

Palaeoenvironmental and Archaeological Implications of a Sediment Core from Polje Čepić, Istria, Croatia

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Abstract

Palaeoenvironmental and archaeological records provide an invaluable framework for land and water management in karstic areas of the Mediterranean realm. We present the results from analyses carried out on three segments of a sediment core extracted in 2004 from a portion of Polje Čepić (Istria, Croatia), a tectono-karstic depression covered in water until artificial drainage took place in 1932. We used bulk sediment analyses, pollen analysis and radiocarbon dating to assess the possible contribution of people to the progressive siltation of the lake, and compared our results with recent archaeological discoveries made on the polje margins. The dating of the sequence points to the presence of a predominantly wet landscape at the coring location since at least 7000 years cal BP. The coincidence of cereal type pollen grains with several open-air archaeological sites indicates that small-scale agricultural practices possibly developed around the polje in Neolithic times, ca 6500 years cal BP. Concentrations of charcoal in the sediment core at this time suggest the use of fire clearance as part of the agricultural practice.

During the Bronze and Iron Ages, the possible intensification of forest clearance and agricultural practices is indicated by: (1) an increase in the number and type of archaeological sites found around the polje; (2) a more open plant landscape in the upper part of the analysed sequence; and (3) a three-fold increase in the sedimentation rate, possibly starting as early as 4000 years cal BP. Wetter climate conditions and higher erosion of the surrounding slopes probably led to the progressive siltation of the lake. Finally, in 1932 the lake was artificially drained and Istria lost its largest natural basin of fresh water.

1. PALAEOENVIRONMENT AND ARCHAEOLOGY: OVERVIEW ON THE PROJECT AIMS

This paper further develops the study of the prehistoric population of Istria launched a decade ago (MIRACLE & FORENBAHER, 2006). The initial study focused on the exploration and excavation of archaeological cave sites. In the last two years, we have undertaken a new geoarchaeological study of open environments situated around Polje Čepić, not far from some of the richest caves excavated in Istria (Fig. 1). Our overall aim is to provide palaeoenvironmental and archaeological information for land and water management in karstic areas of the Mediterranean realm.

The Slavic word *polje* literally translates into field or plane. In karstic geomorphology polje indicates a tectono-karstic depression typically found in Dalmatia and often occupied by a karstic lake (JENNINGS, 1971, 1985; O'SULLIVAN, 2004). The Holocene environments and landscapes of Istria are not well known, mainly due to the lack of suitable palaeoecological sites. In addition, the neighbouring locations studied so far are close to the Adriatic coast and reflect changes over wide areas for the mid and late Holocene (BEUG, 1967, 1977; CULIBERG, 1995, 1997). At the few inland sites that have been investigated, for example Zajezeri–Vodenjak (CULIBERG, 1995) and Prapoče (ANDRIČ, 2001, 2006), pollen and organic remains are only seldom preserved in Holocene sequences. Polje Čepić constitutes an optimal site for the development of a comprehensive palaeoenvironmental/palaeoclimatic study in the east-Adriatic region because its position and size are likely to reflect both local and regional changes, and organic and pollen preservation is excellent.

Our research aims to: (1) determine for how long a lake had existed in Polje Čepić before 1932; (2) determine whether people had been living around the polje in prehistoric times, and how they could have contributed to the progressive siltation of the basin; (3) explore the relationships between the population of open-air landscapes and the environmental changes that took place during the Holocene. In 2004 we undertook a systematic survey to identify open-air archaeological sites and reconstruct past environmental conditions around

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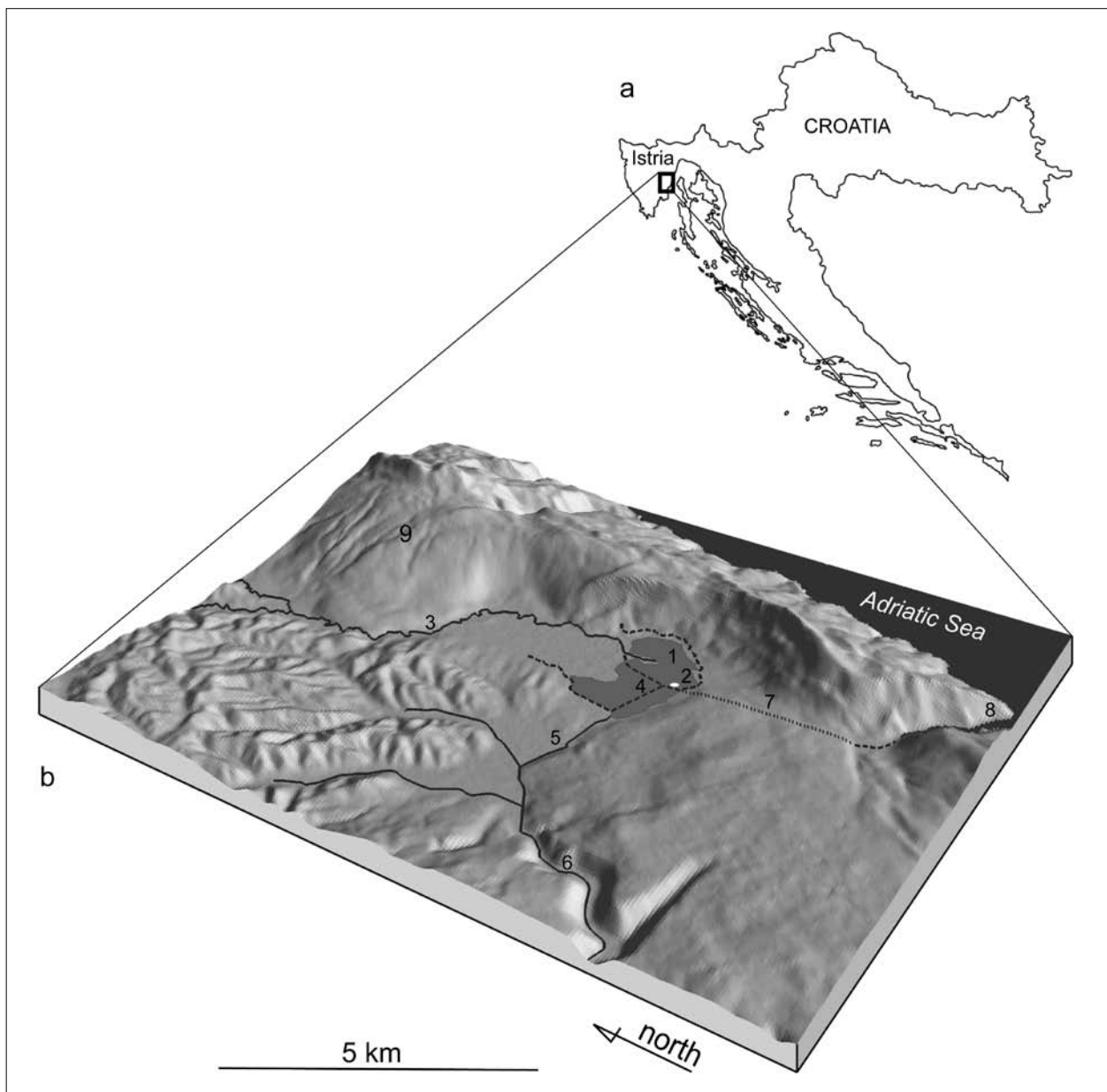


Fig. 1 Location of Polje Čepić within Istria and Croatia (a). A three-dimensional model of the study area shows (b): the approximate extent of the lake occupying the polje before 1932 (1), the location of the core (2), the course of the Boljunčica River (3), the main artificial channel (4) connecting the Boljunčica River to the Rakita channel (5) and the Raša River (6), the artificial tunnel through which the lake was drained (7), Plomin Bay (8), and Mount Učka (9).

Polje Čepić (BALBO et al., 2004). We discovered fourteen previously unknown prehistoric areas, and test-excavated four of them (BALBO, 2006; BALBO et al., in press). In addition, we extracted an exploratory core from the polje, the analysis of which is presented in this paper.

1.1 The study area

Polje Čepić is situated in the eastern–central part of the Istrian peninsula, at the northernmost tip of the Adriatic Sea (Fig. 1). Most historical maps of Istria, dating back to the 16th century show that Polje Čepić was occupied by a shallow lake, until its complete drainage in 1932

(PARENZAN, 1928; LAGO & ROSSIT, 1981; BALBO, 2005). The Boljunšćica River constituted its main natural inlet. Most of the lake water used to outflow through underground sinkholes, mainly situated on the southern margin of the polje. When high water levels occurred, the lake drained into the Raša River (Fig. 1). The polje formed following Miocene tectonic movements and is situated on an elongated depression developed on the western side of a structurally complex anticline (MIHLJEVIĆ, 1998; ROGLIĆ, 1950). The polje is surrounded and underlain by terrigenous Eocene bedrock, flysch (ŠIKIĆ & POLŠAK, 1973). These flysch deposits form a low relief landscape on the eastern and northern parts of the polje, characterised by a network

of shallow river incisions. To the east the polje is contained by the western flank of a N–S trending anticline, characterised by thrust structure of Cretaceous carbonates (HERAK, 1991). This flank forms the steep slopes of the Učka Mountains incised with a series of deep gullies. Most soils within the polje catchments developed both on terrigenous rocks of the Flysch zone and on the carbonates of the Učka/Čičarija and Central Istria zones (DURN, 2003; ŠKORIĆ et al., 1987).

2. CORING TECHNIQUE

The exploratory core presented here was extracted from Polje Čepić in August 2004, at the geographical position N 45°.18759, E 14°.15909, at an altitude of 27 m asl. The drilling equipment used was a rotation/percussion wire line drill, normally used for commercial geological research. The core was recovered in 12 drives, reaching a maximum depth of 17.43 m. Due to the nature of the coring equipment, portions of the core were deformed during its extrusion (Fig. 3a). The top portion of each drive had deformations caused by the rotation of the coring piston and the water-pressure extrusion technique (LEROY & COLMAN, 2001). All segments of the core were extruded into half-cut pipes and sealed with cling film and aluminium foil to preserve moisture and avoid penetration of light. Each segment was labelled and stored in a cold room at the Archaeological Museum of Istria (Pula), before being transported to Cambridge for sampling and analysis. The disturbed segments of the core were not analysed, and archive core segments were kept for future reference. Although the three undisturbed core segments from the lowermost three drives are discontinuous, they provide useful information about the history of the basin. Analyses of the core were carried out at the Department of Geography, Quaternary Research (QR), University of Cambridge, at the Institute of Archaeology, Research Centre of the Slovenian Academy of Sciences and Arts, Ljubljana, and at the Institutes of Botany and Geology, University of Bergen. Accelerator mass spectrometry (AMS) radiocarbon dating was carried out at the Poznan Radiocarbon Laboratories (PRL).

3. METHODS

3.1. Radiocarbon dating

Seven samples for AMS radiocarbon dating were prepared following the protocols established at the Norwegian Past Environments & Climate Centre (NORPEC) and at QR. Based on sediment analyses and on the obtained dating we decided to restrict our analyses to the three undisturbed segments presented in this paper. The equipment was washed before each operation and all samples were taken in 1 cm slices. The materials to be dated were separated from the core with steel spatulas, sieved through a 100 µm mesh, and picked up with

steel forceps under the stereomicroscope. Non-carbonised terrestrial plant remains and carbonised remains were sampled for dating. Aquatic plant remains were excluded in order to avoid distortion due to the reservoir effect (BJÖRCK & WOHLFARTH, 2001; GEYH et al., 1998). Sediment residue was removed from the plant materials under the stereomicroscope using soft steel forceps and a synthetic pencil. Plant remains were identified as precisely as possible before being dried in the oven at 60°C, weighed, and sent to PRL.

3.2. Sediment analysis

Non-destructive methods were initially applied to determine the best-preserved parts of the core and the location of irregularities, clasts, and laminations. The lowermost 10 m of the core were X-rayed using a SMR Ltd NOVA HF 30 set at 68 kV and 20 mA, to obtain good luminosity and contrast. Rapid film with no grid was used, maintaining a constant focus of 100 cm. Whole-core magnetic susceptibility (MS) measurements were taken using a Bartington magnetic susceptibility meter connected to a PC and a loop sensor (NOWACZYK, 2001). Following these first analyses the core segments were split and described. The first description of the split core segments involved the semi-quantitative colour determination of the sediments using a Munsell soil colour chart. A fully quantitative digital colour (DC) determination was carried out with a Stellarnet Spectrometer. Sediment samples were taken at regular intervals of 2 cm, with a 1 cm³ brass volumetric sampler.

Samples for particle size determination (PSD) were put in 50 ml test tubes, a 4.5% sodium pyrophosphate (Na₄P₂O₇) solution was added and test tubes were left in a water bath at 90°C (194°F) for 5 hours to disperse clay particles. Each sample was then centrifuged and run through a Malvern Mastersizer 2000, to measure particle sizes between 0.02 and 2000 µm (LAST, 2001). Further subsamples were run through the Mastersizer two more times: first after eliminating the OM in a 30% hydrogen peroxide solution (H₂O₂), and second after treatment in a 7% hydrochloric acid solution (HCl) to eliminate carbonates. Particle size categories are as defined in LAST (2001).

The relative moisture, OM, charcoal, and carbonate (CaCO₃) contents in the sediments were measured through loss-on-ignition (LOI), using a 1000°C muffle furnace. All samples were weighed, kept at room temperature (20°C) for 3 hours, and reweighed to determine percentage moisture content. Samples underwent three more overnight (12 hours) heating cycles at 400°C (752°F), 480°C (896°F) and 950°C (1742°F). At the end of each heating cycle, samples were cooled at 105°C and weighed. The mass loss between 105°C and 400°C was used as a proxy for OM content, while the mass loss between 105°C and 480°C was assumed to represent the content in charcoal. Finally, the mass loss between 105°C and 950°C was taken as an indicator of the carbonate content (NELSON & SOMMERS, 1996).

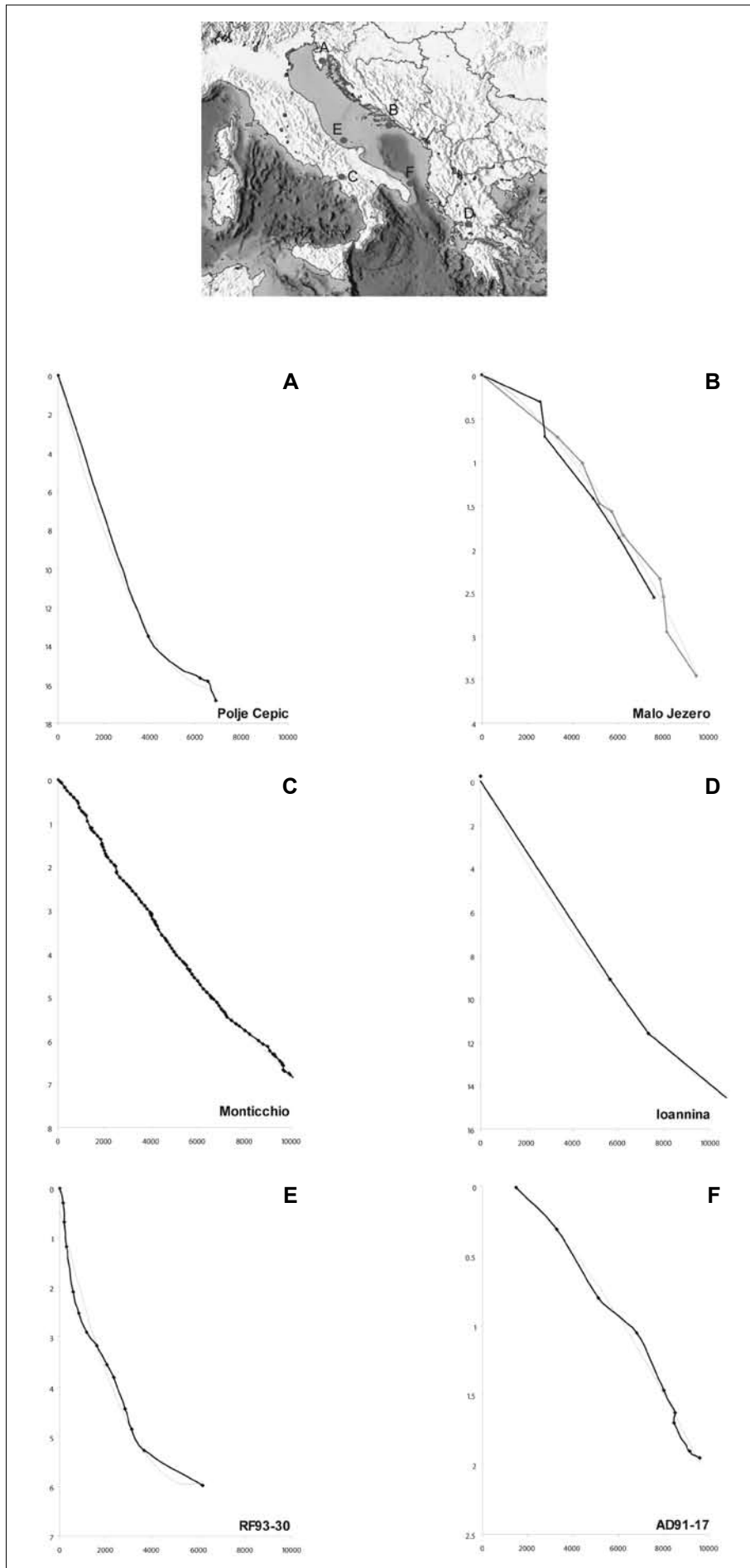


Fig. 2 Comparison of age–depth models from the Adriatic Sea and circum-Adriatic lakes. All age–depth models, excluding that for Polje Čepić, have been drawn based on published primary data. All dates were calibrated using Calib Rev 5.0.1[®]. Ages on the horizontal axis are in years cal BP, depths below the sediment surface are in metres. A polynomial trend-line of order 2 has been fitted to each age–depth model. Polje Čepić (A). Malo Jezero (B) Croatian lake on the Island of Mljet, Dalmatia; two age–depth models are proposed: black line (JAHNS, 2002), and grey line (WUNSAM et al., 1999). Lake Monticchio (C) Italian volcanic lake (ALLEN et al., 1999; WULF et al., 2004). Lake Ioannina (D) Greek polje lake in Epirus (LAWSON et al., 2004). RF93–30 (E) Adriatic core (OLDFIELD et al., 2003). AD91–17 (F) Adriatic core (SANGIORGI et al., 2003).

Photographs were taken with a scanning electron microscope (SEM) from core segment S2, to determine the origins and nature of the carbonates present in the sediments. Samples were coated with 30% gold and 70% palladium using a Polaron Equipment Limited Self Coating Unit E5100, before observation on a Philips XL30FEG SEM.

3.3. Pollen analysis

Samples for pollen analysis were collected using a 1 cm³ brass volumetric sampler. Standard laboratory procedures were used for sample preparation (7% HCl, 10% NaOH, 40% HF, acetolysis, staining with safranine, silicone oil, method B in BERGLUND & RALSKA-JASIEWICZOWA, 1986; BENNET & WILLIS, 2002). Two tablets with a known number of clubmoss spores (*Lycopodium*) were added to each sample during the first stages of laboratory preparation, in order to determine pollen concentration (STOCKMARR, 1971). A Nikon Eclipse E400 light microscope at 400x magnification was used. Pollen types were identified by comparison against pollen keys (MOORE et al., 1991; REILLE, 1992, 1995) and the pollen reference collection held at the Institute of Archaeology in Ljubljana. Microscopic charcoal from each sample was also counted, considering two size classes: <40 µm and >40 µm.

4. RESULTS FROM THE STUDY OF POLJE ČEPIĆ SEDIMENTS

4.1. Preliminary age–depth model

Seven radiocarbon dates were obtained from the sediment core extracted from Polje Čepić, three of which gave reverse ages. Each of the three lowermost core drives considered in this thesis measured ca 2-m in length. Two of these core drives had a diagnostic V-shaped ‘wavy’ feature at ca 50 cm from their base (Fig. 3a). Such features can sometimes result from sudden alluviation, with consequent mixing of sediments, ulti-

mately leading to reverse ages. In alternative, mixed sediments and reverse ages can result from distortion of the core during extrusion. In this case study, the 2 V-shaped features occur at the same point (50 cm from the base) in two different core drives, in axis with the vertical coring direction. Based on the recurrence of these factors, the three reverse dates were attributed to deformation of the core drives during extrusion. As a result, the three reverse dates (1532 cm, 1665 cm and 1678 cm depth) were dismissed. The portions of each core drive situated above these V-shaped features were therefore excluded from further analysis. The final age–depth model is based on the remaining 4 dates. Dates were calibrated using Calib Rev 5.0.1[®] based on the IntCal 04 calibration dataset (Table 1) (STUIVER & REIMER, 1993; STUIVER et al., 2005). Median ages were used to create a preliminary age–depth model (Fig. 2a).

4.1.1. Comparison with age–depth models from neighbouring regions

Attempts to compare heterogeneous records (e.g. from ice, sea, and lakes), covering different spatial and temporal scales, have allowed correlating climatic and environmental events at local, regional, and global levels (BARTLEIN, 2007). The age–depth model obtained for Polje Čepić has been compared with five continental and marine sediment sequences recovered around the Adriatic (Fig. 2): (a) Three age–depth models were obtained from continental sequences extracted from Lake Ioannina (also Pamvotis, Greece – LAWSON et al., 2004), Malo Jezero (Island of Mljet, Croatia – JAHNS & VAN DEN BOGAARD, 1998; WUNSAM et al., 1999; JAHNS, 2002), and Lake Monticchio (Central Italy – ALLEN et al., 1999; WULF et al., 2004); (b) Two age–depth models were based on marine sediment sequences from Adriatic cores RF93–30, and AD91–17 (OLDFIELD et al., 2003; SANGIORGI et al., 2003). The discontinuity of the record recovered from Polje Čepić did not allow a multi-proxy correlation. The preliminary comparison proposed here is solely based on radiocarbon dating and has been restricted to the past 10000 years.

Table 1 Results from the AMS dating. Following the occurrence of reverse dating, PRL repeated two samples at 1678 cm and 1686 cm depth obtaining similar results to those from the original analyses.

Laboratory code	Midpoint	Material	Weight (gr)	Conventional age 14C BP	Age years cal BP (1σ)	Age years cal BP (2σ)	Median years cal BP
Poz-10877	1351 (S3)	bark, stem, 1 Scirpus seed	0.0051	3620±35	3887–3978	3839–4074	3931
Poz-10878	1532	bark	0.0281	3490±35	dismissed		
Poz-10880	1568 (S2)	9 Scirpus seeds	0.0104	5370±35	6119–6273	6007–6279	6185
Poz-10881	1582 (S2)	bark	0.0159	5720±40	6446–6560	6412–6633	6514
Poz-10882	1665	bark, stem, 1 Scirpus seed, charcoal	0.0122	5290±40	dismissed		
Poz-10883	1678	bark, charcoal	0.0105	4740±35	dismissed		
Poz-10884	1686 (S1)	charcoal (Juniperus)	0.0152	6040±40	6802–6945	6759–6997	6889
Poz-12231	1678	bark, charcoal	0.0105	4765±35	replica		
Poz-12232	1686	charcoal (Juniperus)	0.0152	6080±35	replica		

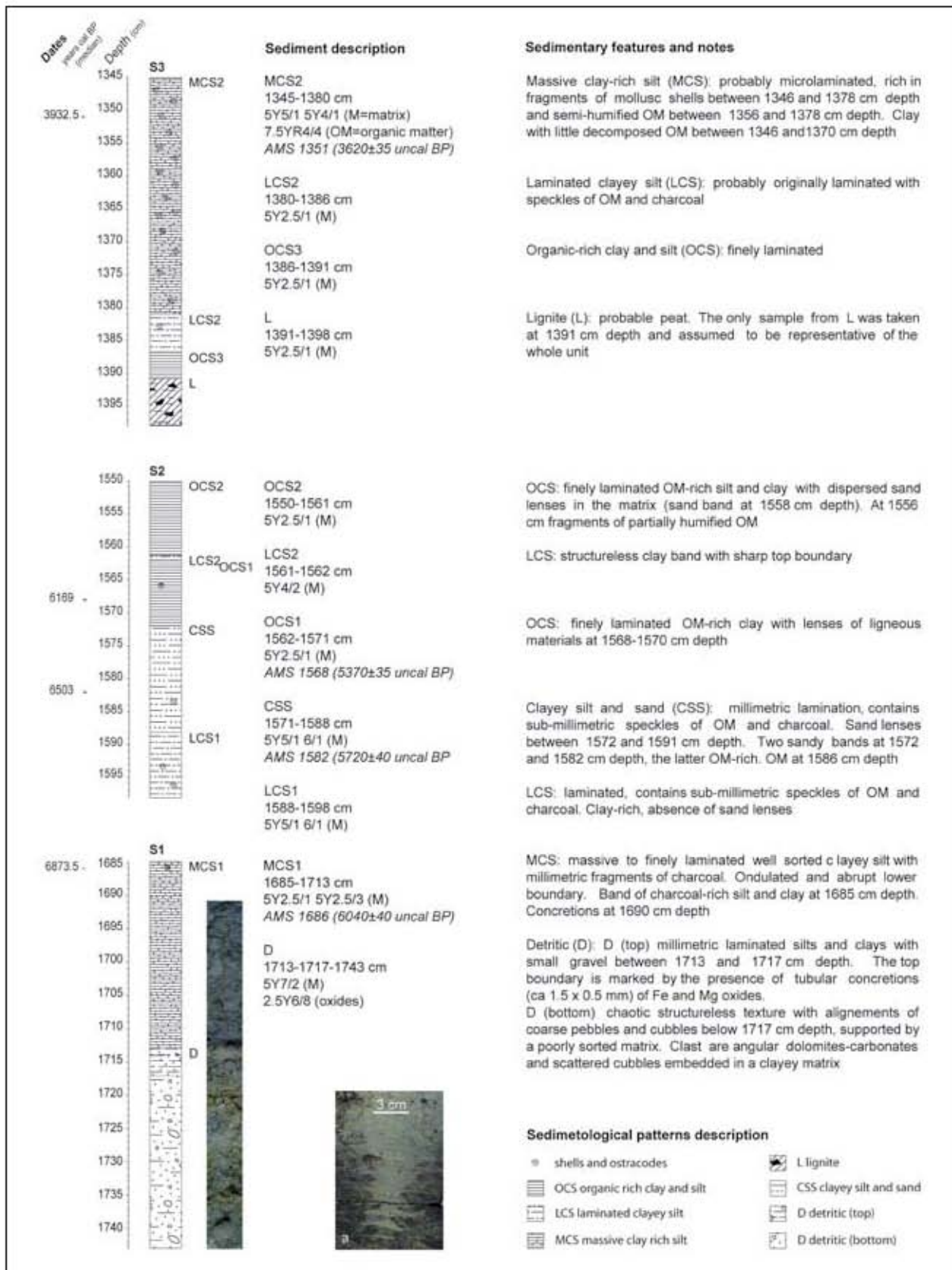


Fig. 3 Core log and sediment description. (a) Example of a V-shaped core deformation.

In contrast with Polje Čepić, Malo Jezero (a coastal Dalmatian lagoon) features a decreasing sedimentation trend throughout the Holocene. A linear sedimentation trend is noticed at Monticchio Lake, a volcanic lake,

pointing to constant sediment accumulation throughout the Holocene. Among the continental sequences, Lake Ioannina (a shallow polje lake) shows a sedimentation trend similar to Polje Čepić (BROUSOULIS et

al., 1999). However, accelerated sedimentation at Lake Ioannina seems to have begun earlier than at Polje Čepić. Marine sediment core RF93–30, extracted from a shallow portion of the Central Adriatic, presents a sedimentation trend matching the results from Polje Čepić (OLDFIELD et al., 2003). In contrast, core AD91–17, extracted from a deep portion of the Southern Adriatic, shows an inverted trend compared to Polje Čepić. Similarities observed between RF93–30, Polje Čepić and Lake Ioannina may partly result from their shallowness. The rapid increase in sedimentation observed in core RF93–30 after ca 4 ka cal BP has been interpreted as anthropogenic (OLDFIELD et al., 2003). This hypothesis will be discussed in relation to the observations made at Polje Čepić.

4.2. Core description and physical analyses

4.2.1. Core description

Most of the observed sequence is composed of laminated or sub-laminated sediments of limnic origin. The only peat (lignite) layer was found between 1391 and 1398 cm. The three core segments described here are from the bottom part of the three lowermost drives and are (from the bottom upwards) S1, S2, and S3. Each of these segments has been subdivided into several units, based on sediment observations (Fig. 3). These units are characterised by well-preserved horizontal bedding lamination planes.

Core segment S1 represents the bottom of the sequence, between 1685 and 1743 cm depth. This segment was subdivided into two units. The lower detritus unit (D) represents the transition from a heterogeneous assemblage of clasts and sandy-clay (D bottom) to finer laminated sediments (D top). Organic matter (OM) is almost absent in this unit. The upper unit is composed of massive to finely laminated clay and silt (MCS1), with millimetric fragments of charcoal.

Core segment S2 was extracted between 1550 and 1598 cm depth, and subdivided into five units. Laminated clayey silt (LCS1 and 2) and clayey silt and sand units (CSS) characterise the lower part of this core section, while organic-rich clay and silt units (OCS1 and 2) are found towards the top.

Core segment S3 was extracted between 1345 and 1398 cm depth, and divided into four units. The lower unit represents the only lignite (L) found within the analysed core segments. In this core segment the OM content seems to be gradually decreasing towards the top. Above L, sediments gradually shift from organic rich clay and silt (OCS3) to laminated clayey silt (LCS2) and massive clay-rich silt (MCS2). This core segment is rich in partially decomposed speckles of horizontally-layered OM and shells.

4.2.2. Particle size determination

Core segment S1 is the best sorted, with the lowest inclusive standard deviation throughout the PSD analy-

sis (Fig. 4). The bottom unit D of core segment S1 could not be processed with the Mastersizer because of its detritic nature. Unit D is mainly composed of cobbles and angular clasts embedded in a clayey-silt matrix. The MCS1 unit shows little variations in the size distribution of its components through the three phases of measurement. Its sedimentary regime appears to be very stable throughout its extension, with a net dominance of silts (>80%), followed by clay (8–10%), and sand (5–10%).

The distribution of particles through core sediment S2 shows a generalised increase of clay size particles (5 to 15%) compared to silt and sand particle sizes after treatment with H₂O₂. The grain size distribution pattern remains similar after treatment with HCl. Sand size particle peaks occur at 1578 cm (30%), and 1568 cm and 1558 cm depth (40%).

In core section S3 the particle distribution shows little change after treatment with H₂O₂ and HCl. There is a generalised gain of about 20% on the clay particle size compared to sand size after treatment with H₂O₂, while changes are minimal after treatment with HCl. Two contrasting trends can be observed. A first one towards decreasing particle sizes up to 1366 cm depth, and a second one towards sand sized particles towards the top of this core segment. Core segment S3 is the most poorly sorted before treatment with H₂O₂ and HCl, while S2 is the most poorly sorted after OM and carbonates are eliminated.

4.2.3. Magnetic susceptibility

MS values remain constant throughout core segment S1, where they reach the highest readings. MS values decrease gradually through core segment S2, reaching minimal values just over 1.0 SI units. As for core segment S3, MS values increase steadily, stabilising around 4.5 SI units above 1365 cm depth.

4.2.4. Loss-on-ignition

In core segment S1 unit MCS1 shows a very stable pattern throughout LOI analysis, with a net prevalence of silicate residue (90%) and low OM (5–7%), carbon (less than 2%), and CaCO₃ (5%) content. Inclusive mean is stable around 6.5 ϕ , pointing to medium and coarse silts as the predominant particle sizes. In core segment S2 inclusive mean values are generally lower than those registered for core segment S1. A general trend is observed, with increasing particle sizes towards the top, where particle sizes from the silt–sand boundary are the most represented. A peak in carbonate content is recorded at 1580 cm depth, followed by a rapid increase in the amount of carbon (4 to 6%) and OM (10 to 35%). The highest peak in carbon content is recorded at 1568 cm depth. Clay-size detritus is the main component of the carbonates from this core segment. Some sponge needles and diatom fragments are present (Fig. 5), as well as infrequent shells and ostracods. Core segment S3 is generally dominated by silicate residue, stable around

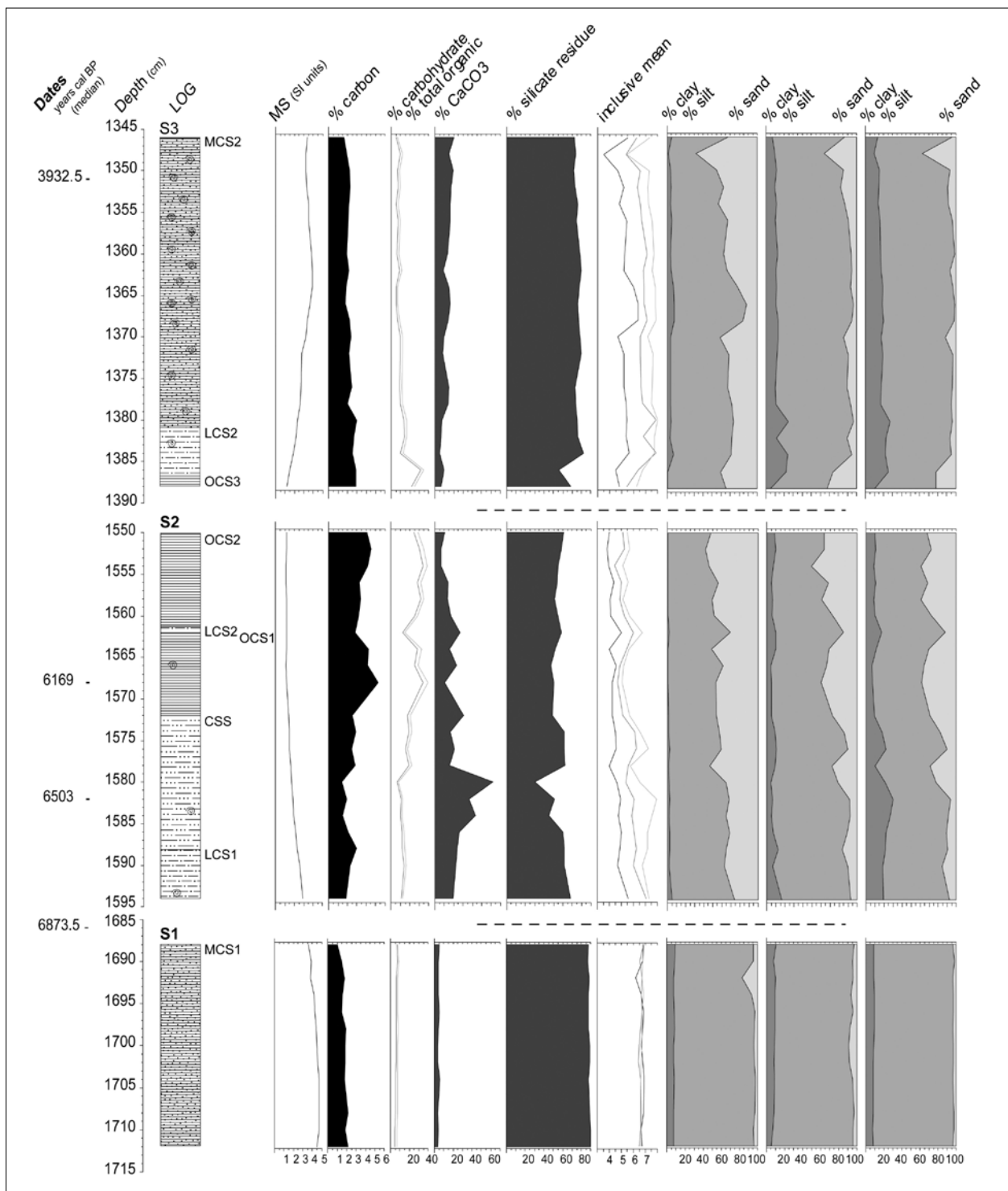


Fig. 4 Results from MS, PSD, and LOI. MS is measured in SI units; LOI results are presented in %; inclusive mean is measured in ϕ ; clay, silt and sand proportions are presented in % and in a cumulative way following the results from PSD analyses after treatment with $\text{Na}_4\text{P}_2\text{O}_7$ (dark grey), H_2O_2 (grey) and HCl (light grey).

80%. This core segment is characterised by a progressive decrease in OM, in coincidence with a progressive increase in carbonates.

4.3. Pollen record

Polje Čepić is located in a relatively large tectonic depression. Historically, the polje has been occupied

by a lake extending over an area up to 6 km² (PARENZAN, 1928). Therefore, the pollen record from this basin is likely to represent past plant composition at local, extra-local and regional scales. While the effects of the early introduction of local small-scale forest clearance and agriculture are detectable through pollen analysis in small basins (with <30 m diameter) they are overwhelmed by the regional pollen record deposited

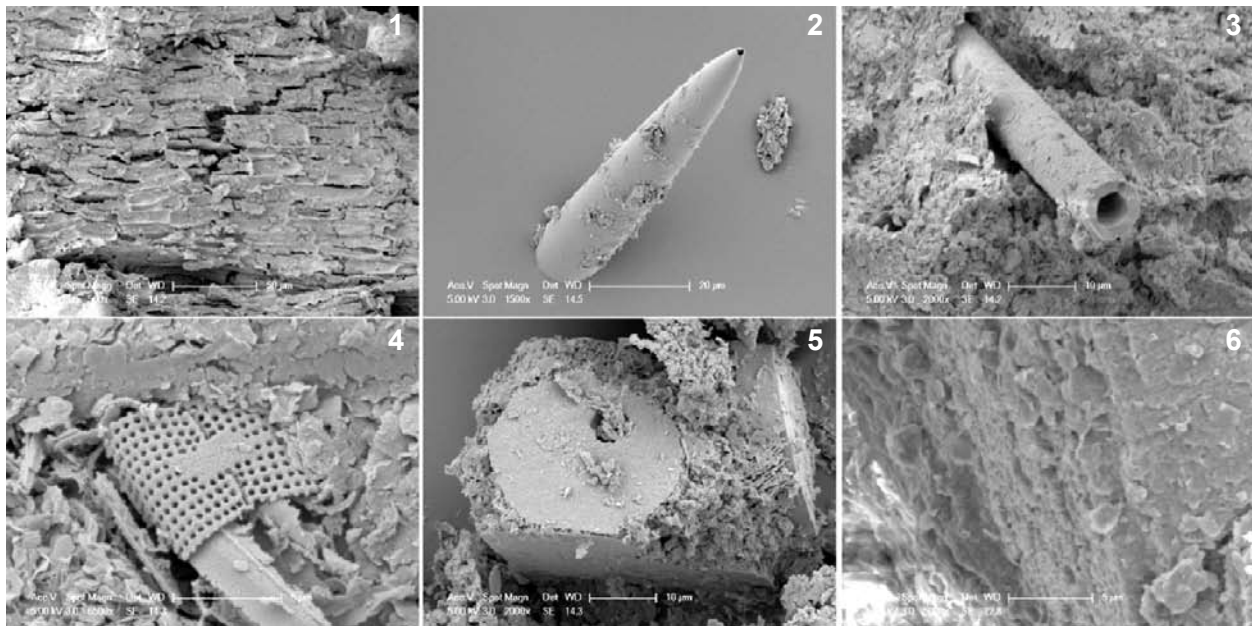


Fig. 5 Six photographs of the sediments taken with SEM. The top three photos were taken from 1568 cm depth, the bottom ones from 1580 cm depth. Photos 1, 5 and 6, show clay particles and structures (5) potentially indicating the formation of shallow hydromorphic soils during low water stands; photos 2 and 3 a sponge spicule, and photo 4 part of a diatom.

in larger basins (JACOBSON & BRADSHAW, 1981), such as Polje Čepić. Nevertheless, the accurate observation of seemingly minimal changes in the pollen record recovered from larger basins can be used to detect the possible effects of agro-pastoral practices on changes in plant and forest composition (Fig. 6).

Preliminary examination of the three core segments showed that pollen was only preserved in the upper two segments. Pollen is not preserved throughout the lowest core segment S1. No pollen is preserved in the lowest levels of core segment S3, at 1384 cm and 1390 cm depth. The best pollen preservation is recorded for the middle core segment S2, with pollen concentrations reaching 7000–14000 grains/cm³. A major peak in the input of coarse microcharcoal (>40µm) is registered at 1568 cm depth. Only one sample was analysed from core segment S3 at 1360 cm depth, where pollen concentration is lower than that observed for core segment S2, with less than 2000 grains/cm³. Throughout most of the time span covered by core segments S2 and S3 the environment around the coring location was wet enough to allow pollen preservation.

The pollen record suggests that beech (*Fagus*) was an important tree taxon before 6500 years cal BP, which is consistent with charcoal and phytolith analyses from the archaeological site of Pupićina Cave where beech abounds in the mid-Holocene layers (FLETCHER, 2002; FLETCHER & MADELLA, 2006). This is probably because the Čićarija and Učka Mountains provide an orographic barrier to the north and east (up to 1394 m asl) of the study area, retaining the clouds coming from the Adriatic Sea, and increasing precipitation. Pollen diagrams from Škocjanski Zatok near Koper

suggest that the mid-Holocene vegetation of northern Istria was dominated by broadleaved taxa, with a high percentage of beech (CULIBERG, 1995, 1997). Conversely, pollen analyses from Vrana lake, on the island of Cres, 50 km eastwards, suggest that oak (*Quercus*) was there the most important tree taxon throughout the Holocene, although an increase of beech and fir (*Abies*) occurred after ca 9600 cal BP (SCHMIDT et al., 2000).

5. INTERPRETATION OF CORE EVIDENCE

5.1. S1 (1743–1685 cm, previous to ca 6830 years cal BP)

The lowest part of core section S1 (Fig. 3, unit D) has not yet been dated, but is significantly different from the others studied here. Unit D is the result of a massive colluvial discharge and therefore a sedimentation gap could exist between units D and MCS1. If so, unit D could have been deposited during a period of rapidly changing climate at the lateglacial–early Holocene transition. Alternatively, the predominant siliceous component, with its steady trend towards more laminated and finer particle sizes and the almost complete absence of OM and pollen could be due to slope failure associated with a major tectonic event, such as the one recorded on Mljet Island by WUNSAM et al. (1999). High MS values in this part of the core point to a significant, and perhaps rapid, input of mineral sediments. The laminated clays and silts of unit MCS1 and its stable and well-sorted particle size pattern seem to reflect the establishment of a lake fed by intermittent streams.

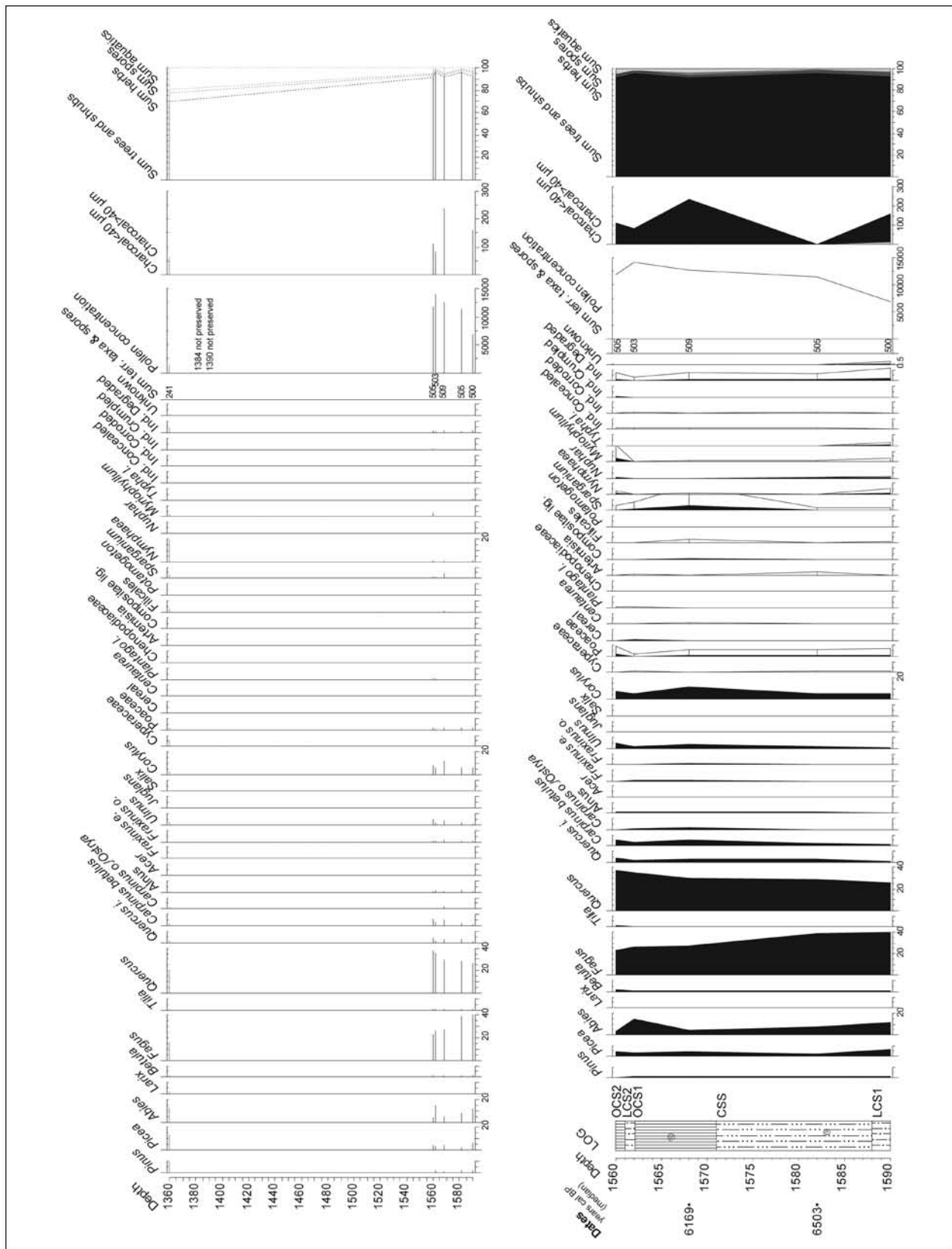


Fig. 6 Pollen diagrams (selected taxa). Radiocarbon dates are reported in years cal BP. The quantity of individual pollen taxa is presented in percentages (calculated from the sum of all terrestrial-taxa and spore pollen). For summary diagram the percentage of trees and shrubs (AP) and herbs, spores and aquatics (NAP) was calculated from the sum of all taxa. The sum of terrestrial taxa and spores is in absolute numbers. Pollen and charcoal concentration are given in number per cm^3 . All pollen data is presented (a) as well as a detail of the results obtained for S2 alone (b). In (a) data are presented as simple bars in reason of the large gap between S2 and S3. The only exception was made for the AP/NAP ratio, where bars are linked by dashed lines to show the changing AP/NAP trend between samples 1560 and 1360 cm depth. Abbreviations to be read as follows: *Quercus i.* (*ilex* type), *Carpinus o.* (*orientalis* type), *Fraxinus e.* (*excelsior*), *Fraxinus o.* (*ornus* type), *Cereale* (type), *Plantago l.* (*lanceolata* type), *Compositae lig.* (*liguliflorae* type), *Typha l.* (*latifolia* type) and *Sum terr.* (*terrestrial*) taxa and spores. Ind – indeterminable. Italic is used for taxa if pollen is determined to genus level, while normal letters are used for taxa if pollen is determined to family level.

5.2. S2 (1598–1550 cm, ca 6600–6000 years cal BP)

Core segment S2 probably represents a progressive lowering of the water level in the polje. The lower portion of this core segment, represented by units LCS1 and CSS, contains microlaminations and occasional fine sand laminae. The intermittent input of coarser materials represented by the sand peaks at 1578, 1568, 1554 and 1558 cm depth could be due to sudden wet and erosive episodes, but generally this core segment seems to suggest the onset of progressively drier conditions. The clay particles and structures characterising the sediments from unit CSS (Fig. 5) potentially indicate the formation of shallow hydromorphic soils during low water stands. The peak in carbonates at 1580 cm depth could be a consequence of a higher concentration of microorganisms and aquatic plants fixing CaCO₃ in the lake, due to lower water levels (MACKERETH, 1966; KELTS & TALBOT, 1990). This carbonate peak is followed by a significant increase in OM and charcoal within the lake sediments. The content in OM increases toward the top of core segment S2, in units OCS1, LCS2 and OCS2, also indicating the establishment of low water levels. Furthermore, the relatively low MS readings from this part of the core point to lower terrigenous input with siliceous sediments only episodically reaching the basin.

Tree pollen is dominant throughout core segment S2, constituting ca 90% of the total pollen sum: the record suggests that ca 6600 years cal BP (1590 cm depth) the landscape around Polje Čepić was covered by a thick forest of shade-tolerant beech (40%), and oak (26%), fir (11.8%), and hazel (*Corylus* 5.8%). Herb-type pollen remains stable around 2% throughout core segment S2, but after 6500 years cal BP forest composition changed appreciably towards a more open type of forest, characterised by the decline of beech (27.3%) at 1568 cm depth (ca 6150 years cal BP), and an increase of oak (29.8%) and hazel (11.7%).

5.3. S3 (1398–1345 cm, ca 4420–3870 years cal BP)

The absence of pollen grains at 1384 and 1390 cm depth, as well as the presence of lignite (unit L) and the abundance of only partially humified OM within unit OCS3 suggest a low water level stand at the coring site. The 3 units L, OCS3, and LCS2 probably represent a transitional phase from dry conditions with peat formation, to a wetter environment with deepening water, also indicated by laminated and massive clayey and clay-rich silt (units LCS2 and MCS2) towards the top of core segment S3. The top unit MCS2 contains abundant amounts of shells, indicative of established limnic conditions at the top of this core segment.

At ca 3900 years cal BP (1360 cm depth) Polje Čepić was surrounded by relatively open, mixed woodland. When compared to core segment S2, S3 denotes a relative decline of oak and other tree pollen taxa, with

trees and shrubs representing only 70% of the total pollen sum. This decline and the simultaneous increase of non-arboreal taxa, with herbs reaching 7.3% of the total pollen sum, indicate a more open landscape.

6. DISCUSSION

This study covers three time periods between ca 7000 years cal BP and 3800 years cal BP providing new evidence on palaeoenvironmental and vegetation change in Polje Čepić and its surroundings. Using a combination of archaeological and palaeolimnological evidence, we suggest the following account of Polje Čepić and the people living on its margins during those periods (Fig. 7).

6.1. Archaeological evidence

A recent archaeological survey carried out on the margins of Polje Čepić, provides strong evidence for the presence of people during the last 25,000 years (BALBO, 2006; BALBO et al., 2006). The periods covered by the core segments are well represented in the archaeological record. Human occupation for the period covered by S2 is characterised by five open-air lithic scatters on the margins of the polje. Organic material was not preserved at these locations, owing to exposure to weathering and modern agricultural practices. In the absence of absolute radiocarbon datable materials, the age of these archaeological assemblages was inferred by association with radiocarbon-dated cave sites studied in the wider region. In particular, the lithic assemblages from the open-air sites discovered at Frankoli and Ivšiče present artefacts that could be associated with those found at Pupičina Cave, located less than five kilometres northwards (MIRACLE & FORENBAHER, 2005; BALBO et al., 2006).

Within the lithic assemblages discovered at Frankoli and Ivšiče three obsidian fragments of probable Liparian origin were found (BALBO, 2006; BALBO et al., in press). Fragments of the same raw material were found in the Late Neolithic horizon G at Pupičina Cave, dated between 6219 and 6477 years cal BP at 1σ (MIRACLE & FORENBAHER, 2005). The most recent periods, covered by core segment S3, are associated with the presence of large communities living around Polje Čepić. Such communities have been well documented (PETRIĆ, 1979). Kožljak and Kršan are two major examples of late medieval settlements erected upon protohistoric hillforts (*castellieri*) dating back to the 2nd millennium BC. In a recent archaeological survey a probable Bronze Age settlement was (re)discovered on the northern tip of the polje (BALBO et al., 2006), on a hilltop locally known as Gradina (MARCHESETTI, 1903). Six previously unknown lithic scatters and buried agricultural soil horizons possibly of the same age, were also discovered on the margins of the polje (BALBO et al., 2006).

6.2. Palaeolimnological evidence

The neotectonic depression represented by Polje Čepić has been occupied by a wet, mainly lacustrine landscape, for most of the time span covered by the present study. Our analyses suggest that the water body and

surrounding vegetation underwent significant changes during these periods of time. The archaeological, sedimentological, and palynological records, notably the increase in non-arboreal pollen (NAP) in S3, support the hypothesis that forest clearance by people living on the margins of the polje contributed to such chang-

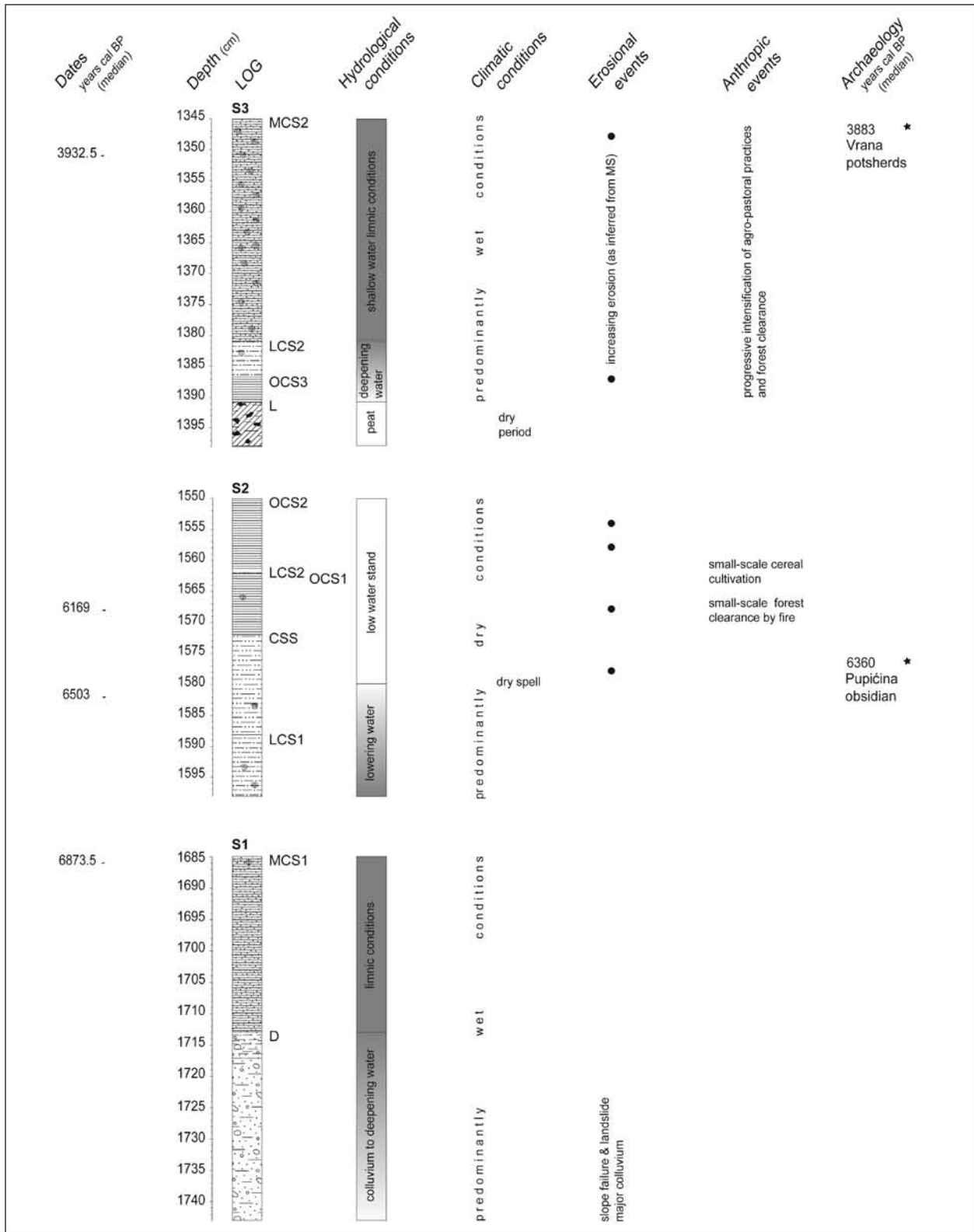


Fig. 7 Diagram summarising the main results issued from the present study.

es since ca 6500 years cal BP, and particularly so after 4000 years cal BP.

A high carbonate peak around 6500 years cal BP, may indicate a sudden lowering of the water level in the lake occupying the polje, with a consequent acceleration in the fixation and deposition of carbonates and possible soil formation. After ca 6500 years cal BP, the amount of carbonates deposited in the lake decreased. This and a progressive lowering in MS values suggest the establishment of low water conditions. The early phases of this period coincided with a sudden increase in the input of OM and charcoal. The relative coarseness of the charcoal (>40 μm) points to its input in the basin from relatively short distances within its catchments (WHITLOCK & LARSEN, 2001). After ca 6150 years cal BP (1568 cm) and within about a 100 years, a significant forest composition change seems to have taken place around Polje Čepić. Beech declined in favour of oak, indicating the establishment of a more open forest, dominated by photophilic (light-demanding) oak. At the same time cereal-type pollen grains made their first appearance in the region, just after 6150 years cal BP at 1562 cm depth. Five of the sites recently found on the margins of the polje have been associated through typo-chronological comparison with the Late Neolithic horizon G dug in the nearby Pupičina Cave, dated between 6219 and 6477 years cal BP. The simultaneous appearance of cereal-type pollen grains and the unusual concentration of microcharcoal (also revealed by LOI analysis) indicate a possible link between the decreased tree cover and the introduction of small-scale forest clearance and burning by Neolithic settlers just before 6000 years ago.

Our preliminary age–depth model, with its increased sedimentation rate after 4000 cal BP, is consistent with the model proposed by OLDFIELD et al. (2003). The lowermost 3 m of sediments accumulated at the core location over 3000 years, between 7000 and 4000 years ago, at an average rate of 1 mm/yr. In contrast, the average sedimentation rate in the top 14 m of the core tripled in the last 4000 years to 3.5 mm/yr. Sedimentological analyses of the sediments for the period represented by S3 point to higher water level in the shallow lake occupying the polje. At the same time, a steady increase in magnetic susceptibility throughout S3 indicates an increase in the input of sediments within the polje. Such peaks in MS are often linked to periods of deforestation, and consequent erosion of mineral soils (SANDGREN & SNOWBALL, 2001). In addition, the comparison between the pollen record from core segment S2 and the sample from core segment S3 shows a trend toward an ever more open forest environment. In core segment S2 beech decreases (40 to 26%) to the slight advantage of oak (26 to 30%). In core segment S3 beech and oak decrease even further, respectively reaching 16% and 20%. This trend in vegetation change is also reflected by the decreasing ratio of arboreal versus non-arboreal plants (AP/NAP), indicating a shift towards a more open landscape. We propose that the concurrence of

wetter conditions, and perhaps the cumulative intensification of forest clearance and agro-pastoral practices, may have resulted in a sharp acceleration of the silting of the lake occupying Polje Čepić.

In the wider region, the study carried out by OLDFIELD et al. (2003) on core RF93–30, extracted from the Adriatic, revealed a sedimentary pattern similar to that obtained for Polje Čepić. This was interpreted as being the result of increased soil erosion in the Po plain due to the intensification of agro-pastoral practices during the Bronze Age. Similarly, the studies carried out at the nearby Vrana Lake suggest that Bronze Age communities played an important role in the shaping of the local landscape (SCHMIDT et al., 2000; MIKO & MESIĆ, 2004; MIKO et al., 2005). Potsherds embedded within colluviums were found on the margins of Vrana Lake (Island of Cres), and dated between 3853 and 3926 years cal BP at 1σ range (median of 3883 years cal BP from the original date of 3580 ± 40 years uncal BP in MIKO et al., 2005). This age range has been correlated with a greater input of sediments in the lake, and seems to coincide with the beginning of oak forest clearance through burning between 3693 and 3895 years cal BP at 1σ range (median of 3796 years cal BP from the original linear extrapolated date of 3518 ± 80 years uncal BP in SCHMIDT et al., 2000).

7. AVAILABLE PROXIES FOR FURTHER STUDIES

Microscopic observations carried out on the core sediments have revealed the presence of several other proxies available for use in palaeoclimatic research. Among them were shells, diatoms, midges (Chironomidae and related diptera), and ostracods. Some of them have been sampled and kept for future observations. Reference samples have also been collected from several ponds and rivers within the catchments of Polje Čepić for the isotopic study of ostracods and water. Seeds and other plant macroremains also abound. Moreover, the location and characteristics of Polje Čepić makes it an optimal site for furthering palaeoenvironmental and palaeoclimatic research in connection with other continental and marine sequences available in the Mediterranean realm.

8. CONCLUSIONS

In this paper we have demonstrated the potential of Polje Čepić for enhancing our knowledge of the past in the Istrian peninsula and beyond. We propose that lacustrine/wet landscapes have characterised Polje Čepić and its surroundings before historical times. Polje Čepić, and other poljes, are ideal sites to study the introduction of agro-pastoral practices and their effects on the transformation of the Mediterranean realm during the Neolithic and later times. Using sedimentological and palynological analyses we have detected hydrologi-

cal and palaeoclimatological variations affecting Polje Čepić and its surroundings. We have shown that people played a significant role in shaping this typical Mediterranean karstic wet landscape.

Palaeoenvironmental and archaeological data suggest that the introduction of agro-pastoral practices contributed to the transformation of the area of study. Specifically, we propose that: (1) around 6500 years ago, people may have introduced forest clearance by fire in tandem with small-scale agricultural practices on the margins of the lowered karstic lake, triggering a slight change in forest composition near Polje Čepić; (2) around 4000 years ago wetter climatic conditions and perhaps the intensification of agro-pastoral practices, coincide with appreciably more open vegetation; (3) these factors probably resulted in increased erosion and sedimentation, leading to the siltation of the lake until its artificial drainage in 1932.

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9. REFERENCES

- ALLEN, J.R.M., BRANDT, U., BRAUER, A., HUBBERTEN, H.W., HUNTLEY, B., KELLER, J., KRAML, M., MACKENSEN, A., MINGRAM, J., NEGENDANK, J. F.W., NOWACZYK, N.R., OBERHANSLI, H., WATTS, W.A. & WULF, S. (1999): Rapid environmental changes in southern Europe during the last glacial period.– *Nature*, 400, 740–743.
- ANDRIČ, M. (2001): Transition to Farming and Human Impact on the Slovenian Landscape.– Unpubl. PhD Thesis, University of Oxford, 152 p.
- ANDRIČ, M. (2006): Prapoče pollen core and Holocene vegetation change in northern Istria.– In: MIRACLE, P.T. & FORENBAHER, Š. (eds.): Prehistoric Herders in Istria (Croatia): the Archaeology of Pupičina Cave. Archaeological Museum of Istria, 31–62, Pula.
- BALBO, A.L. (2005): The last days of a Mediterranean wet landscape. Human impact on and draining of shallow lake Arsa, Polje Čepić, Istria, Croatia.– 10th UNESCO Universities Heritage Forum, Newcastle, 9 p.; <http://www.ncl.ac.uk/unescolandscapes/files/BALBOAndrea%20Luca.pdf>.
- BALBO, A.L. (2006): People and wetlands in the open karst of Istria, Croatia.– *Newsletter of the Prehistoric Society*, 52, 2–3.
- BALBO, A.L., KOMŠO, D. & MIRACLE, P.T. (2004) Geoarchaeological survey of Polje Čepić and part of its hydrological basin (Istria Peninsula, Croatia): Report on the first field season.– *Histria Archaeologica*, 33, 265–276.
- BALBO, A.L., KOMŠO, D. & MIRACLE, P.T. (2006): Prehistory of the open karst, further discoveries from the geoarchaeological survey of Polje Čepić, Croatia.– *Histria Archaeologica*, 35, 33–42.
- BALBO, A.L., KOMŠO, D. & MIRACLE, P.T. (in press): Open-air Mesolithic settlements in a mutable karstic Mediterranean biotope. Polje Čepić (Istria, Croatia).– In: McCARTAN, S., WOODMAN, P., SCHULTING, R. & WARREN, G. (eds.): Mesolithic Horizons: Papers presented at the Seventh International Conference on the Mesolithic in Europe, Belfast 2005. Oxbow Books, Oxford.
- BARTLEIN, P.J. (2007): Time scales of climate change.– In: ELIAS, S. (ed.): *Encyclopedia of Quaternary Science*. Elsevier, Amsterdam, 1873–1883.
- BENNET, K.D. & WILLIS, K.J. (2002): Pollen.– In: SMOL, J.P., BIRKS, H.J. & LAST, W.M. (eds.): *Tracking Environmental Changes Using Lake Sediments*. Dordrecht, Kluwer Academic, 5–32.
- BERGLUND, B.E. & RALSKA-JASIEWICZOWA, M. (1986): Pollen analysis and pollen diagrams.– In: BERGLUND, B.E. (ed.): *Handbook of Holocene Paleoecology and Paleohydrology*. New York, Chichester, John Wiley and Sons, 455–484.
- BEUG, H.-J. (1967): On the forest history of the Dalmatian coast.– *Review of Palaeobotany and Palynology*, 2, 271–279.
- BEUG, H.-J. (1977): Vegetationsgeschichte Untersuchungen in Küstenbereiche von Istrien (Jugoslawien) (Research of vegetation development in coastal areas of Istria (Yugoslavia).– *Flora*, 166, 357–381.
- BJÖRCK, S. & WOHLFARTH, B. (2001): ¹⁴C Chronostratigraphic techniques in paleolimnology.– In: LAST, W.M. & SMOL, J.P. (eds.): *Tracking Environmental Change Using Lake Sediments*. Dordrecht, Kluwer Academic Publishers, 205–245.
- BROUSOULIS, F., IOAKIM, C., KOLOVOS, G. & PAPANIKOS, D. (1999): The Ioannina basin: geological and palaeoenvironmental evolution in Quaternary and historical times.– In: BAILEY, G.N., ADAM, E., PANAGOPOULOU, E., PERLÈS, C. & ZACHOS, K. (eds.): *The Palaeolithic Archaeology of Greece and Adjacent Areas*. British School at Athens, Athens, 87–96.

- CULIBERG, M. (1995): Dezertifikacija in reforestacija Slovenskega krasa (Desertification and reforestation of the karst in Slovenia).– Poročilo o raziskovanju paleolitika, neolitika in eneolitika v Sloveniji, 22, 201–217.
- CULIBERG, M. (1997): Sermin: prazgodovinska in zgodnjerska naselbina v severozahodni Istri (Sermin: a prehistoric and early Roman settlement in northwestern Istria).– In: HORVAT, J. (ed.): *Paleovegetacijske razmere v Koprskem primorju*. Opera Instituti archaeologici sloveniae ZRC SAZU, 3, 135–139, Ljubljana.
- DURN, G. (2003): Terra rossa in the Mediterranean region: parent materials, composition and origins.– *Geologia Croatica*, 56, 83–100.
- FLETCHER, W.J. (2002): Late-glacial and Holocene vegetation and prehistoric wood-use in the Istrian Karst, Croatia.– In: THIÉBAULT, S. (ed.): *Charcoal Analysis. Methodological Approaches, Palaeoecological Results and Wood Uses*. 1st ed. Paris, BAR, 87–94.
- FLETCHER, W.J. & MADELLA, M. (2006): Characterising the Post-Mesolithic landscape at Pupičina peć: results of charcoal and phytolith analyses.– In: MIRACLE, P.T. & FORENBAHER, S. (eds.): *Prehistoric Herders in Istria (Croatia): the Archaeology of Pupičina Cave*. Archaeological Museum of Istria, Pula, 429–446.
- GEYH, M.A., SCHOTTERER, U. & GROSJEAN, M. (1998): Temporal changes of the ¹⁴C reservoir effect in lakes.– *Radiocarbon*, 40, Proceedings of the 16th International Radiocarbon Conference, 921–931.
- HERAK, M. (1991): Dinarides – mobilistic view of the genesis and structure.– *Acta Geologica*, 21, 35–117.
- JACOBSON, G.L.J. & BRADSHAW, R.H.W. (1981): The selection of sites for palaeovegetational studies.– *Quaternary Research*, 16, 80–96.
- JAHNS, S. (2002): An improved time scale for the Holocene history of vegetation and environment on the South Dalmatian Island of Mljet.– *Vegetation History and Archaeobotany*, 11, 315–316.
- JAHNS, S. & VAN DEN BOGAARD, C. (1998): New palynological and tephrostratigraphical investigations of two salt lagoons on the island of Mljet, South Dalmatia, Croatia.– *Vegetation History and Archaeobotany*, 7, 219–234.
- JENNINGS, J.N. (1971): *Karst*.– M.I.T. Press, Cambridge, Massachusetts and London, England, 252 p.
- JENNINGS, J.N. (1985): *Karst Geomorphology*.– Blackwell Ltd, Oxford, Basil, 293 p.
- KELTS, K. & TALBOT, M.R. (1990): Lacustrine carbonates as geochemical archives of environmental change and biotic/abiotic interactions.– In: TILZER, M.M. & SERUYA, C. (eds.): *Large Lakes. Ecological structure and functions*. Springer-Verlag, London, 288–315.
- LAGO, L. & ROSSIT, C. (1981): *Descriptio Histrie. La penisola istriana in alcuni momenti significativi della sua tradizione cartografica sino a tutto il secolo XVIII. Per una corologia storica (Descriptio Histrie. The Istrian peninsula in its cartographic tradition until the 18th century)*.– Trieste, Università Popolare di Trieste. Edizioni Lint, 349 p.
- LAST, W.M. (2001): Textural analysis of lake sediments.– In: LAST, W.M. & SMOL, J.P. (eds.): *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers, Dordrecht, 41–81.
- LAWSON, I., FROGLEY, M., BRYANT, C., PREECE, R. & TZEDAKIS, P. (2004): The Lateglacial and Holocene environmental history of the Ioannina basin, North-west Greece.– *Quaternary Science Reviews*, 23, 1599–1625.
- LEROY, S.A.G. & COLMAN, S.M. (2001): Coring and drilling equipment and procedures for recovery of long lacustrine sequences.– In: LAST, W.M. & SMOL, J.P. (eds.): *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers, Dordrecht, 107–135.
- MACKERETH, F.J.H. (1966): Chemical investigation of lake sediments and their interpretation.– *Proceedings of the Royal Society. Series B, Biological Sciences*, 161. A discussion on the Development of Habitats in the Post-Glacial, 295–309.
- MARCHESETTI, C. (1903): I castellieri preistorici di Trieste e della regione Giulia (Prehistoric hillforts of Trieste and the Giulia region).– *Il Museo Civico di Storia Naturale, Trieste*, 206 p.
- MIHLJEVIĆ, D. (1998): Relief of structural origin and the structural–geomorphological regions of the Istria and Kvarner.– *Proc. Natural History Researches of the Rijeka Region*, 23, 277–302.
- MIKO, S. & MESIĆ, S. (2004): Geochemical record of Holocene land use change and anthropogenic Pb deposition in a Northern Adriatic karst lake (Lake Vrana, Cres Island). – 32nd International Geological Congress, Abstracts, Florence, 35.
- MIKO, S., MESIĆ, S., FORENBAHER, S. & BELAK, M. (2005): Archeometric analysis of Bronze Age potsherds from Vrana Lake (Cres Island): a study of provenance and dating of slope processes.– *Abstracts Book of 3rd Croatian Geological Congress, Opatija*, 99–100.
- MIRACLE, P.T. & FORENBAHER, S. (2005): Neolithic and Bronze Age herders of Pupičina Cave, Croatia.– *Journal of Field Archaeology*, 30, 255–281.
- MIRACLE, P.T. & FORENBAHER, S. (eds.) (2006): *Prehistoric herders in Istria (Croatia): the Archaeology of Pupičina Cave, Pula*. Archaeological Museum of Istria, Pula, 542 p.
- MOORE, P.D., WEBB, J.A. & COLLINSON, M.E. (1991): *Pollen Analysis*.– Blackwell Science, Oxford, 216 p.
- NELSON, D.W. & SOMMERS, L.E. (1996): Total carbon, organic carbon, and organic matter.– In: BIGHAM, J.M. (ed.): *Methods of Soil Analysis: Part 3 Chemical Methods*. Madison, Soil Science Society of America, 961–1010.
- NOWACZYK, N.R. (2001): Logging of magnetic susceptibility.– In: LAST, W.M. & SMOL, J.P. (eds.): *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers, Dordrecht, 155–170.
- OLDFIELD, F., ASIOLI, A., ACCORSI, C.A., MERCURI, A.M., JUGGINS, S., LANGONE, L., ROLPH, T., TRINCARDI, F., WOLFF, G., GIBBS, Z., VIGLIOTTI, L., FRIGNANI, M., VAN DER POST, K. & BRANCH, N. (2003): A high resolution late Holocene palaeoenvironmental record from the central Adriatic sea.– *Quaternary Science Reviews*, 22, 319–342.

- O'SULLIVAN, P.E. (2004): Palaeolimnology.– In: O'SULLIVAN, P.E. & REYNOLDS, C.S. (eds.): *The Lakes Handbook: Limnology and Limnetic Ecology*. Blackwell Publishing, Malden, Oxford, Carlton, 609–666.
- PARENZAN, P. (1928): *Il Lago d'Arsa (The Arsa Lake)*.– *Histria Nobilissima*, 1, 47–51.
- PETRIĆ, N. (1979): *Introduzione alla preistoria dell'Istria (Introduction to the Prehistory of Istria)*.– *Atti*, 9, 185–248.
- REILLE, M. (1992): *Pollen et spores d'Europe et d'Afrique du nord (European and north African pollen and spores)*.– *Laboratoire de Botanique Historique et Palynologie URA CNRS, Marseille*, 520 p.
- REILLE, M. (1995) *Pollen et spores d'Europe et d'Afrique du nord (Supplement) (European and north African pollen and spores)*.– *Laboratoire de Botanique Historique et Palynologie. URA CNRS, Marseille*, 327 p.
- ROGLIĆ, J. (1950): *Čepićko Polje (Polje Čepić)*.– *Geografski glasnik*, 11–12, 147–148.
- SANDGREN, P. & SNOWBALL, I. (2001): Application of mineral magnetic techniques to palaeolimnology.– In: LAST, W.M. & SMOL, J.P. (eds.): *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers, Dordrecht, 217–237.
- SANGIORGI, F., CAPOTONDI, L., COMBOURIEU NEBO-UT, N., VIGLIOTTI, L., BRINKHUIS, H., GIUNTA, S., LOTTER, A.F., MORIGI, C., NEGRI, A. & REICHART, G.-J. (2003): Holocene seasonal sea-surface temperature variations in the southern Adriatic Sea inferred from a multiproxy approach.– *Journal of Quaternary Science*, 18, 723–732.
- SCHMIDT, R., MULLER, J., DRESHER-SCHNEIDER, R., KRISAI, R., SZEROCZYNSKA, K. & BARIĆ, A. (2000): Changes in lake level and trophy at Lake Vrana, a large karstic lake on the Island of Cres (Croatia), with respect to palaeoclimate and anthropogenic impacts during the last approx. 16,000 years.– *Journal of Limnology*, 59, 113–130.
- ŠIKIĆ, D. & POLŠAK, A. (1973): *Osnovna geološka karta (OGK) SFRJ 1:100000, Tumač za list LABIN (Basic Geological Map of SFRJ 1:100000, Geology of the Labin Sheet)*.– *Institut za geološka istraživanja Zagreb (1963), Savezni geološki zavod, Beograd*, 55 p.
- ŠKORIĆ, A., MAYER, B., VRANKOVIĆ, A. & BAŠIĆ, F. (1987): *Pedološka karta Istre (Soil Map of Istria)*.– *Institute for Pedology at the Faculty of Agriculture, University of Zagreb, 1st ed. Zagreb*.
- STOCKMARR, J. (1971): Tablets with spores used in absolute pollen analysis.– *Pollen et Spores*, 13, 615–621.
- STUIVER, M. & REIMER, P. (1993): Extended ¹⁴C database and revised CALIB radiocarbon calibration program.– *Radiocarbon*, 35, 215–230.
- STUIVER, M., REIMER, P.J. & REIMER, R.W. (2005): CALIB 5.0.– <http://calib.qub.ac.uk>
- WHITLOCK, C. & LARSEN, C. (2001): Charcoal as a fire proxy.– In: SMOL, J.P., BIRKS, H.J.B. & LAST, W.M. (eds.): *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers, Dordrecht, 75–97.
- WULF, S., KRAML, M., BRAUER, A., KELLER, J. & NEG-ENDANK, J.F.W. (2004): Tephrochronology of the 100 ka lacustrine sediment record of Lago Grande di Monticchio (southern Italy).– *Quaternary International*, 122, 7–30.
- WUNSAM, S., SCHMIDT, R. & MULLER, J. (1999): Holocene lake development of two Dalmatian lagoons (Malo and Veliko Jezero, Isle of Mljet) in respect to changes in Adriatic sea level and climate.– *Palaeogeography, Palaeoclimatology, Palaeoecology*, 146, 251–281.

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