UDK 902.65:911.52(497.4):903.4"634/636":551.581.2
Documenta Praehistorica XXXV (2008)

Settlements, landscape and palaeoclimate dynamics on the Ižica floodplain of the Ljubljana Marshes

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ABSTRACT – *In this paper we present the results of the radiocarbon dating of organic sediments from palaeochannels we have mapped by LiDAR (Light Detection and Ranging) imagery on the Ižica floodplain. We point out that the palaeochannels and the settlement structures at Maharski prekop site are contemporaneous. We hypothesise that the episodes in past river behaviour on the Ljubljana Marshes correspond with climate anomalies in European palaeoclimate records in the Holocene.*

IZVLEČEK – *V članku predstavljamo rezultate radiokarbonskega (^{14}C) datiranja organskih depozitov v paleostrugah, ki smo jih kartirali z LiDAR posnetkom površja v poplavni ravnici Ižice. Dokazujemo, da so paleostruge in prazgodovinsko naselje Maharski prekop sočasni. Ugotavljamo, da se spremembe v rečni mreži in hidrološkem režimu časovno prekrivajo z nizom klimatskih anomalij v holocenu.*

KEY WORDS – *Ljubljana Marshes; Holocene; LiDAR; palaeochannels; neo-eneolithic settlements; radiocarbon dating; climate anomalies*

Introduction

Simplified interpretative postulates in the perception of the prehistoric settlement patterns and palaeolandscapes on the Ljubljana Marshes that 'lake chalk' and 'vertical piles' can be representamens of a 'prehistoric lake' and pile-dwellings built on it, and that they can mark the shift of post-Mesolithic, supposedly Neolithic settlements from the land to the lake were recently replaced by the model of an active river floodplain and settlements and catchment areas within. The interpretative reduction that a series of vertical piles relates to the function of platform holders exclusively was compensated by the complex interpretation of a series of 2432 vertical wooden piles at the Maharski prekop site that show the number of rectangular wooden structures (group of houses), and a structure running parallel with the palaeochannel that is believed to protect the settlement against river bank erosion (for details see *Budja 1994 (1995); 1997; Budja, Mlekuž 2001; Mlekuž, Budja, Ogrinc 2006*).

In this paper, we present the results of the radiocarbon dating of the organic sediments from palaeochannels we have mapped by the LiDAR (Light Detection and Ranging) imagery. These data are than compared with and discussed in relation to Holocene climate anomalies. We hypothesise that the episodes in past river behaviour on the Ljubljana Marshes correspond with climate anomalies in European palaeoclimate records.

Ižica floodplain and LiDAR

The Ižica is a river with an extensive karstic watershed in the Dinaric plateau south of the Ljubljana Marshes. It is a low energy river characterized by a very low gradient, broad floodplain and dominant fine-grained sedimentation. The Ižica was a mobile river and left earlier channels scattered across the floodplain. They can be identified on aerial photos as cropmarks, mainly as faint, broad anomalies, which do not enable the identification of individual channels. Aerial photographs reveal a very complex palimpsest of palaeochannels.

In order to create a more complete picture of the Ižica floodplain an airborne LiDAR survey of the part of the floodplain was commissioned. An area of 1300 x 600m (78 hectares) was surveyed. Eneolithic and Bronze Age sites (Resnikov prekop and Maharski prekop) are located in the surveyed area. LiDAR is frequently used as a tool for examining aspects of river floodplains, most often for geomorphological mapping or flood prediction purposes (*Lohani and Mason 2001; Charlton et al. 2003; Cobby et al. 2001; Marks and Bates 2000; Challis 2005; 2006; Jones et al. 2006*).

A LiDAR digital terrain model exposes extensive geomorphological detail of the study area and allows us to resolve fine details of the floodplain and terrace (Fig. 1). Three-dimensional elevation data enable us to discern the stratigraphic relations between floodplain features and to create cross-channel profiles. LiDAR provides us with a much more complete and detailed picture of the geomorphology than aerial photography (*Jones et al. 2007*). The results of LiDAR allow us to discern two main geomorphological units in the study area – an older terrace and a younger and lower active floodplain. The difference in elevation between units is up to 40cm. The most obvious features of the study area are the palaeochannels, visible as slight depressions in the landscape; however, LiDAR reveals other features, such as levees, and ridge and swale.

Based on the relative stratigraphic positions of palaeochannels, at least four distinctive phases of fluvial activity can be discerned. The first phase is characterized by a number of thin, relatively straight channels preserved on the terrace, suggesting a past

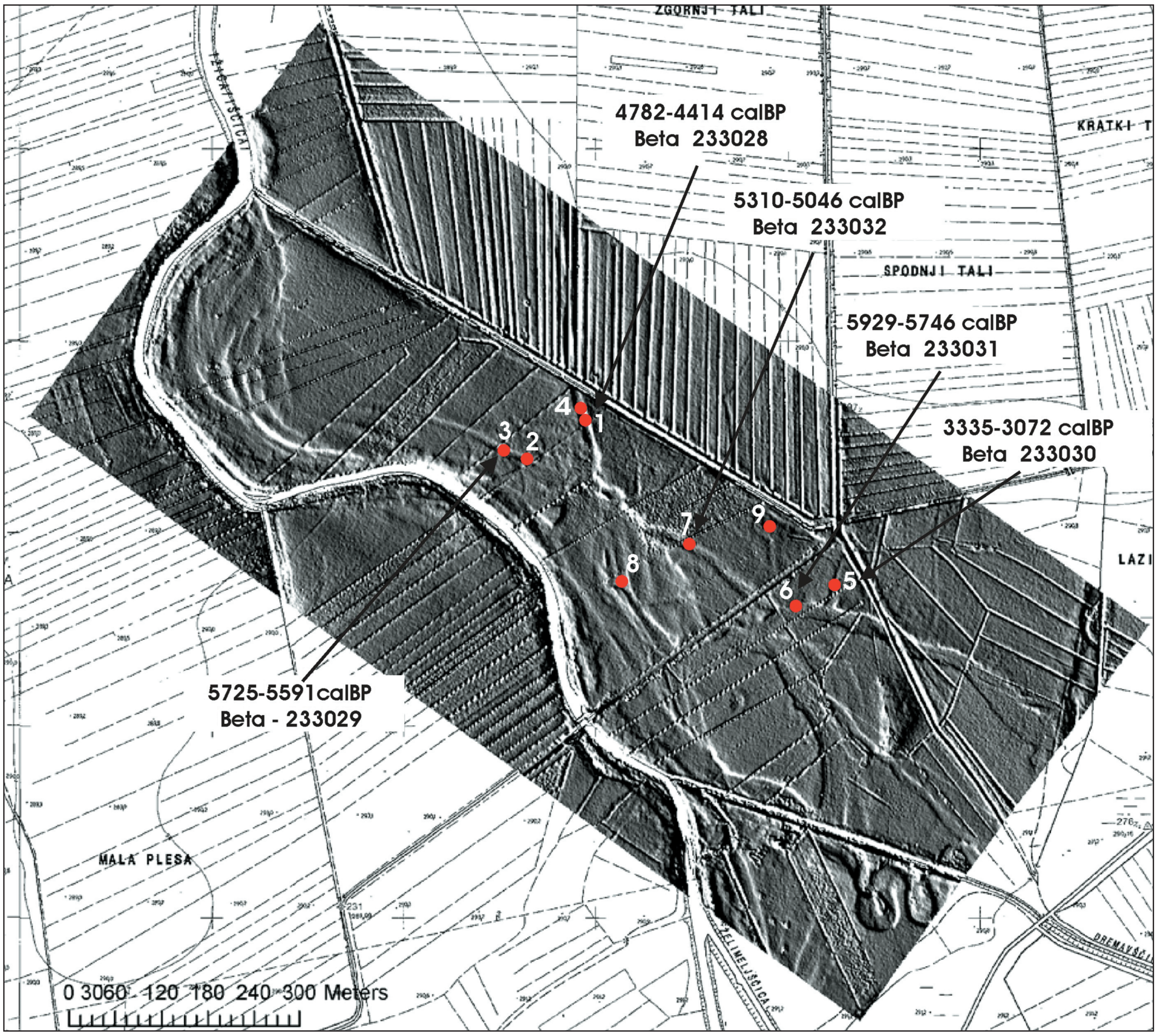

Fig. 1. LiDAR terrain model with the location of borehole records and radiocarbon dates of channels infill.

anastomosing regime. The second phase is represented by wide anastomosing channels in direct superposition with some phase one channels. Third phase is marked by the degradation of the Ižica and the creation of an active floodplain. This process created a well-developed terrace edge and preserved phase 1 and 2 channels on the terrace. Ižica became a more sinuous river. The most distinctive features of this phase are the ridge and swale features in the floodplain, with thalwegs, indicating significant lateral channel migration and meander core growth. And lastly, the fourth phase is a modern network, the result of flood-control and irrigation works in the 19th and 20th centuries (Fig. 2).

The change from straight and anastomosing to sinuous/meandering channels and degradation of the Ižica shows that there were significant changes in the hydrological regime of the streams draining the Ižica floodplain that were probably connected to Holocene climate anomalies.

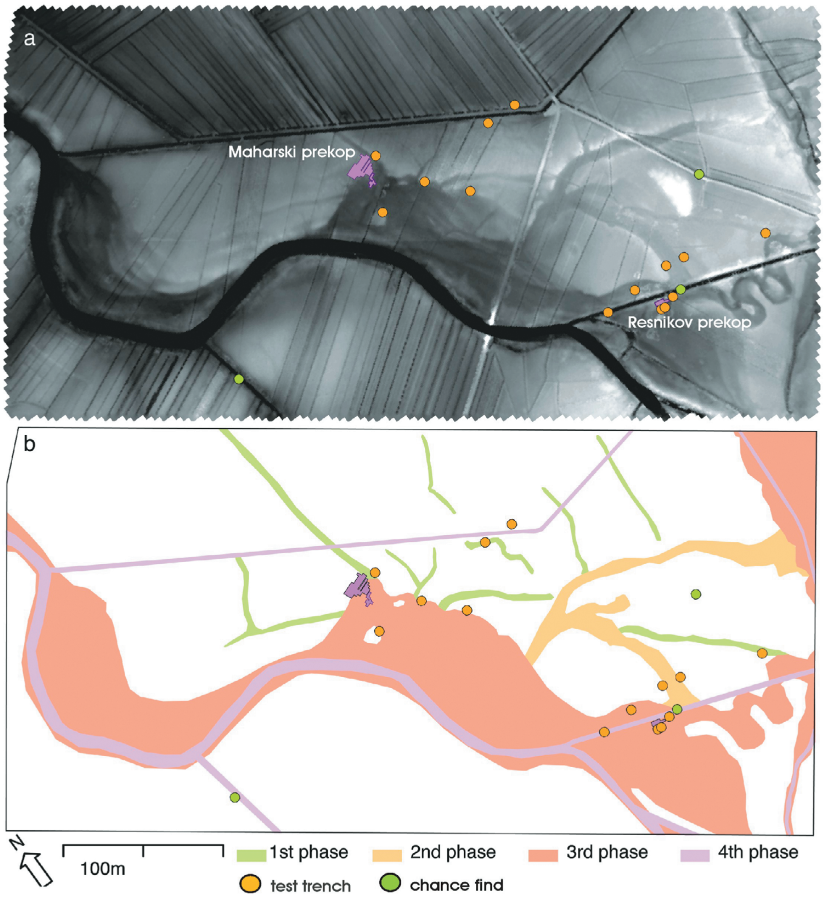

Fig. 2. LiDAR image (a) and, Maharski prekop and Resnikov prekop sites in the context of Ižica floodplain. The landscape is structured by an interlocking pattern of palaeochannels, and at least three phases of superimposed palaochanels can be observed (b) (after **Mlekuž, Budja, Ogrinc 2006.Fig.2*).***

Dating of palaeochannels

Systematic mapping of the study area allowed the selection of key localities for direct dating of the palaeochannels. Locations for boreholes were chosen on the base of LiDAR map and field inspections (Fig. 1). Boreholes were drilled with a motorized auger of 8cm diameter. Only substantial, spatially contiguous stratigraphic units were recorded. The model records the details of at least three sedimentary units: topsoil, organic deposits and lacustrine marls.

In total, 9 boreholes were drilled and examined; five samples from five boreholes were directly dated in the first phase of the project (Fig. 1). Samples for AMS radiocarbon dates were collected from the bottom of organic channel infill, 5 to 20cm above the lacustrine marl. This assumes that dates post-date channel cutting and provide maximum age (*terminus ante quem*) for channel infilling and abandonment.

Borehole 1 was located in a phase 1 palaeochannel near the site of Maharski prekop. On the ground, the depression is very evident. The borehole was comprised of topsoil underlain by fibrous dark organic deposit. At 120cm there is a sharp transition to chalky lacustrine marls. A sample of the organic deposit collected from 110cm yielded a radiocarbon age range 4782–4414 calBP (Beta-233028)[1].

Borehole 3 was drilled in a straight phase 1 channel, southwest of the Maharski prekop site. It shows very similar stratigraphy, with topsoil, organic rich sedi-

1 All the dates in the text are calibrated with the program CALIB version 5.10., and given in two sigma ranges (*Reimer et al. 2004*). The conventional radiocarbon dates are presented on Table 1.

ment and a sharp transition to lacustrine marls at 115cm. A sample from 110cm yielded age range 5725–5591 calBP (Beta-233029).

Borehole 7 was recovered from the phase 1 palaeochannel southeast of the Maharski prekop site. The sample was taken from a depth of 50cm, 5cm above the marl, and yielded age range 5310–5046 calBP (Beta-233032).

Borehole 5 was located at the junction of the straight channel and wider, second phase channel. A sample of organic sediment from 125cm, 20cm above the lacustrine marl, yielded age range 3335–3072 calBP (Beta-233030).

Borehole 6 was located at the edge of the wide, second phase palaeochannel, 50m west of borehole 5. A sample from a depth of 100cm, 20cm above the marls, yielded age range 5929–5746 calBP (Beta-233031). This date can be considered as too early for the infill of the second phase channel. The dated channel is in direct superposition with the first phase channel, dated with borehole 7 (see above) to age range 5310–5046 calBP. The date from borehole 5 suggest that this second phase channel could be dated to before age range 3335–3072 calBP. We assume that the date pre-dates channel cutting and actually dates the terrace surface. This is supported by a piece of prehistoric pottery found in the borehole, indicating that we dated an undisturbed surface, predating channel cutting. We therefore suggest that 5929–5746 calBP is the age range of the terrace surface.

Radiocarbon dates place the first phase of the palaeochannels before 5725 calBP. Thus, at the latest at 3776 calBC this part of Ljubljana Marshes was an active floodplain and not a shallow lake, as the traditional view suggests.

Maharski prekop settlement on the Ižica floodplain

The radiocarbon data indicate that the south-eastern part of Ljubljana Marshes was already settled in the tenth millennium BP. The earliest series of conventional radiocarbon dates from the Breg and Babna Gorica sites are followed by radiocarbon dates from Resnikov prekop and Maharski prekop (Tab. 1).

Palynological data indicate that the floodplain supported mixed-deciduous woodland, composed predominantly of *Quercus*, *Corylus, Fagus* and *Alnus*, but with some coniferous elements and open ground herbaceous taxa. In addition, the presence of cereal type pollen is attested at least from 6000 calBP (*Šercelj 1975.121–122; Gardner 1999.130, 189*). Extensive burning in the period 5550–5330 calBP that may have related to human activity in the area is hypothesised from high values in the charcoal curve. Increased burning (clearance) correlates with a sharp decline in arboreal pollen and an expansion of herbaceous taxa, particularly cereal type pollen and Poaceae, and thus supports the notion of fields surrounded by woodland (*Gardner 1999.130, 165, 168*; see also *Andrič 2007*).

In the composite plan of 2432 vertical wooden piles at Maharski prekop site, two patterns are recognized (Fig. 3). The first consists of rectangular wooden structures that were recognized as a group of houses with sizes of around 8–10 x 3.5–4.5m arranged in parallel. Each house is built of three rows of structural timbers, with a central row of centre-posts supporting a roof ridge pole; the lateral rows are wall posts. The floors were plastered with clay, and the stone features are probably the remains of thermal structures in the front/back of the house, or might be paved surfaces. Pottery, stone and bone tools are often deposited directly upon burned clay surfaces. The superpositions of clay floors separated by a thin layer of occupational debris may indicate the periodic rebuilding of surfaces. Houses were oriented with the longer side parallel to the channel. However, there is at least one house which is oriented perpendicularly to the others. Three woods, oak (*Quercus*), ash (*Fraxinus*) and rowan (*Sorbus*), comprise more than 90% of identified taxa (*Bregant 1974; 1975; Šercelj 1973; 1975; Budja 1994 (1995); 1997; Mlekuž, Budja, Ogrinc 2006*).

The second relates to two or three dense linear concentrations of piles running on the eastern side of the excavated area. The piles, of much smaller diameters than those mentioned above, were hammered into the palaeochannel slope, recognized at the hypothesised settling outskirts (*Bregant 1975.18–20; Šercelj 1973; 1975*). The structure is believed to have protected the site from floods and river bank erosion.

Abrupt climate changes in the Holocene

The 8200 calBP 'climate event' which abruptly and drastically changed global environments during the transition to farming in southeastern Europe is recently an intensively discussed topic. Less attention is being devoted to later climate oscillations and associated contrasting patterns of hydrological changes in Europe in response to abrupt climate changes and cooling phases. There were several cooling oscillations, hydrological reversals and major atmospheric circulation changes, recorded globally at *c.* 8200, 5200, 4200, 3500, 1200, and 600 calBP (*Rohling et al. 2002a; 2002b; Alley et al. 2003; Mayewski et al. 2004*) (Fig. 4).

From the central European Neo-Eneolithic perspective the most important are the climate oscillations in the period 5600–5000 calBP. The records from various regions in both hemispheres show global cooling and contrasting patterns of hydrological changes. The changes in vegetation cover, glacier advance and decline in tree lines in the mountains, increasing permafrost and retreating timberlines at high latitudes, cooler sea surface temperatures and ice-sheet isotope records at the poles have been recorded. In the European Alps the cooling has been assessed at 1–1.5° C for mean summer temperatures. While in central Asia, in the northern part of Africa and in the southern Mediterranean region where drier conditions were predominant, there were wetter conditions over intermediate latitudes between approx. Latitudes 40° and 60° in west-central Europe, where large fluctuations in river and lake levels and regional humidity have been recorded (*Mayewski et al. 2004; Magny 2004; Magny and Hass 2004*). These climate oscillations were being more recently recognized in western central European palaeoenvironmental and archaeological data as an abrupt tripartite climate change associated with drastic lake level fluctuations at 5550–5320 calBP (*Magny et al. 2006*). It is defined as 'Episode 9' in the long sequence of Alpine lake level fluctuations (*Magny 2004.74*).

The sequence consists of 15 successive episodes of higher lake levels in the Holocene. 'Episode 1' is dated just prior to 1394 AD, and 'Episode15' to a age range between 11 250 and 11 050 calBP (*Magny 2004; Magny et al. 2006*). The reconstruction of the episodes is based on regional patterns of palaeohydrological changes and lake level transgressions and regressions that have been recognized recently in palaeoenvironmental data and in a set of 180 radiocarbon, tree-ring and archaeological dates obtained from 26 lakes in the Jura Mountains, the northern French Pre-Alps and the Swiss Plateau.

'Episode 9' shows three successive peaks of higher water levels in Lake Constance (Bodensee), Lake Ge-

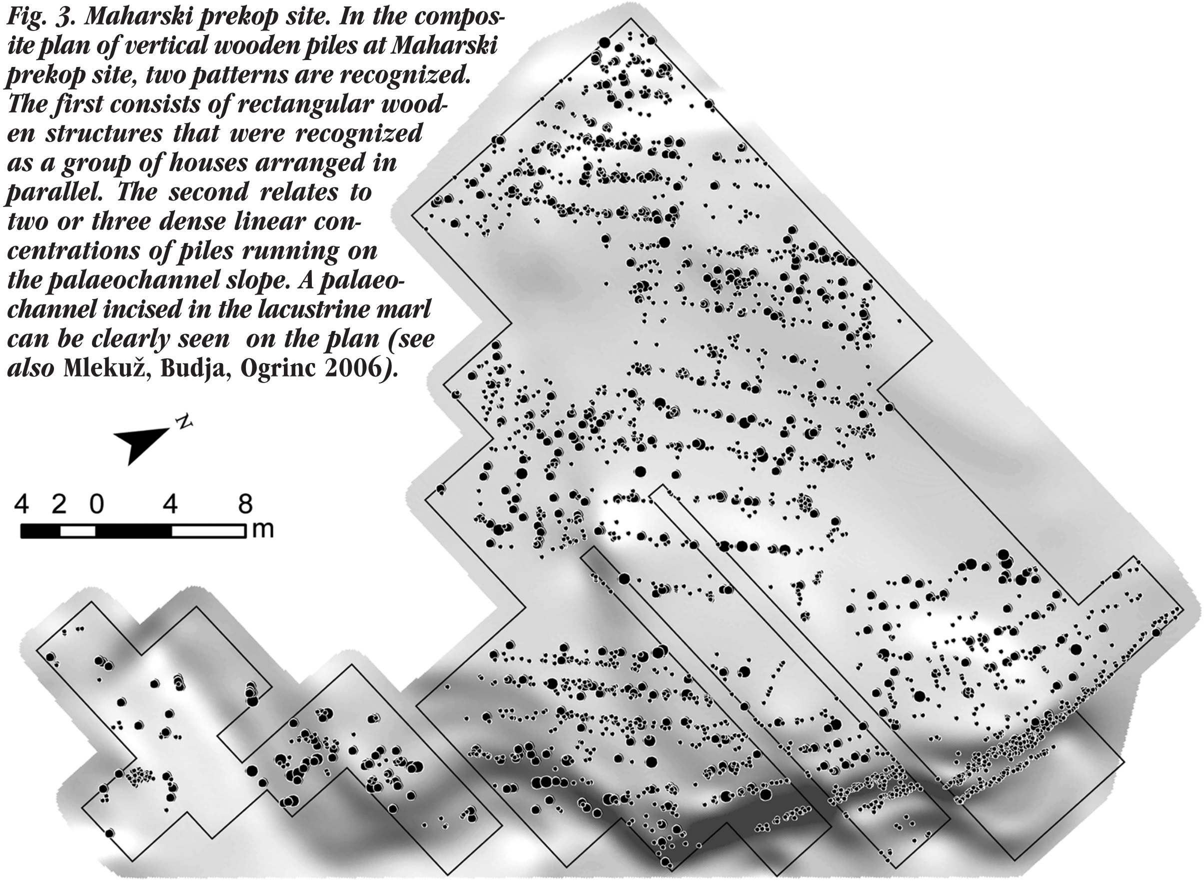

Fig. 3. Maharski prekop site. In the composite plan of vertical wooden piles at Maharski prekop site, two patterns are recognized. The first consists of rectangular wooden structures that were recognized as a group of houses arranged in parallel. The second relates to two or three dense linear concentrations of piles running on the palaeochannel slope. A palaeochannel incised in the lacustrine marl can be clearly seen on the plan (see also* Mlekuž, Budja, Ogrinc 2006*).

Labcode	Conventional radiocarbon age (BP)	CalBP age range (2σ)	CalBC age range (2σ)	Material	Context	Reference
Babna Gorica						
GrA–9855	5900±50	6881–6569	4932–4620	Charcoal	Excavations 1995; SU 09	
GrA–9856	6290±50	7321–7025	5372–5076	Charcoal	Excavations 1995; SU 19	
GrA–9857	6200±50	7249–6976	5300–5027	Charcoal	Excavations 1995; SU 17	
GrA–9440	6700±50	7660–7483	5711–5534	Other/Chalky lacustrine marls	Excavations 1995; SU 20	
Resnikov prekop						
Z–345	5850 ± 150	7142–6312	5193–4363	Wood	Excavations 1962, pile 5	*Srdoć et al. 1987.354*
Hd–24038	5718 ± 23	6627–6437	4678–4619	Wood (*Alnus glutinosa*)	Excavations 2005, trench 3, pile 33	*Čufar and Korenčič 2006.124*
Beta–182667	2120 ± 40	2301–1991	352–42	Sediment	Profile depth 120 cm	*Andrič 2006.Tab. 2*
Beta–184792	2220 ± 40	2331–2123	382–174	Sediment	Profile depth 115 cm	*Andrič 2006.Tab. 2*
Maharski prekop						
Z–278	4633 ± 117	5594–4974	3645–3025	Wood (*Quercus?*)	Excavations 1972, grid 12?, pile 40	*Srdoć et al. 1975.152*
Z–305	4345 ± 113	5305–4617	3356–2668	Wood (*Fraxinus*)	Excavations 1973, grid 15, pile 1	*Srdoć et al. 1975.152*
Z–314	4964 ± 99	5919–5482	3970–3533	Wood		*Srdoć et al. 1975.152*
Z–315	4701 ± 104	5644–5055	3695–3106	Wood (*Sorbus*)	Excavations 1972, grid 15, pile 4	*Srdoć et al. 1975.152*
Z–351	5080 ± 110	6174–5594	4225–3645	Wood (*Sorbus*)	Excavations 1974, test trench 4 grid 42, pile 156	*Srdoć et al. 1977.465–475*
Z–353	4330 ± 120	5300–4580	3351–2631	Wood	Excavations 1974, test trench 4	*Srdoć et al. 1977.465–475*
AA–27182	4680 ± 55	5581–5311	3632–3362	Charcoal	MP1 sediment exposure, charchoal layer 61–63 cm	*Gardner 1999.Table 5.1*
AA–27183	4980 ± 60	5892–5601	3943–3652	Charcoal	MP1 sediment exposure, charchoal layer 138cm	*Gardner 1999.Table 5.1*
Beta–219606	4740 ± 40	5586–5326	3637–3377	Bone (*Ovis*)	Grid square 42	*Mlekuž et al. 2006*
Beta–219607	4720 ± 40	5583–5323	3634–3374	Bone (*Ovis*)	Grid square 42	*Mlekuž et al. 2006*
Beta–219608	4710 ± 40	5582–5321	3633–3372	Bone	Grid square 42	*Mlekuž et al. 2006*
Beta–219609	6570 ± 40	7563–7424	5614–5475	Bone	Grid square 34	*Mlekuž et al. 2006*
Beta–219610	4750 ± 50	5589–5325	3640–3376	Bone	Grid square 34	*Mlekuž et al. 2006*
Beta–219611	4740 ± 40	5586–5326	3637–3377	Bone	Grid square 32	*Mlekuž et al. 2006*
Palaeochannels						
Beta–233028	4020 ± 40	4782–4414	2833–2465	Organic sediment	Borehole 1, 110 cm	
Beta–233029	4920 ± 40	5725–5591	3776–3642	Organic sediment	Borehole 2, 110 cm	
Beta–233030	3000 ± 40	3335–3072	1386–1123	Organic sediment	Borehole 3, 50 cm	
Beta–233031	5110 ± 40	5929–5746	3980–3797	Organic sediment	Borehole 4, 105 cm	
Beta–233032	4520 ± 40	5310–5046	3361–3097	Organic sediment	Borehole 5, 100 cm	

Tab. 1. Radiocarbon dates for Maharski prekop and Resnikov prekop sites, and Ižica floodplain palaeochannels. Calibration performed with CALIB version 5.10., and given in two sigma ranges (*Reimer et al. 2004*).

neva and Jurassic lakes that correlate to abrupt tripartite climate changes between 5550 and 5320 calBP, supposedly caused by varying solar activity, as it corresponds with climatic cooling and/or changes in moisture conditions in various regions in both hemispheres. Moreover, the mid-Holocene climate oscillations appear to have been characterised by intermediate warm spells within a distinct succession of strong cooling episodes.

The tripartite sequence of abrupt increases in lake water levels was reconstructed from sediment and pollen analyses of a sediment sequence at Lake Constance. The first abrupt high level event was dated to age range 5647–5478 calBP. The second abrupt rise in lake level appears to have occurred in three distinct episodes of rising lake levels at *c.* 5500 calBP. The third sudden rise in lake level was dated before a range of 5583–5317 calBP. This event is marked by rapid depositions of sediment shortly after building destruction at Arbon-Bleiche 3, the 'Neolithic pile-dwellings site' located at the lake shore (*Magny 2004; Magny et al. 2006*). It has been suggested that this was associated with settlement abandonment at 5320 calBP, according to dendrochronological dating (*Leuzinger 2000*).

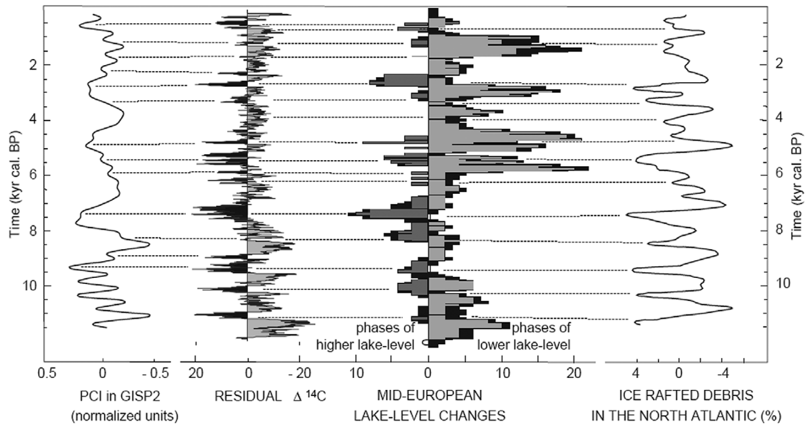

Fig. 4. The correlation of mid-European lake level fluctuations and the Holocene climate anomalies, recorded in Polar Circulation Index at GISP2, the atmospheric residual ^{14}C variations, and the ice-rafting debris (IRD) events in the North Atlantic Ocean (after **Magny 2004.Fig 3*).***

Although available data does not allow us to correlate episodes of Alpine lake level fluctuations with the development and change of fluvial network on the Ižica floodplain directly, we may hypothesise that this mid-Holocene abrupt climate change and associated reversion to wetter conditions affected regional hydrological regimes and river behaviour on the Ljubljana Marshes and their catchments in the karstic Dinaric Mountains and Julian Pre-Alps. The dynamics of channel bed movements (in different directions) and their abundance in the first phase of fluvial activity on the Ižica floodplain in the age ranges 5725–5591 calBP and 5310–5046 calBP are broadly contemporary with the tripartite climate reversal and the sequence of abrupt increases and decreases in water levels in Lake Constance, Lake Geneva and Jurassic lakes (Fig. 5). Similar age ranges of 5644–5055 (Z-315) and 5305–4617 (Z-305) were obtained for the wooden structure believed to protect the Maharski prekop settlement against floods and river bank erosion.

The third phase of fluvial activity on the Ižica floodplain is marked by larger streams, lateral channel movement, and bank erosion. The LiDAR image clearly shows that the Resnikov prekop site is situated in the area, damaged by the third phase channels. Recently performed stratigraphical, sedimenological and palynological analyses at the Resnikov prekop site showed that the settlement deposit was washed out by intensive river erosion (*Andrič 2006; Velušček 2007.426*). Two radicarbon dates of the channel infill, in the age ranges 2336–2146 calBP (Beta – 184792) and 2148–2040 calBP (Beta – 182667), both post-date the event, may indicate that it corres-

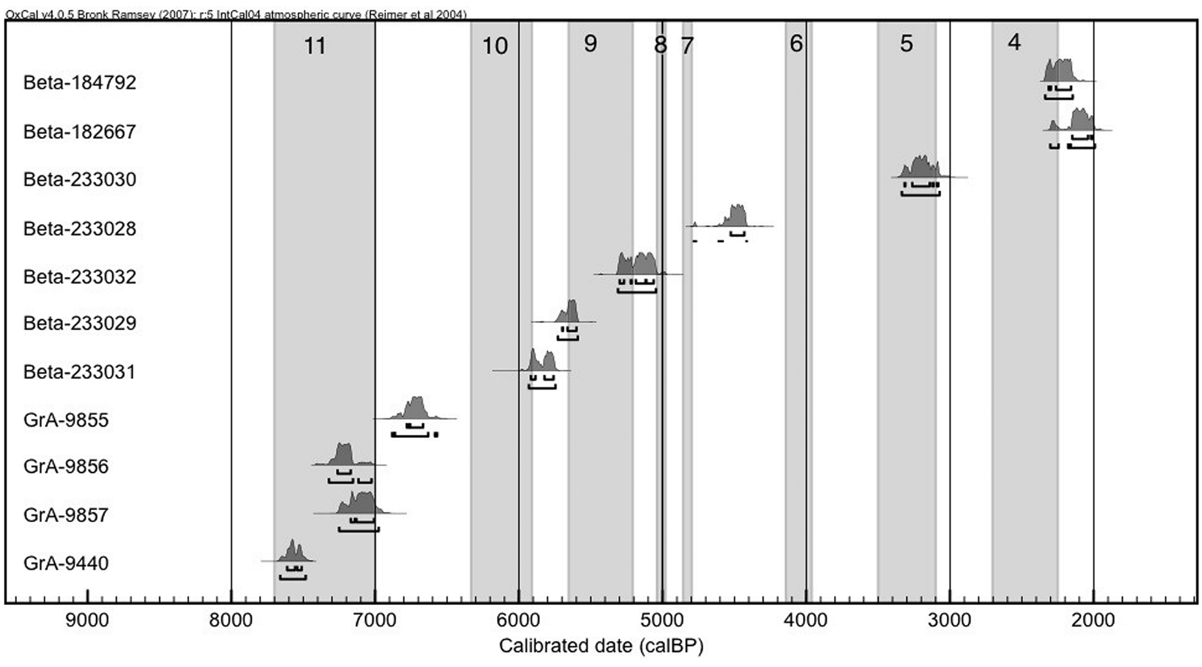

Fig. 5. The chronological sequence of 'episodes' (4–11) of abrupt increases in lake water levels in the Jura Mountains, the northern French Pre-Alps and the Swiss Plateau (**Magny 2004; Magny et al. 2006*), and calibration ranges at 1 and 2 standard deviations (calBP) of radiocarbon dates from Babna gorica and palaeochannels in Ižica floodplain.***

ponds to an abrupt cooling phase, and to the major flood event in west-central Europe 'after *c.* 2700 calBP and before *c.* 2265 calBP' as Michel Magny (*2006. 13*) suggests.

It is worth pointing out the complex floodplain lake level fluctuations and fluvial dynamics on the north-eastern edge of the Ljubljana Marshes that predate those on the Ižica floodplain. Microclimate proxy data from the bottom part of the stratigraphic sequence of the Babna Gorica test trench indicate dynamic events in the age range of 7660 to 6976 calBP. In the bottom part of the stratigraphic sequence transgression/regression dynamics of a probable floodplain lake are recorded. A layer of lacustrine marls is dated to age range 7660–7483 calBP (GrA-9440). It is covered by an organogenic layer dated to age range 7249–6976 calBP (GrA-9857) associated with a buried soil horizon. The area was inundated again, as demonstrated by a thin layer of lake marl. Above it, another buried soil horizon was identified. Wood stumps and charcoal deposition in age range of 7321–7025 calBP (GrA-9856) were contextualised within it. Thereafter, a series of loam, sand and gravels deposits was recorded after the age range 6881–6569 calBP (GrA9855) that indicates the dynamic alluvial episodes (*Vidic 1997; Mlekuž, Budja, Ogrinc 2006.257*). The floodplain lake transgression and regression sequence runs parallel with the 'Episode 11 (7550–7250 calBP)' of abrupt central European lake-level fluctuations (*Magny 2004.72*) (Fig. 6).

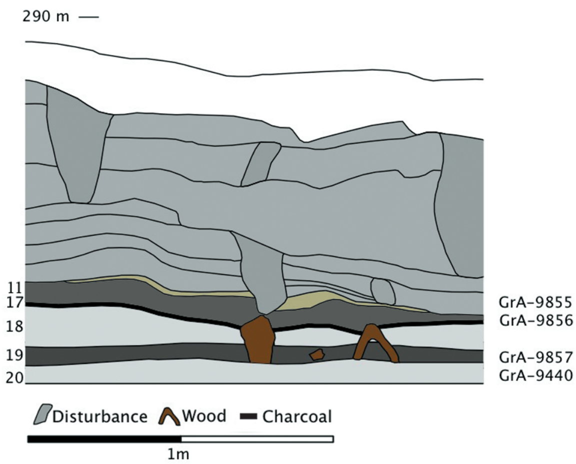

Fig. 6. Babna gorica test section 2. A layer of lacustrine marls (20) is covered by an organogenic layer associated with a buried soil horizon (19). The area was inundated again, as demonstrated by a layer of lake marl (18). Above it, another buried soil horizon was identified (11) with well preserved wood stumps and charcoal deposition contextualised within (17). Thereafter, a series of loam, sand and gravels deposits was recorded that indicates the dynamic alluvial episodes (for stable isotope δ13C and δ15N analysis see* Mlekuž, Budja, Ogrinc 2006.257–258*).

Conclusions

The absolute dates of the first phase palaeochannels identified on LiDAR imagery are contemporary with the dates from the Maharski prekop site. The wooden structures, either rectangular buildings or structure that run parallel with the channel, demonstrate the overlapping age range. It is worth noting, however, that the abandoned channel was already identified and excavated in the 1970s (*Bregant 1975.18–20*). The palaeochannels and the settlement reveal a microtopography suitable for settlement which, although prone to seasonal flooding, offered an attractive resource for floodplain agriculture. Therefore, we can imagine Maharski prekop as a dispersed settlement with several settlement foci located on the channel levees and surrounded by fields.

We suggest that the complexity of fluvial and alluvial process on the Ljubljana Marshes, dependent on palaeoclimate oscillations, must be incorporated in an adequate understanding of landscape dynamics and settlement patterns in the microregion. Furthermore, the age ranges of changes in the Ižica floodplain palaeochannel system and Babna Gorica floodplain lake transgression and regression correspond with Alpine lake level fluctuations and mid-Holocene global cooling and contrasting patterns of hydrological changes.

We present here fragmentary data that can have heuristic value only at the southeastern part of Ljubljana Marshes to show that at least at the time of occupation (and probably even earlier) of the Resnikov prekop and Maharski prekop sites, this part of the Ljubljana marshes was not covered by a shallow lake, as the traditional view suggests, and that changes in hydrology correspond to abrupt climate changes. However, intensive multidisciplinary palaeoenvironmental research and adequate radiometric dating of particular contexts can be the way forward in interpreting the complex archaeological and palaeoenvironmental records of the Ljubljana Marshes.

ACKNOWLEDGEMENTS

We would like to acknowledge the research was supported by the Slovenian Research Agency: Project J6-6013-0581-04' and, Research Programme Arheologija P6-247.

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