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ORIGINAL ARTICLE

The potential of pollen analyses from urban deposits: multivariate statistical analysis of a data set from the medieval city of Prague, Czech Republic

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Abstract In the 12th and 13th centuries, the land which is now the Czech Republic underwent deep social and landscape changes, defined by historians and archaeologists as a transitional period between the early and late medieval periods. This study aims to analyze this transition as reflected by 142 pollen spectra from urban deposits so far excavated in the city of Prague. Multivariate statistics and critical assessment of the results has brought general conclusions on the potential of pollen analysis for urban archaeological research. They reveal an early medieval urban environment as a fine mosaic formed by extensive management, and composed of many habitats without sharp borders between them. Since human impact increased with time and the use of land became more rationalized and intensive, this mosaic developed a relatively coarser structure in the high medieval period. Our results support findings of the earlier subjective and uncertain characteristics of two differing types of medieval pollen spectra (Cerealia-dominated ones with low pollen diversity versus those with a higher proportion of arboreal and wild herbal pollen and high pollen diversity) obtained from various archaeological sites.

Keywords Early medieval · High medieval · Urban archaeobotany · Archaeological layers · Pollen taphonomy · Multivariate statistics

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Introduction

Archaeology of medieval Prague

Prague (Praha) is situated in the centre of Bohemia, in a basin formed on both banks of the river Vltava. The settlement history of early medieval Prague has been mainly studied from archaeological excavations, as the first written sources only date from the tenth century. However, there is no general consensus about the beginnings of local early medieval settlement there. Some excavations have shown human activity in Malá Strana (Lesser Town) as early as the eighth century (Fig. 1). During the ninth century, Pražský hrad (Prague Castle) was gradually established as the seat of the ruling Czech duke. By the tenth century there already existed a fortified settlement over an area of 35 ha directly below Prague Castle. A few other villages spread to the south, west and east of this fortified agglomeration (Čiháková and Havrda 2008). The detailed structure and organization of early medieval settlement on the left bank of the Vltava is not yet clear. So far we can

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only guess from some excavated foot-paths and the remains of non-agrarian activities such as the production of iron ore, which could have been mined at Malá Strana in the close vicinity of the settled area (Havrda et al. 2001).

Until the end of the tenth century, the settlement which was to become Prague was spread solely on the left bank of the Vltava. The opposite bank originally served as a place for funerals and by the end of the tenth century it started to be used by ironworkers. At the same time, the Vyšehrad castle was established here. Archaeological excavations on one of the former river islands have found an early medieval field close to a village (Hrdlička 1972). In the twelfth century Prague grew into a large settlement and finally into a high medieval town. It had two castles and was built from wood, clay and sometimes stone. There was a stone bridge connecting the old centre of Prague with a yet unfortified part of the town on the right bank where the main market at the place of present-day Staroměstské náměstí (Old Town Square) was situated. The thirteenth century brought many radical changes that gradually affected the whole country and hence are referred to as the Great Medieval Change (Klápště 2006). During this time Romanesque Prague, which had so far developed spontaneously, was transformed into a Gothic town with a strictly organized structure.

Closely connected with the interpretation of pollen spectra from urban deposits is the matter of waste disposal. The character of anthropogenic urban deposits reveals much about the approach of the inhabitants towards their environment. There are two distinct types of urban anthropogenic

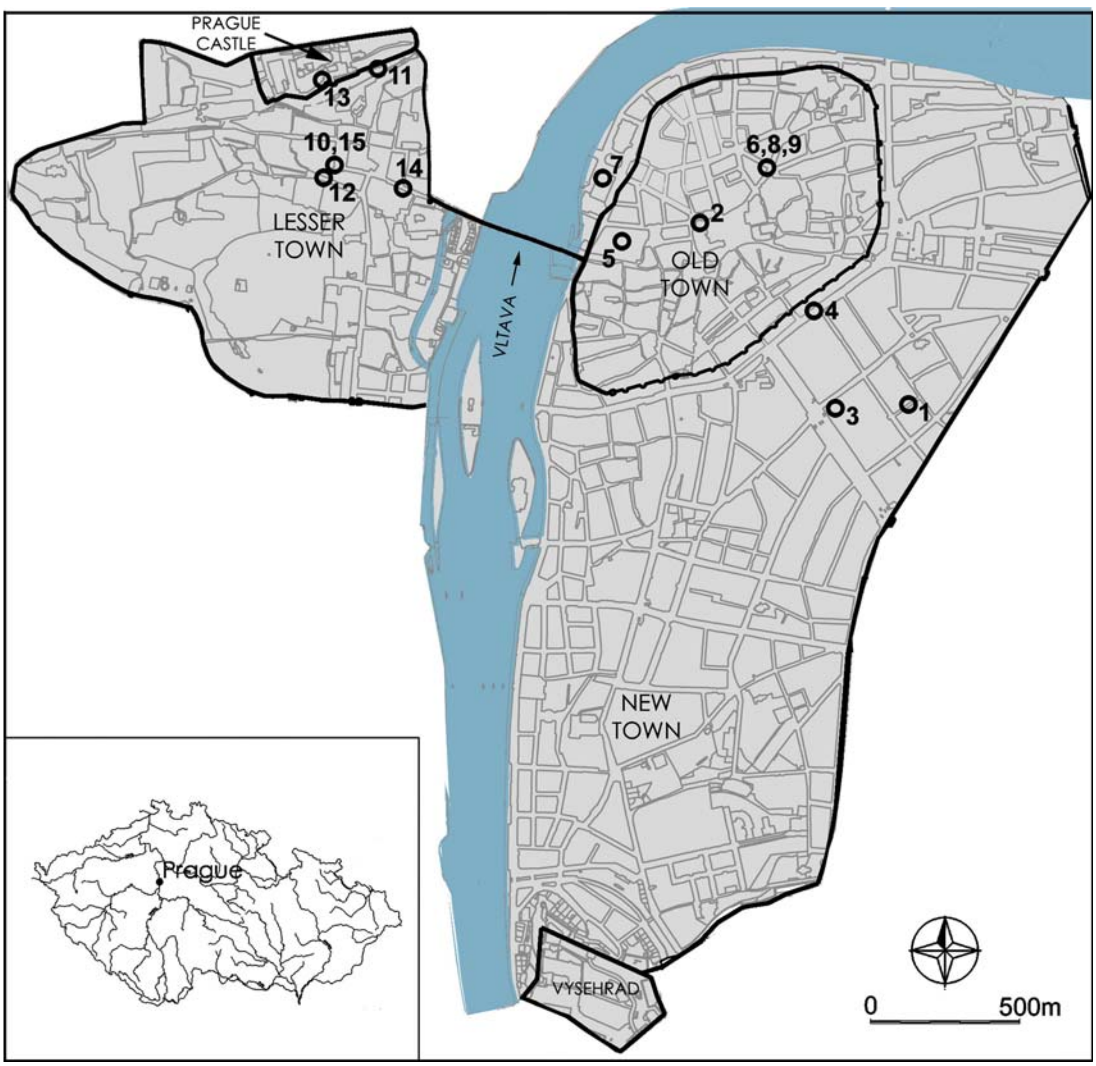

Fig. 1 Map of Prague with old settlement zones marked. Points show archaeological sites from which pollen data were used in this study. Numbers of sites correspond to numbers in Table 1. Prague castle—Pražský hrad, Lesser Town—Malá Strana, Old Town—Staré Město, New Town—Nové Město, Vysehrad—Vyšehrad

strata, differing in their type of deposition—an older, unorganised type and a later, regulated one. The transition between them follows the transformation of early medieval Romanesque Prague into a high medieval Gothic city (Hrdlička 2000a). In the first phase, waste was deposited in the form of cultural layers in backyards; in the second phase, deep pits for rubbish were dug instead and also many old wells or sand pits were re-used for waste deposition. An alternative was to throw waste over the town walls. The deliberate and organized treatment of street surfaces and routes started only in the second third of the fourteenth century (Ledvinka and Pešek 2000). From then on, streets were paved and regularly cleaned. During the fourteenth century, the streets of Prague acquired their final structure—one that is still the same in today's city centre.

Urban pollen analysis

The study of continuous profiles through natural sediments that contain a record of a relatively long time-span, aiming at the reconstruction of past landscapes, can be considered as the traditional methodological basis for pollen analysis. Peat and lake deposits are then the material of choice. Under such circumstances, pollen analysis has a more or less adequate spatial and taxonomic resolution. Pollen analysis as a part of archaeobotanical research has a different position, as the expectations are fundamentally different. Urban archaeobotany is mostly connected with deposits made by humans that were formed over relatively short time periods. It is mostly focused on some special problems concerning human subsistence and these are usually successfully resolved by the analysis of macro-remains as a rule (Jacomet 1994; Karg 1995; Hellwig 1997; Rösch 1998; Borojević 2005; Ruas 2005 and many others). Even though some papers point out the value of pollen analyses in connection with questions relating to past diet (for example Kalis et al. 2005), the role of pollen analysis in such research remains a subsidiary one compared to the analysis of plant macro-remains.

A bigger random component is one aspect in which the taphonomy of microscopic pollen grains is different from seeds and fruits (Greig 1982; Schofield 1994). Also, taxonomic problems play an important role as pollen types often include groups of species which differ in ecological characteristics. On the other hand, some non-pollen microscopic objects preserved in pollen samples, such as ova of intestinal parasites, can yield interesting supplementary information (Kalis et al. 2005; Wiethold 1999, 2000a, b, 2001).

Owing to the above-mentioned problems, it is obvious that the potential of pollen analysis as a sovereign part of archaeobotanical research of urban deposits is not yet clear—and this is what we would like to address in this paper. To this end, we use an example from historical Prague, the present-day capital of the Czech Republic. We believe that a critical assessment of our data set should result in some general conclusions concerning the potential of pollen analysis for use in urban archaeological research. We should be able to see how sensitive pollen analysis can be and what aspects it can reveal. Once known, we should be able to give some advice leading to improved sampling and research strategies.

Vegetation background

Although situated in a lowland valley, the area of Prague city is highly diverse in terms of its bedrock, soils and morphological relief. Without human influence, the local vegetation would be mixed deciduous woodland with dominant *Quercus petraea*, *Q. robur*, *Carpinus betulus*, *Tilia cordata* and *T. platyphyllos*. Among other tree taxa could be mentioned *Acer pseudoplatanus*, *A. platanoides*, *Ulmus glabra*, *U. minor*, *U. laevis*, *Fraxinus excelsior*, *Alnus glutinosa*, *Prunus padus*, *Betula pendula* and *Pinus sylvestris* (Moravec and Neuhäusl 1991). *Fagus sylvatica*, *Abies alba* and *Picea abies* could grow primarily on northern slopes or in the bottom of narrow valleys. The area of Prague has many places where secondary biotopes of xerophilous grasslands mainly belonging to the Festuco-Brometea class could develop. Other common non-arboreal vegetation would be mesophilous or wet meadows and pastures with taxa more recently belonging to the orders Arrhenatheretalia and Molinietalia (Ellenberg 1988).

Materials and methods

Pollen data set from medieval Prague

In the city of Prague there are several archaeological sites where pollen analyses have been performed and where particular researchers have striven to draw a picture of the local environmental and vegetation conditions (Jankovská 1987, 1991, 1997; Pokorný 2000; Beneš et al. 2002; Kozáková and Pokorný 2007; Kozáková and Boháčová 2008). This effort has so far been rather unsystematic, each particular study site being considered in isolation from the others. Moreover, the interpretation of pollen data has always been somewhat subjective. Here we would like to study a data set from Prague as a whole, consisting of 15 sites and 142 samples, using multivariate statistics. We ask the following questions:

- What feature or factor causes the largest differences between samples?
- Are there any specific pollen spectra for particular archaeological contexts?

– Are social and cultural changes that happened in Prague during the thirteenth century somehow reflected in the composition of pollen spectra?
– Does pollen diversity change with time?

The analyzed data set includes samples from various archaeological sites and contexts (Table 1). In some cases, the exact character of excavated layers was unclear and it therefore remained unspecified. Since all the analyzed data comes from the authors of this paper, their original data were used in most cases. The pollen data set from Prague includes 76 early medieval samples dated before the thirteenth century and 66 samples of late medieval age (Table 1). Thus both the very early and later phases of the town's development are well represented.

The list of main pollen taxa identified in analyzed samples is included as a legend to Fig. 2. The nomenclature of plant taxa follows Kubát (2002). Pollen types were defined and modified according to Moore et al. (1991), Reille (1992), Beug (2004) and Punt (1980). Pollen nomenclature respects the following conventions:

1. The name of a pollen type is identical to a taxon name (of any rank) if the pollen type represents this taxon and no other. Examples: *Centaurea cyanus*, *Salix*, Cyperaceae.
2. The name of a pollen type has the suffix 'type' if it could represent a taxon or taxa other than the taxon mentioned in the pollen type. Examples: *Trifolium repens* type, *Aster* type. In this case pollen types include taxa according to Beug (2004).
3. The name of a pollen type representing two taxa only consists of both taxon names separated by a slash. Examples: *Sambucus nigra*/*S. racemosa*.
4. All these pollen-morphological considerations are restricted to taxa occurring at present in the Czech Republic and within an altitude corresponding to the studied locality (Prague basin in the Czech thermophyticum, up to approximately 300 m asl.)

Data analyses

The pollen data set from medieval urban deposits in Prague was processed by multivariate statistical methods with Canoco (Lepš and Šmilauer 2003). Principle component analysis (PCA) was used to show the independent distribution of the pollen taxa. The influence of three environmental variables—archaeological context, age and pollen diversity—was investigated using redundancy analysis (RDA). Data were transformed by the square roots method, and standardized over taxa and samples in order to strengthen the role of rare taxa and equalize the impact of pollen sums counted. To reduce the effect of the low number of samples compared to the number of variables, taxa with extremely low ratios (mostly one pollen grain per sample) connected with rare occurrences (not more than in five samples) were excluded from the database.

The analyzed samples were derived from sites where the archaeological research had a rescue character. For this reason, samples were dated archaeologically, which due to the lack of time often resulted in greater date ranges. For statistical analysis, it was necessary to use a single date—derived as the mean value of each particular age range given in Table 1. The pollen diversity coefficient was derived from the results of Rarefaction Analysis using the Polish palynological program, POLPAL (Nalepka and Walanus 2003).

Results

The data set includes 142 samples and 97 taxa which resulted in relatively low percentages of overall explained variability by the first three axes of the PCA plot (Fig. 2). Our recent database consists of data that are highly diversified. This is why a greater number of analysed samples would be needed to get stronger statistical results. In the case of direct multivariate analyses (RDA), the F values are relatively high when testing the roles of age and diversity. Archaeological context turned out to be a less strong factor. This is primarily caused by unequal representation of particular archaeological contexts (see Table 1) and by the distribution of a relatively small number of samples among many environmental variables. Bearing in mind these problems of our database, we are sure that the statistics described all the major trends in the data set that were evident even from preliminary subjective evaluations of the pollen results.

A dominant feature that repeats in all data visualizations (Figs. 2, 3, 4, 5) is the contrast between anthropogenic and natural pollen spectra. Strong anthropogenic impact is represented by pollen from crops and weeds—Cerealia, Chenopodiaceae, *Centaurea cyanus*, Brassicaceae, *Arctium* or Viciaceae. The pollen of imported plants such as *Myrtus/Eugenia* type, Oleaceae or *Fagopyrum* also belongs to human-induced spectra. The same is true for the empty ova of parasites indicating some faecal pollution of analyzed sediments—*Trichuris* and *Ascaris*. The correlation of *Calluna vulgaris* with all these pollen types probably shows that this dwarf shrub was collected and used for some special purpose in medieval households.

The extremely non-natural character of the pollen spectra gradually changes into a relatively natural one as expressed by the arrow in the PCA diagram (Fig. 2). Samples between these two extremes are characterised by

Table 1 List of sites included in statistical analyses

Site number	Site name	Publication	Archaeological dating	Archaeological context	Number of analysed samples	Pollen analysis made by	Source of pollen data
1	Olivová ulice	Starec (2000c)	15th or turn of 15th and 16th cent.	Infilled pit	6	Jankovská	Original data
2	U Radnice	Dragoun (1984, 1988)	Middle of 15th cent	Infilled pit	6	Jankovská	Jankovská (1987)
3	Václavské náměstí 1282/II	Starec (2000a)	Turn of 14th and 15th cent	Infilled well	2	Jankovská	Original data
4	Na Příkopě	Beneš et al. (2002)	Turn of 14th and 15th cent	Dump site layers infilled moat	16	Pokorný	Original data
5	Klementinum	Havrda (2000, 2001)	Turn of 13th and 14th cent.	Infilled pit	1	Jankovská	Original data
6	Ungelt 630	Richterová 1998a, b	Turn of 13th and 14th cent.	Bottom of well	1	Jankovská	Original data
7	Alšovo nábřeží	Starec (2000b)	From 12th up to the 16th cent	Dump site	10	Jankovská	Original data
8	Týnský dvůr 1049/I	Hrdlička (1990b, 2000b)	Second third of 13th cent	Unspecified	5	Jankovská	Original data
9	Týnský dvůr	Hrdlička (1990a, 1998)	From second half of 12th to first third of 13th cent.	Drainage ditch	3	Jankovská	Jankovská (1991)
10	Malostranské náměstí 260/III	Unpublished	Turn of 14th and 15th cent. (6 samp.); turn of 13th and 14th cent. (2 samp.); 11th cent. (1samp.); 10th cent. (1 samp.); 9th century (5 samp.); break of 9th and 10th cent. (11 samp.)	Infilled moat (6 samp.), path deposits (6 samp.), cultural layers (5 samp.), unspecified (9)	26	Kozáková	Original data
11	Valdštejnská ulice	Unpublished	End of 10th cent. (8 samp.); from middle of 13th to 15th cent. (8 samp.)	Cultural layers (10 samp.), path deposits (6 samp.)	16	Kozáková	Original data
12	Tržiště 259/III	Čiháková (1995, 1996)	Turn of 10th and 11th cent	Unspecified	19	Jankovská	Jankovská (1997)
13	Pražský hrad	Boháčová (1998)	First half of 10th cent	Cultural layers	9	Kozáková	Original data
14	Mostecká ulice	Čiháková (1998a, b)	Turn of 9th and 10th cent	Unspecified	19	Jankovská	Original data
15	Hartigovský palác	Unpublished	Turn of 7th and 8th cent.	Cultural layers	3	Kozáková	Original data

the presence of quite special weeds such as *Nigella arvensis* or *Valerianella*. In the same spectra, some pollen types can originate from grazed thermophilous vegetation—*Eryngium*, *Falcaria* type or *Carduus*. Apiaceae pollen type may include plants growing in both natural and synanthropic biotopes which is a good reason for being in the middle of this gradient. Other "transitional" taxa are *Campanula*, *Centaurea jacea/C. stoebe*, *Reseda*, *Cirsium*, *Sambucus* and *Acer*. Their pollen certainly belongs to plants that could have grown on human-influenced sites within the interior of the town. A special case is apparently *Acer*; the large numbers of its pollen grains in some samples are striking (Kozáková and Pokorný 2007). In these cases we may have expected something other than pollen of wind-blown origin: leafy branches (together with the flowers) might have been brought to the site for cattle fodder (Greig 1982). This interpretation seems to correspond well with the relatively weak correlation of *Acer* with other trees (Fig. 2).

Samples bearing more natural pollen spectra are always relatively rich in arboreal pollen. In these samples pollen of *Pinus*, *Abies*, *Betula*, *Corylus*, *Alnus* and partly of *Fagus* is

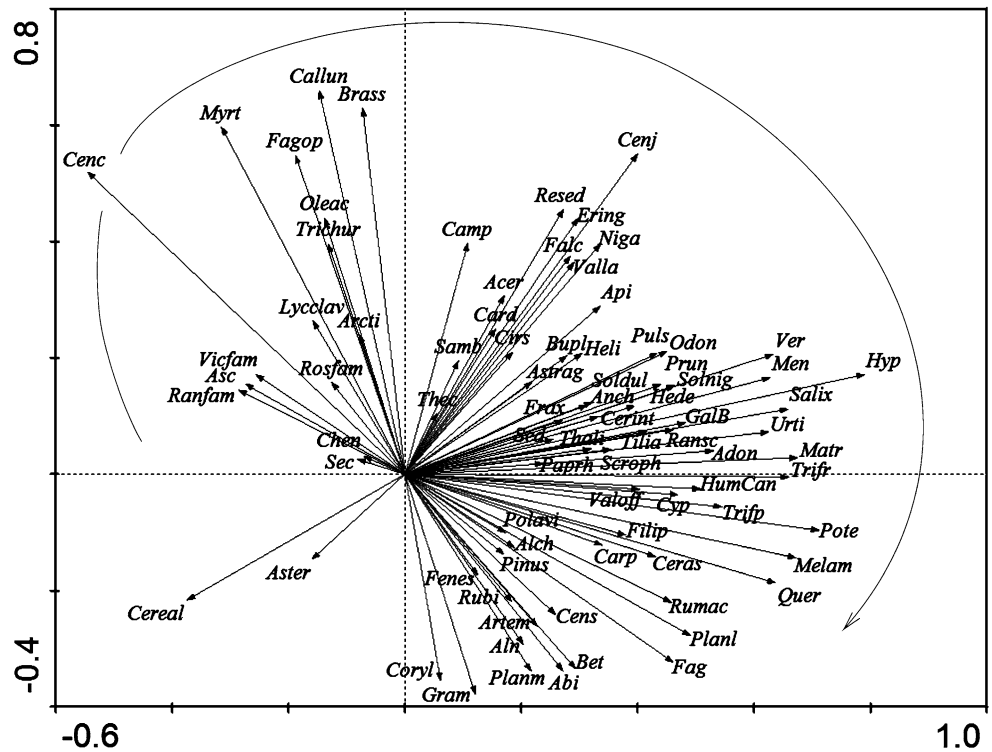

Fig. 2 PCA analysis showing distribution of taxa on first two axes. Explained variability by first three axes is 12.1, 6.1, 5.0%, respectively. The *arrow* expresses a gradient from highly human-induced pollen spectra to more natural ones Abi-*Abies alba*, Acer-*Acer*, Adon-*Adonis aestivalis/A. flammea*, Alch-*Alchemilla*, Aln-*Alnus*, Anch-*Anchusa/Pulmonaria*, Anthoc-*Anthoceros punctatus*, Api-Apiaceae, Arcti-*Arctium*, Artem-*Artemisia*, Aster-*Aster* type, Asc-*Ascaris*, Astrag-*Astragalus*, Bet-*Betula*, Brass-Brassicaceae, Bupl-*Bupleurum falcatum* type, Callun-*Calluna vulgaris*, Camp-*Campanula/Phyteuma*, Card-*Carduus*, Carp-*Carpinus betulus*, Cenc-*Centaurea cyanus*, Cenj-*Centaurea jacea/C. stoebe*, Cens-*Centaurea scabiosa*, Ceras-*Cerastium*, Cereal-Cerealia, Cerint-*Cerinthe minor*, Chen-Chenopodiaceae, Cirs-*Cirsium*, Cons-*Consolida regalis*, Coryl-*Corylus avellana*, Cyp-Cyperaceae, Ering-*Eryngium*, Fag-*Fagus sylvatica*, Fagop-*Fagopyrum*, Falc-*Falcaria vulgaris* type, Fenes-Asteraceae-Fenestratae, Filip-*Filipendula ulmaria/F. vulgaris*, Frax-*Fraxinus*, GalB-*Galeopsis-Ballota* type, Gram-Gramineae, Hede-*Hedera helix*, Heli-*Helianthemum*, HumCan-*Humulus/Cannabis*, Hyp-*Hypericum*, Lycclav-*Lycopodium clavatum*, Matr-*Matricaria* type, Melam-*Melampyrum*, Men-*Mentha* type, monsp-monolete spore, Myrt- *Myrtus/Eugenia* typ, Niga-*Nigella arvensis*, Odon-*Odontites*, Oleac-Oleaceae, Paprh-*Papaver rhoeas* type, Pinus-*Pinus sylvestris*, Planl-*Plantago lanceolata*, Planm-*Plantago major/P. media*, Polavi-*Polygonum aviculare*, Pote-*Potentilla/Fragaria* type, Prun-*Prunus* type, Puls-*Pulsatilla*, Quer-*Quercus*, Ranfam-Ranunculaceae, Ransc-*Ranunculus sceleratus* type, Resed-*Reseda*, Rosfam-Rosaceae, Rhin-*Rhinanthus/Euphrasia*, Rubi-Rubiaceae, Rumac-*Rumex acetosa* type, Rumaq—*Rumex aquaticus* type, Salix-*Salix*, Samb-*Sambucus nigra/S.racemosa*, Scab-*Scabiosa*, Sclerann—*Scleranthus annuus*, Scroph-Scrophulariaceae, Sec-*Secale cereale*, Sed-*Sedum*, Soldul-*Solanum dulcamara*, Solnig-*Solanum nigrum*, Tilia-*Tilia*, Thali-*Thalictrum*, Thec-*Thecaphora*, Trichur-*Trichuris*, Trifp-*Trifolium pratense* type, Trifr-*Trifolium repens* type, Urti-*Urtica*, Valla-*Valerianella*, Valoff-*Valeriana officinalis*, Ver-*Veronica* type, Vic-*Vicia* type, and Vicfam-Viciaceae

rather ubiquitous. On the other hand pollen of *Tilia*, *Fraxinus*, *Salix*, *Prunus* type and partly also of *Quercus* and *Carpinus* occurs in samples often together with various herbal pollen taxa indicating relatively natural biotopes such as *Filipendula*, Cyperaceae, *Melampyrum*, *Thalictrum*, *Pulsatilla*, *Hypericum*, *Valeriana officinalis*, *Potentilla/Fragaria*, *Helianthemum* etc. In contrast, vectors of the former group tend towards the non-natural pole together with *Alchemilla*, Rubiaceae, *Plantago major/P. media*, Gramineae, *Centaurea scabiosa* and *Artemisia* pollen types (Fig. 2). Key non-arboreal pollen taxa that give a more natural character to the pollen spectra are representatives of xerophilous grasslands—*Helianthemum*, *Pulsatilla*, *Sedum*, *Hypericum*, *Melampyrum*, *Potentilla/Fragaria* and *Odontites*, and also taxa from wet habitats—*Filipendula ulmaria/F. vulgaris*, *Humulus/Cannabis*, Cyperaceae, *Solanum dulcamara* and *Thalictrum* cf. *flavum*. These are correlated with certain weeds like *Cerinthe*, *Anchusa/Pulmonaria*, *Adonis aestivalis/A. flammea*, *Solanum nigrum* and *Matricaria* type, and with ruderal or meadow taxa such as *Galeopsis/Ballota* type, *Veronica* type, *Mentha* type, *Rumex acetosa* type, *Cerastium*, Scrophulariaceae, *Trifolium repens* type, *Trifolium pratense* type and *Plantago lanceolata*. Amongst typical ruderals, *Urtica* and *Polygonum aviculare* occur in samples often together with the above mentioned pollen types.

The positions of pollen types on a gradient from strongly human-induced to more natural deposits are similar on the

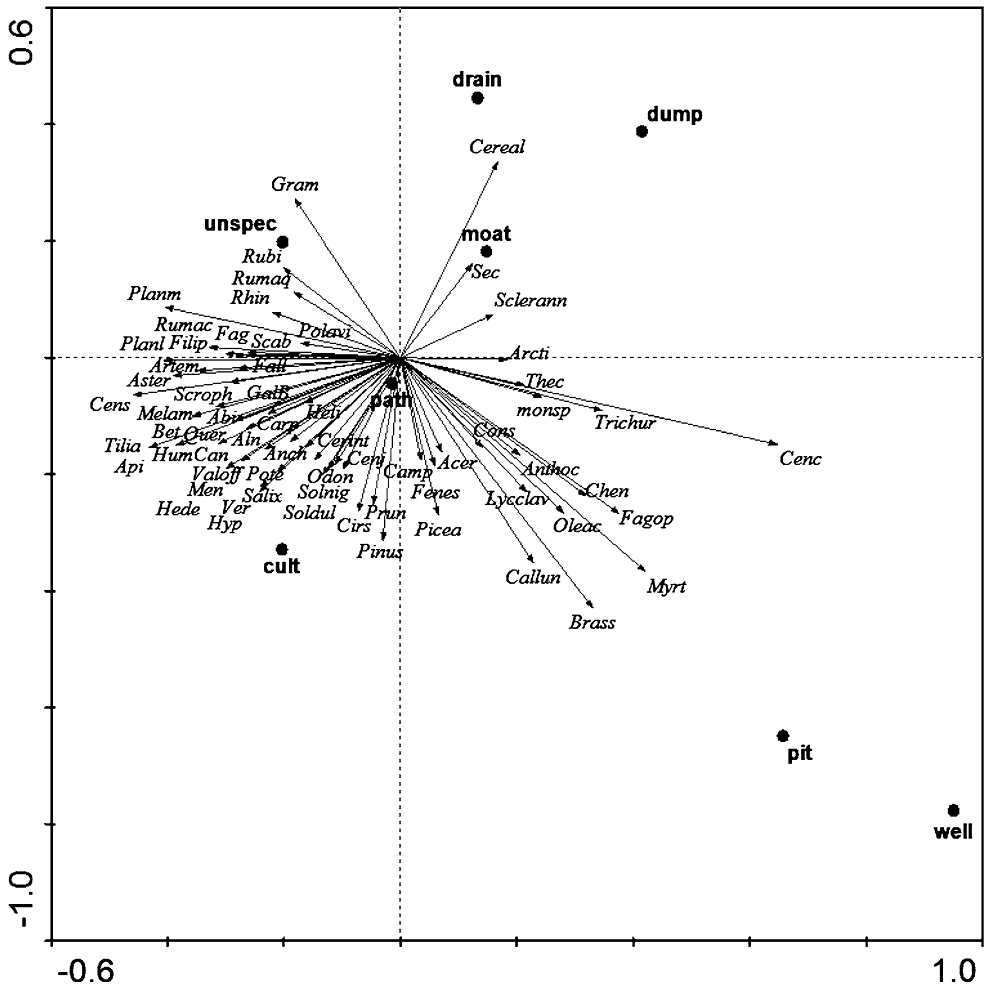

Fig. 3 RDA analysis testing the impact of the archaeological context. Cumulative explained variability: (**a**) first three canonical axes: 5.5, 8.2, 9.6%. Significance of canonical axes together: $F = 2.5$; $P = 0.002$. *pit* infilled pit, *dump* dump site, *moat* infilled moat, *drain* sediment from drainage ditch, *unspec* unspecified character of archaeological layer, *path* deposit from a path, *cult* cultural layer

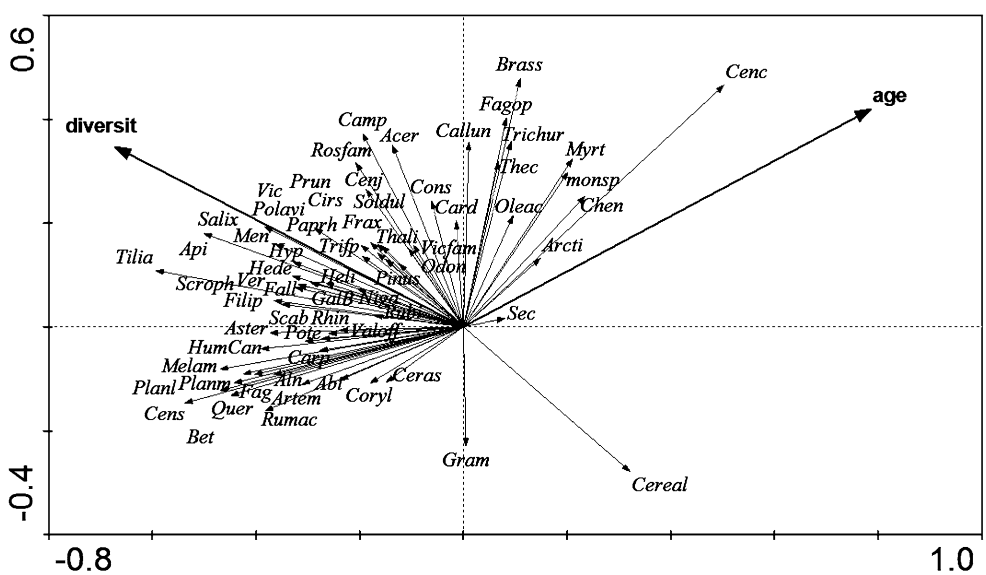

Fig. 4 RDA analysis testing the impact of pollen diversity and age. Cumulative explained variability: (**a**) canonical axes: 6.7%, 9.9%; (**b**) noncanonical axis 15.8%. Significance of canonical axes together: $F = 7.4$; $P = 0.002$. *diversit* pollen diversity, *age* mean value of an interval dated archaeologically (see Table 1)

RDA diagram that shows the archaeological context of analyzed samples (Fig. 3). Here the more natural pollen spectra are derived from cultural layers and partly from path deposits and from an unspecified archaeological context. More human-induced spectra have pollen of *Secale cereale*, Cerealia, *Fagopyrum*, *Scleranthus annuus*, *Centaurea cyanus*, *Myrtus*/*Eugenia*, Oleaceae and Brassicaceae and are typical of the infills of dump sites, moats,

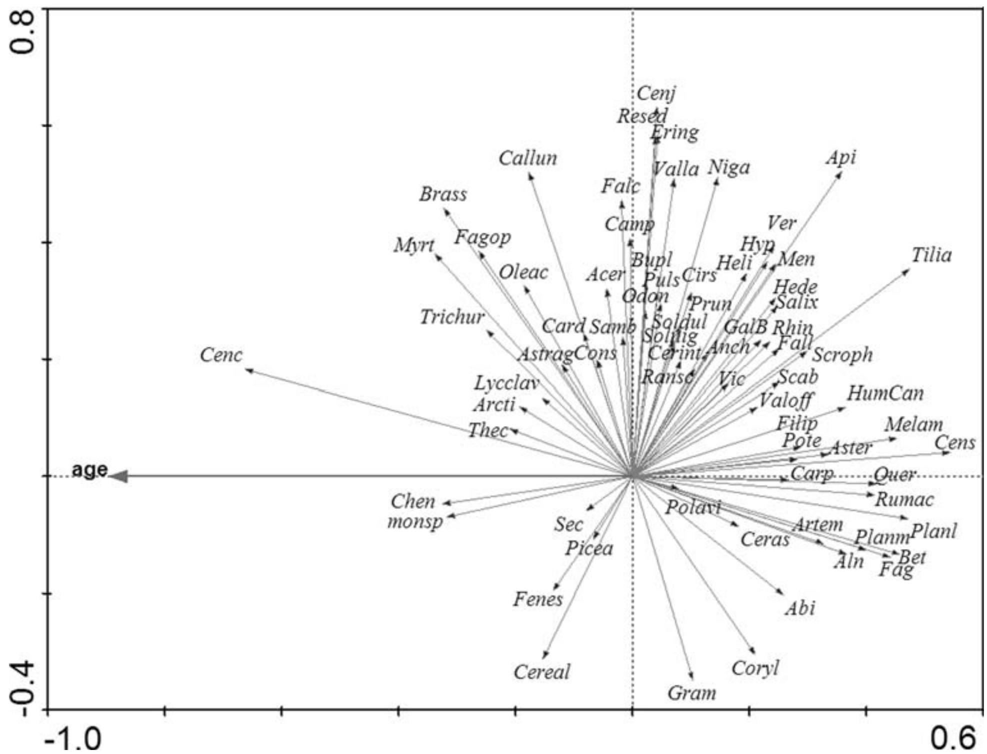

Fig. 5 RDA analysis testing the impact of age. Cumulative explained variability: (**a**) canonical axis: 5.9%; (**b**) noncanonical axis 13.0, 18.0%. Significance of canonical axes together: $F = 8.6$; $P = 0.002$

drainage ditches and pits (Fig. 3). The same applies to Chenopodiaceae and *Alchemilla*, which could be a part of the local vegetation accompanying these sites. In accord with the waste character of such sediments, the ova of the intestinal parasite *Trichuris* are also present. The correlation of *Calluna vulgaris* pollen with pits again points towards some special use of this plant in medieval households. Waste deposits are further correlated with monolete spores belonging to ferns, *Lycopodium clavatum*, *Anthoceros punctatus* and also with the sporangia of the parasitic fungus *Thecaphora*.

Pollen spectra rich in the pollen of trees, shrubs and taxa growing on meadows and pastures come from cultural layers and partly from path deposits and from unspecified archaeological contexts (Fig. 3). These sediments must have had some input from hay or the dung of cattle that grazed somewhere around the town. In contrast to sites where waste was intentionally thrown away, these sediments were deposited rather by chance. They thus yield much more complex information about the plant taxa and biotopes that were a part of the vegetation within and around a settled area.

There is a significant difference between the early and high medieval pollen spectra (Fig. 5) and at the same time pollen diversity is negatively correlated with age (Fig. 4). Woodlands are generally better represented in early medieval samples. The main non-arboreal pollen types characteristic of early medieval samples are *Melampyrum*, *Centaurea scabiosa*, *Potentilla/Fragaria*, *Scabiosa*, *Humulus/Cannabis*, *Filipendula ulmaria/F. vulgaris*, *Valeriana officinalis*, *Mentha* type, *Hedera helix*, *Helianthemum*, *Hypericum*, *Rhinanthus* type and some others. Negatively correlated with age are also several representatives of the common synanthropic flora—*Plantago lanceolata*, *Plantago major/P. media*, *Rumex acetosa* type, *Artemisia*, *Fallopia convolvulus/F. dumetorum*, *Aster* type, *Galeopsis/Ballota* type or Apiaceae. Here it probably means that these taxa have higher ratios in older sediments.

A reliable indicator of high medieval deposits is the presence of *Centaurea cyanus* pollen grains (Figs. 4, 5). As cereals probably remained the main source of nutrition throughout the whole medieval period, its correlation with increasing age is not strong. Generally, it can be inferred that pollen taxa correlated with a high medieval age are the same as those correlated with a lower pollen diversity and from deposits of a waste character (Figs. 3, 5). These are again Brassicaceae, Chenopodiaceae, *Fagopyrum*, *Arctium*, *Calluna vulgaris*, *Eugenia/Myrtus*, Oleaceae and such non-pollen objects as *Lycopodium clavatum*, *Trichuris*, *Thecaphora* and monolete spores of ferns.

Discussion

Pollen analysis of urban anthropogenic deposits in general

Compared to plant macroremains, pollen can be better transported by air and its taphonomy is generally more "fuzzy". It is often the case that numerous taxa belonging to meadow and pasture vegetation leave only their pollen grains but no seeds or fruits in analyzed sediments (Wiethold 1999, 2000a, b, 2001; Kozáková and Boháčová 2008). It is for this reason that we think that all components of pollen spectra can be considered at much more of a "landscape level", in contrast to plant macroremains. Of course, the ratios between the revealed pollen types do not correspond to the ratios found in real vegetation, which is the main problem that pollen analysis from cultural deposits must face. Due to the complicated human-induced taphonomy, the modern analogue approach (Sugita 1994; Sugita et al. 1999; Bunting et al. 2004; Broström et al. 2005; Court-Picon et al. 2005) can be hardly applied here. Hence when interpreting these pollen spectra we have to gain as much as possible from qualitative information.

It can be reasonably argued that such research is better performed from an off-site natural profile and not from particular cultural layers. Unfortunately, it is rarely possible to find a natural sedimentary record in the form of peat or lake sediments containing pollen grains within or very close to the studied urban agglomeration in question (Seppä 1997; Newman et al. 2007). When reconstructing the vegetation of an urban environment by means of pollen analysis we must settle for archaeological layers due to the above-mentioned problems.

There is no doubt that analysis of macroremains can also say much about the environmental conditions prevailing in a town (Čulíková 1995; Latałowa et al. 2003; Vermeeren and Gumbert 2008) and the use of both methods together will provide the best results (Vuorela and Lempiäinen 1993; Latałowa 1999; Wiethold 1999, 2000a, b, 2001). Nevertheless, this paper has aimed to throw some light on the potential of pollen analysis by itself. Moreover, there are no complete plant macroremains data sets for the sites analysed in this article.

Pollen data set from medieval Prague

In the case of our data from Prague, we have to face up to the risk of making a circular argument. We have studied pollen spectra from early medieval anthropogenic deposits and we can generalize that they always contain many pollen types indicating relatively natural biotopes. At the same time, early medieval strata are always less defined so that we call them mostly "cultural layers". We anticipate that in the case of such "cultural layers", pollen sources were numerous. Along with these, we have also studied pollen spectra from high medieval anthropogenic deposits. In their case we can generalize that they are less diverse, containing less arboreal pollen and herbal taxa indicating relatively natural biotopes. High medieval strata are much more defined in their taphonomy compared to early medieval ones—we are able to distinguish wells, pits, dump sites etc. In this case we suspect that the number of pollen sources was limited, because such archaeological features used to serve for a particular purpose and thus were more "closed" in a taphonomic sense. It is not possible to study medieval pollen samples from the same archaeological contexts, simply because urban deposits useful for pollen analysis almost completely changed with the start of the high medieval period. Consequently we cannot say to what extent the differences between early and high medieval pollen spectra do reflect real vegetation changes, because our pollen results are also influenced by social modifications connected with a different organization of the urban environment. Yet we can be sure that some alternations of vegetation inside and around the medieval town of Prague happened throughout the time. Abrupt changes in the landscape at the start of the high medieval period are very obvious even from pollen diagrams derived from natural sediments (mostly peat) found in the central Bohemian lowlands surrounding Prague (Pokorný 2005). These changes reflect enormous intensification of human pressure associated with marked loss of woodland during the transition from the early to the high medieval period. We can consider that human impact, gradually increasing over time, caused an overall reduction of vegetation diversity. The human component that is stronger in the case of urban deposits than in natural ones principally enriches the herbal component of pollen spectra. These specifics of urban deposits enabled us to study in more detail the process of medieval changes that also affected vegetation composition. According to our pollen data from the medieval city of Prague, it seems to us that the urban environment represents a different sort of cultural landscape that underwent parallel changes to those of the landscape from a general point of view.

Changes in a medieval landscape

To start with more concrete conclusions, we can draw particular examples of how overall medieval changes affected the urban and surrounding vegetation. We think that arboreal pollen was mostly transported by wind even in the case of urban deposits. Pollen of trees can be therefore considered as a mainly natural component of an otherwise mostly human-induced taphonomy of pollen spectra. Hence the relative proportions of particular tree taxa correspond to their real ratios in woodland vegetation, while considering their different pollen production and transport. Around early medieval Prague there still were some woods with a diversified species structure. *Quercus*, *Tilia*, *Fagus*, *Abies*, *Betula*, *Corylus*, *Salix*, *Alnus* (Fig. 5) and other trees must have been common in the landscape. Although we do not know how many and how far from sampling sites they were, we can see that all the main taxa that correspond to the geographical and relief conditions of the Prague basin were present (Moravec-Neuhäusl et al. 1991). The numbers of tree pollen grains decline in time. The affinity of *Picea* with later periods (Fig. 5) does not necessarily mean that it spread at the expense of other disappearing tree taxa. Spruce is not a pioneer species nor is the lowland geographical position of Prague optimal for its growth. Since the first though still rare intentional planting of *Picea* occurred in Bohemia as far back as during the seventeenth century (Nožička 1957), this also cannot be an explanatory factor that caused the larger amounts of its pollen in later samples. Thus we have to leave this result without any interpretation. In any case, it is certain that human pressure on natural biotopes strengthened throughout the high medieval period in general. The pollen of *Calluna vulgaris* whose ratio increases with time (Fig. 5) can come from oligotrophic grazed land or directly from heaths that remained around Prague until the middle of the twentieth century. According to relatively low numbers of *Calluna* tetrads found in the deposits of medieval Prague, it seems unlikely that it was used for roofing or flooring as was common in England (Greig 1982; Schofield 1994).

Many pollen taxa representing meadow and pasture vegetation are virtually absent from the high medieval samples. These biotopes (Bromion-like grasslands with *Helianthemum*, *Centaurea scabiosa*, *Scabiosa* or *Hypericum*) are present in Prague even in recent times. Therefore it is clear that they could not have disappeared from high medieval Prague during medieval times, but they became less widespread. The high medieval town with its planned urban layout could have got rid of many small pieces of grasslands that must have been a part of the more chaotic early medieval village-like settled area. Some gradual changes of taphonomy from unorganised deposition into a more regulated one could have impoverished pollen spectra as well. Thus later sediments were probably not receiving deposits of hay or cattle dung to the same degree as older ones. The determination of fungal spores indicating cattle faeces (Van Geel et al. 2003) could help to support this conclusion in future research. The organization of the settled area must have also resulted in certain changes in the composition of urban ruderal vegetation that is rather poor in high medieval samples (Fig. 5).

It is evident that the relatively high pollen diversity, characteristic of the early medieval samples, involves a whole range of biotopes, from ruderal to woodland ones. It reveals an early medieval landscape as a fine mosaic—formed by extensive management and composed of many biotopes without any sharp borders between them. Since human impact increased in time, and the use of land became more rationalized and intensive, this mosaic acquired a coarser structure. At the same time many plant taxa connected with the previous chaotic land-use lost their biotopes.

Conclusions

Pollen spectra derived from urban deposits give a good reflection of the changes that occurred in Bohemia during the early to high medieval transition. These changes were complex and affected all the components of the world at that time—culture, society, art and also landscape (Le Goff 2005). It seems sensible to interpret our pollen analytical results mostly at the landscape level, which is in good agreement with Schofield (1994). The Great Medieval Change in what is now the Czech Republic is reflected by most of the pollen diagrams from natural sediments (Pokorný 2004). Compared to these pollen data from natural sediments, the pollen spectra derived from urban deposits in medieval Prague showed some aspects of this process in more detail. On the other hand, compared to macroremains analysis, pollen analysis provides a less detailed, but more complete view of the broader aspects of vegetation affected by people during the period studied. We focused on the early medieval landscape because its appearance is still rather unknown and we could consider a large pollen data set from cultural sediments as being a rich source of information. It seems to be a general trend that in the early medieval period, human impact still caused some increase in a landscape diversity while in the high medieval period anthropogenic pressure intensified so that that the landscape diversity was reduced. Further in our study, our results have showed that non-specific archaeological contexts such as cultural layers or path deposits yield pollen spectra that can best inform us about the types of biotopes that were a part of the past landscape, including urban vegetation. To carry out good pollen analytical research at any archaeological site we think that following rules are sensible:

- to obtain a rather large set of samples from a particular archaeological site and sample as many archaeological contexts (objects, layers) as possible. Only in this way we can be sure which factors, such as age, taphonomy, etc., caused differences between pollen spectra derived from particular samples
- to search also in high medieval contexts for less defined types of archaeological deposits such as path deposits or other such material that sedimented rather spontaneously
- to pay attention to a parallel sampling and analyses for both pollen and plant macroremains.

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