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Younger Dryas to mid-Holocene environmental history of the lowlands of NW Transylvania, Romania

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Abstract

Pollen, micro-charcoal and total carbon analyses on sediments from the Turbuta palaeolake, in the Transylvanian Basin of NW Romania, reveal Younger Dryas to mid-Holocene environmental changes. The chronostratigraphy relies on AMS ^{14}C measurements on organic matter and U/Th TIMS datings of snail shells. Results indicate the presence of *Pinus* and *Betula* open woodlands with small populations of *Picea*, *Ulmus*, *Alnus* and *Salix* before 12,000 cal yr BP. A fairly abrupt replacement of *Pinus* and *Betula* by *Ulmus*-dominated woodlands at ca. 11,900 cal. yr BP likely represents competition effects of vegetation driven by climate warming at the onset of the Holocene. By 11,000 cal yr BP, the woodlands were increasingly diverse and dense with the expansion of *Quercus*, *Fraxinus* and *Tilia*, the establishment of *Corylus* and the decline of upland herbaceous and shrubs taxa. The marked expansion of *Quercus* accompanied by *Tilia* between 10,500 and 8000 cal yr BP could be the result of low effective moisture associated with both low elevation of the site and with regional change towards a drier climate. At 10,000 cal yr BP, *Corylus* spread across the region, and by 8000 cal yr BP it replaced *Quercus* as a dominant forest constituent, with only little representation of *Picea abies*. *Carpinus* became established around 5500 cal yr BP, but it was only a minor constituent in local woodlands until ca. 5000 cal yr BP. Results from this study also indicate that the woodlands in the lowlands of Turbuta were never closed.

Keywords: Transylvania; Pollen; Total carbon; AMS ^{14}C; U/Th TIMS; Vegetation changes; Lowlands; Younger Dryas; Holocene

Introduction

In recent years, a number of late glacial and Holocene pollen sequences supported by radiocarbon age determinations were published from sites located in Romania. The aims of these studies were to establish the time of arrival, expansion and regression of Holocene forest taxa (Farcas et al., 1999; Rösch and Fischer, 2000; Bodnariuc et al., 2002; Björkman et al., 2003; Tantau et al., 2003, 2006; Feurdean, 2004; Farcas et al., 2006) and investigate the role of climate as a driver of late glacial and Holocene vegetation dynamics in Romania and south-eastern Europe in general (Wohlfarth et al., 2001; Björkman et al., 2002, 2003; Feurdean, 2005; Feurdean and Bennike, 2004; Feurdean et al., 2007; Magyari et al., 2006). Most of the study sites are located at mid to high altitudes in the Carpathian Mountains, with only one radiocarbon dated pollen profile from lower elevation (400 m a.s.l.) situated at the foot of the Southern Carpathians (Tantau et al., 2006). Vegetation dynamics at low elevations (<400 m a.s.l) therefore have remained unstudied. In order to identify the range expansion patterns for several tree taxa, a network of dated sites at different locations and elevations in Romania is needed.

The current study presents results from the lowermost dated profile (Turbuta, 275 m a.s.l.) from Romania. The investigated

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site is situated in the forest-steppe zone of Transylvania, with climate characterized by strong seasonality (hot and dry summers and cold and moist winters). However, due to slight influence of westerlies, the study area is less dry than other low elevation sites in eastern and southeastern Romania. The Turbuta site has a long investigation history. Discovered during the geological mapping of the area in the early 1970s, a first profile from Turbuta Valley was analyzed with respect to pollen content (Diaconeasa et al., 1976), plant macrofossils and malacology (Clichici et al., 1976, 1979) and assumed to be of Eemian age. In 2001, Onac et al. (2001) published preliminary analyses (loss-of-ignition, magnetic susceptibility, molluscs and pollen) of a new sediment profile located within the same ravine. Their thermal ionization mass-spectrometry (TIMS) U/Th ages obtained on stagnant-water snail shells recovered from the middle part of the sequence confirmed an Eemian age (~127,000 yr BP). A flood event in the spring of 2005 opened a new profile across the one described by Onac et al. (2001). A quick visual inspection suggested that both the fossil content and the lithostratigraphy were slightly different than the other previously investigated profiles.

Four AMS ^{14}C and three U/Th TIMS measurements performed on organic material and molluscs indicate that our profile accumulated during the end of the late glacial and Holocene. These dates were complemented by pollen, microscopic charcoal analyses and carbon content investigations. This is the first study to document the Younger Dryas and Holocene vegetational changes at such low elevation in Romania. The present paper addresses the following specific questions: (i) How was the vegetation composition like at low elevation compared to mid and high elevation in the Carpathian Mountains? (ii) If marked differences existed, which were the factors that triggered these differences? (iii) What role did low elevation play for the survival of more sensitive temperate trees (e.g. *Picea* or *Ulmus*) during the Younger Dryas stadial (e.g. has this area been less or more diverse?).

Study site

The site of Turbuta (47°15′ 441” N; 23°18′715”E, 275 m a.s.l.) is located on the Valea Mare gully, southeast of the town of Jibou and at the north-western limit of the Transylvanian Basin (Fig. 1). Turbuta is a palaeolake, which was most likely formed by a landslide that blocked the pathway of a small rivulet (Clichici et al., 1976; Onac et al., 2001). The site appears as a flat area covering 1.5 ha, with a sedimentary fill of 10–20 m resting directly on Upper Eocene marls, clays and sandstones (Mezsaros and Moisescu, 1991).

Modern climate in the region is temperate-continental. The mean annual temperature is ~8.5 °C, mean January and July temperatures are −2 °C and 18 °C, respectively, and precipitation is ~650–700 mm annually (Academia Română, 2002, 2004).

The site lies in the forest steppe zone. The woodland is dominated by *Quercus petraea* and *Quercus robur* but has been significantly reduced by human activity. Additionally, isolated *Carpinus betulus* and *Fagus sylvatica* are present on the northern slopes (Diaconeasa et al., 1976; and observation in field). Meadow-type vegetation develops on the surface of the basin, whereas shrubs and some tall herbs such as *Prunus spinosa*, *Crataegus monogina*, *Rosa* sp. *Rubus* sp., *Murus* sp, *Filipendula ulmaria*, etc., were observed along the stream pathway.

Methods

We surveyed new profiles recently exposed by gully erosion in the Valea Mare brook. Our attempt to core one of the new profiles from the surface of the palaeolake was not successful because the sediments were far too compacted for the Russian corer to penetrate. A new section, ca 1.9 m thick, was identified across from the brook and slightly higher than the one described by Onac et al. (2001). The uppermost unit (9) consists of soil with visible roots that were also observed in units 8 and 7 (Table 1). The lowermost 20 cm of the profile was sampled below the gully bed. Prior to subsampling, lithological description of the profile was performed. Ninety individual samples were contiguously collected at an interval of ca. 2 cm for pollen and micro-charcoal analyses and carbon content. Laboratory analyses were performed at the Department of Geology, Tübingen University, Senckenberg Research Institute and Natural History Museum, and Frankfurt University, Germany.

Pollen analysis

Sediment subsamples (ca. 5 g of dried material) were prepared for pollen analysis mainly following the procedure of Bruch and Pross (1999). One *Lycopodium* tablet with a known number of spores was added to each sample before preparation to help determine the concentration of pollen and micro-charcoal in the sediment (Stockmarr, 1971). Carbonates and minerogenic particles were removed using HCl and HF, respectively, followed by flotation with $ZnCl_2$. The organic material was oxidized with H_2O_2. Pollen and spore identification and nomenclature were performed using the keys and illustrations of Moore et al. (1991) and Beug (2004). An average of 400–500 pollen grains (excluding aquatics and spores) were counted in units 1a to 6 (190 to 40 cm) and less than 100 grains in units 7–9 (40–0 cm) due to very low pollen concentration. Percentages of terrestrial pollen were calculated on the basis of their total sum. Percentages of spores and aquatic pollen types were calculated based on total sum, including spores and the pollen of aquatic plants. The pollen diagram was drawn using TILIA and TG view programs (Grimm, 1992). Micro-charcoal particles longer than 10 mm were counted on each pollen slide.

Carbon geochemical analyses

For measuring the total carbon (TC), the subsamples were first dried overnight at 100 °C, grounded to powder and combusted in a pure oxygen atmosphere using a LECO-Carbon Determinator EC-12. The organic carbon (OC) content was

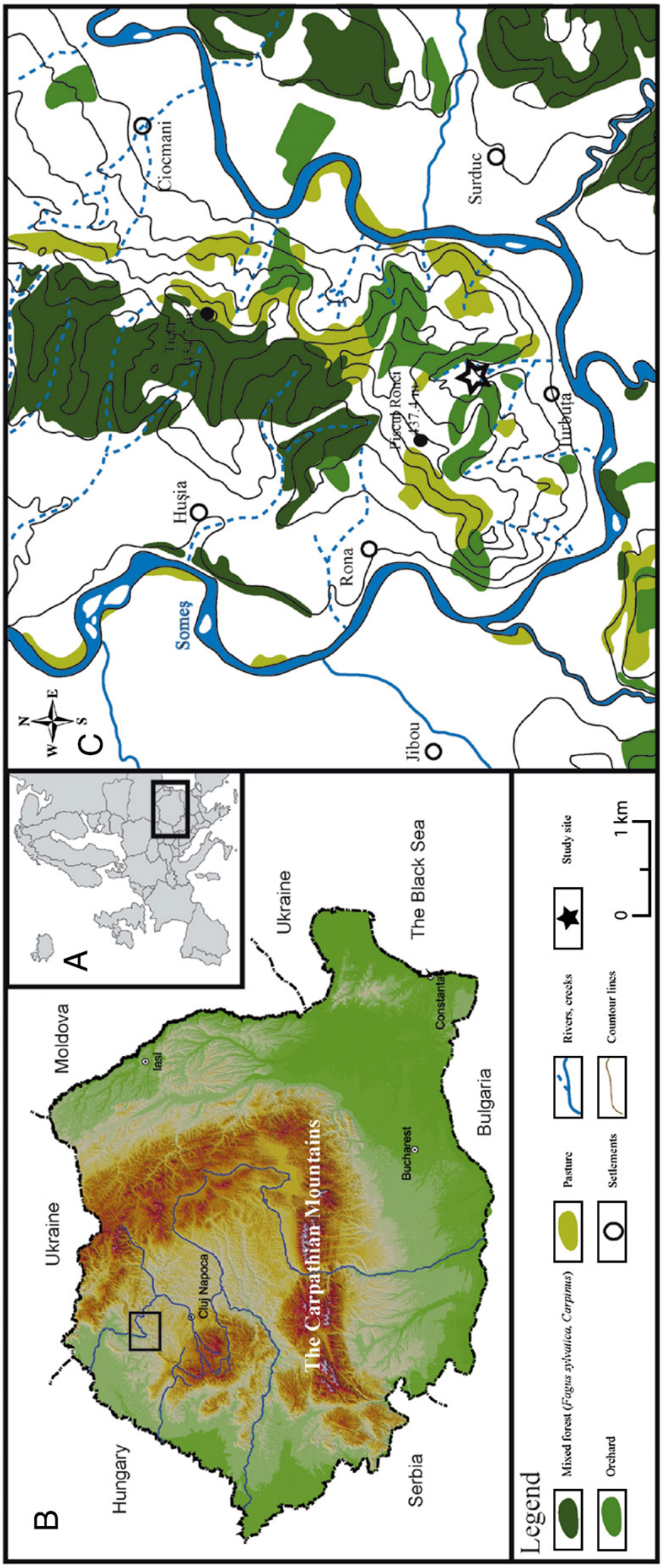

Figure 1. Map showing the location of the study area in eastern-central Europe (A), in NW Romania (B) and at the locality of the Turbuta site (C).

Table 1
Lithostratigraphic description of the sediment sequence at Turbuta

Depth (cm)	Unit	Sediment description
−20–0	9	Soil
0–29	8	Clayey, brown
29–37	7	Silty clay, light brow
37–66	6	Clay with molluscs shells
66–72	5	Silty clay, light brown
72–80	4	Clay gyttja, brown, bown
80–101	3	Clay gyttja with molluscs shells, dark brown
101–142	2b	Detritus gyttja with molluscs shells, light black
142–170	2a	Gyttja with molluscs shells, dark brown
170–180	1b	Clay gyttja, brown green
180–190	1a	Clay gyttja, dark grey

determined by colorimetric analysis, treating the sediment sample with HCl. Inorganic carbon (IC) was calculated as the difference between TC and OC (Meyers and Teranes, 2001). We estimated the amount of organic matter (OM) by multiplying OC times 1.724 and the carbonates by multiplying the IC times 0.12.

Numerical analyses

The percentage pollen diagram was divided into local pollen assemblage zones (LPAZ) using the constrained incremental sum-of-squares CONISS program of Grimm (1987). We used only pollen taxa with percentages over 1%. The Principal Components Analysis (PCA) was run on the same pollen data set in order to reveal the main trends in pollen taxa, and thus major changes in the vegetation. The PCA was calculated on a covariance matrix of the percentage pollen data and the ordinations were performed with the program 'CANACO' (ter Braak and Smilauer, 2002).

Sediment age determination

Four radiocarbon age estimates were performed on bulk material using the AMS facilities at the Poznan Radiocarbon Laboratory (Poland). To avoid contamination by more recent organic material, which can result from root penetration, the dated material was collected only from the lower, roots-free part of the sequence (Table 2a). Additionally, three U-Th TIMS age determinations were performed on stagnant-water snail shells at the Radiogenic Isotopic Laboratory, University of New Mexico in Albuquerque, USA (Table 2b).

Results and interpretation

Lithostratigraphy

The lithological description of Turbuta profile (0–190 cm) is presented in Table 1 and Figure 3 and discussed in the section Lacustrine and wetland development along with the carbon geochemical results.

Chronology

The ^{14}C AMS age estimates (Table 2a) were converted into calibrated years BP with Calib 5.0.2 program (Stuiver et al., 2005) using the INTCAL04 data set of Reimer et al. (2004). The age–depth curve was constructed by linear interpolation between the minimum values of the calibrated ages (Fig. 2). We use these values because the sediments are rich in carbonates and therefore the dated material might have been affected by a reservoir effect (Stuiver et al., 1993). The bottom-most radiocarbon date is stratigraphically reversed, hence not included in the age–depth model.

Shells are generally considered unreliable materials for accurate U/Th dating, and only if one can prove no significant loss or gain of either U or Th (close system assumption) can they be successfully dated (Goodfriend, 1992; Edwards et al., 2003). We X-rayed the samples and found that the dated shell material is still composed of aragonite, showing a lack of diagenetic origin of U in our samples. This assumption is in accordance with the findings of Onac et al. (2001) who demonstrated the existence of a close system at Turbuta by analyzing the U content in both the mollusk shells and the sediments from which the shells were extracted.

The U/Th ages have large (2σ) errors due to low uranium and high detrital thorium content. The two oldest U/Th ages are, however, younger than the corresponding radiocarbon age, but within error of one radiocarbon date and just out of error of the other radiocarbon date. This shows that diagenetic effects from uranium uptake are small. Even so, the bottom two U/Th dates did not improve the overall chronology, but the top age was used to extend the chronology into the middle Holocene (Table 2b).

Table 2a
AMS ^{14}C measurements from Turbuta

Lab number	Depth (cm)	^{14}C age BP	Calibrated yr BP	Date used for age–depth curve (cal yr BP)
Poz-17628	119–120	9030±50	10,185–10,236 10,133–10,267 (92%) 9938–9990 (4,8%)	9938
Poz-17629	141–142	9710±50	11,110–11,209 11,070–11,236 83% 10,863–10,952 14%	10,863
Poz-16415	163–164	10,300±50	12,035–12,145 11,972–12,187 (93%)	11,972
Poz-17630	181–182	9650±50		Not used

Calibrated ages are at both 1 and 2 sigma performed with Calib 5.0.2 program (Stuiver et al., 2005).

Table 2b
Summary of the U/Th measurements from Turbuta

Sample	^{238}U (ppb)	^{232}Th (ppt)	^{230}Th/^{232}Th (activity)	^{230}Th/^{238}U (activity)	δ^{234}U measured	δ^{234}U initial	Uncorrected ^{230}Th age yr BP	Corrected ^{230}Th age yr BP
TRBC-1-1	804±5	303808±2473	1.649±0.064	0.2038±0.0078	354±7	346±9	17682±741	9336±4159
TRBC-1-2	811±13	304311±2097	1.739±0.088	0.2136±0.0113	336±33	346±34	18886±1207	10481±4257
Depth (180 cm)—weight-averaged date								9895±3000
TRBC-2-A1	280±2	22149±97	4.503±0.243	0.1165±0.0063	270±12	277±13	10474±604	8657±1082
TRBC-2-A2	280±2	22137±111	4.580±0.270	0.1185±0.0070	283±40	291±41	10546±747	8749±1143
TRBC-2-A3	280±2	22253±136	5.236±0.283	0.1360±0.0074	279±13	287±14	12236±714	10427±1141
TRBC-2-B1	508±2	106066±375	1.911±0.101	0.1307±0.0069	279±12	284±12	11727±664	6893±2475
TRBC-2-B2	509±4	106558±543	1.766±0.326	0.1210±0.0224	273±12	278±12	10868±2127	5999±3167
TRBC-2-C1	391±3	25808±543	3.802±0.520	0.0822±0.0111	278±11	283±12	7236±1018	5729±1256
TRBC-2-C2	392±3	25855±101	4.367±0.094	0.0943±0.0021	279±11	285±11	8339±209	6834±776
Depth (130 cm)—weight-averaged date								7846±1500
TRBC-3-1	222±2	15938±58	3.332±0.216	0.0784±0.0051	302±19	307±19	6762±466	5150±923
TRBC-3-2	222±3	15880±58	2.927±0.333	0.0686±0.0078	300±37	304±38	5904±716	4295±1062
Depth (70 cm)—weight-averaged date								4782±700

This sample age has smaller standard errors (4782±700; Fig. 2) and was dated in sediments lacking radiocarbon age estimates and might be considered a minimum age. It should be noted that the chronology in the interval 8000–5000 cal yr BP is far from ideal and no age depth modeling was attempted above 70 cm (<5000 cal yr BP) because a linear extrapolation through

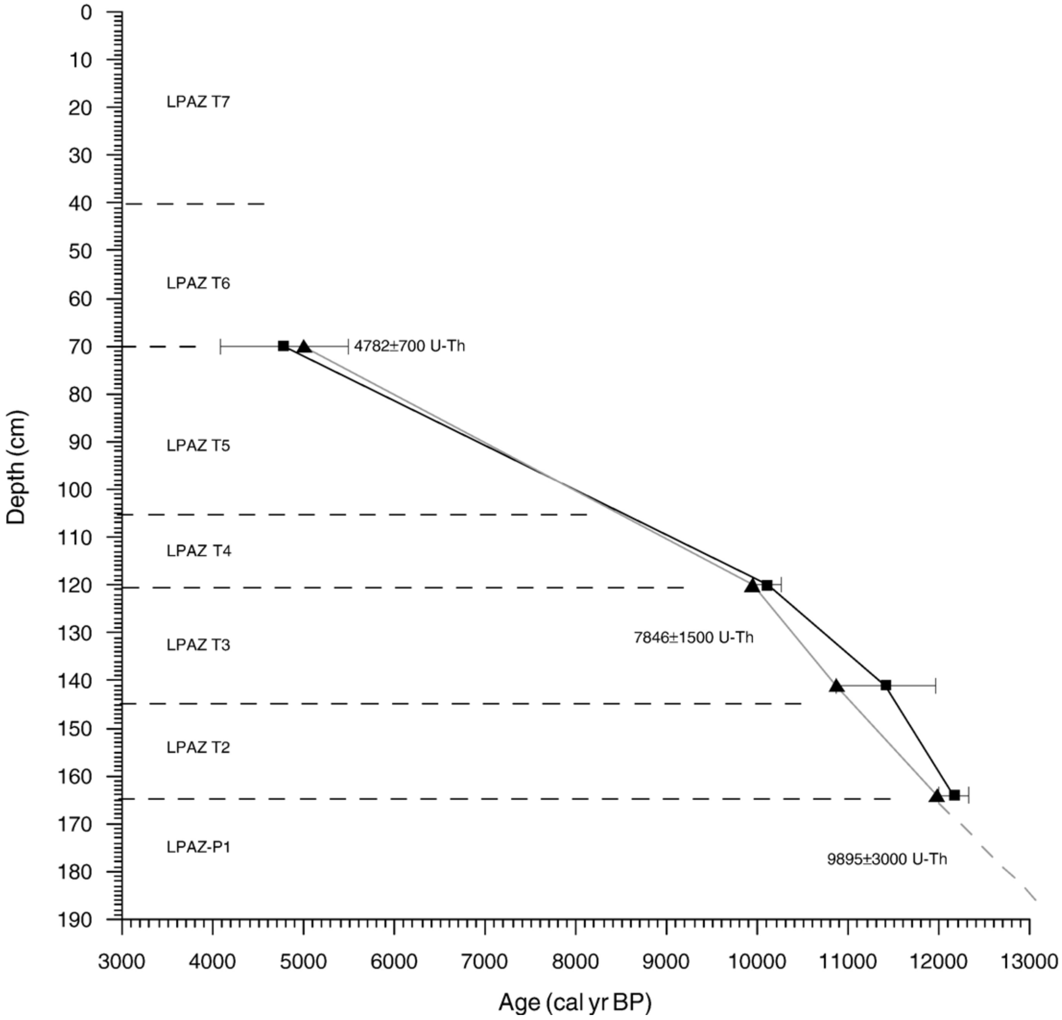

Figure 2. Calibrated AMS radiocarbon dates (black squared) suggested age (dark triangles) and age–depth model for Turbuta (grey line). The uppermost date used in the age–depth model is a U-Th age. The other two U-Th age estimates are also shown aside the adjusted curve. LPAZ are local pollen assemblage zones.

several lithological units would result in a highly speculative chronology.

Lacustrine and wetland development

>12,000 cal. yr BP (190–170 cm)

The bottom-most unit of our profile consists of clay gyttja that gradually changes color from dark gray in Unit 1a (190–180 cm) to brownish-green in Unit 1b (180–170 cm). These sediments were most likely deposited in a shallow lacustrine environment (Table 1, Fig. 3). In Unit 1a, TC fluctuates around 11% and is mainly composed of OC (ca 10%), indicating good productivity in the lake. Limnic plants such as *Lemna*, *Potamogeton* and *Utricularia* occurred in the water body of this shallow and possibly, slightly eutrophic lake (Fig. 4). Although our identification was not made to the species level, many species of *Potamogeton* and *Lemna* are good indicators of eutrophic conditions. Fairly high pollen percentages for wetland indicators, particularly Poaceae, Cyperaceae, *Thalictrum* and Apiaceae indicate that these taxa represented communities around the margins of this lake (the first half of LPAZ T-1; 190–175 cm; Fig. 4).

In the brownish-green clay gyttja of Unit 1b (180–170 cm), OC and OM decrease sharply along with an increase in IC content (Fig. 3). The significant carbonate content in this unit (Fig. 3) indicated by an observed reaction with HCl is most likely derived from molluscs shells, although no visible remains were observed. Limnic plants (mainly *Potamogeton*) are more frequent in the upper part of LPAZ-T1 (175–165 cm) than in the underlying sediments (Fig. 4). The sharp rise in pollen frequency and concentration of *Typha angustifolia*-type could indicate a shallow basin environment (Figs. 4 and 5).

12,000–8,000 cal yr BP (170–105 cm)

In the gyttja of Unit 2a (170–142 cm; >12,000–11,000 cal yr BP), the TC increases slightly and shows a peak at 160 cm (ca. 11,800 cal yr BP) (Table 1, Fig. 3). The carbonates display high values (40%) due to the abundance of finely crushed molluscs shells (Table 1, Fig. 3).

The highest values for OC, OM and carbonates for the entire profile occur in Unit 2b (142–101 cm; 11,000–8000 cal yr BP), which consists of detrital gyttja rich in molluscs, many of which are intact (Table 1, Fig. 3).

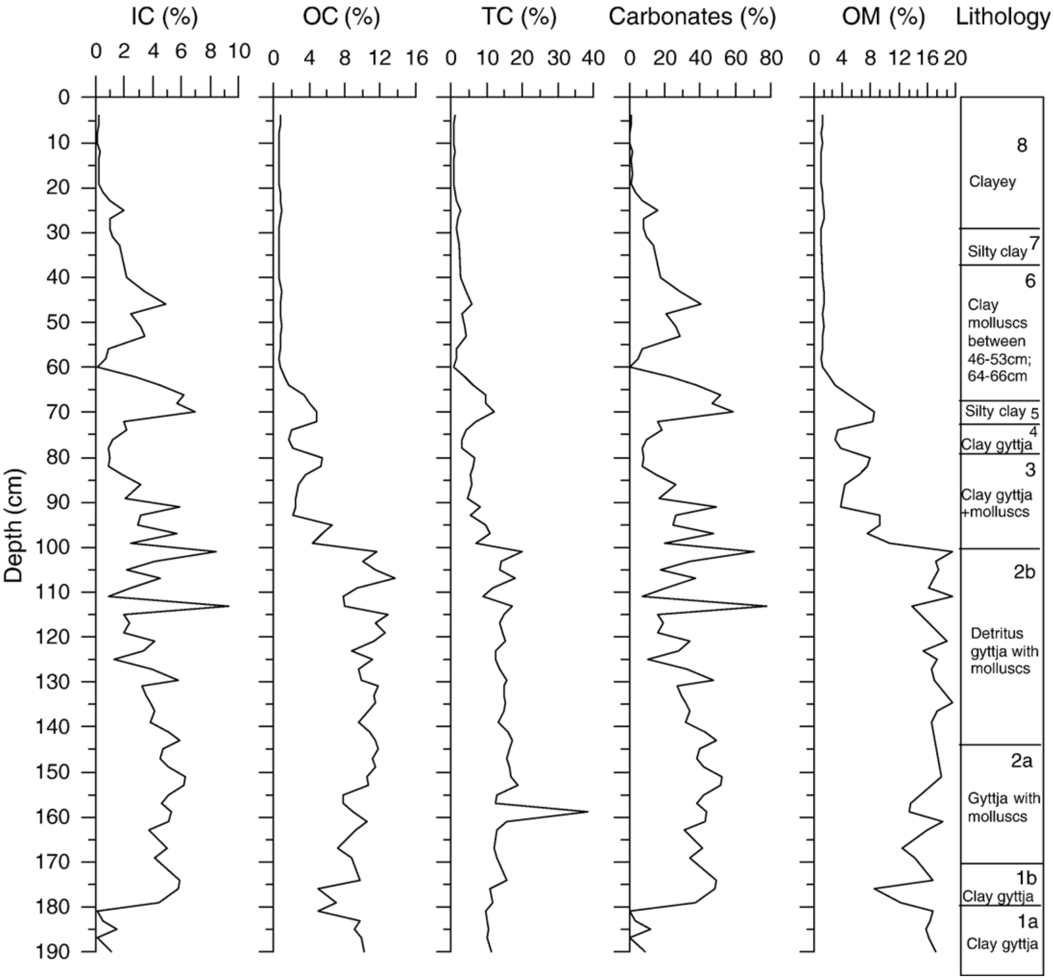

Figure 3. Lithology, inorganic carbon (IC), organic carbon (OC), total carbon (TC), carbonates and OM (organic matter) from Turbuta. Values are presented in percentages of dry weight.

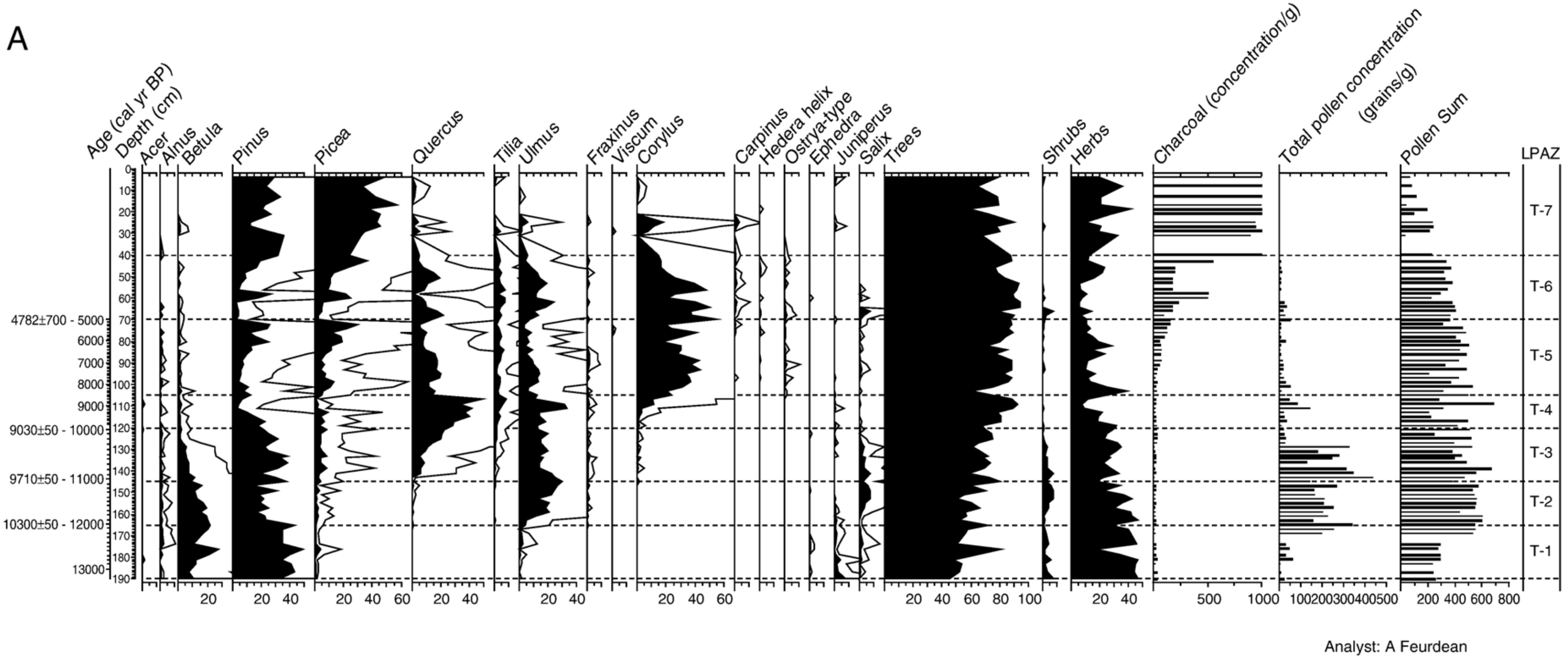

Figure 4. Pollen percentages diagram from Turbuta displaying all tree taxa and selected shrubs, herbaceous and spores taxa plotted on depth and calibrated age scale.

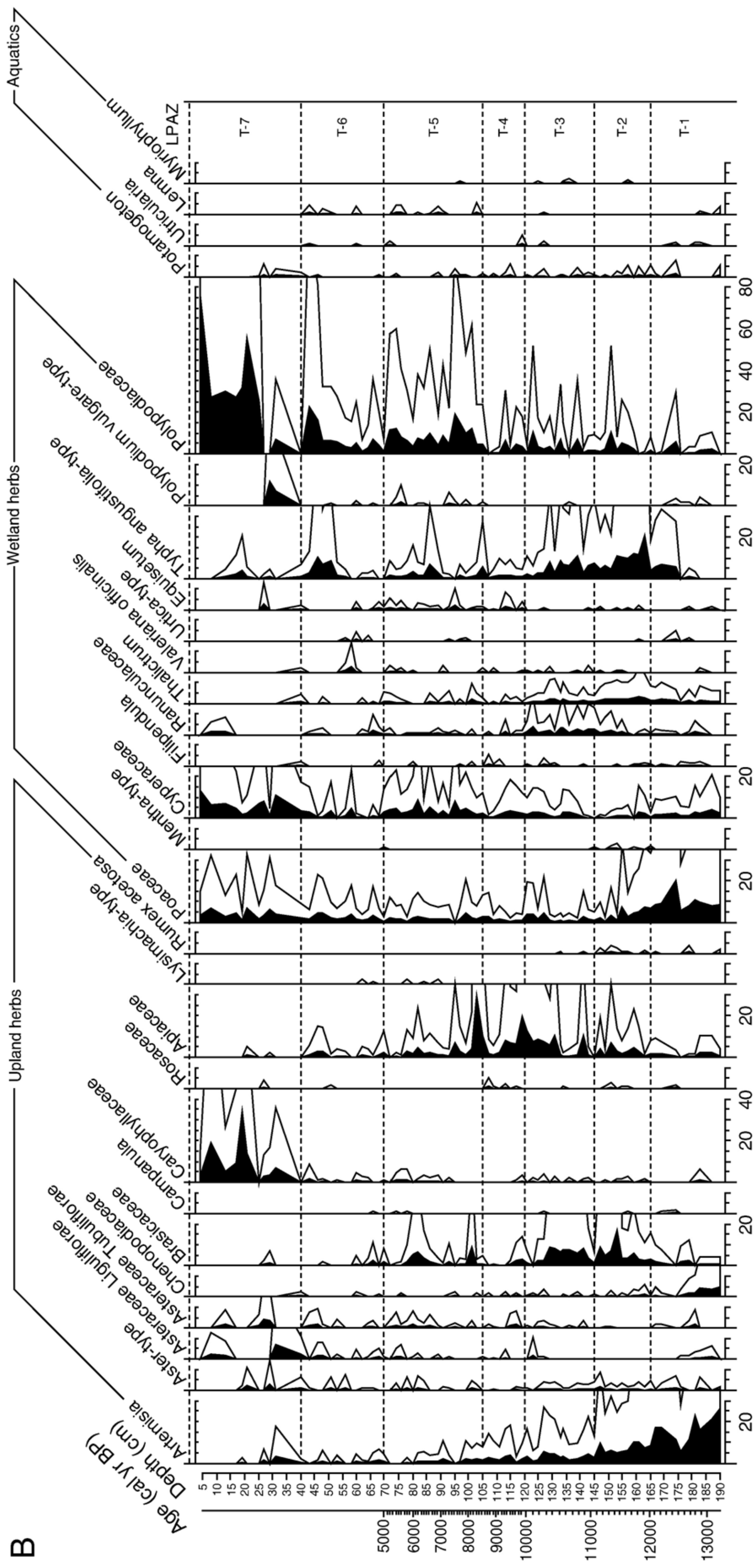

Figure 4 (*continued*).

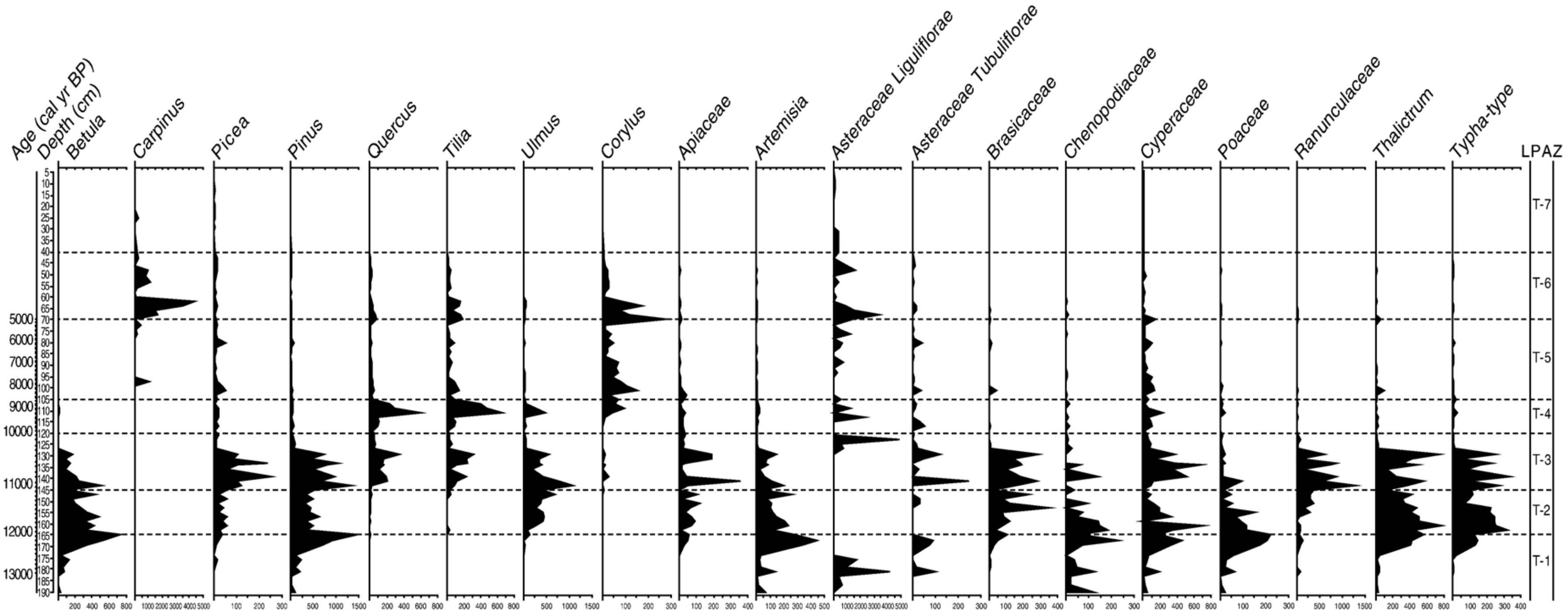

Figure 5. Pollen concentrations diagram of selected taxa from Turbuta (10^3 pollen grains/gram).

In LPAZ-T2 (165–145 cm; >12,000–11,000 cal yr BP) and LPAZ-T3 (145–120 cm; 11,000–10,000 cal yr BP; Figs. 4 and 5), pollen of aquatic plants slightly decrease (*Potamogeton* and *Utricularia*), and the diversity and abundance of pollen of reed mat (*T. angustifolia*-type), wetlands (Cyperaceae, Ranunculaceae, *Valeriana*-type, *Galium*-type and *Thalictrum*), Apiaceae, Brasicaceae and spores (*Equisetum* and Polypodiacea undiff.) is higher than in the previous zone, suggesting they were dominant around the lake shore. The high pollen percentages and concentrations for *Betula*, *Alnus* and *Salix* are most probably related to their occurrence around the lake, particularly close to the sampling point (Figs. 4 and 5). In LPAZ T-4 (120–105 cm; 10,000–8500 cal yr BP), pollen percentages and concentrations of reeds and ferns are distinctly lower, while Apiaceae and Cyperaceae concentrations increase (Figs. 4 and 5). These vegetation shifts along with changes in the sediment composition from gyttja to detrital gyttja (Fig. 3) may indicate a shallowing lake and slight advancement of lake-margin flora towards the inner part of the basin.

8000–5000 cal yr BP (105–70 cm)

Unit 3 (101–80 cm) is composed of clay gyttja with low TC and OC contents (Table 1, Fig. 3). The strong fluctuations seen in the carbonate values are likely related to the molluscs shells imbedded in the clay gyttja (Fig. 3). In LPAZ-T5 (105–70 cm; 8500–5000 cal yr BP), the pollen frequencies and concentrations for most of wetland taxa and marginal reeds (*T. angustifolia*) remain low suggesting that they were no longer important locally. In turn, aquatic taxa (*Potamogeton*, *Lemna*) and ferns become more frequent (Figs. 4 and 5). These are associated with a change in the lithology from detrital gyttja to clay gyttja indicating an increase in the lake level. Higher lake levels and a significant input of minerogenic material into the basin are evident in the upper part of LPAZ-T5 where sediments have high IC and low OC contents (Unit 4, 80–72 cm; 6000–5000 cal yr BP; Fig. 3).

<5000 cal yr BP (70–40 cm)

In the silty clay (Unit 5, 66–72 cm) and clay (Unit 6, 66–37 cm) sediments, the IC increases and OC and OM show lower values (Table 1, Fig. 3). The two layers of mollusc shells observed in Unit 6 are responsible for the high carbonate contents (Fig. 3). Pollen percentages and concentrations for Apiaceae, Brassicaceae, Cyperaceae, Ranunculaceae and *Thalictrum* are low, whereas *T. angustifolia* increase slightly in LPAZ-T6 (70–40 cm; Figs. 4 and 5). The advance and dominance of reed mat at the coring point and the retraction of the other wet-loving plants may indicate rising water level (Fig. 4).

The upper 37 cm of the profile consisting of silty clay (Unit 7, 37–29 cm) and clayey (Unit 8, 20–0 cm) layers with very low OC and IC contents point toward a very low lake productivity (Table 1, Fig. 3). The total and individual pollen concentrations are exceptionally low and the pollen sum does not exceed 100 grains per level, while some samples were almost sterile (LPAZ-T7, 40–0 cm; Figs. 4 and 5). Statistically, the total pollen sum is too low in this part of the sequence for inferring past vegetation dynamics.

Terrestrial and upland vegetation development

Pinus, Betula, NAP (LPAZ-T1), >12,000 cal yr BP

The basal pollen zone shows the highest percentages for non-arboreal-pollen (NAP, 40–50%), represented by *Artemisia* (25%), Poaceae (10%), Chenopodiaceae (5%), *Juniperus*, *Salix*, Asteraceae Tubuliflorae, Asteraceae Liguliflorae, *Aster*-type and *Ephedra*-type. This pollen assemblage points to a great development of open vegetation on the surrounding landscape (Fig. 4). The arboreal pollen sum (AP, ca. 50%) is mainly made up of abundant pollen-producing tree taxa such as *Pinus* and *Betula*, indicating the presence of open pine-birch woodland in the proximity of the basin (Figs. 4 and 5). Low percentages for *Picea*, *Ulmus* and *Alnus* suggest that small populations of these trees were established locally.

Ulmus, Betula, Pinus (LPAZ T-2), 12,000–11,100 cal yr BP

This zone is marked by significant changes in pollen percentages and concentrations of several trees and herbaceous taxa. *Ulmus*, distinctly increases to 35%, while *Pinus*, *Betula* and NAP gradually decrease and suggest the development of mixed coniferous–deciduous woodlands with *Ulmus* dominating the canopy (Figs. 4 and 5). Pollen percentages and concentrations for *Picea* display a slight rise, showing that spruce spread into the local woodlands. Trace amounts of *Quercus*, *Fraxinus* and *Tili*a pollen suggest the presence of isolated stands of these trees or at least a regional presence (Figs. 4 and 5). Total pollen concentration significantly increased during this period and points towards a denser vegetation cover in the vicinity of the basin. This is related, however, to a large contribution of high pollen producers like *Pinus* and *Betula* and by the considerable representation of wetland upland herbs. Overall, this implies that the local vegetation was denser than before (>12,000 cal. yr BP) but the woodland was not yet closed.

Ulmus, Quercus, Pinus, Picea (LPAZ T-3)
11,100–10,000 cal yr BP

The first appearance of *Corylus* pollen occurs in this zone. *Ulmus* woodland still dominated the slopes but the woodlands were increasingly diverse with rising occurrences of other thermophilous taxa such as *Quercus*, *Tilia*, *Fraxinus* and *Corylus* (Figs. 4 and 5). A distinct feature of this zone is the abrupt rise in pollen percentages and concentrations of *Pinus*, associated with a marked rise in pollen concentrations of *Picea* (not so obvious in terms of percentage; Figs. 4 and 5).

Quercus, Ulmus, Tilia, Picea, Corylus (LPAZ-T4),
10,000–8500 cal yr BP

Pollen percentages and concentrations for *Quercus* increase strongly at the beginning of this zone and reach a maximum (40%) in the upper part, suggesting that *Quercus* becomes the dominant tree on the surrounding landscapes (Figs. 4 and 5). *Tilia* shows high pollen concentration and since it is a poor pollen producer, percentages >10% (concentrations >600,000 grains cm^3) indicate a substantial contribution of *Tilia* in the local woodland. The upland herbaceous pollen percentages and concentrations are distinctly lower than in the previous zone, suggesting the development of a closing woodland (Figs. 4 and 5).

Corylus, Tilia, Quercus, Picea, Ulmus (LPAZ-T5)
8500–5000 cal yr BP

In the first half of this zone (105–85 cm; 8500– 6500 cal yr BP) zone, *Corylus* pollen percentages and concentrations rapidly increase, whereas those of *Quercus* and *Ulmus* significantly decline, suggesting that *Quercus*-dominated woodlands were replaced by *Corylus* (Figs. 4 and 5). In the second half of this zone (85–70 cm; 6500–5000 cal yr BP), pollen percentages of *Corylus* decrease temporary coincident with a slight increase of *Picea* and *Pinus*, with the concentration of *Picea* being similar to the preceding zone and the concentration of *Pinus* decreasing dramatically relative to the previous zone, suggesting that only *Picea* was locally important (Figs. 4 and 5). The first appearance of *Carpinus* pollen occurs at the beginning of this zone but its percentages do not exceed 3% throughout the profile, indicating only a minor contribution of *Carpinus* to the local woodlands. Pollen of *Hedera*, *Ostrya*-type and *Viscum* are present in trace amounts indicating a sporadic occurrence in the nearby forest (Figs. 4 and 5).

>5000 cal yr BP

Around 5000 cal yr BP (70 cm), a sharp decline in pollen percentages for *Picea* and *Pinus* along with an increase of *Corylus* suggests the existence of a hiatus (LPAZ-6; Figs. 4 and 5). The deposition of silty clay layers with sharp boundary and abruptly increasing carbonate content support this supposition (Fig. 3).

The LPAZ-7 is characterized by a very low number of pollen counts and extremely low values for total pollen concentration for each individual taxa (see also Lacustrine and wetland development). This zone is, however, dominated by pollen of *Picea* and *Pinus*, and spores of Polypodiaceae undiff., whereas the other trees taxa were reduced to trace amounts. Concomitantly, the charcoal concentrations distinctly increase.

Principal Components Analysis (PCA)

In the PCA ordination, the first axis account for 39.9% variance and the second axis for 27%. In the PCA plot of the first axis, eigenvectors of *Ulmus*, *Tilia*, *Quercus* and *Corylus* have opposite direction to the eigenvectors of *Pinus*, NAP and *Picea*. Species loading correspond to the order in which tree species reached highest values. This axis separates late glacial and Holocene taxa and may be interpreted as reflecting

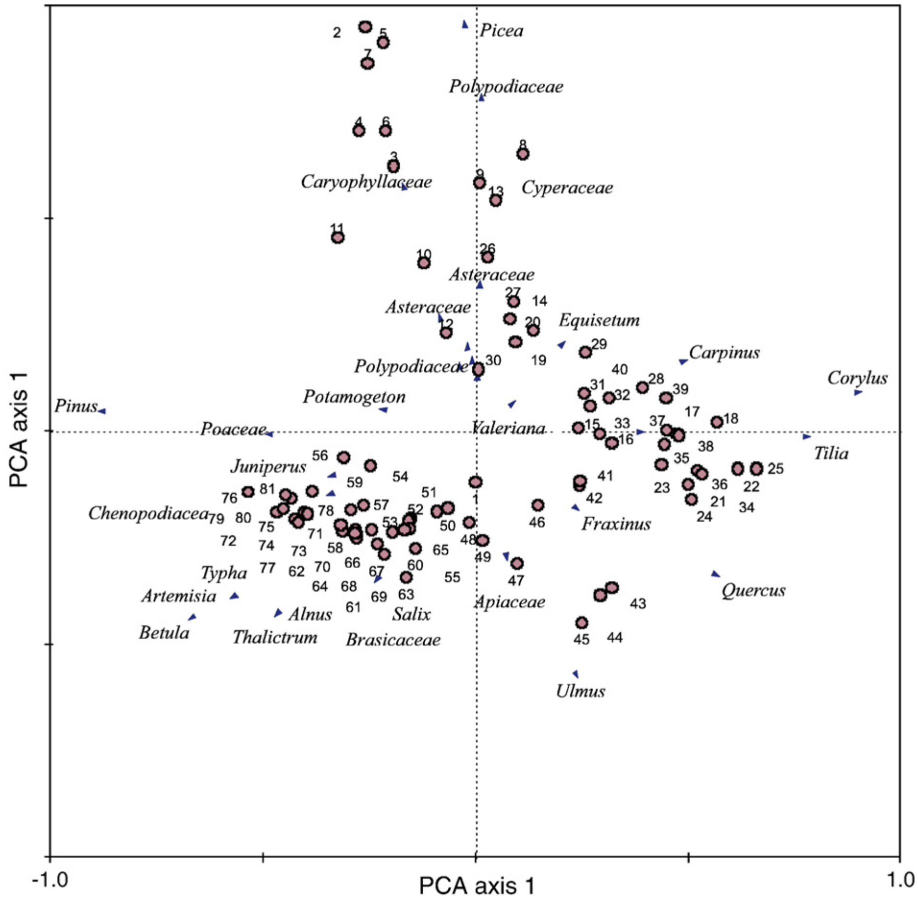

Figure 6. PCA biplot of species loading (arrows) of the pollen type accounting for more than 1% and the pollen sample score (circles) in the stratigraphic order from Turbuta. The first two axes explain 39.9% and 29%, of the variance, respectively.

changes in climate conditions. Axis 2 separates *Pinus*, *Picea*, *Corylus* (positive direction) from *Ulmus*, *Tilia*, *Quercus* and several herbaceous plants such as *Artemisia*, Brassicaceae (negative direction) and may represent interspecific differences (Fig. 6).

The ordination of the pollen samples (numbers) is consistent with the late glacial to Holocene succession. It starts with domination of *Pinus*-NAP (*Artemisia*, Chenopodiaceae, etc.), continues with the development of *Ulmus*-*Quercus*-*Tilia* followed by *Corylus* woodlands and ends with the development of *Carpinus* and *Picea* (Fig. 6).

Discussion

The present study provides information on previously unknown environmental history in lowlands of the northwestern Transylvanian Basin, from the Younger Dryas (>12,000 cal yr BP) until the mid-Holocene (~5000 cal yr BP). It also reveals that our profile is much younger than another nearby profile in the same gully documented to be Eemian in age.

The pollen assemblage in the lowest most section (>12,000 cal yr BP) indicates a mosaic of steppe and forest elements (Figs. 4 and 5). *Pinus* and *Betula* dominated the open woodlands with *Alnus* and *Salix* growing on moist soils. Small populations of *Picea* and scattered *Ulmus* trees, both low pollen producers, occurred within this boreal forest. The composition of vegetation is largely similar with other late glacial records in the Carpathians, although a significant amount of *Ulmus* pollen was only recorded in two sites from the Gutaiului Mountains, some 150 km north of Turbuta (Feurdean et al., 2007). The dominance of forest-steppe vegetation is generally interpreted as indicating cold and dry climate and correlates well with an environment envisioned for the Younger Dryas stadial. Pollen-based temperature reconstruction for the Younger Dryas in the Gutaiului Mountains attests that winter and summer temperatures were ca. 14 °C and ca. 2–6 °C, respectively lower, whereas annual precipitation (ca. 500 mm) was half of present-day values (Feurdean et al., submitted for publication, in press).

Pinus and *Betula* decreased in abundance by 11,900 cal yr BP and were rapidly replaced by *Ulmus* (Figs. 4 and 5). *Ulmus* was among the first deciduous trees to expand and dominate the lowland of Turbuta at the onset of the Holocene, most probably through competition driven by climate warming. The *Ulmus*-dominated woodland also includes a mixture of other deciduous and coniferous species such as *Betula*, *Pinus*, *Picea*, *Fraxinus*, *Alnus*, *Salix* and possibly *Quercus* and *Tilia* (Figs. 4 and 5). This vegetation pattern is in good agreement with previous results from Romania (Farcas et al., 1999; Björkman et al., 2002, 2003; Tantau et al., 2003, 2006; Feurdean, 2005; Farcas et al., 2006; Tantau, 2006; Feurdean et al., 2007). At Turbuta, however, *Ulmus* seems to have spread abruptly after the late glacial with no *Pinus–Betula* phase preceding its expansion (Fig. 4). The rapid increase in population density and distribution area for *Ulmus* at the very beginning of the Holocene, together with its occurrence during the late glacial indicates that the low elevations along Carpathians were important host areas for *Ulmus* (at least during the late glacial), and that this region may have also acted as a glacial refugia. In eastern Hungary, ca. 150 km northwest from Turbuta, *Tilia* dominated woodland (Willis et al., 1995), or a mixture of deciduous trees including *Ulmus*, *Corylus*, *Tilia*, *Fraxinus* and coniferous species (*Pinus* and *Picea*) (Magyari, 2002) were present in early Holocene, but *Ulmus* never played an important role on the Great Hungarian plain. It would be interesting to know if other specific factors, apart from refugia, were driving such clear advanced expansion of *Ulmus* in Romania, compared to the neighboring countries where the early Holocene woodlands contain a relatively uniform proportion of meso-thermophilous deciduous taxa.

Pollen of *Quercus* were not found before 12,000 cal yr BP at Turbuta implying that *Quercus* did not survive in the proximity of the study site during the late glacial (Fig. 4). Local stands of *Quercus* pollen became established between 12,000 and 11,000 cal yr BP, but its local expansion did not occur until about 11,000 cal yr BP and peaked between 10,000 and 8500 cal yr BP (Fig. 4). This is broadly parallel with the time of *Quercus* development in north-western, western and south-western Romania, though in Eastern Carpathians its expansion was dated to ca. 500 yr later (Farcas et al., 1999, 2006; Björkman et al., 2003; Tantau et al., 2003, 2006; Feurdean, 2004, 2005; Tantau, 2006). The amount of *Quercus* pollen at Turbuta by far exceeds the percentages recorded at other sites. This robust representation of *Quercus* was only previously documented in old, undated pollen diagrams from low elevation sites (Pop, 1957; Farcas et al., 2004). Analogous with present-day forest-steppe tree composition in Romania (Farcas et al., 2006), the ancient woodland around Turbuta may have contained several species of *Quercus* usually found in forest-steppe zones (*Q. cerris*, *Q. robur*, *Q. frainetto*, *Q. pedunculiflora*). *Tilia* pollen values are high, whereas *Fraxinus* are considerably lower at Turbuta compared to other pollen diagrams from the Carpathians. *Tilia* thrives on well-drained soils while *Fraxinus* mostly prefers moist soils at low and mid elevations (Grimme et al., 1986; Piggot, 1991). *Quercus* species are generally more resistant to summer drought (Piggot, 1991), and the marked expansion of *Quercus* accompanied by *Tilia* at Turbuta around 10,500 cal BP could be explained by climatic conditions, i.e. well-drained soils and lower effective moisture associated with both low elevation of the site and with regional change towards a drier climate conditions. The transition from gyttja to detritus gyttja with higher organic matter content at 11,000 cal yr BP at Turbuta may be the result of a lake level shallowing. This could be the consequence of a lesser amount of precipitation or to a higher evaporation due to hot summers. Another distinct feature at Turbuta that provides further support for drier condition is the high pollen percentages for *Pinus*, high concentrations for *Pinus* and *Picea* and declining percentages and concentration for *Ulmus* between 11,000 and 10,000 cal yr BP (Figs. 4 and 5). *Quercus*, *Tilia* and *Fraxinus* values remained rather stable. Since the concentration of each individual taxa is independent of the other types, we assume that, except for *Ulmus*, the spread of *Pinus* did not significantly affect the extension of other deciduous trees. *Pinus* and *Picea* must have also spread on the lake shore at the expense of wetland, as suggested by the decline of their percentages and concentrations values (Figs. 4 and 5). Water level lowering may have exposed mineral soils, which were immediately, occupied by *Pinus*.

Corylus avellana is absent during the late glacial and the onset of Holocene and appears to be established locally around 11,000 cal yr BP and spread regionally around 10,000 cal yr BP (Fig. 4). A long pollen tail pattern is seen before the expansion of *C. avellana* at numerous sites in Romania and this was presumably due to the fact that the mixed oaks (*Quercus*, *Ulmus*, *Tilia*, *Fraxinus*) woodlands were already dense (Feurdean, 2005) or it did not persist in glacial refugia in Romania (Tantau et al., 2006). *C. avellana* is not a good competitor against these species (Tallantire, 2002) therefore it is likely that an early *Corylus* expansion was inhibited in the mixed oak woodland. In pollen diagrams in the Carpathians, the spread of *Corylus* is evident mostly after the decline of *Ulmus*. At Turbuta, the expansion of *Corylus* occurred at the retraction of *Quercus* and some *Ulmus* and *Pinus* indicating that *Corylus* mainly invaded the gap left by *Quercus* (Fig. 4). This is also illustrated in the PCA plot where the eigenvectors of *Quercus* and *Ulmus* show a negative correlation to the eigenvector of *Corylus* (Fig. 6). The time of *Corylus* expansion at Turbuta (10,000 cal yr BP) coincides with drier conditions suggested by the lithology and wetland development (Figs. 3 and 4). Analogous climate conditions are indicated by pollen and pollen-based quantitative climate reconstruction in the Gutaiului Mountains around 10,300 cal yr BP (Feurdean, 2005; Feurdean et al., submitted for publication, in press). *Corylus* is a good pollen producer but the amount of pollen is suppressed under shady conditions (Tallantire, 2002). Therefore, abundant *Corylus* pollen at Turbuta from ca. 8800 cal yr BP most probably indicates *Corylus* dominance in the forest canopy rather than only an understory shrub. The raise in *Corylus* pollen coincides with an increase in micro-charcoal concentrations, suggesting enhanced fire activity (Fig. 4). Studies on *Corylus* ecology demonstrate that it benefits from fire (Tinner et al., 2000), hence burning near Turbuta may have helped maintain a *Corylus* woodland. These fires were most probably of natural origin since this is coincident with the lowest values for NAP in the profile, including those taxa indicators of human activity (e.g. *Plantago lanceolata*, *Artemisia*, Chenopodiaceae, Asteraceae, *Urtica*, *Rumex*).

Pollen percentages for *Picea abies* are relatively low at Turbuta between 8800 and 5500 cal yr BP (Fig. 4) and do not resemble those found in the Carpathian Mountains (Farcas et al., 1999; Bodnariuc et al., 2002; Feurdean, 2004; Tantau, 2006; Feurdean et al., 2007). Instead, at Avrig, a low elevation site in southern Transylvania, *Picea* also displays low pollen percentages (Tantau et al., 2006). *P. abies* needs moist soil, cool and humid summers and cold winters; it is sensitive to drought and water availability is the most important factor in limiting its distribution (Tranquilini, 1974; Sykes et al., 1996). Currently *P. abies* forms mountain woodlands in central and southeastern Europe, including the Carpathian Mountains (Dahl, 1998; Toader and Dumitru, 2004). Abundant *P. abies* pollen at mid and high elevation sites in the Carpathian Mountains clearly indicate that such locations offered much more suitable climatic conditions for *Picea* expansion (Feurdean et al., 2007). The dominance of *Corylus* and the slight expansion of *Picea* near Turbuta after 8000 cal yr BP are likely to suggest that climate conditions were slightly cooler and moister. This climate development is also evidenced by lithological changes in the palaeolake of Turbuta that indicate a rise in water level between 8000 and 5500 cal yr BP (Fig. 4). A similar shift towards moister conditions was inferred from pollen from about 8000 cal yr BP (Feurdean and Bennike, 2004) and testate amoeba (Schnitchen et al., 2006) in the Gutaiului Mountains. The effective moisture in the lowland of Turbuta was, however, not sufficient to allow a marked expansion of *P. abies*.

Isolated pollen grains of *Carpinus* appear between 6000 and 5000 cal yr BP, but most likely it became established in the nearby woodlands around 6000 to 5000 cal yr BP (Figs. 4 and 5). Although the chronology in part is not well constrained, the time of *Carpinus* occurrence is largely coincident with *Carpinus* spread in northwestern Romania. *Carpinus* seems to have played a minor role in the surrounding woodlands during this time and its presence is associated with that of warm-demanding taxa such as *Hedera* and *Viscum*.

Results from this study indicate relatively high values of NAP with decreasing trends towards mid Holocene. A large amount of this pollen is derived from plants growing in wet environment, but the significant presence of Apiaceae, Brasicaceae, Asteraceae, *Artemisia* and Poaceae, combined with high values of *Corylus* and *Pinus*, suggests that the forest were not that closed in the lowlands of Turbuta. As there is no evidence of clear anthropogenic influence such as presence of cultivated cereals, weeds and ruderal species, grazing fields or charcoal, we attribute the NAP values to the natural occurrence of open ground herbaceous vegetation. Archaeological sites of Neolithic age (the final phases of the Starcevo-Körös/Cris culture, ca. 7500 yr ago) were, however, reported in the region (Maxim, 1999).

What also emerged from this study, although our profile is incomplete, is that at least until ca. 5000 cal yr BP the nearby landscapes at Turbuta were fairly wooded and hence the formation of steppe-forest environment in the NW part of Transylvanian basin seems to have been the product of human activities that began sometimes after 5000 cal yr BP. Our results therefore shade light over the Romanian botanists and biogeographers debate regarding the origin of the forest-steppe in Transylvanian basin (i.e. is natural or a result of an intense deforestation).

Conclusions

The overall vegetation succession in the proximity of Turbuta is consistent with results provided by previous studies in the Romanian Carpathians. Several distinct features were, however, identified at Turbuta. (i) The presence of *Ulmus* and *Picea* during the Younger Dryas shows that low altitude played an important role in hosting these two taxa, but this area appears to be less diverse than mid-high elevation as no pollen of *Quercus*, *Tilia* and *Corylus* were recorded. (ii) The similarity of the early Holocene vegetation dynamics at Turbuta with other sites in Romania suggests the response of the vegetation to the regional climatic changes. (iii) *Quercus*, *Tilia* and NAP were more abundant and *Picea* is markedly under-represented at

Turbuta during early and mid-Holocene. The different proportion of these tree taxa suggests altitudinal-derived variance in the forest composition. Lower effective moisture, result of less precipitation and higher summer temperatures in the lowlands of Turbuta, may have been a key factor controlling the vegetation composition.

This paper emphasizes the importance of studies conducted at different elevations and how those studies can improve our understanding of the past vegetation dynamics in general and to identify the range expansion patterns for different tree species in particular. Furthermore, the divergent age obtained for different profiles in the Turbuta gully (i.e. Holocene and Eemian respectively) highlights the necessity of further age estimates for new profiles in this gully in order to understand the complex geomorphology of this section.

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