

Maharski prekop, Stare gmajne and Blatna Brezovica settlements and the vegetation of Ljubljansko barje (Slovenia) in the 4th millennium cal BC

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ABSTRACT – ABSTRACT – *In the 4th millennium cal BC the hinterlands of Ljubljansko barje basin were covered by beech-fir (Abies-Fagus) and mixed oak (Quercus) forests. People of several Eneolithic cultural groups were cutting/burning forests to open the landscape for fields and pastures. This paper focuses on high-resolution palynological analyses of pile-dwelling settlements Maharski prekop, Stare gmajne and Blatna Brezovica to investigate human impact on the vegetation, and to compare past economy and vegetation history in various parts of Ljubljansko barje. The results revealed that there were no major changes of vegetation throughout the 4th millennium cal. BC, neither were there any major differences between vegetation of the selected study sites. Cultural layers from archaeological sites (in larger quantities than off-site cores) contain pollen of plants that were brought to the settlement by people: cereals and other cultivars (Cereal t., Linum), weeds (Centaurea), grazing indicators (Plantago lanceolata, Campanula, Ranunculaceae), ruderal taxa (Chenopodiaceae, Artemisia), (gathered) shrubs (Corylus) and herbs. Traces of anthropogenic impacts from older settlements were detected in sediments below archaeological cultural layers at all study sites.*

KEY WORDS – *Ljubljansko barje; Stare gmajne; palynology; vegetation history; Eneolithic pile-dwelling sites*

Naselja in vegetacija na Maharskem prekopu, Starih gmajnah in Blatni Brezovici na Ljubljanskem barju v 4. tisočletju pr. n. št.

IZVLEČEK – *V 4. tisočletju pr. n. št. so na širšem območju Ljubljanskega barja uspevali pretežno bukovo-jelovi in hrastovi gozdovi. Ljudje različnih arheoloških kulturnih skupin so te gozdove občasno izsekavali, da so si odprli površine za potrebe poljedelstva in paše. Raziskava, ki jo predstavljamo v tem članku, se je usmerila na proučevanje palinološkega zapisa na eneolitskih koliščih Maharski prekop, Stare gmajne in Blatna Brezovica, da bi proučili človekov vpliv na rastlinstvo in primerjali razvoj vegetacije in nekdanje gospodarstvo na različnih delih Ljubljanskega barja. Rezultati visokoresolucijskih palinoloških raziskav so pokazali, da v 4. tisočletju pr. n. št. ni prišlo do večjih sprememb vegetacije, prav tako pa nismo zaznali razlik med vegetacijo v okolici posameznih kolišč, ki ležijo na različnih delih Ljubljanskega barja. Kulturne plasti z arheoloških najdišč (v večji meri kot sočasne plasti v vrtinah izven najdišč) vsebujejo pelod rastlin, ki so jih v naselje prinesli ljudje: žita (Cereal t.) in druge kultivirane rastline (npr. Linum), pleveli (Centaurea), pašni indikatorji (Plantago lanceolata, Campanula, Ranunculaceae), ruderalni taksoni (Chenopodiaceae, Artemisia), nekatere grmi (Corylus) in zeli. Na vseh najdiščih smo v plasteh pod arheološko kulturno plastjo odkrili tudi sledove človekovega vpliva na vegetacijo v času (domnevnih) starejših naselbin v okolici.*

KLJUČNE BESEDE – *Ljubljansko barje; Stare gmajne; palinologija; zgodovina vegetacije; eneolitska kolišča*

Introduction

Palaeoecological research at Ljubljansko barje has a very long tradition. After the first archaeological, archaeobotanical and palynological research in the 19th and 20th centuries (*Deschmann 1875*; see *Šercelj 1996.9*), palynological research in the 1960s focused on studies of Late Glacial and Holocene vegetation history, economy, and the impact of local Neolithic/Eneolithic populations on the environment. The results of research to date suggest that in the 4th millennium cal BC the landscape at Ljubljansko barje and its surroundings was forested with predominantly beech-fir and oak forests. The impact of Neolithic/Eneolithic farmers on the vegetation was pronounced: the inhabitants of Ljubljansko barje were cutting forest to open the landscape for agricultural fields and pastures (e.g., *Šercelj 1966*; *Culiberg, Šercelj 1978*; *Šercelj 1996* and references cited there, *Jeraj 2002*; *Jeraj et al. 2009*; *Andrič et al. 2008*; *Tolar et al. 2011*). Furthermore, forest cutting and grazing presumably also led to more subtle changes in vegetation composition. For example, it was suggested that due to small-scale forest clearances and thinning of canopy, forest composition shifted from beech-fir forest towards more open vegetation with more shade-intolerant taxa, such as hazel, oak and hornbeam (*Šercelj 1988*; *1996*; *Gardner 1999*). However, despite widespread archaeological and palynological research, many archaeological study sites excavated before the 1990s lacked high resolution palynological sampling and good chronological control.

With the beginning of dendrochronological research in the 1990s, the chronology of archaeological sites improved significantly, suggesting that individual sites were settled only for short time periods, often a few decades (*Čufar et al. 2010* and references cited there). Therefore, together with archaeological re-excavations and new excavations, the need arose to take samples for high-resolution, pollen analysis with chronological control, comparable to the work done at newly dated archaeological sites. In this paper the palynological record of four sedimentary columns

from three dendrochronologically dated (*Čufar et al. 2010*; *2015*) archaeological sites Maharski prekop (3489 ± 10 cal BC), Stare gmajne (older settlement: 3332 ± 10 cal BC; and younger settlement: 3109 ± 10 cal BC) and Blatna Brezovica (3071 ± 14 cal BC) will be compared to address the questions of: (1) whether the environment of archaeological study sites located in various parts of Ljubljansko barje varied significantly; (2) were there any major changes of vegetation and human impacts on the 4th millennium cal BC environment and (3) how do the environmental changes at Ljubljansko barje resemble/differ from contemporary and similar landscapes in Europe (e.g., Swiss pile-dwelling sites)?

Methods

Samples for palynological research (four sedimentary columns) were collected at three archaeological settlements (Fig. 1, black dots) during the archaeological excavations of a research team of the Institute of Archaeology, ZRC SAZU (led by Anton Velušček): Maharski prekop (excavations 2005), Stare gmajne (excavations 2006 and 2007) and Blatna Brezovica (excavations 2003). The sediment was collected using metal boxes (c. 7 x 7 x 50 cm) from one profile of each archaeological trench, wrapped in cling film, aluminium foil and thick plastic sheeting and stored in a cold store at +4°C. The following analyses were carried out for all four sedimentary columns: sediment description and loss-on-ignition analysis, radiocarbon dating, pollen and microcharcoal analysis.

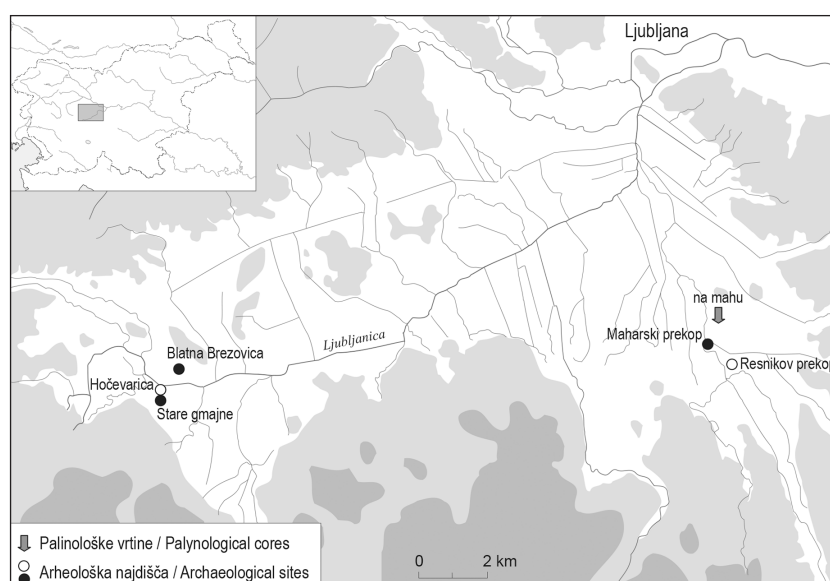


Fig. 1. Ljubljansko barje study area with the archaeological and palaeoecological study sites mentioned in the text. Black dots indicate archaeological sites with palynological results presented in this paper.

The percentage of organic material, carbonates and the remaining inorganic material in the sediment was determined by loss-on-ignition analysis at 550°C and 950°C (Bengtsson, Ennell 1986). The sediment description (Tab. 1) follows Jørgen Troels-Smith (1955).

The age of the sequence was determined by AMS radiocarbon dating of: (a) organic carbon extracted from the sediment (Blatna Brezovica, Stare gmajne 2006, Maharski prekop); (b) plant macrofossils (Stare gmajne 2007); or (c) unidentified plant material (Stare gmajne 2006, Maharski prekop). Laboratory pretreatment for radiocarbon dating varied according to the type of material which was dated: for sam-

ples with bigger plant remains (Beta-229152, Beta-229153, Beta-241776, Beta-269683 and Beta-242461) acid/alkali/acid washes were used, whereas organic carbon was extracted from bulk sediment using acid washes (Beta-210387, Beta-241777, Poz-36293, Poz-36292, Beta-202705 and Beta-192538). The conventional radiocarbon ages were calibrated using CALIB Rev 5.0.1 (CALIB 5.0 Website; Stuiver, Reimer 1993) on the IntCal 04 calibration dataset (Reimer et al. 2004). On study sites with several radiocarbon dates and relatively narrow two sigma ranges (e.g., Maharski prekop and Stare gmajne 2006), the age of the entire sequence was estimated by using linear interpolation between median values (Telford et al. 2004) of radiocarbon dates (Tab. 2) and the dendro-

MAHARSKI PREKOP 2005		
Depth	Troels-Smith symbol	Colour (Munsell soil chart)
0–16cm	Sh ₄ (organic sediment)	10 YR 2/1 (black)
16–27cm	Sh ₃ As ₁ (organic clay)	marbled: 10YR 2/1 (black) and 10YR 4/1 (dark grey)
27–40cm	Sh ₁ As ₃ (organic clay)	marbled: 10YR 2/1 (black) and 10YR 4/1 (dark grey)
40–58cm	Sh ₃ Ag ₁ (organic clay)	10YR 2/2 (very dark brown)
58–63cm	Sh ₁ Ga ₁ Ag ₁ As ₁ (organic silty and sandy clay)	10YR 4/1 (dark grey)
63–99cm	Sh ₂ Ag ₁ Dh ₁ (organic silty clay)	10YR 2/1 (black)
99–111cm	Sh ₁ Ag ₁ Dh ₁ Lc ₁ (organic silty clay)	10YR 4/1 (dark grey)
111–130cm	Sh ₁ As ₁ Lc ₂ (organic silty clay)	2.5Y 4/2 (dark greyish brown)
130–145cm	Sh ₁ Lc ₃ (organic silty clay)	2.5Y 5/2 (greyish brown)
145–160cm	Lc ₄ (silty clay)	2.5Y 5/3 (light olive brown)
STARE GMAJNE 2006		
0–18cm	Sh ₃ As ₁ (organic clay)	2.5 Y 2.5/1 (black)
18–28cm	Sh ₂ As ₂ (organic clay)	2.5 Y 3/1 (very dark grey)
28–45cm	Sh ₁ As ₁ Ag ₂ (organic silty clay)	2.5 Y 4/3 (olive brown)
45–90cm	Sh ₁ As ₁ Th ₁ Th ₁ (organic clay)	2.5 Y 3/2 (very dark greyish brown)
90–103cm	Sh ₂ Th ₁ Th ₁ (organic sediment)	2.5 Y 2.5/1 (black)
103–107cm	Sh ₁ As ₁ Th ₁ Th ₁ (organic clay)	2.5 Y 3/1 (very dark grey)
107–117cm	Sh ₁ As ₂ Ag ₁ (organic silty clay)	2.5 Y 4/2 (very dark greyish brown)
117–130cm	Sh ₂ As ₁ Th ₁ (organic clay)	2.5 Y 3/1 (very dark grey)
STARE GMAJNE 2007		
0–5cm	Sh ₂ Th ₁ Th ₁ (organic sediment)	10 YR 2/1 (black)
5–30cm	Sh ₁ As ₃ (organic clay)	2.5 Y 3/2 (very dark greyish brown)
30–38cm	Sh ₂ As ₂ (organic clay)	2.5 Y 3/1 (very dark grey)
38–62cm	Sh ₁ As ₃ (organic clay)	2.5 Y 3/2 (very dark greyish brown)
62–80cm	Sh ₂ Th ₁ As ₁ (organic clay)	2.5 Y 3/1 (very dark grey)
80–90cm	Sh ₃ As ₁ (organic clay)	2.5 Y 2.5/1 (black)
90–130cm	Sh ₂ As ₁ Ag ₁ (organic, silty clay)	2.5 Y 3/2 (very dark greyish brown)
BLATNA BREZOVICA 2003		
0–20cm	Sh ₄ (organic sediment)	7.5 YR 2.5/1 (black)
20–50cm	Sh ₂ As ₂ (organic clay)	7.5 YR 3/1 (very dark grey)
50–60cm	Sh ₂ As ₁ Ld ₁₃ (organic, silty clay, rich in wood detritus)	7.5 YR 3/1 (very dark grey)
60–110cm	Sh ₂ Ag ₁ Ld ₁₃ (organic, silty clay, rich in wood detritus)	10 YR 3/1 (very dark grey)
110–130cm	Sh ₁ Ag ₂ As ₁ (silty clay)	10 YR 4/2 (dark greyish brown)

Tab. 1. Troels-Smith (1955) description of the sediment: Maharski prekop (western cross-section of trench 2), Stare gmajne 2006 (southern cross-section of trench 2), Stare gmajne 2007 (southern cross-section of trench 3) and Blatna Brezovica 2003 (southwestern cross-section of trench 2).

chronological age of the cultural layer at each archaeological site (Čufar et al. 2010).

At Maharski prekop sample Beta-229153 (80cm) was omitted from the age-depth model due to age reversal and incompatibility with dendrochronological dating (Čufar et al. 2010). At Stare gmajne 2006 two types of material from the same level (126cm) were dated in order to test the suitability of plant macrofossils and organic sediment for radiocarbon dating (Tab. 2; Beta-241777 and Beta-242461). Two sigma ranges of radiocarbon dates partly overlap, suggesting that both types of material are reliable for dating and the organic sediment is not (significantly) older than the plant macrofossils.

For pollen analysis, 1cm³ of sediment was subsampled with a 4cm resolution throughout most of the profile, i.e. 35 samples at Maharski prekop, 26 samples at Blatna Brezovica, and 33 and 32 samples at Stare gmajne 2007 and 2006 profiles, respectively. A standard laboratory procedure was used (HCl, NaOH, HF, acetolysis, staining with safranin, mounting in silicone oil, Bennett, Willis 2002) and pollen concentration was determined by adding *Lycopodium* spores (Stockmarr 1971). Pollen was identified using a Nikon Eclipse E400 light microscope at 400x magnification, reference collection at the Institute of Archaeology ZRC SAZU and pollen keys (Reille 1992; 1995; Moore et al. 1991). A minimum of 500 pollen

grains of terrestrial taxa and spores (= pollen sum) were counted in each sample, with the exception of silty and sandy layers with very low pollen concentrations at some study sites (e.g., at Blatna Brezovica), where the pollen sum was lower. The concentration of microscopic charcoal was established using two methods: microscopic charcoal (in two size classes, <40µm and >40µm) was counted along with pollen and, in addition to this, Clark's (1982) point count method was used. The pollen and 'loss-on-ignition' data were analysed and plotted using PSIMPOLL 3.00 software (Bennett 1998; PSIMPOLL website). All pollen diagrams were divided into statistically significant zones using binary splitting by sum of squares. Values lower than 0.5 are marked with a solid dot. The archaeological cultural layer is marked by a shaded bar.

Results

The results of sediment description and radiocarbon dating are presented in Tables 1 and 2, the results of loss-on-ignition analyses in Figures 2, 5, 7 and 9, and the results of pollen and microcharcoal analysis in Figures 3, 6, 8 and 10.

Radiocarbon dating and age-depth modelling

The results of radiocarbon dating (Tab. 2) are in accordance with the results of previous, dendrochronological research (Čufar et al. 2010), indicating

MAHARSKI PREKOP 2005						
Sample number	Depth	Material dated	Conventional radiocarbon age	¹³ C/ ¹² C ratio	2σ calibrated result [cal BC]	Median [cal BC]
Beta-229152	44cm	Charred material	4730±50 BP	-24.6 ‰	3636–3494	3522
Beta-229153	80cm	Unidentified plant material	3910±50 BP	-28.2 ‰	2564–2209	2390
Beta-210387	124cm	Organic sediment	5560±40 BP	-30.0 ‰	4461–4338	4401
STARE GMAJNE 2006						
Beta-241776	40cm	Peat	3610±40 BP	-27.1 ‰	2131–1881	1970
Beta-269683	96cm	Unidentified plant material	4480±40 BP	-28.2 ‰	3348–3026	3210
Beta-241777	126cm	Organic sediment	5210±40 BP	-30.4 ‰	4226–3954	4016
Beta-242461	126cm	Peat	5170±40 BP	-29.3 ‰	4049–3809	3980
STARE GMAJNE 2007						
Poz-36293	70–71cm	<i>Stachys</i> sp.	4560±60 BP 0.21mg C	/	3501–3030	3244
Poz-36292	90–91cm	<i>Linum</i> u.	4580±60 BP 0.17mg C	/	3516–3096	3313
BLATNA BREZOVICA 2003						
Beta-202705	48cm	Organic sediment	4450 ± 40 BP	-28.7 ‰	3338–2933	3151
Beta-192538	80cm	Organic sediment	4730±40 BP	-28.2 ‰	3635–3376	3526

Tab. 2. Radiocarbon dates: Maharski prekop (western cross-section of trench 2), Stare gmajne 2006 (southern cross-section of trench 2), Stare gmajne 2007 (southern cross-section of trench 3) and Blatna Brezovica 2003 (southwestern cross-section of trench 2).

that the final phase of each archaeological settlement (presumably settled for a few decades only) is dated to: Maharski prekop: 3489 ± 10 cal BC, Stare gmajne: 3332 ± 10 cal BC (older phase) and 3109 ± 14 cal BC (younger phase), and Blatna Brezovica: 3071 ± 14 cal BC. However, due to long two sigma ranges and fast changes in sedimentation rates, the chronological precision of palynological sequences is lower in comparison with dendrochronology. Therefore, an attempt to estimate the sedimentation rate and produce an age-depth model was carried out only on longer sequences with a higher number of radiocarbon dates (for Maharski prekop and Stare gmajne 2006).

The sedimentary record on study sites covers the time periods between *c.* 5000–2000 cal BC at Maharski prekop and *c.* 4000–2000 cal BC at Stare gmajne and Blatna Brezovica. Before archaeological occupation, the sedimentation rate at Maharski prekop between 5000–3400 cal BC was *c.* 0.05 cm/yr, which is comparable with that at Stare gmajne 2006 (0.04 cm/yr between *c.* 4000 and 3200 cal BC). The sedimentation rate in the archaeological cultural layers of all study sites was presumably much faster,

for example, *c.* 0.29 cm/yr at Stare gmajne 2007, due to the higher input of organic material (*e.g.*, wood, plants, bones, artefacts) which was brought to the settlement by people. Sediment younger than *c.* 2500–2000 cal BC seems to be missing on all study sites: it was probably removed during peat cutting in the 18th and 19th centuries AD (Melik 1927), and possibly also by Late Bronze Age flood erosion at *c.* 1700 cal BC (Andrić et al. *in preparation*).

Sediment description, loss-on-ignition and pollen analysis

Maharski prekop

The pollen column which was collected in 2005 from the western profile of archaeological trench 2 (for archaeological excavations see Velušček, Čufar 2008) is 160 cm long. The archaeological cultural layer is located at *c.* 86–48 cm.

Sediment at the bottom of the profile (160–114 cm) is calcareous silty clay (Tab. 1), with a very low percentage of organic material (*c.* 5–15%) and 25–40% of carbonates, whereas the percentage of remaining inorganic material without carbonates is more than 50% of sediment dry weight (Fig. 2). At 114–62 cm

the amount of organic material increases to *c.* 10–31% (highest in the archaeological cultural layer at 80–68 cm), whereas carbonates decrease to 1–22% of sediment dry weight. The percentage of carbonates also remains low at the top of the profile (62–0 cm), whereas the amount of organic material decreases and the remaining inorganic material increases, especially at 62–32 cm.

In the pollen zone M-1 (160–114 cm, *c.* 5000–4200 cal BC; Fig. 3) tree and shrub pollen dominates with 77–93%. The main tree/shrub pollen taxa are *Corylus* (19–42%), *Alnus* (9–24%), *Quercus* (8–18%) and *Fagus* (9–12%, 25% only at 156 cm), whereas *Abies* is present with very low values (0.1–2%). The percentage of herb pollen is low (*c.* 10%), but increases towards the top of the zone. The main herb taxa present are Cyperaceae (0.5–5%), Poaceae (1–3%), and anthropogenic indicator taxa

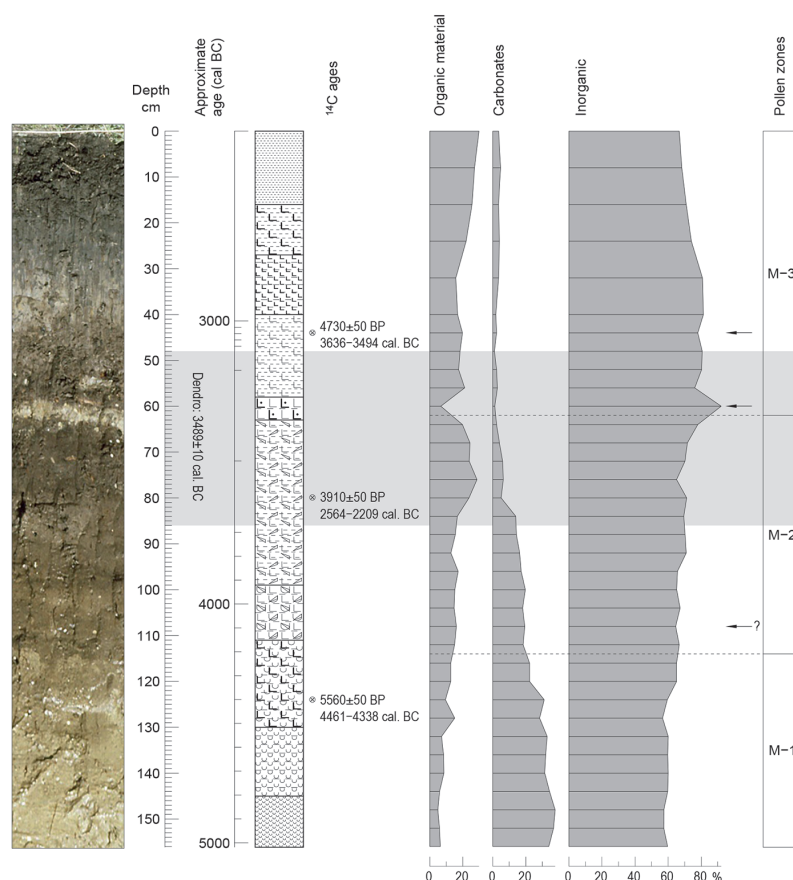


Fig. 2. Maharski prekop, 'loss-on-ignition' diagram. The grey shaded bar at 48–86 cm marks the position of the archaeological cultural layer. Arrows on Figs. 2, 3, 5–10 mark flood layers.

(e.g., Cereal type, *Secale*, Chenopodiaceae, *Artemisia*, *Plantago lanceolata*, each c. 0–2%). Microscopic charcoal and *Pediastrum* algae are also present in this pollen zone.

In the pollen zone M-2 (144–62cm, c. 4200–3500 cal BC) the vegetation composition changes significantly. The percentages of *Fagus* and *Abies* increase (to c. 14–31% and 4–14% respectively), whereas those of *Alnus* (6–15%) and *Corylus* (12–26%) decline. In the archaeological cultural layer towards the top of the zone (86–62cm), the percentage of tree pollen (especially *Abies* and *Fagus*) starts to decline, whereas anthropogenic indicator taxa (e.g., Cereal t., Chenopodiaceae) increase.

The main characteristic of the pollen zone M-3 (62–0cm, after c. 3500 cal BC) is the change in forest composition: *Picea* and *Pinus* increase to 4–28% and 2–12% respectively, whereas *Abies*, *Fagus*, *Quercus*, and *Corylus* decline. The tree pollen sum declines and there is an increase in herbs (Cyperaceae, Poaceae, Cichoriaceae) and monolete fern spores (Filicales). The percentage of degraded pollen grains increases to c. 2–10%.

Stare gmajne 2006

The pollen column which was collected in 2006 from the southern cross-section of archaeological trench 2 (for archaeological excavations see *Velušček 2009a*) is 130cm long. The archaeological cultural layer is located at c. 90–43cm.

The sedimentary composition of the column is very heterogenous (Tab. 1 and Fig. 5). Sediment at 130–116cm is mineral with 14–21% of carbonates, 11–23% of organic material and 63–71% of remaining inorganic material. Further up the profile (116–108cm) the amount of organic material drops to 3–4%, whereas the remaining inorganic material increases. A major change in sediment composition occurs when the percentage of carbonates (106cm) and inorganic material (102cm) declines; the organic material increases to 23–90% of sediment dry weight. At 90–43cm the percentage of carbonates remains low (1–5%), whereas the percentage of organic material (14–59%) and the remaining inorganic matter (37–84%) fluctuates. Above 43cm the percentage of inorganic material is high (74–91%), the amount of organic material is similar to that seen at the bottom of the profile, but with a lower percentage of carbonates.

In the pollen zone S-1 (130–90cm, c. 4100–3200 cal BC; Fig. 6), the percentage of tree and shrub pol-

len is high (53–92%), the main taxa are *Fagus* (7–21%), *Quercus* (7–21%), *Abies* (0–12%), *Picea* (3–9%), *Alnus* (0.5–13%) and *Corylus* (9–25%). Herb taxa include Cyperaceae (0–12%), Poaceae (1–5%) and occasional occurrence of anthropogenic indicator taxa (e.g., Cereal t., *Secale*, Chenopodiaceae, *Artemisia*). The pollen concentration is c. 3500–9000 pollen grains per 1cm³, and in mineral part of the profile at 108–116cm it was very low (c. 400–1100 pollen grains/1cm³) and thus not possible to count a statistically significant pollen sum (>300). Towards the top of the zone the percentage of tree pollen declines, whereas the percentage of monolete fern spores (Filicales) and *Thelypteris palustris* increases.

The main characteristic of pollen zone S-2 (90–58cm, c. 3150–3100 cal BC) is the lower percentage of tree pollen (40–84%): all tree taxa decline, whereas *Corylus* slightly increases and fluctuates between 17 and 51%. Herbs increase to 13–58%. The percentage of anthropogenic indicator taxa (e.g., Cereal t. 1–10%, *Secale* c. 0.5%, Chenopodiaceae up to 40%, *Artemisia* 0.5–1%) and microscopic charcoal (0.1–0.7cm²cm⁻³) is high.

The pollen composition in zone S-3 (58–43cm; c. 3100–2500 cal BC) is similar to that in S-2, but towards the top of the zone, immediately above the archaeological cultural layer, *Pinus* and *Picea* increase to c. 2–13%. The percentage of degraded pollen is higher than in previous zones, with a very low pollen concentration (c. 300–650 grains/1cm³) and highest percentage of degraded pollen grains (27%) at the transition between zones S-3 and S-4.

The percentage of tree taxa stays low in the pollen zone S-4 (43–0cm, after c. 2500 cal BC). The concentration of microscopic charcoal decreases, whereas *Alnus*, Filicales, Trilete spores and Cichoriaceae increase.

Stare gmajne 2007

The pollen column which was collected in 2007 from the southern cross-section of archaeological trench 3 (for archaeological excavations see *Velušček 2009a*) is 130cm long. The archaeological cultural layers are located at c. 95–85cm (older phase) and c. 85–70cm (younger phase).

The sediment below the archaeological cultural layers (130–95cm) is calcareous silty clay (Tab. 1), with a very low percentage of organic material (c. 9–17%) and 10–21% of carbonates, whereas the percentage of remaining inorganic material is 69–72% of sedi-

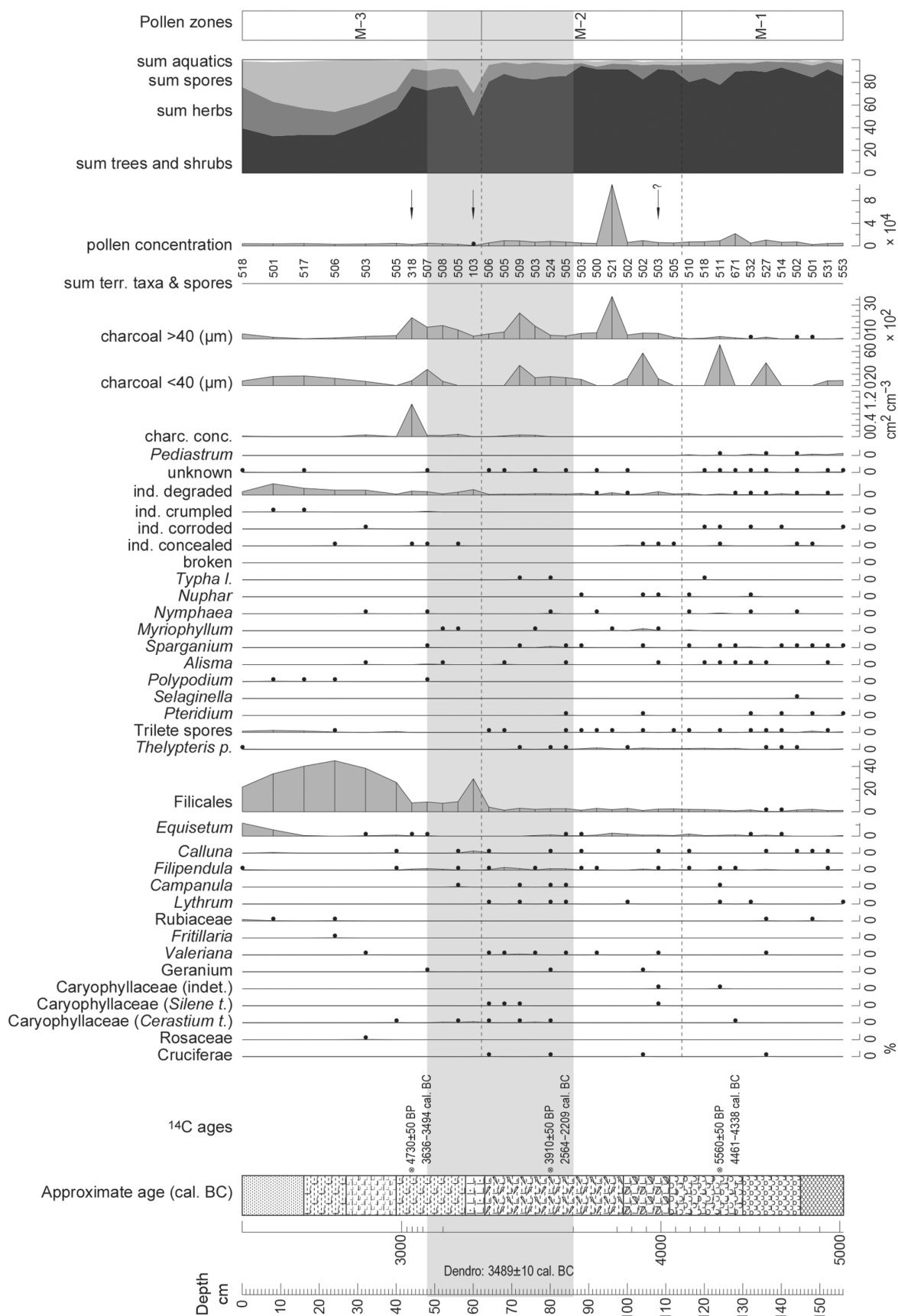


Fig. 3. Maharski prekop, pollen diagram. Values lower than 0.5 are marked with a solid dot. The archaeological cultural layer is marked by a shaded bar. Dendrochronological date (grey) after Čufar et al. 2010.

ment dry weight (130–95cm, Fig. 7). Further up the profile the percentage of organic material in the archaeological cultural layers increases to 19–33%, whereas carbonates decline to c. 1–4%. At 70–38cm the percentage of organic material decreases again to c. 10% and inorganic material increases to c. 85%. At the top of the profile (38–0cm) there is 15–27% of organic material, the percentage of carbonates remains low (2–4%), and the remaining inorganic material is between 68 and 82%.

There are only two statistically significant pollen zones (Fig. 8): S-1 (130–37cm) and S-2 (37–0cm). In zone S-1 the percentage of tree and shrub taxa is relatively high (70–94%), but declines in archaeological cultural layers (66–82%) and towards the top of the zone (only 44%). The main tree taxa are *Fagus* (11–20%), *Quercus* (18–24%), *Alnus* (5–14%) and *Corylus* (11–20%). The main herb taxa are Cyperaceae and Poaceae, Cichoriaceae, Apiaceae, Cereal t., *Linum*, *Plantago lanceolata*, Chenopodiaceae and *Ranunculus a.* The sediment also contains microscopic charcoal. In the older archaeological cultural layer (95–85cm) the percentage of *Fagus* and *Quercus* declines to c. 5% and 10%, respectively, whereas *Corylus*, Cereal t. and microscopic charcoal increase. In the younger archaeological cultural layer (85–70cm) *Fagus* and *Quercus* increase again, whereas anthropogenic indicator taxa and microscopic charcoal decrease. At 68cm *Pinus*, *Picea*, *Abies* and herb taxa (e.g., Cyperaceae, Poaceae, Filicales, *Sparganium*) increase, whereas other tree taxa decline.

The main characteristic of the pollen record in zone S-1 (38–0cm) is the low percentage of tree pollen (29–49%; only *Alnus* increases to 7–37%), and increase in Filicales (19–57%) and Trilete spores (4–10%).

Blatna Brezovica

The pollen column which was collected in 2003 from the southwestern cross-section of archaeological trench 2 (for archaeological excavations see Velušček 2009c) is 130cm long. The archaeological cultural layer is located at c. 77–57cm depth.

Silty clay at 128cm contains only 7% of organic material, 25% of carbonates and 68% of remaining inorganic material. Up the profile the percentage of carbonates gradually decreases to c. 2–5%, whereas the organic material at 56cm increases to 30%. The main characteristic of sediment between 54 and 34cm is the higher percentage of organic material

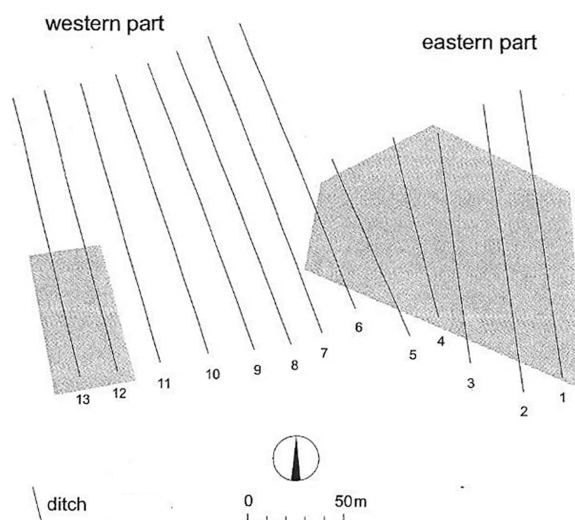


Fig. 4. Plan of Stare gmajne with irrigation ditches, grey areas marking the western and eastern parts of the settlement, after Velušček 2009a, Sl. 1.3 and 1.4.

(28–32%) with wood remains, whereas the percentage of inorganic material decreases to 62–70%. Sediment above 34cm is similar, but with less organic material (25–30%).

In pollen zone B-1 (128–77cm; Fig. 10) the percentage of trees and shrubs at 110–128cm is 85–94%, with the following main tree taxa: *Quercus* (19–33%), *Fagus* (17–22%), *Corylus* (12–20%), *Abies* (4–9%) and *Picea* (4–8%). The pollen concentration is very low (1300–1800 pollen grains per 1cm³). At 105cm tree taxa (especially *Fagus* and *Quercus*) decrease, whereas herbs including anthropogenic indicator taxa (such as Cereal t., Chenopodiaceae, *Artemisia*), Poaceae, Filicales, trilete spores and microscopic charcoal concentration, start to increase. In zone B-2 (54–34cm) trees (e.g., *Fagus*, *Quercus* and *Corylus*) decrease, but there is a short term increase in *Abies*, Cyperaceae, *Equisetum* and Filicales. The pollen concentration increases to c. 9000–35000 grains per 1cm³, but decreases again in zone B-3. The main taxa in zone B-3 (34–0cm) are *Picea* (11–30%), *Alnus* (5–23%) and Filicales (2–15%).

Discussion

Taphonomy and palaeohydrological conditions before, during and after archaeological settlement

The sediment composition was affected by palaeohydrological conditions and human activities. In the first half of the 4th millennium cal BC, before the establishment of archaeological settlements, the percentage of carbonates is higher at all study sites (15–

20% of sediment dry weight; Figs. 2, 5, 7 and 9). At Maharski prekop the sediment contains *c.* 20–40% of carbonates and *Pediastrum* algae, suggesting high CaCO_3 precipitation in lake deposits between *c.* 5000–4100 cal BC. Later the percentage of carbonates declines to 20% of sediment dry weight (which is comparable with pre-settlement layers of Stare gmajne and Blatna Brezovica), and *Pediastrum* algae are no longer present. Sedimentological research at Stare gmajne and Blatna Brezovica (Turk, Horvat 2009) demonstrated that sediment below the archaeological cultural layer contains ostracode valves and oogonia of Characeae, diatoms and fine grain carbonate aggregates (with 60–80% of carbonates in <0.2mm fraction), which presumably deposited in a shallow lake to marshy environment. At the current state of research it is difficult to estimate whether all carbonates in pollen profiles were authigenic, or some were also brought to the basin by river transport.

In the archaeological cultural layers of all study sites the proportion of mineral grains increased, whereas the proportion of carbonates is low, suggesting a marsh environment (Turk, Horvat 2009). Similarly, the results of archaeobotanical research at Maharski prekop indicate that the settlement was presumably located near water, probably lakeshore and/or wetland, which were occasionally flooded (Tolar 2018). Pollen of water plants is, in small quantities, present at all study sites and throughout all sequences (Figs. 3, 6, 8 and 9), but does not show any patterns (*e.g.*, hydrosere succession). On-site taphonomic processes were also affected by people. Both loss-on-ignition (this study; Figs. 2, 5, 7 and 9) and sedimentological research (Turk, Horvat 2009) have shown an increased percentage of organic matter. A faster sedimentation rate and consequently lower pollen concentration at some sites were also detected as a result of human activity, and possibly also changed hydrological conditions (lower CaCO_3 precipitation).

The sediment above archaeological cultural layers contains mostly organic material (this study;

Figs. 2, 5, 7 and 9), quartz grains and an increasing percentage of clay towards the top of the profile which deposited on the floodplain (Turk, Horvat 2009). The percentage of degraded pollen increases in the top part (= above *c.* 60–50cm) of all analysed profiles (Figs. 3, 6, 8 and 9) because of drier conditions due to (present-day) draining activities, farming, and dry and warm summers, which endanger the preservation of the palaeoecological and archaeological record in the area.

Flood events and local vs. regional variability

Several layers containing more quartz (Turk, Horvat 2009) and remaining inorganic material, lower pollen concentration and more degraded pollen (this study; Figs. 2–10, layers marked with arrows) were discovered at all study sites. It is assumed that they formed during flood events, however the subsequent results are only preliminary and further, more detailed geological research (sedimentological, mineralogical and geochemical analysis) is needed to address this topic in more depth.

No clear regional pattern with distinct, synchronous flood events was reconstructed. Due to unprecise chronology (no annually laminated sediment) it is difficult to pinpoint individual flood events. Traces of flooding in the first half of the 4th millennium

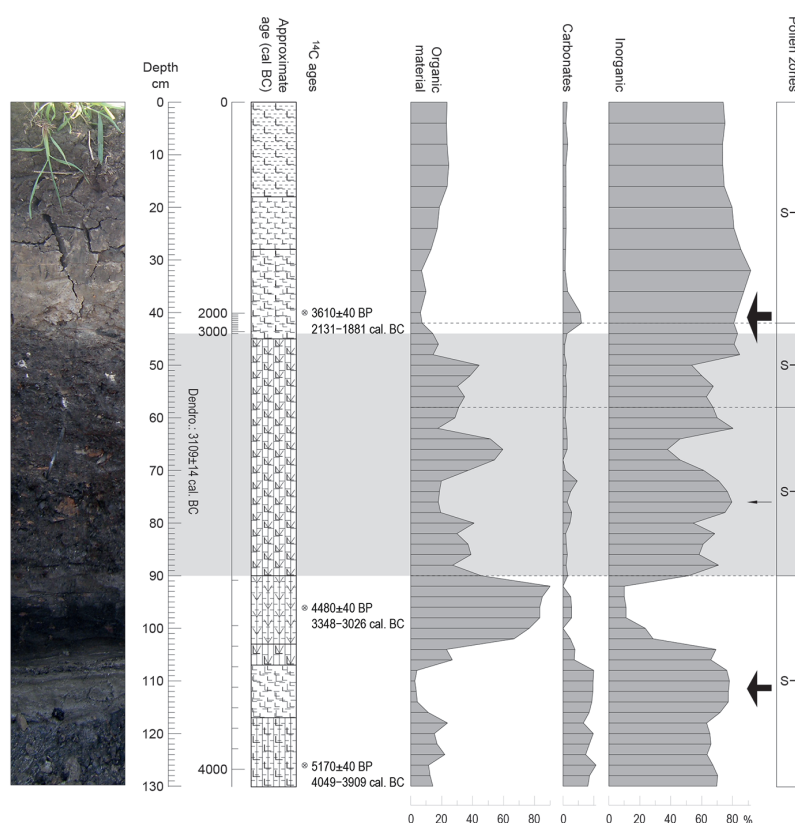
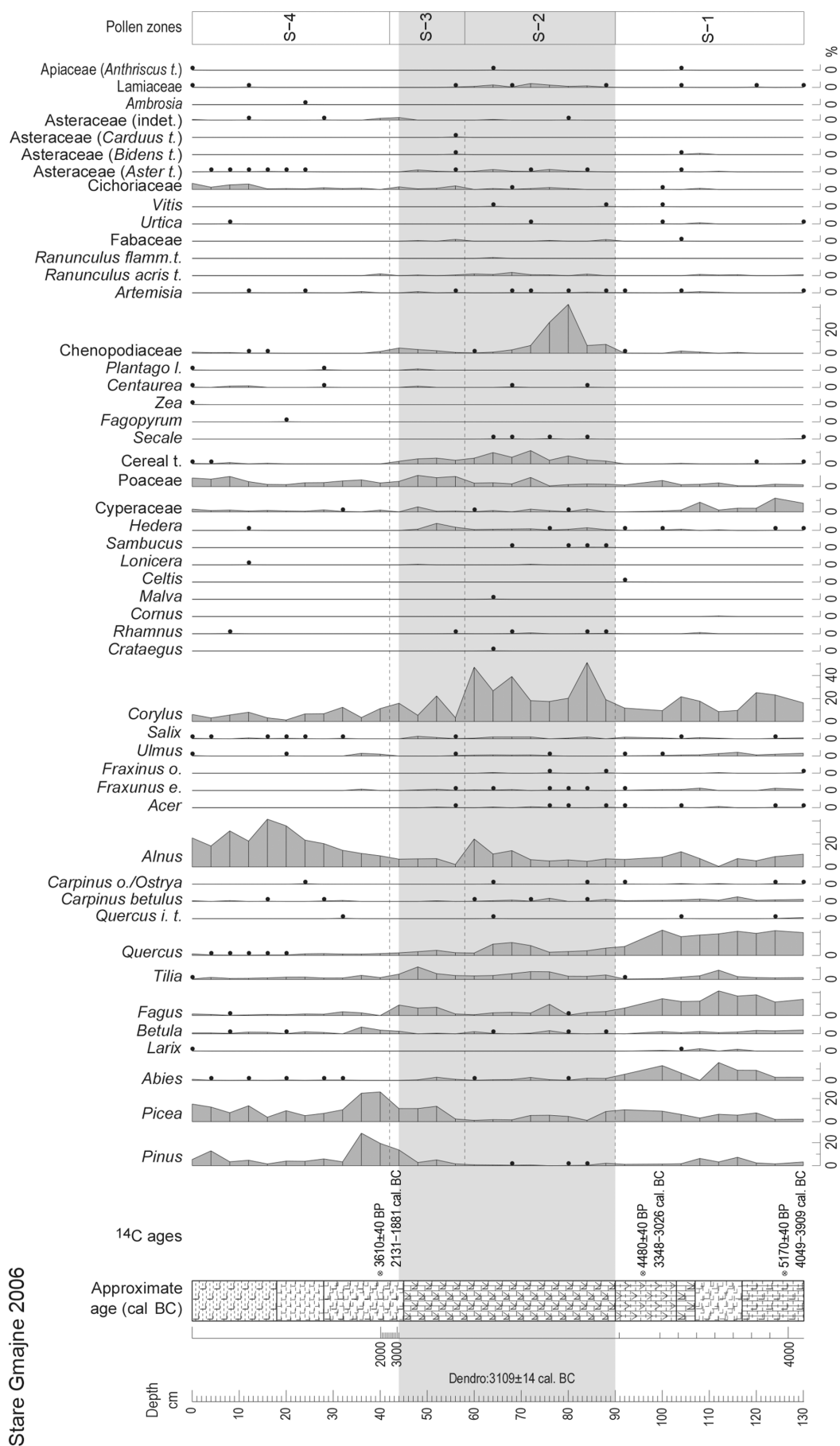


Fig. 5. Stare gmajne, trench 2006, 'loss-on-ignition' diagram.



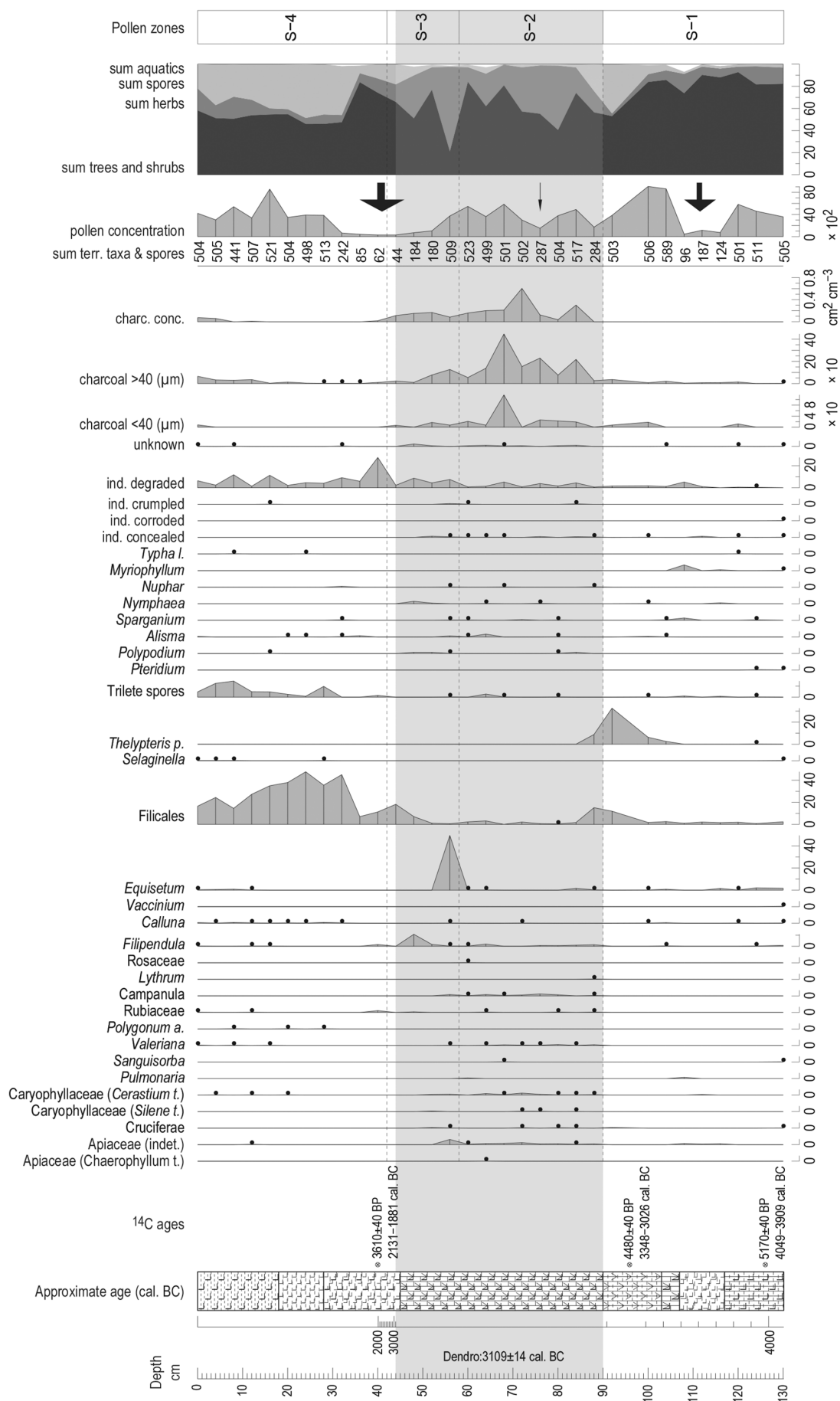


Fig. 6. Stare gmajne, trench 2006, pollen diagram. Values lower than 0.5 are marked with a solid dot. The archaeological cultural layer is marked by a shaded bar. Dendrochronological date (grey) after Čufar et al. 2010.

cal BC (c. 3750–3450 cal BC and 3200–3100 cal BC) are more apparent and better dated on some (e.g., Stare gmajne 2006) than other study sites. They can be correlated with the 3700–3250 cal BC phase of higher lake levels (Magny 2004; with tripartite flooding in the Alps at c. 3650–3370 cal BC, Magny et al. 2006) and CE cold phase 5 (c. 4200–3650 cal BC, Haas et al. 1998). The 3200–3100 cal BC flooding event partly coincides with the 3332–3160 cal BC ‘dendrochronological occupational hiatus’ when no archaeological sites were discovered at Ljubljansko barje (Čufar et al. 2010). The only flooding event that clearly appears on all study sites is located above archaeological cultural layers and coincides with an increase of *Picea*, *Pinus* and *Abies* and decline of other tree taxa (e.g., *Fagus*, *Quercus*). A cold (wet) climate favours the spread of needle-leaved taxa (Ellenberg 1988), whereas an increase of *Pinus* can also be associated with forest regrowth after the abandonment of the settlements and/or metallurgical activities at the beginning of 3rd millennium cal BC (Velušček 2004b).

The visibility and extent of (short-term, annual/decadal?) floods was presumably affected by the (local) topography, hydrological network and other factors. Even in sedimentary profiles, located just few hundred metres apart, differences in sediment composition can be significant, illustrating how local variability *vs.* regional events shaped the landscape.

These differences are clearly seen in the Stare gmajne 2006/2007 profiles. In the western part of the settlement (Stare gmajne 2007; see Figs. 4, 7), changes appear to be more gradual and more similar to the Maharski prekop and Blatna Brezovica study sites, whereas in the east (Stare gmajne 2006; Fig. 5) the sediment composition changes more. Here a high concentration of organic material was found immediately below the archaeological cultural layer (Fig. 5, 100–92cm), suggesting that before archaeological settlement the hydrological conditions probably became drier (but still waterlogged), with a slower sedimentation rate and

thus slightly higher pollen concentration (Fig. 6). The sediment in a very thin layer at 96cm contained so much organic material (unidentified plant material, Fig. 11) that the pollen concentration was too low to yield pollen results. The sediment immediately below and above this layer contained an increased percentage of monolete fern spores, especially *Thelypteris palustris* (the marsh fern growing in sunny wetland areas, e.g., at the edges of marshes and bogs), which presumably started to grow *in situ* after the hydrological conditions became drier. *Alnus* tree stumps were also found below the archaeological cultural layer (Velušček 2009b). A rapid transition between a lake-marsh and organic, humous layer was detected also by sedimentological research (Turk, Horvat 2009) in drainage ditch 6 (profile SG6), located c. 100m west of the palynological sequence. This rapid transition is in contrast with the gradual lake-marsh to humous sediment transition found in the western part of the settlement (profile SG12, Turk, Horvat 2009). In contrast to Janez Turk and Aleksander Horvat (2009), who suggested that the lack of a gradual transition in profile SG6 was either because the sediment was decomposed or did not form at all (due to sedimentological or erosional gaps), palynological research, presented in this

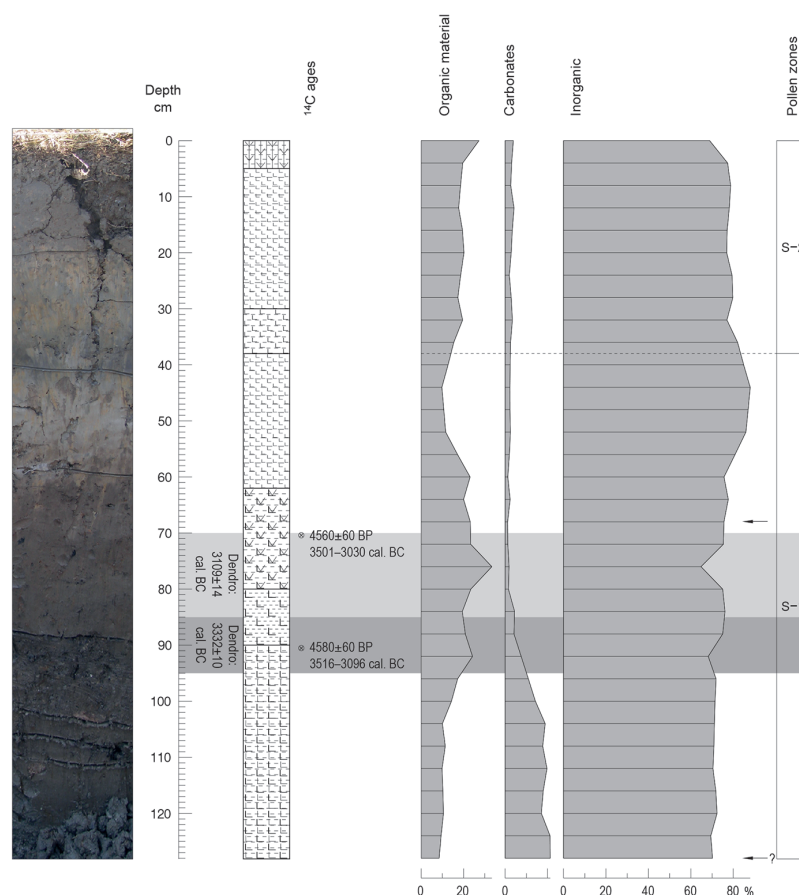


Fig. 7. Stare gmajne, trench 2007, 'loss-on-ignition' diagram.

paper (at least in archaeological trench 2) indicates that there seems to be no hiatus at the transition between the lake-marsh sediment and organic layer at c. 102cm (Fig. 5), neither were there any traces of intensive peat degradation (e.g., corroded or degraded pollen; Fig. 6). To summarize, it appears that the eastern part of Stare gmajne (2006) settlement was located in a topographically slightly different environment to the other study sites, possibly in the vicinity of a tributary to the Bistra river feeding the lake, which probably affected the sedimentological processes.

Vegetation history and human impact on the environment of Ljubljansko barje

In this chapter the vegetation composition and sedimentological characteristics at each individual study site, before, during and after archaeological settlement, will be analysed in order to better understand the short-term environmental changes and human impact, and to compare study sites located in different parts of Ljubljansko barje.

Maharski prekop

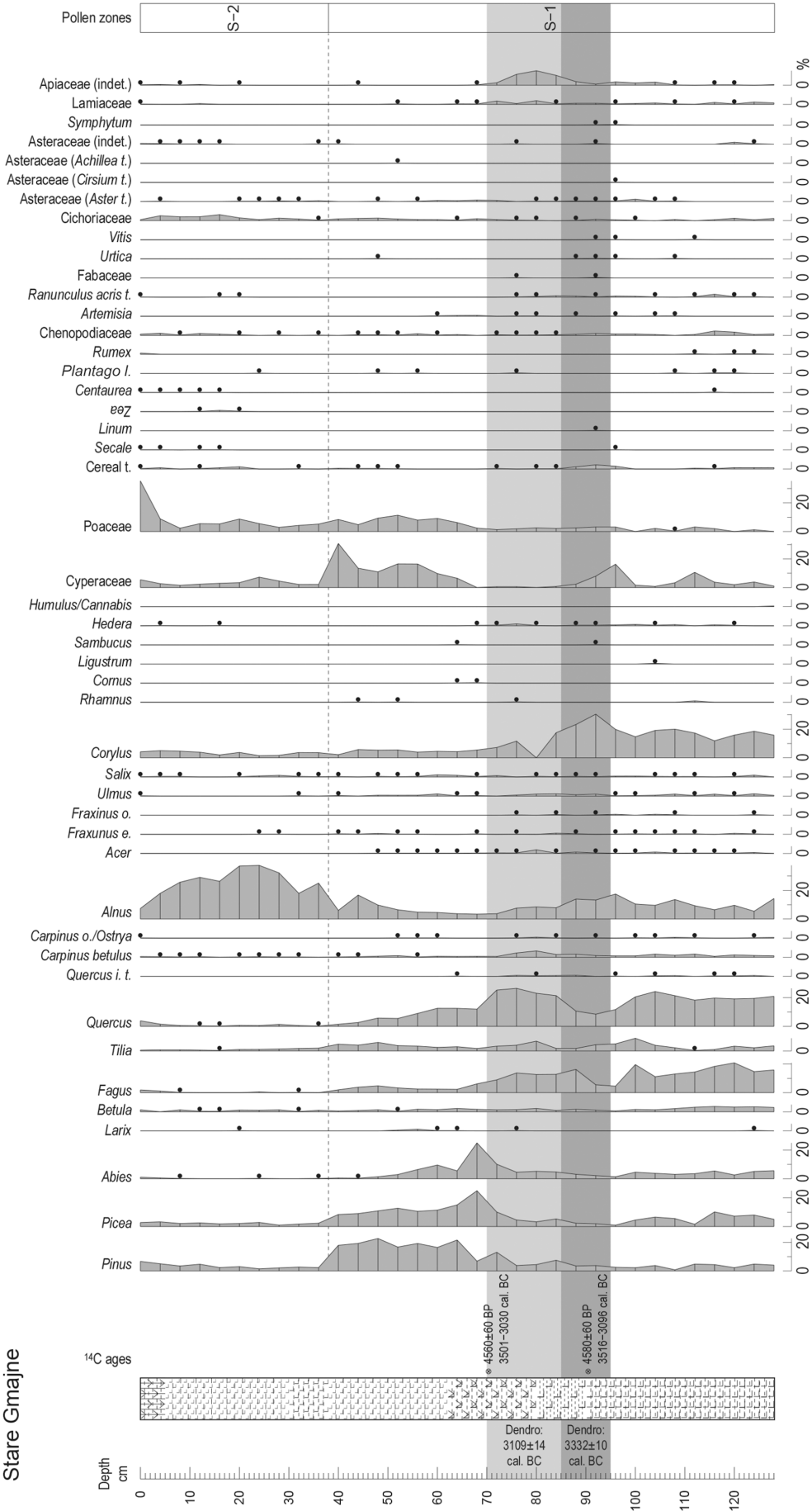
At c. 5000–4100 cal BC the landscape around Maharski prekop was predominantly forested. The main tree taxa were *Fagus* and *Quercus* (Fig. 3), which is comparable with previous research at a study site (Šercelj 1975) and on the pollen record of a 'Na mahu' core (Andrič et al. 2008; Andrič 2009), which is located c. 1km north of Maharski prekop (Fig. 1). *Alnus* pollen, together with Cyperaceae, *Pediastrum* algae and a relatively high percentage of carbonates (Fig. 2), suggests freshwater (lake-wetland) hydrological conditions. The landscape around Maharski prekop was not completely forested. Anthropogenic indicator taxa of cereals and weeds (e.g., Cereal type pollen, *Secale*, Chenopodiaceae, *Artemisia*) occur as early as c. 5000 cal BC, with a peak at c. 4400 cal BC. They can be associated with the farming activities of people living at the Resnikov prekop site (located c. 1.5km southeast of the study site, Fig. 1), which is dated to c. 4500 cal BC (Velušček 2006; Čufar, Korenčič 2006). Unfortunately, these activities were not studied in detail *in situ* since part of the sedimentary sequence at the Resnikov prekop settlement (including pollen and plant macrofossils) was removed by water (Andrič 2006; Culiberg 2006).

After c. 4100 cal BC the forest composition at Maharski prekop changed: the percentage of *Abies* and *Fagus* pollen increased, whereas Poaceae and Cyperaceae declined. A similar change was detected also in the 'Na mahu' core, where an increase of *Fagus* (and

later *Abies*) after c. 4000 cal BC was associated with a wetter climate (Andrič et al. 2008). *Abies* and *Fagus* thrive well in a humid climate and are susceptible to human impact (Ellenberg 1988). *Abies* in particular, which needs plenty of rain, is sensitive to fire and grazing (Tinner et al. 1999). Therefore, this change of regional forest composition at the beginning of the 4th millennium cal BC (which was less clearly seen in other regions of Slovenia, e.g., Bela krajina, Andrič 2007), can be associated with a globally colder and wetter climate (e.g., Mayewski et al. 2004; Magny 2004; Denton, Karlén 1973; Seppä, Birks 2001; O'Brien et al. 1995).

Despite generally more forested landscape, people were still cutting/burning smaller surfaces of forest for fields (cereal peak at c. 3900 cal BC) and grazing (*Plantago lanceolata* pollen). To date no archaeological sites unambiguously dated to 3900 cal BC have been discovered at Ljubljansko barje, with the exception of Črnelnik, and possibly Gornje mostišče (Velušček et al. 2018). On the basis of archaeological typology (pottery with stab-and-drag incisions) and dendrochronological research, Maharski prekop settlement was dated to c. 3500–3400 cal BC (3489±10 cal BC, Velušček, Čufar 2008; Čufar et al. 2015; Toškan et al. *in press*, see also paragraph below), which is c. 400 years younger than the traces of weak human impact detected on the pollen diagram. Additionally, a new series of radiocarbon dates for samples of animal bones, wood, charcoal and food residue on pottery from Maharski prekop were obtained by researchers of the University of Ljubljana (Mlekuž et al. 2012, Tab. 1). At least 14 of these new dates (mostly carbonized food/organic residues on pottery) and two wooden piles fall into the period between 4400 and 4000 cal BC, which is significantly older than dendrochronological dating. On the basis of this data a much longer settling period of Maharski prekop was suggested, with intensive occupation between 4400 and 3550 cal BC and two peaks (4400–4000 and 3800–3550 cal BC) (Mlekuž et al. 2012).

Archaeobotanical research also indicates early farming activities, dated at the transition between the 5th and 4th millennium cal BC. At the Strojanova vode site, located c. 200m southeast of Maharski prekop, plant macrofossil remains of crushed red dogwood seeds (*Cornus sanguinea*) and cereal remains (*Hordeum* and *Hordeum/Triticum*) indicate human activities (c. 4225–3948 cal BC), which are older than dendrochronologically dated remains of wooden piles at Strojanova voda (3586 cal BC = young-



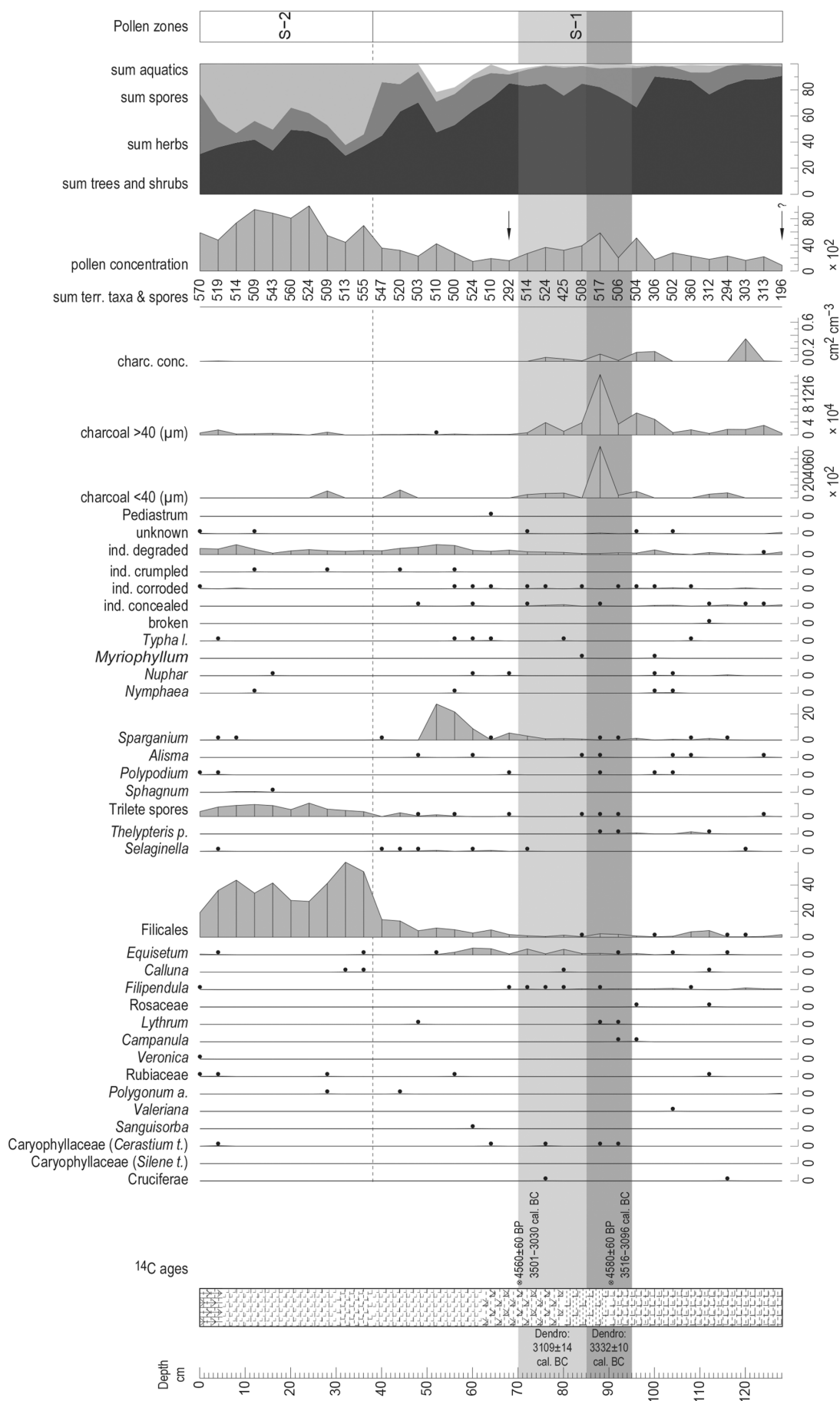


Fig. 8. Stare gmajne trench 2007, pollen diagram. Values lower than 0.5 are marked with a solid dot. The archaeological cultural layer is marked by a shaded bar. Dendrochronological date (grey) after Čufar et al. 2010.

est date, oldest *c.* 3700 cal BC, Čufar et al. 2015; Tolar 2018). Both palynological and archaeobotanical research therefore suggest early farming activities in a wider Maharski prekop region. People were present in the landscape, but at the current state of research it is not possible to suggest the exact location of this older settlement (there is no dendrochronological data or Lasinja pottery dated to 4350–3900 cal BC to support this assumption about older settlement, Velušček pers. comm.). The main reasons for the current state of research are very complex palaeohydrological conditions and taphonomic processes in this part of Ljubljansko barje. The LIDAR record shows traces of past fluvial activity (Budja, Mlekuž 2008; 2010; Mlekuž et al. 2012). At Resnikov prekop part of the sequence was removed by water (Andrić 2006), and thus water erosion and displacement of artefacts and sediment (including plant micro and macroremains) is possible. The archaeological and palaeoecological record were shaped by taphonomic processes, and further research is needed in the area.

The base of the archaeological cultural layer in the pollen profile at Maharski prekop is not reliably dated. Due to age reversal, the ^{14}C date of unidentified plant material at 80cm (Tab. 2, Beta-229153) was omitted from the age model (Fig. 3). It is possible that roots of younger plants growing on the site after the abandonment of the settlement were dated, or sediment was redeposited by water. On the other hand, horizontal mobility of animal finds at Maharski prekop seems to be limited and bones were not affected by water erosion (Toškan et al., *in press*). A cultural layer, dendrochronologically dated to *c.* 3500 cal BC, is clearly seen in the pollen diagram (Fig. 3): there is a decline in tree pollen (*Fagus*, later also *Abies* and *Quercus*) and increase in cereals, weeds (e.g., *Centaurea*, *Chenopodiaceae*), other herbs (e.g., *Poaceae*, *Lamiaceae*, *Apiaceae*, *Filipendula*) and microscopic charcoal concentration. The taxonomic precision of archaeobotanical research is better than for pollen, and macroremains of the following culti-

vated plants were discovered in the cultural layer: *Hordeum vulgare*, *Triticum monococcum*, *Triticum dicoccum* (in the pollen record shown as Cereal type), *Brassica rapa* (Cruciferae pollen) and *Pisum* sp. (Fabaceae pollen) (Tolar 2018).

After the abandonment of Maharski prekop at *c.* 3500 cal BC (end date 3489 ± 10 cal BC; Čufar et al. 2015) the forest composition changed again. *Picea* and *Pinus* spread, whereas other tree taxa decline. A similar vegetation change was detected at other study sites (Stare gmajne, Blatna Brezovica, 'Na mahu'), which might be associated with a colder climate (Haas et al. 1998) and/or forest regrowth after the abandonment of the settlement.

Stare gmajne 2006

At *c.* 4100 cal BC the landscape around Stare gmajne was (similar to at Maharski prekop) surrounded by beech-fir and mixed oak forests. Traces of human presence in the landscape are already visible in the pollen record (Cereal t., *Secale*, *Artemisia*), although to date no archaeological sites dated to *c.* 4100 cal BC have been discovered in the western part of Ljubljansko barje. A low presence of Cereal t. and other

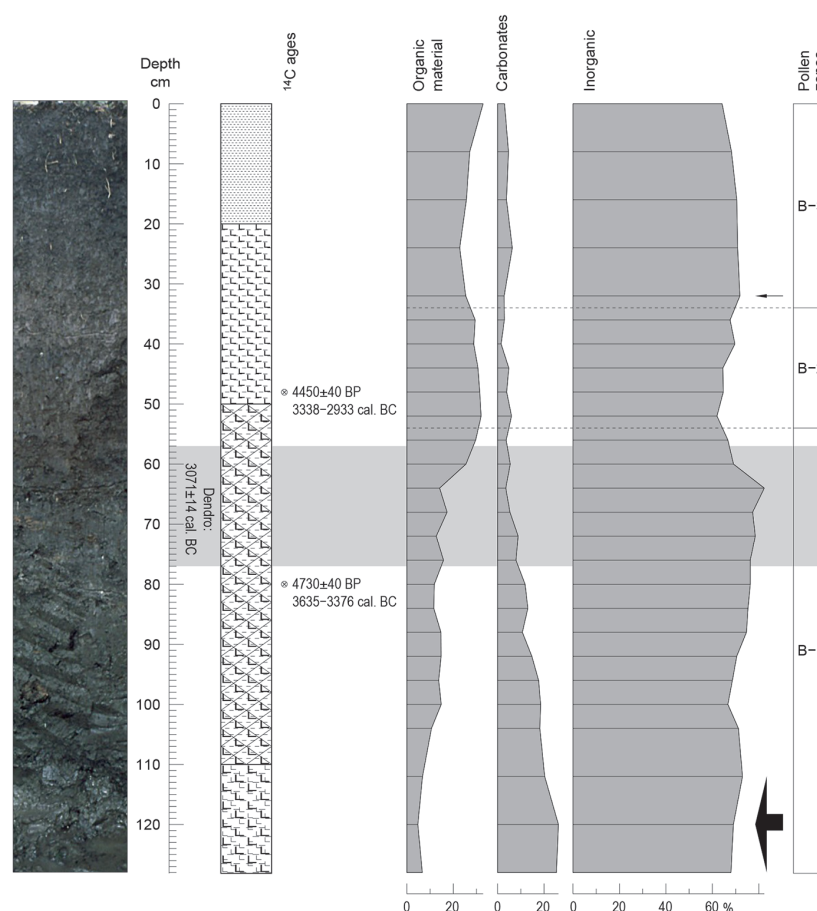


Fig. 9. Blatna Brezovica, 'loss-on-ignition' diagram.

anthropogenic indicator pollen below the archaeological cultural layer was also detected in the pollen diagram from Hočevarica, located 250m northwest of Stare gmajne (Fig. 1; Jeraj 2002.280, Fig. 2; Jeraj et al. 2009.286–287, Fig. 7).

Human impact on the environment in the vicinity of the Stare gmajne site increased again at c. 3500–3400 cal BC, when small-scale forest clearance occurred (decline of *Abies*, *Fagus*, *Alnus*, *Tilia*), with an increase in herb pollen (Cereal t., Chenopodiaceae, Ranunculaceae) indicating farming activities, which can be associated with the Hočevarica archaeological site (Velušček 2004a; end date: 3547±10 cal BC, Čufar et al. 2010). Archaeobotanical and palynological research at Hočevarica (Jeraj 2004) suggest significant human impact on the surrounding landscape, especially in the reduction of nearby forest and usage of cleared land for farming. Pile-dwellers from Hočevarica were cultivating barley and wheat (Jeraj 2002; 2004; Jeraj et al. 2009) and kept domesticated animals (pigs, sheep, goat and cattle, Toškan, Dirjec 2004), which is also visible in the pollen record of Stare gmajne.

In archaeological trench 2, excavated at Stare gmajne in 2006, only a younger archaeological layer, dated to c. 3109±14 cal BC (Velušček 2009b; Čufar et al. 2010) was discovered. The pollen record from the cultural layer (90–43cm, Fig. 8) shows a pronounced decline in tree pollen (apart from *Corylus* and *Tilia*) and an increase in anthropogenic indicator taxa (sensu Behre 1981; e.g., Cereal t., *Secale*, Chenopodiaceae, *Artemisia*, *Centaurea*) suggests intensive farming. After the settlement was abandoned, *Pinus*, *Betula*, *Picea* (and later *Alnus*) spread, whereas other tree taxa (e.g., *Fagus*, *Tilia*) decreased.

Stare gmajne 2007

Archaeological trench 3 was excavated just c. 270m west of trench 2 (see Fig. 4), therefore both pollen diagrams from Stare gmajne (Figs. 6 and 8) are very similar, which is not unusual considering that they were (partly) surrounded by the same vegetation. The main difference between study sites is that in the western part of Stare gmajne an older cultural layer (3332±10 cal BC) was also discovered in addition to the younger one (3109±10 cal BC, Velušček 2009a). Both cultural layers are visible on the pollen diagram (Fig. 8), but human impact in the time of the older phase is more pronounced, which is in accordance with the results of archaeobotanical (Tolar et al. 2011) research. During the older settlement phase at about 3300 cal BC people were cutting fo-

rest (decline of *Fagus*, *Abies*, *Quercus* and *Tilia*) and there is an increase in cultural plants (Cereal t., *Linum*), Chenopodiaceae and microscopic charcoal. Plant macrofossils analysis demonstrated that the main cultivars at Stare gmajne were *Triticum dicoccum*, *Triticum monococcum*, *Hordeum vulgare*, *Papaver somniferum*, *Linum usitatissimum* and *Pisum sativum* (Tolar et al. 2011). In the younger cultural layer at about 3100 cal BC, human impact is less pronounced and pollen of some tree taxa (*Fagus*, *Tilia*, *Quercus*) increases again.

Blatna Brezovica

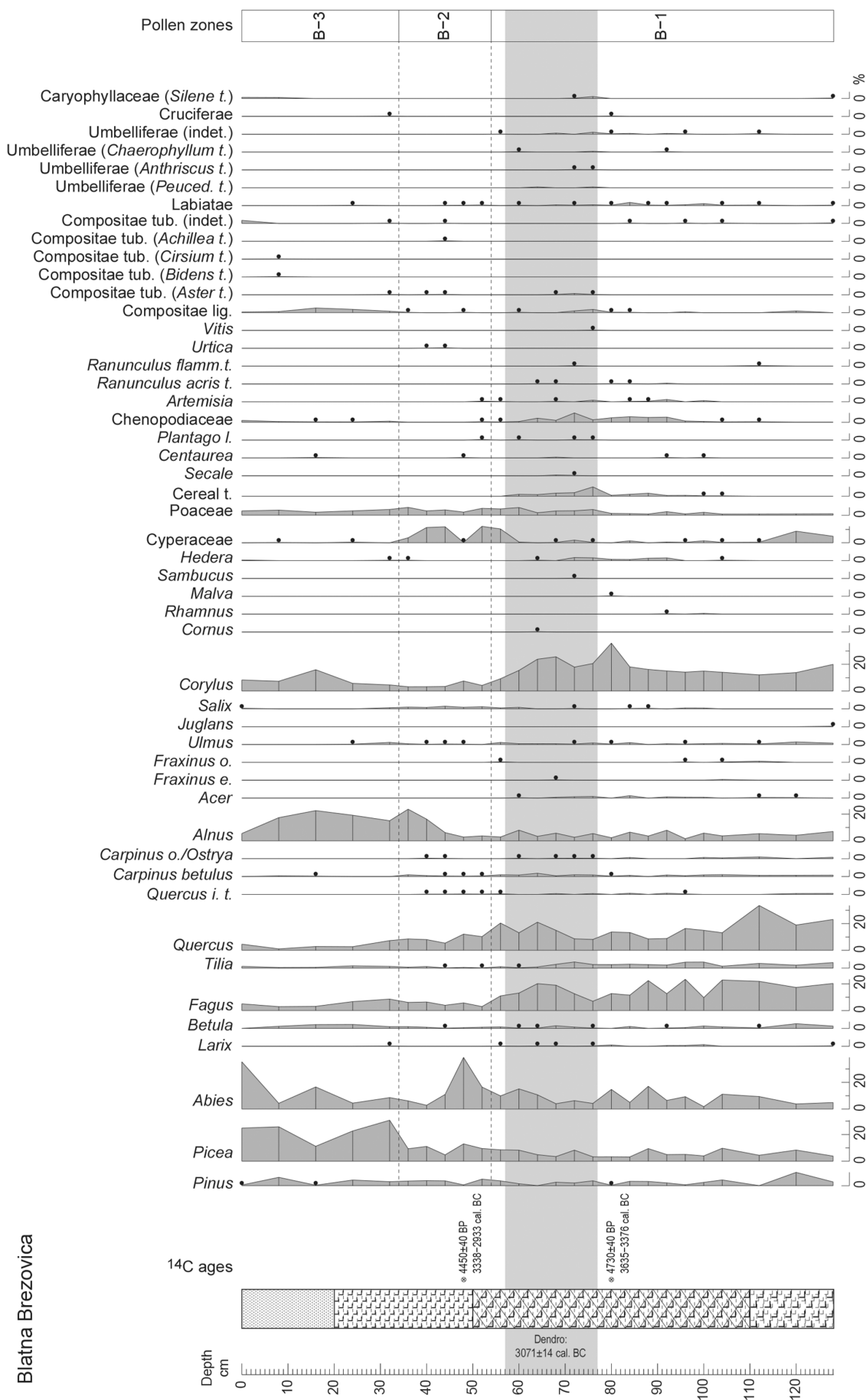
A complete pollen diagram is presented in this chapter while in a previous paper (Golyeva, Andrič 2013) only selected data were published. Prior to archaeological settlement, which is dated to c. 3071±14 cal BC (Čufar et al. 2010), forest of *Fagus*, *Abies* and *Quercus* grew in the area. The first traces of human impact on the environment (forest clearance and anthropogenic indicator taxa at c. 112–80cm) could be connected with the activities of people living in older archaeological settlements at Hočevarica (c. 3650–3550 cal BC) and Stare gmajne (c. 3300 and 3100 cal BC), located just across the Ljubljanska river.

During the archaeological settlement the landscape became more open due to forest clearance of *Fagus* and *Quercus*, with the latter needed for building material (Korošec 1963; Šercelj 1981–82; Čufar et al. 2010). Similar to at other study sites, an increased percentage of *Corylus* and herbs (e.g., Cereal t., Chenopodiaceae, Poaceae) was found in the archaeological cultural layer. People living at Blatna Brezovica were cultivating barley (Golyeva, Andrič 2014), and possibly also other cereals. The results of phytolith analysis also suggested that Poaceae pollen from the cultural layer could (partly) belong to *Phragmites*. Phytoliths of young *Phragmites* plants that were found in the archaeological cultural layer suggest that they were probably used for roofing or other purposes, e.g., bedding, walls (Golyeva, Andrič 2014), or boats (Karg, Weber 2019).

After the settlement was abandoned, *Abies* spread, but the landscape remained relatively open. Pollen of Cyperaceae and *Equisetum* suggests marsh hydrological conditions.

Comparison of study sites: vegetation history and human impact on the environment

In the 4th millennium cal BC the vegetation growing around the study sites, which were located in different parts of Ljubljansko barje (Fig. 1), was very si-



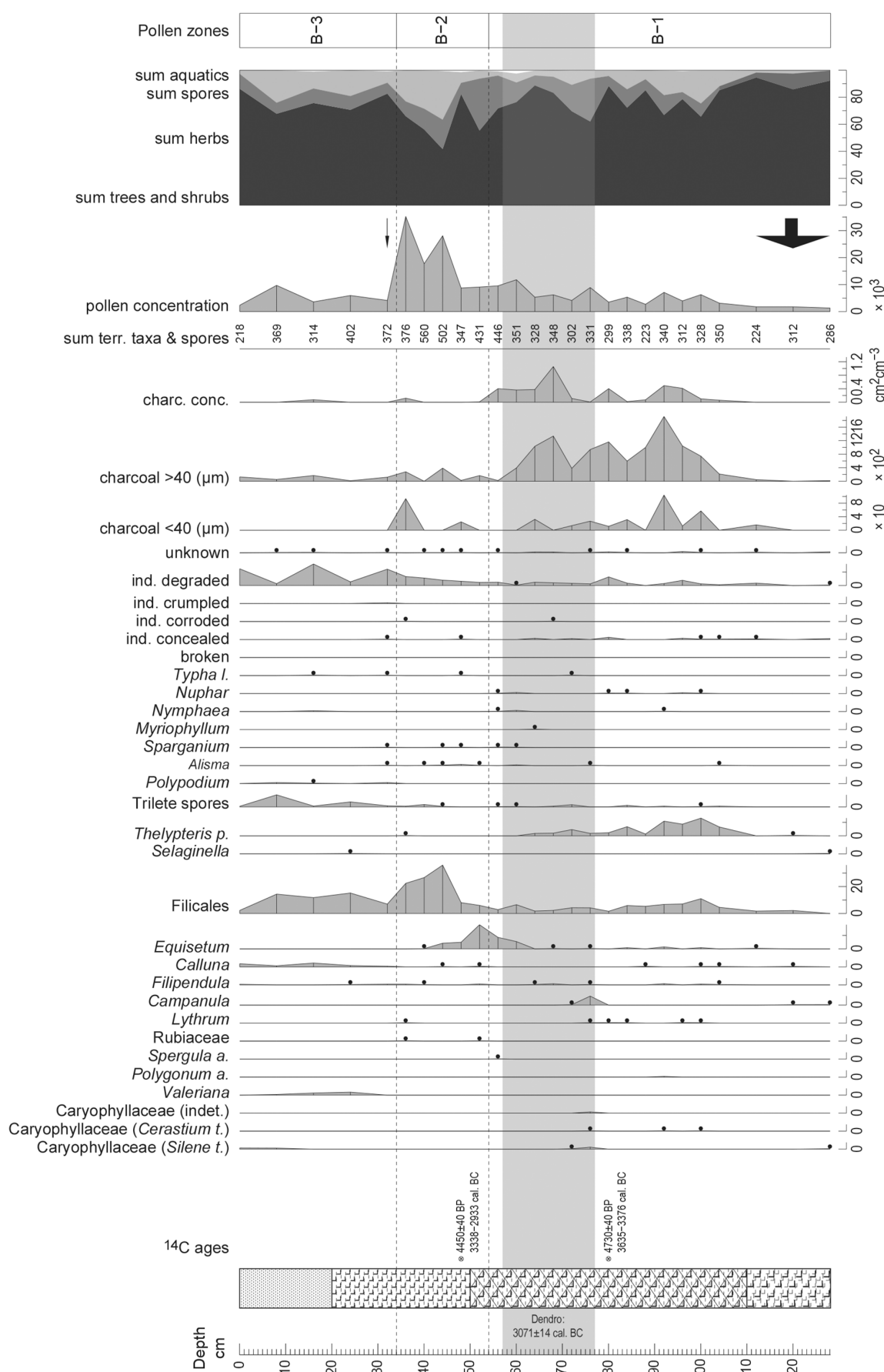


Fig. 10. Blatna Brezovica, pollen diagram. Values lower than 0.5 are marked with a solid dot. The archaeological cultural layer is marked by a shaded bar. Dendrochronological date (grey) after Čufar et al. 2010.

milar. No major dissimilarities in forest composition were detected, and the main difference between archaeological sites is associated with the fact that each was inhabited in slightly different time periods, which affected the stratigraphic position and thickness of archaeological cultural layers. Pollen of 'anthropogenic indicator taxa' (sensu Behre 1981) such as cultivated plants, weeds and grazing indicators, as well as microscopic charcoal, was found in the cultural layers of all study sites, whereas tree pollen is present in lower percentages.

The cultural layers of all study sites contain pollen of cultivars: c. 0.5–10% of Cereal type pollen, 0–0.5% of *Secale*, whereas only one *Linum* pollen grain (flax is self-pollinated and produces only a little pollen) was found in the cultural layer of Stare gmajne (2007). To date no *Secale* plant macrofossils have been discovered at Ljubljansko barje (Tolar et al. 2011; Tolar 2018), and it is assumed that in prehistory it was a weed growing on cereal fields (Marinova 2006; Maier, Schlichterle 2011). Fabaceae pollen and plant macrofossils (*Pisum sativum*; Tolar et al. 2011) are also rarely found at Stare gmajne. Fabaceae are insect-pollinated and do not produce much pollen, whereas seeds are rarely preserved due to taphonomic reasons (Jacomet 2009). Ruderal plants and weeds (Chenopodiaceae, *Artemisia* and *Centaurea*) probably came to the settlements together with crops, although they were possibly also growing in the settlement, along footpaths and riverbanks. Chenopodiaceae pollen in particular is abundant at Stare gmajne 2006 (up to 40%) and Blatna Brezovica (up to 10%), whereas seeds of *Chenopodium album* were found in large quantities and it is assumed that they could have been gathered as well (Tolar et al. 2011). In contrast to this, *Vitis* pollen is not very abundant, although numerous grape pips were discovered (Tolar et al. 2008).

The increased percentage of *Corylus* and *Hedera* pollen in archaeological cultural layers can be a consequence of more open landscape and therefore more widespread flowering of these two taxa, or plants were brought to the settlement by people as winter/spring fodder for domestic animals. Hazelnuts were found in considerable numbers at Stare gmajne (Tolar et al. 2011) and Hočevarica (Jeraj 2004), whereas to date no *Hedera* macroremains have been

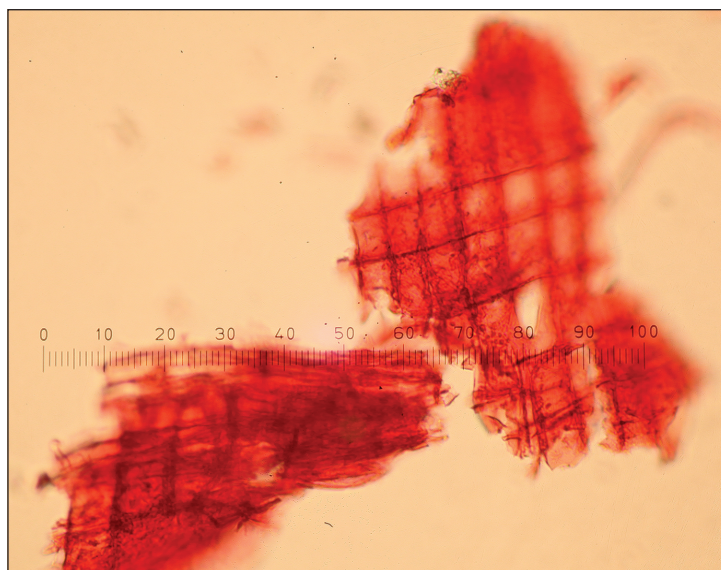


Fig. 11. Stare gmajne 2006, unidentified plant material at 96cm, 400x magnification. Photo Igor Lapajne.

found. *Hedera* pollen was also found at Italian (Palù di Livenza, Pini 2004) and Swiss pile-dwelling sites, where it is assumed that the plant was used for animal fodder (Arbon Bleiche 3, Brombacher, Hadorn 2004; Kühm, Hadorn 2004).

Pollen of plants characteristic of meadows and pastures was also discovered. The increased percentage of Poaceae pollen in cultural layers can be a consequence of forest clearance and thus more open landscape with grasslands, although not many grassland plant macrofossils were discovered at Stare gmajne (Tolar et al. 2011). Combined pollen-phytolith research at Blatna Brezovica (Golyeva, Andrič 2014) suggested that Poaceae pollen grains can also belong to (young) *Phragmites* plants, which were brought to the settlement by people. Pollen of Apiaceae, Lamiaceae, *Plantago lanceolata*, *Ranunculus*, Caryophyllaceae, *Campanula*, Cichoriaceae, Asteraceae and *Filipendula* is often present in the cultural layers of all studied sites, but due to palynological taphonomic imprecision it is difficult to identify them at the species level, which would help us to reconstruct environmental conditions. Possibly some of these plants (e.g., *Mentha* sp. and *Thymus* sp. which belong to Lamiaceae family) were gathered for uses as spices or for medicinal purposes (Tolar et al. 2011). *Plantago lanceolata* is a meadow and footpath plant, and a characteristic grazing indicator associated with the impact of domesticated animals (sheep, goat and cattle; Toškan, Dirjec 2004).

The above review and comparison of pollen with macrofossil and phytolith plant remains indicates

that some (cultivated) plants are more visible/abundant than the others. The visibility of plants varies due to: (a) the amount of pollen produced (insect *vs.* wind pollinated taxa), (b) the distance between fields and the settlement, (c) taphonomic processes on site (e.g. plants brought to the site by people), and (d) the taxonomic precision with which pollen can be identified.

Differences between the pollen record of (off-site) palynological cores and (on-site) archaeological profiles are associated with taphonomy. Pollen that deposited at off-site palaeoecological sites was predominantly transported by wind and water, whereas at archaeological sites it was also brought to the settlement by people. Pollen samples, collected at archaeological sites, therefore contain more anthropogenic indicator taxa (e.g., Cereal type pollen) than palynological cores. The 'Na mahu' palynological core, for example, contains only up to c. 0.5% of Cereal type pollen and c. 0.5% of Chenopodiaceae (Andrič et al. 2008), whereas in the cultural layers of archaeological sites this percentage is much higher (0.5–10% and 2–40% respectively; Figs. 3, 6, 8 and 10). Cereals *Triticum*, *Hordeum* and *Linum* (with the exception of *Secale*, which is allogamous) produce only a little pollen which stays in chaff and is released only during harvesting and threshing (Vuorela 1973), therefore the majority of Cereal t. pollen grains arrived at the settlements together with plants. At all study sites, Cereal t. pollen, which was also found below the archaeological cultural layers, can be associated with older archaeological sites in the vicinity. The percentages of Cereal t. pollen in these layers are usually lower than in the archaeological cultural layer, but often bigger than in off-site cores, probably due to the vicinity of economic activity areas and/or fields of near-by settlements.

The environmental conditions and human impact on the vegetation of Ljubljansko barje can be compared with contemporary study sites in the Swiss Alps, e.g., Arbon Bleiche 3 (Bodensee, 3384–3370 cal BC; Jacomet et al. 2004). The Arbon Bleiche 3 pollen record suggests a wooded landscape (*Fagus*, *Quercus*, *Abies*) with traces of forest clearances and more open landscape in the vicinity of the archaeological sites. Although *Abies* pollen at Arbon Bleiche is not as abundant as at Ljubljansko barje (c. 5% in both regions), its wood was more often used as a building material. Cereal t. and *Linum* pollen was found in the archaeological cultural layers of both regions, whereas Chenopodiaceae pollen (< 5%) and seeds (rarely found) at Arbon Bleiche are less abundant

than at Ljubljansko barje (Brombacher, Hadorn 2004; Haas, Magny 2004; Jacomet et al. 2004). In both study regions pollen of *Corylus* and *Hedera* was found in archaeological cultural layers. At Arbon Bleiche 3 pollen of winter flowering plants (including *Corylus* and *Hedera*) was also found in ruminant coprolites, and it was suggested that they derive from leafy hay that was used for winter fodder (Brombacher, Hadorn 2004; Kühm, Hadorn 2004).

Conclusions

A comparison of pollen diagrams from four archaeological settlements (Maharski prekop, Stare gmajne (both settlements) and Blatna Brezovica) confirmed that in the second half of the 4th millennium cal BC all study sites were surrounded by predominantly wooded landscape. Hilly, hydrologically drier areas further away from the settlements were presumably covered by *Fagus-Abies* forests, which were in the 4th millennium cal BC more widespread than in the 5th millennium BC (presumably due to climatic reasons; Andrič et al. 2008). Mixed *Quercus* woodland, shaped by anthropogenic activities and hydrological conditions, was probably growing closer to the settlements. No major differences between the vegetation of different parts of Ljubljansko barje were detected, and there seems to be no major change in vegetation composition throughout the 4th millennium cal BC.

Due to human impact (agriculture, grazing, metalurgy), smaller surfaces covered by forest were cut, and the vegetation became more open. Although late-successional, shade-tolerant plants like *Fagus* and *Abies* are most susceptible to human impact, the decline of *Quercus* (and to lesser extent *Fraxinus*), which was cut for building material (piles), was also detected.

The pollen record was shaped by taphonomic processes, specific to the archaeological sites and associated with economic activities. The sediment of the cultural layers contains more pollen of plants that were brought to the settlement by people: pollen of crops (e.g., cereals), weeds (*Centaurea*), grazing indicators (*Plantago lanceolata*, *Campanula*, Ranunculaceae), ruderal taxa (Chenopodiaceae, *Artemisia*), gathered shrubs/nuts (*Corylus*) and herbs.

In the 4th millennium cal BC people living at Ljubljansko barje were also affected by floods, which were significant part of their lives.

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