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# The Holocene vegetation dynamics and the formation of Neolithic and present-day Slovenian landscape

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ABSTRACT *– *This paper presents the results of palaeoecological research to investigate the Holocene vegetation development of the Slovenian landscape and the impact of the first farmers upon it. Four study sites were selected and at each site a complete Holocene sedimentary sequence was analysed by using the following techniques: loss-on-ignition, geochemistry, radiocarbon dating, pollen analysis and analysis of micro-charcoal concentration. The results of the study suggest that the Neolithic landscape was probably very dynamic and composed of small patches with different vegetation composition. This vegetation has no present-day analogues. The present-day Slovenian landscape formed only several millennia after the transition to farming.*

IZVLEČEK** – *V članku so predstavljeni rezultati paleoekološke raziskave, katere cilj je bil ugotoviti, kakšen je bil razvoj slovenske pokrajine in vegetacije v holocenu in kakšen je bil vpliv prvih kmetovalcev na okolje. Na štirih izbranih paleoekoloških najdiščih so bile izvedene sledeče analize: "loss-on-ignition", geokemična analiza, radiokarbonsko datiranje sedimenta, pelodna analiza in analiza koncentracije mikrooglja. Rezultati raziskave kažejo, da je bila neolitska pokrajina verjetno zelo dinamična in mozaična – sestavljena iz območij z različno vegetacijo. Ta vegetacija nima sodobnih analogij. Današnja slovenska pokrajina je nastala kasneje, več tisočletij po prehodu na kmetovanje.*

KEY WORDS – *palynology; Neolithic archaeology; palaeoecology; Slovenia; the Holocene vegetation developmen;, soil erosion; charcoal*

## INTRODUCTION

The origins of agriculture are one of the most commonly discussed topics of the Neolithic archaeology. It is thought that the transition from predominantly hunting and gathering economy to farming economy first occurred in the Near East (in the Levant and the middle Euphrates valley) in the 9th millennium cal. BC (*Harris 1996; Bar-Yosef & Belfer-Cohen 1989; Bökönyi 1974; Garrard et al. 1996; Legge 1996; Hole 1996*) or even earlier (*Hillman et al. 2001*). The reasons why Near Eastern hunter-gatherers increased their dependence on domesticated plants and animals at the beginning of the Holocene are not clear. It has been suggested that the agriculture in the Near East either emerged because of the climatic change (*Childe 1936; COHMAP Members 1988; Wright 1993; Hole 1996; Sherratt 1997b; Hillman et al. 2001*) or population pressure (*Cohen 1977*) or a combination of both (*Bar-Yosef & Belfer-Cohen 1989; Binford 1968; Dolukhanov 1979; Hillman 1996*). However, other reasons than climatic change or population increase have also been suggested. For example, it has been argued that agricultural surpluses were produced in order to develop trade (*Runnels & van Andel 1988; Sherratt 1997a; Sherratt 1997b*).

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In Europe the bulk of the first evidence for the beginning of plant cultivation is of much later date than in the Near East. It seems that in Greece domesticated plants and animals occurred simultaneously, at the beginning of the 7th millennium cal. BC (*Dolukhanov 1979; Zohary & Hopf 1993; Halstead 1996*). Elsewhere in Europe the oldest macrobotanical remains of cultivated plants are dated after *ca.* 6000 cal. BC. On the Mediterranean coast the remains of domesticated plants and animals have been discovered on sites of the Impresso culture, dated from the beginning of the 6th millennium cal. BC (*e.g. Batović 1979; Chapman & Müller 1990; Zilhão 1993; Whittle 1996*). At the same time (*ca.* 6000 cal. BC) the first evidence for the transition to farming occurs also on the early Neolithic sites of Starčevo, Körös and Criş culture in the central Balkans (*Bökönyi 1989; Zohary & Hopf 1993; Whittle 1996*). In central Europe the first agricultural villages of the Linear pottery culture are dated only after 5500 cal. BC (*Milisauskas & Kruk 1989; Whittle 1996*).

This temporal grade of macrobotanical remains – from the oldest in the Near East to the youngest in the north-western Europe – was one of the main reasons to suggest that in the early Holocene the first farming economy originated in the Near East and spread across Europe (*Ammerman & Cavalli-Sforza 1984*). The rate, direction and method of this presumable dispersal are a point of controversy, however it has been suggested, for example, that the agriculture in Europe spread together with Near Eastern farmers, who moved towards Europe, settling on territories previously uninhabited or only sparsely inhabited by the Mesolithic population (*Ammerman & Cavalli-Sforza 1971; 1984; Van Andel & Runnels 1995; Sherratt 1997a*). In contrast another group of researchers suggested that no population movement was involved in the spread of agriculture, but domesticated plants and animals arrived from the Near East (*e.g.* emmer, sheep, goat) through exchange networks and some species (possibly barley, pig and cattle) were domesticated locally (*Dennell 1983; Barker 1985; Whittle 1996; Budja 1999; Kyparissi-Apostolika 2000*). A third suggestion is a combination of the previous two, that is that there was a limited population movement in some parts of southern, south-eastern and central Europe, whereas elsewhere the local Mesolithic population gradually adopted farming (*Zvelebil & Zvelebil 1988*).

The question of why the transition to farming occurred is still highly debated and for many parts of Europe it is not known what the landscape of the late Mesolithic hunter-gatherers and early Neolithic farmers looked like. The question of when the transition to farming occurred and the impact of farmers on the landscape is also often a matter of dispute. For the south-eastern Europe, for example, it has been demonstrated that the impact of early agriculture on the vegetation was neither on a landscape scale nor in a form of a time-transgressive wave of forest clearance (*Willis & Bennett 1994; Willis 1995*).

Slovenia is an important area to study Neolithic agriculture because of its geographical position (Fig. 1, Fig. 2) It is located between the Pannonian plain and the Mediterranean, between the areas of the early Neolithic Starčevo and Impresso cultures, where the transition to farming economy presumably occurred in the early Neolithic at the beginning of the 6th millennium cal. BC. The earliest evidence for the transition to farming in Slovenia however appears much later. The oldest remains of cultivated plants, charred seeds of cereals and pulses discovered in the middle Neolithic cave site Ajdovska jama in eastern Slovenia were radiocarbon dated to the second half of the 5th millennium cal. BC (*Culiberg et al. 1992*; Tab. 1). On the Ljubljana Moor numerous charred seeds of cereals and pulses were discovered on the open air archaeological sites dated in the 4th and 3rd millennium cal. BC (*Šercelj 1975; 1981–82; Šercelj & Culiberg 1980*).

One reason why the earliest macrobotanical evidence for the transition to farming in Slovenia appears so late might be that no reliably dated early

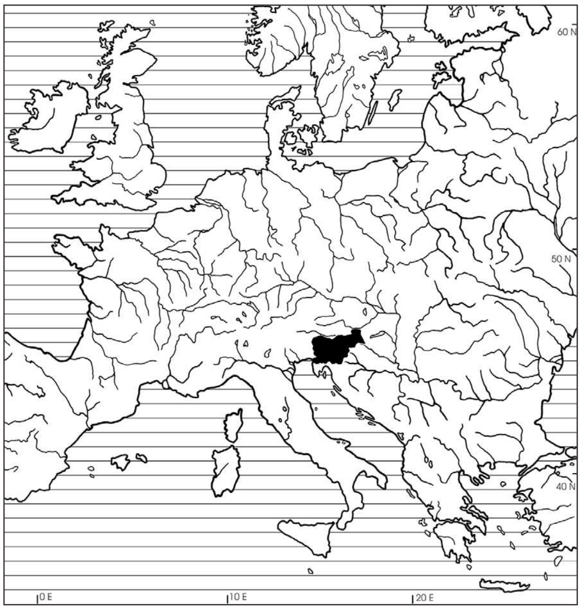

***Fig. 1. Geographic position of Slovenia.***

***Fig. 2. Archaeological sites with first macrobotanical and bone evidence for the transition to farming in Slovenia and neighbouring countries.***

Neolithic sites have been discovered so far. Several pieces of impresso pottery excavated at the end of 19th and the beginning of 20th century in Trieste karst caves near the Slovenian south-western border (*Korošec 1960a; 1960b; Leben 1967; 1973; Batović 1973; Budja 1993*) might derive from early Neolithic sites. The decoration style of this pottery is similar to the impressed ware found on the early Neolithic Impresso sites on the eastern Adriatic coast, which were radiocarbon dated in the first half of the 6th millennium cal. BC (*Batović 1979; Chapman & Müller 1990; Müller 1991*). All impresso pottery from Trieste karst was found in contexts that were not stratigraphically excavated, fine sieved or radiocarbon dated. No macrobotanical or bone remains were collected and hitherto no reliable evidence for the early Neolithic transition to farming was found.

In the vicinity of Slovenia the evidence for the early Neolithic transition to farming suggests that domesticated sheep/goats were present in Trieste karst (Edera cave, Italy) and Čičarija (Pupićna cave, Croatia) at *ca.* 5700 cal. BC (*Budja 1993; Miracle 1997; Boschin & Riedl 2000*). Macrobotanical remains of wheat, barley and legumes at the open air site Sammardenchia on the Po plain (northern Italy) were dated to *ca.* 5500–4600 cal. BC (*Pessina & Rottoli 1996; Rottoli 1999*). Therefore it is possible that in the future the remains of first domesticates of similar age will be found also in Slovenia. However, it is also possible that the situation described above is not just a consequence of the state of research (and un-

| Archaeological site | Period | Radiocarbon dates | Macrobotanical remains of domesticated plants/animals | Reference |
|---|---|---|---|---|
| **Slovenia** | | | | |
| Ajdovska jama | Late Neolithic,<br>Eneolithic | 5560±150 uncal. BP<br>(6280±160 cal. BP)<br>4830±120 uncal. BP<br>(5360±200 cal. BP) | *Hordeum vulgare*, *Hordeum vulgare* var. *nudum*, *Triticum monococcum*, *Triticum dicoccum*,*Triticum aestivum*, *Avena sativa*, *Vicia cracca*, *Vicia faba*, *Pisum* sp. | Šercelj & Culiberg 1984,<br>Culiberg, Horvat & Šercelj 1992 |
| Maharski prekop | Middle Neolithic,<br>Eneolithic | 5080–4345 uncal. BP<br>(3880–2930 cal. BC) | *Triticum spelta* | Šercelj 1981–82,<br>Šercelj & Culiberg 1980 |
| Parti | Eneolithic,<br>Bronze age(?) | 4000±100 uncal. BP<br>3910±100 uncal. BP<br>(ca. 2500 cal. BC) | *Hordeum* sp. | |
| **North–Eastern Italy** | | | | |
| Sammardenchia | Early, middle Neolithic | 5684±58 uncal. BP<br>6570±74 uncal. BP<br>(ca. 5400–4500 cal. BC) | *Triticum moncoccum*, *Triticum dicoccum*, *Triticum aestivum/durum*, *Hordeum vulgare*, *Hordeum* cf. *Distichum*, *Pisum* sp., *Lens culinaris*, *Vicia faba minor* | Pessina & Rottoli 1996 |
| Edera cave | Mesolithic | 6700±140 uncal. BP<br>(ca. 5600 cal. BC) | Domesticated sheep/goat | Boschin & Riedl 2000 |
| **North-Western Croatia** | | | | |
| Pupićna cave | Mesolithic | 5679–5275 cal. BC | Domesticated sheep/goat | Miracle 1997 |

***Tab. 1. Macrobotanical and bone evidence for the beginning of farming in Slovenia and neighbouring countries (for locations see Fig. 2).***

favourable conditions for the preservation of paleobotanical and paleozoological material in some areas of Slovenia) and the transition to farming in Slovenia did occur later than in neighbouring countries and in the areas of early Neolithic Starčevo and Impresso cultures. This suggestion is in accordance with to date results of palynological research, which detects no human impact on the environment before 5th millennium cal. BC. In the last fifty years an extensive pollen analysis of sediments from palaeoecological sites in several regions of Slovenia has yielded a general picture of the Holocene vegetation development (*Šercelj 1996*). Most lowland study sites are concentrated on the Ljubljana Moor where archaeological sites are numerous and pollen preservation is good. It has been suggested that the impact of prehistoric populations living on the Ljubljana Moor triggered a change in the middle Holocene forest composition-an increase of oak and decline of beech and fir (*Šercelj 1988; 1996; Culiberg & Šercelj 1991; Gardner 1997*). In the Podpeško jezero palaeoecological site the decline of beech and an increase of hazel, presumably caused by small-scale agricultural activity has been radiocarbon dated to 6400 cal. BP (*ca.* 4400 cal. BC, *Gardner 1999a; 1999b*). Therefore the first changes of the environment caused by human activity appear on the pollen diagrams as early as in the middle Neolithic and seem to be contemporary with the earliest Neolithic sites on Ljubljana Moor, Resnik (dated to 5856±93 uncal. BP, 4690±93 cal. BC, *Budja 1995*) and Babna gorica (6290 cal. BP, *Mihael Budja, pers. comm., unpublished data*).

On the basis of archaeological and palaeoecological research in Slovenia and neighbouring countries, several models, explaining the process of neolithisation and transition to farming in Slovenia have been suggested. The earliest archaeological explanations for the origin of Neolithic are based on typology of material culture and do not consider economic aspects such as agricultural production. Korošec (*1960b*) defined the characteristics of Slovenian Neolithic pottery, which were formed under the influences of the Lengyel culture. He argued that the influences from the central area of the Lengyel culture located in the Danubian region reached central and north-eastern Slovenia in the middle Neolithic. There are no Lengyel pottery types in south-western Slovenia and this led Korošec (*1960a*) to suggest that the influence of Lengyel culture did not reach these areas. The earliest pottery in the Trieste Karst caves near the south-western Slovenian border was assigned to the early Neolithic. It was impressed ware, similar to that used in early Neolithic Dalmatia. These similarities led Korošec (*1960a*) to suggest that Neolithic people from Dalmatia colonised Slovenian littoral area twice – first in the early Neolithic (Impresso pottery culture) and second time in the middle Neolithic (Danilo culture).

Similarly the spread of agriculture and pottery production from Dalmatia into the Slovenian littoral area in the middle of the 6th millennium cal. BC has been suggested by Chapman and Müller (*1990*). They used radiocarbon dates from charcoal, seeds and bones, found in cultural layers of Neolithic sites along eastern Adriatic coast to demonstrate that the oldest sites are located in the south-east and the youngest sites in the north-west of the region. They have argued that the farming economy probably spread through local diffusion of agricultural techniques from the south-east and the first farmers in the Slovenian littoral area appeared only in the middle Neolithic (Vlaška group, *Chapman & Müller 1991*).

In contrast with Chapman & Müller (*1990*) and Korošec (*1960a*) predominantly 'migrationist' models, Budja (*1993*) has argued that the transition to farming economy in the northern Adriatic area began simultaneously with the other groups along the east Adriatic coast. His model is based on the pottery, palaeobotanical evidence and bones of domesticated sheep/goat found in the Mesolithic contexts of cave sites in Trieste karst (Podmol pri Kastelcu and Edera cave, dated to *ca.* 5600 cal. BC) (*Budja 1993; 1996a; 1996b*). Results from these sites have led to the suggestion that the pastoral economy was the main activity of these groups. It has been suggested that the development of nomadic pasture on the Karst Plateau was connected with the change of natural environment due to the transgression of the Adriatic sea in the middle Holocene and the loss of early Holocene freshwater marshy areas in the Trieste bay. Since the mid Holocene communities of the northern Adriatic presumably lost lowland marsh areas, they probably moved to the Karst Plateau and developed pastoral economy (*Budja 1993; 1996a; 1996b*).

The review of the palaeobotanical research suggests that there is only little evidence for the transition to farming in Slovenia. It is not known when the first domesticated plants and animals were included in the human diet. Another controversial question is whether the farming economy spread to Slovenia from one or several neighbouring countries. This study aims to address the problem of transition to farming in Slovenia using palaeoecological techniques. It does not aspire to cover all the aspects of the process of the neolithisation, associated with the transition to farming, such as changes in the archaeological settlement pattern, material culture and social structure (*e.g. Hodder 1990; Whittle 1996; Sherratt 1997a; Zvelebil 1998; Bailey 2000*). Neither it will enter into diffusionist versus indigenous origins of agriculture debate. It will rather concentrate on the biological component of the transition to farming – the appearance of first domesticated plants and animals and, in particular, human impact on the landscape. The primary aim of this study therefore is to analyse the Holocene vegetation development and the impact of the farming economy on the early postglacial landscape. It aims to investigate what the Slovenian landscape looked like in the Mesolithic and Neolithic period, which vegetation changes might have been triggered by the transition from hunting-gathering to the farming economy, when they occurred and whether the differences between several phytogeographic regions of Slovenia were significant.

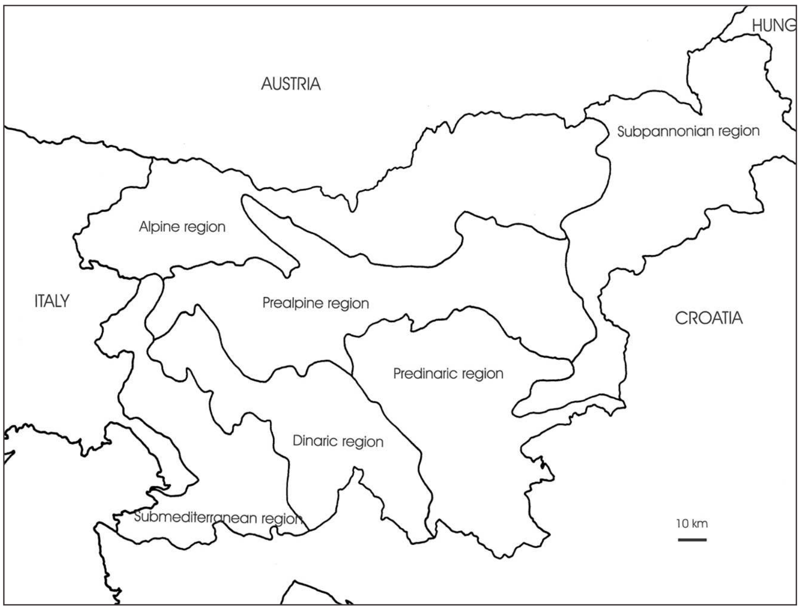

***Fig. 3. Phytogeographic division of Slovenia (*****after Wraber 1969*****).***

The present-day Slovenian landscape is divided into six phytogeographic regions (alpine, prealpine, submediterranean, dinaric, predinaric and subpannonian phytogeographic region) with distinctive relief, climate and vegetation (*Wraber 1969*, Fig. 3). In order to analyse the transition to farming in this wide variety of environments, nine palaeoecological sites (Fig. 4) were investigated. After preliminary pollen analysis four best sequences (in terms of pollen preservation and presence of complete Holocene sequence) were selected for further analysis. The sites selected were Prapoče, Gorenje jezero, Mlaka and Noričká graba (Figs. 5–8, Tab. 2).

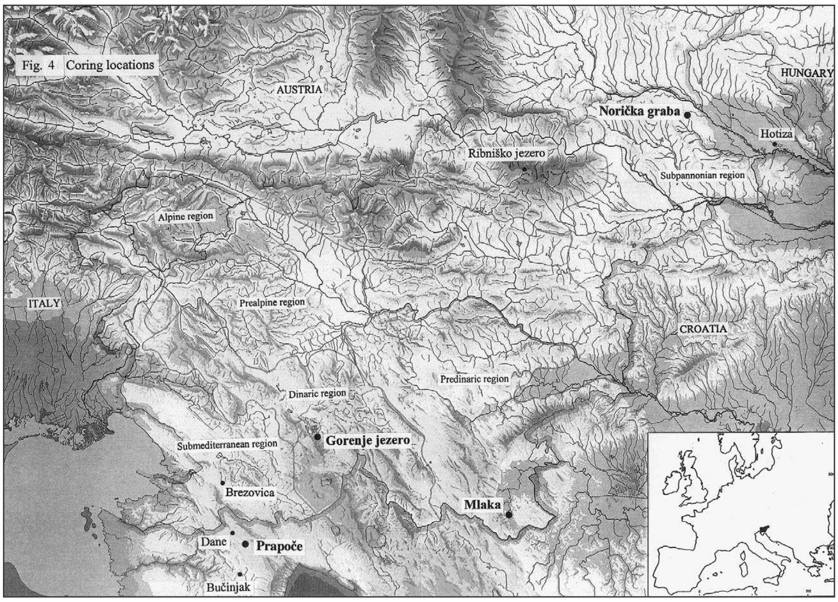

***Fig. 4. Study sites.***

Each study site is located in a different phytogeographic region of Slovenia (and north-western Croatia). They form a southwest-northeast transect across Slovenia, following a climatic gradient from predominantly Mediterranean to predominantly continental climate. All study sites are small marshy areas, located in the vicinity of archaeological sites. They detect changes of the local vegetation (*Jacobson & Bradshaw 1981*) and are therefore suitable for studying presumably weak and local scale early Neolithic human impact on the environment.

At each study site sedimentary cores covering a complete Holocene sequence were collected and the sediment was analysed using the following techniques: loss-on-ignition, geochemistry, pollen analysis and radiocarbon dating.

| Coring location | Phytogeographic region | Coordinates | Altitude |
|---|---|---|---|
| Prapoče | submediterranean | 45°25’25”N, 14°04’30”E | 480 m |
| Gorenje jezero | dinaric | 45°43’40”N, 14°24’50”E | 550 m |
| Mlaka | predinaric | 45°30’10”N, 15°12’20”E | 140 m |
| Norička graba | subpannonian | 46°37’35”N, 16°00’45”E | 240 m |

***Tab. 2. Study sites.***

The percentage of tree pollen, changes in the forest composition, microscopic charcoal concentration and presence of herb pollen, especially ‘anthropogenic indicators’ (*sensu Behre 1981*) on the pollen diagrams were analysed in order to detect forest clearance and burning, presumably used by prehistoric farmers to open the landscape. The results were then statistically analysed using the methods of palynological richness and principal components analysis to assess the biodiversity of the landscape (*Birks et al. 1990*) and the main direction of variance within the entire pollen dataset reflecting changes in the vegetation composition (*Birks et al. 1990; Fuller et al. 1998; Odgaard & Rasmussen 2000*). The techniques of loss-on-ignition and geochemical analysis were used to measure land degradation and soil erosion, again to assess the impact of the Neolithic farmers on the landscape.

An important aspect of the study was also the temporal and spatial scale of the analysis. This research therefore concentrated mainly on changes of the environment in a relatively short period of the Holocene (*ca.* 3000 years of the Neolithic, 6000–3000 cal. BC) and intended to detect changes perceivable on a human timescale. The temporal resolution of the analysis was high wherever the pollen preservation and sedimentation rate permitted, ranging from *ca.* 25 years (Mlaka site) to *ca.* 500 years (Norička graba site).

This paper is divided into six sections. In the first section the present-day vegetation, climate and bedrock at each study site are presented. The information about the archaeological settlement pattern in each area was compiled from the archaeological literature and is presented on Figures 9–12. The second section outlines the methodology used and describes the fieldwork, laboratory procedures and numerical methods used in this research. Section three presents results from radiocarbon, sedimentary and pollen analysis for each site. The Holocene vegetation development for each study site is presented in the section four, where the reasons for changes of the vegetation are discussed. An attempt is made to distinguish between the changes of the vegetation caused by human activity and other factors (*e.g.* climate, internal vegetation dynamics). The fifth section addresses the question of what the Slovenian landscape looked like at the transition from hunting and gathering economy to farming. It then goes on to describe what was the human impact on the environment and possible reasons for the transition to farming. The last section draws the conclusions from the study and suggests future work.

Pollen taxonomy in the paper follows Tutin *et al.* 1964–1980. Plant taxonomy is based on Martinčič *et al.* (*1999*). All radiocarbon dates are in calibrated years before present (determined as 1950 AD, cal. BP), calibrated years BC (cal. BC) or AD. Calibration was performed using INTCAL 98 database (*Stuvier et al. 1998*) and CALIB 4.2 program (*Stuvier & Reimer 1986; 1993*).

## STUDY SITES

### Prapoče (Submediterranean phytogeographic region)

Prapoče study site is located in a marshy area south of the Prapoče village (480 m.a.s.l.) in Čičarija (NE Istria) and lies on an isolated flysch patch in otherwise mainly limestone region (Geological map 1: 100 000, *Ilirska Bistrica 1972*). Tertiary flysch covers the bottom of the valley, which is *ca.* 600 m wide and 4500 m long, located in NW–SE direction. Hills surrounding the valley consist of Tertiary marl and limestones (Geological map 1: 100 000, *Ilirska Bistrica 1972*). The sedimentary core was collected at the bottom of the valley, *ca.* 1000 m south of the Prapoče village (Fig. 5).

The climate of Čičarija 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 (*Roglič 1981*) and the annual amount of precipitation in nearby Lanišče is 1664 mm (*Makjanić & Volarić 1981*).

The Čičarija 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 (*Iljanić 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. 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 surrounding the valley.

***Fig. 5. Prapoče coring location.***

Data concerning archaeological sites in the area are very scarce (Fig. 9). They include a list of prehistoric (probably Bronze and Iron age) fortified settlements, which was compiled at the beginning of the 20th century.

## Gorenje jezero (Dinaric phytogeographic region)

Cerkniško jezero (the lake of Cerknica) is an intermittent lake (usually flooded in the spring and autumn), lying on a karst polje in the Dinaric phytogeographic region of Slovenia, at 550 m.a.s.l. Over 80% of the bedrock in the drainage basin of Cerkniško jezero consists of permeable rocks such as Jurassic and Cretaceous limestones, which cover the entire south and southwestern part of the drainage area, whereas Triassic and Jurassic dolomites prevail on the northern slopes (Geological map 1: 100 000, *Postojna 1967; Pleničar 1953; Kunaver 1961; Kranjc 1985*). The sedimentary core was collected at the south-eastern edge of Cerkniško polje, *ca.* 50 m south of the Gorenje jezero village (Fig. 6), where previous palynological research (*Šercelj 1974*) indicated that a complete Holocene sedimentary sequence is preserved.

Cerkniško jezero has a modified continental climate with cold winters. The maximum precipitation is in the autumn, which is a characteristic of the modified Mediterranean rather than continental precipitation regime. Although Cerkniško polje has a marked temperature inversion and the annual amount of precipitation in Cerknica is 1300 mm, the influence of the Mediterranean shows as a dry summer with minimum precipitation in July and August. Warm air from the Mediterranean reaches Cerkniško polje through the Postojna gap (650 m.a.s.l.); therefore, with respect to precipitation and temperature, the climate of Cerkniško polje is transitional between the mediterranean and the continental type of climate (*Kranjc 1985*).

***Fig. 6. Gorenje jezero coring location.***

The slopes surrounding Cerknica lake are covered by a Dinaric beech-fir forest (*Abieti-Fagetum dinaricum*, *Zupančič 1969*). The southern slopes of Cerknica lake are covered by thermophilous vegetation, which consists mainly of oak (*Quercus pubescens* Willd.

and *Quercus petraea* (Matt.) Liebl.) and hop hornbeam (*Ostrya carpinifolia* Scop.) (*Querco-Ostryetum carpinifoliae*, *Zupančič 1969*) and has been interpreted as a remnant from the warmer early Holocene (*Wraber 1960, Zupančič 1969*). Meadows and fields, with several grassland and marshland species, cover the bottom of Cerknica polje.

*Fig. 7. Mlaka coring location.*

Mesolithic, Neolithic and Bronze Age sites are very rare in the Cerknica region (Fig. 10). Stone tools that could be dated in the Mesolithic have been discovered during the archaeological survey on Cerkniško jezero jezero and in test trenches in the Rakov škocjan (*Drole 1995; Schein 1993; Turk and Dirjec, unpublished report, database of Research Centre of Slovenian Academy of Science and Technology, Institute of Archaeology in Ljubljana*). The majority of fortified settlements at the northern and eastern edge of Cerkniško polje were established in the Iron Age (8th–5th century BC) and belong to the Notranjska group (*Guštin 1973*). In the Roman period the area was an important communication centre (*Urleb 1968*).

## Mlaka (Predinaric phytogeographic region)

Mlaka, a swamp with diameter *ca.* 30 m lies in Bela krajina, in Predinaric phytogeographic region. It is located on Cretaceous and Jurassic limestone and dolomite bedrock, at 150 m.a.s.l., 500 m south of Mala Lahinja village (Geological map 1: 100 000, *Črnomelj 1983*). The sedimentary core was collected 5 m from the edge of the swamp, situated in a small doline. At the time of the coring the doline was covered by *ca.* 10 cm of standing water and overgrown by sedges (Fig. 7).

The climate of Bela krajina is moderate continental-subpannonian with submediterranean precipitation regime (1200–1300 mm annually in western parts) and hot summers. Primary precipitation maximum is in the autumn (November) and primary precipitation minimum is in the late winter and early spring (February). The average temperatures of the coldest month are between –3°C and 0°C and at the warmest month the average is between 15°C and 20°C. Temperatures in October are higher than in the April, which is characteristic of the continental climate (*Bernot 1984; Ogrin 1996; Plut 1985*).

Presently Mlaka is surrounded by meadows and fields. Woodlands of scots pine (*Pinus sylvestris* L.) and birch (*Betula pendula* Roth) with juniper (*Juniperus communis* L.) and bracken (*Pteridium aquilinum* L. Kuhn) cover acid soils. Oak (*Quercus petraea* (Matt.) Liebl.) and hornbeam (*Carpinus betulus* L.) prevail in patchy lowland woodlands of Bela krajina, whereas beech (*Fagus sylvatica* L.) forest covers

*Fig. 8. Norička graba coring location.*

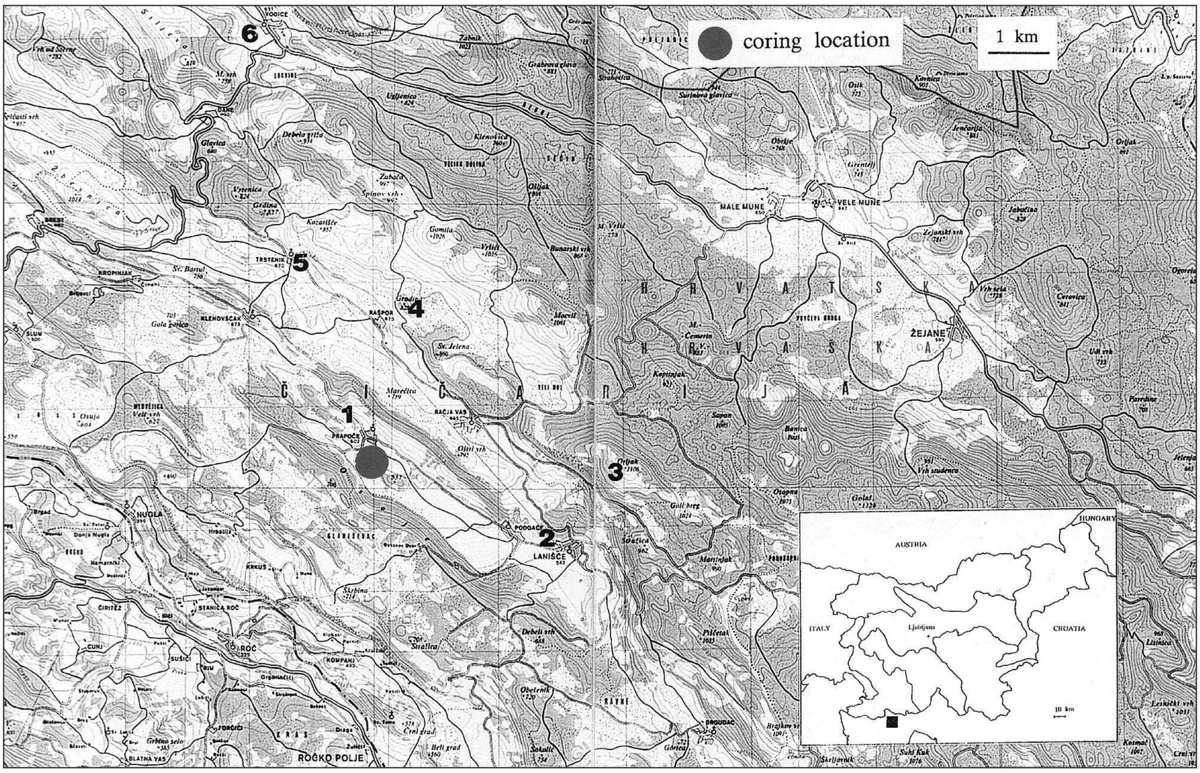

*Fig. 9. Archaeological sites in the Prapoče area.*[1]

higher altitudes. Therefore it has been suggested that the potential natural vegetation of the lowland Bela krajina would be oak-hornbeam forest (*Zupančič & Wraber 1989*).

Several archaeological sites lie close to Mlaka swamp (Fig. 11); the Neolithic/Eneolithic site Pusti Gradac (*Arheološka najdišča Slovenije 1975; Dular 1985*), Eneolithic site Gradinje (*Phil Mason, pers. comm. 2000*), an Iron Age cemetery Brezjece (*Dular 1985; Spitzer 1974*) and the Roman cemetery Šipek (*Arheološka najdišča Slovenije 1975; Dular 1985*) all lie less than 2 km from the coring location.

## Noričká graba (Subpannonian phytogeographic region)

The coring location is situated at 240 m.a.s.l., in marshy area surrounding the spring of tributary of the Ščavnica river. The sedimentary core was taken at the edge of alder (*Alnus glutinosa* (L.) Gaertn.) wood *ca.* 500 m south of Janžev vrh (Fig. 8). The bedrock of the area is Miocene sand and sandy marl (Geological map 1: 100 000, *Čakovec*).

The climate of the subpannonian phytogeographic region is temperate-subpannonian. The annual amount of precipitation is 800–1000 mm and temperatures in April can be higher than in October. Although the precipitation maximum is in July, summers can be very dry (*Ogrin 1996*). The average temperatures of the coldest month are between –3°C and 0°C and at the warmest month the average is between 15°C and 20°C (*Ogrin 1996*).

Due to intensive human impact on the environment meadows, fields and vineyards cover most of the subpannonian region. Patchy woodlands of willow (*Salix* sp.), poplar (*Populus* sp.), hornbeam (*Carpinus betulus* L.) and oak (*Quercus robur* L.) are still growing on gleyed soils of periodically flooded lowlands, whereas many low hills, which rarely exceed 400 m.a.s.l., are covered by acid, degraded soils. Main tree taxa growing in the region are beech (*Fagus sylvatica* L.), oak (*Quercus petraea* (Matt.) Liebl.), chestnut (*Castanea sativa* Mill.) and scots pine (*Pinus sylvestris* L.) (*Wraber 1951; 1961; 1969a; Marinček & Zupančič 1984; Marinček 1987*).

Remains of supposed Neolithic settlement, Bronze Age settlement and cemetery and Iron Age cemetery have been discovered in Gornja Radgona 5 km north of the coring location (*Arheološka najdišča Slovenije 1975*, Fig. 12). Several Iron and Roman age barrows have also been found in Ščavnica valley, to the south and south-west of Noričká graba (*Arheološka najdišča Slovenije 1975*).

## METHODS

In June 1997 and 1998 several overlapping sedimentary cores were collected at each study site using a modified Livingstone piston corer (*Wright 1967*), mounted upon a portable drilling rig. Samples were extracted from the corer, wrapped in cling film, tin foil and plastic sheeting and transported to the laboratory where they were stored in dark at 4°C in order to prevent microbial growth.

The characteristics of the sediment were described following Troels-Smith (*1955*) and the colour of the sediment was determined by Munsell soil chart. The amount of organic material and carbonates in the sediment was determined by loss-on-ignition analysis (*Bengtsson & Ennell 1986*). 1 cm$^3$ of the sediment was put in a muffle furnace at 105°C, 550°C and 950°C and the loss of weight due to heating was recorded after each step. Samples for geochemical analysis were prepared by an acid digestion method (a variation of method 2 of *Bengtsson & Enell 1986, Misi Braun, pers. comm.*) using 65% $HNO_3$ and 30% $H_2O_2$. The concentration of 21 chemical elements was measured by inductively coupled plasma atomic-emission spectroscopy using Perkin Elmer Optima 3300 RL spectrometer facility at the Department of Geology, Royall Holloway, University of London, Egham.

For the pollen analysis 1 cm$^3$ of the sediment (or more, up to 4 cm$^3$ in levels with low pollen concentration) was prepared using standard laboratory procedures (method B of *Berglund & Ralska Jasiewiczowa 1986; Bennett & Willis, in press*) with the following steps: hot 7% HCl, hot 10% NaOH, sieving (sieves with 180 μm mesh), cold 7% HCl, hot 60% HF, hot 7% HCl, acetolysis, staining (0.2% aqueous

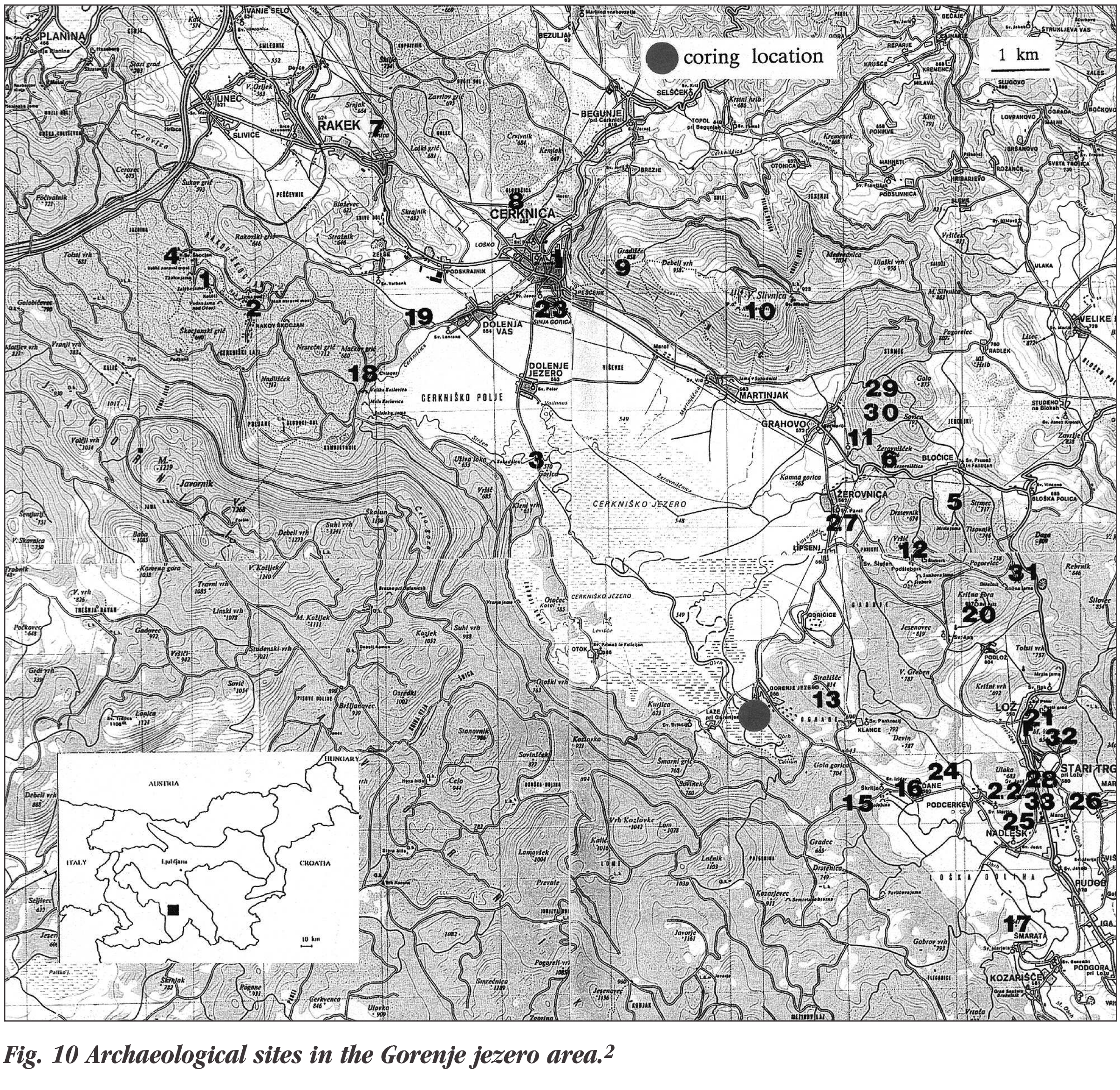

*Fig. 10 Archaeological sites in the Gorenje jezero area.*[2]

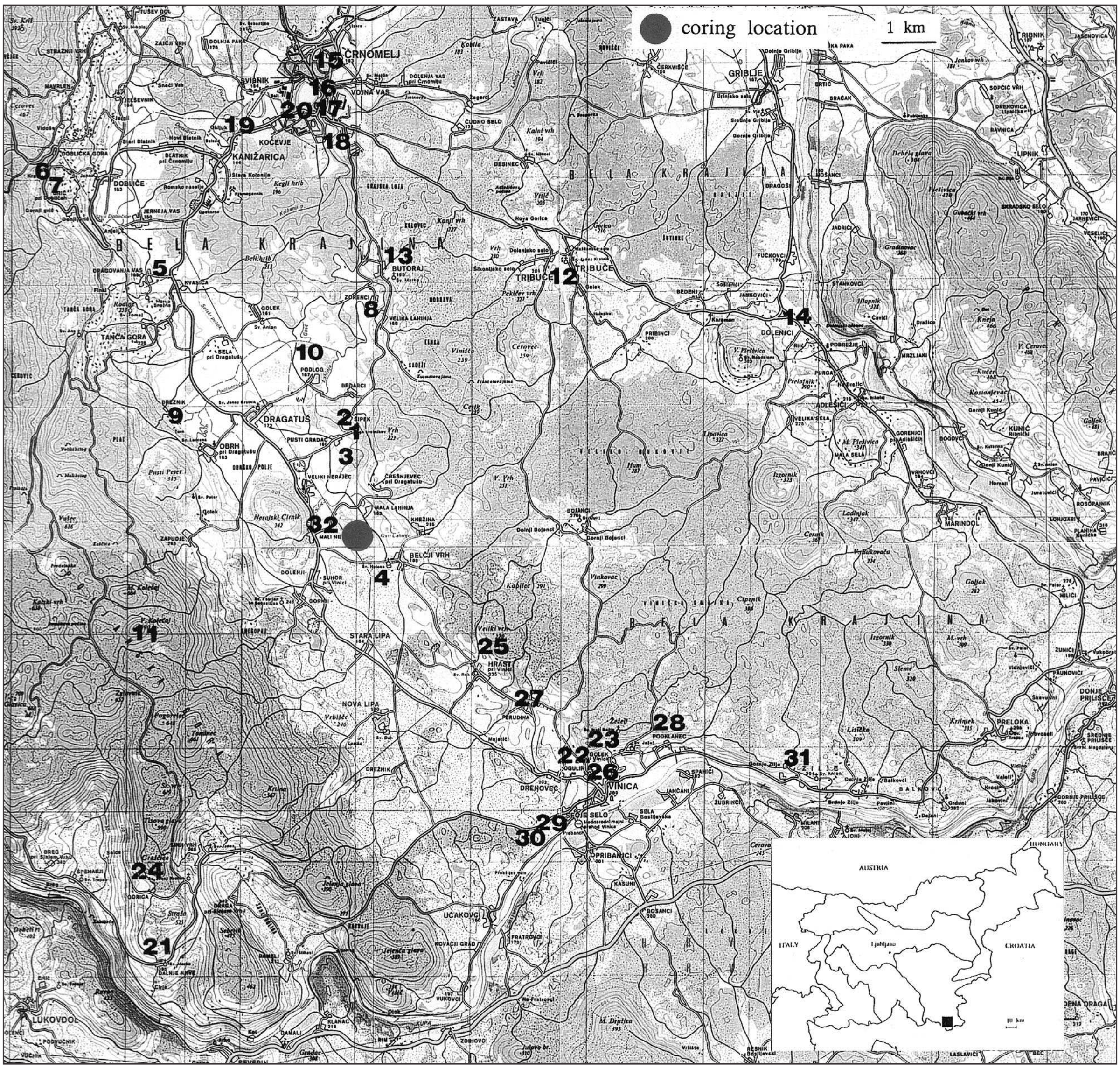

*Fig. 11 Archaeological sites in the Mlaka area.*[3]

safranine), tertiary butyl alcohol (TBA), silicone oil. At the beginning of pollen preparation 2 tablets with a known number of *Lycopodium* spores were added to each sample in order to determine the pollen concentration (= number of pollen grains per 1 cm$^3$ of the sediment). Pollen was identified using Leitz and Nikon Eclipse E400 light microscopes at 400x magnification, with the help of the following pollen keys: *Moore, Webb & Collinson 1991; Reille 1992; 1995; Punt et al. 1976–1995* and by comparison with the pollen reference collection at the Department of Geography, Oxford University. A minimum count of 600 grains of terrestrial pollen and spores (others than *Lycopodium*) per sample was made and *Lycopodium* spores were counted along the pollen to determine the pollen concentration (*Stockmarr 1971*). The abundance of microscopic charcoal in the pollen samples was established by Clark's (*1982*) point count method. The number of events when charcoal 'touched' the graticule was counted in 50 randomly selected vision fields. The number of *Lycopodium* spores in each vision field was also counted.

After preliminary pollen analysis 8–10 cm long section of the core (*ca.* 200g) near presumable Pleistocene/Holocene transition was sent to Beta Analytic Inc., Florida for radiocarbon dating. Since none of the samples yielded enough carbon for radiometric dating, AMS dating of organic carbon extracted from the sediment was carried out. To obtain more detailed chronology for the Holocene part of each core additional samples were sent for radiocarbon dating, 1 cm of the core (*ca.* 20g of the sediment) each time. Material pre-treatment included acid washes and direct atomic counting was performed using an

*Fig. 12 Archaeological sites in the Noričrka graba area.*[4]

accelerator mass spectrometer. The results are presented on Table 3.

The raw data were analysed by 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/*). For the age modelling the intercept of the radiocarbon age with the calibration curve (in cal. years BP) was used and the position of these dates are plotted on each diagram. All five age models available in the PSIMPOLL 3.00 (linear interpolation, cubic spline interpolation, general line-fitting by weighted least-squares, general line-fitting by singular value decomposition and curve-fitting by Bernshtein polynomial, *Bennett 1994*) were run, and, due to rapidly changing sedimentation rate throughout all four sequences, the linear interpolation was selected. The principal components analysis (PCA) was also run with the PSIMPOLL program. During the PCA 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*).

The sediment description and radiocarbon dates are presented on Tables 3–7. The results of loss-on-ignition, geochemistry and pollen analysis are presented as three separate diagrams for each site. On each diagram the suggested timescale (in years cal. BP) is plotted on the far left, followed by the position of each radiocarbon date (in years cal. BP) and the results of the analysis. For geochemical analysis only the elements with highest concentration (Ca, Na, Mg, K, Fe, Al, and Mn) were plotted. The concentration of other elements (B, Ba, Cd, Co, Cr, Cu, Li, Ni, Pb, Sr, Ti, V, Y and Zn) on none of the study sites exceeded 5 mg per 1 kg of dry sediment. Similarly, only selected taxa were included in the pollen diagrams. The proportion of each taxon has been calculated as a percentage of the pollen sum of all terrestrial taxa and spores. Pollen of monolete fern spores *(Filicales)*, which is overrepresented due to an assumed local source, has been excluded from the sum.

## RESULTS

### Prapoče

The radiocarbon date for the bottom of the Prapoče core at 206 cm indicates that the sequence extends back to *ca.* 7500 cal. BC. Three radiocarbon dates have been obtained and the results are presented in Table 3.

Prapoče core is clay-rich throughout (Tab. 4).

The results of loss-on-ignition are presented on Figure 13. 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%. In the section of the core dated between *ca.* 9800–7000 cal. BP (7800–5000 cal. BC) the amount of carbonates is higher (5–15%) than in the rest of the core.

The results of geochemical analysis (Fig. 14) are plotted as weight (in mg) of each element per 1kg of dry sediment. The concentration of iron (Fe) and aluminium (Al) fluctuate between approximately 20–40 mgkg$^{-1}$. The amount of magnesium (Mg) and potassium (K) stay constant throughout the whole sequence, *ca.* 10 mgkg$^{-1}$. The calcium (Ca) curve, however, is high at the bottom of the core (up to 120 mgkg$^{-1}$) and decreases after *ca.* 8000 cal. BP (6000 cal. BC).

The results of pollen analysis, presented on Figure 15 indicate that the main characteristic of the lowest section of the core (*ca.* 9500–6000 cal. BP, 7500–

| Sample number | Depth | Conventional $^{14}$C age | $^{13}$C/$^{12}$C ratio | Intercept of radiocarbon age with calibration curve cal. BC (cal. BP) | 2 sigma calibrated results |
|---|---|---|---|---|---|
| **Prapoče** | | | | | |
| Beta–145368 | 140 | 3050±40 BP | –24.5 o/oo | 1310 cal. BC (3260 cal. BP) | 1410–1200 cal. BC |
| Beta–123732 | 163–172 | 5250±60 BP | –27.7 o/oo | 4035 cal. BC (4985 cal. BP) | 4235–3960 cal. BC |
| Beta–141212 | 206 | 8360±40 BP | –25.4 o/oo | 7475 cal. BC (9425 cal. BP) | 7530–7330 cal. BC |
| **Gorenje jezero 1** | | | | | |
| Beta–145366 | 38 | 1740±40 BP | –28.9 o/oo | Cal. AD 260, 290, 320 (1690, 1660, 1630 cal. BP) | 220–400 cal. AD |
| Beta–142232 | 112 | 7020±60 BP | –27.5 o/oo | 5885 cal. BC (7835 cal. BP) | 6005–5750 cal. BC |
| Beta–123731 | 128–138 | 20640±140 BP | –10.5 o/oo | / | / |
| **Gorenje jezero 2** | | | | | |
| Beta–145367 | 55 | 2670±40 BP | –28.2 o/oo | 820 cal. BC (2770 cal. BP) | 900–790 cal. BC |
| Beta–141213 | 77 | 8710±40 BP | –28.4 o/oo | 7730 cal. BC (9680 cal. BP) | 7915–7905 cal. BC and 7830–7605 cal. BC |
| **Mlaka** | | | | | |
| Beta–148848 | 102 | 1000±40 BP | –28.3 o/oo | 1020 cal. AD (930 cal. BP) | 980–1060 cal. AD and 1080–1150 cal. AD |
| Beta–141215 | 136 | 3480±40 BP | –29.2 o/oo | 1765 cal. BC (3715 cal. BP) | 1900–1695 cal. BC |
| Beta–141216 | 168 | 7350±40 BP | –27.4 o/oo | 6220 cal. BC (8170 cal. BP) | 6250–6090 cal. BC |
| Beta–124727 | 204–212 | 8720±40 BP | –26.7 o/oo | 7700 cal. BC (9650 cal. BP) | 7915–7590 cal. BC |
| **Norička graba** | | | | | |
| Beta–141214 | 144 | 1420±30 BP | –27.1 o/oo | 640 cal. AD (1310 cal. BP) | 600–665 cal. AD |
| Beta–124725 | 196–204 | 10730±40 BP | / | 10915 cal. BC (12864 cal. BP) | 11012–10494 cal. BC |

***Tab. 3. Radiocarbon dates.***

4000 cal. BC) is high percentage of pine pollen (*Pinus*, 20–40% in most levels). The other taxa present are hazel (*Corylus*, 0–45%), grasses (*Gramineae*, 0–25%), *Compositae tubuliflorae* (0–50%) and monolete fern spores (*Filicales*, 0–60%). Oak *(Quercus)*, lime *(Tilia)* and alder *(Alnus)* are present with less than 10%. In the section of the core dated 6000–3000 cal. BP (4000–1000 cal. BC) the percentage of pine declines to *ca.* 10%, whereas the other tree taxa - 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 betulus*, 2–5%) increase. The herb pollen *(Gramineae, Compositae liguliflorae)* increases and reaches 50%. The first appearance of Cereal type pollen grains is estimated to *ca.* 2300 cal. BC. In the top section of the core (after 3000 cal. BP, 1000 cal. BC) the percentage of tree pollen is below 10% and herbs reach *ca.* 80%. The rate of change is highest at *ca.* 1000 cal. BC, whereas palynological richness is highest at *ca.* 300–0 cal. BC and 1700–2000 AD.

The results of principal components analysis (PCA) are presented on Figure 16. 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)*, 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 a chronological order (Fig. 17). The main direction of variance on the first axis is between samples from the top of the core (dated after 1000 cal. BC) and mid-Holocene samples. The main direction of variance on the second axis is between early Holocene samples and samples dated between 1000–200 cal. BC.

## Gorenje jezero

The stratigraphic position and age of two cores collected at Gorenje jezero is presented on Figure 18. Three radiocarbon dates have been obtained for the core 1 and two for the core 2 (Tab. 3). The lowest section of the core 1 covers Late Glacial and early Holocene, whereas the top section of core 1 covers the vegetation development for the last 2400 years. Core 2 covers most of the Holocene. Due to a substantial difference in sedimentation rate between core 1 (Gorenje jezero 1, 1.4 cm/100 years) and core 2 (Gorenje jezero 2, 0.8cm/100 years) the results are plotted separately for each core (Figs. 19, 20, 21, 22). The bottom radiocarbon date of core 1 (Beta-123731, 20640±140 uncal. BP) is beyond a good calibration range and was not used for the age modelling.

The sediment description of cores is presented on Table 5. The sediment is clay throughout. Core 1 becomes silty and sandy below 126 cm.

In core 1 the amount of organic material increases from *ca.* 3% at the bottom to 10–20% towards the top of the sequence (Fig. 19). Carbonates decline from 20% to *ca.* 3% from bottom to the top. The

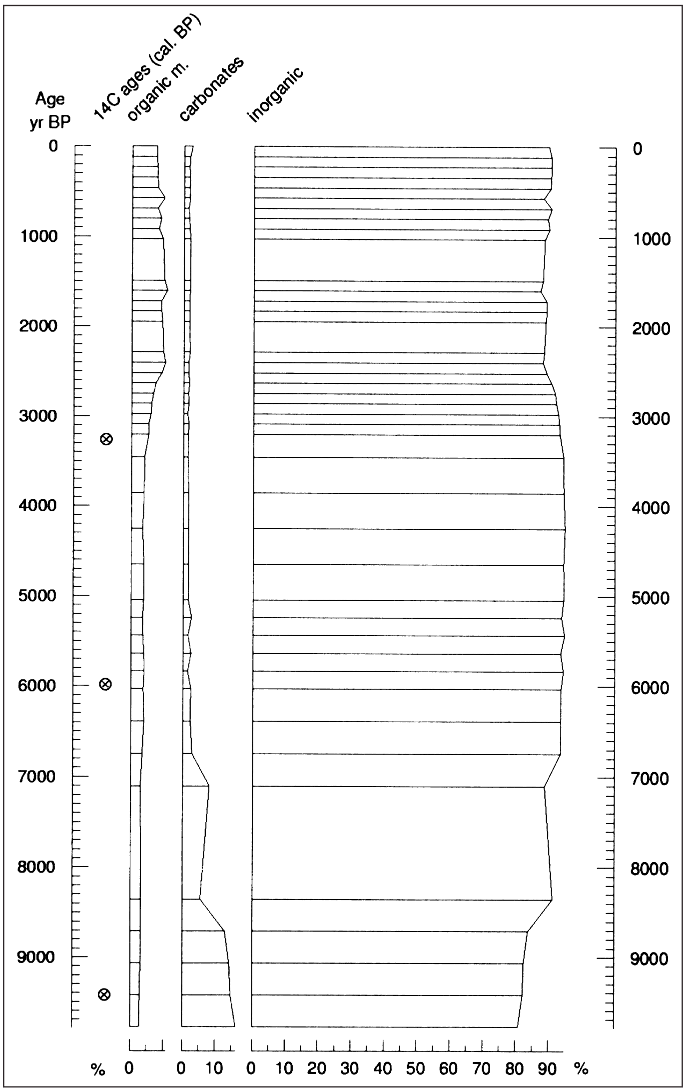

*Fig. 13. Prapoče. Loss-on-ignition.*

| 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 |

***Tab. 4. Prapoče. Description of the sediment follows Troels-Smith (*1955*).***

amount of inorganic residue is *ca.* 70–85% throughout. Core 2 (Fig. 19) does not show major changes of sediment composition (10–20% of organic material, 70–85% of inorganic residue).

The results of geochemical analysis are plotted on Figure 20a and 20b. At the bottom of the core 1 the concentration of calcium (Ca) and magnesium (Mg) is *ca.* 70 mg and 40 mg per 1 kg of dry sediment respectively. After *ca.* 9000 cal. BP (7000 cal. BC) calcium and magnesium curves decline to 10 mgkg$^{-1}$, whereas potassium (K) and aluminium (Al) increase from 2 to 10 mgkg$^{-1}$. The concentration of elements in core 2 is similar as in the Holocene part of core 1.

On the pollen diagrams (Figs. 21, 22) the percentage of each taxon has been calculated as a percentage of the pollen sum of all terrestrial taxa and spores. *Filicales* and *Cyperaceae* (overrepresented due to an assumed local source) have been excluded from the sum. The main characteristic of the lowest section of core 1 (10 000–8800 cal. BP, 8000–6800 cal. BC) is high percentage of pine (*Pinus*, 20–70%). Other tree taxa present include spruce *(Picea)*, lime *(Tilia)*, oak *(Quercus)* and hazel *(Corylus)*. The percentage of pine and birch declines after *ca.* 8800 cal. BP (6800 cal. BC) and high percentage of alder (*Alnus*, 20–40%) and fir (*Abies*, 10–20%) is characteristic for the section of the core dated to *ca.* 8000–7000 cal. BP. The main characteristic of the top section of the core 1 is high percentage of herb pollen *(Cyperaceae, Compositae liguliflorae)*. The pollen record of core 2 is similar to core 1 – 20–60% of pine *(Pinus)* in the section dated to *ca.* 10 000–8800 cal BP (8000–6800 cal. BC), an increase of alder *(Alnus)* and fir *(Abies)* in the middle section (8800–2000 cal. BP, 6800–1 cal. BC) and high percentage of herb pollen in the top section of the core (1000–0 cal. BP, after 1000 AD). Palynological richness on both diagrams increases till the beginning of first millennium cal. BC, but starts to decline at the chord distance curve peak.

The comparison of pollen curves in the section below 8000 cal. BP (6000 cal. BC) suggests that the difference between age modelling of the cores is *ca.* 500 years. The reason for this difference is probably a rapid change in the sedimentation rate of core 1 at the Late Glacial-Holocene transition. Therefore the dating of this transition as suggested by age modelling of core 2 (*ca.* 10 000 cal. BP, 8000 cal. BC) has been accepted.

The results of principal components analysis (PCA) of the pollen data for the core Gorenje jezero 2 are presented on Figure 23. On the axis 1 the main direction of variance is between mainly tree taxa (*Alnus, Abies, Fagus, Quercus, Corylus* and charcoal) and mainly herb taxa (*Compositae liguliflorae, Cyperaceae* and *Pinus*). The main direction of variance on the second axis is between *Pinus, Filicales, Tilia, Picea* and *Cyperaceae, Abies*. The sample scores (Fig. 24) have also been plotted and the points (each point on the diagram represents one sample) were connected in a chronological order. The main direction of variance on the first axis is between the samples from the top of the core (dated after 800 AD) and mid Holocene samples (6700–5800 cal. BC). The main direction of variance on the second axis is between early Holocene samples and samples dated after 5800 cal. BC.

## Mlaka

Four radiocarbon dates (Tab. 3) have been obtained from the top 212 cm of the Mlaka core. In the sec-

| Depth (m) | Troels-Smith symbol | Colour (Munsell soil chart) |
|---|---|---|
| **Gorenje jezero 1** | | |
| 0–0.25 | Sh2Th1As1 | 10 YR 2/1 black |
| 0.25–0.44 | As4 (clay) | 10 YR 3/2 very dark greyish brown |
| 1.00–1.22 | As4 (clay) | 10 YR 3/1 very dark grey |
| 1.22–1.26 | As4 (clay) | 10 YR 4/2 dark greyish brown |
| 1.26–1.34 | As1 Ag3 (silt) | 10 YR 4/2 dark greyish brown |
| 1.34–1.38 | Ag4 (silt) | 2.5 YR 5/3 light olive brown |
| **Gorenje jezero 2** | | |
| 0.42–0.78 | As4 (clay) | 10 YR 3/2 very dark greyish brown |

***Tab. 5. Gorenje jezero. Description of sediments follows Troels-Smith (*1955*).***

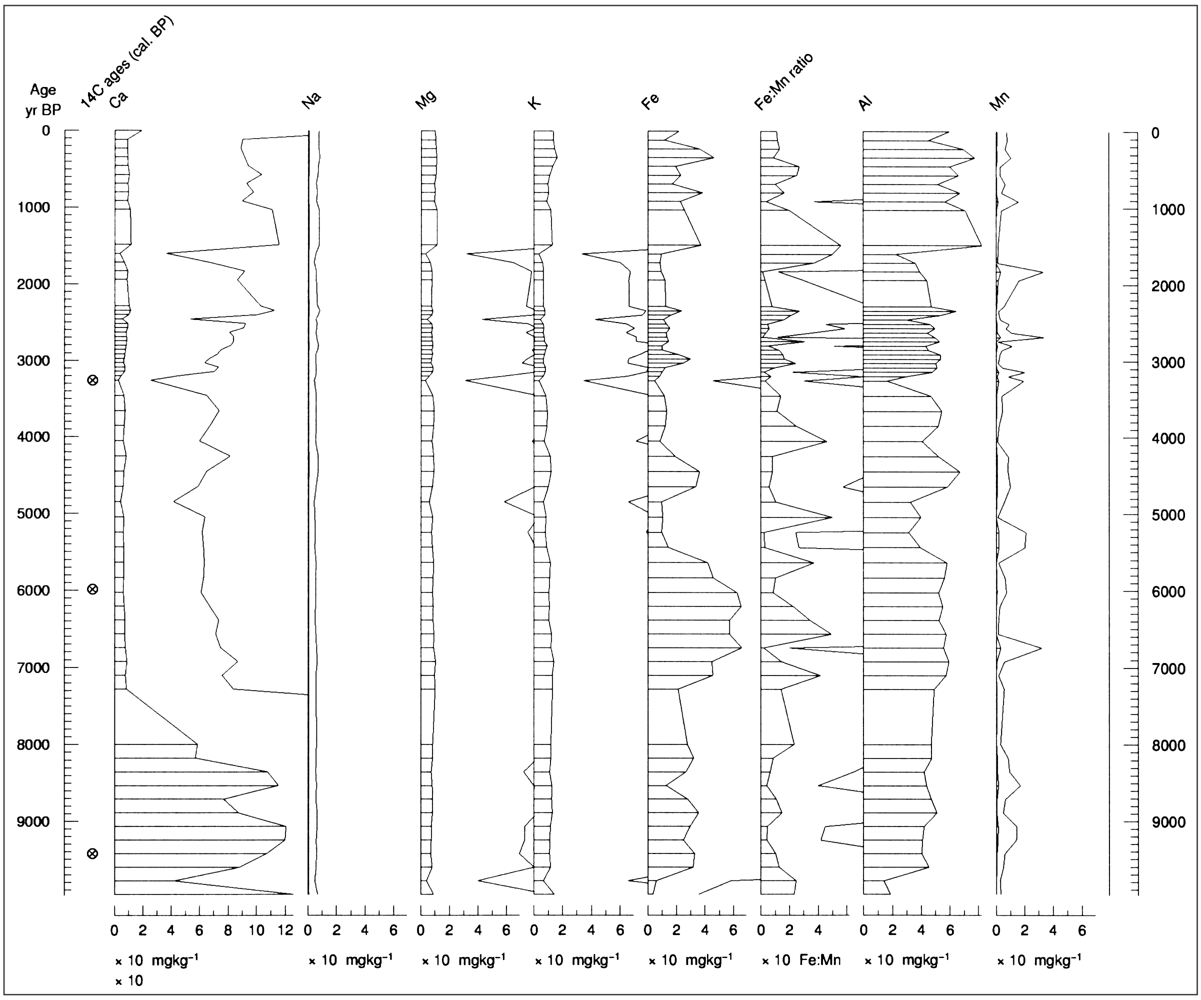

***Fig. 14. Prapoče. Geochemistry (selected elements).***

tion of the core below 228 cm pollen is not preserved therefore no radiocarbon dating has been carried out in the section of the core older than 7700 cal. BC.

The Mlaka core is clay rich (Tab. 6), with a distinctive organic layer in the middle of the core (0.75-1.35 cm)

Loss-on-ignition (Fig. 25) reveals that the amount of organic material (25-50%) is especially high in the section dated 4000-1000 cal. BP (2000 cal. BC - 1000 AD) and in the top 10 cm of the core.

Results of geochemical analysis for Mlaka are presented on Figure 26. Sediment is rich in calcium (Ca, 5-30 mgkg$^{-1}$), sodium (Na, 5 mgkg$^{-1}$), magnesium (Mg, 10 mgkg$^{-1}$), potassium (K, 10mgkg$^{-1}$), iron (Fe, 5-20 mgkg$^{-1}$) and aluminium (Al, 10-70 mgkg$^{-1}$). The concentration of Ca is highest in the section dated 4000-1000 cal. BP (2000cal. BC-10 00AD, 10-20 mgkg$^{-1}$), whereas the concentration of Fe and Al is highest in the section of the core dated after 5000 cal. BP (3000 cal. BC, *ca.* 10 mgkg$^{-1}$ and 20-60 mgkg$^{-1}$ respectively).

Pollen data is presented as a percentage of the sum of terrestrial pollen and spores (Fig. 27). Pollen of monolete fern spores *(Filicales)*, which is overrepresented due to an assumed local source, has been excluded from the sum. High percentage of lime (*Tilia*, 5-60%) is characteristic for the bottom section of the core (10 400-8900 cal. BP, 8400-6900 cal. BC). The other tree taxa present are hazel *(Corylus)*, oak *(Quercus)*, beech *(Fagus)*, and alder *(Alnus)*. The pollen record drastically changes at 8900 cal BP (6900 cal. BC), when the amount of beech *(Fagus)* pollen suddenly increases (30-50%). At *ca.* 7500 cal. BP (5500 cal. BC) the pollen composition changes again. All tree taxa decline and the percentage of beech pollen declines to only 10%. This beech decline is followed by an increase of hazel, oak and hornbeam at *ca.* 6800-6000 cal. BP (4800-4000 cal. BC). Later beech increases again, but only for a

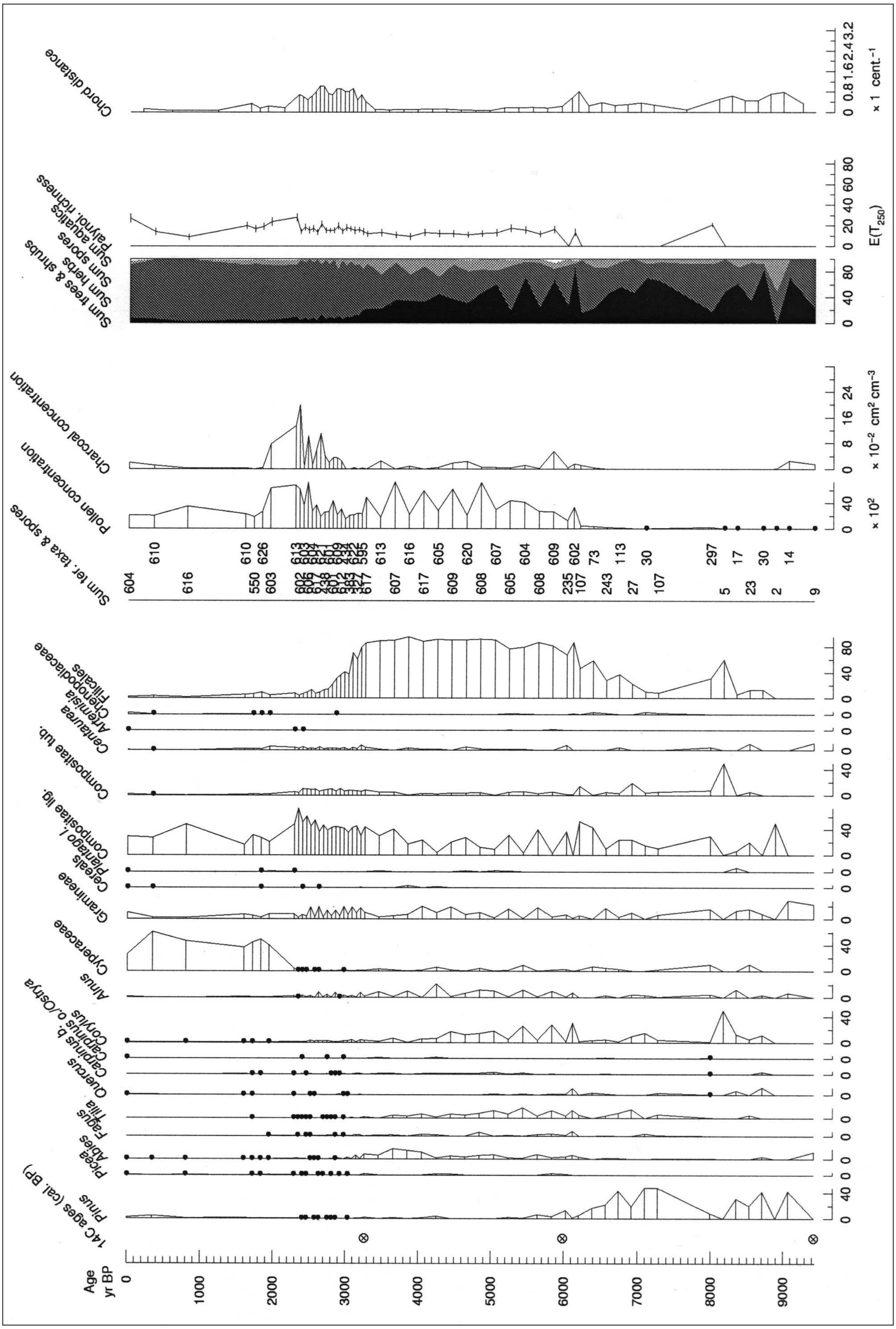

*Fig. 15. Prapoče. Percentage pollen diagram (selected taxa).*

short period (5300–4300 cal. BP, 3300–2300 cal. BC) Its decline is followed by an increase of fir at 4000–2100 cal. BP (2000 cal. BC – 1100 AD). At 1200 BP (800 AD) the abundance of tree pollen starts to decline for the last time and the main characteristic of the pollen record after 800 cal. BP (1200 AD) is low percentage of tree pollen (10–20%). *Compositae liguliflorae* (*ca.* 20%), *Cyperaceae* (*ca.* 20%) and *Gramineae* (*ca.* 5%) are the most abundant among herb pollen, whereas pine *(Pinus)* increases at the top of the sequence. Palynological richness increases throughout the Holocene, whereas the chord distance curve has two peaks – at *ca.* 8900–8300 cal. BP (6900–6300 cal. BC) and 1100 AD.

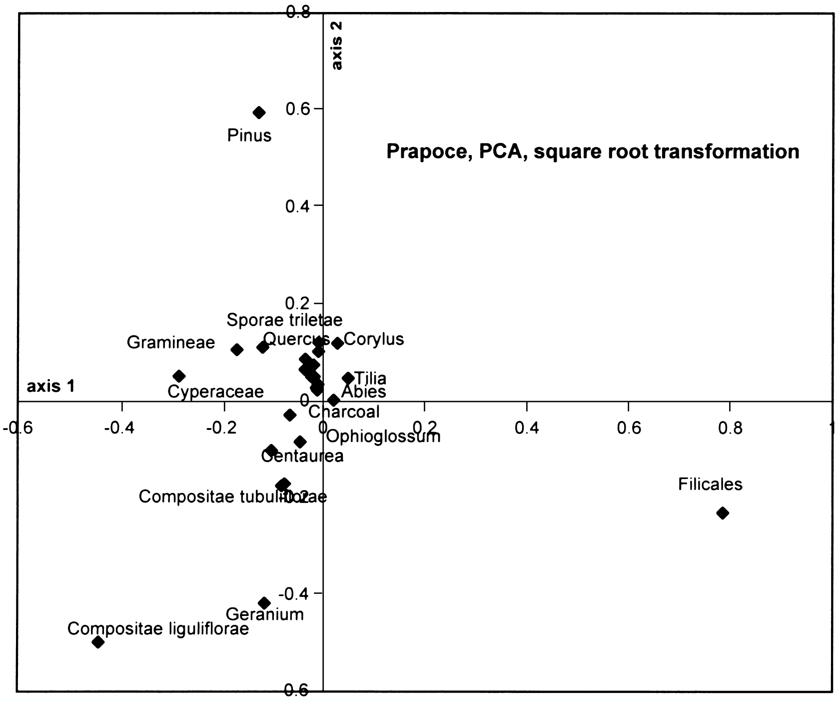

*Fig. 16. Prapoče. PCA. Taxa scores.*

The results of principal components analysis are presented on Figure 28. The main direction of variance on the first axis is between predominantly tree taxa (*Fagus, Corylus, Tilia, Carpinus betulus, Quercus, Abies* and *Filicales*) and herbs (*Compositae liguliflorae, Cyperaceae, Gramineae, Centaurea, Pinus*, charcoal). The main direction of variance on the second axis is between *Filicales, Tilia* and *Carpinus betulus, Corylus.* The sample scores have also been plotted (Fig. 29) and the points (each point on the diagram represents one sample) were connected in a chronological order. The main direction of variance on the first axis is between the samples from the top of the core (younger than 1200 AD) and mid Holocene samples (8900–8400 cal. BP, 6900–6400 cal. BC). The main direction of variance on the second axis is between most early Holocene samples (dated before 6900 cal. BC) and some mid Holocene samples (dated 7200–1200 cal. BP, 5200 cal. BC–800 AD).

## Norička graba

Two radiocarbon dates have been obtained from the Holocene section of the core and the results are presented on Table 3.

Norička graba core alternates between being clay and silt rich (Tab. 7).

The results of loss-on-ignition analysis are presented on Figure 30. The percentage of organic material is low (below 10%) throughout the sequence, being slightly higher only at the bottom (14 500–10 500 cal. BP, 12 500–8500 cal. BC) and top section (after 4000 cal. BP, 2000 cal. BC). The inorganic content of the core is 80–95%.

The results of geochemical analysis, presented on Figure 31 indicate that the the concentration of calcium (Ca), sodium (Na), magnesium (Mg) and potassium (K) does not exceed 10 mg per 1 kg of dry sediment and does not vary much throughout the Holocene section of the core. Iron (Fe) and aluminium (Al) are more abundant, especially in sections 14 500–10 000 cal. BP (12 500–8000 cal. BC) and 500–0 BP (1500–1950 AD), with concentrations of *ca.* 30 mgkg$^{-1}$ and 40 mgkg$^{-1}$ respectively.

Pollen diagram of selected taxa (Fig. 32) shows the proportion of each taxon, calculated as a percentage

| Depth (m) | Troels-Smith symbol | Colour (Munsell soil chart) |
|---|---|---|
| 0–0.13 | Ld4 (organic material) | 10 YR 3/3 dark brown |
| 0.13–0.75 | As4 (clay) | 10 YR 3/3 dark brown |
| 0.75–1.10 | Ld4 (organic material) | 10 YR 2/1 black |
| 1.10–1.35 | As1Ld4 (organic m., clay) | 10 YR 3/1 very dark grey |
| 1.35–2.77 | As4 (clay) | 2.5 Y 4/2 dark greyish brown |

*Tab. 6. Mlaka. Description of sediments follows Troels-Smith (1955).*

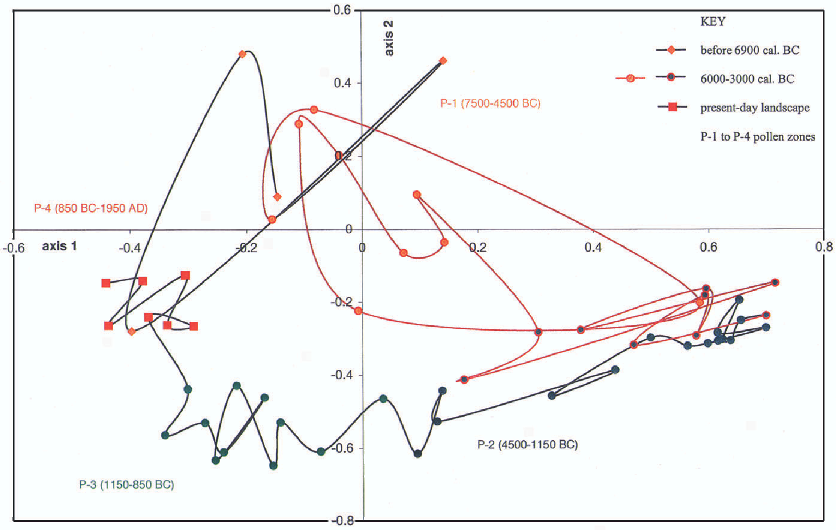

***Fig. 17. Prapoče. PCA. Sample scores.***

of the pollen sum of all terrestrial taxa and spores. Pollen of monolete fern spores *(Filicales)*, which is overrepresented due to an assumed local source, has been excluded from the sum. In the section of the core with an estimated age of 14 500–10 000 cal. BP (12 500–8000 cal. BC) the main tree taxa present are pine (*Pinus*, 10–60%), spruce (*Picea*, 10–15%), lime *(Tilia)*, oak *(Quercus)*, hazel *(Corylus)* and alder *(Alnus)*. The percentage of herb pollen is high (20–50%) and the main herb types present are *Compositae liguliflorae* and *Gramineae*. In the section dated to *ca.* 9500–7000 cal. BP (7500–5000 cal. BC) the pollen curves for lime *(Tilia)*, oak *(Quercus)* and hazel *(Corylus)* increase up to 30%, 5% and 10% respectively. Short-term peaks of alder, pine, beech and *Compositae liguliflorae* follow their decline. In the uppermost section (600–0 cal. BP, 1400–1950 AD) the percentage of herb taxa is 30–60% (*Compositae liguliflorae*, 25–60% of the pollen sum) and the main tree taxon is pine (*Pinus*, 2–35%). Chord distance is highest at 800–1000 AD.

The results of principal components analysis (PCA) are presented on Figure 33. The main direction of variance on the first axis is between predominantly tree taxa (*Tilia, Alnus, Corylus, Fagus* and *Filicales*) and mainly herbs (*Compositae liguliflorae, Cyperaceae, Pinus* and charcoal). The main direction of variance on the second axis is between *Pinus, Filicales, Tilia, Picea* and *Alnus, Sporae triletae*. The sample scores have also been plotted and the points (each point on the diagram represents one sample) were connected in a chronological order (Fig. 34). The main direction of variance on the first axis is between the samples from the top of the core (dated *ca.* 1800 AD) and some of the mid Holocene samples. The main direction of variance on the second axis is between some early and mid Holocene samples.

## THE HOLOCENE VEGETATION DEVELOPMENT

The results of pollen analysis suggest that vegetation history at each study site was different; although the maximum distance between any two sites does not exceed 200 km. Therefore the vegetation development for each study site will be presented first.

### Prapoče

Pollen record for Prapoče suggests that in the early Holocene (9500–6500 cal. BP, 7500–4500 cal. BC) woodland of pine, oak and hazel was probably growing in the region. Due to low pollen concentration (in most levels below 500 pollen grains per 1 cm$^3$ of sediment) and high percentage of degraded pollen grains (10–60%) it is difficult to estimate whether pollen record reflects the real vegetation composition or was it changed due to a selective degradation. Since pollen sum in most levels does not exceed 250 (and therefore confidence intervals for pollen counts are wide), the vegetation composition cannot be discussed in detail.

The reason for low pollen survival might be in dry, aerobic conditions and high microbial activity in the sediment (*Moore et al. 1991*) triggered by presumably warm and dry climate. Loss-on-ignition and geo-

| Depth (m) | Troels-Smith symbol | Colour (Munsell soil chart) |
|---|---|---|
| 0–0.22 | Sh2Th1As1 | 10 YR 2/2 very dark brown |
| 0.22– 0.80 | As4 (clay) | 2.5 Y 4/2 dark greyish brown |
| 0.80–0.96 | As3Ag1 (silty clay) | 5 Y 4/2 olive grey |
| 0.96–1.11 | As2Ag2 (silty clay) | 5 Y 4/2 olive grey |
| 1.11–1.40 | As3Ag1 (silty clay) | 5 Y 3/2 dark olive grey |
| 1.40–1.46 | As4 (clay) | 5 Y 4/1 olive grey |
| 1.46–1.80 | As1Ag2Ga1 (silt) | 5 Y 4/1 dark grey |
| 1.80–2.08 | As4 (clay) | 5 Y 3/1 very dark grey |

***Tab. 7. Noričká graba. Description of sediments follows (*Troels-Smith 1955*).***

chemical 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 progressive evaporation of the lake water could cause the precipitation of calcium carbonate into the sediment. In the section of the core dated between *ca.* 10 000–7500 cal. BP (8000–5500 cal. BC) the concentration of carbonate (10–20% of the sediment dry weight, Fig. 13) and calcium (60–120 mgkg-1, Fig. 14) is higher than in the upper part of the core and might indicate arid climate before 7500 cal. BP (5500 cal. BC). An increase of iron (Fe), which followed at *ca.* 7000–6500 cal. BP (5000–4500 cal. BC) was probably caused by changes of redox conditions in both, the catchment and marsh area. Iron has, similarly as manganese (Mn) very low solubility under oxidising conditions, but becomes mobile under reducing conditions. Reducing conditions in the catchment can be caused by waterlogging or build-up of raw humus on the soil surface (*Mackereth 1966; Engstrom & Wright 1984*) Therefore slightly higher iron at *ca.* 5000 cal. BC might suggest that the climate either became wetter or the basin became waterlogged.

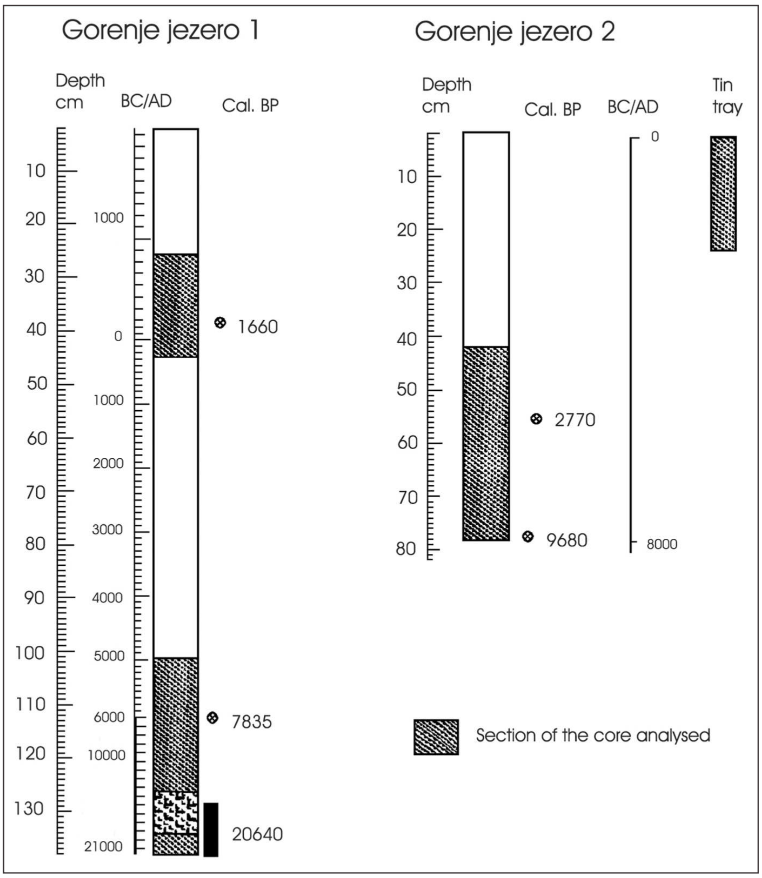

***Fig. 18. Gorenje jezero. Stratigraphic position of cores 1 and 2.***

In the section of the core dated after 6500 cal. BP (4500 cal. BC) the percentage of degraded pollen grains declines and pollen concentration increases to 2000–6000 grains per 1cm$^3$ of the sediment. This indicates that the pollen record in this section of the core is reliable and pollen composition was probably not changed due to a selective preservation. Still rather low pollen concentration is most likely a consequence of sedimentation rate and vegetation composition.

The vegetation growing in the Prapoče area between 6500 and 4000 cal. BP (4500–2000 cal. BC) was probably 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 percentage of hazel (5–25%) and herb pollen (20–60%) suggests 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. 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 to see how open was the landscape before 4500 cal. BC and whether these 'anthropogenic indicators' were actually growing also in the 'natural' early and mid Holocene landscape. Present-day habitats 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.* 4300 cal. BP (2300 cal. BC). The cereal pollen production is low and pollen does not spread far from the plant (*Behre 1988; Rösch 2000*), therefore they indicate that fields and Eneolithic/Bronze Age site must have been located in the vicinity of the coring location. Since the beginning of the second millennium cal. BC the human pressure on the environment started to increase. The amount of tree pollen declined and a change in forest composition occurred at 4000–3500 cal. BP

(2000–1500 cal. BC) when fir became more numerous. The reason for this increase of fir might be climatic (increased precipitation, similar increase of fir appears on the Mlaka site between 2000 and 100 cal. BC) 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 *ca.* 1000 cal. BC.

## Gorenje jezero

In the Late Glacial (before *ca.* 10 000 cal. BP, 8000 cal. BC) mixed woodland of pine, birch, spruce, lime, oak, hazel ash and elm was growing in the Gorenje jezero region. Geochemical record suggests that the landscape was not stable. Increased inorganic input and high concentration of calcium (Ca) and magnesium (Mg) indicate that erosion probably occurred due to open vegetation and low temperatures.

In the early Holocene (10 000–8900 cal. BP, 8000–6900 cal. BC) broadleaved taxa (beech, lime, oak, hazel) and spruce replaced pine and birch. At *ca.* 8900 cal. BP (6900 cal. BC) the composition of forest growing in the Gorenje jezero area changed. The amount of spruce declined, whereas fir became more numerous. Alder, growing on the floodplain also increased, probably because of the change in the hydrology of the basin. Cerkniško jezero is a karst field, usually flooded in spring and autumn. The extent and duration of the floods is connected with the amount of precipitation in its watershed (*Kranjc 1985*). Therefore it is possible that the observed change of vegetation (an increase of alder and fir) was triggered by an increase in precipitation.

At *ca.* 8900 cal. BC (6900 cal. BC) alder and fir started to grow around Gorenje jezero site and by 7000 cal. BP (5000 cal. BC) fir became the most common tree in the region. Alder, which was probably growing in the floodplain, suddenly declined at 5000 cal. BC. Two reasons could be suggested for this decline: change of the hydrology in the basin or human impact (the first cereal type pollen grains appear on the diagram at this point). Although no Neolithic or Eneolithic sites have been found in the area, it is possible that Neolithic populations were clearing and burning forest on the floodplain.

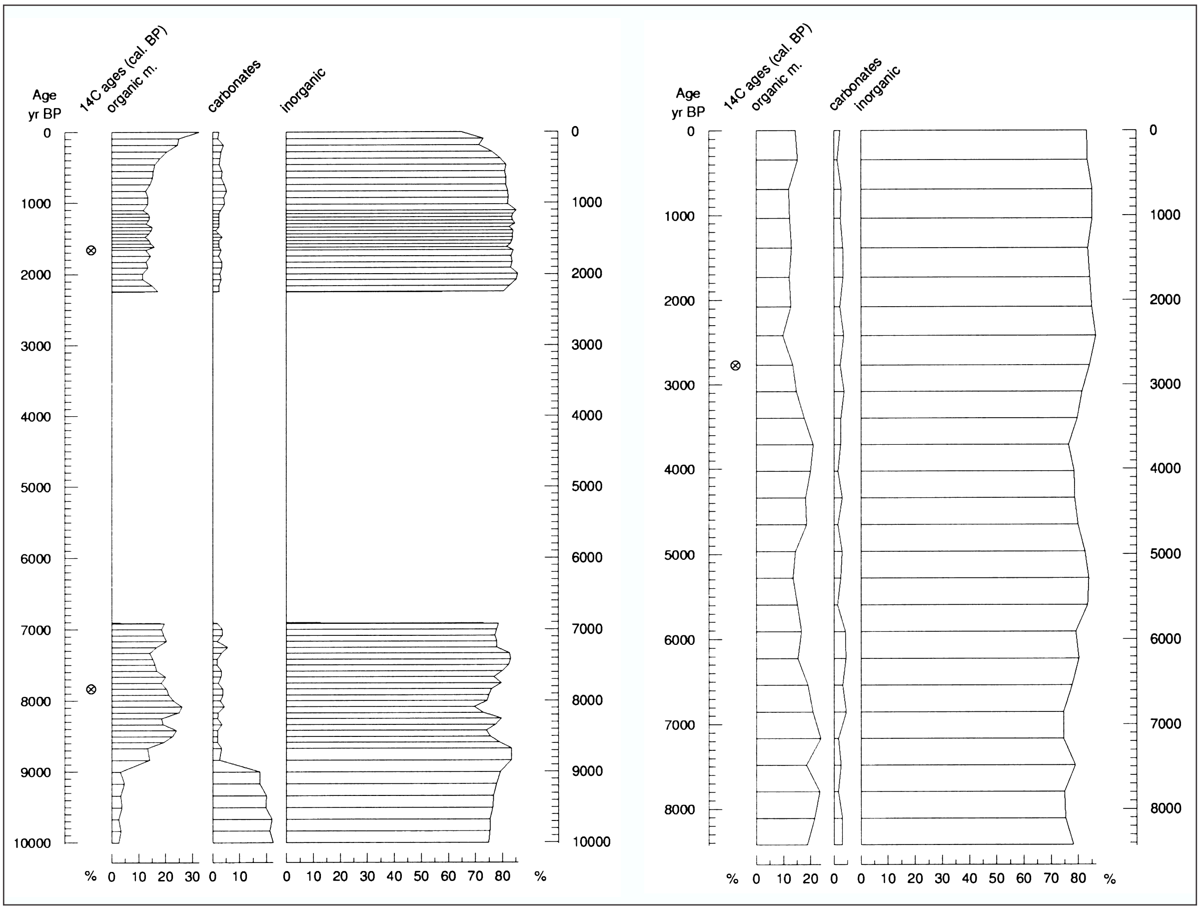

*Fig. 19. Gorenje jezero 1 and 2. Loss-on-ignition.*

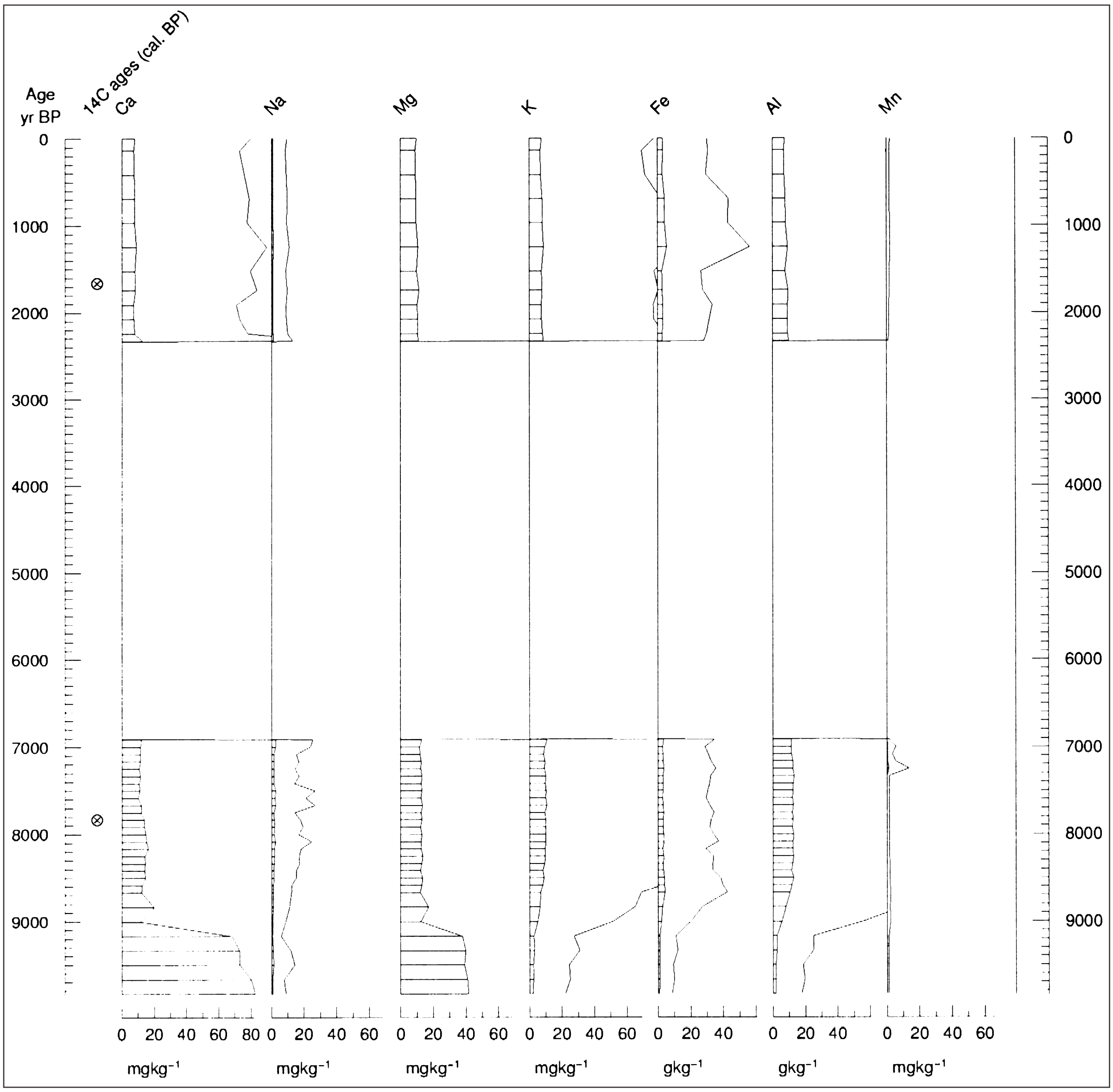

***Fig. 20a. Gorenje jezero 1. Geochemistry (selected elements).***

In contrast to Neolithic/Eneolithic settlement pattern, the Bronze and Iron Age sites in the area are numerous. Most Iron Age fortified settlements and cemeteries are located on the northern edge of the Cerknica polje (*Arheološka najdišča Slovenije 1975*). A presumable late Bronze and/or early Iron Age site in Gorenje jezero village was located *ca.* 200 m from the coring location. On the basis of several pieces of potsherds found in the village during the construction of a pipeline, the site was dated into 9th/8th century BC (*Alma Bavdek, pers. comm., 1999*). Pollen record for this period shows a decline of fir dated *ca.* 3000 cal. BP (1000 cal. BC). Alder started to decline again, whereas herbs were increasing. These changes suggest that the landscape was gradually becoming more open and present-day landscape with meadows and fields at the bottom of Cerknica polje formed already in the Roman period at *ca.* 300 AD. Input of geochemical elements has remained stable throughout the Holocene suggesting that no soil erosion occurred.

## Mlaka

In the early Holocene (10600–8900 cal. BP, 8600–6900 cal. BC) Mlaka swamp was surrounded by broad-leaved forest in which lime dominated. The other tree taxa also growing in the region were hazel, oak, hornbeam, hop hornbeam, maple, fir, spruce, birch, pine, elm, alder and willow.

At 8900 cal. BP (6900 cal. BC) thick beech forest replaced predominantly lime woodland within only a hundred years. Fir, although probably growing in

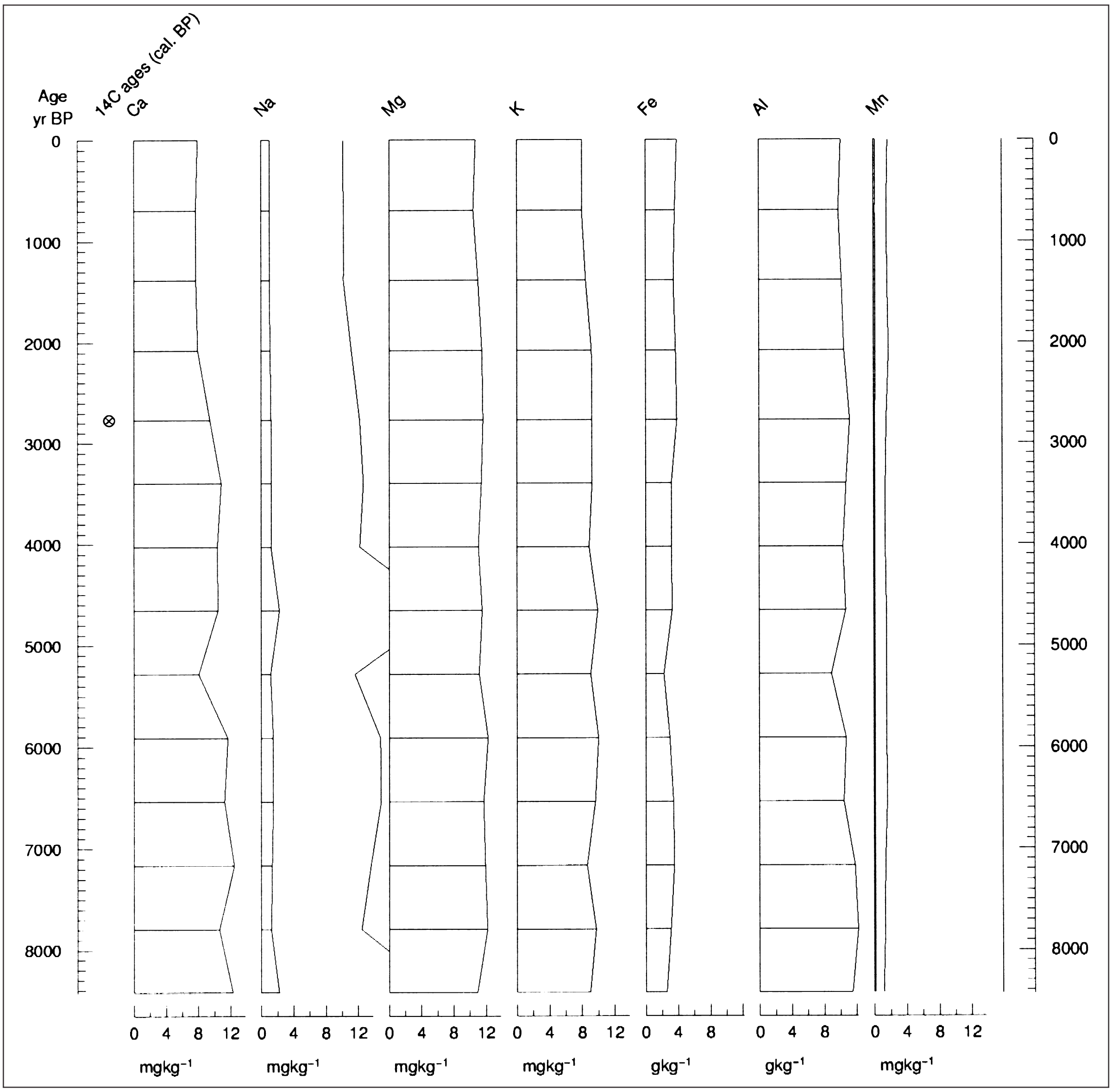

*Fig. 20b. Gorenje jezero 2. Geochemistry (selected elements).*

the area, was not very numerous. The reason for this vegetation change was probably, similarly as in other regions of Slovenia, climatic. Maybe the increase of precipitation was intensive enough to allow the spread of beech, but summers were still too dry for fir expansion. Another factor that limited the spread of fir might have been burning of the forest. Fir has been classified as fire-intolerant tree taxon (*Tinner et al. 2000*) and in the southern Switzerland, for example, the results of palaeoecological research have suggested that high fire incidence was responsible for the extinction of fir from Swiss lowland forests (*Tinner et al. 1999*). The charcoal record at Mlaka suggests that regular burning of the landscape occurred throughout the Holoceme. The fluctuation of beech curve and relatively high percentage of lime and hazel pollen suggests that occasional small-scale openings of the canopy did occur between 8900 and 8000 cal. BP (6900-6000 cal. BC). It is difficult to estimate what was the role of the Mesolithic population in shaping the landscape (forest burning) since to date no Mesolithic sites have been discovered in the area.

At 8200 cal. BP (6200 cal. BC) the amount of beech growing around Mlaka swamp started to decline and by 7500 cal. BP (5500 cal. BC) the landscape became very open again. The vegetation composition at 5500 cal. BC was similar as in the early Holocene with lime being the most important tree taxon. What was the reason for this drastic change of vegetation? Two possible explanations will be discussed – climatic change and human impact on the environment.

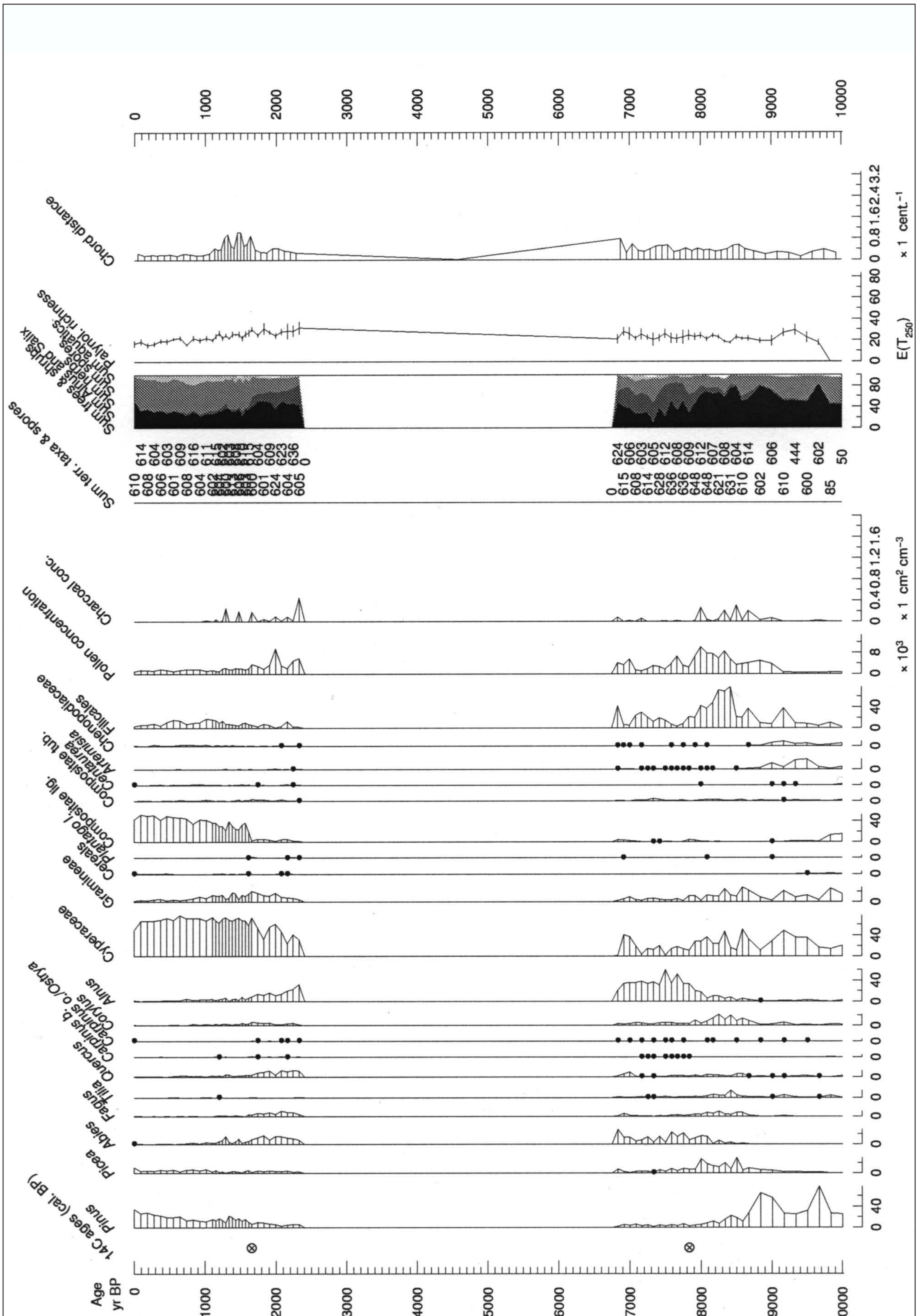

*Fig. 21. Gorenje jezero 1. Percentage pollen diagram (selected taxa).*

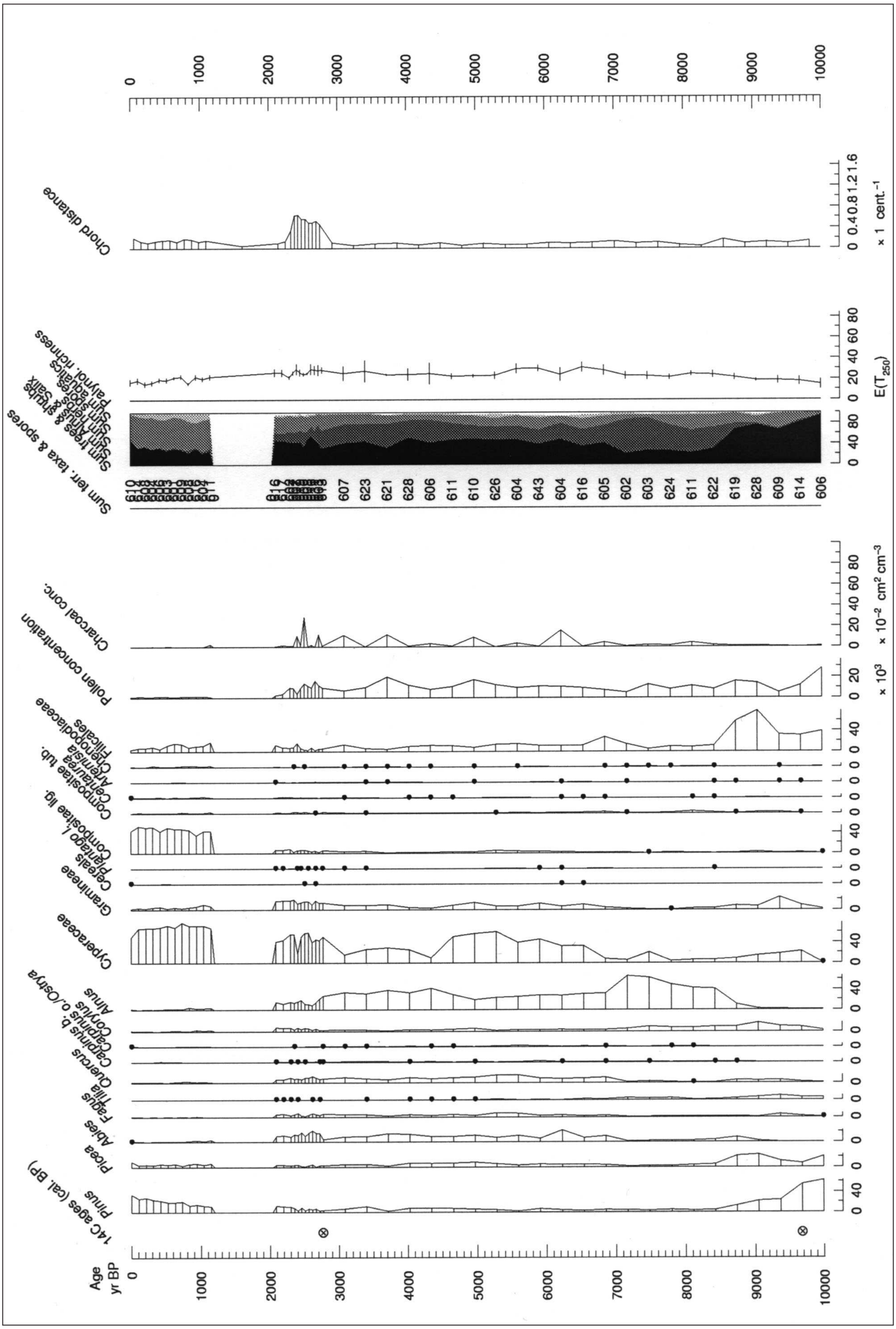

*Fig. 22. Gorenje jezero 2. Percentage pollen diagram (selected taxa)*

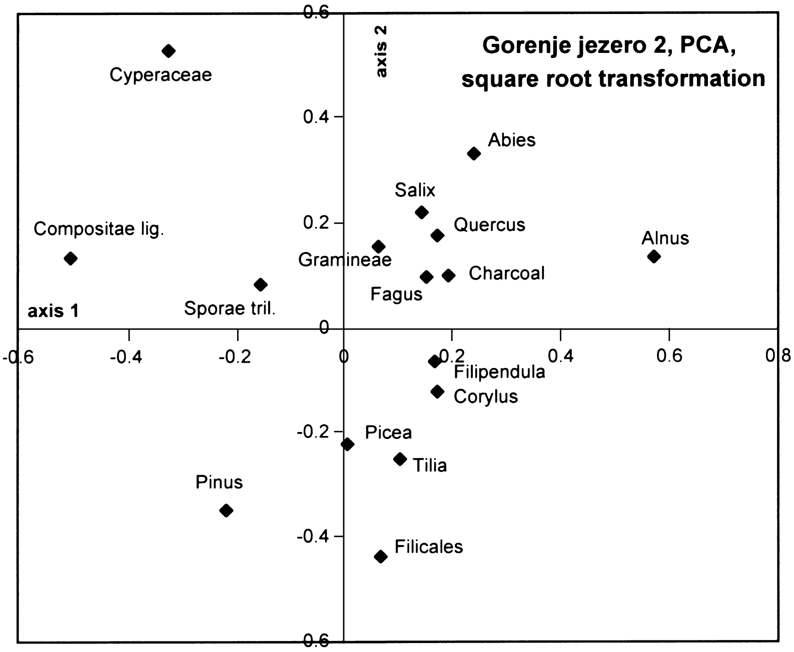

*Fig. 23. Gorenje jezero 2. PCA. Taxa scores.*

Since the vegetation composition at 6200-5500 cal. BC was similar as in the early Holocene, it could be argued that it was caused by similar climate – presumably warm and dry summers and cold winters (*Kutzbach et al. 1998*). The beech decline at Mlaka also coincides with cold period detected in the Greenland ice cores and Swiss palaeoecological record. The main difference between Greenland and Swiss palaeoecological record is that the former was interpreted as "cold and dry" event (*Alley et al. 1993; Meese et al. 1994*), whereas the latter has been reported as "cold and humid phase", which might include a drier episode recorded in the lowlands only (*Haas et al. 1998*). The problem with the climatic explanation for the vegetation change at Mlaka is that such a drastic change in vegetation composition does not occur anywhere else in Slovenia, which suggests that the presumable climatic change was neither intensive nor widespread.

Therefore the other option – human impact on the environment – should also be considered. Mlaka is small swamp with diameter 30 m and the pollen source area for such small sites is mainly local. Most of the pollen derives from plants growing less than 300 m from the site (*Jacobson & Bradshaw 1981*). An individual, small-scale forest clearance in the vicinity of Mlaka would cause a major change of local vegetation and pollen record. It is possible that forest clearance and burning opened the landscape to an extent when it was not only more attractive to the herbivores, but also allowed cereal cultivation and pasture of domestic animals. The most intensive pressure on the vegetation lasted for *ca.* 700 years. Afterwards, at 5500 cal. BC, forest started to regenerate through a phase of hazel, oak and hornbeam. Predominantly hornbeam forest was growing around Mlaka between 4500 and 3800 cal. BC. It seems that the hornbeam forest was maintained by coppicing and burning, which prevented beech to regenerate. Long coppice rotation and wood pasture might increase the proportion of hornbeam against other trees and it is possible that it was grown for firewood (*Rackham 1980; Ellenberg 1988*).

At 3800 cal. BC the hornbeam forest was cleared and an increase of ash and pine suggests that the landscape became very open again. An increase of grass and herb pollen *(e.g. Centaurea, Plantago l., Compositae liguliflorae)* and cereal type pollen indicates that meadows and fields were located in the vicinity of the Mlaka site. Between 3300 and 2500 cal. BC some of these fields were abandoned and thick beech forest spread again. The spread of forest was interrupted for a short period only at *ca.* 2800 cal. BC, when beech declined an geochemical record (an increase of Fe:organic and Al:organic ratio) suggests that forest clearance and burning caused soil erosion.

For the Neolithic and Eneolithic period the archaeological settlement pattern in the area is very well known – most Neolithic sites are located in river meanders and bends in the lowland Bela krajina (*Dular 1985; Budja 1989; 1992 (1995); Mason 1995*). Yet no early Neolithic sites have been discovered in the Bela krajina so far and the oldest, mid Neolithic levels of Moverna vas site, were radiocarbon dated to 4904–4874 cal. BC (*Budja 1989; 1992; 1993*). The Pusti Gradac site, located 2 km north of Mlaka, has been, on the basis of pottery, which is similar to the pottery discovered in the Moverna vas, dated in the 5th, 4th and 3rd millennium BC (*Arheološka najdišča Slovenije 1975; Dular 1985; Budja 1989*). Therefore the forest clearance detected in the palynological record of Mlaka site pre-dates the earliest Neolithic site in the area for *ca.* 1000 years and suggests that the first farmers were probably living in Bela krajina in the Early Neolithic, but their sites still need to be discovered. The first soil erosion, which followed forest clearance at *ca.* 2800 cal. BC

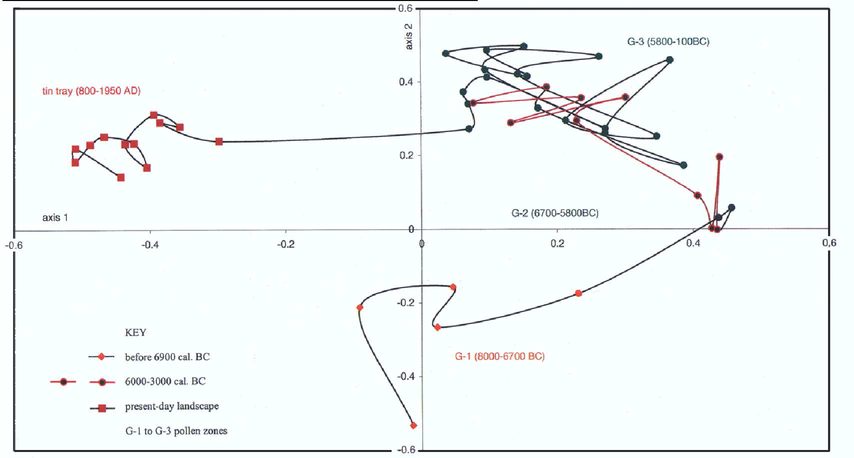

*Fig. 24. Gorenje jezero 2. PCA. Sample scores.*

was probably associated with a recently discovered Eneolithic site Gradinje, located just 300 m west of the coring location (*Phil Mason, pers. comm., 2000*).

At 2000 cal. BC beech declined again. The sediment of Mlaka core became organic and more fir started to grow in the area. This change in the sediment composition and an increase of fir could be a consequence of climatic changes (increased precipitation). Intensive metallurgy could also favour fir since more beech was probably cut for the fuel (*similarly as suggested for Hungary, Willis et al. 1998*). An increase of pine and herb pollen suggests that human pressure on the environment was gradually increasing until *ca.* 1000 AD when the present-day landscape with patchy woodlands and extensive meadows and fields formed. Geochemical record suggests that soil erosion occurred again with the formation of the present-day landscape.

## Noričkagraba

In the Late Glacial (14 500–10 000 cal. BP, 12 500–8000 cal. BC) predominantly pine-birch-spruce woodland was growing around Noričkagraba. High percentage of herb pollen and high charcoal concentration suggests that woodland in the Late Glacial and Early Holocene was very open due to a high incidence of natural fires. This open landscape was not very stable and high concentration of iron and aluminium (the concentration of Ca, Mg and Mn is also slightly higher) probably indicates catchment erosion.

In the early Holocene (*ca.* 10 000–8900 cal. BP, 8000–6900 cal. BC) broad-leaved taxa (mainly lime and oak) gradually replaced pine-birch-spruce woodland. Spread of lime-dominated forest is dated to 9000–7000 cal. BP (7000–5000 cal. BC). It seems that beech and fir were never important taxa in the Noričkagraba region. Due to very low pollen concentration (and therefore low pollen sums and low resolution) in the section of the core between 8000 cal. BP (6000 cal. BC) and 1300 AD

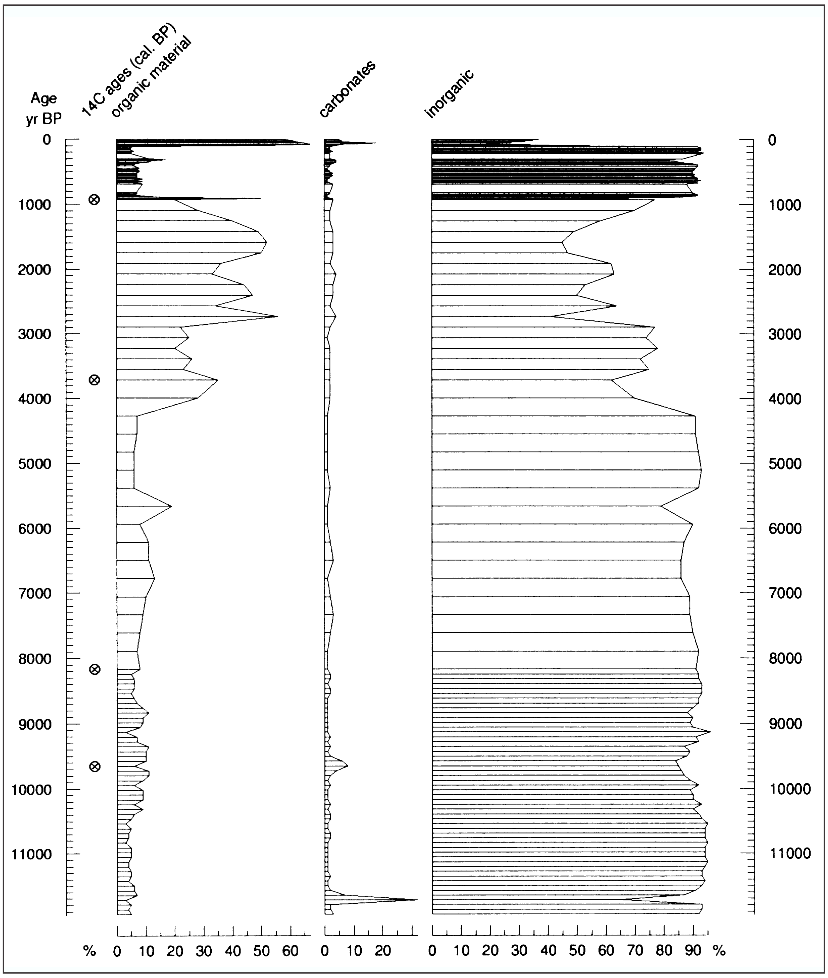

*Fig. 25. Mlaka Loss-on-ignition.*

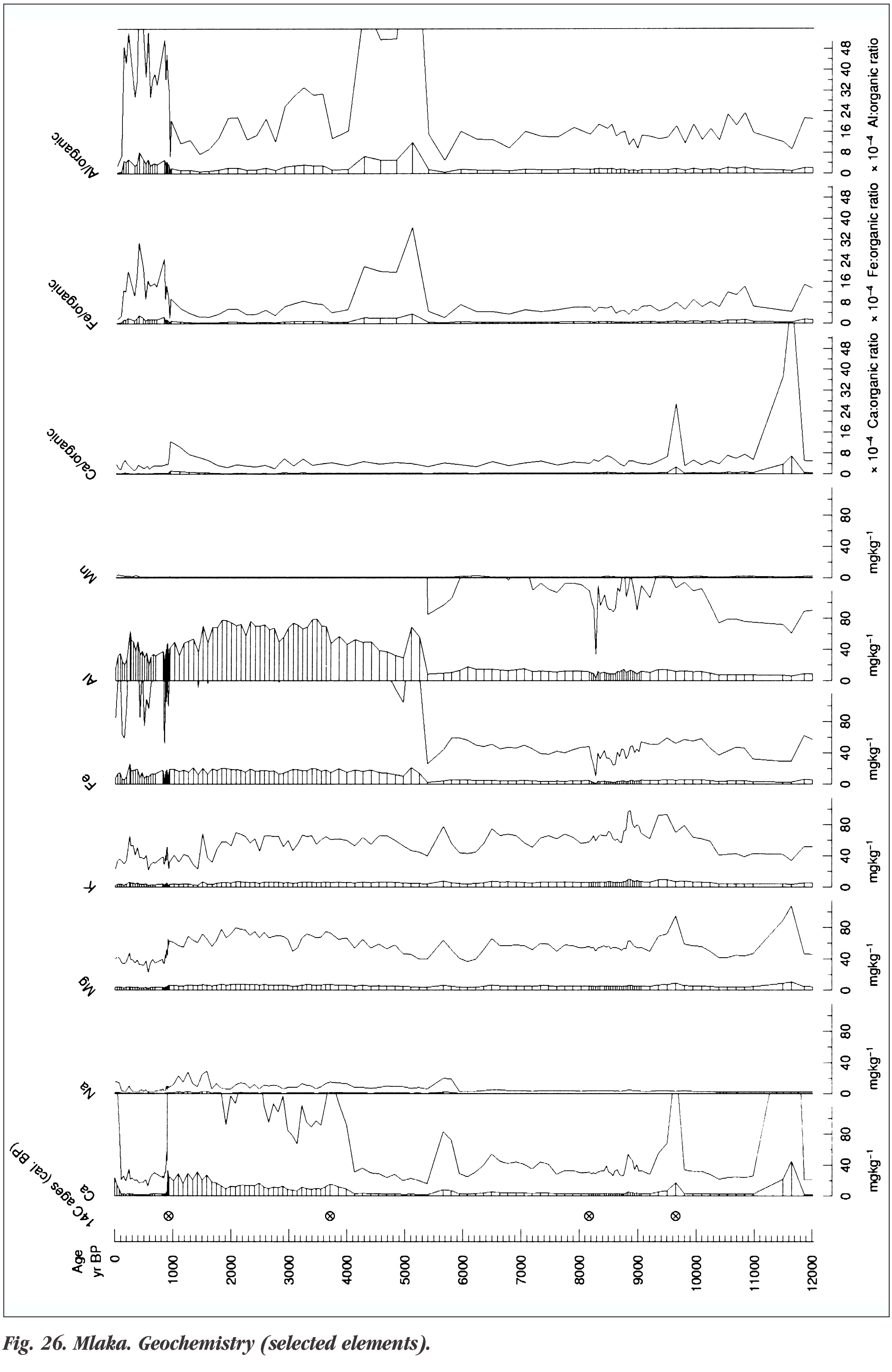

*Fig. 26. Mlaka. Geochemistry (selected elements).*

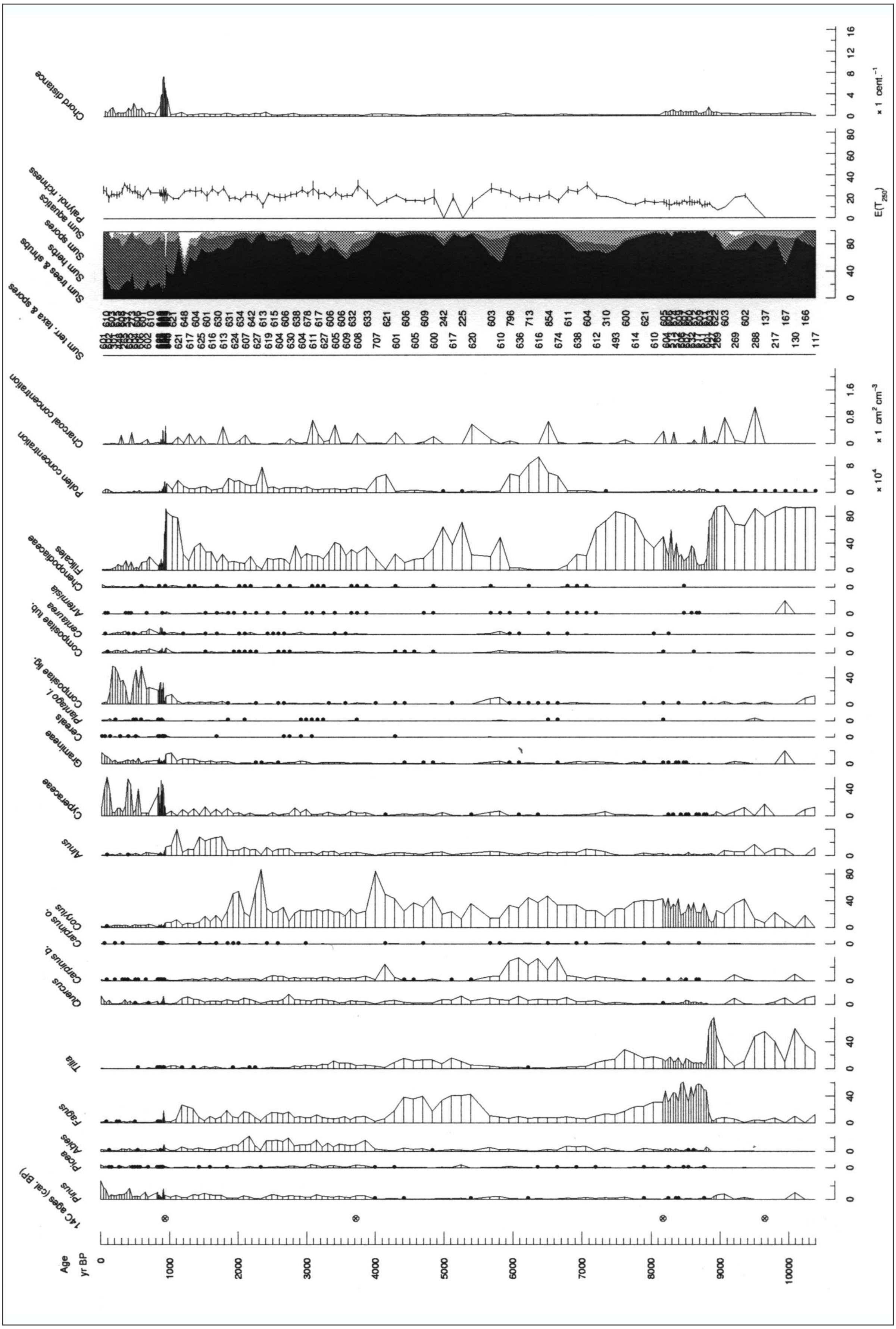

*Fig. 27. Mlaka. Percentage pollen diagram (selected taxa).*

it is difficult to estimate when the present-day landscape appeared. The lime decline (*ca.* 7000 cal. BP, 5000 cal. BC), the appearance of cereal type pollen grains and soil erosion that followed at 6000 cal. BP (4000 cal. BC) indicate human activity. Herb pollen curves however suggest that the present-day landscape might not form before 1400 AD, when soil erosion occurred again.

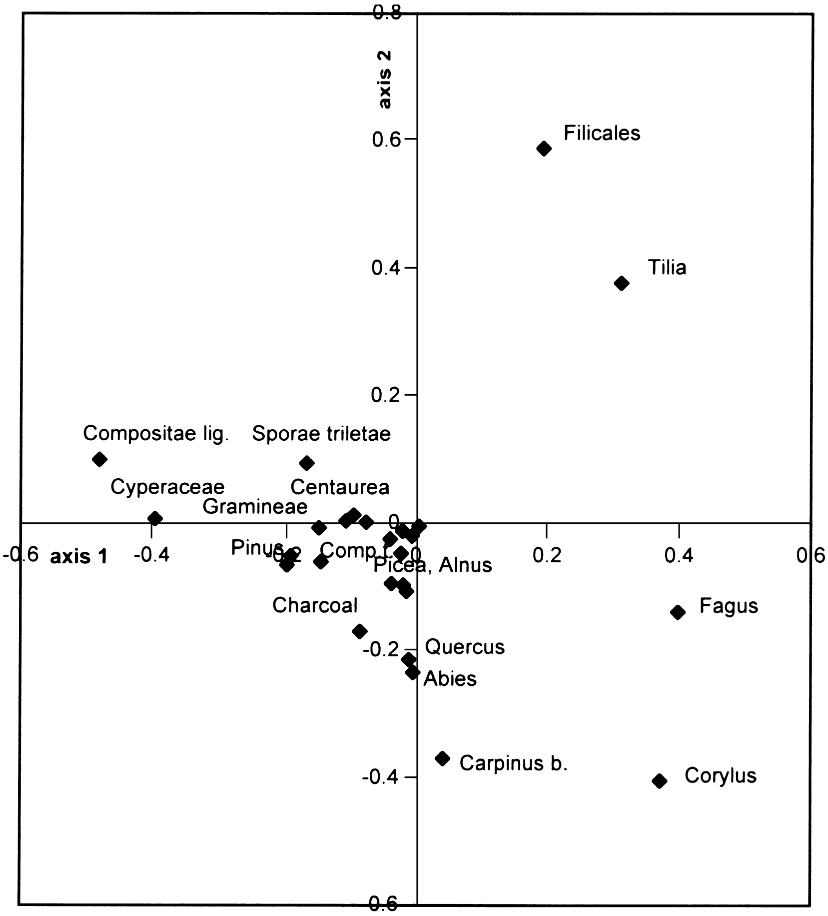

*Fig. 28. Mlaka. PCA. Taxa scores.*

## THE NEOLITHIC TRANSITION TO FARMING

Archaeological research suggests that major changes in the Neolithic settlement pattern, economy and material culture in the south-eastern Europe occurred at 6500 cal. BC. Changes included the construction of more permanent settlements, pottery production and domestication of plants and animals (*Hodder 1990; Whittle 1996; Sherratt 1997a; Zvelebil 1998; Bailey 2000*). Some of these changes reached the central and western Europe only after 5500 cal. BC (*Whittle 1996*). Slovenia is situated between south-eastern and central Europe. Studies of Slovenian Neolitic pottery style have suggested contacts with two major farming Neolithic cultural complexes: Impresso-Cardium/Danilo/Hvar culture in the Mediterranean and Starčevo-Körös-Criş/Vinča/LBK in the Balkans and central Europe (*Korošec 1960a; 1960b; Bregant 1974; Batović 1973; Budja 1983; Tomaž 1999 and references therein*). The oldest stratigraphically excavated and radiocarbon dated Neolithic levels in Slovenia are dated in the middle Neolithic (Moverna vas: 4904–4874 cal. BC, *Budja 1993*). No reliably dated early Neolithic sites have been discovered and the nature of the Neolithic transition to farming is not very well known. This section aims to ask what did the Slovenian landscape look like in this transitional period, what was the human impact on the environment and what might be the reasons for the transition to farming?

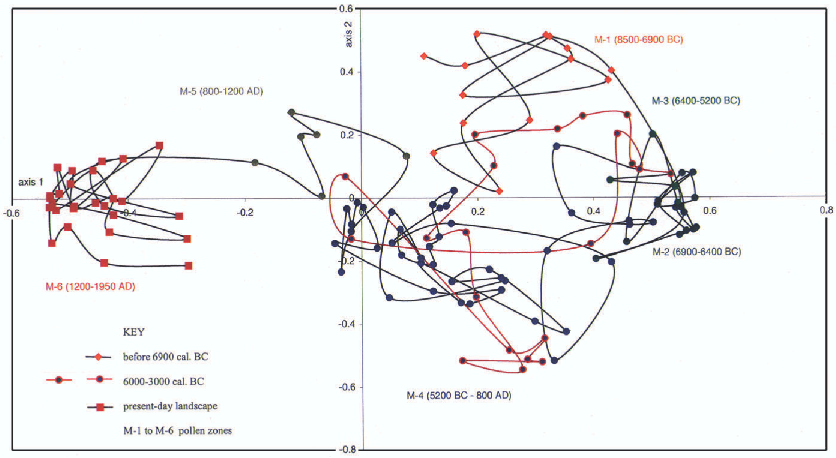

*Fig. 29. Mlaka. PCA. Sample scores.*

The Late Quaternary vegetation development in Slovenia was very dynamic. In the Late Glacial the landscape was covered by predominantly pine-birch woodland. At the beginning of the Holocene lime, oak, elm and hazel replaced pine and birch. At 6900 cal. BC – several centuries before presumable transition to farming –

a major change of vegetation occurred throughout Slovenia. Shade-tolerant trees (such as beech and fir) started to dominate. Distinctive phytogeographic regions appeared: beech-fir forest spread in the Dinaric region, the main tree taxon in the Predinaric region became beech, whereas predominantly lime forest became established in the Subpannonian and Submediterranean regions. The reasons for this simultaneous change of vegetation were presumably climatic, an increase of precipitation.

The results from this study suggest that in Slovenia Mesolithic and Neolithic landscapes were different. During the Mesolithic the dominant vegetation in all study regions was open woodland of lime, oak and hazel. A sudden change of forest composition occurred with the spread of shade-tolerant trees at 6900 cal. BC and several regional 'Neolithic landscapes' formed.

These results open several questions and at the present state of research only some of them can be addressed. The first question is what were the consequences of this vegetation change for the hunter-gatherer subsistence? Did the change of vegetation trigger a change in the fauna composition? Did supposed change in fauna (loss of grazers?), associated with the forest change prompt the transition to farming? How did hunter-gatherers adapt to a change in the variety of plant food available? Did the 'last' hunter-gatherers and 'first' farmers fight against thicker forest by cutting trees and burning forest? And, finally, did they change their settlement pattern after 6900 cal. BC?

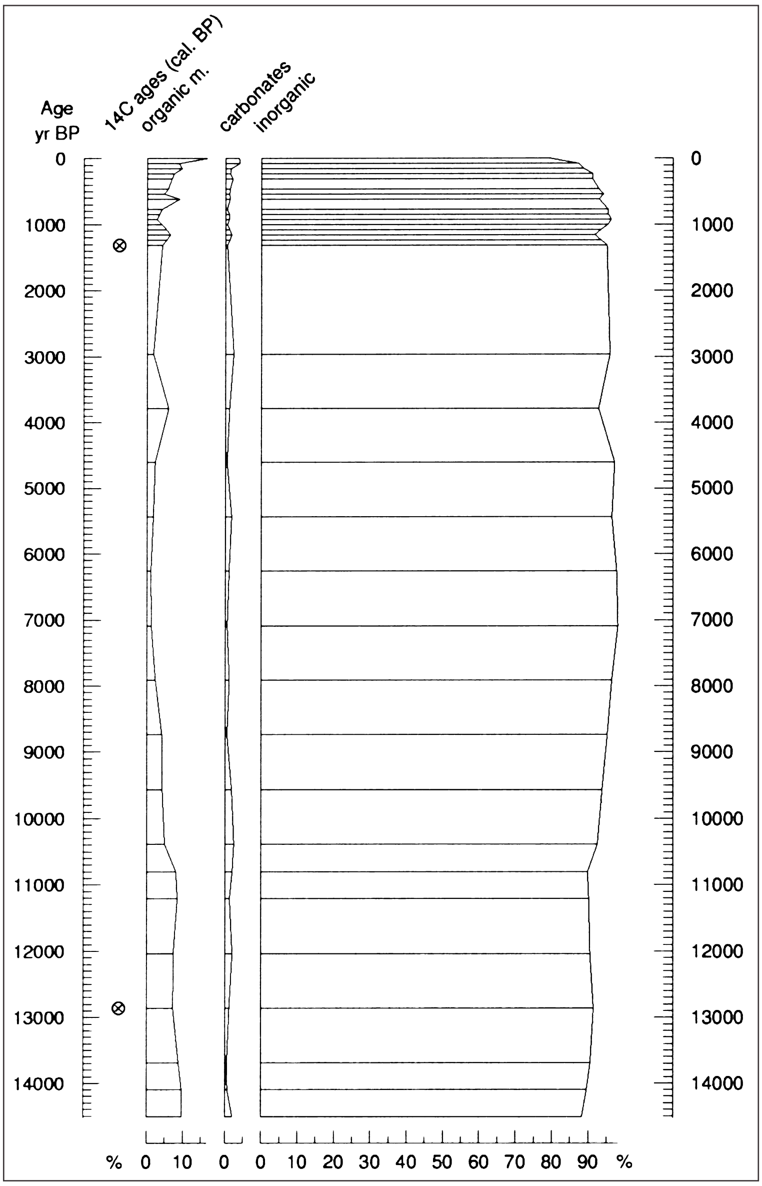

*Fig. 30. Noričke graba. Loss-on-ignition.*

The results from this study, combined with the archaeological research, can be used to address the last two questions. High resolution pollen analysis at Mlaka site suggests that small-scale openings of the beech canopy occurred after 6900 cal. BC. Some of these canopy gaps coincide with the charcoal peaks. It is possible that these subtle fluctuations of the forest composition were caused by a small-scale forest burning of the local Mesolithic populations. Admittedly, fire regimes can be climatically driven and since charcoal analysis cannot be used to distinguish whether individual fire events were natural or anthropogenic, the possibility that the Mesolithic populations were using fire to manipulate the environment cannot either be confirmed or ruled out. Never the less, the Mlaka area has a good prospect to study Mesolithic settlement pattern and the transition to farming. In the Prapoče area, where the Mesolithic settlement pattern has been studied in detail, radiocarbon dates from six cave sites range from 9500 to 7000 cal. BP (*Miracle & Fornbaher 2000*). In the levels dated after 7000 cal. BC archaeological finds are scarce. This suggests that after 7000 cal. BC the archaeological settlement pattern changed and caves were not visited very frequently any more.

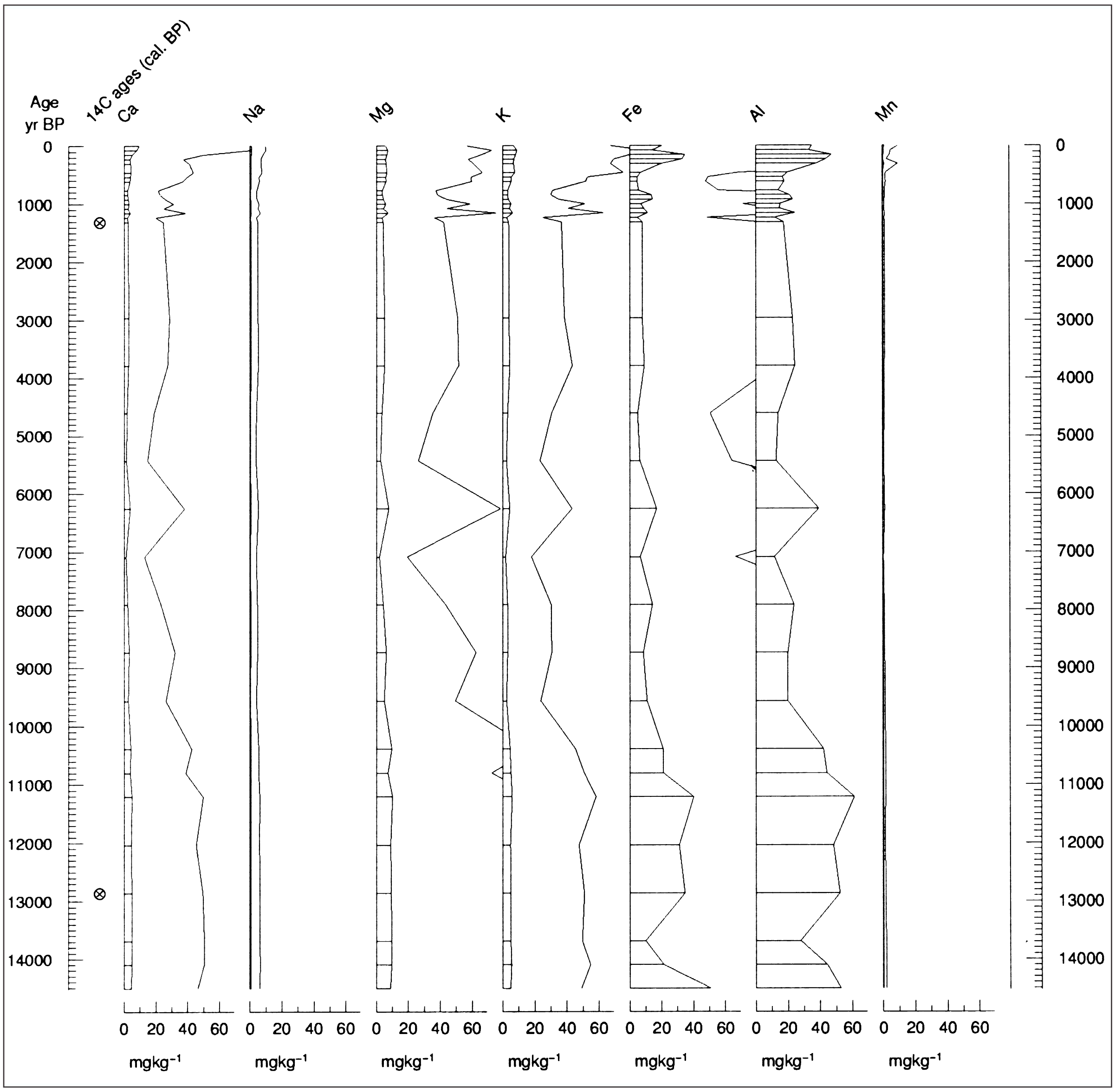

*Fig. 31. Noricka graba. Geochemistry (selected elements).*

These two examples suggest that the Mesolithic people might be involved in small-scale forest clearance and/or burning and that in some regions a change in vegetation composition at *ca.* 6900 cal. BC was possibly followed by a change in the archaeological settlement pattern.

Previous research suggested that no major (landscape scale) forest clearance occurred at the transition to farming in the south-eastern Europe (*Willis & Bennett 1994; Gardner 1999a; 1999b*). The results of this study are in agreement with previous research – in Slovenia there seems to be no signs of significant pressure on the environment connected with major population movement and the introduction of agricultural economy. In that sense, there seems that no time-transgressive spread of agriculture to Slovenia took place. Major forest clearance at all four study sites occurred only at the formation of the present-day landscape which ranged in date from 1000 cal. BC to 1400 AD. Although no major Neolithic forest clearance was carried out on the regional level, pollen record indicates that small-scale forest clearance, burning and coppicing can be detected with high resolution pollen analysis of small sites.

The forested Neolithic landscape was never the less, very dynamic and varied in time and space. The results of principal components analysis (PCA, Figs. 17, 24, 29 and 34) indicate that three distinctive phases of vegetation development, early Holocene (8000–6900 cal. BC), middle Holocene (after 6900 cal. BC) and the formation of the present-day land-

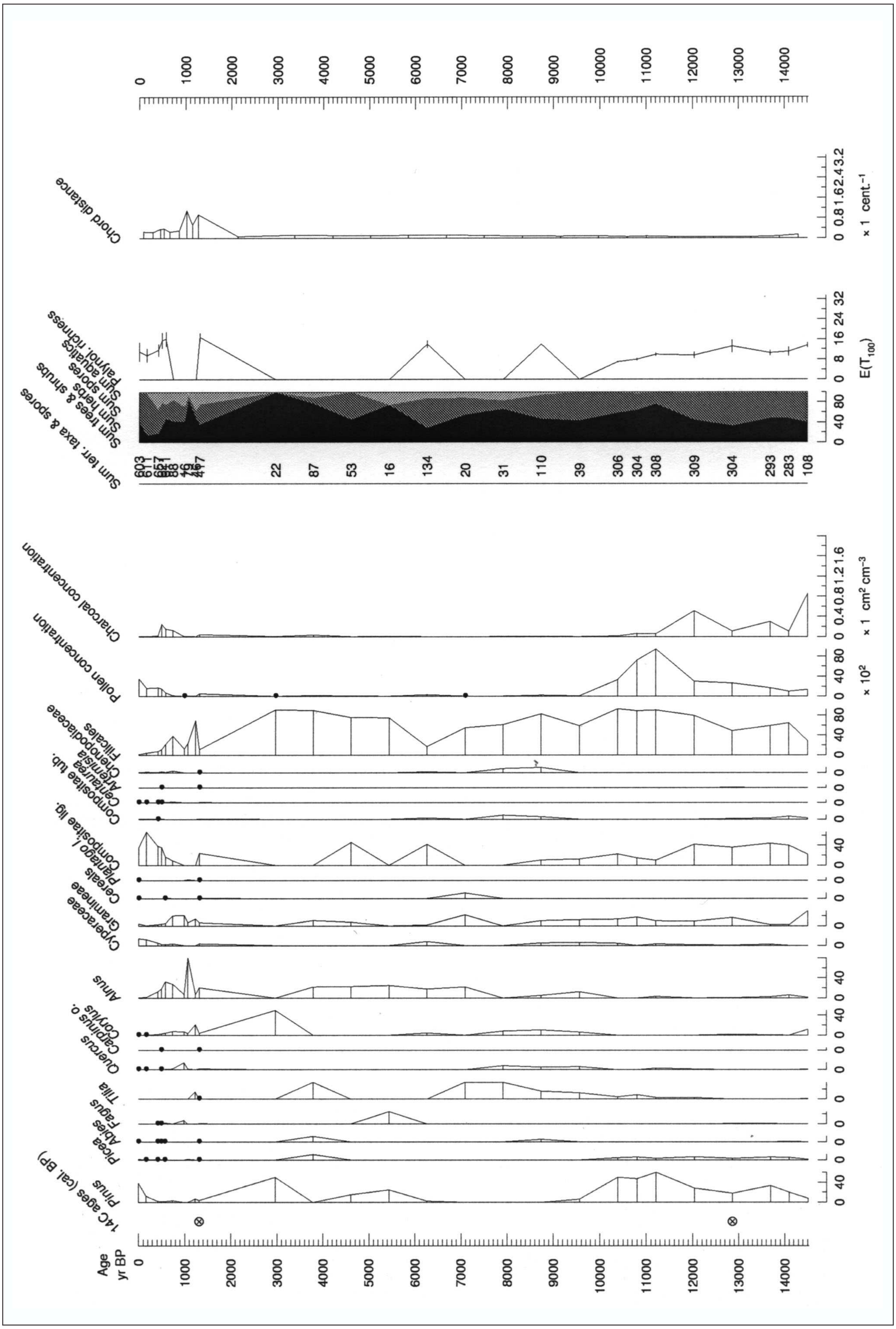

*Fig. 32. Norička graba. Parcentage pollen diagram (selected taxa).*

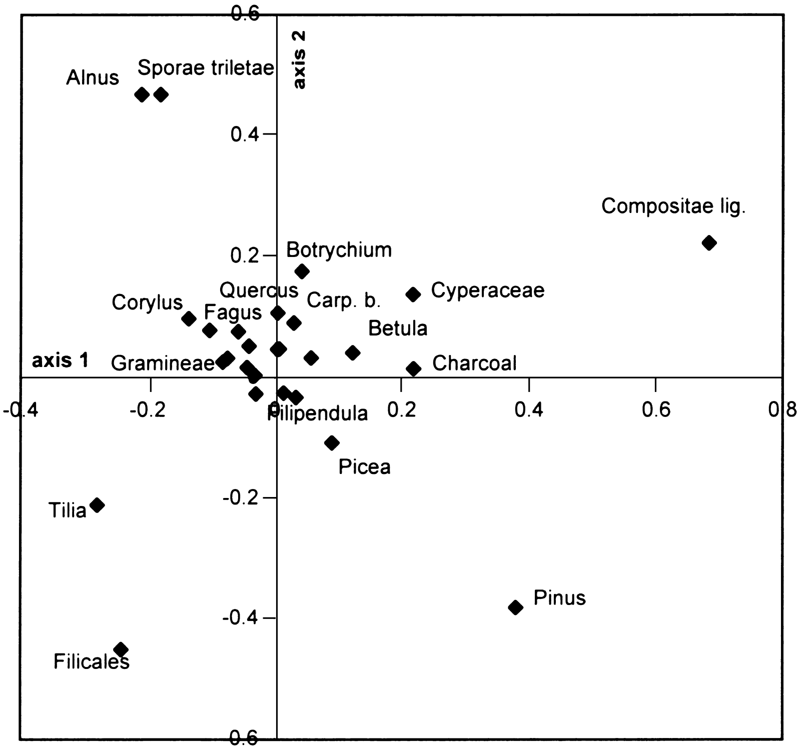

*Fig. 33. Noričká graba. PCA. Taxa scores.*

scape can be distinguished on each study site. Both, early and middle Holocene vegetation were very specific and have no present-day analogues. In particular, no analogues for the Neolithic vegetation exist today. Although the vegetation composition in the middle Holocene occasionally 'swung' towards the present state, the formation of the present-day landscape was a sudden event. It was an irreversible change and once human pressure passed the threshold, the modern landscape formed. PCA of the pollen data (Fig. 29) also shows that between 6000 and 3000 cal. BC the vegetation of Mlaka site, for example, changed from beech forest to open landscape (similar to early Holocene woodland), hornbeam forest, very open landscape again (similar to landscape at *ca.* 500 AD) and back to the beech forest. The main direction of vegetation change at Gorenje jezero (Fig. 24) between 6000 and 3000 cal. BC was from predominantly alder forest to fir-beech forest and more open landscape. The results of PCA (Figs. 17, 24, 29 and 34) also show that the landscape was most dynamic between 6000 cal. BC and the formation of the present-day landscape.

This landscape dynamics possibly reflects human activity. The small-scale forest clearance, burning and coppicing probably created a mosaic landscape, composed of patches with different vegetation. Biodiversity of this environment was high and increased with human impact (*Birks 1990; Birks et al. 1990*). An increase of palynological richness detected on all pollen diagrams can probably be connected with the Neolithic transition to farming. Palynological richness at four study sites shows some similar general trends. It increases by *ca.* 5000 cal. BC and then it stays constant (Gorenje jezero, Fig. 22) or slightly increases (Mlaka, Fig. 27). At Prapoče the palynological richness is highest after 1300 cal. BC (especially at 300–1 cal. BC), in the period when charcoal record suggests burning of the landscape. This is in accordance with ecological studies suggesting that fire disturbance increases biodiversity (*Whelan 1995*). Palynological richness decreases with or after the formation of the present-day landscape (Prapoče after ca. 1 cal. BC, Gorenje jezero after 300 AD, Noričká graba at 1400 AD), probably because the human impact was very intensive and habitat diversity declined.

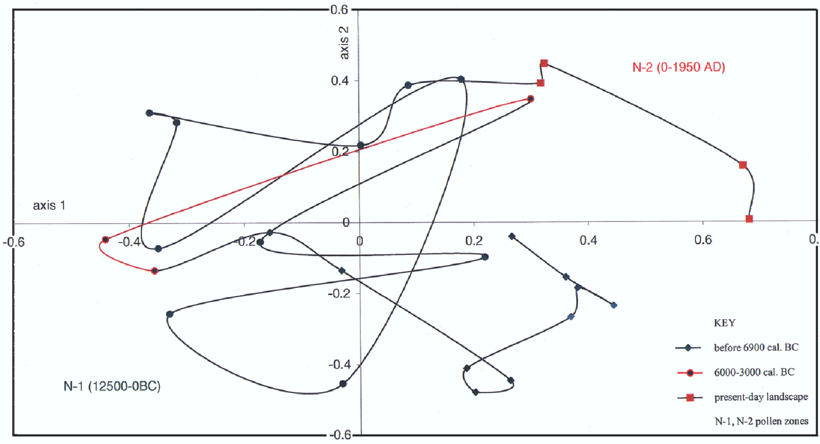

*Fig. 34. Noričká graba. PCA. Sample scores.*

## CONCLUSIONS

The results from this study indicate that the impact of the first farmers on the Slovenian landscape (small-scale forest clearance, burning and coppicing) can be detected by high resolution pollen analysis of small palaeoecological sites. Human activity in the Neolithic probably led to the formation of mosaic landscape. The present-day Slovenian landscape however formed only several millennia after the transition to farming.

The archaeological implications from this research are that in several study regions hitherto undiscovered archaeological sites are probably located in the vicinity of the coring locations (*e.g.* Eneolithic/Bronze Age site at Prapoče and Neolithic sites at Gorenje jezero and Mlaka). The forest clearance at Mlaka site at *ca.* 6000 cal. BC pre-dates the earliest Neolithic site in the area (Moverna vas) for *ca.* 1000 years and suggests that it is possible that hunter-gatherers and early farmers lived in Bela krajina, but their sites have not been discovered yet. Further archaeological and palaeoecological research at Mlaka and in other parts of Bela krajina will help us to better understand the process of transition to farming.

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1 List of archaeological sites that lie ca. 15 km around all coring locations is based on information derived from the database of Research centre of Slovenian Academy of Science and Technology, Institut of Archaeology in Ljubljana and the database of Dr. P. Miracle, Department of Archaeology, University of Cambridge. For the literature published before 1975 see “Arheološka najdišča Slovenije. Ljubljana. 1975”: 1.Prapoče, prehistoric hillfort (Marchesetti 1903.109; Calafati 1903); 2. Nilinum (Gradina di Lanischie), prehistoric hillfort (Benussi 1927–28.267); 3. Orljak iznad Lanišča, prehistoric and Roman hillfort (Marchesetti 1903.96; De Franceschi 1964); 3. Rašpor, prehistoric hillfort (Marchesetti 1903.109; Calafati 1903; Benussi 1927–28); 4. Trstenik, site of unknown age (Benussi 1927–28.269); 5. S. Martin kod Vodica, site of unknown age (Marchesetti 1903.109; Calafati 1903); Benussi, B. 1927–28. Dalle annotazioni di Alberte Puschi per la carta archeologica dell’Istria. Arch. Triest. Ser. III, 14, 267; Calafati, A. 1903. Il Tourista 1–4. Trst; De Franceschi, C. 1964. Storia documentata della Dantea di Pisino, AMSI. 10–12; Marchesetti, C. 1903. Castellieri della Venezia, Biulia. Trieste.

2 List of archaeological sites: 1. Farovka, Mesolithic, Neolithic and Eneolithic (?) open air settlement (Drole 1995, 140); 2. Srednje njive, prehistoric pottery and stone tools found, (Schein 1993, 45); 3. Gorica, prehistoric (?) pottery and stone tools found, (topographic notes of J. and B. Dirjec); 4. Sv. Kancijan, prehistoric fortified settlement (Bronze Age, Roman and Medieval finds) (Schein 1993.41–45); 5. Turščeva skedenica,

cave, Early Bronze Age site; 6. Žerunček (Žerovinšček), prehistoric hillfort (Schein 1988, Teržan 1995.127); 7. Peskovec, Tičnica, prehistoric fortified settlement (Schein 1988); 8. Kamna gorica, Iron Age settlement (Schein 1988); 9. Gradišče and Casermanov laz, Iron Age settlement and cemetery (Schein 1985.212; Slabe 1981.224; Guštin 1978.Tab. 36; Schein 1988); 10. Velika Slivnica, prehistoric settlement (Schein 1988, Slabe 1983.278; Guštin 1979.Tab. 3); 11. Lijevka (Tomšičeva jama, jama nad Grahovim), Iron Age site (Leben 1978.14); 12. Šteberk, prehistoric fortified settlement; 13. Stražišče (Gorenje jezero), fortified prehistoric settlement (Schein 1988); 14. Markovski grič, prehistoric settlement; 15. Gradec, Dane, prehistoric fortified settlement (Schein 1988); 16. Dane, Iron Age site (Kim 1978.10, 33); 17. Šmaraški vrh, Ušenična, Iron Age settlement, prehistoric and Roman graves (Schein 1988); 18. Cvinger, Iron Age and Roman settlement (Urleb 1981.179–194); 19. Tržišče, Iron Age and Roman settlement, Iron Age cemetery (Guštin 1978; Schein 1988); 20. Križna gora, prehistoric, Roman and Medieval settlement, late Bronze Age, Iron Age and Medieval cemetery (Guštin 1978; Urleb 1977; Ciglenečki 1987); 21. Janeževa hiša, Lož, Iron Age and Roman site; 22. Ulaka, Stari trg pri Ložu, Prehistoric and Roman settlement (Slabe 1983.215–216; Urleb 1977; Guštin 1978; Schein 1988.VS 25, 215); 23. Svinja gorica, Roman cemetery (Urleb 1981; Rešena...1980; Urleb 1983; Urleb 1979; Urleb 1981a); 24. Dane, pod češnjo, Roman grave (Slabe 1974.417–423; Slabe 1974a.195); 25. Nadleški grič, Roman site; 26. Gradišče, Stari trg pri Ložu, Roman villa; 27. Sv. Pavel, medieval cemetery (VS 1979; Arheološki... 1977); 28. Sv. Jurij, medieval cemetery (Urleb 1977); 29. Špiček, fortified settlement of unknown age; 30. Zajčji grič, fortified settlement of unknown age; 31. Križna jama, prehistoric cave site (Schein 1988); 32. Mali vrhek, Iron Age and Roman settlement (?), (Urleb 1977); 33. Podcerkev, cemetery of unknown age.

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3 List of archaeological sites: 1. Pusti gradac, Neolithic/Eneolithic, Bronze Age and Roman settlement, Medieval castle (Teržan 1995.86; Dular 1985.67–68); 2. Šipek, Roman cemetery (Dular 1985.68–69); 3. Veliki Nerajac – Brezjece, Iron Age cemetery (Dular 1985.69–70); 4. Belčji vrh – Pečni vrh, settlement and cemetery of unknown age (Dular 1985.66); 5. Dragovanja vas, Eneolithic (?) site (Dular 1985.66–67); 6. Doblička gora, Eneolthic (?) site (Dular 1985.58–59); 7. Dobliče – Vrti, Prehistoric (?) site (Dular 1985.58); 8. Zorenci, Neolithic, Eneolithic and Bronze Age site (Dular 1985.65); 9. Breznik, site of unknown age (Dular 1985.66); 10. Golek, Medieval settlement (Dular 1985.67; Ciglenečki 1978); 11. Veliki Koležaj, late Roman settlement (Dular 1985, 70–71); 12. Tribuče, Roman cemetery (Dular 1985, 64–65); 13. Butoraj, Bronze Age and Roman cemetery (Dular 1985, 56); 14. Dolenjci, Eneolthic (?) site (Dular 1985, 55); 15. Črnomelj, Sadež, Bronze Age, Iron Age, Roman and Medieval cemetery (Dular 1985, 57; Mason 1998); 16. Črnomelj – župna cerkev, Bronze Age and Iron Age settlement, Medieval cemetery (Dular 1985, 58); 17. Črnomelj – Sv. Duh, late Roman settlement and cemetery; 18. Loka pri Črnomlju – Grajska cesta, Iron Age cemetery (Dular 1985, 59–60); 19. Loka pri Črnomlju – Okljuk, Roman settlement and cemetery (Dular 1985, 60); 20. Loka pri Črnomlju – Rdeči hrib, Eneolthic (?) site (Dular 1985, 61); 21. Daljne njive, cemetery of unknown age (Dular 1985, 105); 22. Drenovec, Iron Age site (Dular 1985, 105–106); 23. Golek pri Vinici, Iron Age settlement, Iron Age and Latene cemetery (Dular 1985, 106); 24. Gorica, Iron Age settlement (Dular 1985, 108); 25. Hrast pri Vinici, site of unknown age (Dular 1985, 108–109); 26. Ogulin, Roman site (Dular 1985, 109); 27. Perudina, Roman (?) site (Dular 1985, 109–110); 28. Podklanec, Roman cemetery (Dular 1985, 110); 29. Sečje selo – Učakovske stene, site of unknown age (Dular 1985, 111); 30. Sečje selo – Veliki zjot, Eneolithic and Bronze Age site (Dular 1985, 111; Leben 1991); 31. Zilje, Roman grave (Dular 1985, 112–113); 32. Gradinje, Eneolithic settlement and Roman cemetery (Phil Mason, pers. comm. 2000).

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4 List of archaeological sites: 1. Plitvica, Roman cemetery; 2. Črešnjevci, cemetery of unknown age; 3. Gornja Radgona, presumably Neolithic settlement, Bronze Age, Iron Age and Latene settlement, Iron Age and Roman cemetery (Šavel 1980; Šavel 1987; Tušek 1989; Tušek 1990; Tušek 1995; Horvat-Šavel 1981; Teržan 1995, 52); 4. Hercegovščak, Bronze Age site and Roman cemetery; 5. Lastomerci, Roman cemetery; 6. Spodnja Ščavnica, cemetery of unknown age; 7. Boračeva, cemetery of unknown age; 8. Hrastje – Mota, cemetery of unknown age; 9. Kapelski vrh, Neolithic (?) site, Roman (?) site; 10. Murski vrh, Roman site; 11. Ptujska cesta, Roman (?) cemetery; 12. Radenci, Roman (?) cemetery, Neolithic (?) site;

13. Radenski vrh, Eneolithic (?) site; 14. Rihtarovci, Roman (?) cemetery; 15. Sp. Kocjan, Bronze Age, Roman and Medieval site; 16. Berkovci, site of unknown age; 17. Biserjane, Neolithic (?), Bronze and Iron Age site; 18. Blaguš, Roman (?) cemetery; 19. Dragotinci, Roman cemetery; 20. Galušak, Eneolithic (?) site; 21. Jamna, Roman settlement; 22. Okoslavci, Eneolithic (?) site; 23. Selišči, Eneolithic (?) site; 24. Slaptinci, Roman cemetery; 25. Stanetinci, Eneolithic (?) site; 26. Stara gora, Roman cemetery; 27. Terbegovci, Bronze Age (?) settlement; 28. Videm, Neolithic (?) settlement; 29. Ženik, Iron Age site; 30. Gornji Ivanjci, cemetery of unknown age; 31. Grabonoš, Roman cemetery; 32. Kunova, Eneolithic (?) site; 33. Negova, Eneolithic (?), Bronze Age and Roman site; 34. Očeslavci, Neolithic (?) site; 35. Spodnji Ivanjci, Roman cemetery; 36. Stavešinci, Roman cemetery; 37. Osek, Eneolithic site.

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