Journal of Archaeological Science: Reports 36 (2021) 102837

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Too young for tinder? The palaeoecological context and possible function of subfossil fungi (basidiomes) found in the settlement from the Early Iron Age in Podłęże, S Poland

Karol Dzięgielewski [a,*], Dorota Nalepka [b], Andrzej Chlebicki [b], Adam Walanus [c]

[a] Institute of Archaeology, Jagiellonian University, Gołębia 11, 31-007 Kraków, Poland
[b] W. Szafer Institute of Botany, Polish Academy of Sciences, Lubicz 46, 31-512 Kraków, Poland
[c] Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland

A R T I C L E I N F O

Keywords:
Subfossil fungi
Fomes
Fomitopsis
Peatbog
Tinder
Early Iron Age
S Poland

A B S T R A C T

Two well-preserved fungal remains (basidiomes of polypores *Fomes fomentarius* and *Fomitopsis pinicola*) were found in a fossil peatbog in Podłęże, near Kraków (S Poland), in the context of culture layers dated to the Early Iron Age (mid-1st millennium BCE). Their context, age, and the cause of their occurrence in peat, which is exceptional, are discussed. Due to the location on the outskirts of an inhabited prehistoric settlement and because of the traces of detachment of the upper part in the *Fomes fomentarius* basidiocarp, we argue for their deposition in the peat layer via a human action. The host trees, however, could have grown *in situ*, since a drainage episode enabled the peatbog to be overgrown by sparse riparian forest at the onset of the Subatlantic. The possible use of the *F. fomentarius* fragment as tinder is discussed against the limited evidence of such use from later European prehistory.

1. Introduction

In contrast to other plant and animal remains, fungi are not really a common category of finds at archaeological sites. This is due to their fragile nature that rarely enables their preservation, rather than the minor role that they could have played in prehistoric societies. Their importance is, however, well-known and underlined by ethnographic data from all over the world (Boa, 2008). An exhaustive account on the presence of fungi in the archaeological record of prehistoric Europe was recently delivered by Berihuete-Azorín et al. (2018) on the occasion of presentation of some fungal fruiting bodies (basidiocarps, or basidiomes) found at the Neolithic site of La Draga (Spain). Due to the ecological requirements of the recorded taxa, as well as the traces of manipulation on some items, the authors interpreted the finds as a result of a deliberate collection of fungi from different woods near the settlement in order to use them as tinder. The same interpretation is widely employed for other cases of polypore species preservation in archaeological contexts, including the most recognized find, that of Ötzi (the Iceman), who carried with him some dried pieces of *Fomes fomentarius* and *Piptoporus betulinus*, initially prepared as tinder (Peintner and Pöder, 2000).

In 2006, in Podłęże, Wieliczka district, near Kraków (south Poland), during archaeological rescue excavations preceding the construction of a motorway, a compressed peat layer was discovered. In this peat, several dozen archaeological artefacts were found connected with culture layers of the nearby multi-phase settlement (Fig. 1) dated to the Neolithic, Bronze Age, Iron Age, Middle Ages, and Modern times. Traces of occupation of these periods were documented over the whole terrain elevated above the flood plain (Dzięgielewski, 2010, 2012; Dzięgielewski et al., 2008, 2013, 2015). In the upper part of the peat layers, two almost complete fungi basidiomes were found, identified by D. Karasiński as *Fomitopsis pinicola* and *Fomes fomentarius*. The two fungi are of later age (mid-1st millennium BCE) than the examples from the Neolithic which we referenced earlier. Since the occurrence of polypores is rather exceptional in a growing peatbog, a number of questions arose concerning their precise age and the circumstances of their occurrence in the peat: (1) were they of the same age as the peat layers in which they were found?, (2) how did they get to the peatbog? In a natural way, or brought by humans?, (3) if by humans – was it accidentally (with wood), or on purpose?, (5) if in a natural way (from trees overgrowing the peatbog) – why, despite the location close to a settlement, was only a fraction of one of them used by settlers? Was it in connection with lesser

* Corresponding author.
E-mail addresses: karol.dziegielewski@uj.edu.pl (K. Dzięgielewski), D.Nalepka@botany.pl (D. Nalepka), a@adamwalanus.pl (A. Walanus).

https://doi.org/10.1016/j.jasrep.2021.102837
Received 29 November 2020; Received in revised form 20 January 2021; Accepted 21 January 2021
Available online 10 February 2021
2352-409X/© 2021 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

popularity of fungal tinder at the onset of the Iron Age, or just with the sparse population of the area?

2. The material, its context, and methods

2.1. The material and its general context

The subfossil basidiocarps of *Fomes fomentarius* (Fig. 2:1–2) and *Fomitopsis pinicola* (Fig. 2:3–6) excavated from the peatbog in Podłęże are well preserved. *F. fomentarius*, now approx. 13 cm wide and 6 cm thick, was more shaved (deliberately damaged) than dropped out, as indicated by the quite sharp edges of its removed upper part (Fig. 3, top) (cf. Pegler, 2001). Basidiospores of this species were preserved in the material (Fig. 3, bottom). *Fomitopsis pinicola*, now approx. 20 cm wide and 7 cm thick, was not damaged. The structure of fungal hymenium (Fig. 4) persisted in the studied specimen. Both basidiocarps were partially covered by gypsum crystals.

The fen in Podłęże near Kraków (Fig. 1) developed since the Late Glacial in the valley of the Forecarpathian tributary of the Vistula River Podłężówka (Podłężanka), with a very wet or even permanently swampy alluvial plain. Reclamations carried out in 1955/56 caused lowering of the ground water level, and the drained bog was used as meadows and pastures (Lipka et al., 1975). The peatbog was examined several times from different points of view including lithology (Lipka et al., 1975), palaeobotany (Nalepka, 1991, 1994a, 1994b) and geomorphology (Gębica et al., 1994; Kalicki, 1997). The latest palaeoecological studies were carried out in this area in the course of rescue investigations preceding the motorway construction (Dzięgielewski et al., 2008, 2013, 2015; Dzięgielewski and Nalepka, 2009).

2.2. The archaeological context

The layers in which the fungi were found arose naturally, as a peatbog growing in the late Holocene, but due to their location directly on the northern border of the early Iron Age settlement (Fig. 1), they have also a clear archaeological context. The fen itself was not only penetrated during the functioning of the settlement, which resulted in the deposition of artifacts such as fragments of pottery vessels, stone objects and animal bones, but also – during drier periods – it was directly used by the settlers, as evidenced by structures dug in peat layers, such as pits and a well (see below). For this reason, a part of the peatbog, covering an area of about 3600 m^2 north of the settlement, was archaeologically recovered by manual exploration, with three-dimensional tracing of artifacts, which made it possible to determine the extent of exploitation of the fen. It did not allow us, however, to state whether the remains of trunks (mainly alders) (Fig. 1; Fig. 5) occurring in the strata originate from naturally or anthropogenic fallen trees.

2.3. The palaeobotanical context

The nearest palynologically investigated material originated from profile P3, collected from the wall of an archaeological trench (Fig. 1). The deposit was built from highly decomposed, compressed, and dried-up peat (13–130 cm from the top of the profile; since the profile was not taken from the top of the humus, this depth range corresponds to 95–225 cm from the modern topsoil; cf. Fig. 6). The peat was covered by sandy clay containing some humus and overlaid by silty clays. Pollen analysis was done from the whole profile (Nalepka, in prep.) using standard methods (Faegri et al., 1989; Stockmarr, 1971). The samples contained mainly amorphic particles and exceptionally fine brown organic detritus which could not be removed in the course of the

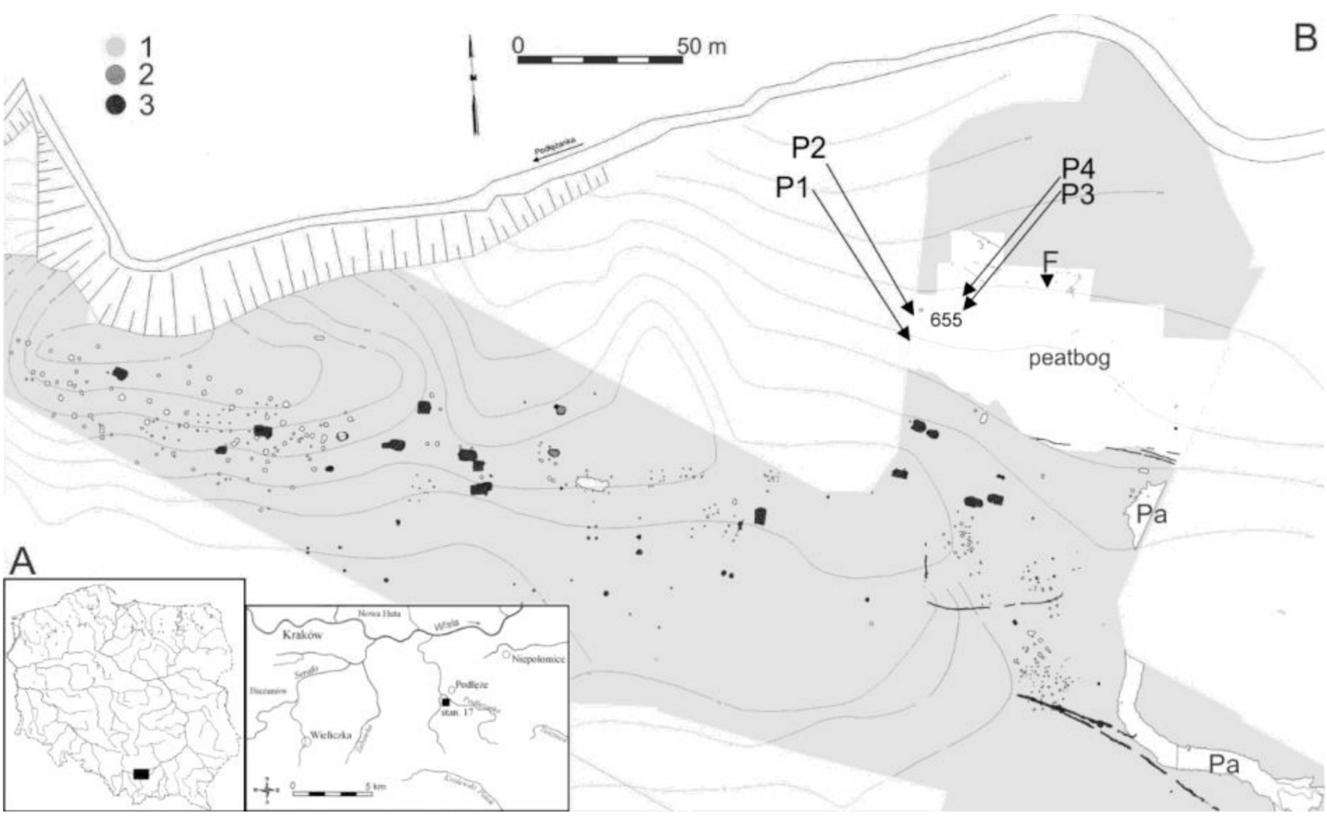

Fig. 1. Location of archaeological site 17 in Podłęże near Cracow (A) and site plan of the excavated settlement (B), with the range of the Holocene peatbog (white) and the distribution of the Iron Age settlement features: 1 – early Iron Age, 6th-5th cent. BCE, 2 – early Pre-Roman Period, 4th cent. BCE, 3 – middle Pre-Roman Period, La Tène culture, 3rd-2nd cent. BCE; P1-P4 – location of palynological profiles; F – findspot of the fungi, 655 – a well dendro-dated to 600 BCE; Pa – paleochannel of a small Late Bronze Age-Early Iron Age Podłężanka tributary.

Fig. 2. The subfossil basidioma of *Fomes fomentarius*: half-top view (1), bottom view (2); the subfossil basidioma of *Fomitopsis pinicola*: cross-section through the fruit-body (3); bottom view (4), front view (5), side view (6). Photo A. Walanus.

Fig. 3. *Fomes fomentarius*: basidiocarp with shaved upper part (top) and its basidiospores (bottom). Photo A. Chlebicki.

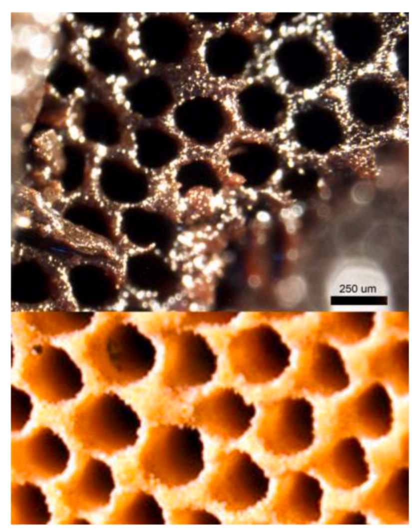

Fig. 4. *Fomitopsis pinicola*: subfossil pores (top), living pores (bottom, for reference). Photo A. Chlebicki.

preparation of material for pollen analysis. In some samples no sporomorphs were found, some contained a few of them, and in the others the poor preservation of most of the sporomorphs did not allow their identification. Despite the difficulties, most samples were analyzed for the content of sporomorphs. Palynological analysis was carried out with a greater number of microscopic preparations from one sample than in the case of well-preserved materials. Tagged and untagged (Indeterminable: Corroded, Concealed, Degraded, Varia) pollen grains and spores were counted in each sample. Percentage calculations were performed including and excluding undetermined sporomorphs from the calculation sum. The palynological interpretation was carried out taking into account information on the number of undetermined sporomorphs. A few fungal spores were recorded. Complete results of palynological analysis will be presented in a separate publication. The present article contains an abbreviated pollen diagram (Fig. 6) drawn in the POLPAL program (Nalepka and Walanus, 2003). All radiocarbon age

Fig. 5. Alder (*Alnus* sp.) macrofossils within the late Holocene peatbog during excavation. Photo K. Dzięgielewski.

determinations in the present paper (of peat deposit as well as of the fungal remains) were calibrated using the IntCal13 calibration curve (Reimer et al., 2013) and their calibrations are presented as 2σ ranges (95% confidence level).

3. Results

3.1. The age of the basidiocarps and the age of peat layers

While exposing the successive peat layers, alder wood pieces (*Alnus* sp.) were found within the investigated area, including trunks, branches, and root systems (Fig. 5; Krąpiec, 2006). Fungal basidiomes, not adherent to trunks, were excavated from a depth of 120–130 cm below the modern topsoil on are 530/230, in the archaeological stratigraphic unit designated as layer 895c. The peat in which these basidiomes were preserved also contained plant macrofossils (wood), ecofacts, and archaeological artefacts (animal bones, pottery shards and flint objects) connected with the settlement existing on the site since the Early Iron Age (Dzięgielewski, 2010). The basidiomes were found at a distance of about 12 m to the east from profile P3, on which pollen analysis was conducted (Fig. 6) (Dzięgielewski et al., 2013; Dzięgielewski and Nalepka, 2009). In order to define their age, the fruiting body of *Fomitopsis pinicola* and peat plant tissues adherent to it were radiocarbon dated separately. The ^{14}C BP age of fruiting body is 2650 ± 60 (conventional date, Lab. no. MKL-1581; 2σ calibration: 974–592 BCE), and of the tissues of plants covering the basidioma is 2360 ± 30 (AMS date, Lab. no. Poz-53381; 2σ calibration: 522–383 BCE).

In the immediate surroundings of profile P3, in peat layers covering an area of about 1500 m^2, pieces of prehistoric pottery were recovered which were chronologically concordant with the radiocarbon and palynological dating of these layers (i.e. the youngest ceramics occurring in a given level is not younger than the radiocarbon and palynological age of each sediment) (Fig. 6).

The basidiomes were found in peat layer 895c, at level IJ (depth: 120–130 cm from topsoil = 50–60 cm from the top of the P3 profile). By the interpolation of this level's dates in profile P3, it can be stated that the upper part of 895c peat was formed ca. 780–240 BCE (P3: MKL-855: 2390 ± 80; 2σ: 776–239 BCE). On the other hand, the JK peat level (130–140 cm) must have been formed before 600 BCE because on are 490/220, precisely at level J (130 cm = 60 cm from the top of the P3 profile), a waste-heap of light-yellow silty sediment was documented, which was formed while a well was being dug, the casing of which was built from oak felled after 603 BCE (dendrochronological date: Dzięgielewski, 2010; Dzięgielewski et al., 2013). In addition to being an indication that the swamp was drying out at this time (see discussion), it

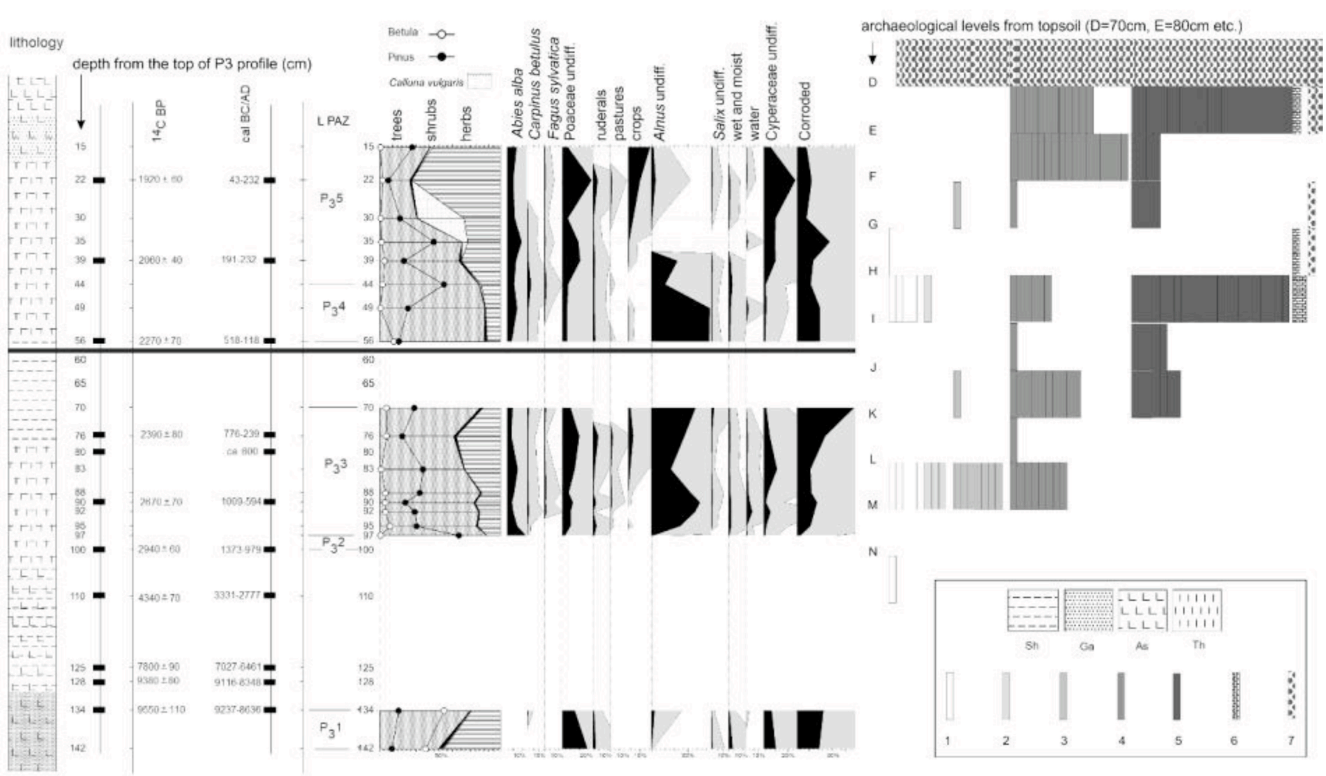

Fig. 6. Synchronization of palynological, archaeological and radiocarbon data for the palynological profile P3 (for location see Fig. 1). Black horizontal line refers to interpolated vertical location of *Fomitopsis* fructifications. Vertical bars (1–7) refer to archaeological artifacts (one bar represents a single pottery shard from the area of 1500 m^2 around the P3 profile; chronology: 1 – Neolithic, 2 – Early Bronze Age; 3 – Late Bronze Age; 4 – Early Iron Age/Hallstatt, 5 – Iron Age/La Tène; 6 – Late Iron Age/Roman period; 7 – Modern Era, 17th-20th cent.). Key for lithology (cf. Troels-Smith 1955): Sh – humus; Ga – sand, As – clay, Th – peat.

also means that the IJ peat level must be younger than 600 BCE and is concordant with the ^{14}C AMS dating of peat adhering to the fungus (Poz-53381; 2σ: 522–383 BCE), hence it confirms the correctness of the above interpolation.

To sum up: the calendar age of the *Fomitopsis pinicola* basidiocarp from Podłęże is 974–592 BCE, while the age of peat directly adhering to this fruit body is 522–383 BCE. The general age of peat layer 895c at the depth from which the fungus comes is 780(600)-240 BCE (the age interpolated from the P3 profile) and this practically covers the age of both the basidiocarp and the peat adhering to it. This indicates that the (probably dead for some time) fruit body – either together with a tree trunk or wood fragment or separately – got to the growing peatbog not earlier than at the end of the 6th century BCE and remained there in anaerobic conditions, because it did not decay but was successively covered by peat.

3.2. Local environmental conditions

In the older and younger deposit levels in Podłęże, between which the basidiomes of *Fomitopsis pinicola* and *Fomes fomentarius* were found (they were located in a pollen zone correlated with the hiatus) (Fig. 6), a diversified landscape was recorded, characterized by the predominance of the forests with pine, fir, oak, spruce, hornbeam and beech in variable shares. A smaller share of *Pinus*, *Betula* and *Alnus* pollen grains in the lower level (70–95 cm; $P_3$3 *Ab-Al*-Po L PAZ) suggests the participation of pine as well as that of alder forests and birch thickets increasing towards the top. Forest clearings were present. Agricultural and other economic activities were carried out in the surroundings (pine was probably exploited). In the upper horizon (at 44–56 cm; $P_3$4 *Ab-Al* L PAZ) a slight reduction of open areas was recorded in connection with the spread of pine and hornbeam. The local overgrowing of abandoned areas perhaps resulted from diminished anthropogenic pressure on the environment. Considerable reduction of alder forests points to drier conditions. Evidently it was the late Subboreal or the transition between the Subboreal and Subatlantic, when all these trees, including fir, were already present, and this is consistent with the radiocarbon dating. We synchronize this transition with the climatic deterioration starting at 850 cal BCE (cf. van Geel et al., 1996; Speranza et al., 2000; Starkel et al., 2013), or with the 2.8 k rapid climate change (RCC) event (Wanner et al., 2011; Kobashi et al., 2013; for justification for the use of the updated Blytt-Sernander periodization as climatostratigraphic chronological division, beside the time control with radiocarbon, see e.g. Schrøder et al., 2004; Starkel et al., 2013).

4. Discussion

4.1. The contemporary context of the occurrence of Fomitopsis pinicola and F. fomentarius

Fomes fomentarius (L.) Fr. is a parasitic fungus common in the Northern Hemisphere. It infects various tree species (especially beech and birch) and grows on dead wood as well. The basidiomes look like a horse's hoof. *F. fomentarius* is an inedible fungus. In the past it was used as tinder, but also to make clothing and other items, and it also has been used for medicinal purposes (Boa, 2008; Gilbertson and Ryvarden, 1986; Guminska and Wojewoda, 1985; Mukhin and Votintseva, 2002; Pegler, 2001; Scholian, 1996; Schwarze, 1994).

Fomitopsis pinicola (Sw.) P. Karst. is a parasitic fungus common in Central Europe. It infects conifers (mostly pine as well as spruce and fir), rarely deciduous trees (e.g. birch, beech) and grows on dead wood as well. The basidiomes look like a horse's hoof. Their skin melts under torrid heat (Guminska and Wojewoda, 1985). *F. pinicola* is an inedible fungus. In the past, its cut and dried fruiting bodies were smashed into plaster and, thanks to their very high hygroscopic properties, were used to staunch blood and as an antibiotic (Boa, 2008; Gminder, 2011; Guminska and Wojewoda, 1985).

4.2. Palaeoecological context of Fomes – fossil evidence in Europe

The basidiomes of fungi are not common finds in fossil layers dated to various ages. Among others, Skirgiełło (1961) described the fruiting body of *Fomes* cf. *fomentarius* (L. ex Fr.) Kickx, from brown coal layers in a mine near Bogatynia-Turów (Poland), which contained numerous remains of Miocene vascular plants. Another example of *F. fomentarius* was found in an old bed of the Odra River in Wrocław (Chlebicki and Lorenc, 1997; Krąpiec et al., 2001), in the Holocene sediments, where numerous logs of subfossil oak (*Quercus robur*), as well as morphologically various remains of alder (*Alnus* sp.), willow (*Salix* sp.), and beech (*Fagus sylvatica*) were deposited. The last species were probably the host of the *F. fomentarius*. Those trunks were remnants of an ancient forest that fell into the river (Lorenc and Chlebicki, 1993). Their approximate age (based on age of oak logs) was probably more than 5 000 years (with the radiocarbon date of the closest oak log Q9: 4890 ± 60 BP, Krąpiec et al., 2001; calibration with IntCal13, Reimer et al., 2013: 3840–3540 BCE, 95% confidence level). In Europe outside Poland, the first information about the discovery of *F. fomentarius* concerned a northern German bog with peat dated to the Allerød (Late Glacial) near a Final Palaeolithic archaeological site in Vorpommern (Kreisel and Ansorge, 2009). Among younger finds there is an Irish bog with a peat layer dated to the early Holocene (Boreal) (Gennard and Hackney, 1989). In the older literature, only finds of *Fomes* sp. were mentioned (e.g. Monthoux and Lundstrom-Baudais, 1979; Purdy and Purdy, 1982). Skirgiełło in her work (1961) also quoted the finds of fungi from Germany (Kirchheimer, 1941), Willershausen (Straus, 1952), and Hohen-Viecheln in Mecklenburg from the Mesolithic (Kreisel, 1956). More complete information was given in the context of the 5,000-year-old Ötzi (the Iceman), who carried four pieces of *F. fomentarius,* possibly to be used as tinder (e.g. Peintner et al., 1998; Peintner and Pöder, 2000). The same interpretation was employed for the *F. fomentarius* finds from the Neolithic site La Draga in Spain (Berihuete-Azorín et al., 2018). Several other sites with the occurrence of this species are known from Mesolithic and Neolithic (early and middle Holocene) archaeological sites from many regions of Europe (Kreisel and Ansorge, 2009; Berihuete-Azorín et al., 2018). In this context it is puzzling why are they usually not reported for younger sites, i.e. from those of the Bronze or the Iron Age. A substance similar to tinder fungus was mentioned only from a few early Bronze Age graves in Denmark, sometimes occurring in functional sets consisting of lumps of pyrite (mineral composed of iron and sulphur), and flint strike-a-lights (Jensen, 2018). With regards to the few younger fungal finds there is scant evidence of their relationship with human activity, for instance at Viking age settlement in Haithabu, Germany (Kreisel and Ansorge, 2009).

4.3. How did the basidiocarps find their way into the bog?

To answer this question one should first consider whether the fungal remains might have been found *in situ*. If they were growing on a living tree, it would be possible only by hydrological conditions favourable for trees to grow in a strongly dried peatbog. In the level correlated with the occurrence of these basidiocarps, numerous fragments of alder (*Alnus* sp.) were found (Fig. 5), and in the surrounding area typical host plants for both fungi were also growing (*Fagus sylvatica*, *Betula* sp. and *Pinus sylvestris*) (Fig. 6). Therefore it seems very likely that at least the *Fomitopsis pinicola* could have occurred *in situ* in the peatbog layer. Although both basidiocarps survived thanks to isolation from oxygen access caused by the rising water level, they were nevertheless partially covered by gypsum crystals (Fig. 7). Those crystals form in drying out lakes and seas with salt presence, but Smieja-Król and Fiałkiewicz-Kozieł (2014) also found gypsum that precipitated *in situ* and impregnated plant tissues in the peatbog at a depth of 15–18 cm. The presence of gypsum crystals on basidiocarps' surfaces in Podłęże might therefore indicate that this peatbog was dry or drying at the time of deposition.

As stated above, the occurrence of fungi in the peatbog was

Fig. 7. Gypsum crystals found on the surface of *Fomes fomentarius* basidiocarp from Podłęże.

contemporary with the Early Iron Age settlement phase. The palaeobotanical and archaeological data indicate that about the turn of 7th/6th century BCE the peatbog was so dried that trees could overgrow it and people could exploit this part of the site (by digging pits and wells). Most of the archaeological data indicate that the beginning of this dry phase is marked by the digging of a well (feature No. 655) within the peatbog about 600 BCE (dendro dating of the well: Dzięgielewski, 2010; Dzięgielewski et al., 2013). We did not find local factors (e.g. forest clearance) solely responsible for such a degree of groundwater lowering which made it necessary to dig a well to obtain water from the swamp (the well was more than 1 m deep). Therefore we are inclined to consider that it was also connected with short-term warmer and drier climatic oscillation (650–450 BCE) of the early – generally cooler and wetter – Subatlantic (starting at about 850 BCE). This oscillation is distinguished in oak tree-ring sequences from the upper Vistula river catchment (Starkel et al., 2013) and also on a hemisphere level (Maise, 1998; Kobashi et al., 2013). The episode was probably one of the fine-grained oscillations within the generally colder Bond event 2 (Bond et al., 2001), or the "2.8 k rapid climate change event", which is believed to have had two sequential cooling events, at about 800 and 400 BCE (Wanner et al., 2011; Kobashi et al., 2013), with warmer conditions inbetween, at 600 BCE. Taking into account the age of the fungal fruit bodies and of the peat which surrounded them (the bracket of overlapping dates is around 600–500 BCE) the hypothesis can be formulated that the tree on which they were growing was cut by humans when that part of the site was settled and exploited in the relatively warm and dry part of the Early Iron Age (mid. 6th cent. BCE). Did the fungi, however, get detached from trees and fall to the bog in a natural way? There is yet another, less probable but conceivable way of their penetration into peat: the transferring of fungi to the settlement by inhabitants with wood by accident. Finally, it seems least likely that an old but not decomposed fruit body was found somewhere else and was later deposited on purpose in peat near the settlement. In the last two scenarios one thing is striking: the fungi were to a minimum extent used by their finders. The only trace of human processing was an artificial cut of a top of *Fomes fomentarius* (cf. Pegler, 2001). This choice may indicate that this part of the specimen was meant for tinder.

4.4. Limited need for tinder?

The percussion method with a fire striker and pyrite was still the basic way of starting fires in Iron Age Europe, although there is no evidence for fire steels from the onset of the Iron Age in north Central Europe (8th-4th cent. BCE) (Weiner, 2012), in contrast to the later Pre-Roman and Roman periods, when they were already in common use (e.g. Kokowski, 1985; Weiner, 2012). Flint strike-a-lights could play this role at the discussed period (e.g. Van Gijn, 2010; Libera, 2018). Regardless of the material of the fire striker, the percussion method needs tinder to be used for fire to be lit from sparks. However, fungi are only one of the possible materials for tinder. The others include dry leaves, grasses, strips of birch bark, and old fabrics (cloths). One cannot exclude that some of these materials were more commonly used as tinder in Bronze and Iron Age Europe, which may to some extent explain the lower frequency of polypore fungi in archaeological sites dated to these periods (cf. Weiner, 1997 for comprehensive bibliography) (Fig. 8). One can argue however, that the general lower frequency of fungal remains in Bronze and Iron Age sites in Europe shown in Fig. 8 may be to some extent biased by the generally more frequent identification of early Holocene sites within waterlogged contexts (the Mesolithic camps and the Neolithic lake settlements). On the other hand there are enough "wet" sites such as lake settlements (palafittes, *Pfahlbauten*) also of later chronology, especially of the Late Bronze and the Early Iron Age (1st millennium BCE), across Europe to yield such finds if they were in common use, but for some reason they are not reported. The find from Podłęże is therefore exceptional due to its age and if we accept the evidence for its use as tinder (spatial relation to the settlement, shaving traces), it partially fills that gap. Nevertheless, the general trend of the reduced need for fungal tinder in younger prehistory seems not to be challenged by this single find.

5. Conclusions

The occurrence of basidiocarps of two polypores in the Early Iron Age peatbog in Podłęże was most probably a consequence of human activity. Earlier they had been plausibly growing on trees in the surrounding area, such as beech, birch, or pine. It is fairly probable, however, that they were thrown out by people who were cutting trees in the partly dried section of the peatbog close to settlement inhabited at the beginning of the Early Iron Age. The drainage of the peatbog plausibly has to be linked with the drier climate oscillation within the generally cooler 2.8 kya RCC event. One of the basidiocarps (*F. fomentarius*) was partially damaged (artificially devoid of top parts) most probably by

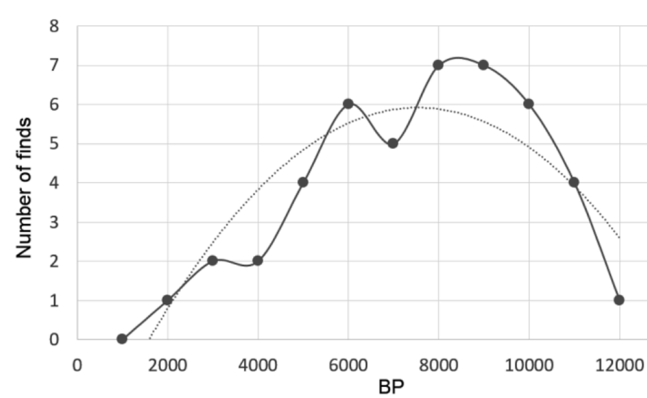

Fig. 8. Frequency of polypore fungi found in archaeological contexts in Europe throughout the Holocene. Only species fit for use as tinder (mostly *Fomes fomentarius* and *Piptoporus betulinus*) and finds with reported relation with human activity at each site were taken into account. Finds dated generally (as for example "Late Mesolithic") were assigned proportionally to one of the appropriate millennia. (The chronological data derived from literature are obtained by various methods, not only by radiocarbon, and have varied accuracy). Data after lists (updated) in: Weiner, 1997; Kreisel and Ansorge, 2009 (remark: there are some confused BP and BC datings there); Robson, 2018; Berihuete-Azorín et al., 2018. The parabolic approximation added to the data (dotted line) is just to emphasize what kind of precision we are dealing with when there are, for example, 6 findings. The Poisson probability distribution of expected value = 6 gives: p(4) = 0.13, p(5) = 0.16, p(6) = 0.16, p(7) = 0.13. It is almost equally probable to find 4, 5, 6, 7 (8?) polypore at the given situation (expected 6).

humans, which might indicate that it was used as tinder. Although the record of such fungi use is numerous for the Mesolithic and the Neolithic, it is clearly declining for the younger sections of prehistory. Therefore, the meaning of the discovery in question is ambiguous: on the one hand, the lack of analogies from the Iron Age may weaken the hypothesis of the use of a given specimen as tinder, while on the other hand, if the human-action hypothesis is accepted as correct, it may testify to the persistent (although rare) utilization of *Fomes fomentarius* as tinder. Nevertheless, the palaeoecological significance of the discovery remains clear, as it provides further evidence for an episode of warming and drying within the generally humid onset of the Subatlantic.

CRediT authorship contribution statement

Karol Dzięgielewski: Conceptualization, Data curation, Writing - original draft, Funding acquisition. **Dorota Nalepka:** Conceptualization, Data curation, Formal analysis, Writing - original draft. **Andrzej Chlebicki:** Data curation, Visualization. **Adam Walanus:** Formal analysis, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The research was financed by The Cracow Team for the Excavation on the Motorway (Krakowski Zespół do Badań Autostrad) and party supported by statutory funds of the W. Szafer Institute of Botany, Polish Academy of Sciences, Krakow, and by statutory funds of the Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology, Kraków, Poland. A part of this study was made thanks to the support of the National Science Center (Poland) grant “Inheritance, social network or local adaptation? Bronze and Early Iron Age societies in western Małopolska”. The authors thank Anna Łatkiewicz for SEM and microanalysis of a fragment of the fungi tissue, as well as two anonymous reviewers for their valuable comments that helped to improve the paper. This article is made open access with funding support from the Jagiellonian University under the Excellence Initiative – Research University programme (the Priority Research Area Heritage).

References

Berihuete-Azorín, M., Girbal, J., Piqué, R., Palomo, A., Terradas, X., Biehl, P.F., 2018. Punk’s not dead. Fungi for tinder at the Neolithic site of La Draga (NE Iberia). PLoS ONE 13 (4), e0195846. https://doi.org/10.1371/journal.pone.0195846.

Boa, E., 2008. Wild edible fungi. A global overview of their use and importance to people. Biology. Publishing Management Service Information Division FAO, Rome.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., et al., 2001. Persistent solar influence on north atlantic climate during the Holocene. Science 294 (5549), 2130–2136. https://doi.org/10.1126/science.1065680.

Chlebicki, A., Lorenc, M.W., 1997. Subfossil Fomes fomentarius from a holocene fluvial deposit in Poland. Holocene 7 (1), 101–103. https://doi.org/10.1177/095968369700700109.

Dzięgielewski, K., 2010. Younger phase of the Early Iron Age in the Western Małopolska (Little Poland) according to results of excavation in Podłęże, dist. Wieliczka. *Śląskie Sprawozdania Archeologiczne* 52, 153–169.

Dzięgielewski, K., 2012. Problemy synchronizacji danych paleoklimatycznych i archeologicznych na przykładzie tzw. wahnięcia subatlantyckiego/Problems of paleoclimatic and archaeological data synchronization as exemplified by the Subatlantic abrupt climatic shift. In: Blajer, W. (Ed.), Peregrinationes archaeologicae in Asia et Europa Joanni Chochorowski dedicatae. Institute of Archaeology Jagiellonian University, Profil-Archeo, Kraków, pp. 109–119.

Dzięgielewski, K., Kalicki, T., Szczerba, R., 2008. Fluvial processes as factors in redistribution of archaeological artefacts on the flood plain: a case study of palaeochannel of the Podłężanka river, near Cracow (southern Poland). In: Kalicki, T., Szmoniewski, B.S. (Eds.), Man and mountains: palaeogeographical and archaeological perspectives, Prace Instytutu Geografii Uniwersytetu Jana Kochanowskiego w Kielcach. Kielce, IG UJK, pp. 85–95.

Dzięgielewski, K., Nalepka, D., 2009. Zapis archeologiczny i palinologiczny działalności człowieka odzwierciedlony w holoceńskim profilu z Podłęża koło Krakowa (wyniki wstępne), in: Zapis działalności człowieka w środowisku przyrodniczym. VII Warsztaty Terenowe, IV Sympozjum Archeologii Środowiskowej, 20-22 maja 2009. Stowarzyszenie Archeologii Środowiskowej, Kórnik 40–41.

Dzięgielewski, K., Nalepka, D., Walanus, A., 2013. Dry swamp? : researching a peatbog and settlement in Podłęże near Kraków as a contribution to climate reconstruction in the early Subatlantic period. Archaeologia Polona 49 (2011), 31–36.

Dzięgielewski, K., Nowak, M., Dzięgielewska, M., 2015. Osadnictwo prehistoryczne w dolinie Podłężanki w świetle wyników badań wykopaliskowych na stanowisku 22 w Podłężu, pow. wielicki/ Prehistoric occupation of the Podłężanka valley in light of the results of excavations conducted at site 22 in Podłęże, district Wieliczka. In: Chochorowski, J. (Ed.), Od epoki brązu do czasów nowożytnych: Wybrane odkrycia i znaleziska, Via Archaeologica. Źródła z badań wykopaliskowych na trasie autostrady A4 w Małopolsce. Krakowski Zespół do Badań Autostrad, Kraków, pp. 311–470.

Faegri, K., Kaland, P.E., Krzywinski, K., 1989. Textbook of pollen analysis. Wiley & Sons Ltd, Chichester-Singapore.

Gębica, P., Kalicki, T., Krąpiec, M., Kruk, J., Nalepka, D., Starkel, L., et al., 1994. Excursion route in the Vistula river valley near Kraków. In: Baumgart-Kotarba, M. (Ed.), Holocene environmental changes and human impact in Poland and Sweden. Excursion Guide-Book. The Carpathians and Vistula Valley. IB PAN, Kraków.

Gennard, D.E., Hackney, C.R., 1989. First Irish record of a fossil bracket fungus *Fomes fomentarius (L ex Fr.) Kickx*. Irish Naturalists’ J. 23 (1), 19–21.

Gilbertson, R.L., Ryvarden, L., 1986. North American Polypores. Fungiflora, Oslo.

Gminder, A., 2011. Atlas grzybów. Jak bezbłędnie oznaczać 340 gatunków grzybów Europy Środkowej. Weltbild Media Sp. z o.o.

Guminska, B., Wojewoda, W., 1985. Grzyby i ich oznaczanie. Wydanie II. Państwowe Wydawnictwo Rolnicze i Leśne, Warszawa.

Jensen, H.J., 2018. Blade knives and strike-a-lights from Bjerre 7: A functional study of two special implements. In: Bech, J.H. (Ed.), Bronze Age settlement and land-use in Thy, Nortwest Denmark. ISD LLC: Jutland Archaeological Society Publications, Højbjerg, pp. 365–373.

Kalicki, T., 1997. The reflection of climatic changes and human activity on sediments of small forecarpathian tributaries of the Vistula river near Cracow, Poland. Studia Geomorfologica Carpatho-Balcanica 31, 129–141.

Kirchheimer, F., 1941. Ein neurer Beitrag zur Kenntniss der Braunkohlenflora in der Lausitz. Beiträge zur Biologie der Pflanzen 27, 189–231.

Kobashi, T., Goto-Azuma, K., Box, J.E., Gao, C.-C., Nakaegawa, T., 2013. Causes of Greenland temperature variability over the past 4000 yr: implications for northern hemispheric temperature changes. Clim. Past 9, 2299–2317. https://doi.org/10.5194/cp-9-2299-2013.

Kokowski, A., 1985. Die Feuerstahlwerkzeuge der Przeworsk-Kultur. Mémoires Archéologiques. Lublin 109–127.

Krąpiec, M., 2006. Zestawienie wyników analiz anatomicznych prób drewna ze stanowiska Podłęże nr 17, gm. Niepołomice (unpublished manuscript in the archives of The Cracow Team for the Excavation on the Motorway (Krakowski Zespół do Badań Autostrad) in Kraków-Branice).

Krąpiec, M., Pazdur, A., Lorenc, M.W., 2001. Subfossil oaks from Odra alluvium in Wrocław. Poster and abstract at the 7th International Conference “Methods of Absolute Chronology”, 23-26.04.2001, Ustroń, Poland.

Kreisel, H., 1956. Zunderschwamme, Fomes fomentarius L. ex Fr., aus dem Mesolithicum. Wiesensch. Zeitschr. der Ernst Moritz Arndt-Universität Greifswald VI, 299–301.

Kreisel, H., Ansorge, J., 2009. Subfossile Baumschwämme aus dem Quartär Vorpommerns. Zeitschrift für Mykologie 75 (1), 33–50.

Libera, J., 2018. Materiały krzemienne odkryte na cmentarzysku kultury łużyckiej (summary: Flint materials discovered in Lusatian culutre cemetery), in: Kłosińska E. M., Radom-Wośniki, site 2. Cemetery of the Lusatian culture in Radom region, Ocalone Dziedzictwo Archeologiczne/Saved Archaeological Heritage 7, Muzeum im. Jacka Malczewskiego, Profil-Archeo: Radom – Pękowice, pp. 104–112.

Lipka, K., Szczurek, J., and Sanek, A., 1975. Badania torfowiskowo-geodezyjne w dolinie rzeki Podłężówki w woj. krakowskim (summary: Investigations of a peatbog with application of geodesy in the valley of river Podłężówka (voivodship of Krakow). Zeszyty Naukowe Akademii Rolniczej w Krakowie 108 (Geodezja 5), 13–43.

Lorenc, M.W., Chlebicki, A., 1993. Czarne dęby” z Wrocławia (Black oaks from Wrocław). Wszechświat 94 (12), 309–310.

Maise, C., 1998. Ärchäoklimatologie : Vom Einfluss nacheiszeitlicher Klimavariabilität in der Ur- und Frühgeschichte. Jahrbuch der Schweizerischen Gesellschaft für Ur- und Frühgeschichte 81, 197–235. https://doi.org/10.5169/seals-117553.

Monthoux, O., Lundstrom-Baudais, K., 1979. Polyporacées des sites néolitiques de Clairvaux et Charavines (France). Candollea 34, 153–166.

Mukhin, V.A., Votintseva, A.A., 2002. Basidiospore germination and conidial stages in the life cycle of *Fomes fomentarius* and *Fomitopsis pinicola* (Fungi, Polyporales). Polish Botanical J. 47 (2), 265–272.

Nalepka, D., 1991. Lateglacial and early Holocene pollen diagrams in the western part of the Sandomierz Basin. Preliminary results. In: Starkel, L. (Ed.), Evolution of the Vistula River valley during the last 15 000 years, part IV, Geographical Studies, Special Issue 6. IGiPZ PAN, Warszawa, pp. 63–74.

Nalepka, D., 1994a. Historia roślinności w zachodniej części Kotliny Sandomierskiej w czasie ostatnich 15 000 lat (summary: The History of Vegetation in the western part of Sandomierz Basin during the last 15 000 years). Wiadomości Botaniczne. 38 (3/4), 95–105.

Nalepka, D., 1994b. Historia roślinności w dolinie Wisły od Krakowa po ujście Raby w późnym Vistulianie i Holocenie (summary: History of Vegetation in the Vistula Valley from Cracow to the Mouth of the Raba River in the Late Vistulian and Holocene). In: Starkel, L., Prokop, P. (Eds.), Przemiany środowiska przyrodniczego

Karpat i Kotlin Podkarpackich. Institute of Geography and Spatial Organization Polish Academy of Sciences, Warszawa, pp. 19–32.
Nalepka, D., Walanus, A., 2003. Data processing in pollen analysis. Acta Palaeobotanica 43 (1), 125–134.
Pegler, D.N., 2001. Useful Fungi of the World: Amadou and Chaga. Mycologist 15 (4), 153–154.
Peintner, U., Pöder, R., 2000. Ethnomycological remarks on the Iceman's fungi. In: Bortenschlager, S., Oeggl, K. (Eds.), The Iceman and his Natural Environment. Springer, Vienna, pp. 143–150. https://doi.org/10.1007/978-3-7091-6758-8_12.
Peintner, U., Pöder, R., Pümpel, T., 1998. The Iceman's Fungi. Mycological Research 102 (10), 1153–1162.
Purdy, L.H., Purdy, B.A., 1982. Ancient polypores from an archaeological wet site in Florida. Botanical Gazette 143 (4), 551–553. https://doi.org/10.1086/337336.
Reimer, P.J., Bard, E., Bayliss, A., Warren, B.J., Blackwell, P.G., Ramsey Bronk, C.h., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C.h., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon 55 (4), 1869–1887. https://doi.org/10.2458/azu_js_rc.55.16947.
Robson, H.K., 2018. The Star Carr fungi. In: Milner, N., Conneller, C., Taylor, B. (Eds.), Star Carr Volume 2: Studies in Technology, Subsistence and Environment. White Rose University Press, York, pp. 437–445. https://doi.org/10.22599/book2.q.
Scholian, U., 1996. The tinder fungus (*Fomes fomentarius*) and its use. Schweizerische Zeitschrift fur Forstwesen 147, 647–665.
Schrøder, N., Højlund Pedersen, L., Juel Bitsch, R., 2004. 10,000 years of climate change and human impact on the environment in the area surrounding Lejre. J Transdiscip. Environ. Stud. 4 (1), 1–27.
Schwarze, F., 1994. Wood rotting fungi: *Fomes fomentarius* (L.:Fr.) Fr.: hoof or tinder fungus. Mycologist 8 (1), 32–34.
Skirgiełło, A., 1961. Ascomycetes, Basidiomycetes. The fossil flora of Turów near Bogatynia II (in Polish). *Prace Muzeum Ziemi* 4 (Prace Paleobotaniczne) 5–12.
Speranza, A., van der Plicht, J., van Geel, B., 2000. Improving the time control of the Subboreal/Subatlantic transition in a Czech peat sequence by 14C wiggle-matching. Quatern. Sci. Rev. 19 (16), 1589–1604. https://doi.org/10.1016/S0277-3791(99)00108-0.
Starkel, L., Michczyńska, D.J., Krąpiec, M., Margielewski, W., Nalepka, D., Pazdur, A., 2013. Progress in the holocene chrono-climatostratigraphy of Polish territory. Geochronometria 40 (1), 1–21. https://doi.org/10.2478/s13386-012-0024-2.
Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores 13, 615–621.
Straus, A., 1952. Beiträge zur Pliocänflora von Willershausen III. Die niederen Pflanzengruppen bis zu den Gymnosperm. Paleontographica 93 B(1–3), 1–44.
Smieja-Król, B., Fiałkiewicz-Kozieł, B., 2014. Quantitative determination of minerals and anthropogenic particles in some Polish peat occurrences using a novel SEM point-counting method. Environ. Monit. Assess. 186 (4), 2573–2587. https://doi.org/10.1007/s10661-013-3561-0.
Troels-Smith, J., 1955. Karakterisaring af Løse Jordarter (Characterisation of unconsolidated sediments). *Danmarks Geologiske Undersøgelse* IV 3, 1–73.
Van Geel, B., Buurman, J., Waterbolk, H.T., 1996. Archaeological and palaeoecological indications of an abrupt climate change in the Netherlands, and evidence for climatological teleconnections around 2650 BP. J. Quatern. Sci. 11 (6), 451–460.
Van Gijn, A., 2010. Not at all obsolete! The use of flint in the Bronze Age Netherlands, in: Eriksen, B.V., (Ed.), Lithic technology in metal using societies: Proceedings of a UISPP Workshop, Lisbon, September 2006, Jutland Archaeological Society Publications Vol. 67, Århus: Aarhus University Press, pp. 45–60.
Wanner, H., Solomina, O., Grosjean, M., Ritz, S.P., Jetel, M., 2011. Structure and origin of Holocene cold events. Quatern. Sci. Rev. 30 (21–22), 3109–3123. https://doi.org/10.1016/j.quascirev.2011.07.010.
Weiner, J., 1997. Pyrite vs. marcasite/ Or : is everything that glitters pyrite ? (with a structured bibliography on firemaking through the ages). Les Chercheurs de la Wallonie 37, 51–80.
Weiner, J., 2012. Feuerschlagsteine und Feuererzeugung. In: Floss, H. (Ed.), Steinartefakte vom Altpaläolithikum bis in die Neuzeit. Tübingen Publications in Prehistory. Kerns Verlag, Tübingen, pp. 943–960.