PREHISTORIC HERDERS OF NORTHERN ISTRIA

THE ARCHAEOLOGY OF PUPIĆINA CAVE

Volume 1

PRETPOVIJESNI STOČARI SJEVERNE ISTRE

ARHEOLOGIJA PUPIĆINE PEĆI

1. svezak

Editors / Urednici

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Peludna jezgra iz Prapoča i promjene vegetacije za holocena u sjevernoj Istri

Maja Andrič

2.1 Introduction

The aim of this chapter is to present the results of palaeoecological research in the Ćićarija region of north-eastern Istria and, in particular, to analyse the Holocene vegetation development at Prapoče palaeoecological site. The development of Holocene landscape in this region is poorly investigated since previous palynological research in Istria concentrated mainly on sites located on the western coast of the Istrian peninsula (Figure 2.1). The pollen record of three study sites – Palud, a brackish swamp on the south-western coast, and Škocjanski zatok and Zajezeri-Vodenjak in the north-west – indicates that the vegetation composition of the northern and southern Istria probably differed significantly. The pollen record of Škocjanski zatok sedimentary core, which has been collected at the mouth of the Rižana river, extends back to at least *ca.* 4000 Cal. BC, whereas at Zajezeri-Vodenjak pollen is preserved only in the section of the core dated after *ca.* 1000 AD (Culiberg 1995). On both sites the most important tree taxa include beech *(Fagus)*, oak *(Quercus)*, hazel *(Corylus)*, hornbeam *(Carpinus)* and fir *(Abies)* and on the basis of these results it has been argued that the natural vegetation of the northern Istria was predominantly beech-fir and oak-hornbeam forest (Culiberg 1995). The present-day open landscape with oak (*Quercus petraea* and *Quercus pubescens*), hop hornbeam *(Ostrya carpinifolia)* and pine *(Pinus sylvestris)* woodland developed due to intensive forest clearance and pasture in the last centuries (Culiberg 1995, 1997). On the Palud site in the south, on the other hand, oak was the most common tree type throughout most of the Holocene sequence and the percentage of beech was lower than at Škocjanski zatok (Beug 1977). It has

2.1. Uvod

Cilj je ovog poglavlja predstaviti rezultate paleoekoloških istraživanja na Ćićariji u sjeveroistočnoj Istri te, napose, analizirati razvoj holocenske vegetacije na paleoekološkom lokalitetu Prapoče. Razvoj holocenskog krajolika ove regije slabo je istražen jer su prijašnja istraživanja peluda u Istri posvećivala pažnju uglavnom lokalitetima na zapadnoj obali istarskoga poluotoka (slika 2.1). Građa prikupljena s lokaliteta (Palud, brakična močvara) na jugozapadnoj obali te Škocjanski zatok i Zajezeri-Vodenjak na sjeverozapadu) ukazuje da se sastav vegetacije u sjevernoj i južnoj Istri vjerojatno znatno razlikovao. Pelud iz jezgrovane taložine iz Škocjanskog zatoka, prikupljen na izvoru rijeke Rižane, proteže se u prošlost barem do oko 4000. pr. Kr. (kalibrirano), dok je onaj iz Zajezeri-Vodenjaka sačuvan tek u dijelu jezgre koji je mlađi od oko 1000 po Kr. (Culiberg 1995). Na oba lokaliteta najvažniji drvenasti taksoni su bukva *(Fagus)*, hrast *(Quercus)*, lijeska *(Corylus)*, bijeli ili obični grab *(Carpinus)* i jela *(Abies)* pa je na temelju toga zaključeno da se prirodna vegetacija sjeverne Istre pretežno sastojala od šumskih zajednica bukve i jele te hrasta i graba (Culiberg 1995). Današnji otvoreni krajolik sa šumskom zajednicom hrasta (*Quercus petraea* i *Quercus pubescens*), crnoga graba *(Ostrya carpinifolia)* i bora *(Pinus sylvestris)* razvio se u posljednijih nekoliko stoljeća zbog intenzivnog krčenja šuma i ispaše (Culiberg 1995, 1997). S druge strane, na lokalitetu Palud, na jugu, hrast je bio najčešći tip stabla tijekom najvećeg dijela holocena, dok je postotak bukve bio manji nego u Škocijanskom zatoku (Beug 1977). Pretpostavlja se da je današnja vegetacija s priobalnim pojasom makije

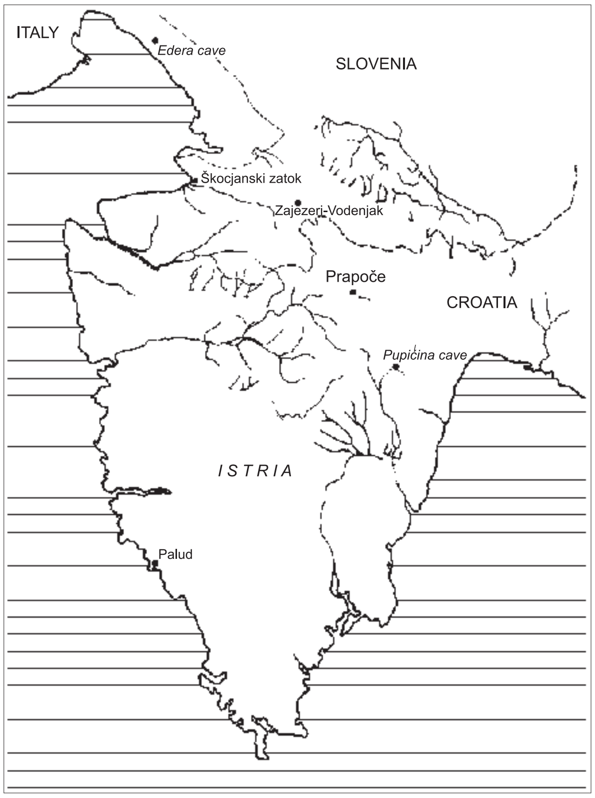


Figure 2.1. Palaeoecological and archaeological study sites discussed in Chapter 2.

Slika 2.1 Paleoekološka i arheološka nalazišta spomenuta u 2. poglavlju.

been suggested that the present-day vegetation with *ca.* 200 m wide belt of *Phillyrea-Quercus ilex* maquis near the coast probably formed due to forest clearance in the Roman period (Beug 1977). A similar vegetation development was also suggested for Vransko jezero on the northern Adriatic island of Cres (Schmidt *et. al.* 2000).

The Holocene vegetation development in Istria described above is very general and it is complicated by the fact that most study sites are located on the Adriatic coast. It is possible that the pollen deposited in the sediment was brought to the site by sea water and the pollen record deriving from different source areas (Jacobson & Bradshaw 1981) therefore reflects the vegetation changes of a very wide area.

Relatively little palynological research has been carried out in the interior of the Istrian peninsula, even where the above mentioned problem of pollen source area could be avoided, because of the bedrock composition. Most of Istria is covered by Mesozoic limestones and has no surface water. Rivers are limited to a belt of Tertiary flysch, which diagonally crosses central Istrian peninsula (Roglić 1981; Crnković 1981; Rodić 1987). Due to dry summers, permanent marshy areas, suitable for palynological research, are extremely rare.

The aim of this research was therefore to find a small palaeoecological site located in the interior of the Istrian peninsula in order to study changes of local and extra-local vegetation (*sensu* Jacobson & Bradshaw 1981) in the vicinity of Pupićina cave and other archaeological sites located in north-eastern Istria. This study therefore concentrates on the Ćićarija region of north-eastern Istria

(*Phillyrea-Quercus ilex*) širokim oko 200 m vjerojatno nastala kao posljedica krčenja šume za antičkog razdoblja (Beug 1977). Sličan razvoj vegetacije predložen je za Vransko jezero na otoku Cresu u sjevernom Jadranu (Schmidt *et. al.* 2000).

Opisani razvoj holocenske vegetacije u Istri vrlo je općenit, a komplicira ga i činjenica da se većina proučavanih lokaliteta nalazi na jadranskoj obali. Moguće je da je pelud koji je odložen u taložinu nanesen na lokalitet morem pa stoga navedena građa potječe iz različitih predjela (Jacobson & Bradshaw 1981) i odražava promjene vegetacije vrlo široka područja.

Čak i ondje gdje se spomenuti problem porijekla peluda mogao izbjeći, u unutrašnjosti istarskog poluotoka, provedeno je relativno malo palinoloških istraživanja i to zbog sastava kamene podloge. Najveći dio Istre sazdan je od mezozoičkih vapnenaca i nema površinskih voda. Rijeke su ograničene na pojas tercijarnog fliša koji dijagonalno presijeca središnji dio istarskog poluotoka (Roglić 1981; Crnković 1981; Rodić 1987). Zbog suhih ljeta, stalna močvarna područja pogodna za palinološka istraživanja vrlo su rijetka.

Cilj ovog istraživanja bio je pronaći mali paleoekološki lokalitet smješten u unutrašnjosti istarskog poluotoka koji bi omogućio proučavanje promjena vegetacije u bližoj i daljoj okolici (*sensu* Jacobson & Bradshaw 1981) Pupićine peći i drugih arheoloških lokaliteta sjeveroistočne Istre. Ova je studija stoga usmjerena na područje Ćićarije u sjeveroistočnoj Istand will present the results of pollen, loss-on-ignition and geochemical analysis at Prapoče site, a marshy area located *ca.* 15 km north-west of the Pupićina cave. It aims to address the following questions: What did the Prapoče landscape look like in the Holocene? Was the 'Mesolithic' landscape significantly different from the 'Neolithic', 'Bronze Age' or present-day landscape? And, finally, which changes in the vegetation cover were triggered by climatic changes and what was the human impact on the landscape?

ri i predstavit će rezultate peludnih analiza, analiza gubitka mase žarenjem i geokemijskih analiza lokaliteta Prapoče, močvarnog područja smještenog oko 15 km sjeverozapadno od Pupićine peći. Željeli bismo odgovoriti na sljedeća pitanja: Kako je izgledao krajolik Prapoča u holocenu? Je li se "mezolitički" krajolik značajnije razlikovao od "neolitičkoga", "brončanodobnog" ili današnjeg okoliša? I na kraju: Koje su promjene u biljnom pokrovu izazvane klimatskim promjenama te kako je čovjek utjecao na krajolik?

2.2 Study Area and Methodology

Samples for pollen analysis at Prapoče study site (45°25′25″N, 14°04′30″E, Figure 2.2) were collected in a marshy area 1000 m south of the Prapoče village (480 m/sl, Figure 2.3). The Prapoče valley is located on an isolated flysch patch in otherwise mainly limestone region. Tertiary flysch covers the bottom of the valley, which is *ca.* 600m wide and 4500m long, extending in a northwest-southeast direction. Hills surrounding the

2.2. Područje studije i metodologija

Uzorci za analizu peluda na lokalitetu Prapoče (45°25′25″N, 14°04′30″E, slika 2.2) prikupljeni su u močvarnom području, oko 1000 m južno od zaseoka Prapoče (480 m/sl, slika 2.3). Dolina Prapoča nalazi se na izoliranoj plohi fliša u regiji koja je inače uglavnom sazdana od vapnenca. Tercijarni fliš pokriva dno doline koja je široka oko 600 m i duga 4500 m te se pruža pravcem sjeverozapad-jugoistok. Brda koja okružuju

Figure 2.2. Geographical position of Prapoče study site.

Slika 2.2 Zemljopisni položaj nalazišta Prapoče.

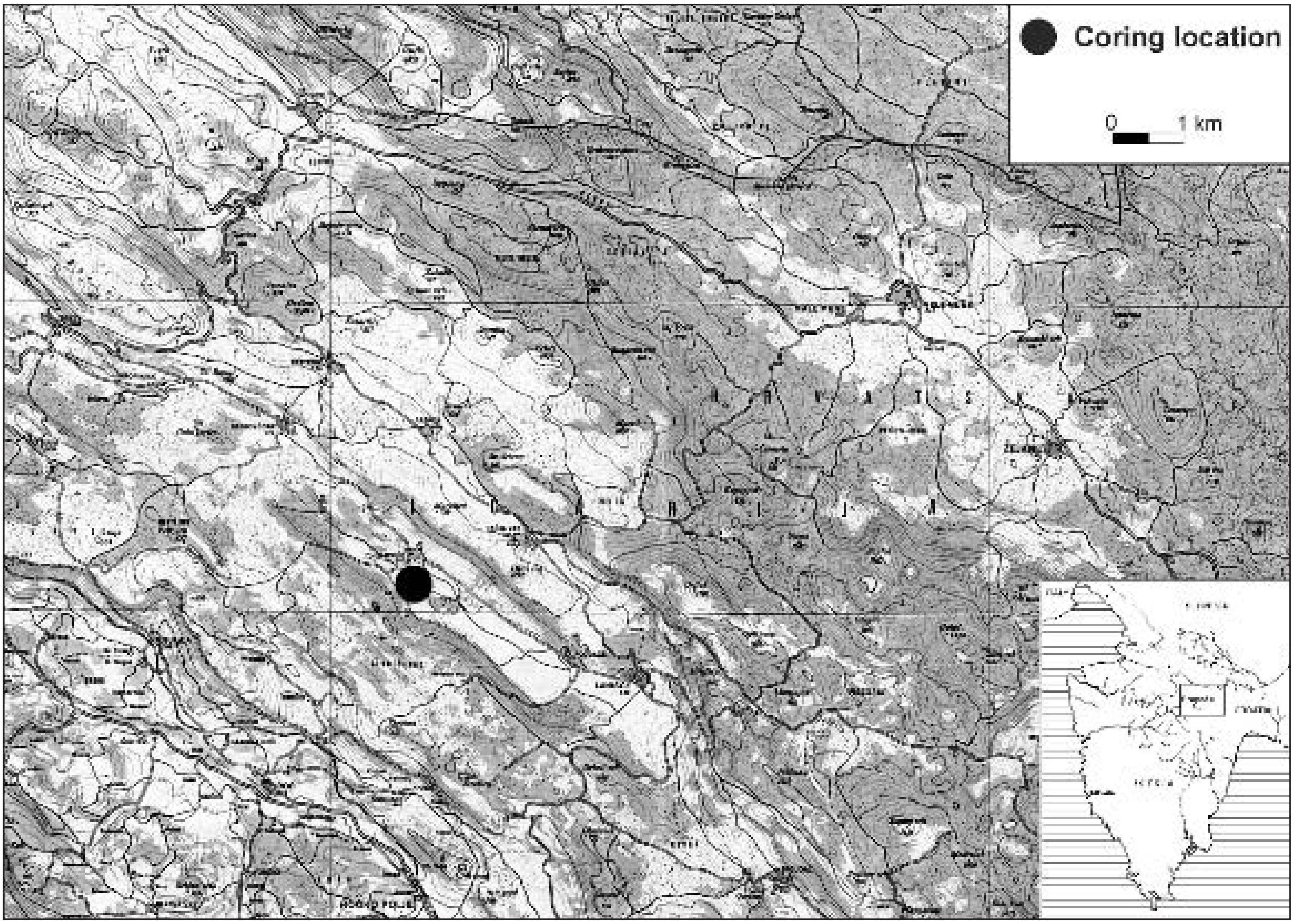


Figure 2.3. Prapoče valley.
Slika 2.3 Dolina Prapoča.

valley consist of Tertiary marl and limestones and exceed 700 m/sl (Šikić & Pleničar 1975).

The climate of Ćićarija has some mediterranean and some continental characteristics. The main mediterranean characteristic is that the precipitation maximum is in the autumn (October). The secondary precipitation maximum occurs in the spring (Roglić 1981). The annual amount of precipitation in nearby Lanišće is 1664 mm (Makjanić & Volarić 1981). Another mediterranean characteristic of the climate is that the autumns are warmer than springs. The average annual temperature in Buzet, located 7.5 km south-west from Prapoče is 12.8°C (7-year average) and the maximum and minimum temperature measured there (before 1981) were 38.6°C and -14.1°C respectively (Tomić 1981).

The Ćićarija area has been classified in terms of its vegetation as a submediterranean region, where thermophilous forest of oak (*Quercus pubescens* Willd.) and hop hornbeam *(Ostrya carpinifolia* Scop.) prevails (Ilijanić 1981). The vegetation at the coring location is wet meadow with meadowsweet (*Filipendula ulmaria* L.) and individual poplar (*Populus* sp.) and willow (*Salix* sp.) trees (Figure 2.4). Meadows and fields cover the bottom of the valley, whereas open, predominantly broadleaved forest (a mixture of several species of oak, hornbeam, ash, maple, lime, hazel and pine) grows on the slopes

dolinu sastoje se od tercijarnog lapora i vapnenaca te nadmašuju nadmorsku visinu od 700 m (Šikić & Pleničar 1975).

Klima Ćićarije ima dijelom sredozemne, a dijelom kontinentalne karakteristike. Glavna sredozemna karakteristika je to što je oborina najviše u jesen (u listopadu). Sekundarni maksimum oborina je u proljeće (Roglić 1981). Godišnja količina oborina u obližnjem Lanišću je 1664 mm (Makjanić & Volarić 1981). Drugo sredozemno obilježje klime su jeseni koje su toplije od proljeća. Prosječna godišnja temperatura u Buzetu (7.5 km jugozapadno od Prapoča) je 12.8°C (sedmogodišnji prosjek), najviša ondje izmjerena temperatura iznosi 38.6°C, a najniža -14.1°C (Tomić 1981).

Na temelju vegetacije, područje Ćićarije klasificirano je kao subsredozemna regija gdje prevladava termofilna šuma hrasta (*Quercus pubescens* Willd.) i crnoga graba *(Ostrya carpinifolia* Scop.) (Ilijanić 1981). Vegetacija na uzorkovanom lokalitetu je barska livada s končarom (*Filipendula ulmaria* L.) te pojedinim stablima topole (*Populus* sp.) i vrbe (*Salix* sp.) (slika 2.4). Livade i polja prekrivaju dno doline, dok na okolnim padinama raste rijetka, uglavnom listopadna šuma (mješavina nekoliko različitih vrsta hrasta, graba, jasena, javora, lipe, lijeske i bora). Vegetacija koja prekriva brežuljke u neposrednoj blizini uzorkovanog lokaliteta sastoji surrounding the valley. The vegetation covering smaller hills in close vicinity of the coring location consists of lime (*Tilia platyphyllos* Scop.), oak (*Quercus petraea* [Matt.] Liebl.) and hazel (*Corylus avellana* L.). Only a few people live in Prapoče today, but the village was much bigger several decades ago. The local people still remember that several hundred head of cattle were kept in the village, and due to this grazing pressure the slopes surrounding the valley were devoid of forest.

In June 1997 a sedimentary core was collected in the marsh area south of Prapoče village using a modified 7-cm diameter Livingstone piston corer (Wright 1967), mounted upon a portable drilling rig. Samples were extracted from the corer in the field, wrapped in cling film, tin foil and thick plastic and transported to the laboratory where they were stored in dark at 4°C. The sediment characteristics of this 212 cm long core were described following Troels-Smith (1955) and the colour of the sediment was determined using Munsell soil chart. The following analyses of the sediment were carried out: radiocarbon dating, loss-on-ignition, geochemical and pollen analysis.

First, 1 cm^3 of the sediment was subsampled from selected levels of the core using a metal volumetric subsampler. A preliminary pollen analysis with sampling resolution *ca.* 16 cm was carried out in order to roughly estimate which part of the core might be of the Holocene age and the quality of pollen preservation. After the preliminary pollen analysis, 9 cm section (200 g) of the core was sent to Beta Analytic Inc., Florida for radiocarbon dating. Since the sample did not yield enough carbon for standard ra-

se od lipe (*Tilia platyphyllos* Scop.), hrasta (*Quercus petraea* [Matt.] Liebl.) i lijeske (*Corylus avellana* L.). Danas u Prapoču živi tek nekoliko ljudi, no selo je prije nekoliko desetljeća bilo znatno veće. Domaći ljudi se još sjećaju da je u selu bilo nekoliko stotina grla stoke, i upravo su zbog pritiska ispaše ogoljene padine koje okružuju dolinu.

U lipnju 1997. gorine, taložine močvarnog područja južno od zaseoka Prapoče jezgrovane su modificiranom 7-centimetarskom Livingstoneovom klipnom bušilicom (Wright 1967) postavljenom na prijenosno bušaće postolje. Uzorci su na terenu izvađeni iz uređaja, umotani u tanku plastičnu foliju, aluminijsku foliju i debelu plastiku te preneseni u laboratorij gdje su pohranjeni u mraku na 4°C. Svojstva taložine te 212 cm duge jezgre opisana su prema Troels-Smithu (1955), a njena je boja određena prema Munsellovoj skali. Provedene su sljedeće analize taložine: datiranje radioaktivnim ugljikom, analiza gubitka mase žarenjem te geokemijske i peludne analize.

Najprije je pomoću metalnog volumetričkog pribora za uzimanje uzorka uzet preliminarni uzorak po 1 cm^3 taložine iz odabranih razina jezgre. Preliminarna analiza peluda s rezolucijom uzorkovanja od oko 16 cm provedena je kako bi se grubo odredio dio jezgre koji bi mogao pripadati holocenu te procijenila kvaliteta očuvanosti peludnih zrnaca. Nakon te preliminarne analize, odsječak jezgre dug 9 cm (200 g) poslan je u laboratorij Beta Analytic na Floridi radi datiranja radioaktivnim ugljikom. Budući da uzorak nije sadržavao dovoljno ugljena za standardni postupak ^{14}C datiranja, organski ugljik izdvo-

Figure 2.4. The coring location.

Slika 2.4 Mjesto na kojem je provedeno jezgrovanje.

diometric dating, AMS dating of organic carbon extracted from the sediment was carried out. Four additional samples, 1 cm of the core each time (*ca.* 20 g of the sediment), were sent for radiocarbon dating, in order to obtain more detailed chronology. For all four samples material pretreatment included acid washes and direct atomic counting was performed using an accelerator mass spectrometer. All radiocarbon dates were calibrated by Beta Analytic using INTCAL 98 database (Stuvier *et al.* 1998).

The amount of organic material and carbonates in the sediment was determined using loss-on-ignition analysis (Bengtsson & Enell 1986). For geochemical analysis an acid digestion method (a variation of method 2 of Bengtsson & Enell 1986, M. Braun, personal communication) was used to process the samples. The concentration of 21 elements in each sample was measured by inductively coupled plasma atomic-emission spectroscopy using Perkin Elmer Optima 3300 RL spectrometer facility at the Department of Geology, Royal Holloway, University of London, Egham.

Samples for pollen analysis were prepared using the standard laboratory procedures (method B of Berglund & Ralska-Jasiewiczowa 1986; Bennett & Willis 2002), which include the following steps: hot 7% HCl treatment, hot 10% NaOH treatment, sieving (180µm mesh), cold 7% HCl, hot 60% HF, hot 7% HCl, acetolysis, staining (0.2% aquaeous safranine), dehydration in TBA and mounting in silicone oil. Two tablets of *Lycopodium* spores with a known number of spores were added to each sample at the beginning of pollen preparation and *Lycopodium* spores were counted along with the pollen in order to determine the pollen concentration (Stockmarr 1971). For pollen identification Leitz and Nikon Eclipse E400 light microscopes at 400x magnification were used. Pollen grains were identified by comparison with the reference collection of the Department of Geography, University of Oxford and consulting the following pollen keys: Moore, Webb and Collinson (1991), Reille (1992, 1995), and Punt *et al.* (1976–1995). A minimum count of 600 grains (terrestrial pollen and spores) per sample was made in the levels with the pollen concentration above 1000 pollen grains per 1 cm^3 of the sediment. The concentration of microscopic charcoal in the pollen samples was established using Clark's (1982) point count method.

The diagrams were plotted using PSIMPOLL 3.00 and PSCOMB 3.01 C programs for plotting pollen diagrams and analysing pollen data (Bennett 1998, http://www.kv.geo.uu.se/software.html/). The percentage pollen diagram was divided into zones using optimal splitting by information content and the number of significant zones was determined by the broken-stick model (Bennett 1996, 1998). For age modelling all five models available in the PSIMPOLL 3.00 (linear interpolation, cubic spline interpolation, general line-fitting by weighted least-squares,

jen iz taložine datiran je metodom akceleratorske masene spektrometrije. Četiri dodatna uzorka, od po 1 cm jezgre za svaki (oko 20 g taložine), poslana su na datiranje metodom radioaktivnog ugljika radi određivanja točnije kronologije. Priprema materijala svih četiriju uzoraka sastojala se od ispiranja kiselinom, a izravno je mjerenje provedeno metodom AMS. Svi ^{14}C datumi kalibrirani su u laboratoriju Beta Analytic koristeći bazu podataka INTCAL 98 (Stuvier *et al.* 1998).

Količina organskog materijala i karbonata u taložini određena je analizom gubitka mase žarenjem (Bengtsson & Enell 1986). Za potrebe geokemijske analize korištena je metoda kiselinske obrade uzoraka (prilagođena metoda 2 prema Bengtsson & Enell 1986, M. Braun, osobno priopćenje). Svakom je uzorku izmjerena koncentracija 21 elementa induktivnom plazma emisijskom spektroskopijom pomoću Perkin Elmer Optima 3300 RL spektrometra Odsjeka za geologiju, Royal Holloway, Londonskog sveučilišta u Eghamu.

Uzorci za peludnu analizu pripremljeni su prema standardnim laboratorijskim procedurama (metoda B prema Berglund & Ralska-Jasiewiczowa 1986; Bennett & Willis 2002), koje uključuju sljedeće korake: obrada vrućom 7% HCl, obrada vrućim 10% NaOH, prosijavanje (otvori sita veličine 180µm), obrada hladnom 7% HCl, vrućom 60% HF, vrućom 7% HCl, acetoliza, bojenje (0,2% vodenom otopinom sufranina), dehidracija u TBA i priprema preparata sa silikatnim uljem. Na početku pripreme, svakom su uzorku dodane po dvije tablete spora *Lycopodiuma* s poznatim brojem spora. Te su spore izbrojane usporedo sa zrncima peluda kako bi se odredila koncentracija peluda (Stockmarr 1971). Za identifikaciju peluda korišteni su mikroskopi Leitz i Nikon Eclipse E400 povećanja 400x. Zrnca peluda identificirana su usporedbom s referentnom zbirkom Odsjeka za zemljopis Sveučilišta u Oxfordu te prema sljedećim ključevima za pelud: Moore, Webb i Collinson (1991), Reille (1992, 1995) i Punt *et al.* (1976–1995). U razinama s koncentracijom peluda iznad 1000 zrnaca po 1 cm^3 taložine, izbrojeno je najmanje 600 zrnaca po uzorku kopneni pelud i spore). Koncentracija mikroskopskih čestica drvenog ugljena u uzorcima peluda određena je koristeći metodu brojanja po Clarku (1982).

Dijagrami su iscrtani koristeći programe za crtanje peludnih dijagrama i analizu peludnih podataka PSIMPOLL 3.00 i PSCOMB 3.01 C (Bennett 1998, http://www.kv.geo.uu.se/software.html/). Dijagram procentualne zastupljenosti peluda podijeljen je na zone optimalnim cijepanjem prema sadržaju informacija, dok je broj značajnih zona određen prema *"broken-stick"* modelu (Bennett 1996, 1998). Za modeliranje starosti iskušano je svih pet modela dostupnih u PSIMPOLL 3.00 (linearna interpolacija, interpolacija *splineovima* trećeg reda, opća aproksimacija pravcem ponderiranom metodom najmanjih kvadrata, opća aproksimacija pravcem general line-fitting by singular value decomposition, curve-fitting by Bernshtein polynomial, Bennett 1994) were run and, due to the irregular sedimentation rate throughout the sequence, the linear interpolation was selected as the most appropriate age model. The intercept of radiocarbon age with the calibration curve (in calibrated years BP) was used for the age modelling and the positions of these dates are plotted on each diagram. The principle components analysis (PCA) was also run with the PSIMPOLL program (Bennett 1998) and during the analysis of the pollen data the square root transformation of the dataset was carried out to diminish the influence of more numerous taxa (Birks & Gordon 1985; Grimm 1987; Bennett 1998).

singularnom dekompozicijom, aproksimacija krivulje Bernsteinovim polinomom, Bennett 1994). Budući da je brzina taloženja slojeva kroz čitav slijed bila neujednačena, kao najpodesniji model odabrana je metoda linearne interpolacije. Za modeliranje starosti koristili smo sjecišta ^{14}C datuma i kalibracijske krivulje (u kalibriranim godinama pr. Kr.) pa smo navedene datume unijeli u sve dijagrame. Analiza glavnih komponenata (PCA) također je provedena pomoću programa PSIMPOLL (Bennett 1998). Za potrebe analize peludnih podataka provedena je transformacija kvadratnim korjenovanjem kako bi se umanjio utjecaj bolje zastupljenih taksona (Birks & Gordon 1985; Grimm 1987; Bennett 1998).

2.3 Results

The results of loss-on-ignition, geochemical and pollen analysis of the sediment are presented on several diagrams (Figures 2.6–2.7, and 2.9–2.11). The sediment description of the core and radiocarbon dates, presented on Tables 2.1 and 2.2, are included also in the loss-on-ignition, geochemistry and pollen diagrams (Figures 2.6, 2.7 and 2.9). On each of these diagrams the sample depth is presented on the far left side, followed by the age estimation (in years BC/AD), sedimentary column and the position of each radiocarbon date (in years Cal. BP). The results of analyses (loss-on-ignition, geochemistry, pollen and charcoal) follow, and each diagram concludes with the column marking pollen zones. Only the results of pollen analysis were used for this zonation, although the pollen zones are plotted also on loss-on-ignition and geochemistry diagrams in order to facilitate comparison between diagrams.

2.3.1 Radiocarbon dates and age modelling

The radiocarbon date for the bottom of the Prapoče core at 206 cm indicates that the sequence extends back to *ca.* 7500 Cal. BC. Five radiocarbon dates have been obtained by AMS dating of organic carbon extracted from the sediment and the results are presented in Table 2.1.

Radiocarbon dates plotted against depth (Figure 2.5) suggest that the sedimentation rate increased towards the end of the Holocene, from *ca.* 1.1 cm of

2.3. Rezultati

Rezultati analize gubitka mase žarenjem, geokemijske analize i analize peluda predstavljeni su na nekoliko dijagrama (slika 2.6 – 2.7, i 2.9 – 2.11). Opis taložina jezgre i ^{14}C datumi, predstavljeni u tablicama 2.1 i 2.2, uključeni su i u dijagrame gubitka mase žarenjem, geokemijske i peludne dijagrame (slika 2.6, 2.7 i 2.9). Na svakom dijagramu, sasvim lijevo, naznačena je dubina uzorka, zatim slijedi procjena starosti (u godinama pr. Kr./po Kr.), taložinski stupac i položaj svakog ^{14}C datuma (u godinama pr. Kr. kalibrirano). Slijede re zultati analiza (gubitka mase žarenjem, geokemije, peluda, drvenog ugljena), a svaki dijagram završava stupcem koji naznačuje peludne zone. Za odredbu zona korištene su samo peludne analize, premda su zbog lakše usporedbe dijagrama peludne zone također prikazane i na dijagramima gubitka mase žarenjem i geokemijskim dijagramima.

2.3.1. ^{14}C datumi i modeliranje starosti

Starost dna jezgre iz Prapoča na dubini 206 cm, određena metodom radioaktivnog ugljika, ukazuje da slijed seže u prošlost do oko 7500. godine pr. Kr. (kalibrirano). Pet ^{14}C datuma dobiveno je AMS metodom datiranja organskog ugljena izdvojenog iz taložine. Rezultati su prikazani na tablici 2.1.

^{14}C datumi, prikazani pored dubine (slika 2.5), ukazuju da se brzina taloženja povećala pri kraju holocena,

Table 2.1. *Prapoče radiocarbon dates.*

Tablica 2.1 *^{14}C datumi iz Prapoča.*

Sample Number	Depth (cm)	Conventional ^{14}C age	$^{13}C/^{12}C$ ratio	Intercept with Calibration Curve BC (BP)	2 S.D. Calibrated Range
Beta-183918	131	1660±40 bp	-26.3 o/oo	400 AD (1550 BP)	260–290, 320–450 AD
Beta-145368	140	3050±40 bp	-24.5 o/oo	1310 BC (3260 BP)	1410–1200 BC
Beta-183919	150	3680±40 bp	-22.9 o/oo	2040 BC (3990 BP)	2190-2170, 2150-1940 BC
Beta-123732	163-172	5250±60 bp	-27.7 o/oo	4035 BC (5985 BP)	4235–3960 BC
Beta-141212	206	8360±40 bp	-25.4 o/oo	7475 BC (9425 BP)	7530–7330 BC

sediment /100 years at the bottom of the core to *ca.* 8 cm/100 years in the section of the core dated after *ca.* 1500 Cal. BP.

od oko 1.1 cm taložine na 100 godina pri dnu jezgre na oko 8 cm na 100 godina u dijelu jezgre datiranom nakon oko 1500. prije sadašnjosti (kalibrirano).

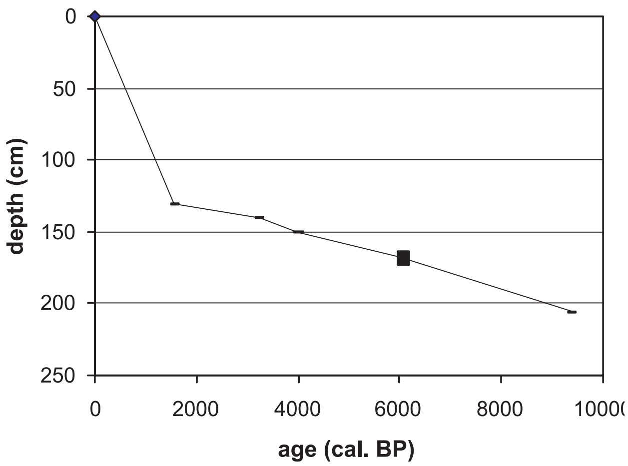


Figure 2.5. Prapoče: Sediment age (calibrated 2 S.D. ranges) plotted against depth (data from Table 2.1).

Slika 2.5 Prapoče: starost taložine (kalibrirani rasponi od 2 S.D.) po dubini (podaci iz tablice 2.1).

2.3.2 Sediment description and loss-on-ignition analysis

The Prapoče core is clay-rich throughout (Table 2.2). Results of loss-on-ignition are presented on Figure 2.6. Pollen zones (P-1 to P-4) have been included in this diagram in order to facilitate the comparison between loss-on-ignition and pollen data.

The amount of organic material, carbonates and inorganic residue is presented as a percentage calculated from the dry weight of 1 cm^3 of the sediment. The percentage of organic material in the bottom half of the core is below 10% and slightly increases towards the top. The inorganic content of the core is 80–90%. At the bottom of the core in the zone P-1 the amount of carbonates is higher (5–15%) than in the rest of the core (*ca.* 2.5%).

2.3.2. Opis taložine i analiza gubitka mase žarenjem

Jezgra iz Prapoča po čitavoj je dužini bogata glinom (tablica 2.2). Rezultati analize gubitka mase žarenjem predstavljeni su na slici 2.6. Peludne zone (P-1 do P-4) uključene su u navedeni dijagram kako bi se ti rezultati mogli lakše usporediti s podacima o peludu.

Količine organskog materijala, karbonata i anorganskih ostataka prikazane su kao postoci od težine 1 cm^3 suhe taložine. Količina organskog materijala u donjoj polovici jezgre je ispod 10% te lagano raste prema njenom vrhu. Količina anorganskih tvari je 80–90%. Pri dnu jezgre u zoni P-1 količina karbonata je veća (5–15%), nego u ostatku jezgre (oko 2,5%).

Table 2.2. *Prapoče sediment column. Description of the sediment follows Troels-Smith (1955).*
Tablica 2.2 *Prapoče: opis taložine prema Troels-Smith (1955).*

Depth (m)	Troels-Smith symbol	Colour (Munsell soil chart)
0.25-0.43	As4 (clay)	10 YR 4/2 dark greyish brown
0.43-1.00	As4 (clay)	2.5 YR 4/2 dark greyish brown
1.00-1.06	As4 (clay)	2.5 Y 3/2 very dark greyish brown
1.06-1.14	As4 (clay)	5Y 2.5/1 black
1.14-1.45	As4 (clay)	marbled, 2.5 Y 4/2 dark greyish brown
1.45-1.60	As4 (clay)	marbled, 2.5 Y 4/3 olive brown
1.60-1.90	As4 (clay)	marbled, 2.5 Y 4/4 olive brown
1.90-2.20	As4 (clay)	marbled, 2.5 Y 5/2 olive grey

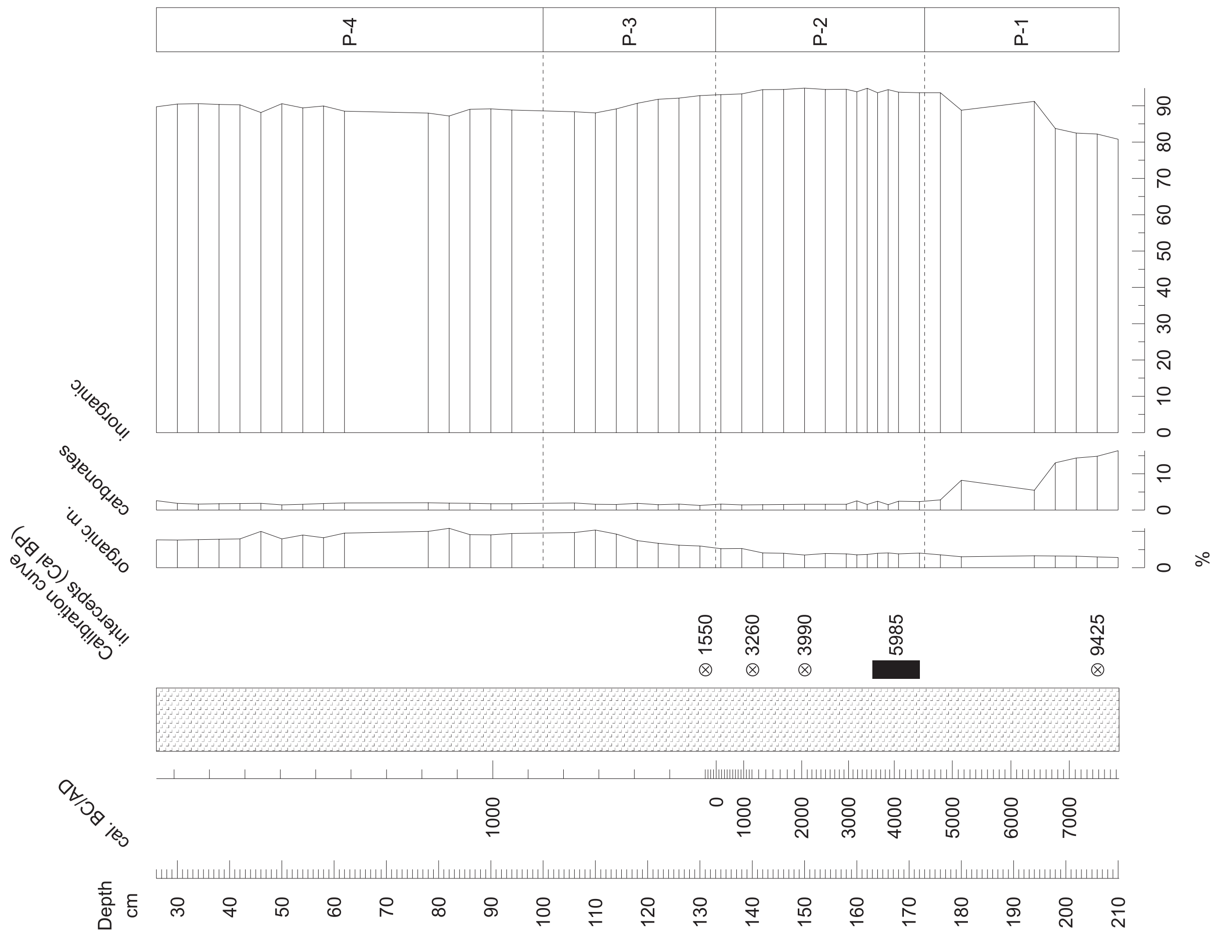


Figure 2.6. Prapoče: Loss-on-ignition. "⊗" marks position of 0.5-cm section of core for AMS ^{14}C date; "☐" marks position of 9-cm section of core for AMS ^{14}C date.

Slika 2.6 Prapoče: gubitak mase žarenjem. "⊗" označava položaj odsječaka jezgre dužine 0,5 cm uzetih za AMS ^{14}C datiranje; "☐"označava položaj 9 cm odsječka jezgre uzetog za AMS ^{14}C datiranje.

2.3.3 Geochemistry

The results of geochemical analysis (Figure 2.7) are plotted as weight (in mg) of each element per 1 kg of dry sediment. Pollen zones (P-1 to P-4) have been included in this diagram in order to facilitate the comparison between geochemistry and pollen data. The concentrations of iron (Fe) and aluminium (Al) fluctuate between approximately 20–40 mg/kg. The amount of magnesium (Mg) and potassium (K) stay constant throughout the whole sequence, *ca.* 10 mg/kg. The calcium (Ca) curve, however, is high at the bottom of the core (up to 120 mg/kg) and decreases at the top of the zone P-1. This calcium peak coincides with higher carbonates, determined by the loss-on-ignition (Figure 2.6).

The PCA of geochemical analysis (Figure 2.8) shows that the main direction of variance on the first axis is between calcium (Ca) and aluminium (Al). The main direction of variance on the second axis is between iron (Fe) and aluminium (Al). The variance along the first axis (accounting for 36% of total variance) can be associated with changes of temperature and wetness, controlling the precipitation of calcium carbonate into the sediment. The reasons for variance along other axes are still poorly understood. It might be connected with changes in the redox conditions of the sediment.

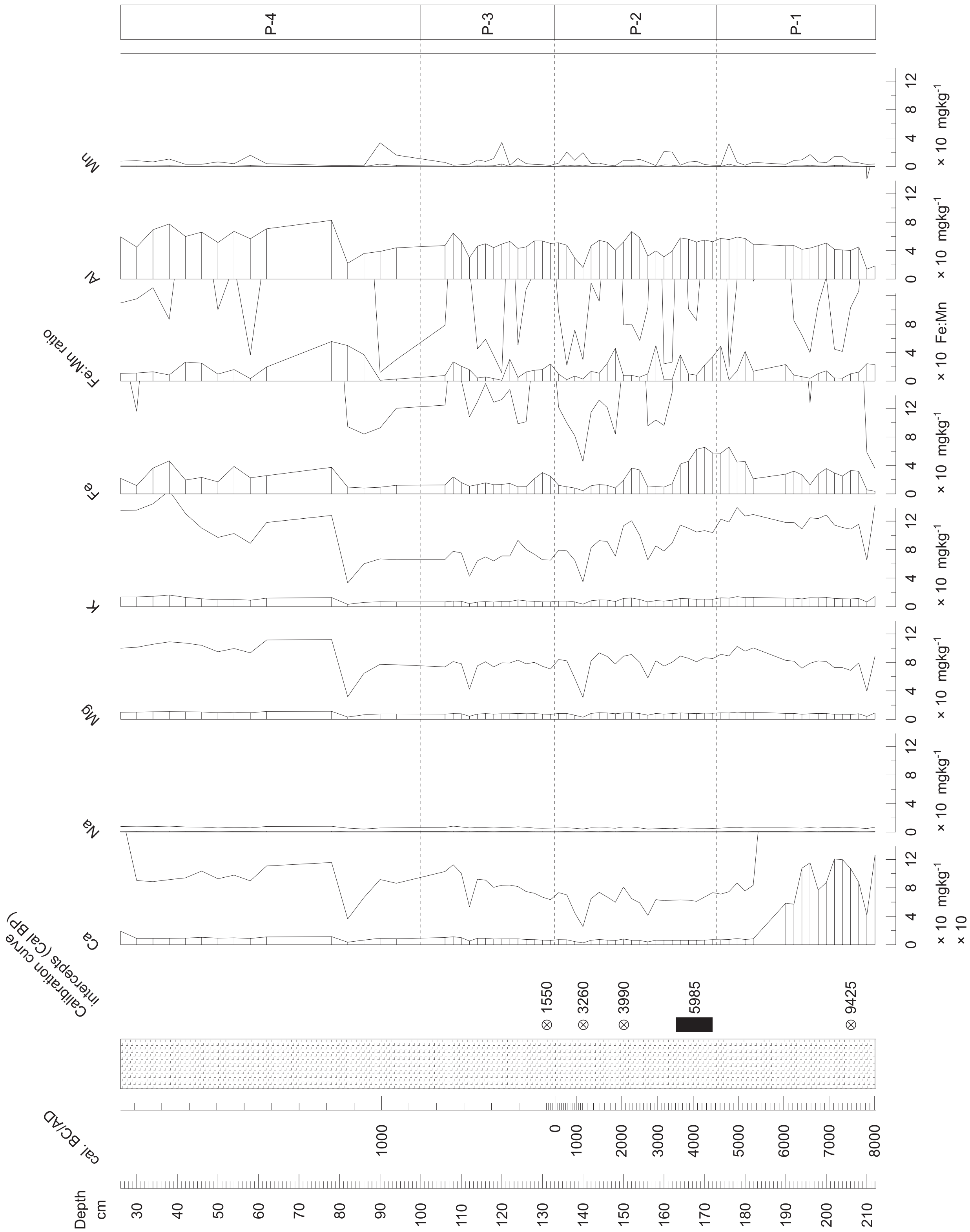
2.3.3. Geokemijska analiza

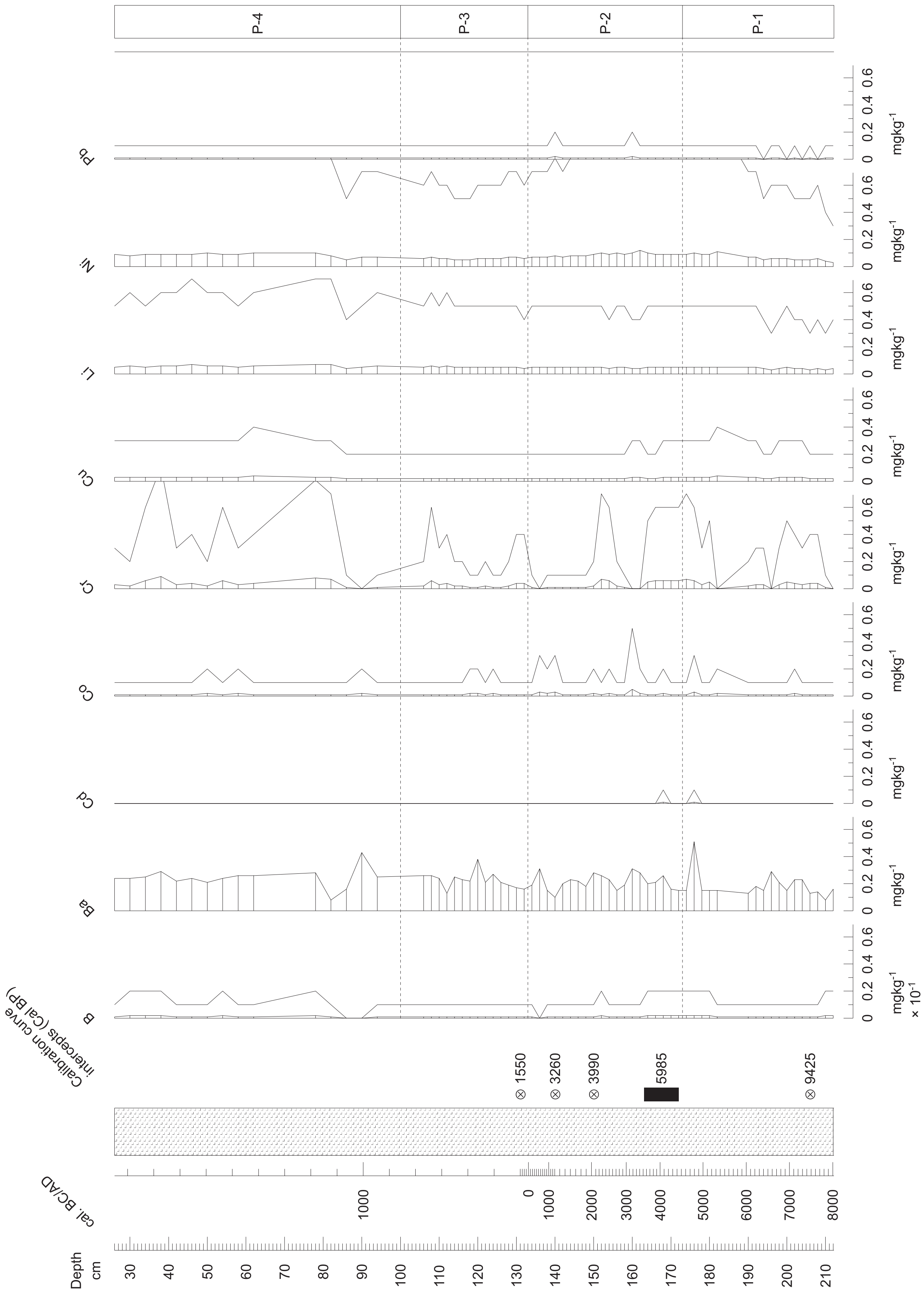
Rezultati geokemijske analize (slika 2.7) prikazani su kao težina svakog elementa (u mg) po 1 kg suhe taložine. Peludne zone (P-1 do P-4) prikazane su s namjerom da olakšaju usporedbu između geokemijskih podataka i podataka o peludu. Koncentracije željeza (Fe) i aluminija (Al) kolebaju se između otprilike 20 – 40 mg/kg. Količine magnezija (Mg) i kalija (K), oko 10 mg/kg, konstantne su kroz čitav slijed. Krivulja kalcija (Ca) pokazuje visoke vrijednosti pri dnu jezgre (do 120 mg/kg), dok se one prema vrhu zone P-1 smanjuju. Ovaj maksimum kalcija podudara se s povišenim vrijednostima karbonata, određenih analizom gubitka mase žarenjem (slika 2.6).

Analiza glavnih komponenata (slika 2.8) pokazuje da je prva glavna komponenta saturirana kalcijem (Ca) i aluminijem (Al). Druga glavna komponenta saturirana je željezom (Fe) i aluminijem (Al). Varijanca duž prve osi (koja objašnjava 36% od ukupne varijabilnosti) može se dovesti u svezu s promjenama temperature i vlažnosti, koje određuju obaranje kalcijevog karbonata u taložini. Uzroci varijance duž druge osi zasad su nejasni. Moguće je da je ona povezana s promjenama oksidacijsko-redukcijskih uvjeta unutar taložine.

Figure 2.7. Prapoče: Geochemistry. "⊗" marks position of 0.5-cm section of core for AMS ^{14}C date; "☐" marks position of 9-cm section of core for AMS ^{14}C date.

Slika 2.7 Prapoče: geokemija. "⊗"označava položaj odsječaka jezgre dužine 0,5 cm uzetih za AMS ^{14}C datiranje; "☐"označava položaj 9 cm odsječka jezgre uzetog za AMS ^{14}C datiranje.




P-4
P-3
P-2
P-1
Pb
Ni
Li
Cu
Cr
Co
Cd
Ba
B
mgkg-1
mgkg-1 × 10-1
Calibration curve intercepts (Cal BP)
1550
3260
3990
5985
9425
cal. BC/AD
Depth cm

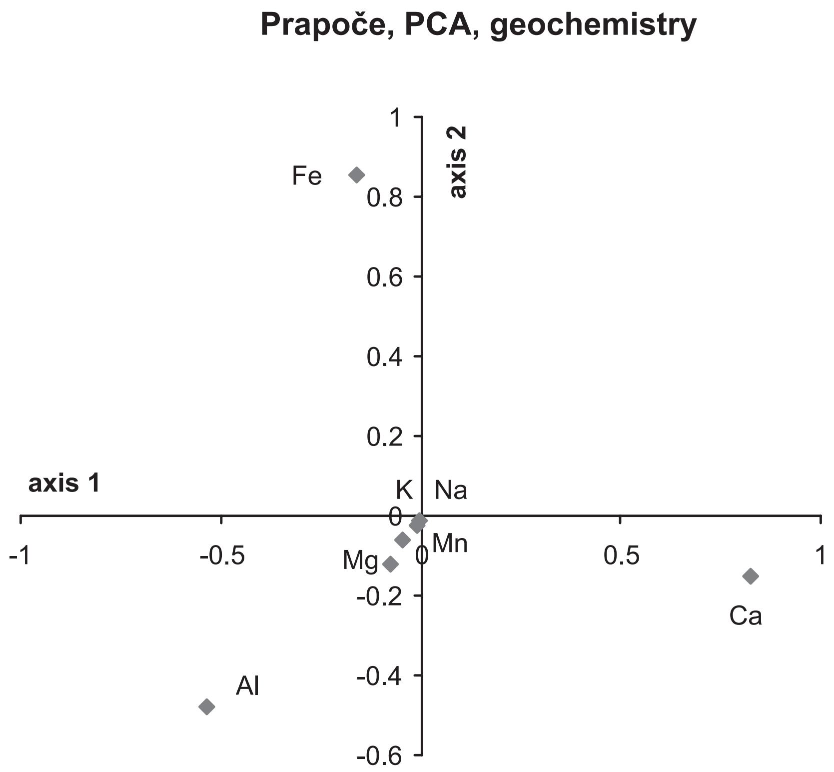


Figure 2.8. Prapoče: Geochemistry. PCA. Axes 1 and 2 account for 36% and 16% of the total variance.

Slika 2.8 Prapoče: geokemija. PCA. Osi 1 i 2 objašnjavaju 36% i 16% od ukupne varijance.

2.3.4 Pollen analysis

The percentage pollen diagram (Figure 2.9) shows the abundance of all taxa, presented as percentage data. The proportion of each taxon has been calculated as a percentage of the pollen sum of all terrestrial taxa and spores. Monolete fern spores (*Filicales*), which are over-represented due to an assumed local source, have been excluded from the sum.

Zonation by optimal splitting by information content suggested four discrete pollen zones. The zone P-1 has been radiocarbon dated (using linear interpolation) to *ca*. 7500–4500 Cal. BC. The main characteristic of this zone is the constantly high percentage of pine pollen (*Pinus*, 20–40% in most levels). The other taxa present in this zone are hazel (*Corylus*, 0–45%), grasses (*Gramineae*, 0–25%), *Compositae tubuliflorae* (0–20%) and monolete fern spores (*Filicales*, 0–35%). Oak *(Quercus)*, lime *(Tilia)* and alder *(Alnus)* are present with less than 10%, whereas the percentage of other tree taxa *(Betula, Abies, Fagus, Carpinus betulus)* in most levels does not exceed 5%.

The age of the zone P-2 has been determined to *ca*. 4500–1 Cal. BC. The percentage of pine *(Pinus)* in this zone is much lower than in the previous zone (P-1) and does not exceed 10%. The percentage of the other tree taxa is however higher than in the zone P-1. The main tree taxa are lime (*Tilia*, 5–10%), hazel (*Corylus*, 5–20%), alder (*Alnus*, 5–15%), fir (*Abies*, 2–10%), beech (*Fagus*, 2–5%), oak (*Quercus*, 2–10%), and hornbeam (*Carpinus*

2.3.4. Analiza peluda

Peludni dijagram prikazuje u postocima (slika 2.9) zastupljenost svih taksona. Udio svakog taksona izračunat je kao postotak od zbroja svih kopnenih taksona peluda i spora. Monoletne spore paprati (*Filicales*) pretjerano su zastupljene zbog (pretpostavljenog) postojanja nekoga lokalnog izvora, stoga su izuzete iz ukupnoga zbroja.

Podjela na zone optimalnim cijepanjem prema sadržaju informacija sugerira postojanje četiriju zasebnih peludnih zona. Zona P-1 datirana je metodom radioaktivnog ugljika (koristeći linearnu interpolaciju) oko 7500. – 4500. pr. Kr. (kalibrirano). Glavna karakteristika ove zone je stalan visoki postotak peluda bora (*Pinus*, 20 – 40% u većini razina). Drugi taksoni prisutni u ovoj zoni jesu lijeska (*Corylus*, 0 – 45%), trave (*Gramineae*, 0 – 25%), *Compositae tubuliflorae* (0 – 20%) i monoletne spore paprati (*Filicales*, 0 – 35%). Hrast *(Quercus)*, lipa *(Tilia)* i joha *(Alnus)* prisutni su s manje od 10%, dok postotak drugih taksona drveća *(Betula, Abies, Fagus, Carpinus betulus)* u većini slojeva ne prelazi 5%.

Starost zone P-2 je oko 4500. – 1. pr. Kr. (kalibrirano). Postotak bora *(Pinus)* u ovoj je zoni mnogo niži, nego u prethodnoj zoni (P-1) te ne prelazi 10%. Za razliku od toga, postotak drugih taksona drveća veći je nego u zoni P-1. Glavni taksoni drveća su lipa (*Tilia*, 5 – 10%), lijeska (*Corylus*, 5 – 20%), joha (*Alnus*, 5 – 15%), jela (*Abies*, 2 – 10%), bukva (*Fagus*, 2 –

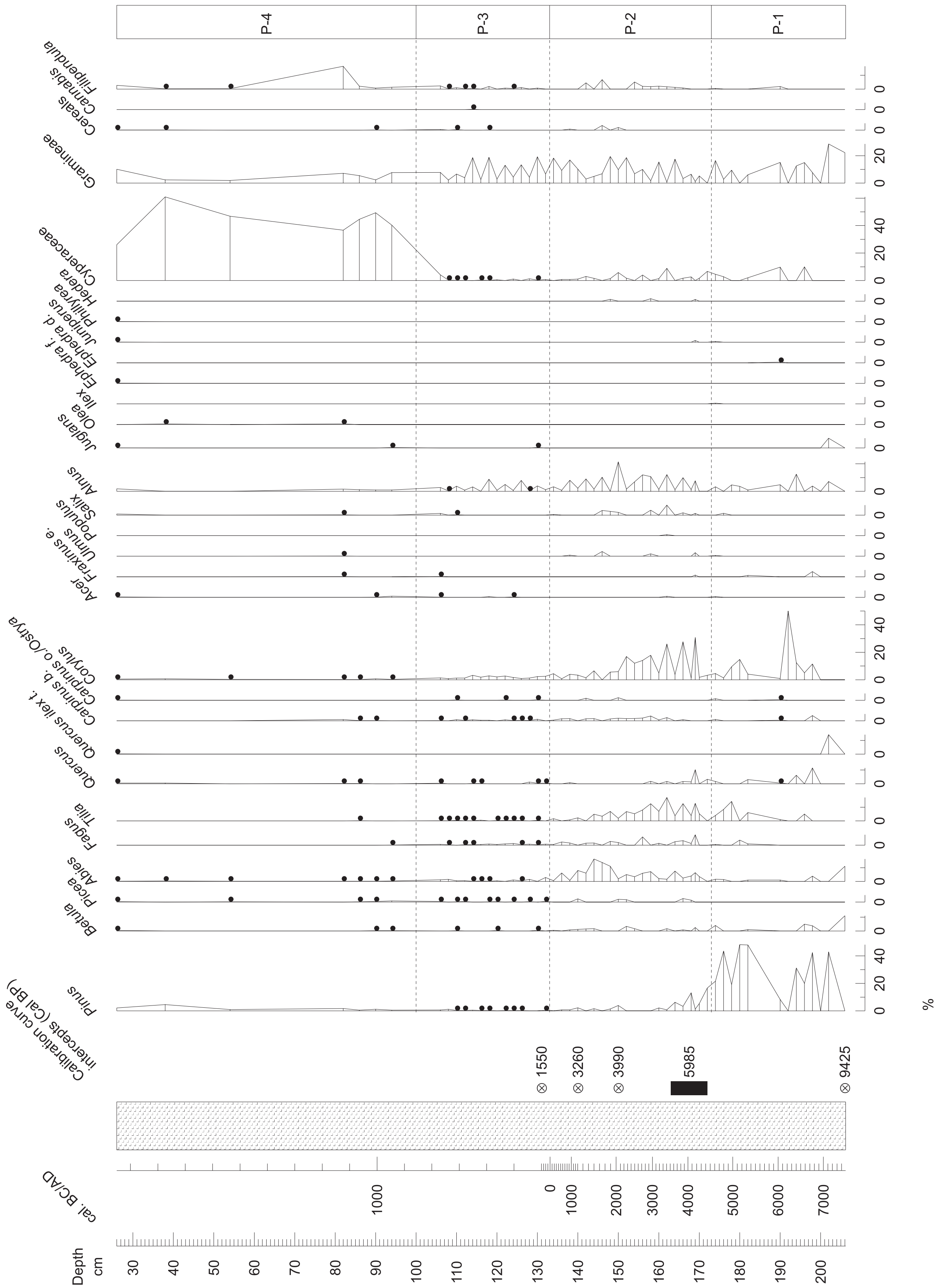
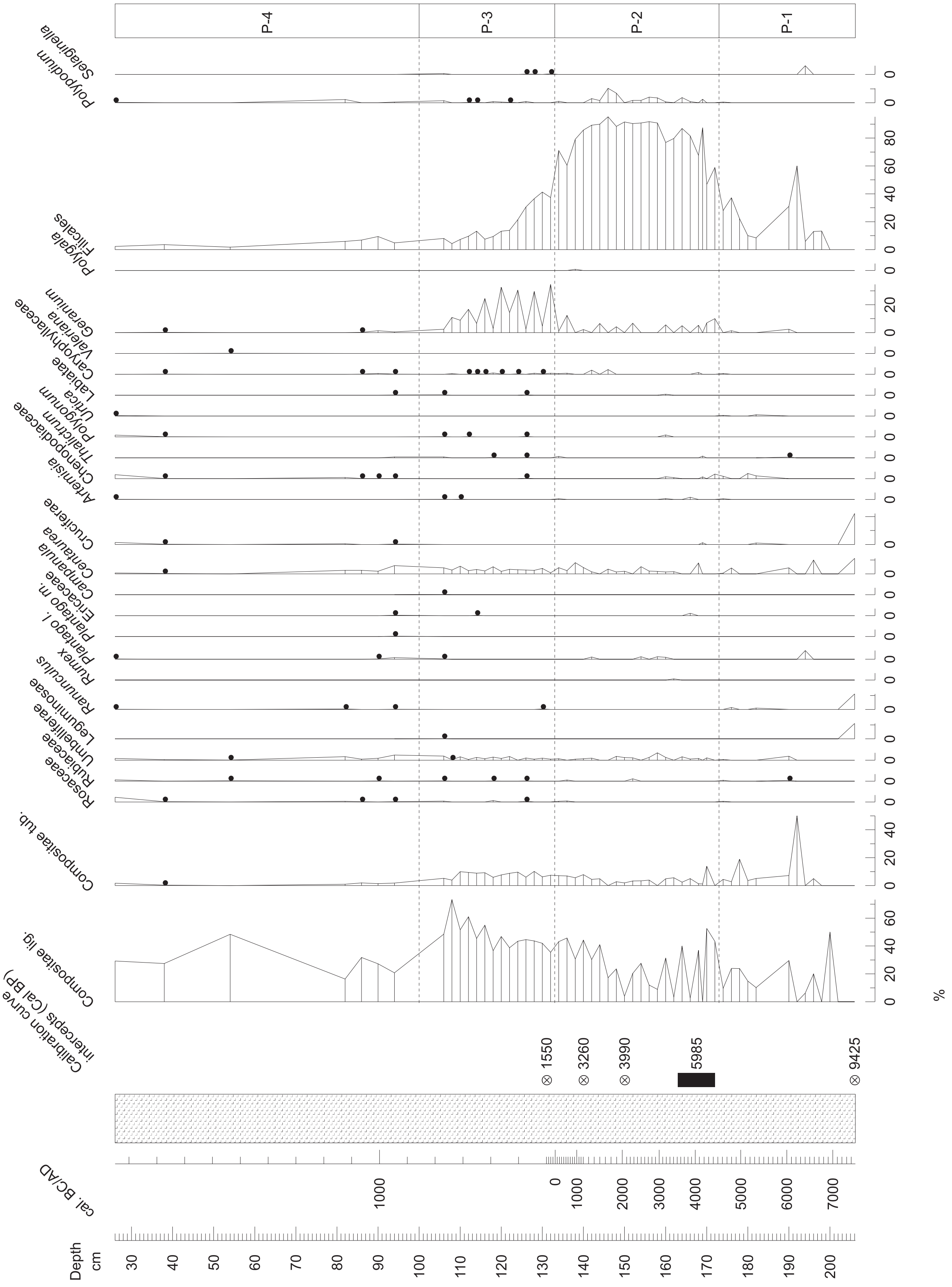
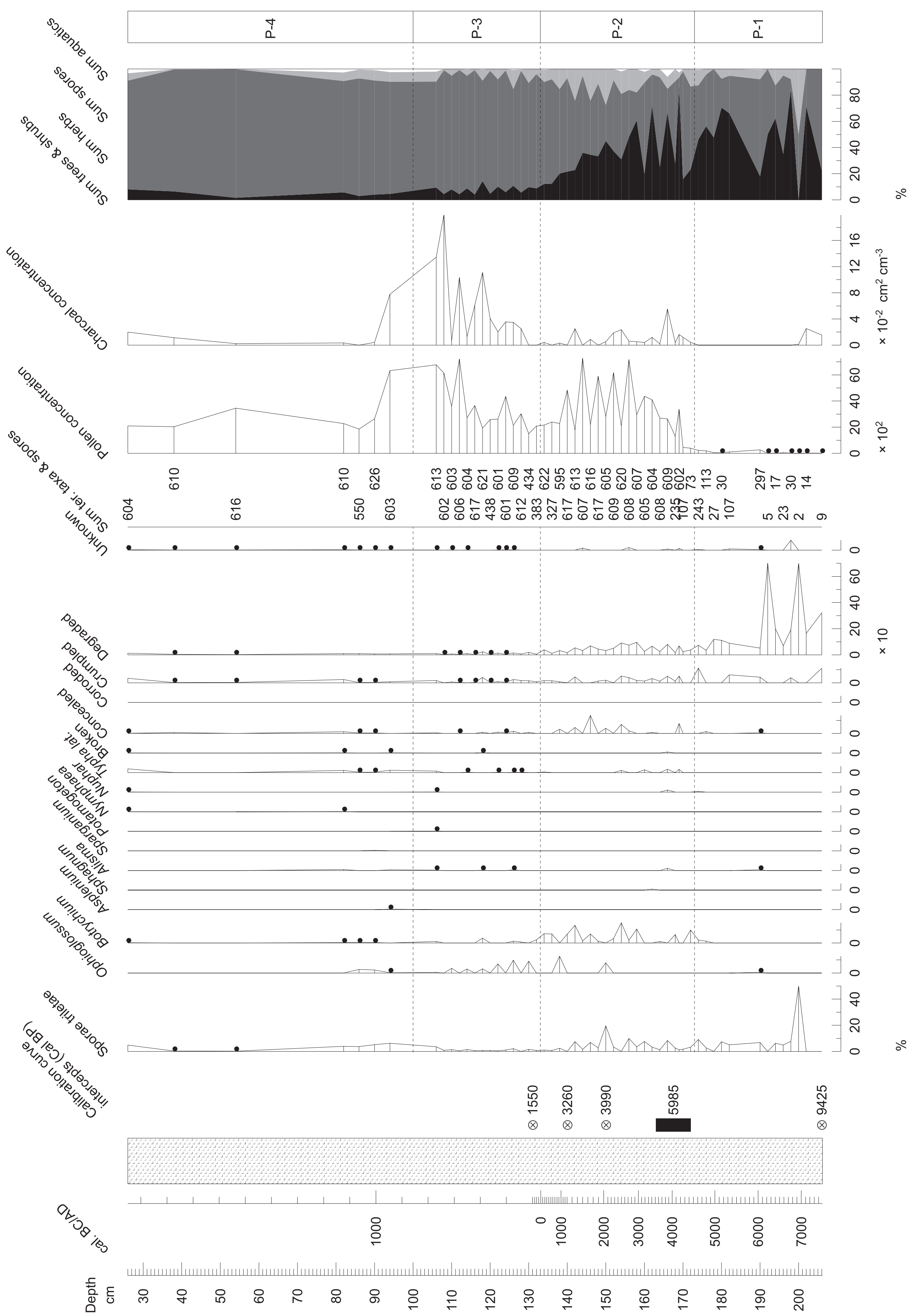


Figure 2.9. Prapoče: Percentage pollen diagram. "⊗" marks position of 0.5-cm section of core for AMS ^{14}C date; "☐" marks position of 9-cm section of core for AMS ^{14}C date.

Slika 2.9 Prapoče: dijagram procentualnog udjela peluda. "⊗"označava položaj odsječaka jezgre dužine 0,5 cm uzetih za AMS ^{14}C datiranje; "☐"označava položaj 9 cm odsječka jezgre uzetog za AMS ^{14}C datiranje.



P-4
P-3
P-2
P-1
Selaginella
Polypodium
Filicales
Polygala
Geranium
Valeriana
Caryophyllaceae
Labiatae
Urtica
Polygonum
Thalictrum
Chenopodiaceae
Artemisia
Cruciferae
Centaurea
Campanula
Ericaceae
Plantago m.
Plantago l.
Rumex
Ranunculus
Leguminosae
Umbelliferae
Rubiaceae
Rosaceae
Compositae tub.
Compositae lig.
%
Calibration curve intercepts (Cal BP)
⊗ 1550
⊗ 3260
⊗ 3990
5985
⊗ 9425
cal. BC/AD
1000
0
1000
2000
3000
4000
5000
6000
7000
Depth cm
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200


P-4
P-3
P-2
P-1
Sum aquatics
Sum spores
Sum herbs
Sum trees & shrubs
Charcoal concentration
Pollen concentration
Sum ter. taxa & spores
Unknown
Degraded
Crumpled
Corroded
Concealed
Broken
Typha lat.
Nuphar
Nymphaea
Potamogeton
Sparganium
Alisma
Sphagnum
Asplenium
Botrychium
Ophioglossum
Sporae trilete
Calibration curve intercepts (Cal BP)
1550
3260
3990
5985
9425
cal. BC/AD
Depth cm
%
× 10⁻² cm² cm⁻³
× 10²
× 10

betulus, 2–5%). Towards the top of the zone herb pollen (mainly *Gramineae, Compositae liguliflorae* and *Geranium*) starts to increase and exceeds 50%. The first cereal type pollen grains appear at the middle of the zone P-2 which is dated to *ca.* 2100 Cal. BC.

In the zone P-3 (1 Cal. BC–850 AD) the percentage of tree pollen is below 10% and herbs reach *ca.* 80%. Among tree taxa the alder *(Alnus)* and hazel *(Corylus)* pollen reach values of *ca.* 5%, whereas the pollen of other trees, although constantly present, usually does not exceed 1%. Herbs characteristic for this pollen zone are *Compositae liguliflorae* (40–70%), *Gramineae* (5–15%), *Geranium* (5–30%), and *Compositae tubuliflorae* (*ca.* 10%).

The percentage of tree pollen remains low in zone P-4 (850–1950 AD). The percentage of alder *(Alnus)* and hazel *(Corylus)* decreases below 2%. The main characteristic of this pollen zone is an increase of *Cyperaceae* (*ca.* 40%) and *Filipendula* pollen (exceeds 10% in one level), whereas the percentage of *Compositae liguliflorae* (10–40%), *Compositae tubuliflorae* (*ca.* 2%) and *Geranium* (*ca.* 2%) decreases.

Due to low pollen concentration (in some levels below 500 pollen grains per 1 cm^3) the pollen sum in some sections of Prapoče core does not exceed 250. Therefore the percentage pollen diagram with 95% confidence intervals (Figure 2.10) has been plotted against age in order to evaluate the precision of percentages displayed on the pollen diagram. Horizontal bars at each level indicate where the percentage values for each taxa would be located (with 95% probability) if pollen counting would be repeated (Maher 1972; Bennett 1998). Palynological richness (measuring the number of taxa in the pollen spectrum) and chord distance (rate-of-change analysis measuring dissimilarity between adjacent pairs of samples) have also been included in this diagram. The rate of change is highest at *ca.* 500 AD, whereas the palynological richness is highest at *ca.* 800 AD and in the present-day landscape. Owing to additional radiocarbon dating of the Prapoče core, the estimated age of 'rate of change' and 'palynological richness' peaks is several centuries younger than suggested previously (Andrič 2001a, 2001b).

The influx pollen diagram (Figure 2.11) presents the dataset in grains per cm^2 per year. In the zone P-1 pollen influx is below 10 grains per cm^2 per year, then it gradually increases, being highest at the transition between zones P-3 and P-4 (100–200 grains per cm^2 per year).

The results of principal components analysis (PCA) are presented on Figures 2.12 and 2.13. During the PCA the square root transformation was carried out in order to diminish the influence of more numerous taxa and therefore more clearly see the variance in the dataset. Only taxa with a significant percentage (at least 5% of the pollen sum) were included and results are presented

5%), hrast (*Quercus*, 2 – 10%) i obični grab (*Carpinus betulus*, 2–5%). Pri vrhu zone počinje rasti udio peluda zeljastog bilja (uglavnom *Gramineae, Compositae liguliflorae* i *Geranium*) te prelazi 50%. Prva peludna zrnca tipa žitarica pojavljuju se pri sredini zone P-2 koja se datira oko 2100. pr. Kr. (kalibrirano).

U zoni P-3 (1. pr. Kr. [kalibrirano] – 850. po Kr.), postotak peluda drveća je ispod 10%, dok zastupljenost zeljastih biljaka dostiže oko 80%. Među taksonima drveća, pelud johe *(Alnus)* i lijeske *(Corylus)* dostiže vrijednost od oko 5%, dok pelud drugog drveća, iako je stalno prisutan, ne prelazi 1%. Ovu peludnu zonu obilježuju zeljaste biljke, *Compositae liguliflorae* (40 – 70%), *Gramineae* (5 – 15%), *Geranium* (5 – 30%), i *Compositae tubuliflorae* (oko 10%).

Postotak peluda drveća u zoni P-4 (850. – 1950. po Kr.) i dalje je nizak. Postotak johe *(Alnus)* i lijeske *(Corylus)* pada ispod 2%. Glavna karakteristika ove peludne zone jest porast zastupljenosti peluda šaševa *(Cyperaceae)* (oko 40%) i *Filipendule* (preko 10% u jednoj od razina, dok se postotak *Compositae liguliflorae* (10 – 40%), *Compositae tubuliflorae* (oko 2%) i *Geraniuma* (oko 2%) smanjuje.

Zbog niske koncentracije peluda (manje od 500 peludnih zrnaca po 1 cm^3 u nekim razinama), njegov ukupan zbroj u nekim sekcijama jezgre iz Prapoča ne prelazi 250. Zbog toga su, pored starosti, na dijagramu procentualne zastupljenosti prikazani i intervali 95% pouzdanosti (slika 2.10), kako bi se preciznost tih podataka mogla uzeti u obzir. Vodoravne linije naznačuju, za svaku razinu, gdje bi se (s vjerojatnošću 95%) nalazile procentualne vrijednosti za svaki od taksona kad bi se brojanje peludnih zrnaca ponavljalo (Maher 1972; Bennett 1998). Bogatstvo peluda (mjereno brojem vrsta u peludnom spektru) i udaljenost akorda (analiza brzine promjene, mjerene različitošću između susjednih parova uzoraka) također su uključeni u dijagram. Brzina promjene najveća je oko 500. godine po Kr., dok je bogatstvo peluda najveće oko 800. godine po Kr. te u današnjem krajoliku. Zahvaljujući dodatnim ^{14}C datumima za jezgru iz Prapoča, starost maksimuma 'brzine promjene' i 'bogatstva peluda' procijenjena je na nekoliko stoljeća kasnije, no što je to prije bilo predloženo (Andrič 2001a, 2001b).

Dijagram priliva peluda (slika 2.11) pruža podatke o broju zrnaca po cm^2 na godinu. U zoni P-1, priliv je ispod 10 zrnaca po cm^2 godišnje, zatim se postepeno povećava, a najveći je pri prijelazu između zona P-3 i P-4 (100 – 200 zrnaca po cm^2 godišnje).

Rezultati analize glavnih komponenata (PCA) predstavljeni su na slikama 2.12 i 2.13. Za potrebe PCA provedena je transformacija kvadratnim korjenovanjem kako bi se umanjio utjecaj brojnije zastupljenih taksona i tako jasnije uočila varijanca podataka. Uzeti su u obzir samo taksoni sa značajnom procentualnom

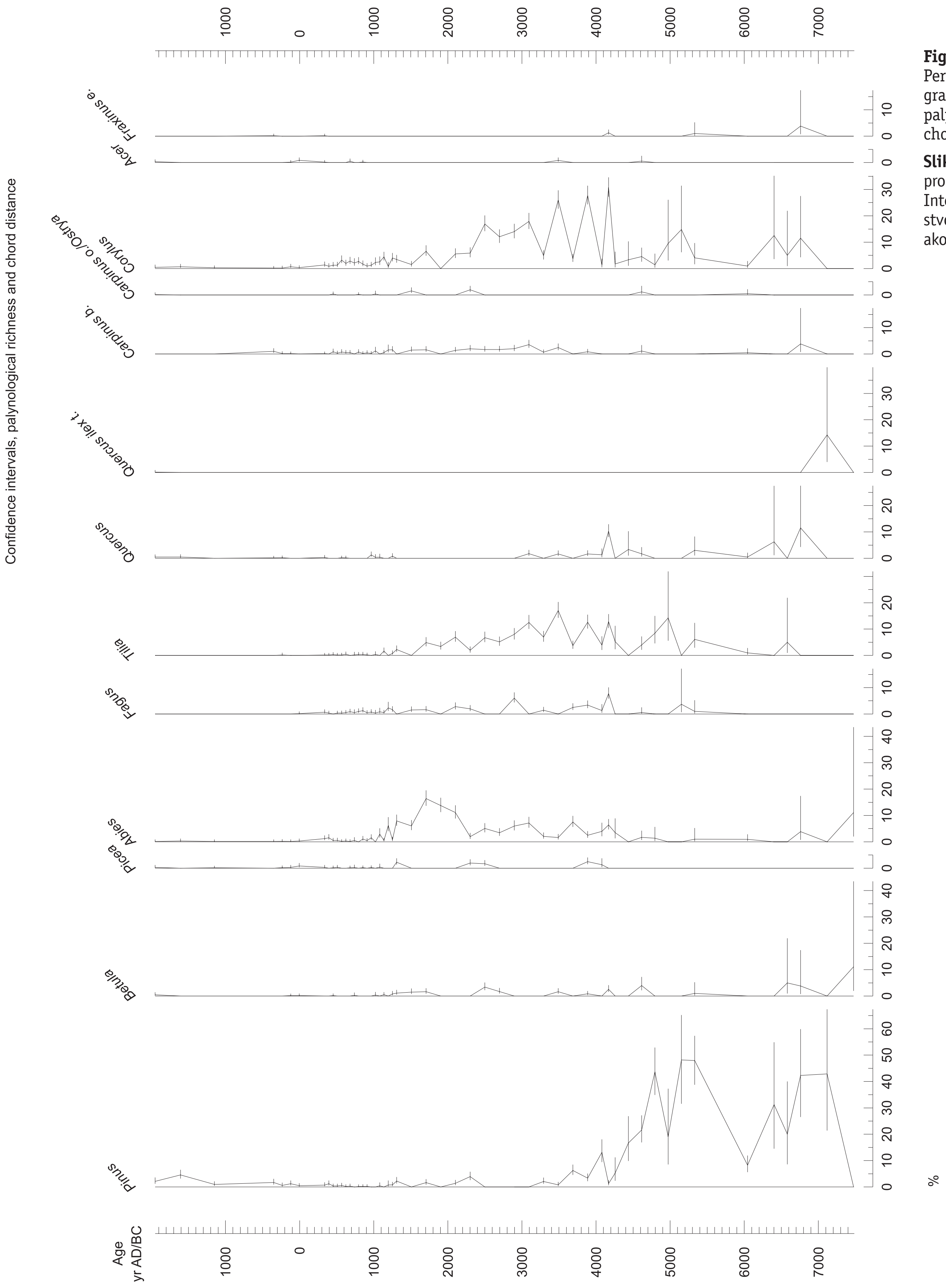
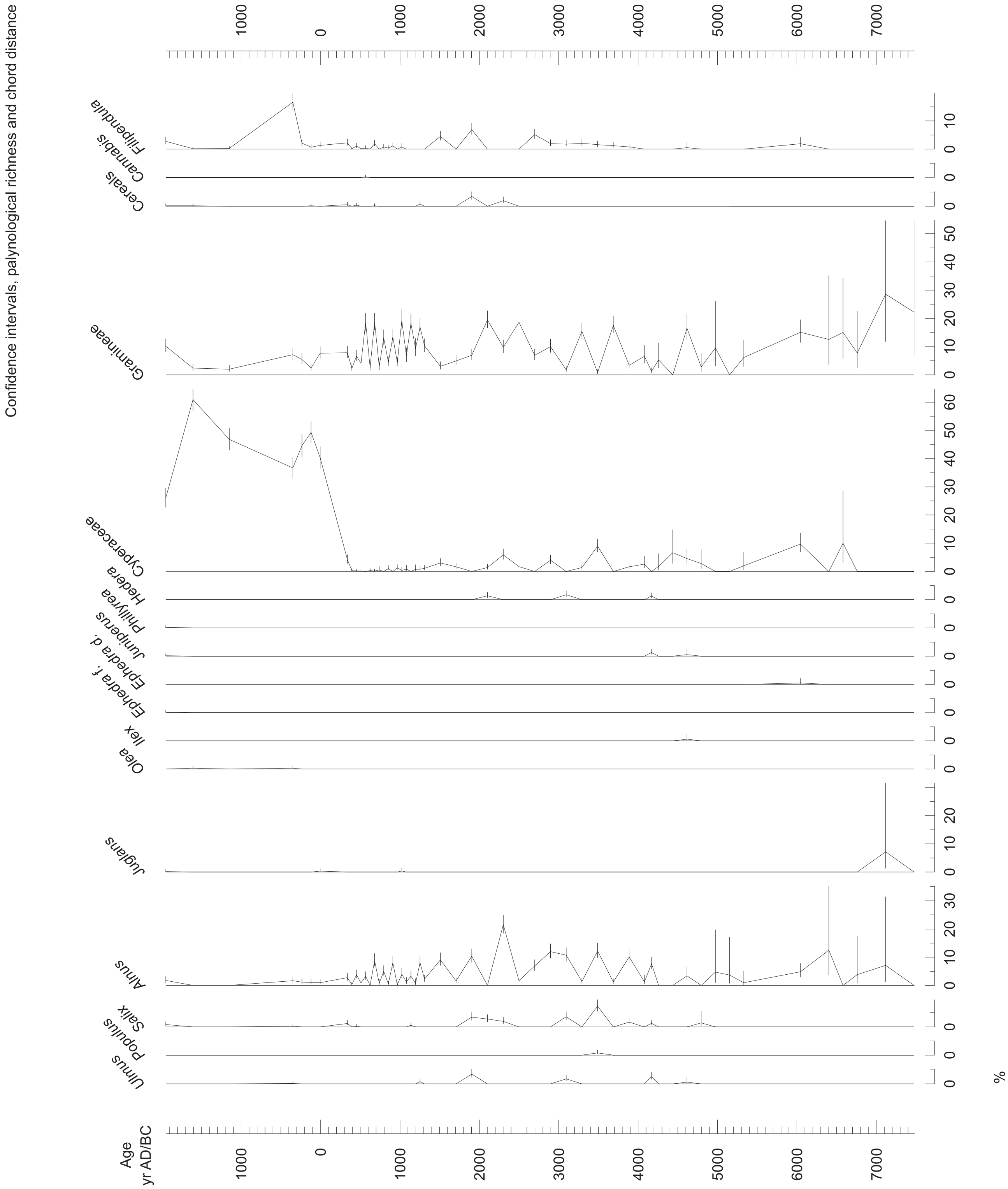
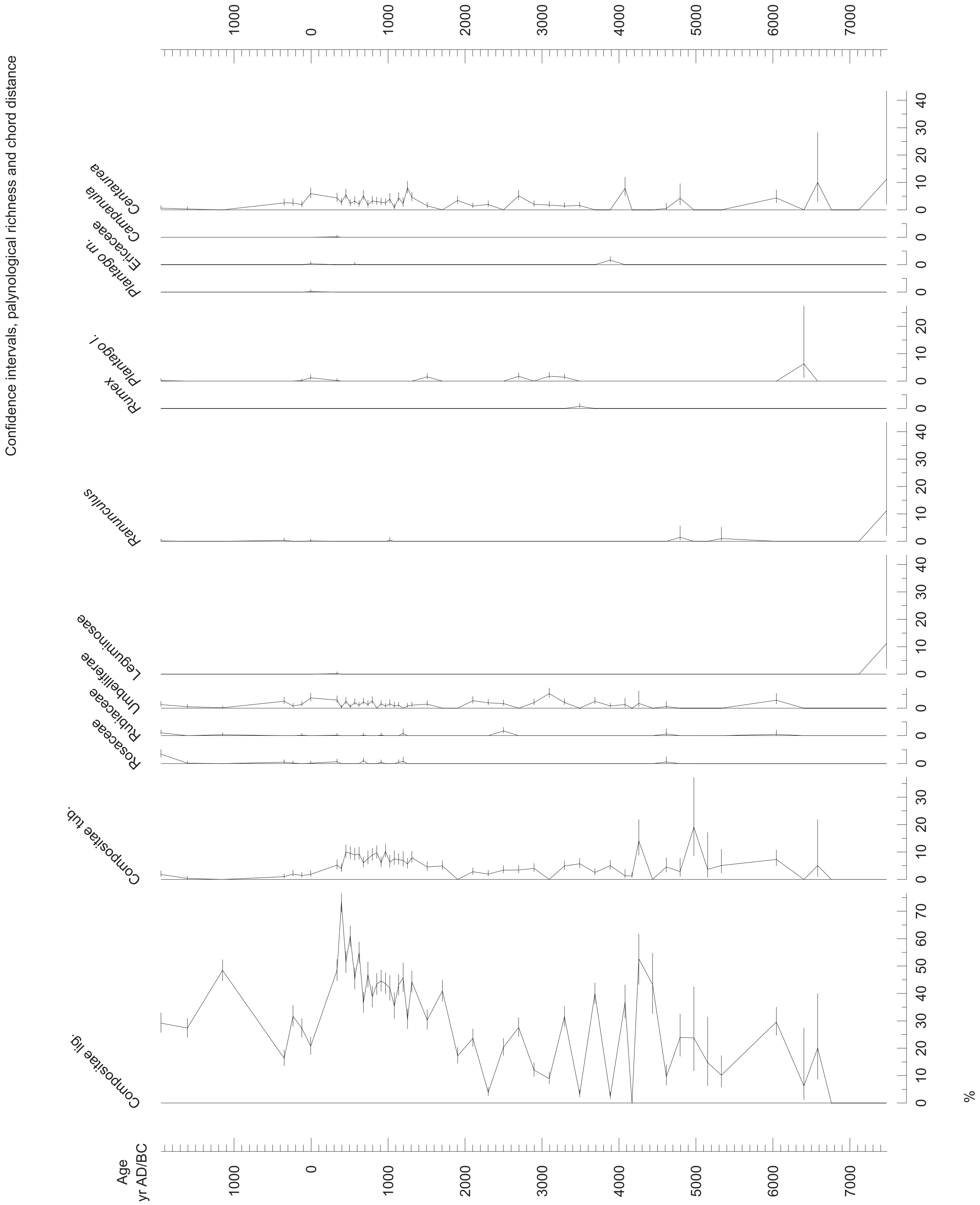
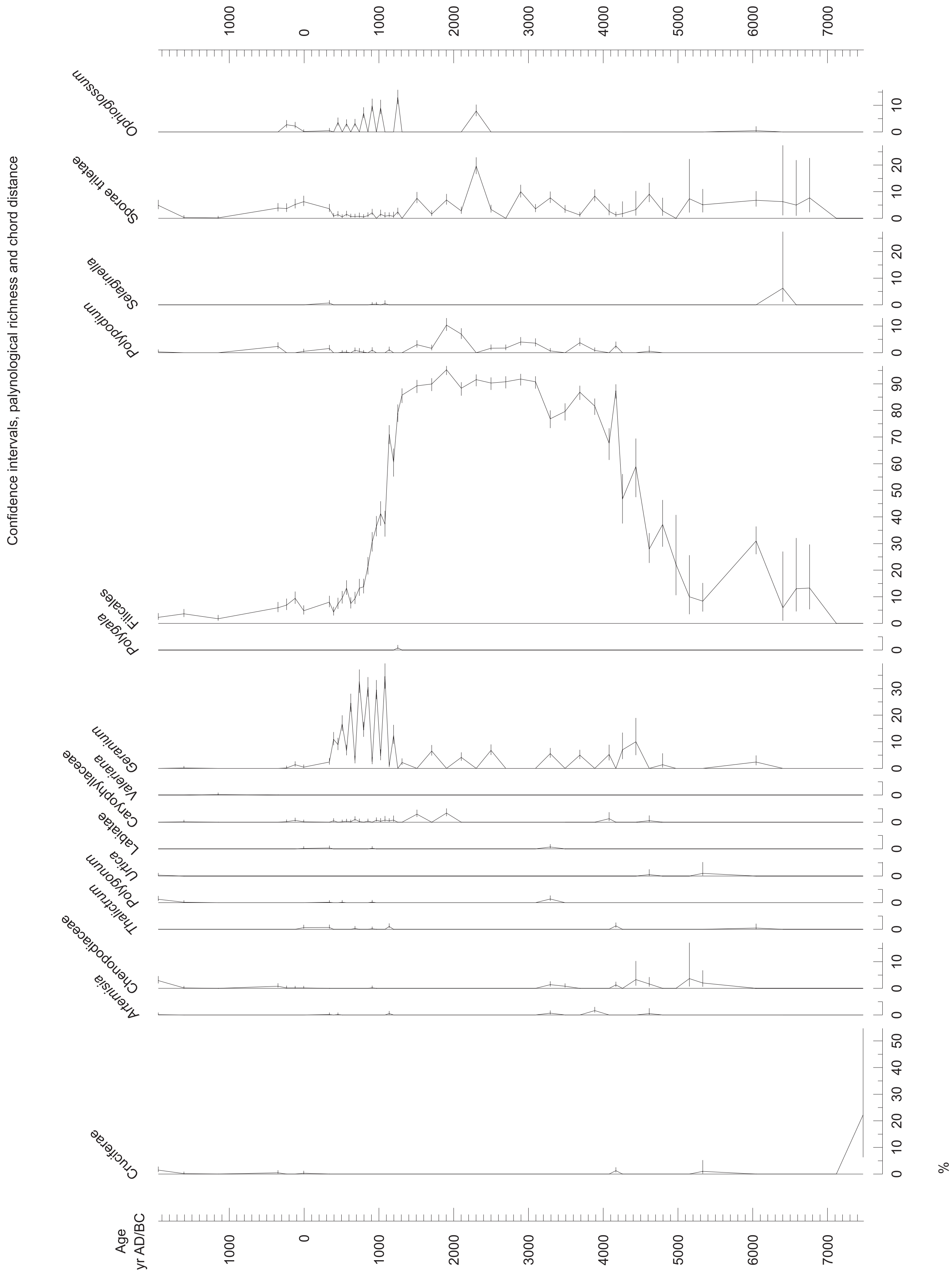


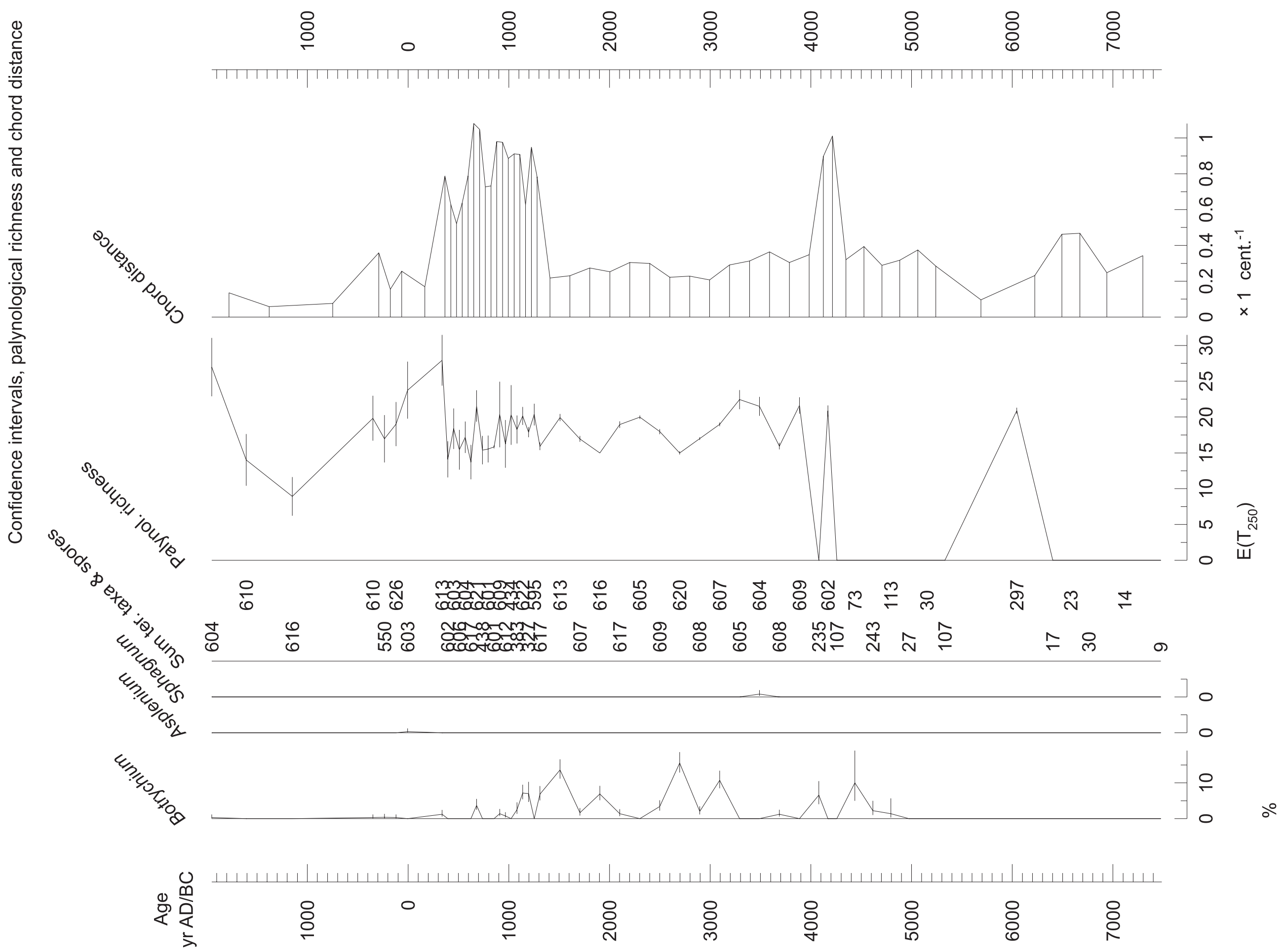
Figure 2.10. Prapoče: Percentage pollen diagram. Confidence intervals, palynological richness and chord distance.

Slika 2.10 Prapoče: dijagram procentualnog udjela peluda. Intervali pouzdanosti, bogatstvo polena i udaljenost akorda.


Confidence intervals, palynological richness and chord distance
Age
yr AD/BC
1000
0
1000
2000
3000
4000
5000
6000
7000
Ulmus
Populus
Salix
Alnus
Juglans
Olea
Ilex
Ephedra f.
Ephedra d.
Juniperus
Phillyrea
Hedera
Cyperaceae
Gramineae
Cereals
Cannabis
Filipendula
%


Confidence intervals, palynological richness and chord distance
Centaurea
Campanula
Ericaceae
Plantago m.
Plantago l.
Rumex
Ranunculus
Leguminosae
Umbelliferae
Rubiaceae
Rosaceae
Composiae tub.
Composite lig.
Age
yr AD/BC
%


Confidence intervals, palynological richness and chord distance
Ophioglossum
Sporae triletae
Selaginella
Polypodium
Filicales
Polygala
Geranium
Valeriana
Caryophyllaceae
Labiatae
Urtica
Polygonum
Thalictrum
Chenopodiaceae
Artemisia
Cruciferae
Age
yr AD/BC
%


Confidence intervals, palynological richness and chord distance
Chord distance
Palynol. richness
Sum ter. taxa & spores
Sphagnum
Asplenium
Botrychium
Age
yr AD/BC
× 1 cent.-1
E(T250)
%

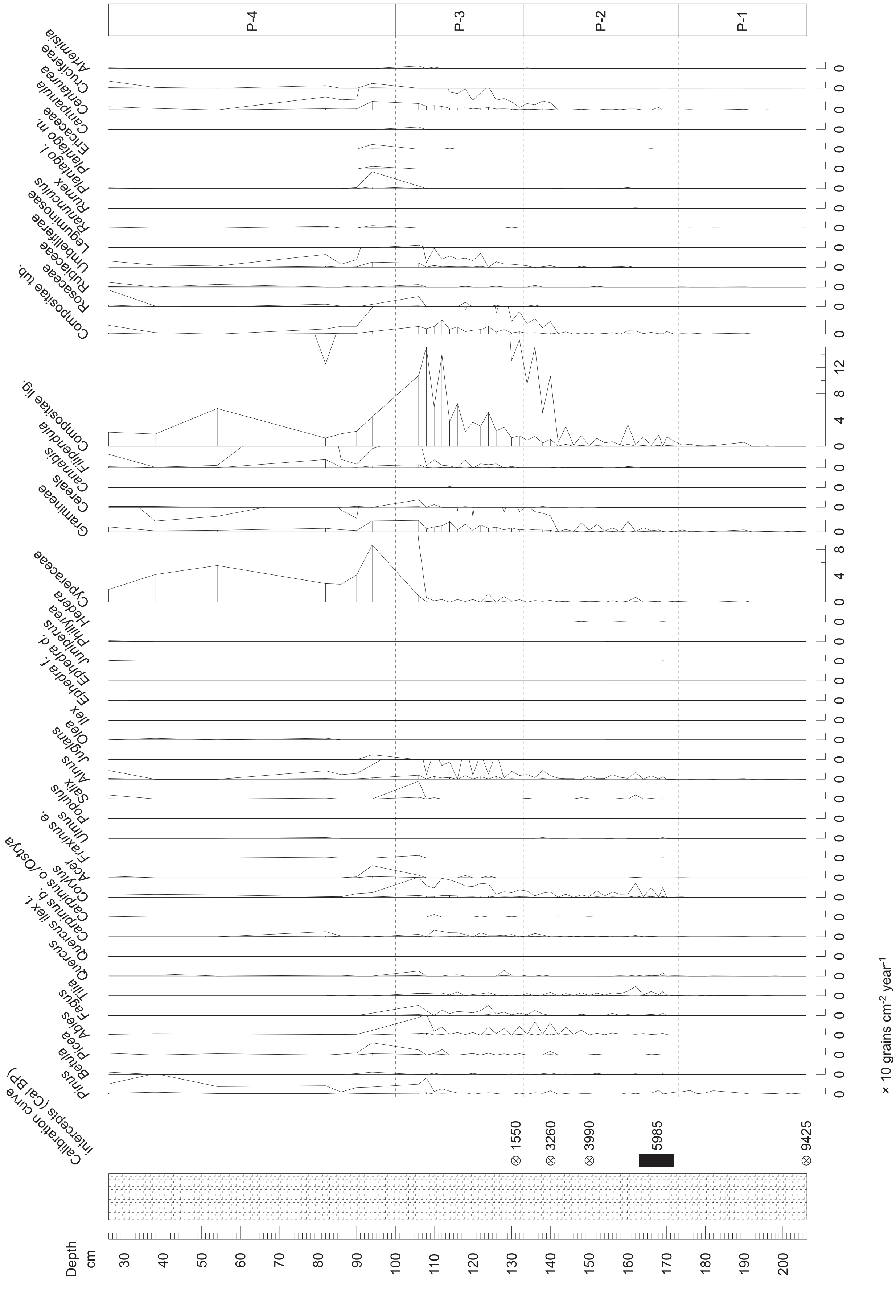
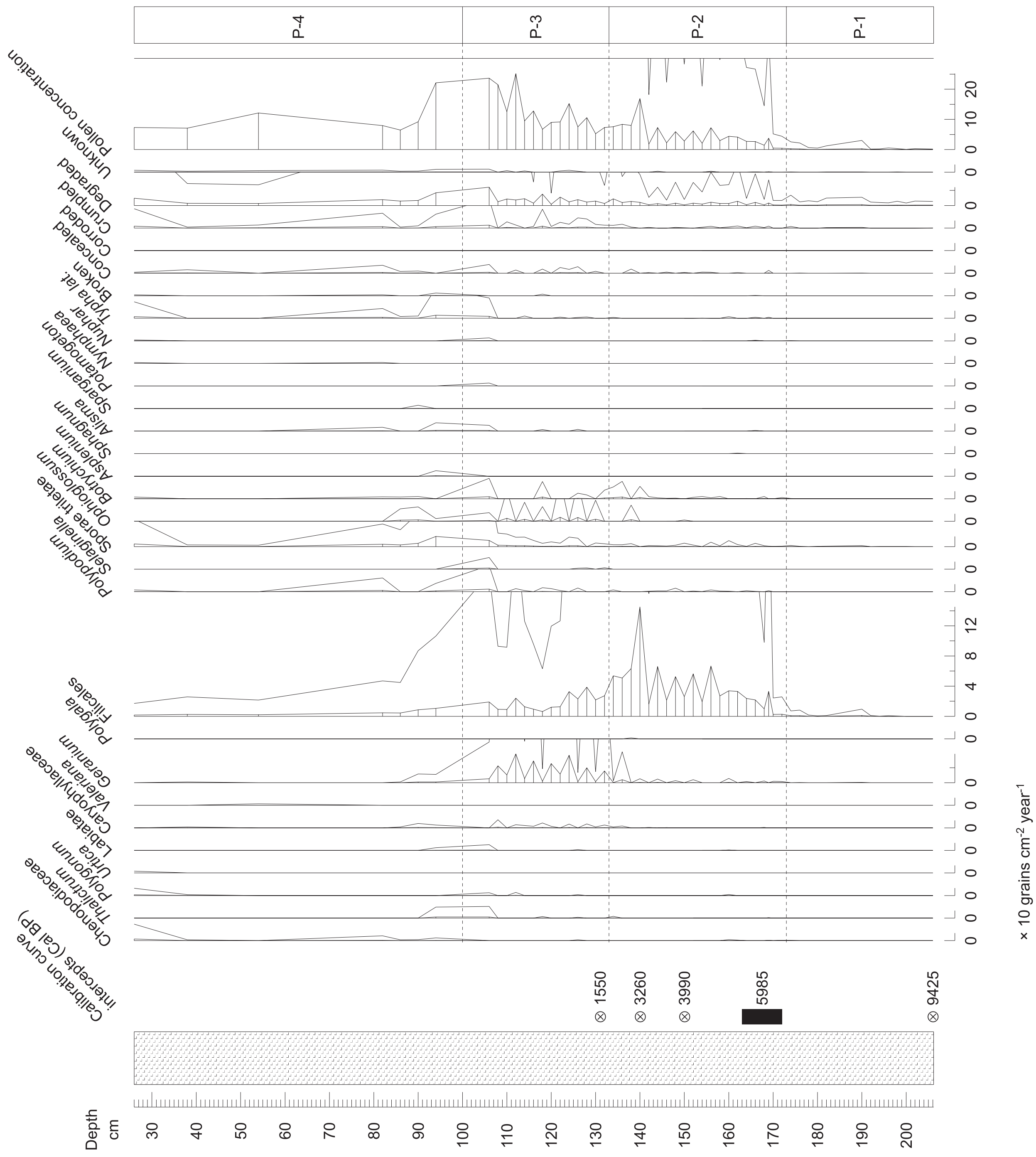


Figure 2.11. Prapoče: Pollen influx diagram. "⊗" marks position of 0.5-cm section of core for AMS ^{14}C date; "☐" marks position of 9-cm section of core for AMS ^{14}C date.

Slika 2.11 Prapoče: dijagram unosa peluda. "⊗" označava položaj odsječaka jezgre dužine 0.5 cm uzetih za AMS ^{14}C datiranje; "☐"označava položaj 9 cm odsječka jezgre uzetog za AMS ^{14}C datiranje.



P-4
P-3
P-2
P-1
Pollen concentration
Unknown
Degraded
Crumpled
Corroded
Concealed
Broken
Typha lat.
Nuphar
Nymphaea
Potamogeton
Sparganium
Alisma
Sphagnum
Asplenium
Botrychium
Ophioglossum
Sporae trilete
Selaginella
Polypodium
Filicales
Polygala
Geranium
Valeriana
Caryophyllaceae
Labiatae
Urtica
Polygonum
Thalictrum
Chenopodiaceae
Calibration curve intercepts (Cal BP)
1550
3260
3990
5985
9425
× 10 grains cm-2 year-1
Depth cm
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

on Figure 2.12. Axis 1 and 2 account for 39% and 18%, respectively, of the total variance in the dataset. The main direction of variance on the first axis is between herbaceous types (*e.g. Compositae liguliflorae, Gramineae, Compositae tubuliflorae, Centaurea*), sedges *(Cyperaceae)*, pine *(Pinus)*, oak *(Quercus)*, charcoal and monolete fern spores *(Filicales)*, lime *(Tilia)*, fir *(Abies)*, and hazel *(Corylus)*. The main direction of variance on the second axis is between pine *(Pinus)* and some herbaceous types *(Compositae liguliflorae, Geranium, Filicales)*.

The sample scores have also been plotted and the points (each point on the diagram represents one sample) were connected in chronological order (Figure 2.13). Axis 1 and 2 account for 58% and 12%, respectively, of the total variance in the dataset. The main direction of variance on the first axis is between samples from the top of the core (dated after 1000 AD) and mid-Holocene samples. The main direction of variance on the second axis is between early Holocene samples and samples dated between *ca.* 100 Cal. BC – 850 AD.

zastupljenošću (barem 5% od ukupnog zbroja peluda), a rezultati su predstavljeni na slici 2.12. Osi 1 i 2 objašnjavaju 39%, odnosno 18% od ukupne varijance podataka. Prva glavna komponenta zasićena je zeljastim biljnim tipovima (*e.g. Compositae liguliflorae, Gramineae, Compositae tubuliflorae, Centaurea*), šaševima *(Cyperaceae)*, borom *(Pinus)*, hrastom *(Quercus)*, drvenim ugljenom i monoletnim sporama paprati *(Filicales)*, lipom *(Tilia)*, jelom *(Abies)* i lijeskom *(Corylus)*. Druga glavna komponenta zasićena je borom *(Pinus)* i nekim zeljastim biljnim tipovima *(Compositae liguliflorae, Geranium, Filicales)*.

Vrijednosti za pojedine uzorke prikazane su dijagramom (slika 2.13) na kojem svaka točka predstavlja po jedan uzorak, a spojene su kronološkim redom. Osi 1 i 2 objašnjavaju 58%, odnosno 12% ukupne varijance podataka. Prva glavna komponenta zasićena je uzorcima s vrha jezgre (datiranih nakon 1000. godine po Kr.) i uzorcima iz sredine holocena. Druga glavna komponenta zasićena je uzorcima iz ranog holocena i uzorcima datiranim oko 100. pr. Kr. (kalibrirano) – 850. po Kr.

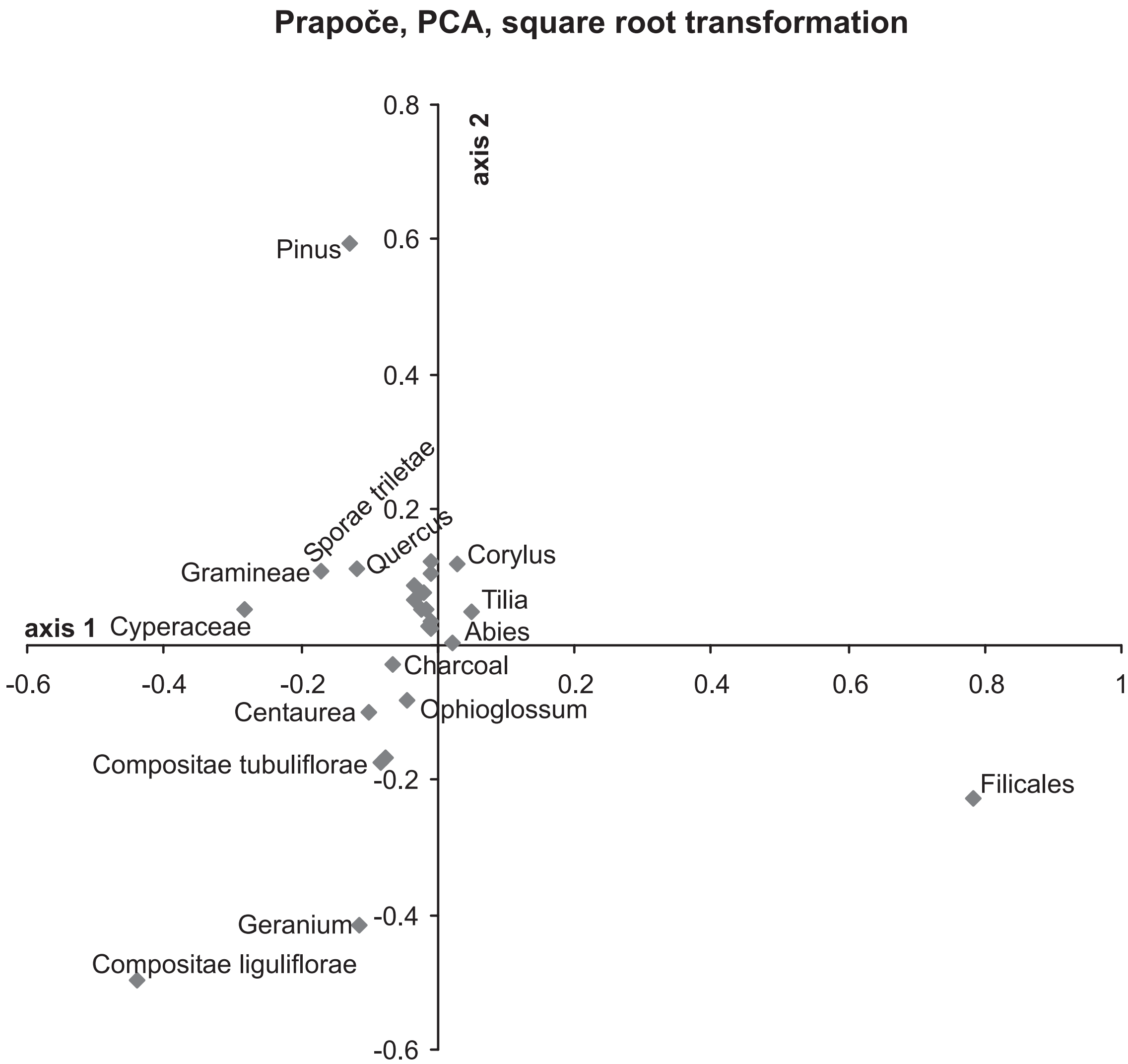


Figure 2.12. Prapoče: PCA. Axes 1 and 2 account for 39.6% and 18.2% of the total variance in the dataset. (The unlabelled points in the middle of the diagram are scores for *Betula, Quercus ilex type, Alnus, Juglans, Filipendula, Leguminosae, Ranunculus, Plantago l., Cruciferae and Selaginella*.)

Slika 2.12 Prapoče: PCA. Osi 1 i 2 objašnjavaju 39,6% i 18,2% od ukupne varijance. (Neoznačene točke pri sredini dijagrama rezultati su vrijednosti ua *Betula*, tip *Quercus ilex*, *Alnus, Juglans, Filipendula, Leguminosae, Ranunculus, Plantago l., Cruciferae* i *Selaginella*.)

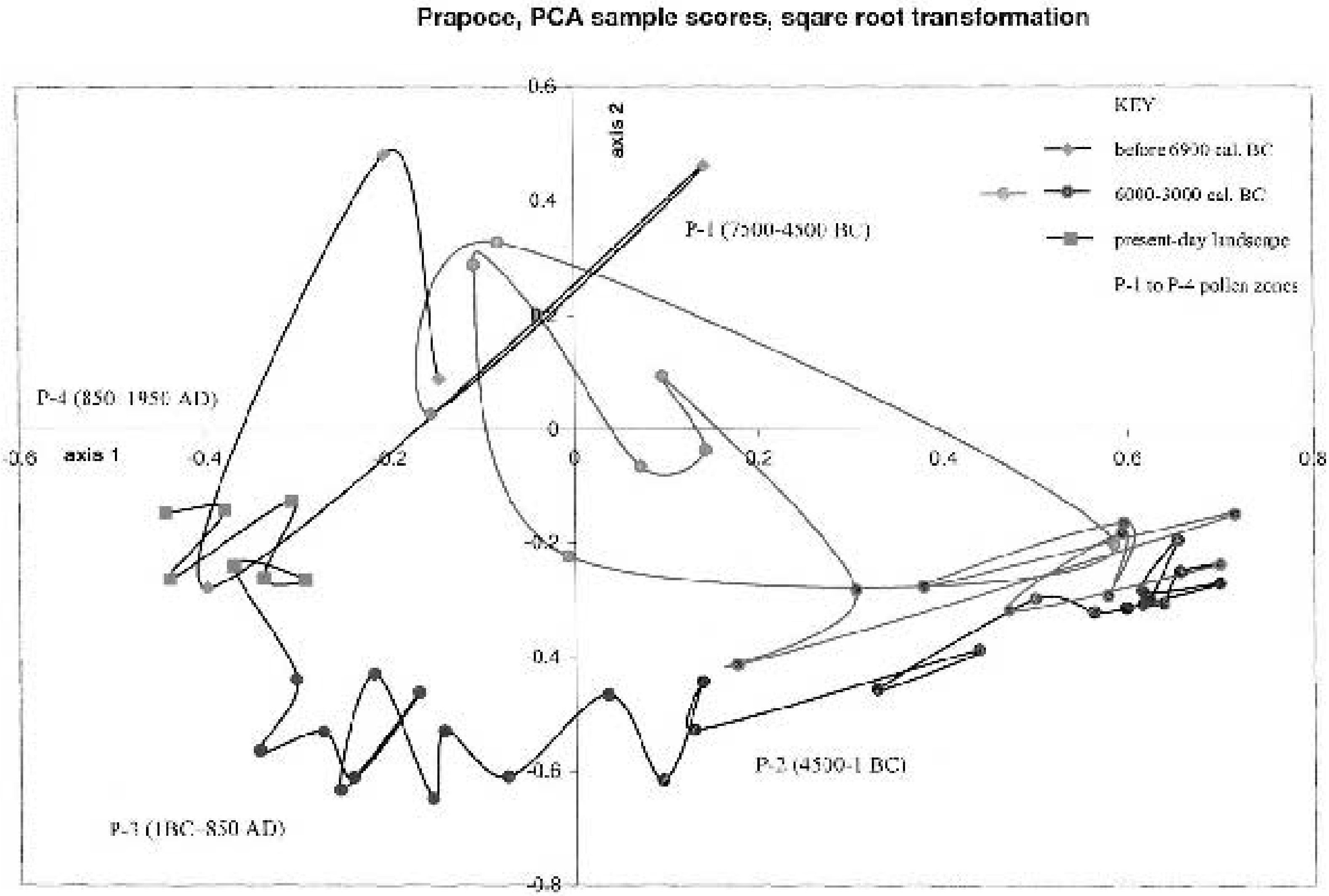


Figure 2.13. Prapoče: PCA sample scores.

Slika 2.13 Prapoče: PCA vrijednosti uzoraka.

2.4 The Holocene Vegetation in the Prapoče area

In the early Holocene (7500–4500 Cal. BC) Prapoče area was probably surrounded by woodland of pine, oak, lime and hazel. Due to the low pollen concentration and high percentage of degraded pollen grains it is difficult to estimate whether the pollen record reflects the real vegetation composition or postdepositional preservation due to a selective degradation. The pollen sum in most levels does not exceed 250, confidence intervals for pollen counts are wide (Figure 2.10) and vegetation composition cannot be discussed in detail. Degraded pollen and low pollen concentration might indicate a warm and dry climate in the early Holocene. Pollen survival tends to be poor in dry, aerobic conditions with high microbial activity in the sediment (Moore *et al.* 1991). Loss-on-ignition and geochemical results support this suggestion. The concentration of calcium (Ca) in the sediment depends on the temperature (Cole 1979; Williams *et al.* 1998). Increased temperature and pro-

2.4. Holocenska vegetacija na području Prapoča

U ranom holocenu (7500. – 4500. pr. Kr. [kalibrirano]), područje Prapoča bilo je vjerojatno okruženo šumama bora, hrasta, lipe i lijeske. Zbog niske koncentracije peluda i velikog postotka degradiranih peludnih zrnaca, teško je procijeniti odražava li građa stvarni sastav vegetacije ili je posljedica selektivne degradacije peluda nakon odlaganja. Ukupni zbroj peluda u većini razina ne prelazi 250, intervali pouzdanosti za broj peludnih zrnaca su široki (slika 2.10) pa ne možemo podrobno raspravljati o sastavu vegetacije. Degradacija i niska koncentracija peluda mogli bi upućivati na toplu i suhu klimu za ranog holocena. Pelud se obično loše čuva u suhim, aerobnim uvjetima, u taložini s velikom aktivnošću mikroorganizama (Moore *et al.* 1991). Analize gubitka mase žarenjem i geokemijski rezultati podupiru ovu pretpostavku. Koncentracija kalcija (Ca) u taložini ovisi o temperaturi (Cole 1979; Williams *et al.* 1998). Povećana temperatura i postupno isparavanje gressive evaporation of the lake water could cause the precipitation of calcium carbonate into the sediment. In the section of the core dated between *ca*. 8000–5500 Cal. BC the concentration of carbonates (10–20% of the sediment dry weight, Figure 2.6) and calcium (60–120 mg per kg, Figure 2.7) is higher than in the upper part of the core and might indicate relatively more arid conditions before 5500 Cal. BC than after this date. Our results match with palaeoecological research on the island of Mljet (southern Dalmatia), where the pollen record and the concentration of pigments in the sediment suggest that between *ca*. 6000–4400 Cal. BC the climate on the eastern Adriatic coast was dry (Jahns & van den Bogaard 1998).

An increase of iron (Fe), which followed at *ca*. 5000–4500 Cal. BC was probably caused by changes of redox conditions due to waterlogging of the basin. Under oxidising conditions iron has, similar to manganese (Mn) very low solubility. It only becomes mobile under reducing conditions. The difference between the two elements is that manganese can become mobile already under moderately anaerobic conditions. When anaerobic conditions in the soil surrounding the basin increase, manganese is washed out of the soil before iron (Mackereth 1966; Engstrom & Wright 1984). The low values of the Fe:Mn ratio before the iron peak on the diagram (Figure 2.7) therefore suggest that the valley gradually became waterlogged at *ca*. 5000 Cal. BC. The fluctuation of the iron and Fe:Mn ratio curves after 5000 Cal. BC indicate that the redox conditions in the basin were fluctuating.

In the section of the core dated after 4500 Cal. BC the percentage of degraded pollen grains declines and pollen concentration increases to 2000–6000 grains per 1 cm^3 of the sediment (Figure 2.9). This indicates that the pollen record in this section of the core is reliable and pollen composition was probably not changed due to selective preservation. Here a rather low pollen concentration is most likely a consequence of sedimentation rate and vegetation composition.

The vegetation growing in the Prapoče area between 4500 and 2000 Cal. BC was probably an open forest of lime, oak, beech, fir, hornbeam, hop hornbeam, and hazel. Alder and willow were growing in the marshy areas in the bottom of the valley. High percentages of hazel (5–25%) and herb pollen (20–60%) suggest that open areas, presumably meadows and fields, were located in the vicinity of the coring location. Several lines of evidence suggest that human activity in the area might be the reason for this forest thinning. The charcoal record detects regular, small-scale burning of the landscape, and several 'anthropogenic indicators' *(Plantago l., Centaurea, Artemisia, Chenopodiaceae)* appear on the pollen diagram. The poor pollen preservation at the bottom of the core does not allow one to see how open was the landscape before 4500 Cal. BC and whether these, 'anthropo-

jezerske vode može uzrokovati obaranje kalcijeva karbonata u taložinu. U dijelu jezgre datiranom otprilike između 8000. – 5500. pr. Kr. (kalibrirano), koncentracija karbonata (10 – 20% težine suhe taložine, slika 2.6) i kalcija (60 – 120 mg po kilogramu, slika 2.7) veća je nego u gornjem dijelu jezgre, te možda upućuje na relativno suše uvjete prije 5500. pr. Kr. u usporedbi s kasnijim razdobljima. Naši rezultati podudaraju se s paleoekološkim istraživanjem na otoku Mljetu (u južnoj Dalmaciji), gdje peludne analize i koncentracija pigmenata u taložini ukazuju da je otprilike između 6000. – 4400. pr. Kr. (kalibrirano) klima duž istočne obale Jadrana bila suha (Jahns & van den Bogaard 1998).

Povećanje udjela željeza (Fe), koje je uslijedilo otprilike nakon 5000. – 4500. pr. Kr. (kalibrirano), vjerojatno je posljedica promjena redukcijsko-oksidacijskh uvjeta do kojih je došlo zbog zasićenja bazena vodom. Željezo, slično kao i mangan (Mn), u oksidacijskim je uvjetima vrlo slabo topivo. Postaje pokretljivo tek u redukcijskim uvjetima. Razlika između ta dva elementa jest da mangan može postati pokretljiv već u umjereno anaerobnim uvjetima. Kada u tlu koje okružuje bazen ojačaju anaerobni uvjeti, mangan će biti ispran iz tla prije željeza (Mackereth 1966; Engstrom & Wright 1984). Prema tome, niske vrijednosti omjera Fe/Mn prije maksimuma željeza na dijagramu (slika 2.7) upućuju da je oko 5000. pr. Kr. (kalibrirano) dolina bila postupno zasićena vodom. Kolebanje krivulja za željezo i omjer Fe/Mn nakon 5000. pr. Kr. (kalibrirano) upućuje na kolebljivost redukcijsko-oksidacijskih uvjeta u udolini.

U odsječku jezgre datiranom nakon 4500. pr. Kr. (kalibrirano), postotak degradiranih peludnih zrnaca opada, a koncentracija peluda raste na 2000 do 6000 zrna po 1 cm^3 taložine (slika 2.9). To ukazuje da je građa u tom odsječku jezgre pouzdana te da sastav peluda vjerojatno nije izmijenjen selektivnom očuvanošću. Ovdje je niska koncentracija peluda vjerojatno posljedica brzine taloženja i sastava vegetacije.

Vegetacija koja je rasla na području Prapoča između 4500. i 2000. pr. Kr. (kalibrirano) vjerojatno je bila rijetka šuma lipe, hrasta, bukve, jele, crnog i bijelog graba te lijeske. Joha i vrba rasle su u močvarnim dijelovima u dnu doline. Visoka procentualna zastupljenost peluda lijeske (5 – 25%) i zeljastog bilja (20 – 60%) ukazuje da su se u blizini mjesta na kojem je provedeno jezgrovanje nalazila otvorena područja, vjerojatno livade i polja. Nekoliko različitih izvora podataka ukazuje da je uzrok prorjeđivanju šume u tom području mogla biti ljudska aktivnost. Prikupljena građa drvenog ugljena svjedoči o učestalim spaljivanjima krajolika manjih razmjera, a u peludnom dijagramu pojavljuje se nekoliko 'antropogenih indikatora' *(Plantago l., Centaurea, Artemisia, Chenopodiaceae)*. Slaba očuvanost peluda pri dnu jezgre ne dopušta procjenu otvorenosti krajolika prije 4500. pr. Kr. (kalibrirano), kao niti odgovor genic indicators' were also growing in the 'natural' early and mid Holocene landscape. The present-day habitat of many species from *Chenopodiaceae, Centaurea* and *Artemisia* family are dry, rocky places in the Submediterranean region (Martinčič *et al.* 1999), and it is possible that they were growing in similar habitats also in the middle Holocene. The first cereal type pollen grains appear at *ca.* 2100 Cal. BC. Cereal pollen production is low and pollen does not spread far from the plant (Behre 1988; Rösch 2000); therefore, they indicate that Eneolithic/Bronze Age fields and/or sites must have been located in the vicinity of the coring location. Since the beginning of the second millennium BC human pressure on the environment started to increase. The amount of tree pollen declined and a change in forest composition occurred at 2000–1500 Cal. BC, when fir became more numerous. The reason for this increase of fir might be climate (increased precipitation, similar increase of fir appears on the Mlaka site in south-eastern Slovenia between 2000 and 100 cal BC, Andrič 2001a, 2001b) and/or development of metallurgy (more beech was cut for fuel, similarly as suggested for Hungary, Willis *et al.* 1998). Despite this change in the forest composition the areas covered by forest diminished and the present-day landscape formed already at the beginning of the 1st Millennium BC.

Earlier it has been argued that due to poor pollen preservation in the early Holocene section of the core, the vegetation composition in the Prapoče area cannot be reconstructed in detail. Nevertheless, the pollen record, in combination with archaeological data, does give us some information about Mesolithic and Neolithic landscape. The seven Mesolithic sites investigated to date (Miracle 1997; Miracle *et al.* 2000; Miracle & Forenbaher 2000) in north-eastern Istria are all located within 15 km radius from the Prapoče site. Radiocarbon dates from Mesolithic levels in cave sites range from *ca.* 9500 to 7000 Cal. BC (*ca.* 11500–9000 Cal. BP). Rich faunal remains suggest that the main hunting animals during the Early Holocene were red deer *(Cervus elaphus)*, roe deer *(Capreolus capreolus)*, and wild boar *(Sus scrofa)*, with rare chamoix/ibex *(Rupicapra/Capra)* and aurochs *(Bos primigenius)* (Miracle 1997, 2001; Miracle & Forenbaher 2000, Miracle *et al.* 2000).

These faunal and charcoal remains are important since they give indirect information about the early Holocene vegetation in the Prapoče area. Grass is an important part of the diet of red deer and wild boar and the aurochs are specialised grass eaters (Vera 2000). Several authors have even argued that the impact of large grazers on the vegetation was significant (Kuiters & Kirby 1999; Bradshaw & Mitchell 1999), and the lowlands of central and western Europe were a park-like landscape throughout the Holocene (Vera 2000). Therefore it is possible that the early Holocene vegetation had significant openings.

na pitanje jesu li navedeni 'antropogeni indikatori' rasli već i u 'prirodnom' krajoliku ranog i srednjeg holocena. Današnja staništa brojnih vrsta iz porodica *Chenopodiaceae, Centaurea* i *Artemisia* su suhi, stjenoviti položaji u submediteranskoj regiji (Martinčič *et al.* 1999) pa je moguće da su te vrste rasle na sličnim staništima i sredinom holocena. Prva zrna peluda žitarica pojavljuju se oko 2100. pr. Kr. (kalibrirano). U žitarica je proizvodnja peluda niska, a pelud se ne širi daleko od biljke (Behre 1988; Rösch 2000), stoga spomenuta zrnca peluda upućuju na postojanje bakrenodobnih ili brončanodobnih polja ili nalazišta u blizini mjesta na kojem je provedeno jezgrovanje. Od početka drugog tisućljeća pr. Kr. počinje rasti pritisak čovjeka na okoliš. Količina peluda drveća se smanjuje, a oko 2000. do 1500. pr. Kr. (kalibrirano) dolazi do promjene sastava šuma (jele postaju brojnije). Porast udjela jele mogao je biti uvjetovan klimom (više oborina; do sličnog povećanja udjela jele dolazi na nalazištu Mlaka u jugoistočnoj Sloveniji između 2000. i 100. pr. Kr. [kalibrirano] (Andrič 2001a, 2001b) ili razvojem metalurgije (više je bukve sječeno za gorivo, slično kao što je zabilježeno u Mađarskoj, Willis *et al.* 1998). Unatoč ovoj promjeni u sastavu šume, pošumljena područja su se smanjila, a današnji krajolik nastao je već početkom prvog tisućljeća pr. Kr.

Ranije je navedeno da se, zbog slabe očuvanosti peluda u ranoholocenskom dijelu jezgre, sastav vegetacije na području Prapoča ne može podrobno rekonstruirati. Unatoč tome, navedena građa, zajedno s arheološkim podacima, ipak pruža ponešto informacija o mezolitičkom i neolitičkom Svih sedam do danas istraživanih mezolitičkih nalazišta sjeveroistočne Istre (Miracle 1997; Miracle *et al.* 2000; Miracle & Forenbaher 2000) nalaze se unutar udaljenosti od 15 km od Prapoča. ^{14}C datumi mezolitičkih slojeva špiljskih nalazišta kreću se u rasponu od oko 9500. – 7000. pr. Kr. (kalibrirano) (oko 11500. – 9000. prije sadašnjosti, kalibrirano). Bogati ostaci životinja ukazuju da su za ranog holocena glavne lovne životinje bile jelen *(Cervus elaphus)*, srna *(Capreolus capreolus)* i divlja svinja *(Sus scrofa)*, a tek rijetko divokoza *(Rupicapra/Capra)* i pragovedo *(Bos primigenius)* (Miracle 1997, 2001; Miracle & Forenbaher 2000, Miracle *et al.* 2000).

Ti ostaci životinja i drvenog ugljena važni su jer pružaju posredne informacije o vegetaciji ranog holocena na području Prapoča. Trava je važan dio ishrane jelena i divljih svinja, a pragoveda su specijalizirani travojedi (Vera 2000). Nekoliko je autora, dapače, tvrdilo da je utjecaj velikih travojeda na vegetaciju bio značajan (Kuiters & Kirby 1999; Bradshaw & Mitchell 1999) te da su nizinski dijelovi srednje i zapadne Evrope za čitavog holocena nalikovali na parkove (Vera 2000). Moguće je stoga da je u ranoholocenskoj vegetaciji bilo značajnih otvorenih područja.

Was the early Holocene vegetation in Istria and the Trieste Karst an open, pine-dominated woodland? Among macrobotanical remains, pine charcoal dominates in Early Holocene assemblages of Pupićina cave until at least *ca*. 9700 Cal. BP (*ca*. 7700 Cal. BC, Miracle 1997; William Fletcher, personal communication; Fletcher & Madella, Chapter 10). Similarly, in the Edera cave on the Trieste karst the percentage of pine *(Pinus sylvestris/montana)* in the charcoal assemblages dated to *ca*. 7000 Cal. BC (*ca*. 9000 Cal. BP) is *ca*. 67% (Nisbet 2000). Pine *(Pinus)* is also the most common pollen found in the early Holocene (degraded) section of the Prapoče core (Figure 2.9). Recent palaeobotanical research thus suggests that pine was growing in Ćićarija and the Trieste Karst during the early Holocene. These results, however, do not allow an estimation of the frequency of pine trees in early Holocene forests. The charcoal composition on an archaeological site could reflect the human selection of the wood and might not agree with the vegetation composition (Fletcher & Madella, Chapter 10). Likewise, with pollen, individual pine *(Pinus sylvestris,* L.*)* trees could grow on shallow, sandy soils near the study site. It is also possible that high percentage of pine pollen in the early Holocene section of Prapoče core is a consequence of selective pollen degradation. Therefore a new palynological site with better preserved early Holocene sediments is needed to allow a more detailed vegetation reconstruction.

The comparison of Holocene vegetation development with the archaeological settlement pattern is difficult because to date no systematic archaeological excavations of open-air Neolithic, Bronze or Iron Age sites have been carried out in the vicinity of the Prapoče village. Archaeological reports from the beginning of the 20th century mention several prehistoric fortified settlements in the area (Benussi 1927–28; Marchesetti 1903). The pollen record suggests that the area was densely inhabited since the Late Bronze Age, when human pressure on the environment increased and the present-day landscape formed.

2.5 Conclusions

The results from this research suggest that in the early and middle Holocene (7500–4500 Cal. BC) the Prapoče valley and surrounding hillslopes were probably covered by open woodland. Poor pollen preservation in this section of the core does not allow more detailed reconstruction of the vegetation composition and development. Tree taxa present in the region were pine, lime, oak, and hazel. For the period after 4500 Cal. BC the pollen record is reliable and suggests that the vegetation growing in the Prapoče area was probably open, predominantly lime

Je li ranoholocenska vegetacija Istre i tršćanskog Krasa bila rijetka šuma u kojoj prevladava bor? Drveni ugljen bora prevladava među makrobotaničkim ostacima ranoholocenskih skupova nalaza iz Pupićine peći barem do oko 9700. prije sadašnjosti, kalibrirano (oko 7700. pr. Kr. [kalibrirano], Miracle 1997; William Fletcher, osobno priopćenje; Fletcher & Madella, 10. poglavlje). Slično tome, u špilji Edera u tršćanskom Krasu postotak bora *(Pinus sylvestris/montana)* u skupovima nalaza ugljena datiranim oko 7000. pr. Kr. (kalibrirano; oko 9000. prije sadašnjosti, kalibrirano) je oko 67% (Nisbet 2000). U ranoholocenskom (degradiranom) dijelu jezgre iz Prapoča također je najčešći pelud bora *(Pinus)* (slika 2.9). Nedavna paleobotanička istraživanja ukazuju, dakle, da je bor rastao na Ćićariji i u tršćanskom Krasu za ranog holocena. Ovi rezultati ne dopuštaju, međutim, procjenu učestalosti borova u šumama ranog holocena. Sastav ugljena na arheološkim nalazištima može odražavati ljudski odabir drva i ne mora se podudarati sa sastavom vegetacije (Fletcher & Madella, 10. poglavlje). Slično tome, kad se radi o peludu, pojedinačna stabla borova *(Pinus sylvestris,* L.*)* mogla su rasti na plitkim, pjeskovitim tlima u blizini proučavanog lokaliteta. Moguće je i to da je velik postotak peluda bora u ranoholocenskom dijelu jezgre iz Prapoča posljedica selektivne degradacije. Zbog toga bi trebalo pronaći novo nalazište s bolje očuvanim ranoholocenskim taložinama što bi omogućilo detaljniju rekonstrukciju vegetacije.

Usporedba razvoja holocenske vegetacije s prostornim razmještajem arheoloških naselja teško je provediva, jer do danas u blizini zaseoka Prapoče nisu provođena sustavna arheološka iskopavanja neolitičkih, brončanodobnih ili željeznodobnih nalazišta na otvorenom. Arheološki izvještaji s početka 20. stoljeća spominju u tom području nekoliko pretpovijesnih utvrđenih naselja (Benussi 1927–28; Marchesetti 1903). Peludne analize ukazuju da je ovo područje bilo gusto naseljeno od kasnog brončanog doba, kada se povećao pritisak čovjeka na okoliš te je stvoren krajolik kakav je i danas.

2.5. Zaključci

Rezultati ovog istraživanja ukazuju da su u ranom i srednjem holocenu (7500. – 4500. pr. Kr. [kalibrirano]) dolina Prapoča i okolna brda vjerojatno bila prekrivena rijetkom šumom. Slaba očuvanost peluda u tom odsječku jezgre ne dopušta detaljniju rekonstrukciju sastava i razvoja vegetacije. Od drveća, u regiji su bili prisutni bor, lipa, hrast i lijeska. Za razdoblje nakon 4500. pr. Kr. (kalibrirano) građa je pouzdana te ukazuje da se vegetacija na području Prapoča vjerojatno sastojala od rijetke šume kojom je dominirala lipa.

woodland. Meadows and fields were presumably located in the vicinity of the coring location. Human pressure on the environment increased in the Late Bronze Age when, due to forest clearance and burning, the present-day landscape formed at the beginning of the 1st Millennium BC. The principal components analysis (Figure 2.13) of temporal variation in vegetation composition indicates that the 'Neolithic' landscape was different from 'Late Bronze Age' and present-day landscapes. It is difficult to estimate what was the human impact on the landscape and which changes of the vegetation were triggered by climate, especially because little pollen from the early Holocene, 'natural' vegetation in the area is preserved. Nevertheless, pollen record for the last six millennia suggests that due to forest clearance and burning, the biodiversity of the landscape (measured by palynological richness) increased after the formation of the present-day landscape (Figure 2.10). These results are in accordance with the analysis of charcoal from Pupićina cave suggesting an increase in taxonomic diversity from the Late Neolithic and Bronze Age onwards (Fletcher & Madella, Chapter 10). The reason for this increased biodiversity in the Late Bronze and Iron Age was presumably human impact – the creation of a mosaic environment composed of small patches with different vegetation composition (*sensu* Birks *et al.* 1990; Birks 1990).

U blizini mjesta na kojem je provedeno jezgrovanje vjerojatno su se nalazile livade i polja. Pritisak čovjeka na okoliš povećao se za kasnog brončanog doba kada je, početkom prvog tisućljeća pr. Kr., krčenjem i paljenjem šume nastao krajolik kakav je i danas. Analiza glavnih komponenata (slika 2.13) dijakronijske varijabilnosti sastava vegetacije upućuje da se 'neolitički' krajolik razlikovao od 'kasnobrončanodobnog' i od današnjeg krajolika. Teško je procijeniti kakav je bio utjecaj čovjeka na krajolik, odnosno koje su promjene vegetacije bile izazvane klimom, naročito stoga što je sačuvano tek malo peluda ranoholocenske 'prirodne' vegetacije ovog područja. Unatoč tome, peludna građa koja obuhvaća zadnjih šest tisućljeća ukazuje da se, zbog krčenja i paljenja šume, biološka raznolikost (mjerena bogatstvom peluda) povećala nakon stvaranja današnjeg krajolika (slika 2.10). Navedeni rezultati u skladu su s rezultatima analize drvenog ugljena iz Pupićine peći, koja ukazuju na porast taksonomske raznolikosti od kasnog neolitika i brončanog doba nadalje (Fletcher & Madella, 10. poglavlje). Razlog povećanja biološke raznolikosti za kasnog brončanog doba i željeznog doba vjerojatno je utjecaj čovjeka, odnosno stvaranje mozaičkog okoliša sastavljenog od malih ploha vegetacije različitih sastava (*sensu* Birks *et al.* 1990; Birks 1990).

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