

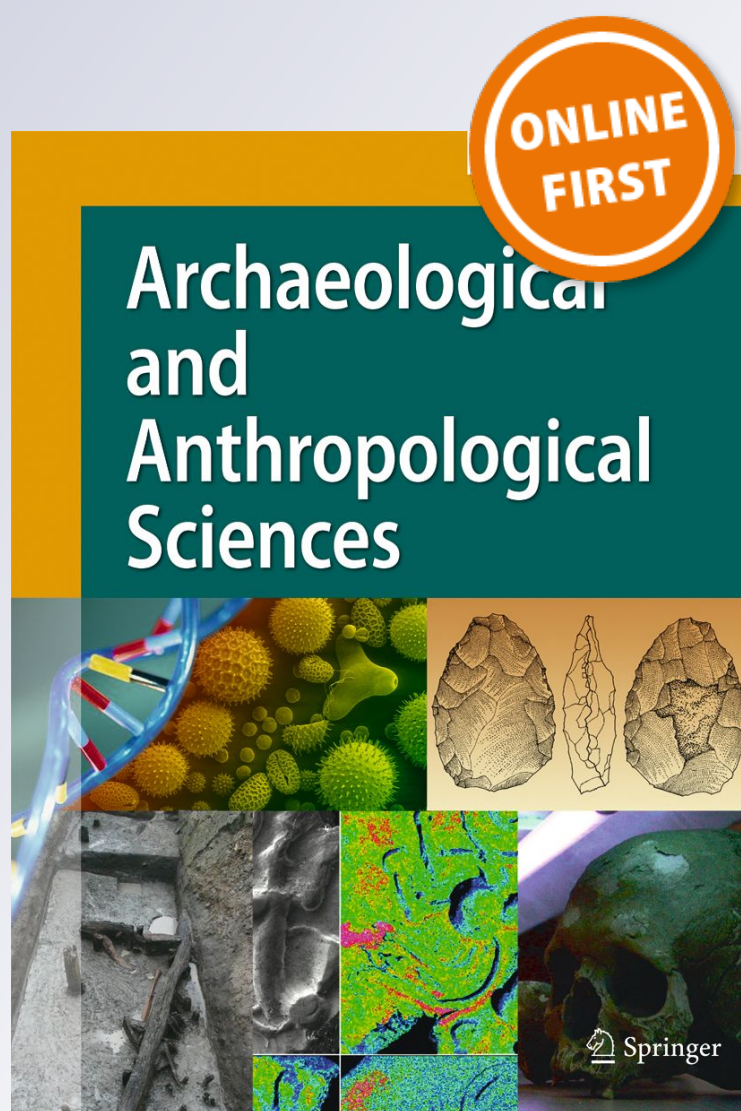
*Settlement activity in later prehistory:  
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# Settlement activity in later prehistory: invisible in the archaeological record but documented by pollen and sedimentary evidence

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## Abstract

The paper deals with landscape and settlement development between ca. 300 BC and AD 600 in a defined area of the northern Czech Republic. Despite favourable natural conditions, human occupation of the area did not begin until the end of the first millennium BC. Natural soil and vegetation development therefore lasted longer than in the traditionally settled lowland areas. Initial settlement activity from the La Tène period caused substantial erosion of deforested luvisols and retisols, well-documented by an accumulation of eroded soil horizons in a local wetland. The erosion process continued for more than 500 years following the end of the La Tène settlement, despite the fact that archaeological research revealed no reliable evidence of occupation prior to the twelfth century AD. Pollen and sedimentary records from the wetland, however, clearly indicate the existence of settlement activity during the “archaeologically invisible” Roman and Migration periods. This case is not unique and underlines the importance of environmental analysis for the detection of settlement history, particularly during periods of poor archaeological visibility or in places that are difficult to research using standard archaeological methods. The change in conditions after the first deforestation and subsequent late prehistoric settlement triggered the degradation of the deforested luvisols and retisols and led to the diversification of the soil cover, which now also includes regosols, gleysols, and truncated luvisols and retisols.

**Keywords** Soils · Sediments · Palynology · Archaeology · Human impact · Late Holocene · Migration period

## Introduction

The character of the landscape during the Holocene was strongly affected by changes in vegetation cover, subsequent soil erosion, and sediment deposition. The two main influences on these processes were climate and anthropogenic impact. Since the Mid-Holocene (Neolithic), the latter has been the dominant factor, which has often made the climatic influence difficult or even impossible to detect (Zolitschka et al. 2003; Leopold and Völkel 2007a). It is therefore necessary to understand the

mechanism, rate, and magnitude of environmental changes caused by humans during various phases of (pre)history.

For this reason, we need to determine the extent and intensity of settlement activity within various time periods, and the types of subsistence practice that make the greatest contribution to changes in the prehistoric landscape. Direct evidence of subsistence strategies can be taken from the archaeological record. In the Early Holocene, exploitation by hunter-gatherers might have caused changes in composition of forest tree species (Davies et al. 2005; Holst 2010). The introduction of agro-pastoralism resulted in partial deforestation, the creation of fields and pastures, and an increase in forest exploitation for a variety of purposes (Dreslerová 2012). However, because of differences in archaeological visibility, that is, the varying ability to detect archaeological evidence of human activity from different archaeological periods, contexts, and environments, archaeological research alone is not sufficient for revealing the extent of these supposed landscape changes. Archaeological visibility depends on survey strategy and intensity, the chrono-typological resolution of features from a given period, and feature visibility, which is in turn influenced

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by cultural behaviour and archaeological depositional and postdepositional transformations (Demján and Dreslerová 2016). The available archaeological information must therefore be understood as only a small fragment of the historical reality. Furthermore, the number and size of fields, pastures, and other elements of the cultural landscape are often unknown because of limited information concerning population density. Estimates of these commodities have largely been made through the use of economic models (e.g. Dreslerová 1995; Ebersbach 2005; Baum 2014; Danielisová and Hajnalová 2014).

Similarly, palynology involves a qualitative interpretation of vegetation using pollen data (e.g. the identification of plant types or changes); a quantitative interpretation is reached with the help of modelling (Sugita 2007a, b; Abraham et al. 2014, 2016). Colluvia and buried soil horizons provide evidence of forest exploitation and deforestation (Evans 1990; Rasmussen and Bradshaw 2005; Dix et al. 2005; Rommens et al. 2006; Dotterweich et al. 2013; Leopold and Völkel 2007b; Reiss et al. 2009; Leopold 2011; Kittel 2014). Soil degradation implies a long-term decline in soil productivity and quality (Lal 2001), and can also lead to changes in soil type. Such changes are generally described in publications which outline soil classification systems (e.g. IUSS Working group, WRB 2015) but they are specifically described only rarely in studies of the development of the original local soil types (Zádorová et al. 2013). One reason may be a lack of suitable localities where the beginnings of human impact can be clearly defined and dated.

A site matching the required parameters was discovered during a research into a residual boreal forest in northern Bohemia (Meduna and Sádlo 2009). Pollen profiles (important as anthropogenic indicators) taken from the sedimentary infill of a wetland near the village of Okna (Fig. 1) suggested sudden changes in the local landscape during the closing centuries of the first millennium BC, and a massive erosion event of silt particles covering several metres of the wetland peat infill. No evidence of previous or contemporaneous settlement or other human activity was known up to this point within several kilometres of the site. During a targeted surface survey of an area around the wetland, pottery fragments were found ca. 1.5 km from the pollen core. Subsequent small-scale archaeological excavations of the site revealed a La Tène period settlement which was typologically dated to a relatively narrow window between 130/110 and 50/25 BC (Dreslerová et al. 2013). The date roughly corresponded with the beginning of an accumulation of a silt layer overlapping several metres of peat in the wetland dated to ca.  $246 \pm 84$  BC (UGAMS-3538, Table 1). The situation was remarkably similar to the erosion event from the same prehistoric period which occurred after the construction of the Celtic *Viereckschanze* (rectangular enclosure) at Poign near Regensburg, southern Germany. In this location, well-developed calcic luvisols in the vicinity of the structure had

been deforested and ploughed for the first time, and this triggered massive erosion (Leopold and Völkel 2007b). In light of this discovery, we considered the silty-textured erosion layer detected in the Okna wetland to be the result of a single event caused by the relatively short existence of the La Tène settlement. The theory was strengthened by the fact that there was no evidence of further human activity in the area until the twelfth century AD. However, an additional sample taken from an organic layer above the silt deposition was radiocarbon dated to ca. 500–550 AD, which suggests that the accumulation of silt particles in the wetland would have lasted for at least 500 years following the demise of the only known settlement in the region. Working on the assumption that the deforested area should have re-forested (in these geographical conditions) shortly after the abandonment of the La Tène site, the erosion of the soil particles and their accumulation in the wetland should have gradually ceased within a period of a few decades. It became clear that either the history of settlement in the region or the mechanics of the erosion events was more complex than expected.

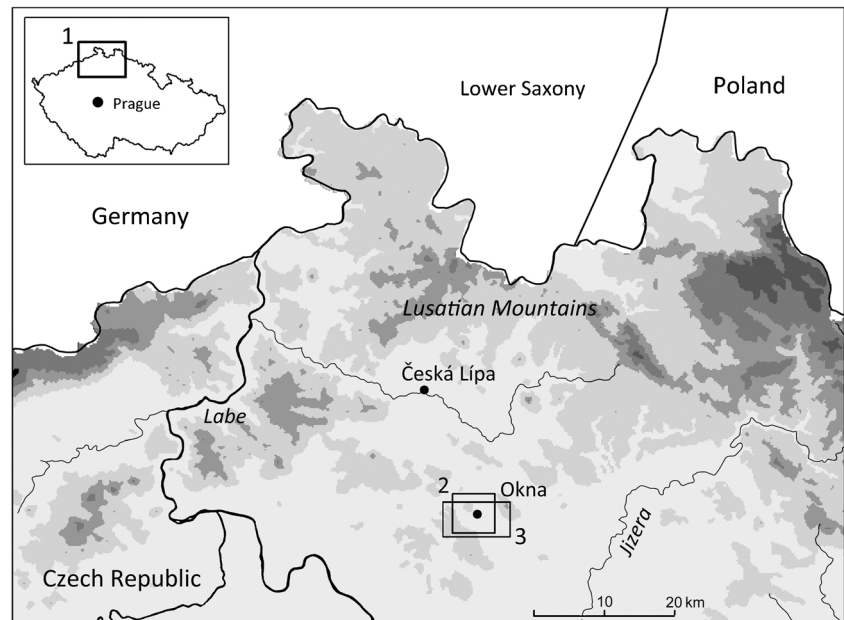
To explore the possible causes of the observed inconsistency in the proxy data, further research (using archaeology, pedology, sedimentology, and palynology) was carried out in order to (1) revise our archaeological knowledge of the region; (2) understand the causes and dynamics of the erosion events, soil development, and the duration of pedogenetic processes in the region; and (3) generalise the results of the regional research to help understand the interplay between the various factors affecting the development of the landscape.

## Regional settings

The Okna site lies in northern Bohemia (the western part of the Czech Republic), ca. 20 km south of the town of Česká Lípa (Fig. 1). The research area is located in a specific region; the natural and cultural history of which differs from the majority of similarly located Bohemian lowland areas where agricultural activity had already begun during the Neolithic (Dreslerová et al. 2013). Here, the agro-pastoral activities started not before the end of the Bronze Age, and therefore, natural soil and vegetation development lasted several thousand more years.

The Okna site is situated in a belt of agricultural land several kilometres wide and within a forested landscape. It extends from the fertile middle Jizera region in the south-east towards Česká Lípa and further north towards the Lusatian Mountains. It is partially covered by good agricultural soils developed on quaternary loess overlying Cretaceous quartz sandstones, but evidence of prehistoric settlement activity is scarce (Dreslerová et al. 2013; Fig. 5). The section of forest to the east and north belongs biogeographically to the hemiboreal taiga, one of the most south-westerly disjunctive patches of such forest in Central Europe (Novák et al. 2012a,

**Fig. 1** Map of the study area. 1—area displayed in Figs. 1 and 5, 2—area displayed in Figs. 2 and 3, 3—area displayed in Fig. 4



b), with extremely poor podzolic soils developed on Cretaceous quartz sandstones. A typical feature of the landscape is the sparsity of rivers and a large area of wetlands with a minimal watercourse gradient because of the high permeability of the weathered sandstones (Meduna and Sádlo 2009).

The wetland within the Okna site is situated at the edge of the Robečský stream (Figs. 2, 3, and 4). The stream's catchment covers an area of 2589 ha, and the present-day wetland covers 10 ha. The local erosional base is at 277 m a.s.l. The

underlying sand is covered with a thick deposit of organic matter which within a short space becomes, in its upper parts, mostly inorganic sediment.

According to the First Military Survey of the Austrian Empire from 1781, there was once a body of water where the current wetland now stands; cadastral maps from 1843 record wet meadows at the same location.

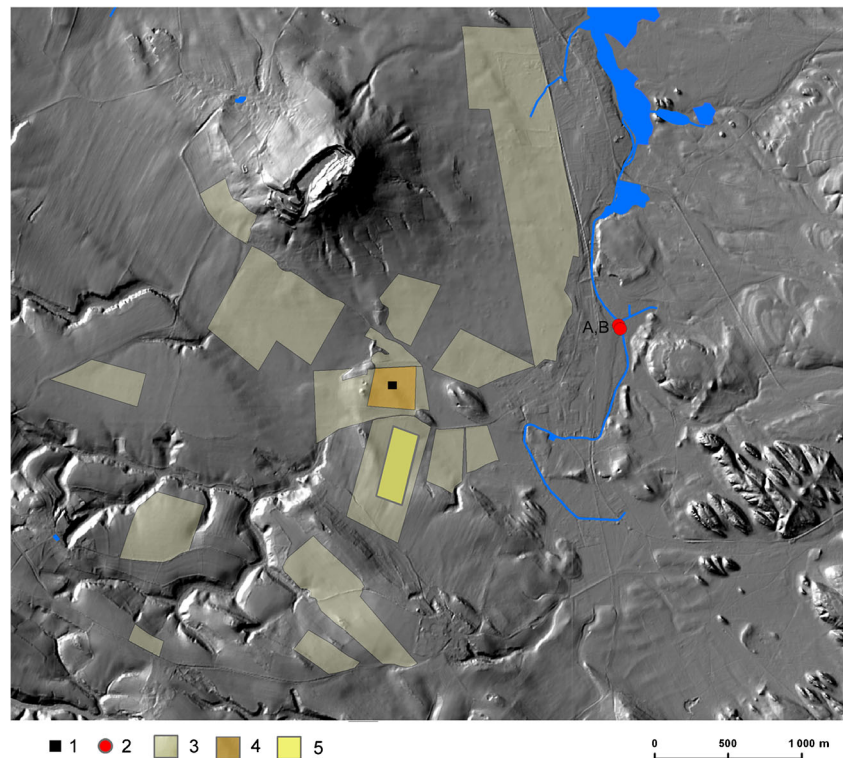
The area has an average annual precipitation of 600–650 mm, and an average annual temperature of 7–8 °C

**Table 1** Overview of radiocarbon dates. For pollen profile B, radiocarbon dates were taken from Dreslerová et al. (2013). The measurements were made in the radiocarbon laboratory in Poznań (AMS method), the University of Georgia (AMS method), and in the CRL radiocarbon laboratory in Prague (AMS and DCM/decay counting methods). The

radiocarbon dates were calibrated using the Cal Pal Online programme (Danzeglocke et al. 2012). Archaeological chronology in pollen diagrams is based on the depth-age model Clam: linear interpolation between dated levels (Blaauw 2010)

| Depth (cm)      | Pollen profile letter | Laboratory number | Method | Radiocarbon age (BP) | Calendric age BC/AD (68% range) | Material                       |
|-----------------|-----------------------|-------------------|--------|----------------------|---------------------------------|--------------------------------|
| 80–82           | B                     | Poz-80561         | AMS    | 740 ± 30             | 1261 ± 15 AD                    | Charcoals, <i>Carex</i> fruits |
| 90–92           | B                     | Poz-67091         | AMS    | 980 ± 30             | 1067 ± 47 AD                    | Charcoals, charred bark, twig  |
| 114–115         | B                     | 16_038            | AMS    | 2041 ± 37            | 58 ± 53 BC                      | Sediment                       |
| 124–125         | B                     | 16_039            | AMS    | 2238 ± 36            | 302 ± 64 BC                     | Sediment                       |
| 126–128         | B                     | Poz-67092         | AMS    | 2325 ± 30            | 397 ± 9 BC                      | Charcoals, pine needles        |
| 147–149         | B                     | Poz-80560         | AMS    | 2905 ± 30            | 1105 ± 57 BC                    | Charcoals, <i>Carex</i> fruits |
| 61–62           | A                     | Poz-33652         | AMS    | 770 ± 35             | 1244 ± 21 AD                    | Plant remains                  |
| 77–78           | A                     | Poz-33653         | AMS    | 1390 ± 80            | 647 ± 71 AD                     | Charcoals                      |
| 100–101         | A                     | UGAMS-3538        | AMS    | 2150 ± 25            | 246 ± 84 BC                     | Charcoals                      |
| 177–178         | A                     | Poz-33654         | AMS    | 3900 ± 60            | 2378 ± 82 BC                    | Charcoals, plant remains       |
| 215–230         | A                     | Crl-7070          | DCM    | 5869 ± 92            | 4737 ± 114 BC                   | <i>Alnus</i> wood              |
| 284–285         | A                     | Poz-33655         | AMS    | 8860 ± 90            | 7997 ± 170 BC                   | Charcoals, plant remains       |
| Test pit number |                       |                   |        |                      |                                 |                                |
| 200–210         | 10                    | Crl-16199         | AMS    | 1375 ± 25            | 649 ± 9 AD                      | Organic sediment               |
| 95–105          | 11                    | Crl-16200         | AMS    | 1525 ± 22            | 518 ± 47 AD                     | Organic sediment               |

**Fig. 2** Detailed map of the study area. 1—archaeological site (excavations), 2—pollen profiles A and B, 3—surface survey areas, 4—area with the La Tène pottery fragments, 5—area with pottery fragments of ill-defined age



(Tolasz et al. 2007). The topography of the catchment is asymmetric. The gently rolling landscape of the catchment on the left bank of the Robečský stream is composed of sandstone covered by quaternary loess, where luvisols and retisols are dominant. At present, arable land is dotted with remnants of mixed

woodland dominated by oak, pine, and hornbeam. The catchment on the right bank is characterised by steep quartz-sandstone rocks and plateaux covered mostly by arsenic podzols and dystic cambisols. The vegetation is predominantly pine forest. The sandstones are penetrated by tertiary volcanic

**Fig. 3** Detailed map of the study area of the Robečský stream. LS-factor map indicating erosion risk according to cumulative slope length and steepness derived from DEM. 1—pollen profiles A and B, 2—pedological test pits, 3—pedological cores, 4—selected pedological cores in the wetland, 5—soil catenae, 6—former wetland

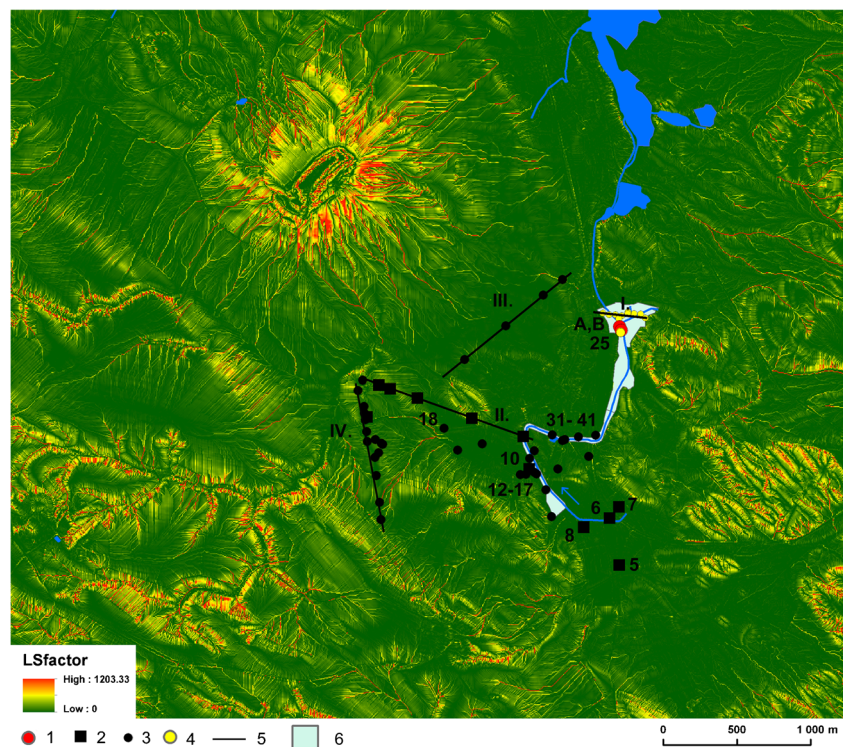
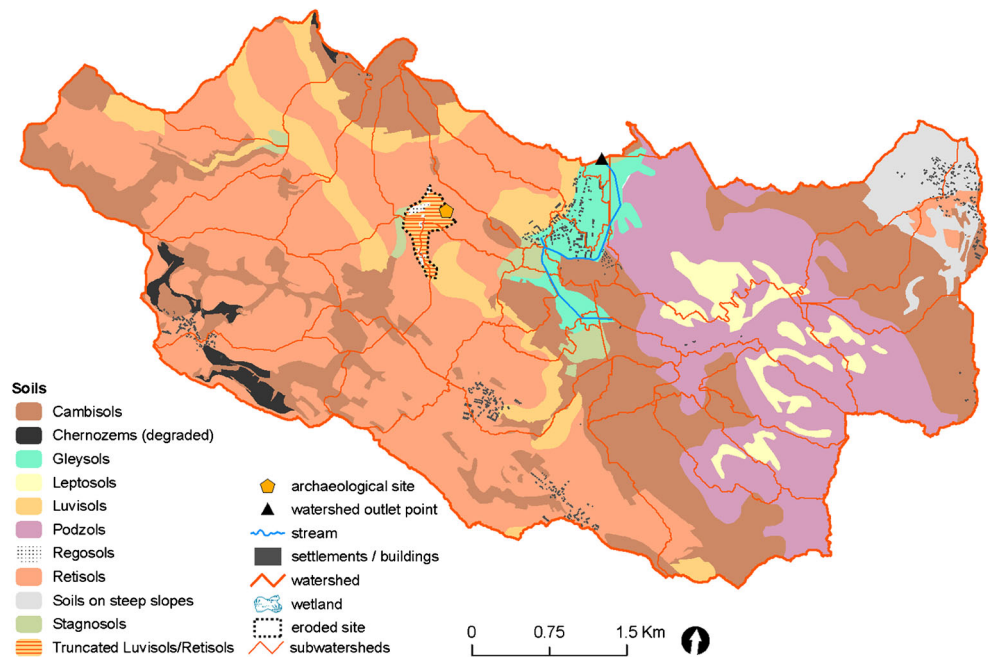


**Fig. 4** Pedological map of the catchment and sub-catchments (A–D) of the Robečský stream. According to the database of the Evaluated Soil Ecological Units produced by the Research Institute for Soil and Water Conservation (<https://bpej.vumop.cz/>) corrected during the field survey



rocks in several places (e.g. Tachovský vrch, Bezděz; Czech Geological Survey 2016). Mixed woodland with spruce, beech, oak, hornbeam, and other deciduous trees is typical for enclaves of volcanic bedrock (Dreslerová et al. 2013).

cultivated fields with conditions conducive to being walked upon (such as weathered, preferably moist surfaces) were surveyed. Altogether, an area of ca. 316 ha was surveyed (Fig. 2), some parts repeatedly.

## The prehistorical and historical setting

The area lies on the outskirts of an ancient traditional settlement zone (Fig. 5). The few traces of human activity from the Upper Palaeolithic until the end of prehistory are mainly from rock shelters, or consist of isolated finds such as single stone axes, coins, and bronze and gold objects. It seems the area was used simply as a transit zone between present day Bohemia and Lower Saxonia.

The oldest written accounts of the wetland and its surroundings are from 1185 and relate to the church or farmstead of Bezděz, probably lying beneath the castle of the same name 3.2 km from the wetland. The first written record of the village of Okna (the name originally means wet area, mire or a pool) is from 1352, but according to the Privilege of Bezděz town, the surroundings had been cultivated as an extensive open-field system prior to 1290 (Dreslerová et al. 2013).

## Methods

### Archaeology

A surface survey of the Robečský basin was carried out over several seasons (from 2009 to 2012, and 2015 to 2016). Only

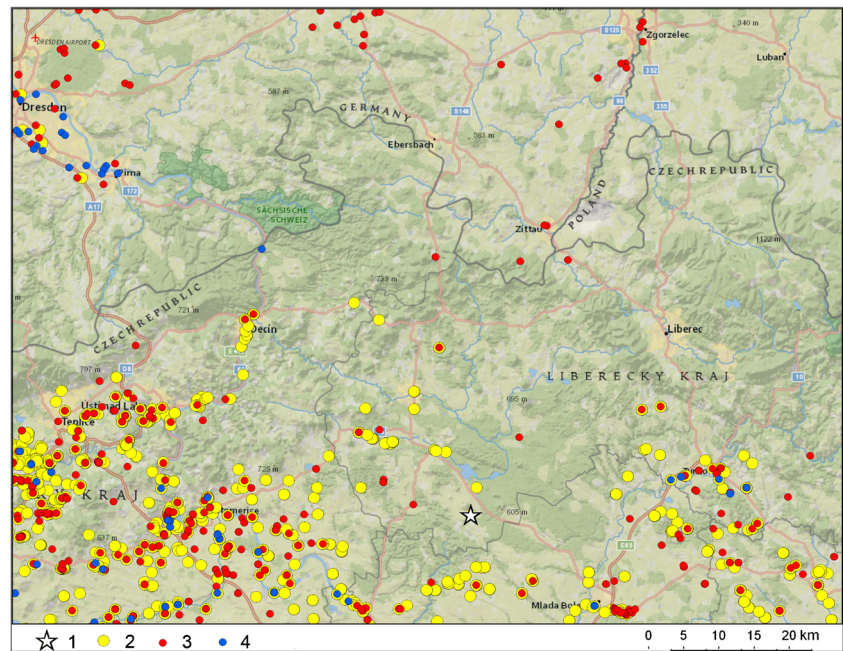
## Pedology and sedimentology

Some 55 pedological cores were drilled by hand gouge augers (3 and 7 cm in diameter) in the wetland to determine the stratigraphy, the depths of the sedimentation layers, and particle size distribution (Fig. 3). A total of 12 manually dug pedological test pits (hereafter referred to as test pits) and more than 40 pedological cores were drilled in the loess part of the catchment in the wider area of the La Tène site in order to detect the source of the eroded material and the possible degradation of the soil by water erosion (Fig. 3).

Samples from each horizon of the test pits were air-dried and passed through a 2-mm sieve. The particle size distribution was measured by laser granulometry (laser granulometer Helos/KF Sympatec) after destroying any soil organic matter in the aggregates with  $H_2O_2$ . The samples were also washed in HCl, distilled water, and sodium hexametaphosphate in order to deflocculate the particles. The texture results are shown in Figs. 6 and 8 using the USDA soil texture classification system for the classification of textural classes. The samples were also tested with 10% HCl for the presence of carbonates.

Samples for micromorphological analysis were taken from wetland profile B into up/down-oriented boxes. Two samples were from the sediment layer between the organic layers; four samples were from the upper sediment layer. After drying, the samples were impregnated under vacuum with a synthetic

**Fig. 5** Margins of the 1—La Tène/pre-Roman, 2—Roman, 3—Migration period settlement in Northern Bohemia and Lower Saxonia, 4—the Okna site. Archaeological data according to Heynowski and Reiss (2010) and Archaeological map of the Czech Republic (Institute of Archaeology of the CAS, Prague)



resin (Bonneau and Souchier 1994) and cut into thin sections ( $5 \text{ cm} \times 2 \text{ cm} \times 20 \text{ }\mu\text{m}$ ).

Soils and their horizons were described according to the World Reference Base for Soil Resources (WRB 2015). Topographic potential for erosion and deposition, known as the LS factor, was derived from DEM with a pixel size of 5 m according to the equation proposed by Mitasova et al. (1996) (Fig. 3).

## Palynology

Two pollen profiles from the Okna wetland (Figs. 2, 9, and 10) were analysed. Prospecting coring was first performed in 2007, and profile A was taken using a piston coring device where the accumulation of sediments was at a maximum. Pollen analysis was carried out on organic sections of the profile only. Later, profile B was taken ca. 2 m from profile A. It was taken primarily for high resolution analysis of clay/silt sections representing erosion events during the time period relevant to the research. The use of a hand corer operated by a hammer prevented the contraction of sediment in profile B (contraction had occurred with profile A). We cannot, therefore, simply match the depths in the two profiles.

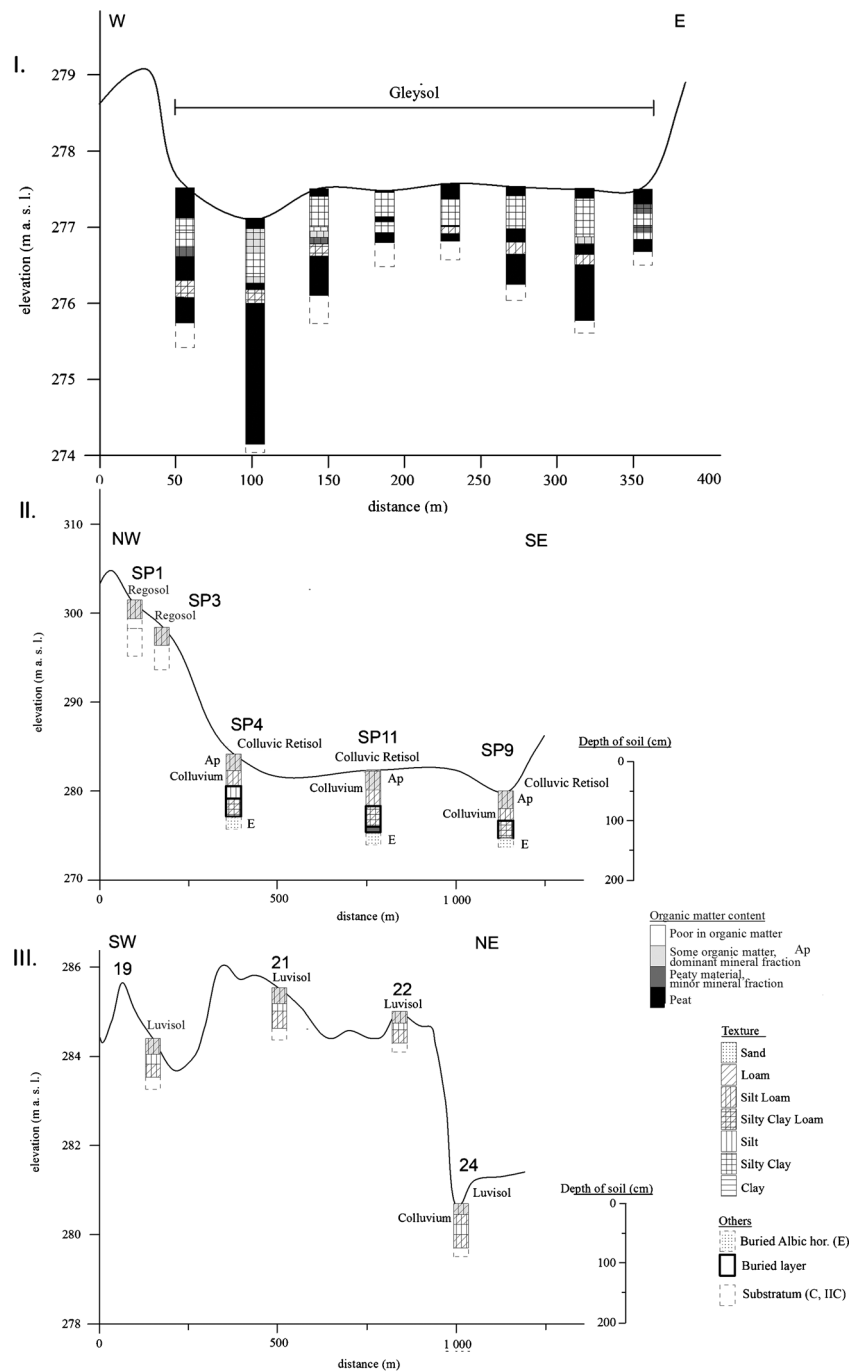
During laboratory preparation of the samples, we followed the methodology of Faegri and Iversen (1989). Sediments were disintegrated in 10% KOH, carbonates were removed by applying 10% HCl, silicates were dissolved in concentrated HF, and most of the organic material was removed by acetolysis, using acetic anhydride and sulphuric acid in a ratio of 1:9. Some samples were extremely low in pollen, but in certain others, more than 500 grains were counted. Pollen types were defined according to Punt (1980), Reille (1992), and Beug (2004).

The pollen diagrams were based on a total terrestrial pollen sum from which the following taxa were excluded: *Alnus*, *Salix*, all aquatic and wetland herbs, and all non-pollen objects. Microscopic charcoal particles were counted using the point-count method (Tolonen 1986), and the charcoal sum was proportional to the pollen sum in the same sector of the slide. The curves of all pollen and non-pollen objects excluded from the sum were calculated as percentages of the total terrestrial pollen sum. Pollen diagrams were plotted using Tilia 1.7.16 software (Grimm 1992). The radiocarbon dates for the profiles are presented in Table 1 alongside all other relevant information.

## Results

The enlarged surface survey of the catchment confirmed our hypothesis that prehistoric settlement took place over a small area of several hectares. Surface ceramics were found repeatedly at the La Tène site and for the first time in close proximity (Fig. 2). During examination of the pottery from the new location, we realised that dating would be problematic. The majority was securely dated to the twelfth, thirteenth, and fourteenth centuries AD and later, suggesting the existence of a village or group of farmsteads prior to the foundation of the village of Okna. The remaining fragments became the subject of disagreement between the researchers. While some dated all fragments to the Medieval period, others classified the disputed sherds as from later prehistory (ca. AD 1–600) or the Early Middle Ages. Environmental research therefore remained the only

**Fig. 6** Soil catenae. I—soils and sediments in the wetland, II—soils at the La Tène site and environs, III—soils west of the wetland



\* texture is presented after labor analysis through USDA triangle

reliable source of any kind of proof of the existence or otherwise of a later prehistoric settlement.

## The wetland

Tertiary sands at the base of the wetland are covered by peat, which began to be laid down ca. 8000 BC. Drilling cores taken from various points on the wetland (Fig. 6I) indicate that the peat layer varies in thickness between 10 and 200 cm. Radiocarbon dating of profiles A and B suggests that peat growth was

interrupted ca. 330 BC (Figs. 9 and 10). It was subsequently covered by a homogenous sediment of a silt or silt loam texture (hereafter referred to as the first silt layer), mostly formed of silt (60–70%), clays (30–40%), and a very small amount of sand (Figs. 7 and 8). This layer, with a particle size distribution typical of loess (Haase et al. 2007), reaches a depth of up to ca. 30 cm. The location of the various layers confirms that loess was deposited in the wetland only during the Holocene, and not during the deposition of the loess in the eastern parts of the catchment in the previous Pleistocene Pleniglacials. In some places, a thin layer of

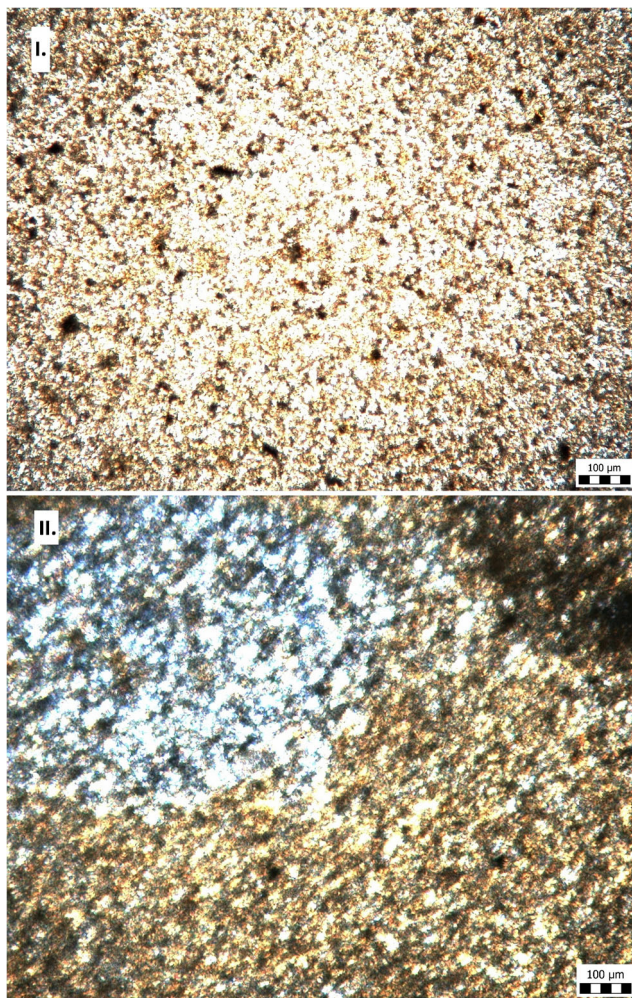


**Fig. 7** Micromorphological observation from profile B in the wetland: A—homogenous silt layer at a depth of 115–120 cm (layer II. in Lithology in Fig. 10); B—an example of protrusion in the silt sediment at a depth of 70–75 cm (layer IX. in Lithology in Fig. 10)

charcoal was observed between the peat and the first silt layer, which may be indicative of anthropogenic activity (forest clearing) in the catchment.

Radiocarbon dating places the end of sedimentation of the first silt layer in profile A at ca. AD 647  $\pm$  71 (Fig. 9, Table 1), and in profile B at ca. AD 530 (Fig. 10, Table 1). After this date, the deposition of a second organic layer, now mixed with inorganic particles, began. Finally, this layer was covered by a second, thick inorganic layer, which according to micromorphological observations is less horizontally homogeneous in particle size distribution (texture) than the first silt layer (Figs. 7 and 10: Lithology, layer IX.).

The second inorganic layer shows variations in sedimentation dynamics both horizontally and vertically. A silty texture is still dominant, forming 60–80% of the material, but the proportion of clays varies, according to depth, between 20 and 40% (Fig. 8). The proportion of sand is still very low. The texture of sediment can be classified as silty clay loam

or silty clay. The high spatial textural variability both horizontally and vertically makes any relationship between depth and particle size distribution impossible to determine. The silty layer became the parent material of the haplic gleysols and histic gleysols found in the current wetland. These soils are overgrown with *Phragmites* (pollen type Poaceae).

The average thickness of both inorganic sediment layers in the wetland is 0.79 m, which means the volume of deposited material in 10 ha of wetland is ca. 79,000 m<sup>3</sup>. A narrow strip of texturally identical inorganic sediments follows the current stream bed upstream from the wetland (Fig. 3). Its stratigraphy is similar to the sediment in the wetland. At about 30–40 cm, a thick organic layer was documented in pedological cores 35, 37, 38, and 41, and in test pit 10 (Fig. 3). This layer varied in depth between 200 and 275 cm. A second organic layer was found in profile 37 at a depth of 325–350 cm. The bulk sample from an organic layer in soil pit 10 (Fig. 3), lying at a depth of 200–210 cm, was dated to AD 649  $\pm$  9 (Table 1). The strip, which could be an extension of the original wetland, is now covered by stagnosols and gleysols. It covers ca. 5 ha and is filled with 1 m of silt/silt loam sediment with an average volume of ca. 50,000 m<sup>3</sup>.

Interpretation of the pollen data from the wetland takes account of the location of the pollen site at an important boundary between two contrasting biotopes (Novák et al. 2012a, b; Dreslerová et al. 2013). We hypothesise that almost all the changes in vegetation mentioned in this study took place in the catchment on the left bank of the Robečský stream. Conversely, the landscape of the right bank, mostly pine forest, has barely changed since the Early Holocene (Dreslerová et al. 2013).

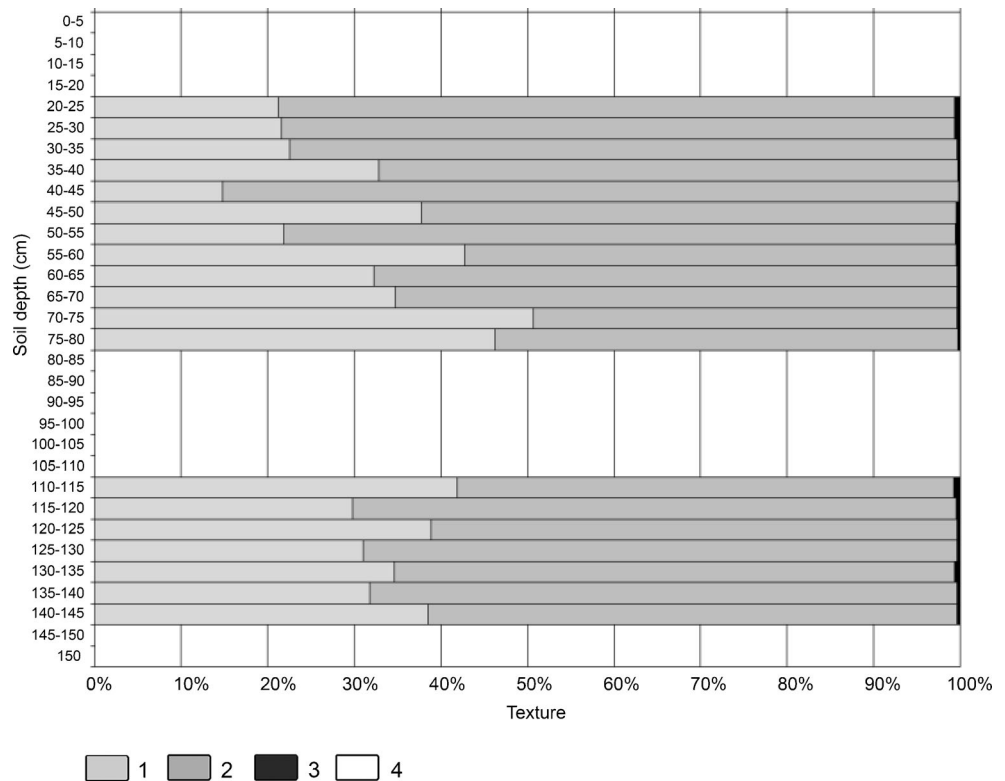
Pollen profile A (Fig. 9, Table 1) reflects a continuous vegetation history from ca. 8000 to around 1000 BC. The period between ca. 8000 and 5700 BC (284–242 cm) is characterised by an expansion of mixed deciduous forest with some admixture of *Picea*. Anthropogenic indicators including *Cerealia* sp. are likely to be a result of natural development as they could have grown in many types of open habitat as part of the natural vegetation.

During the period ca. 5700–3600 BC (242–202 cm), there are elements indicative of an open habitat suggested by the pollen of Poaceae, and more specifically by the presence of *Juniperus* and *Calluna vulgaris*. Forest vegetation on the left bank of the Robečský stream was dominated by mixed deciduous forest with *Quercus*, *Corylus*, *Fraxinus*, *Tilia*, *Ulmus*, and *Acer*.

The decline in *Corylus*, *Ulmus*, *Tilia*, *Quercus*, and *Fraxinus* and the expansion of *Fagus*, *Abies*, and *Carpinus*, starting around ca. 1500 BC (146 cm), corresponds with vegetation common elsewhere in Central Europe. The increase in pollen of *Plantago lanceolata* and Chenopodiaceae probably indicates the onset of human activity, such as pasturing (Fig. 9).

The high-resolution pollen record in profile B reflects a vegetation history from ca. 1100 BC (Fig. 10, Table 1). The

**Fig. 8** Textural composition of inorganic sediment from pedological core 25 (Fig. 3) situated ca. 60 m far from the pollen profile A and B. 1—clay, 2—silt, 3—sand, 4—organic. Lower inorganic layer corresponds roughly to layers II.—IV., and upper inorganic layer to layers VI.—IX. in Lithology in Fig. 10



vegetation development is continuous up to ca. 330 BC (125 cm) and has almost the same characteristics as in the previous period. Only *Rumex acetosa* type appeared among secondary anthropogenic indicators between ca. 600 and 330 BC. An increase in the percentage of *Calluna vulgaris* and *Betula* could indicate some kind of human settlement activity, but the fact that the peat in this area is purely organic, with no indication of erosion, leads us to believe that any such human impact is either from a somewhat distant settlement or from some other kind of (non-settlement) human activity.

A large change in sedimentation dynamics and vegetation development is evident at ca. 330 BC (125 cm). There is a sharp boundary between organic sediment and silt, and a variable but mostly minor addition of organic matter (Fig. 10).

In the mostly inorganic sediment, a number of secondary anthropogenic indicators, such as *Alchemilla*, *Papaver rhoeas* type, *Polygonum aviculare*, *Persicaria maculosa* type, *Plantago major*, *Matricaria* type, and *Cerastium* type, appeared for the first time. The percentage of other weed and ruderal taxa, such as *Artemisia*, *Chenopodiaceae*, *Plantago lanceolata*, *Urtica*, and *Rumex acetosa* type substantially increased. Apart from the pollen of *Cerealia*, agricultural land is indicated by spores of the hornwort *Anthoceros*. Pasture is suggested indirectly by a high proportion of *Sporormiella*, an Ascomycete which grows on dung. Another Ascomycete, *Gelasinospora*, is associated with burned surfaces, which could be connected to the high charcoal counts in the same section (Fig. 9).

Most of the anthropogenic indicators abruptly decline around ca. AD 530 (102 cm, Fig. 10) and remain low until ca. AD 1100 (90 cm; Fig. 10). The sediment in this section of profile B becomes more organic (as described above) suggesting a lower volume of transported inorganic material. This is also evident from pollen data, where there is an increase in the proportion of local pollen taxa such as *Poaceae* (*Phragmites*), *Cyperaceae*, and *Alnus*.

The number of pollen grains in the upper part of profile B (88–70 cm) was very low. Nevertheless, pollen spectra revealed intensive human impact. *Secale cereale* dominates among cereals, and *Centaurea cyanus*, until then occurring only sporadically, seems to have been one of the most common weeds (Fig. 10).

The presence of *Mougeotia* zygospores throughout the whole of profile B indicates periodic flooding and the probable existence of natural pools at the site. The pollen of *Utricularia*, which also grows in standing water, occurs irregularly in both profiles—up to the upper layers in profile B. Both taxa are associated with mildly eutrophicated biotopes.

### Soils and sediments outside the wetland

Pedological investigation of the study region revealed a rather complex soil map. Within a very small area around the La Tène site and the wetland, there is a mosaic of soils comprising retisols, luvisols, regosols, gleysols, cambisols, podzols,

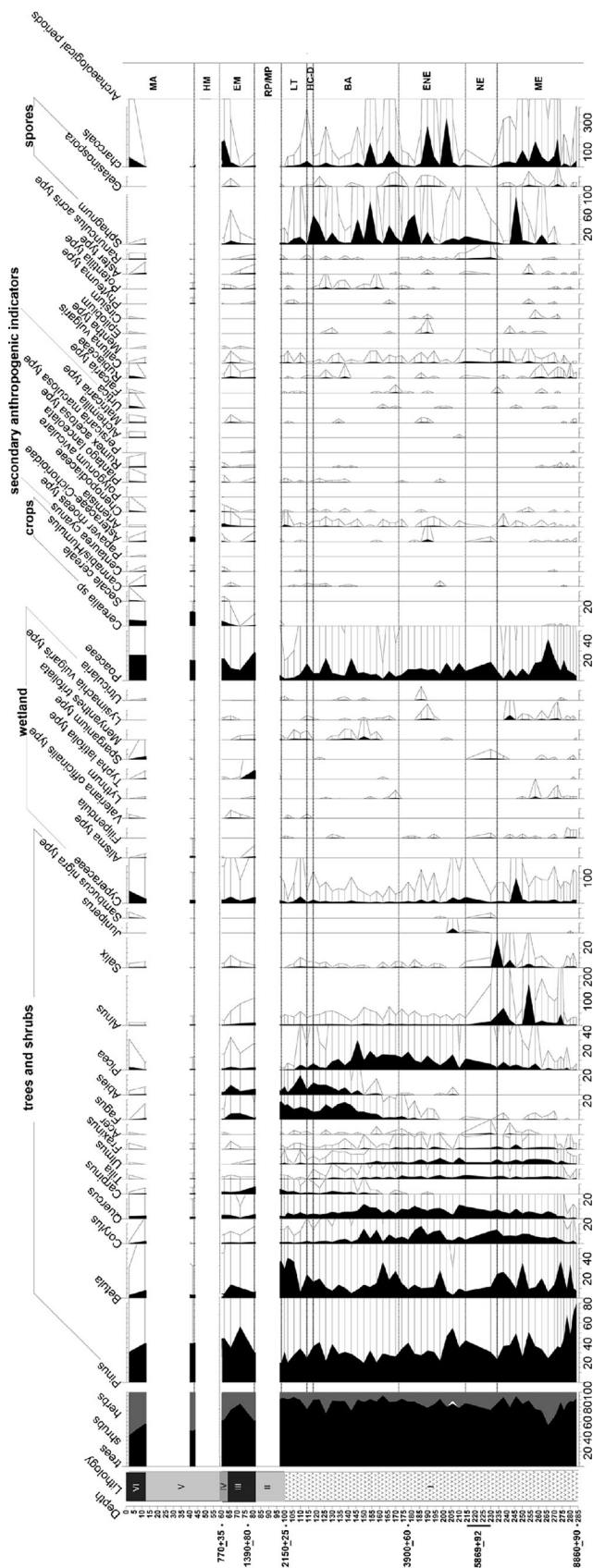


**Fig. 9** Percentage pollen diagram from profile A, selected taxa. Lithology: I—organic sediment (black), II—fine silt with minor organic component (light grey), III—organic layer containing stolons of *Phragmites* (black), IV—fine silt with organic component (dark brown-grey), V—fine silt containing minimum organic matter and pollen (light grey), VI—upper layer of coarse organic matter (black). Archaeological periods: ME Mesolithic, NE Neolithic, ENE Eneolithic, BA Bronze Age, HC-D Hallstatt, LT La Tène, RP/MP Roman and Migration, EM Early Medieval, HM High Medieval, MA Modern Age. Pollen record is absent in the silty layer

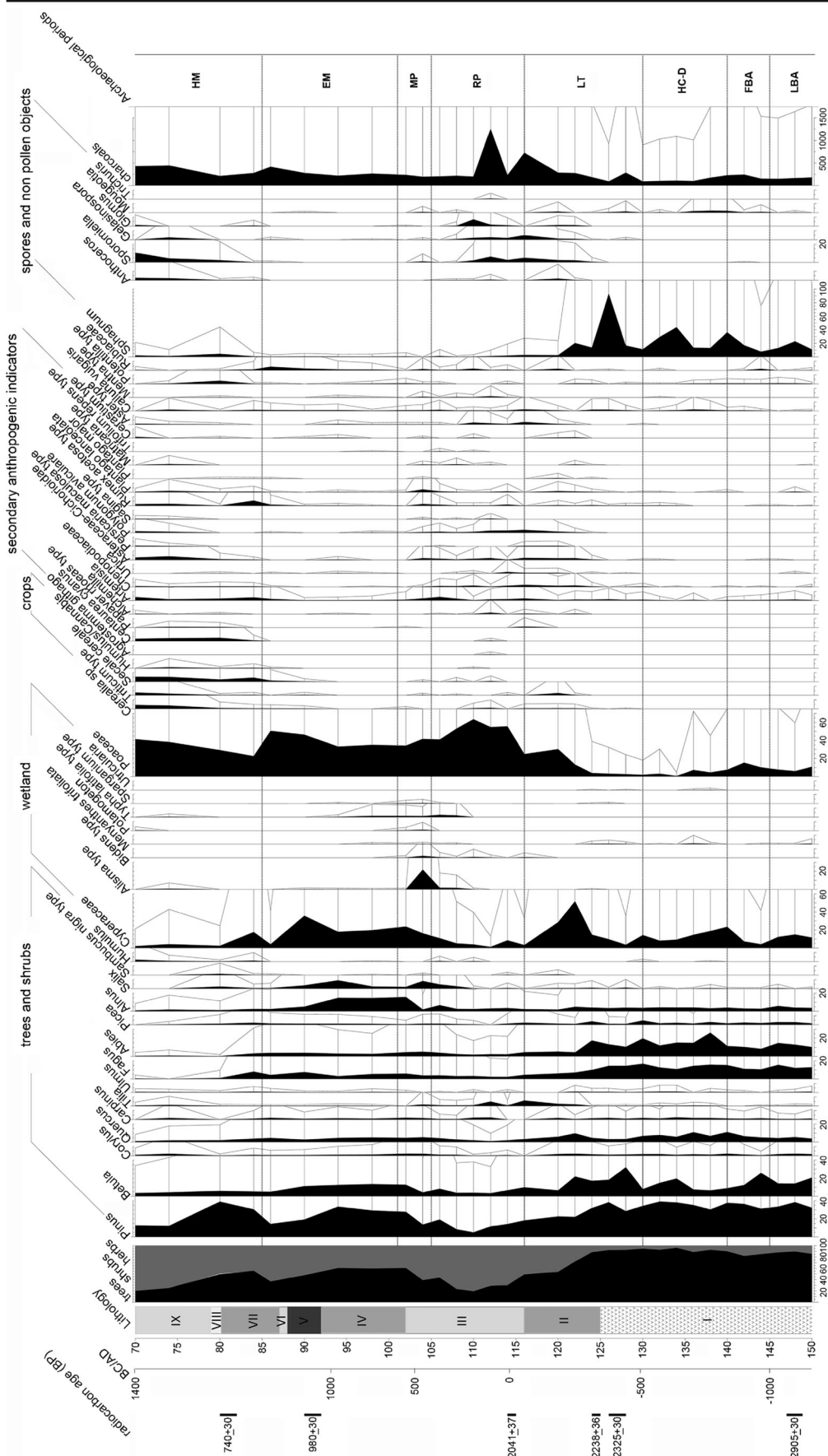


**Fig. 10** Percentage pollen diagram from profile B, selected taxa. Lithology: I organic sediment (black), II fine silt with minor organic component, admixture of very fine sand caused missing pollen grains between 117 and 122 cm (light grey), III fine silt with minor organic component (less than in II) (light grey), IV fine silt with organic component (dark brown-grey), V organic layer containing stolons of *Phragmites* (black), VI clay (rust), VII same as IV, VIII fine silt containing minimum organic matter and pollen (light grey). Archaeological periods: LBA Late Bronze Age, FBA Final Bronze Age, HC-D Hallstatt, LT La Tène, RP Roman, MP Migration, EM Early Medieval, HM High Medieval

stagnosols, and leptosols (Figs. 4 and 6). The causes of this variety are both natural and anthropogenic. Podzols and leptosols on the right bank of the Robečský stream most likely correspond to the natural climatic and geological conditions of the sandstone landscape. The absence of a sandy texture in the wetland sediments, which might have originated in the local underlying sands, indicates that this area was continuously covered by forest, which reduced the amount of erosion. The development of soils on the left bank—the loess-rich section of the catchment—was obviously influenced by human activity, mostly agricultural. The climax soil types are retisol and luvisol (Němeček et al. 2001). Those situated outside the La Tène site, but in similar topographic positions, are well-preserved and show only limited signs of erosion (Figs. 3 and 6III, profile numbers 21, 22). They consist of 25–35 cm of ploughed (Ap) horizon, 20–40-cm albic E horizon, and underlying 40–50 cm thick argic Bt horizon.

The original parent material at the place of the La Tène site was loess. This assumption is based on the evidence that in last the glaciation, the loess in Central Europe deposited either as “cover loess” of constant thickness on plains or alluvial terraces, or on leeward slopes with prevailing wind direction from the west and north-west (Růžicková et al. 2001). As the La Tène site is located directly in such a position, we suppose that loess deposited here as well and its present absence is a consequence of erosion.

Present soils around the La Tène site show truncated soil profiles. Soils are either partially truncated with exposed argic Bt horizon on the surface or completely truncated down to sandstone. The latter implies that whole soil profiles—including the loess parent material—formerly overlying the sandstone were eroded; these sites are now covered by regosols (soil pits 3 and 4). Truncated soils are also found in places where, based on computed LS factor of the RUSLE water erosion model (Fig. 3), there is a very low topographic potential for erosion. The area of truncated soils (regosols and truncated luvisols and retisols) around the La Tène site is ca. 16 ha (Fig. 4). The material from truncated soils was transported downslope, where it is found as colluvium overlying buried luvisols and retisols or is found as inorganic layers in the wetland. The thickness of the colluvium varies from 30 to 95 cm. The colluvium in soil profile 11 overlay a black soil horizon (10 cm thick) containing a high concentration of charcoals (Fig. 6). The dating of the charcoals to AD 518  $\pm$  9 (Table 1) suggests that this horizon represents the original late prehistoric topsoil and that the 95 cm of overlying colluvium was deposited subsequently and is not necessarily very old.

The colluvium downslope from the La Tène site is texturally similar to the wetland inorganic layers and is not enriched by sand despite the presence of regosols. Determining the age of the whole loess soil profile truncation is therefore somewhat problematic. We suggest that the complete denudation of the sandstone, formerly covered by loess, must have occurred relatively recently. The erosion could have been accelerated

by intensive agricultural activity during the twentieth century, as documented in a loess belt in southern Moravia, for example, by Zádorová et al. (2013). The intensive agriculture affected most of the catchment; however, at the La Tène site the thickness of the loess-derived soils was already reduced because of soil erosion during the La Tène phases as a result of local settlement activity. These different temporal starting points of erosion triggered by recent intensive agricultural activity could explain both the current presence of regosols only on the La Tène site and the current absence of a sandy texture in the wetland sediments and colluvium.

## Discussion

New research in the Okna region confirmed a discrepancy between the archaeological and environmental data pertaining to the history of the local landscape. Pollen and sedimentary records suggest two periods of intensive human impact. The first started ca. 330 BC in the La Tène and finished around AD 530 during the Migration period (ca. AD 400–600). After this date, evidence of human activity decreases substantially. The second phase of intensive human impact began around AD 1120 and preceded the High Medieval colonisation of the region and the foundation of the village of Okna (Fig. 9). Archaeological research found no clear evidence of settlement or other activity in the first half of the first millennium AD.

The dominant process in the wetland before the first erosion event consisted of an accumulation of organic matter from local vegetation. The dynamic of the wetland infilling changed rapidly after the allochthonous silt material began to be deposited, an event clearly associated with the beginning of agricultural activity in the catchment. The textural and structural homogeneity of the sediment suggests that it comes from a single source. The textural composition corresponds to silts that are typical of loess in Bohemia (Pelišek 1972).

The only area obviously affected by massive erosion lies in the immediate vicinity of the La Tène site in sub-catchment C (Fig. 4). We therefore suppose that the sediment of the first silt layer found in the wetland came from here. The second sedimentation came sometime after the seventh century AD, but most probably only after medieval colonisation of the region, when arable land covered a wider area than in previous periods.

The volume of eroded material and the extent of its source area are both difficult to assess, as several studies demonstrate (Dotterweich 2012; Schatz 2000; Schmidtchen 2003; Dreibrodt et al. 2010; Leopold and Völkel 2007a). Other authors use computer modelling to reconstruct a landscape free from the influence of erosion (Peeters et al. 2006; Ward et al. 2009). We attempt to combine an estimate of the volume of the sediment in the wetland with an assessment of the area affected by erosion. Taking into account the volume of

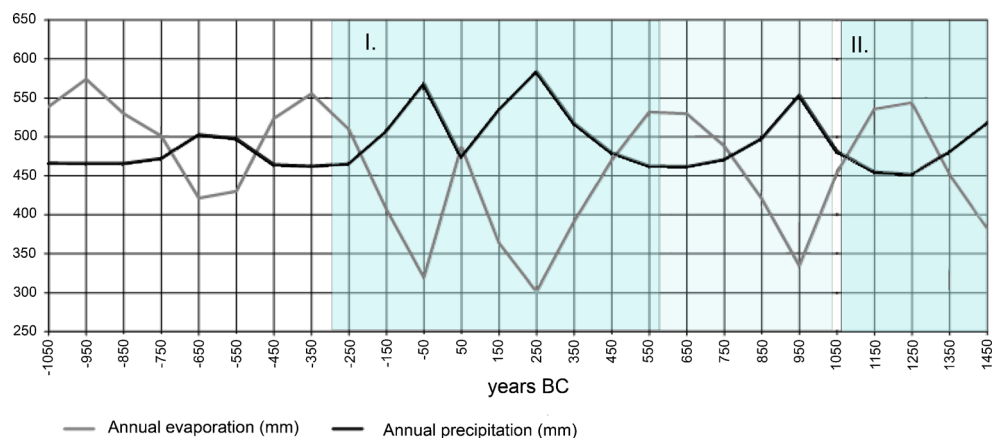
inorganic sediment in the wetland ( $129,000 \text{ m}^3$ ) and the extent of truncated soils (16 ha), we would expect the thickness of the eroded soil to be around 0.8 m. In other words, a soil profile 0.8 m thick was transported downslope and deposited in the wetland. This is consistent with the findings of Leopold and Völkel (2007b) in southern Germany. They, however, estimated that the eroded area they researched also contained soils with remnants of an albic horizon, and their erosion events happened over a short time span of only 300 years. We limited the area of erosion to truncated soils (exposed argic Bt horizon or regosols). The thickness of Ap + E horizons in the preserved soil profiles of luvisols and retisols was 45–75 cm. Shallow profiles can be also considered as partly eroded, and thus, the area of erosion must have been larger, but determining the boundary between areas with eroded and preserved Ap + E horizons is difficult. It is also difficult to estimate how much of the Bt horizon was eroded. Because of its high clay content, the Bt is considered quite resistant to erosion. However, the larger (even when not significant) clay content in the second inorganic layer proves that erosion nonetheless happened. In the area characterised by regosols, the Bt horizon and underlying loess cover were completely eroded. Similar retrograde soil development from other loess areas in the Czech Republic has also been described by Zádorová et al. (2011). Although the volume of eroded material in the wetland and the volume of soil that could have been eroded from the suggested area of erosion seem consistent with one another, there are nonetheless several uncertainties. The volume of material (if any) leaving the wetland during high water discharges is unknown; the volume of material trapped in microtopographic features such as closed depressions, and which never reached the wetland, is also unknown. The volume of such trapped material could be substantial, as shown by Vanwalleghem et al. (2007) in Belgium. Furthermore, the volume of colluvium downslope from the La Tène site could be equally substantial. Its thickness is between 30 and 95 cm and it covers ca. 15 ha. Within this area, there could, at a rough estimate, be a further 45,000–140,000  $\text{m}^3$  of transported material deposited since the late

prehistory (but more likely during the twentieth century) due to intensive agriculture. Zádorová et al. (2013), for example, estimated that up to a 2-m thickness of colluvia from the Chernozem area in Moravia has been deposited within the past 70 years.

The question arises as to whether the observed erosion and accumulation could have been driven by climatological factors. In the almost complete absence of proxy data within the territory of the Czech Republic, we use R. Bryson's Macrophysical Climate Model (MCM) (Bryson and McEnaney de Wall 2007) to determine local climatological conditions. The climate course is expressed by potential evaporation and precipitation curves for Prague (Fig. 11). The MCM shows growing precipitation after ca. 250 BC, short fall around ca. AD 50, maximal precipitation at ca. AD 250, and subsequent decrease of values up to ca. AD 550. Precipitation was low between ca. AD 450 and ca. AD 770. Between ca. AD 770 and ca. AD 1070, precipitation curve fluctuates between high and low values, but prevailing higher evaporation signalises wetter climate. After ca. AD 1070, for almost 300 years, precipitation was low. The beginning of the first erosion event at Okna preceded a change towards a higher precipitation for around a century, and lasted 200 years after precipitation declined. On the contrary, second erosion event appeared in time of low precipitation values. Therefore, erosion and deposition events were most probably caused by human activity. This finding is in agreement with the conclusions of other authors, such as Zolitschka et al. (2003), Lang and Bork (2006), and Leopold and Völkel (2007a).

The varied sedimentation in the wetland created a different pollen taphonomy. While in autochthonous organic sediments, pollen fallout from local vegetation prevails; in silty layers, there must have been a certain (but unknown) component of pollen transported by water together with eroded material. This has a significant effect on pollen ratios, which means we cannot easily read the pollen data throughout the profile as a continuous story, and thus cannot reliably interpret long-term changes in the landscape, such as the rate of deforestation. Assessing the impact of human activity on vegetation

**Fig. 11** MCM of potential mean annual precipitation and evaporation between 1050 BC and AD 1450 for the Prague Karlov meteorological station. Modelled by R. Bryson and M. Hajnalová. I, II.—intervals of silt accumulations in the wetland (shaded)



must also be carried out with some caution. Two examples will illustrate this. In pollen profile B, there is an increase in *Tilia* from a level of 122 cm, which is more likely to be related to *Tilia* pollen transported with eroded material from the catchment area than to an expansion of *Tilia*. *Sambucus nigra* type, which appears only after the start of erosion above 125 cm, could indicate either eutrophication of the wetland margins or its having originated in an area of human settlement (Fig. 10).

A great variety of anthropogenic pollen indicators, including taxa with low pollen production such as *Papaver rhoeas* type, *Alchemilla*, *Polygonum aviculare*, and *Persicaria maculosa* type, is present in the silty layers. Non-pollen items include spores of *Anthoceros* and oval shells of the intestinal parasite *Trichuris*. Such a spectrum of local anthropogenic indicators must originate in settled or cultivated surfaces that were eroded in the catchment of the Robečský stream. The relatively low level of *Cerealia* pollen suggests the lesser influence of fields or other places connected with the manipulation and storage of cereals. It is possible to compare these results with the pollen profile taken from the artificial cistern constructed in the central part of the Iron Age hillfort at Vladař in north-west Bohemia (Pokorný et al. 2006). The clearest evidence of human impact, reflected in the presence of a comparatively specific range of local pollen anthropogenic indicators, was detected in the cistern layers which contained silt and which were therefore, as at Okna, associated with erosion. At the Vladař hillfort, however, the eroded material containing pollen came from the immediate vicinity of the cistern. Therefore, the pollen signal indicating settlement activity (higher numbers of pollen anthropogenic indicators) and cereal cultivation (high numbers of *Cerealia* pollen) are stronger.

Human impact in pollen profiles with a prevailing local atmospheric accumulation of pollen is usually indicated only by regional anthropogenic indicators: wind-pollinated taxa with significant pollen production and extensive pollen dispersal, such as *Plantago lanceolata*, *Rumex acetosa* type, *Chenopodiaceae*, *Artemisia*, and *Urtica*. Taxa with low pollen production are usually absent or very rare in these pollen profiles, which also holds true for the pollen of *Cerealia* (Behre 1981; Court-Picon et al. 2005; Brun et al. 2007; Brun 2011), which is the most important anthropogenic indicator.

The erosion/accumulation event at Okna also caused changes in the wetland biotope. Trilete spores proliferate in the pollen record up to 122 cm. The morphology of the trilete spores and the nature of the organic matter in this section of the profile suggest that *Sphagnum* species originally dominated in the wetland. The decrease in trilete spores at a depth of 122 cm is accompanied by a temporary increase in *Cyperaceae* and a permanent increase in *Poaceae*. The current vegetation of the wetland is dominated by *Phragmites*, with its characteristic rhizomes, and which can also be identified in the profile at a depth of 122 cm. It is therefore likely that

*Phragmites*, which is a strong competitor, expanded in the wetland at a time when silt deposition suppressed the existing vegetation. Starting around 122 cm, the increase in *Phragmites* was accompanied by the presence of certain species of the *Cyperaceae* family (Fig. 9).

The pollen and sedimentary records of human activity at Okna during the Roman period (ca. 30 BC–AD 400), and especially during the Migration period, offer a useful substitute for the missing archaeological data. They bring new insight into the history of the first part of the first millennium AD, as the number of known archaeological sites from the Migration period is extraordinarily low in the Czech Republic, as it is in neighbouring countries. This could be either because of a real decline in settlement activity, or more probably because archaeological findings are quite indistinctive (and therefore difficult to date to the Migration period or any other periods) and low in number. Archaeological visibility is therefore poor (Pleinerová 2007). The lack of archaeological evidence from this period in the vicinity of Okna is consistent with the village's location at the edge of the settled area (Fig. 5). Nevertheless, environmental data certainly document human activity throughout the Roman and Migration periods.

Results from a number of other pollen cores taken in various parts of the Czech Republic support the idea that the population density remained quite static during the first five centuries AD. There are corresponding archaeological findings within 1 to 2 km of most of the pollen sites suggesting human impact during the Roman and Migration periods, namely at Brve, Zahájí, Tišice, and Stará Boleslav-čistička (Fig. 12; Daněček et al. 2014; Dreslerová and Pokorný 2004; Dreslerová et al. 2004).

The sporadic archaeological evidence that we find at Okna is not exceptional, however. Pottery fragments from the Late Hallstatt and La Tène periods were identified during a surface survey in an area ca. 700 m around the pollen profile from Kožlí, southern Bohemia (Dreslerová 2004). The pollen record is unclear with respect to human activity during the Hallstatt period, but does suggest continuous settlement from the La Tène until the Migration period (Fig. 12; Pokorný and Kuneš 2009). The closest known settlement site from the Roman period is ca. 7 km away and from the Migration period 15 km away (Jířík and Simota 2009). A similar picture can be seen in the pollen profile from the Vladař hilltop. The site was certainly occupied during the Early and Middle La Tène periods, partially abandoned by the end of the third century BC, and completely abandoned around the turn of the millennium, after which the site and the surrounding landscape reverted to natural woodland (Pokorný et al. 2006). During the Migration period, however, both primary and secondary anthropogenic indicators reappear in the profile and document human activity of an uncertain nature for which there is no archaeological evidence for a distance of several tens of kilometres (Kozáková et al. 2015).

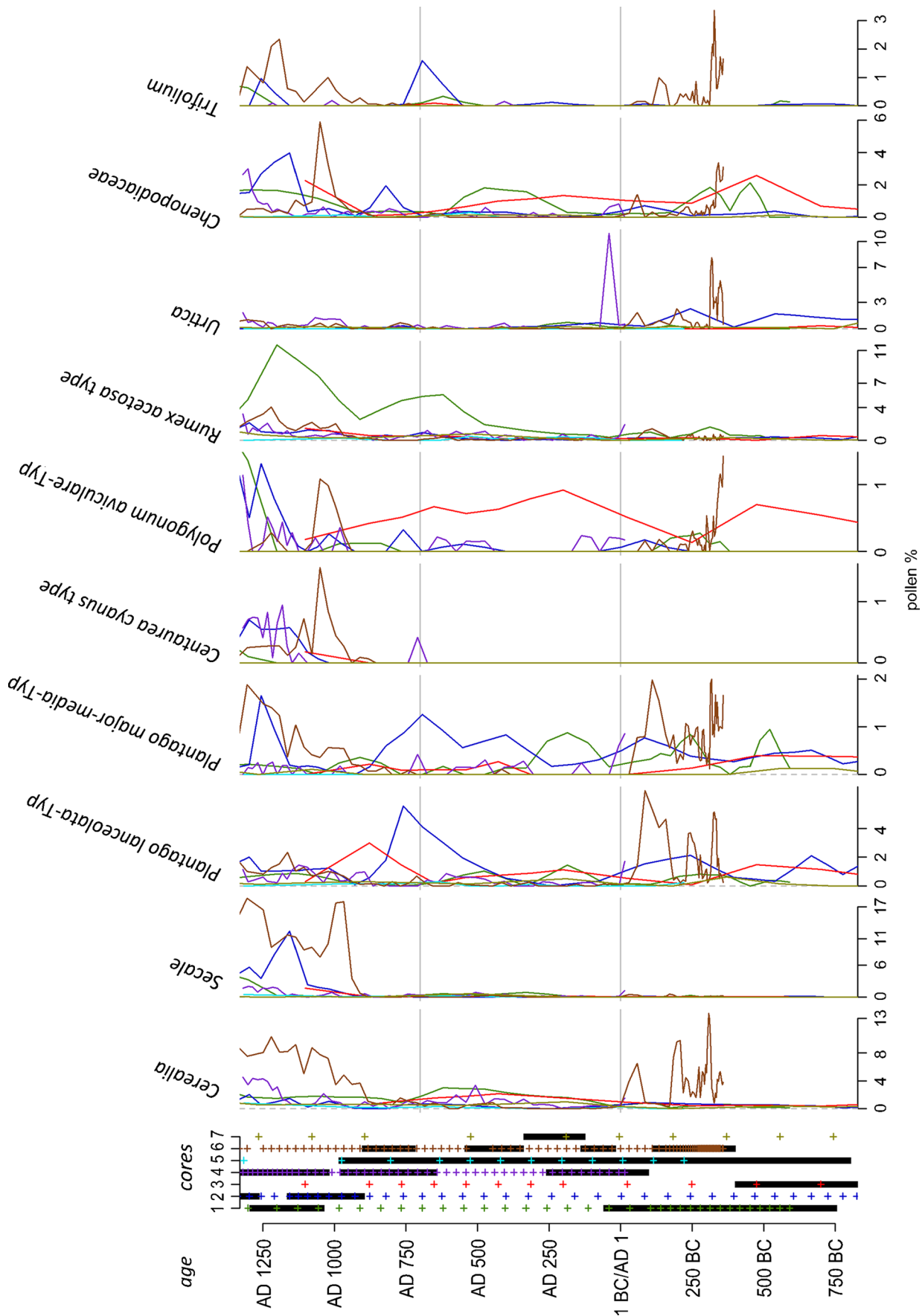


**Fig. 12** Pollen profiles with selected anthropogenic indicators. Horizontal lines define Roman Age and Migration period. 1 - Břve; 2 - Zahájí; 3 - Tišice I; 4 - Stará Boleslav - čistička; 5 - Kožlí; 6 - Vladař; 7 - Jelení louže. After: Dreslerová and Pokorný 2004; Břizová 1999; Pokorný et al. 2006; 2015; Pokorný and Kuneš 2005, 2009; Pokorný and van der Knaap 2011

Similarly, pollen data from Lake Salet in the Mragowo Lake District in Masuria, north-eastern Poland, provide clear evidence of anthropogenic impact during the Migration period (and beyond, up to the mid-ninth century AD) even though archaeological evidence is entirely lacking (Szal et al. 2014). According to the authors of the research, the apparent decline in settlement from the seventh century AD might have been caused not by actual depopulation but by changes in burial practices (most archaeological evidence from this period is based on the study of burial grounds).

These examples clearly demonstrate that human activity leaves undisputed evidence in pollen profiles, especially if the latter is taken from an area in close proximity to the former. It can therefore be reasonably assumed that pollen provides sufficient evidence of past activity that was not, for whatever reason, captured archaeologically. In light of this, records of anthropogenic pollen indicators from profiles situated in regions unsuitable for agriculture, however weak they may be, are of great interest. Profiles such as those demonstrated by the Jelení louže (see Fig. 12) capture unspecified human activity in areas rich in sandstone rock formations. Such places might have been sought out in, for example, times of instability as a (temporary) refuge, or might have supported certain subsistence practices, as shown by Bobek et al. (2017).

## Conclusion

Our research using pollen profiles, sedimentary, and soil records provided conclusive evidence of a link between an erosion event and an archaeological event—something that is rare in the Czech Republic, although similarities can be found at sites elsewhere in Europe (Leopold and Völkel 2007b; Reiss et al. 2009; Schmidtchen 2003; Ertlen et al. 2014). It also determined the possible starting points of processes that led to the formation of soil types which would not exist naturally in the area.

Sedimentary records and pollen records from the Okna wetland provided evidence of landscape changes and human activity that had not been captured by archaeological data. The evidence for settlement during the Migration period is especially interesting as compared to those of the other prehistoric periods; this period is largely under-represented in the literature. Similar findings have important implications for theories concerning landscape development, and concerning population pressure and increases or decreases in the prehistoric population, and significantly affect theoretical research into problems such as uneven archaeological visibility—for example, the ability to detect archaeological evidence of human activity from different archaeological periods, contexts, and environments.

We consider it particularly important that indicators of human activity using similar research (sensu Sugita 1994) are

often supported by archaeological records located within a radius of 2 km. Pollen records can therefore be used as sensitive indicators of human impact in archaeologically unexplored or inaccessible areas.

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