peat with a high proportion of mosses and herbaceous plant remains.

In the ST2 core the following layers were delimited (Fig. 4, Table 2):

- 39–48 cm loam containing roots and epidermis of herbaceous plants as well as relatively numerous charred phytoclasts;
- 48–60 cm moderately-decomposed loamy peat dominated by vertically-arranged wood;
- 60–70 cm poorly-decomposed loamy peat with a high content of wood as well as roots and epidermis of herbaceous plants;
- 70–81 cm moderately-decomposed peat dominated by remains of herbaceous plants;
- 81–115 cm loamy peat and loam with organic substance (mainly wood, some roots and epidermis of herbaceous plants);
- 115–165 cm loamy peat, downwards turning into loam with organic matter and sandy loam with remains of herbaceous plants, mosses, large leaves and chitinous exoskeletons of Cladocera and Chironomidae, as well as silica shells of diatoms and testate amoebae.

Discussion

Bioindicators of authigenic and allogenic deposition

The distinction between organic components accumulated *in situ* and those resulting from sedimentation is essential for the assessment of the intensity and extent of the impact of geomorphological processes. Traditionally, moss remains and fragments of root systems of herbaceous plants are listed among the reliable bioindicators of authigenic deposition (Tobolski 2000). However, when a floating mat develops on the surface of the water, its detached fragments (formed from the remains of moss and roots of herbaceous plants) can be redeposited on the reservoir bottom (Kowalewski 2009). Furthermore, there are interpretational problems connected with

Table 1. The Sławięcice 1 site – morphological composition of organic matter

SW1 core		Organic matter composition [%]										
				Preserved phytoclasts							Zoo-clasts	Fungi
Depth [cm]	Loss on ignition [%]	Amorphous organic matter	Charred phytoclasts	Leaves and stems of mosses	Nonwoody roots and rhizomes	Epidermis	Periderm	Wood	Sporangia, fruits and seeds	Sporomorphs	Chitinous exoskeletons and "survival pods"	Mycelium and sporangia
25–38	52.7	70.9	1.9	0.8	12.5	8.4	2.2	2.7	0.5	0.1	–	–
38–50	66.5	40.2	0.6	2.3	12.9	14.6	11.1	17.5	0.4	0.3	–	0.1
50–64	83.3	59.5	0.3	–	10.2	11.0	7.5	10.6	0.1	0.7	–	0.1
64–79	81.7	64.9	0.3	–	9.6	8.2	9.3	6.9	0.5	0.3	–	–
79–94	80.0	81.8	1.2	–	5.6	3.6	3.0	4.6	0.2	–	–	–
94–108	83.2	57.6	1.2	–	10.6	8.6	4.1	17.5	0.2	0.2	–	–
108–125	86.6	25.1	1.4	3.6	19.3	15.0	6.4	27.2	1.1	0.9	–	–
125–138	85.8	29.4	0.4	7.5	21.2	11.7	7.5	20.6	1.1	0.3	0.3	–
138–150	86.9	28.6	0.4	0.6	15.9	6.9	8.3	38.1	0.3	0.2	0.7	–
150–162	82.1	42.4	1.1	0.6	8.4	2.8	1.1	43.3	–	0.3	–	–
162–175	75.3	41.3	0.3	2.8	22.1	10.2	7.9	13.6	0.8	0.7	0.3	–
175–188	73.2	38.3	0.4	4.2	20.9	12.5	6.6	14.9	0.7	0.7	0.8	–
188–200	64.3	35.6	0.3	6.3	23.7	11.3	6.3	13.2	0.8	1.2	1.3	–
200–220	67.8	37.7	0.1	7.9	29.7	12.1	3.0	6.1	0.6	1.5	1.3	–
220–240	77.7	34.6	0.3	8.8	30.3	12.0	3.2	6.3	1.3	1.8	1.4	–
240–254	61.4	29.4	0.3	29.8	18.0	16.6	1.4	1.4	0.4	0.6	2.1	–
254–267	59.8	27.6	–	32.7	17.7	12.0	3.5	1.4	2.0	0.3	2.8	–

Table 2. The Steblów 2 site – morphological composition of organic matter

ST2 core		Organic matter composition [%]												
				Preserved phytoclasts								Zoo-clasts	Fungi	Pro-tists
Depth [cm]	Loss on ignition [%]	Amorphous organic matter	Charred phytoclasts	Leaves and stems of mosses	Leaves of vascular plants	Nonwoody roots and rhizomes	Epidermis	Periderm	Wood	Sporangia. fruits and seeds	Sporomorphs	Chitinous exoskeletons and "survival pods"	Mycelium and sporangia	Silica shells
39–48	24.1	43.8	3.1	0.8	0.5	20.2	19.2	7.3	1.6	2.1	0.2	0.7	0.5	–
48–60	37.9	31.5	0.7	0.7	–	8.0	8.0	2.7	46.8	0.5	0.2	0.7	–	0.2
60–70	39.2	26.8	5.4	1.3	2.0	14.1	14.1	2.0	31.5	1.3	0.2	0.9	–	0.4
70–81	54.2	42.9	1.1	1.9	3.2	14.5	17.2	1.6	11.8	1.6	0.6	2.2	–	1.4
81–92	47.5	36.7	2.3	2.9	1.7	10.5	10.5	4.1	26.8	1.2	0.7	1.0	–	1.6
92–105	14.4	35.8	3.5	4.7	4.1	9.4	6.5	3.5	28.2	0.3	0.6	2.4	–	1.0
105–115	31.8	38.2	1.8	5.3	5.3	10.6	7.6	1.2	24.1	2.3	0.5	2.3	–	0.8
115–124	41.0	41.0	–	17.1	5.4	14.5	9.1	–	1.6	0.4	0.4	5.9	–	4.6
124–134	19.6	47.6	–	2.4	9.2	17.9	9.7	2.4	1.0	–	0.6	5.8	–	3.4
134–144	15.2	47.2	–	15.6	4.9	9.3	10.8	1.5	0.5	–	0.6	6.4	–	3.2
144–155	10.4	43.1	0.5	8.8	2.6	8.8	17.1	–	7.8	–	0.4	6.7	–	4.2
155–165	8.9	58.8	–	5.8	2.3	5.8	11.2	–	8.1	0.6	0.4	5.0	–	2.0

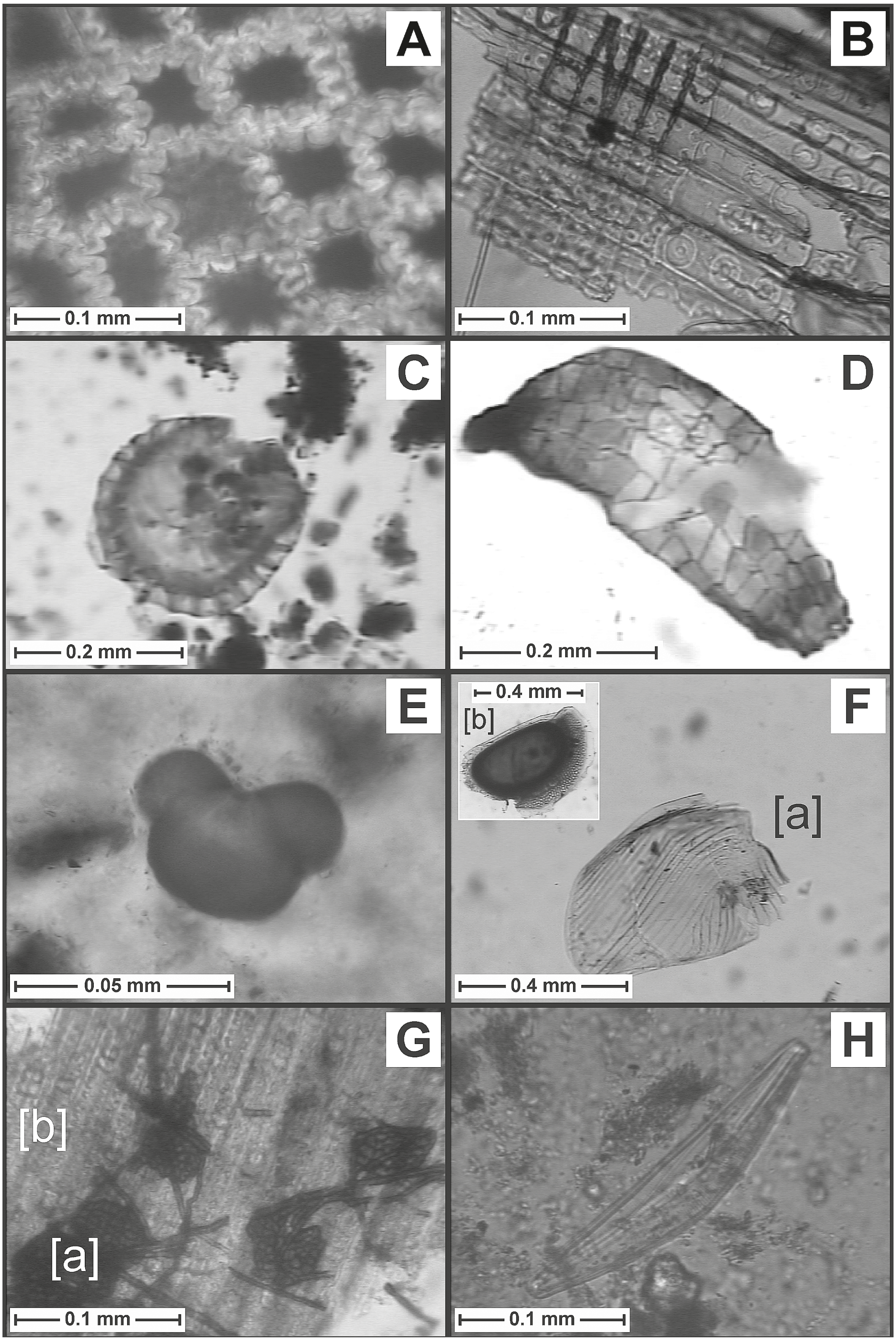

Fig. 6. Morphological forms of organic matter recognized in deposits of the Sławięcice 1 and Steblów 2 sites: A – periderm (*Pinus sylvestris*) – Sławięcice 1; B – wood (*Picea abies*) – Sławięcice 1; C – a sporangium of *Polypodiopsida* (cf. *Thelypteris palustris*) – Sławięcice 1; D – a seed of *Juncus squarrosus* – Sławięcice 1; E – a pollen grain of *Pinus sylvestris* – Steblów 2; F – a chitinous shell [a] and ephippium [b] of Cladocera – Steblów 2; G – fungal thallus [a] on the surface of *Molinia caerulea* epidermis [b] – Sławięcice 2; H – a siliceous shell of Bacillariophyta – Steblów 2

the intrusive nature of root systems. Intrusive components may postsedimentarily change the character of deposits originally composed of allogenic remains. One striking example is the remains of a willow root systems present in the Steblów 2 site (ST2 core) within the series of limnic sediments (Wójcicki 2013). In addition to the above-mentioned residues, mycelium may also be added to the group of authigenic components. Fungal mycelium was identified in the upper part of the analyzed sequences of deposits, which indicates that its development occurred in the acrotelm layer of the fens studied.

The remains of leaves of vascular plants, sporomorphs, sporangia, fruits, seeds, zooclasts and protists can all be classified as reliable bioindicators of allogenic deposition (Tobolski 2000). The remains of the leaves of trees and shrubs, characterised by reticulate venation (Fig. 5E) and deposited in the aquatic environment (as in the lower section of the ST2 core at the Steblów 2 site), represent both an allogenic and allochthonous component (derived from outside the water reservoir). However, zooclasts and remains of Protista represent an autochthonous component at the discussed site. Of similar significance are the fruits and seeds of aquatic plants, which together with the remains of Cladocera, Chironomidae and diatoms are also valuable bioindicators of limnic conditions (Tobolski 2000).

An attempt to identify the origin of wood, epidermis and periderm remains

In research practice there is the problem of distinguishing underground and aboveground plant organs, particularly in fossil material which shows a high degree of fragmentation and advanced decomposition. The problem concerns the basic organic components (i.e. the remains of wood and the outer covering tissue of a plant), and limits the possibility of determining the ratio between the authigenic and allogenic components in the sediment.

The allogenic origin of wood deposited in the limnic environment may be determined based on animal and plant bioindicators, including the fruits and seeds of aquatic plants (Tobolski 2000). However, analysis of the deposits at the Steblów 2 site shows that sediments of the aquatic environment may contain, in addition to detritus, younger, intrusive wood deposited *in situ*. Allogenic wood may also be indicated by the presence of taxa inconsistent with the natural direction of succession. In the SW1 core, at a depth of 150–162 cm there is wood of *Pinus sylvestris* separating the layers rich in wood of *Alnus glutinosa* and *Salix* (Wójcicki 2013). This observation allowed the discovery of an episode of exogenic sedimentation which would have been undetectable with the use of traditional geochemical analyses (organic matter content at this depth remains high). A reliable criterion for proving the authigenic origin of wood seems to be its vertical arrangement associated with the penetration of older sediments by root systems. Vertically stacked pieces of willow root systems were found at, among others, the Steblów 2 site at a depth of 48–70 cm. Thus, despite regular inundation of the floodplain, some of the organic matter was deposited *in situ* at this site. It is more difficult to clearly speak out about the origin of wood arranged horizontally, although such an arrangement of a pine branch at the Sławięcice 1 site at a depth of 150–162 cm confirms the above-formulated conclusion regarding the allogenic origin of this material. Another indicator of the allogenic origin of wood is the specific treatment of fragments of trunks and branches (which includes the mechanical removal of bark), and which is the effect of transportation in a fluvial environment (Tobolski 2000). The observations of this type are more suited for wood deposited in mineral sediment, but fail in the case of finely crumbled wood in highly-decomposed peat.

The small differences in cellular structure of the epidermis and the typically small size of the remains of this group severely limit the ability to correlate them with aboveground or underground plants organs. The situation is improved somewhat by stomata, which occur mainly in the epidermis of the aboveground parts of terrestrial plants (leaves, stems, sepal leaves and fruits) as well as in the epidermis of the upper part of floating leaves of aquatic plants (Tobolski 2000). The remains of these plant organs form the detritus component in sediments. Fragments of the outermost cell layer with stomata (belonging to the tree leaves and stems of *Calamagrostis canescens)* were identified in the organic-rich deposits from the Steblów 2 site (Wójcicki 2013). The fragments of epidermis of the most common taxa (like common reed, horsetail and sedges) were usually devoid of stomata, suggesting they originally covered the underground plant organs, and were accumulated *in situ*. Despite some variation in the cellular structure, however, determining the aboveground or underground origin of the periderm is problematic. It should be noted that in the studied sites the periderm content reaches the maximum values (or close to the maximum) at the top of woody peat layers. This suggests that the analysed periderm comes mainly from the aboveground parts of trees and that the fen surface in the period of woody peat accumulation was vertically stable.

The sedimentological significance of strongly transformed organic remains

Morphological criteria do not allow the origin of amorphous organic matter or charred phytoclasts to be determined. High contents of humic substance can be linked with the development of soil processes in aerobic conditions. The mid-Holocene hiatus, documented by radiocarbon dating and pollen analysis (Nita, Wójcicki 2005), and a lack of mineral admixture indicate that amorphous organic matter in the SW1 core at a depth of 79–94 cm is authigenic in origin (Table 1). Its formation was more probably a consequence of a decrease in the groundwater level as documented by the development of forest communities (alder carrs) in the fen area (Wójcicki 2013). In contrast, the increase in amorphous matter content in the sample at a depth of 25–38 cm is accompanied by the appearance of slopewash sand. In conditions of active soil erosion, the presence of allogenic humic substances can be expected.

Additionally, charred phytoclasts, including charcoal, may be either authigenic or allogenic in origin. Tipping and Milburn (2000) described charcoals deposited as a result of fires involving both the bog surface and its surroundings. In river valleys, however, charcoals are usually of allogenic origin and their deposition is synchronous with flooding episodes related to forest harvesting (Kukulak 2003). It is probable that charred phytoclasts identified in the upper part of the ST2 core share the same origin.

Final Remarks

Organic remains deposited within the floodplain environment show a large genetic diversity. The individual layers in the SW1 and ST2 cores consistently contain amorphous substance, roots, epidermis, wood and sporomorphs. In the vast majority of samples charred phytoclasts, remains of mosses, periderm, sporangia, fruits and seeds were identified, as well as chitinous exoskeletons of Cladocera and Chironomidae. The participation of these groups of components is subject to significant fluctuations in individual samples, which indicates that the composition of organic matter is a sensitive indicator of changes in the depositional environment. The dominance of allochthonous components from outside the sedimentary basin allows the identification of episodes of increased activity of geomorphological processes. This is possible even when mineral components do not participate in processes of transportation and sedimentation and when the geochemical analyses exhibit a constant organic carbon content in the sequence of deposits. On the other hand, in the case of overbank or slope deposits, it can be determined whether the organic matter is authigenic or allogenic in origin.

The materials collected so far indicate that authigenic components often co-occur with allogenic remains. The proposed research methodology requires improvements that will allow for the more precise separation of remains from underground and aboveground parts of plants. At the stage of interpretation of results it is necessary to separate post-accumulation processes that lead to the enrichment of previously-formed layers from intrusive (authigenic) components.

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Manuscript received 20 January 2015,
revised and accepted 25 April 2015