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PALAEOCLIMATE, VEGETATION AND COASTAL LAKE DEVELOPMENT, FROM UPPER PLENIGLACIAL UNTIL EARLY HOLOCENE, IN THE NORTHERN ADRIATIC VALUN BAY (ISLE OF CRES, CROATIA)

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ABSTRACT - A multi proxy approach study (cladocerans, foraminifers, ostracods, pollen, geochemistry/mineralogy) was performed on a core sequence from the northern Adriatic Valun bay (Isle of Cres, Croatia). Since the whole core section was dominated by pine pollen, the differentiation of pine pollen types improved climate interpretations. Dating at the present stage of investigations, however, is tentative.
At the core base, a period was observed, which was dominated by pollen of pine, and to a lesser extent of spruce and deciduous trees (*Tilia*). Freshwater conditions exhibiting a slightly brackish influence, occurred towards the top of the section. The overall picture of this interstadial period is the shift from cold to moderately warm, humid conditions. This interstadial was compared with the vegetation development of the middle Würmian period (isotope stages 3 and 4) known from sites south of the Alps. It was followed by a period rich in *P. mugo*-types. The high abundances of these pine pollen types indicate a situation comparable with the present subalpine *P. mugo* belt. A cold period rich in snow-cover was inferred. Because of the lowest inferred temperatures throughout the core, it was related to the last glacial maximum (LGM). Freshwater and/or brackish ostracods occurred, some of which are only known as fossils in the present-time Adriatic region. The subsequent shift from *P. mugo*-types to *P. Haloxylon*-type indicates rise in timberline. It was followed again by an at least temporarily wet period with fluctuating timberlines. The subsequent pollen increase in *P. sylvestris*-types and low abundances of oak indicates climate amelioration. Ostracods indicate lake salinity and water temperature increase. This development was related to a period of expansion of alpine shrubs and pines at Längsee, Carinthia (Längsee oscillation, Prä-Bölling?), with an upper boundary of about 15.5 ^{14}C ky BP. At Valun it was followed by a pine-rich period of climate regression (Oldest Dryas Ia). Higher values of *P. mugo*-types at the lower part of the section, and catchment erosion indicate more wet conditions relative to the upper part with the highest pollen abundances of *Haploxylon* pine throughout the core. The subsequent pollen shift from alpine pines towards *P. sylvestris*-types together with an increase in elements of the mixed oak forest, was related to late glacial climate amelioration. During this time the marine ingression into the basin took place. Subsequent to a Lateglacial climate fluctuation, as indicated by increased abundances of *P. mugo*- types, enhanced pollen abundances of oak together with submediterranean pine indicate that summer became warmer and drier. The lower boundary of the Younger Dryas biozone was drawn according to the distinct decline of foraminifer abundances concurrent with increasing values of the *P. mugo*-types. In this case, and supported by a ^{14}C date, the YD biozone appeared as a multiphase period. During early Holocene, the expansion of a vegetation favoured by humidity, was related with the onset of a pluvial period in the Adriatic at about 8.4 ^{14}C ky BP. During the lower Younger Dryas and the Holocene pluvial period, increased freshwater incursions were assumed to result in lowered salinity in the bay of Valun.

RIASSUNTO - È stato eseguito uno studio multidisciplinare (cladoceri, foraminiferi, ostracodi, polline, geochimica/mineralogia) su sedimenti di una carota prelevata nella Baia di Valun (Isola di Cherso, Croazia), nell'Adriatico settentrionale. La dominanza di polline di pino nell'intera successione ha permesso un'interpretazione climatica più precisa, basata sui differenti tipi di questo polline. L'inquadramento cronologico, allo stato attuale della ricerca, è comunque preliminare.
La parte basale della carota registra un periodo dominato da polline di pino e, in subordine, di abete e alberi decidui (*Tilia*). Condizioni dulcicole con deboli influenze salmastre si rinvengono nella sua parte sommitale. Caratteristica principale di questo periodo interstadiale è l'evolversi da una fase fredda ad una moderatamente caldo-umida. Questo interstadiale si adatta ad uno sviluppo vegetazionale del W?rmiano medio (stadi isotopici 3 e 4), come si osserva in località a sud della catena alpina, ed è seguito da un periodo ricco in tipi di polline. di *P.mugo*. L'elevata abbondanza di questi tipi di polline indica una situazione confrontabile con l'attuale fascia subalpina a *P. mugo*. Si presuppone un periodo freddo, con abbondante copertura nevosa, attribuibile al last glacial maximum (LGM) in relazione alle temperature ipotizzate, che sono le più basse registrate nella carota. Durante questo periodo si rinvengono ostracodi di ambienti dulcicoli e/o debolmente salmastri, alcuni dei quali sono noti solo allo stato fossile nella regione adriatica. Il successivo cambiamento da i tipi di polline di *P. mugo* a quello di *P. Haploxylon* indica un innalzamento della linea delle foreste; segue un nuovo, almeno temporaneo, periodo umido con fluttuazione della linea delle foreste. Il successivo aumento di tipi di polline di *Pinus sylvestris* e, in subordine, di quercia, indicano un miglioramento climatico. Gli ostracodi testimoniano un aumento di salinità e di temperatura dell'ambiente lacustre. Questo sviluppo è collegato ad un periodo di espansione della vegetazione arbustiva alpina e dei pini a Längsee, Carinzia (oscillazione di Längsee, Pre-Bölling?), il cui limite superiore è datato circa 15.5 ka B.P. con il ^{14}C. A Valun segue un periodo di regressione climatica (Oldest Dryas Ia), segnalato da alte concentrazioni di polline di pino. Le elevate concentrazioni dei tipi *P. mugo*, alla base di questo intervallo, e l'erosione delle aree circostanti indicano condizioni più umide rispetto alla parte alta, con il più elevato contenuto di polline del tipo pino *Haploxylon* di tutta la carota. Il successivo cambiamento del contenuto pollinico da pini alpini ai tipi *P. sylvestris*, con elementi di foreste miste a querceto, è messo in relazione al miglioramento climatico tardi-glaciale. Durante questa fase si registra l'ingressione marina nel bacino. Successivamente alla flut-

tuazione climatica del Tardiglaciale, indicata da un aumento in abbondanza dei tipi *P. mugo*, aumenta la concentrazione di polline di quercia frammisto a quello di pino submediterraneo, indicando che l'estate diventa più calda e secca. Il limite inferiore della biozona Younger Dryas è segnalata dal chiaro declino del contenuto in foraminiferi e dal concomitante aumento dei tipi di polline di *P. mugo*. Con il supporto di dati ^{14}C, si evidenzia che la biozona YD ha un andamento multifasico. Durante l'Olocene inferiore, l'espansione della vegetazione, favorita dall'umidità, è messa in relazione con l'inizio della piovosità in Adriatico, datato circa 8.4 ^{14}C ka B.P. Durante lo Younger Dryas basale e il piovoso periodo dell'Olocene, aumenta l'apporto di acqua dolce che segna l'abbassamento di salinità nella baia di Valun.

Key-words: Last Glacial to early Holocene stratigraphy, Adriatic region, palynology, palaeolimnology, palaeoclimate, sea-level change
Parole-chiave: Tardo Pleistocene-Olocene, Adriatico, palinologia, paleolimnologia, paleoclima, variazioni di livello medio marino.

1. INTRODUCTION

The present investigations are part of a multidisciplinary study within the Austrian IGBP/PAGES project „Palaeolimnology of Alpine – Adriatic Lakes (PAAL)". We compared results from ancient lake sediments, which were detected at the bottom of the present marine bay of Valun, Island of Cres, Croatia, with three other sites: Lake Vrana close to Valun; Längsee, Carinthia; Malo and Veliko Jezero, Isle of Mljet, Croatia. The overall goal of the project is to study climate change since the last glaciation, along a north to south transect. The present study combines palynology with responses of a coastal environment to the Adriatic transgression and to climate.

According to Correggiari *et al.* (1996), areas of the Adriatic with present water depths less than 100 m, have been part of land during the last glacial maximum (LGM). In the Karst region of the present Kvarner islands, northeastern Adriatic, less permeable bedrock "sealing" karstic basins (poljes), which are located within the tectonic faults of the Dinarids, enabled lake formation (Biondič *et al.*, 1992; Biondič *et al.,* 1997). These coastal lakes of different age in the Dinaride Karst respond sensitively to changes in precipitation, temperature/evaporation, and to sea-level rise (Wunsam *et al.,*1999).

During LGM, south of the central eastern Alps, the glacier system of the Drau area terminated east of Klagenfurt, Carinthia. Further south, in Slovenia, only the uppermost parts of the valleys of Save and Soča were glaciated, whereas in the rest of Slovenia glaciers extended only locally (Van Husen, 1997). Based on palynological results from Ljubliansco Barje in Slovenia (Šercelj, 1966), Šercelj (1970, 1978, 1996) suggested the presence of refuges for trees in the northern Dinarides during late Pleistocene. For non-glaciated southern areas (Balkans, Greece, Italian peninsula), sparse refugia were assumed to have existed during the various cold periods of the Pleistocene, which acted as nuclei for expansion when the climate progressed (Beug, 1967; Wijmstra, 1969; Bottema, 1974; Grüger, 1975; Tzedakis, 1993; Willis, 1994). Prior to Lateglacial, an expansion of alpine shrubs and trees was observed palynologically at Längsee, Carinthia, which is located close to the maximum ice-margin of the Drau glacier (Van Husen, 1976). The upper boundary of the Längsee oscillation was dated at about 15.5 ^{14}C ky BP (Schmidt *et al.*, 1998). It was related by Schmidt *et al.* (1998) to a pine-pollen-dominated period older than the late glacial initial shrub-phase, which was found by Schmidt (1975) at Montiggler See (Lago di Monticolo), northern Italy, and which he called Prä-Bölling.

The name "Oldest Dryas" commonly is used in pollen profiles from the Alps for the NAP-rich section preceding the late glacial expansion of trees. At Längsee its usage was restricted by Schmidt *et al.* (1998) to the biozone between the Längsee oscillation and the late glacial expansion of trees. Pollenanalytical results of a more or less distinct initial shrub-phase, commonly dominated by *Juniperus,* preceding the late glacial mass expansion of trees, are widespread at the southern margins of the Alps (Fritz, 1972; Schneider, 1978; Schultze, 1979, 1984; Sercelj & Culiberg, 1984; Culiberg, 1991; Wick, 1996). Most often, however, at these areas there is not a clear boundary in the pollen diagrams between a NAP-dominated section and that of shrub formations; locally also pulses of pine pollen were inserted (Schultze, 1979, 1984). The late glacial mass expansion of trees in northern Italy, however, according to Wick (1996) was at about 12,300 ^{14}C BP.

At Längsee, a tephra was related to the Naples Yellow Tephra (NYT). It is the largest Lateglacial eruption from the Phlegraean fields, Italy (Orsi *et al.,* 1992), providing a new tephra marker across the Adriatic Sea to the south-eastern Alps. NYT gives an average ^{14}C age of 12,300 BP (Alessio *et al.*, 1973). The expansion of *Betula* at Längsee started ca 150 years earlier than NYT (Schmidt *et al.*, submitted).

Shifts in pine pollen relations at Längsee indicated short-term Lateglacial climate fluctuations (Schmidt *et al.*, submitted). The climate fluctuation Lg-FL1, related to the Swiss Aegelsee fluctuation which occurred shortly before 12,000 ^{14}C BP (Lotter *et al.*, 1992), separates the *Betula*-rich period from a period dominated by pine. Two climate fluctuations were observed within the pine-rich period. The lower one (Lg-FL2) occurred at the transition from the lower subzone to the upper one characterized by sparse pollen of deciduous trees. The younger fluctuation (Lg-FL3) might correlate with the Swiss Gerzensee oscillation observed by Eicher (1980).

When compared the late glacial vegetation development at Carinthia with that of the present Mediterranean, at Lago di Monticchio in central Italy, the lower boundary of *Betula*-rich period according to Huntley *et al.* (1999) was dated at about 13,200 ^{14}C BP (expected age range 14,580 to 14,630 cal. BP). According to comparable findings in Lake Albano and Lake Nemi (Lowe *et al.*, 1996), the climate of the birch-rich period was interpreted by Huntley *et al.* (1999) as summer cool with an higher moisture availability. At Lago di Monticchio it was followed by a period of increasing abundances of deciduous trees called late Lateglacial interstadial by Huntley *et al.* (1999). This period is divided into a lower subzone with lower pollen amounts of deciduous trees, and an upper one with the dominance of oak and, subordinately, *Tilia*. The climate of the latter was characterised by Huntley *et al.* (1999) as warm. This is supported by sporadic finds of pollen from *Fraxinus ornus* and *Phillyrea*. The boundary between both subzones was dated at about 12,400 ^{14}C BP (expected range of cal BP: 13,280 – 13,360). A tephra layer slightly above the ^{14}C dated sample according to Huntley *et al.* (1999) revealed a laminae – based age of 13,172 cal. BP.

At lake Vrana, a large and deep karstic lake on the Isle of Cres close to Valun, a sediment gap was related by Schmidt *et al.* (2000) to Alleröd and explained by lake level lowering due to increased summer temperatures and evaporation; the following rise in lake level at about 10.6 ky ^{14}C BP was interpreted with a more wet phase during Younger Dryas (Schmidt *et al.*, 2000).

According to palynological results, the eu-mediterranean evergreen oak (*Quercus ilex)* expanded at the Dalmatian coast at 42° south at about 5.5 to 6 ky ^{14}C BP (Jahns 1991; Jahns & van den Bogaard, 1998); ist expansion in the northern Adriatic, however, commenced not before 4.5 ky ^{14}C BP (Beug, 1977; Schmidt *et al.*, 2000). As a result, these findings were interpreted by Schmidt *et al.* (2000) by a gradient in summer drought. Wunsam *et al.* (1999) differentiated in Malo and Veliko Jezero (Isle of Mljet), two Dalmatian lagoon lakes, a multiphase Holocene pluviale period which initiated at 8.4 ky ^{14}C BP. It was briefly interrupted by a dryer episode from about 7.2 to 7.1 ky ^{14}C BP, and had its maximum between 7 and 6 ky ^{14}C BP. During 5 to 4 ky ^{14}C BP, the oscillating sea level gradually approached the present level. In Lake Vrana, a change in lake level at about 8.5 ky ^{14}C BP from a shallow to the present deep water lake, and its subsequent persistence, indicated that the pluvial period observed for the Dalmatian coast has also affected the northern Adriatic region (Schmidt *et al.*, 2000). The onset of the pluvial period at about 8.4 ky ^{14}C BP corresponds with that of sapropel formation S1 in the Adriatic Sea (Fontugne *et al.*, 1989). Investigations reviewed by Aritztegui *et al.* (2000) from Italian crater lake sediments and marine sequences from the central Mediterranean region in respect to the formation of sapropel S1 and its palaeoclimate background, suggest a similar duration for the pluvial period. They support the palaeoclimatic conclusions obtained from the lagoon lakes at the eastern Adriatic coast: The sapropel formation lasted from ca. 9.0 to 6.8 cal. ky BP. The sapropel in the study area can be divided into two subphases (S1a and S1b) interrupted by a short-lived episode (ca 500 years) of drier conditions. Aritztegui *et al.* (2000) concluded that the key factors of sapropel formation were increased discharge of freshwater into the Mediterranean as a result of a wetter climate. Kallel *et al.* (1997) assumed that enhanced summer rainfall might be responsible for the sapropel formation (S1) in the eastern Mediterranean. These conclusions are supported by palaeolimnological findings from Indinger (1999) at Malo Jezero, although for a different time and on a smaller scale; during younger Holocene, a temporary freshwater influx into the lagoon lake initiated stratification, the onset of a chemocline, and caused sapropel formation. Additionally, nutrient influx from catchment runoff was assumed to have increased the epilimnetic primary production.

2. STUDY SITE

The present 51 m deep bay of Valun on the Isle of Cres, Croatia (Fig. 1), is the lengthening of NW/SE striking faults forming the neighbouring Lake Vrana karstic depression (polje). They are characterized by highly permeable limestones of Cretaceous age, less permeable dolomites, and to a lesser extent, by Flysch (Biondič *et al.*, 1992). A sub-marine karstic spring (vrulja) with a high and permanent discharge is located close to the small village of Valun. The spring water is assumed to originate from Lake Vrana (Bonacci, 1993; Biondič *et al.*, 1997).

Deciduous sub-mediterranean vegetation, similar to that of the Istrian peninsula dominates the northern part of the island. The bay of Valun lies in the transition to the eu-mediterranean *Quercus ilex*-rich zone dominating the south of the island (Mavrovič, 1994). Summer drought in the northern Kvarner area is less pronounced (Walther & Lieth, 1964). Modern mean

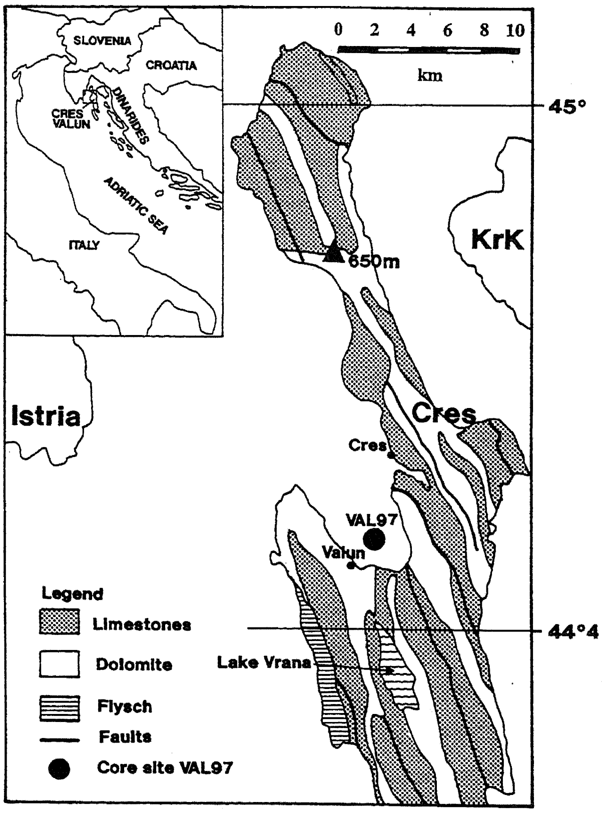


Fig. 1. Location of Valun (Island of Cres) with coring location of VAL97, and main geological features (modified from Randič *et al.*, 1996).

Ubicazione di Valun (Isola di Cherso) e della stazione di prelievo della carota VAL97; sono riportate le principali caratteristiche geologiche (modificato da Randič *et al.*, 1996).

July summer temperature at Cres (town) is 24 °C. On the island of Cres, precipitation increases towards the north (Cres: 1063 mm per year). This is due to the orographic influences of the higher mountains in the north of the island and the peninsula of Istria. In the mountain areas of the northern Dinarids, with respect to high precipitation, *Fagus* predominates. In the calcareous areas of the northern Dinarids, at altitudes above 1600 m, *P. mugo* agg. forms a dwarfed pine belt (Trinajstič, 1970).

3. METHODS

3.1. Coring

The sediment core (VAL97) of 8 m length was taken with a modified Kullenberg piston sampler (Schultze & Niederreiter, 1990). The coring equipment consists of plastic tubes of 2 m length and 5.58 cm inside diameter, placed within a steel chamber, and a piston with a hydraulic rubber closing system to avoid sediment losses. Coring was performed from a stabile platform at 51 m water depth. The site location is illustrated in Fig. 1. For subsampling, the plastic tubes containing the sediment were cut with a saw and divided into halfes with the use of two thin metal plates. Subsample intervals for the different proxies extend from 2.5 to 10 cm.

3.2. Geochemistry and mineralogy

Main constituents of sediments (calcite, dolomite, quartz and layer silicates) were identified by X-ray diffraction methods on bulk samples (1 cm^3 dry material). Organic and inorganic carbon were determined as CO_2 by IR-spectrometry after combustion in a LECO furnace. The analysis was done in two steps. Determination of total carbon was followed by measuring organic carbon content after acid leaching (HCl). The inorganic carbon content was calculated as the difference between total carbon concentration and organic carbon. Quantification of carbonate constituents was calculated using inorganic carbon in the respective stoichiometric proportions. Quartz content was calculated using peak heights comparison with calcite and considering different mass absorption ratios. The remainder (layer silicates) was calculated by expressing organic carbon as organic matter (orgC*2.5).

3.3. Pollen analysis

For chemical treatment of the samples of 1 cm^3 fresh material, a bromide solution (saturated solution of $BrNaO_3$/HBr 9:1) was used prior to acetolysis treatment. According to Klaus (1975), KOH treatment as used in standard techniques is less suitable to differentiate pine pollen grains; instead of KOH he used chloride or bromide solutions, which allow a longer treatment with acetolysis without distroying the exine, however improving light microscopic contrast. Carbonates were removed by 30% HCl, silicates by 70% HF. A total of at least 350 pollen grains was counted. Aquatics and ferns were excluded from the pollen sum. Pollen concentrations were calculated according to Klaus (1977a), using a volumetric method. The programme TILIA (version 2), combined with CONISS for zone clustering, was used for all stratigraphic diagrams.

Since pollen spectra were dominated by *Pinus*, an improvement of information was expected by grouping into pollen-types. The following types were distinguished: *P. mugo*-types correspond with the pollen types described by Klaus (1972) for red and red/violet flowering strains which predominate in the subalpine dwarfed pine belt. White flowering *P. mugo*- and *P. sylvestris*-pollen types, which according to Klaus (1977b) can not be distinguished, were summarized as *P. sylvestris*-types. Pollen from *P. nigra* (Klaus, 1972) and the balcanic *P. heldreichii*, according to Jäger (1975) show similar features. Hence, the name *P. nigra*-type was used for those pollen with *P. nigra/heldreichii* features. The Alpine *P. cembra* (Klaus, 1975) and the balcanic *P. peuce* (Jäger, 1975) could not be differentiated in pollen counts. The name *Pinus Haploxylon*-type (*sensu* Klaus, 1975) was used for pollen with an intersaccate distale ornamentation and a saccus reticulum, as described by Klaus (1975). *Pinus* indet. includes pollen which could not be identified with certainty.

3.4. Cladoceran analysis

Samples of 1 cm^3 fresh material were prepared according to Frey (1986). Carbonates were removed with 10% HCl, then the sediment was boiled with 10 % KOH. The residue was washed and sieved (50µm), filled to 10 cm^3 with distilled water, and stained with safranin. All remains were counted (Ergaval-Zeiss microscope, magnification at least 200 x). Absolute numbers were calculated per 1 cm^3 fresh material.

3.5. Ostracod analysis

Ostracods were determined in the > 0.063 mm sieving fraction using 14 cm^3 fresh material. All remains were picked, and distinguished into autochthonous and allochthonous specimens. Autochthonous forms were plotted. They were represented by species consisting of well preserved adults and juveniles in the same sample.

3.6. Foraminifer analysis

Foraminifers were determined in the > 0.063 mm sieving fraction using the same volume as for ostracods. They were all picked and calculated as abundances per gram dry weight.

3.7. Hystrichosphaeridae

All cysts of marine algae recorded in the pollen slides were summarized under the name "Hystrichosphaeridae". Abundances were calculated as percentages of the total pollen sum.

4. OBSERVATIONS

4.1. Geochemistry and Mineralogy (Fig. 2)

The cored section appears rather homogenous. No significant changes in colour or sediment texture were observed.

The main constituents of the sediments are silicates. Layer silicates (i.e. clay minerals), quartz and felspar are dominant throughout the whole core sequence. Calcite and dolomite represent the major carbonate phases, while aragonite and Mg-calcite are rare and restricted to certain samples between 205 and 245 cm. Organic carbon shows a range from 0.43 to 0.84 %-weight. When calculated as organic matter, the content was slightly more than 2 %.

The most significant changes in mineral composition are observed in the lowermost core section. Below 700 cm, the highest calcite proportions occur, reaching almost 40 %, while quartz, layer silicates and felspar were measured at their lowest concentrations. Between 720 and 680 cm a gradual decrease in the calcite content to ca. 20 % is apparent, a level which continues until the top of the core.

Slight but distinct increases with both, dolomite and the silicate group can be observed within the above mentioned transition zone. These components display different developments above this section. Dolomite shows an increasing trend with a first maximum (> 20%) at 490 cm core depth. A second maximum (> 20%) occurs at a core depth around 300 cm. Above a core depth of 300 cm, a more or less continuous decrease is found reaching a minimum of 12 % in the uppermost sample.

Layer silicates and felspar reach maximum percentages (58 - 64 %) in the core section between 550 – 670 cm. In the upper section, a slight decrease is found with values ranging between 51- 56 % The concentration pattern of quartz is characterized by nearly constant values (10 - 11 %) in the core section 550 - 690 cm. The subsequent upper section exhibits in a similar range, but displays more pronounced variation.

Organic carbon distribution with core depth can roughly be described by concentration fluctuations between 0.5 and 0.6 % in the lowermost section, with high amounts of calcite. With the exception of a distinct peak of organic carbon at 590 cm depth, slightly lower and fluctating proportions follow until 340 cm. Pronounced increases, however, were found at 350 – 330 cm core depth; above a higher level is maintained until the core top.

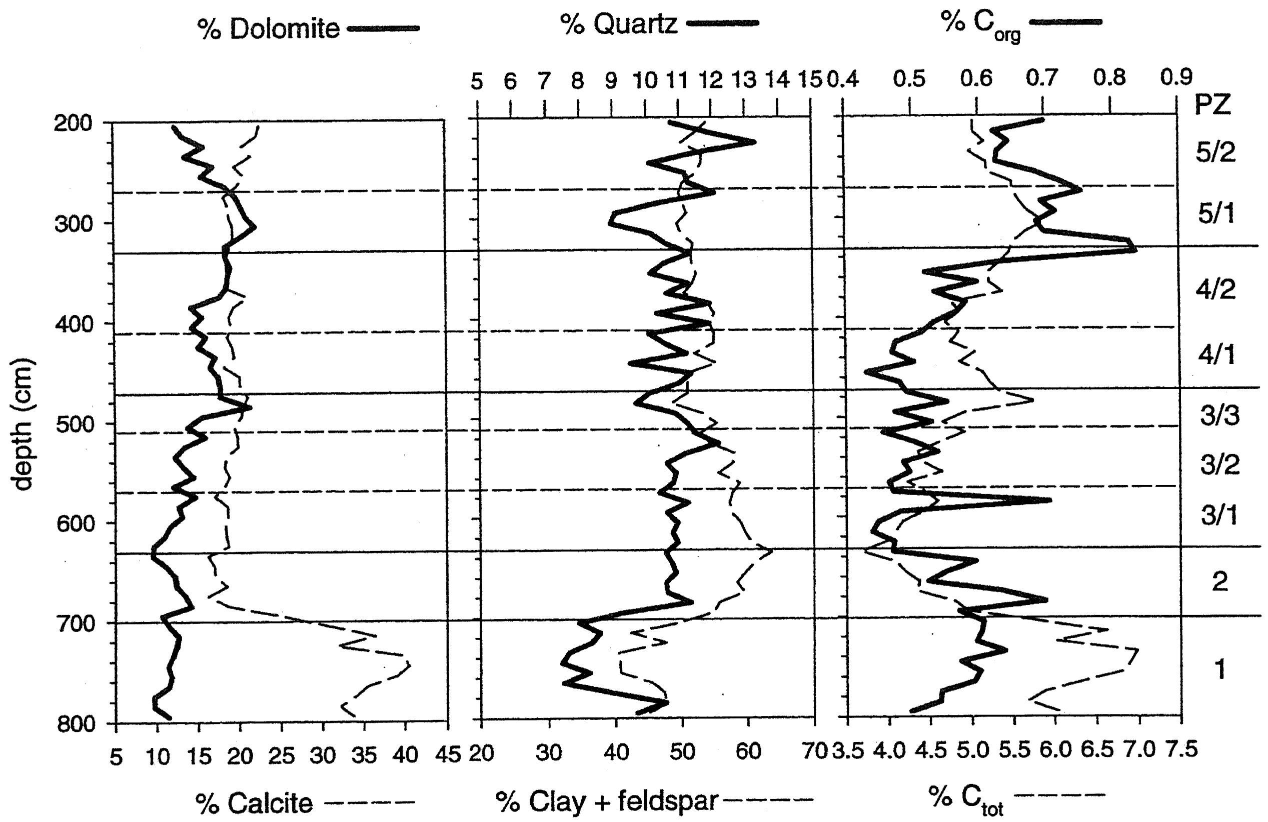


Fig. 2. Proportions of mineral components, and of total and organic carbon, of the core VAL97. Pollen zones are added.

Distribuzione dei componenti mineralogici, del carbonio totale ed organico nella carota VAL97. Sono riportate le zona polliniche.

4.2. Pollen stratigraphy (Figs 3a, b)

The following pollen zones were distinguished:

PZ1 (800 – 700 cm)

A peak of pollen abundance correlated with increasing values of *Quercus* (10%) and low numbers of *Tilia, Ulmus* and *Picea*. *P. mugo*-types decreased towards the top of the core, and values of the *P. Haploxylon*-type were low.

PZ2 (700 – 635 cm)

Pinus reached the highest abundance due to the dominance of the *P. mugo*-types and increasing values of the *P. Haploxylon*-type at the expense of deciduous trees of the former section. Pollen concentration decreased, whereas *Artemisia*, Chenopodiaceae and Cyperaceae increased slightly.

PZ3 (635 – 470 cm)

Total *Pinus,* although remaining a dominant element, decreased and pollen concentration remained low, and was accompanied by reworked pre-Quaternary sporomorphs. *Quercus* increased slightly again. It is divided into the following subzones:

PZ3/1 (635 – 575 cm) differ from PZ3/2 (575 – 515 cm) by less *Quercus*, the temporary decrease of *Artemisia* and Chenopodiaceae at the expense of Cyperaceae. PZ3/3 (515 – 470 cm) is characterized by high values of the *P. Haploxylon*-type. Also *Betula, Alnus glutinosa/incana, Salix (lower part),* and *Picea* increased slightly.

PZ4 (470 – 330 cm)

Pinus was slightly less than in the former zone. It is characterized by short-term fluctuations of most of the elements and in pollen density. It was divided into two subzones: In the upper one (4/2: 410 – 330 cm), the curve of Hystrichosphaeridae began.

PZ5 (330 - 200 cm)

It was divided into two subzones: In the upper one (5/2: 260 – 200 cm) *Corylus*, *Picea*, *Abies* and

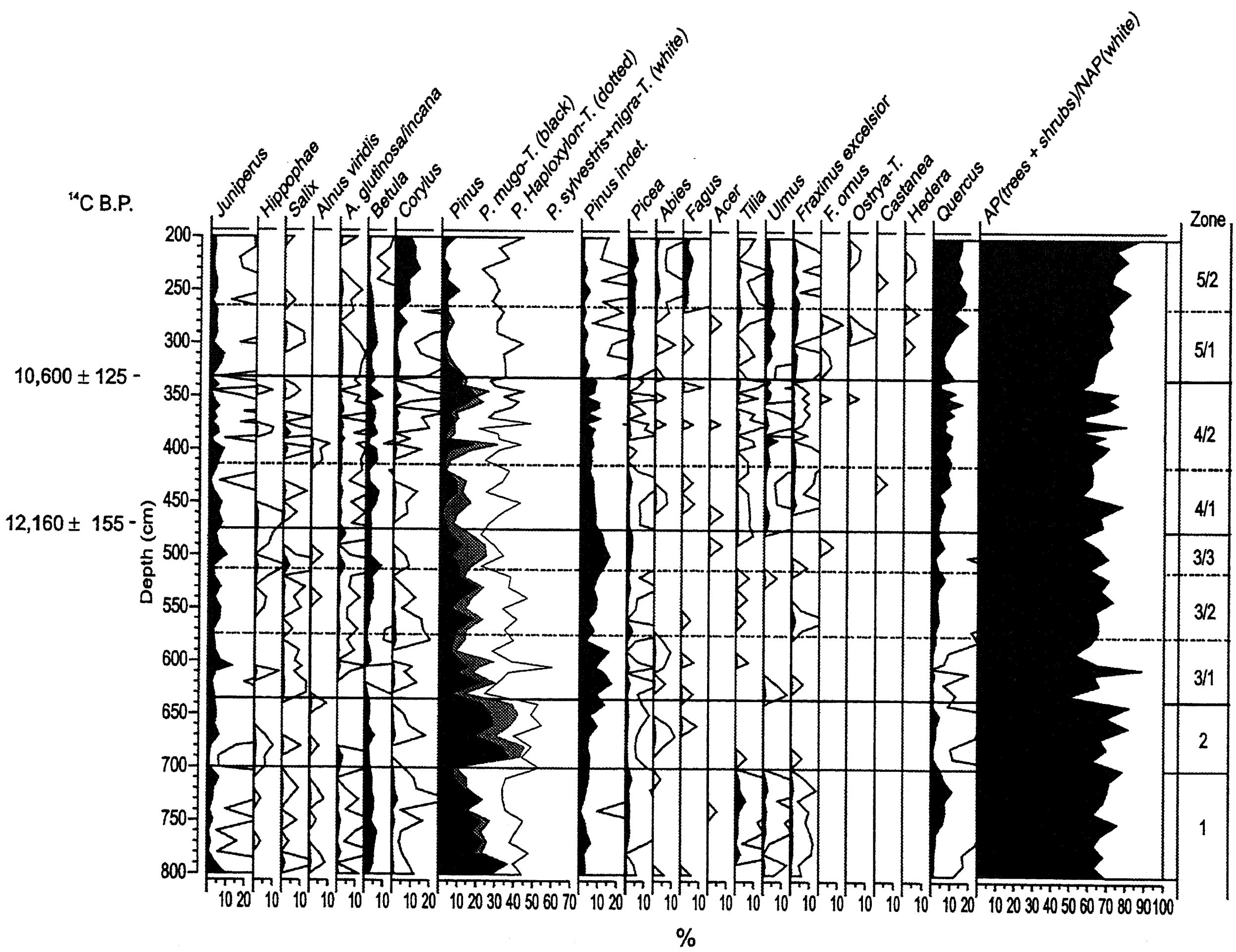


Fig. 3a. Pollen percentage diagram of trees and shrubs of the core VAL97. Radiocarbon dates (^{14}C), ratio of arboreal (AP) and non-arboreal (NAP) pollen, and main zones are added.

Diagrammi pollinici degli alberi ed arbusti nella carota VAL97. Sono riportate le datazioni radiometriche (^{14}C), il rapporto del polline arboreo (AP) e non arboreo (NAP) e le principali zone individuate.

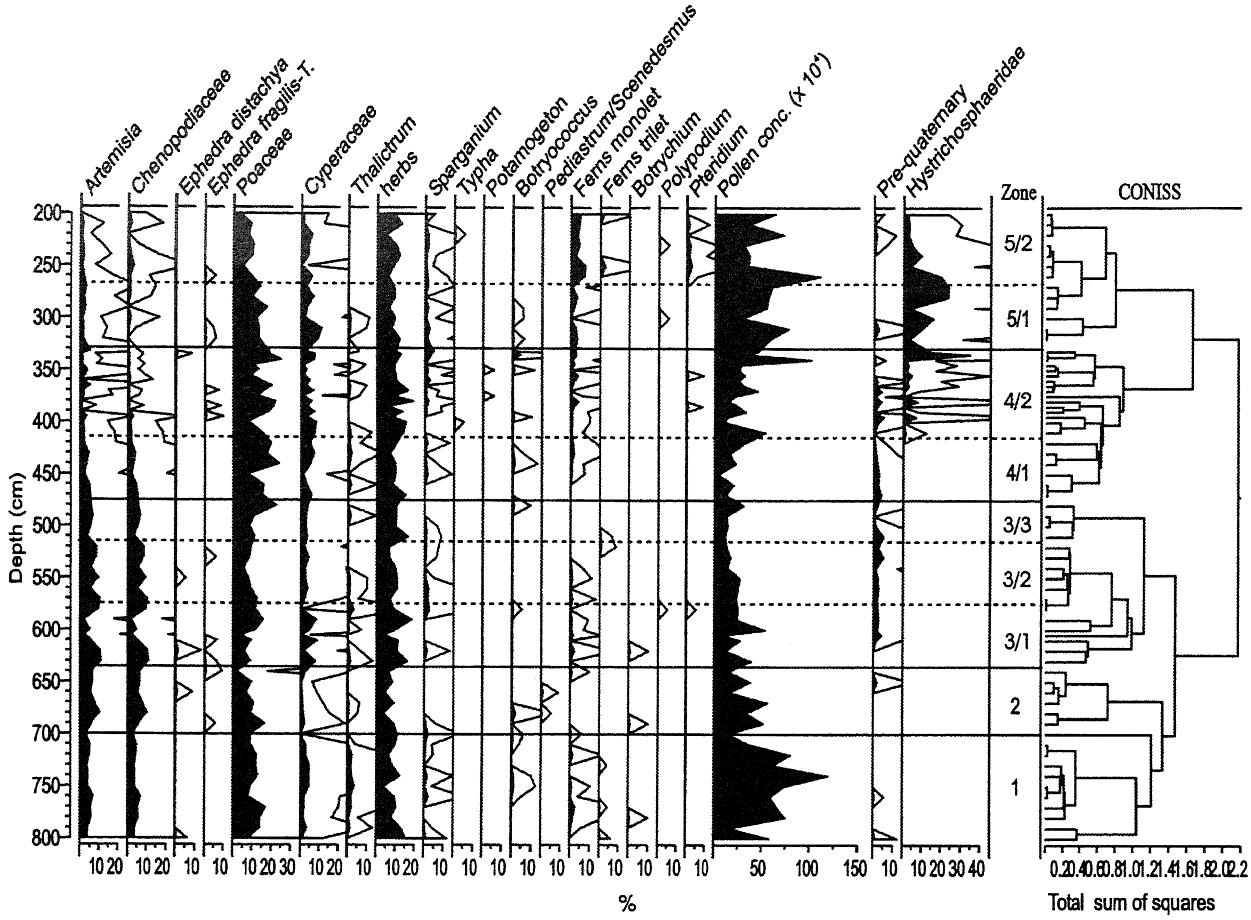
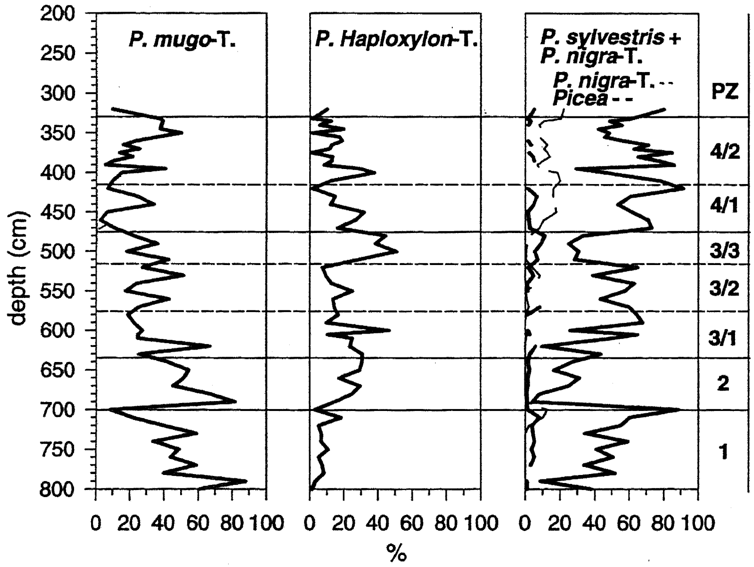


Fig. 3b. Pollen/spore percentage diagram of herbs, aquatics and ferns of the core VAL97. Pollen concentrations, abundances of pre-Quaternary sporomorphes, of Hystrichosphaeridae, and main zones are added.

Diagrama pollinici percentuale polline/spora delle piante erbacee, acquatiche e felci nella carota VAL97. Sono riportate la densità pollinica, l' abbondanza degli sporomorfi pre-Quaternari, di Hystrichosphaeridae e le principali zone.



Fagus increased, whereas Hystrichosphaeridae and pollen concentration decreased or fluctuated. *Hedera* occurred. Temporarily, pre-Quaternary sporomorphes and ferns became more frequent.

Pinus pollen types distribution

The percentages of the *Pinus* pollen types is illustrated in Figure 4.

Fig. 4. Percentages of *Pinus* pollen types and *Picea* (*Pinus* + *Picea* = 100%) of the core VAL97, and pollen zones.

Distribuzione percentuale del polline di Pinus e di Picea (Pinus + Picea = 100 %) nella carota VAL97, riferite alle zone polliniche.

4.3. Cladoceran stratigraphy (Fig. 5)

Abundances of cladocerans were low, and individuals were often badly preserved. Sixteen taxa (3 pelagic and 13 littoral) belong to the families of the Daphnidae, Bosminidae, Chydoridae and Macrothricidae. In addition to *B. longirostris*, shells with an elongated mucro occurred (*Bosmina* sp. "long mucro"). It was not possible to separate *Daphnia* in the material (*Daphnia* sp.). With the exception of *Alona affinis* and *A. quadrangularis,* some head shields looked like *A. salina* (Alonso, 1996). Cladocerans occurred in reliable numbers only from 6 to 8 m. They were accompanied by chironomids and turbellarians. This core section was divided into the following zones:

Zone 1 (800 – 700 cm)

In the lower part (1/1: 800 – 770 cm) only littoral chydorids were present, dominated by *Alona affinis* and *A. quadrangularis*. In the subsection 1/2 (770 – 740 cm), *Daphnia* occurred and littoral chydorids increased in diversity. *Alona* spp. and *Graptoleberis testudinaria* were dominant. In 1/3 (740 – 700 cm), Bosminidae expanded; *B. longirostris* and remains with a long mucro occurred. Within the chydorids, *Alona* spp. became abundant.

Zone 2 (700 – 600 cm)

Abundances and number of taxa decreased significantly, with the exception of the transition subzone 2/1 (700 – 680 cm), where *Alona affinis* dominated. Between 680 to 630 cm (2/2: 680 – 630 cm) only this taxon was left in low numbers and continued also in the following subsection 2/3 (630 – 600 cm). Additionally, a few chydorids were present in one sample (630 cm), whereas *B. longirostris* was found in two samples.

4.4. Ostracod stratigraphy (Fig. 6)

The following zones were distinguished:

Zone 1 (800 – 700 cm)

The dominant *Herpetocypris reptans* was accompanied by *Candona neglecta*, *Ilyocypris* gr. *gibba* and *Cypria ophthalmica*. In addition, rare specimens of *Cytheromorpha fuscata*, *Leucocythere mirabilis*, *Potamocypris smaragdina*, and *Cyprideis torosa* were recorded in a few samples.

Zone 2 (700 – 600 cm)

Cytheromorpha fuscata expanded and *Candona neglecta* was present. It was divided into a lower subsection (2/1: 700 – 660 cm) rich in *Cyprideis torosa*, and a upper section (2/2: 660 – 600 cm) where *Leucocythere mirabilis, Candona candida,* and *Candona* cf. *mülleri* dominated.

Zone 3 (600 – 570 cm)

It was characterized by a peak of *C. fuscata, C. neglecta*, *C.* cf. *mülleri* and *L. mirabilis.*

Zone 4 (570 – 380 cm)

In subzone 4/1 (570 – 470 cm), *C. fuscata* continued to be present at low numbers. *Sylvestra* sp. 2 began. *L. mirabilis* disappeared in the lowermost part. In 4/2 (470 – 380 cm) *C. fuscata* and *Sylvestra* sp. 2

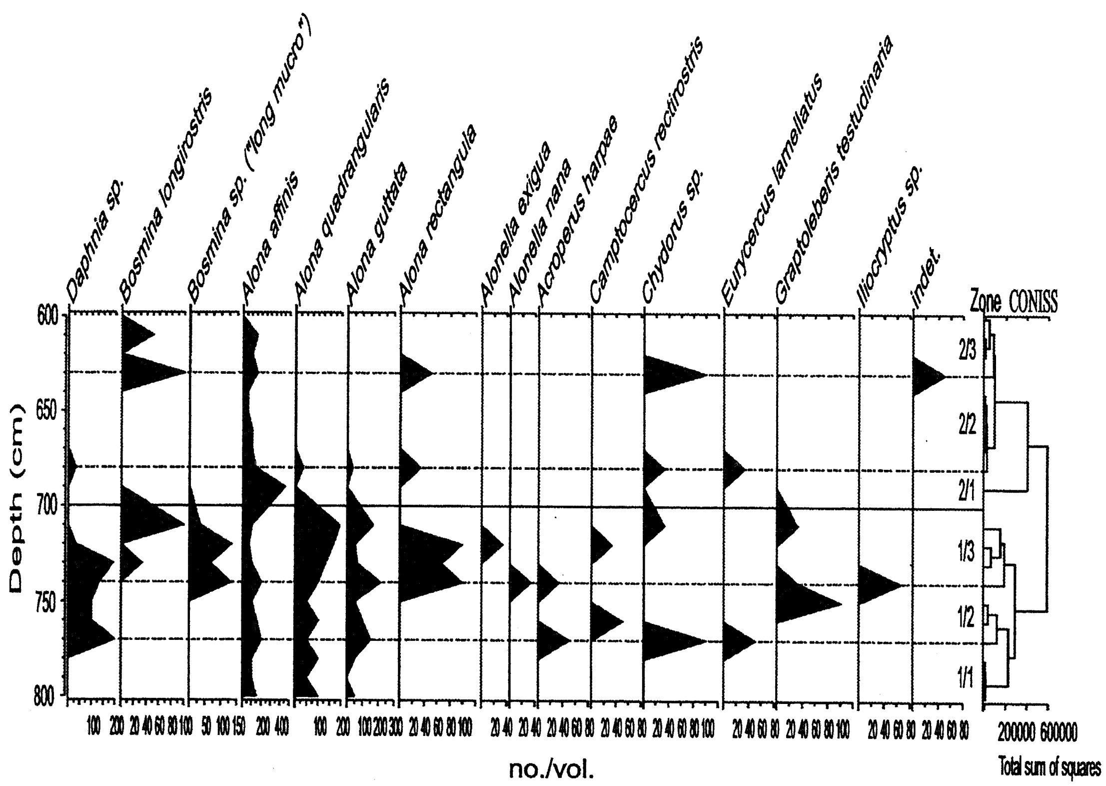


Fig. 5. Absolute numbers of cladocerans of the core VAL97.

Presenza di cladoceri nella carota VAL97 espressa in totalita dei individui.

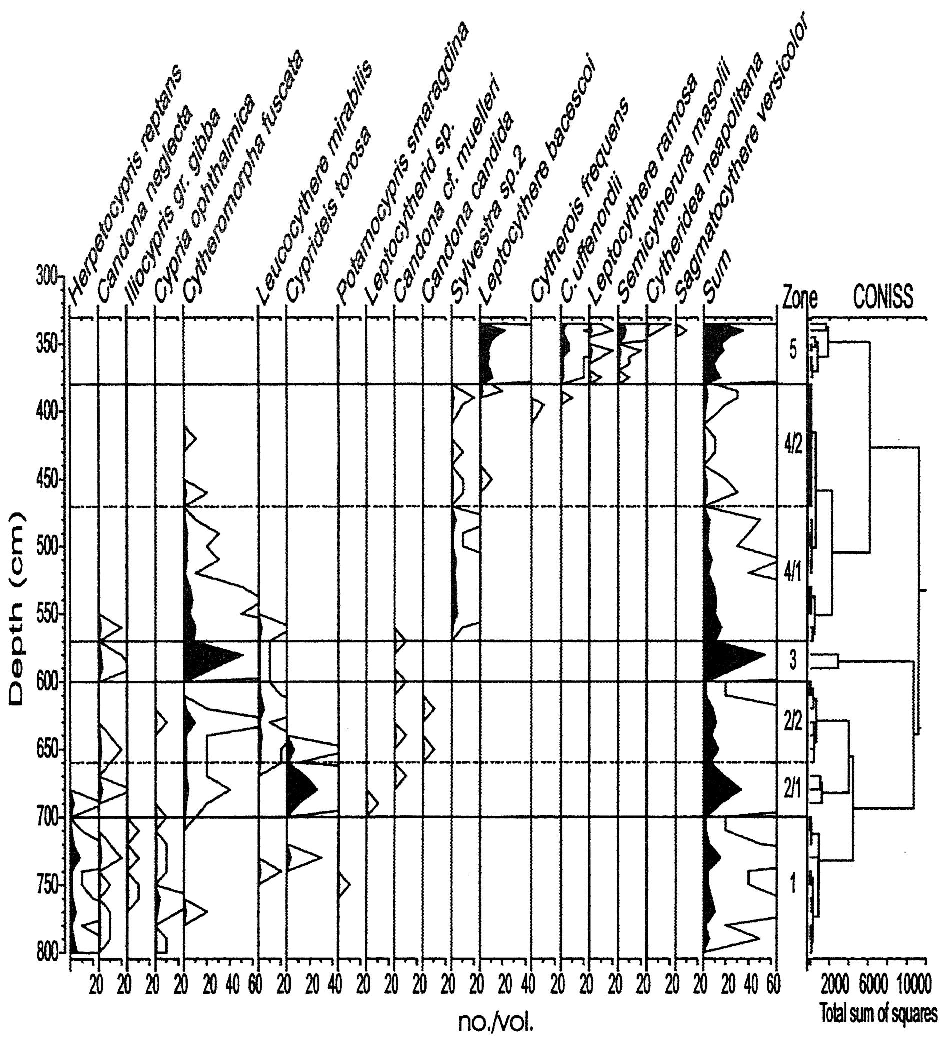


Fig. 6. Absolute numbers of ostracods of the core VAL97.

Presenca di ostracodi nella carota VAL97 espressa in totalita dei individui.

were present in a few samples, but at low numbers. Some of the species (*Leptocythere bacescoi*, *Cytherois frequens*, *C. uffenordei*) which expanded in the following section were found to be rare.

Zone 5 (380 - 330 cm)

L. bacescoi, *C. uffenordei*, *Leptocythere ramosa*, and *Semicytherura masolii* expanded. Towards the top they were accompanied by *Cytheridea neapolitana* and *Sagmatocythere versicolor*.

4.5. Foraminifer stratigraphy (Fig. 7)

Zone 1/1 (600 – 470 cm)

It is characterized by generally low numbers and species diversity, and in between sections with lacking foraminifers. Below 480 cm, which is the onset of the curves of *Ammonia* group *tepida* and *Haynesina depressula*, the samples 510 cm and 600 cm beared a few foraminifers. At 600 cm, in addition to the *Ammonia* group *tepida* and *H. depressula*, *Asterigerinata adriatica*, *Brizalina dilatata*, *Cassidulina carinata*, and *Elphidium* spp. occurred.

Zone 1/2 (470 – 365 cm)

Ammonia group *tepida* and *Haynesina depressula* increased in abundance, accompanied by *Cribroelphidium decipiens*. *Aubignyna perlucida* and *Elphidium translucens* occurred in two samples. Towards the top, abundances decreased.

Inbetween 400 to 365 cm the dominant species of the former subsection remained low in the lower part, followed by fluctuations and an increase towards the top. The curve of *Ammonia inflata* started with a small peak, followed by a decline. *Elphidium granosum*, *E. translucens*, and *Quinqueloculina* sp. appeared for the first time, at least in one sample of this interval.

Zone 1/3 (365 – 340 cm)

Compared with the former zone, species diversity (*Brizalina*, *Bulimina*; *Elphidium*, *Lagena*, *Nonion*, *Nonionella*, *Quinqueloculina*, *Textularia*) increased. Abundances fluctated: an increase was followed by a decline.

Zone 2/1 (340 – 250 cm)

Species diversity and abundances were at their highest during this zone. *Brizalina dilatata*, *Bulimina aculeata*, and various taxa of the genera *Elphidium*, *Lagena*, and *Textularia* occurred first. *Ammonia inflata* formed a distinct peak.

Zone 2/2 (250 – 200 cm)

Most of the taxa being present in the former zone remained. Abundances decreased distinctly.

4.6. Diatoms

They were not preserved at all.

4.7. ^{14}C dating

Since terrestrial plant macrofossils were lacking throughout the core, only two bulk samples were used for AMS-dating (Angström laboratory, Uppsala University). Calibrations were carried out using CALIB, ver-

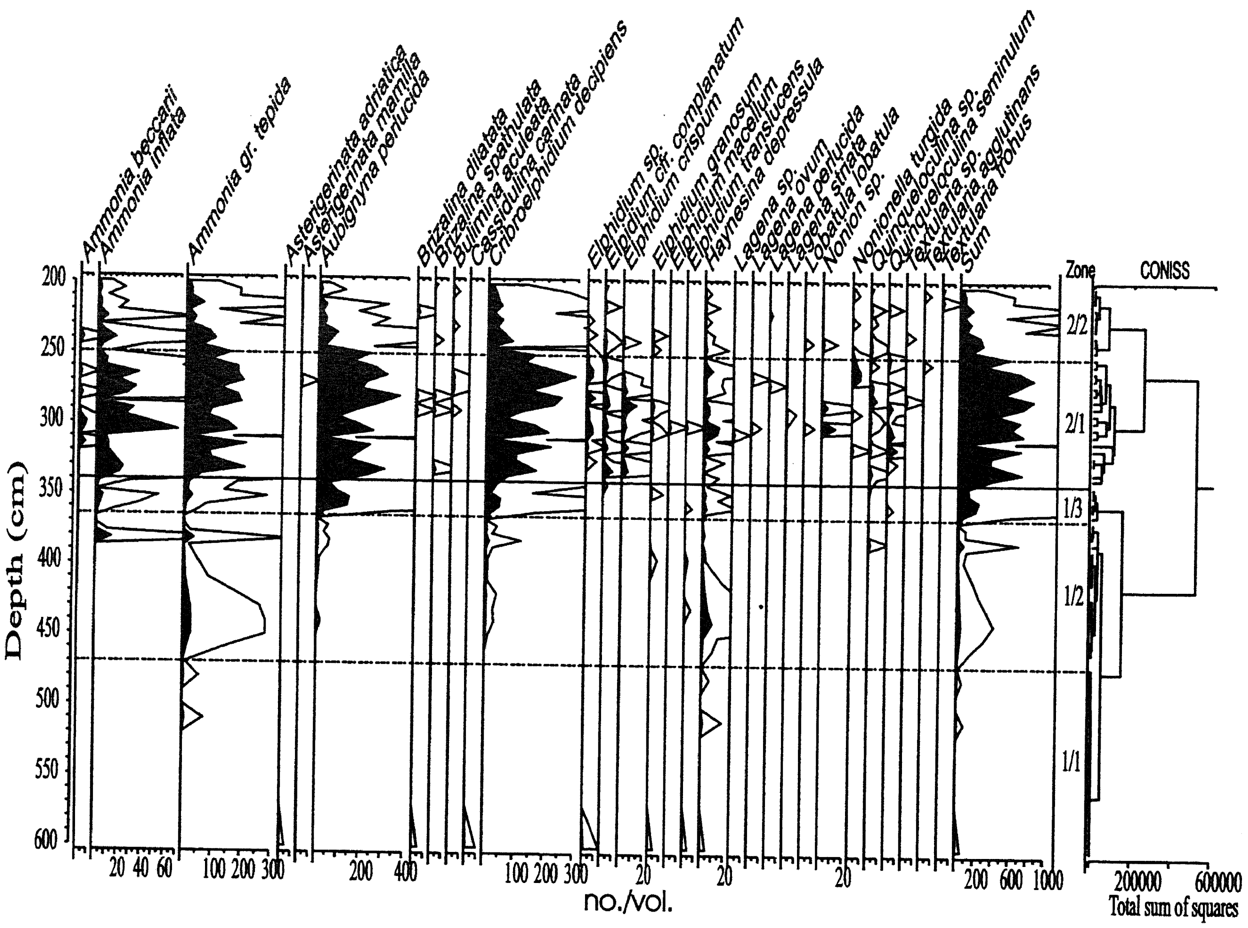


Fig. 7. Absolute numbers of foraminifers of the core VAL97.

Presenca di foraminiferi nella carota VAL97 espressa in totalita dei individui.

Code No.	Core depth (cm)	^{14}C age (yr. BP)	Reservoir corrected ^{14}C age (yr. BP)	Calibrated ^{14}C age (cal. BP)	Range of calibrated age (cal. BP)
Ua-13653	332-334	10,600 ± 125	10,198 ± 125	11,683	10,862-12,346
Ua-13656	470-472	12,160 ± 155	11,758 ± 155	13,521 13,701 13,790	13,061-14,252

Table 1.
AMS ^{14}C age determinations for core VAL97.
Determinazione dell "eta" radiometrica con il ^{14}C attenuto con'l AMS nella carota VAL97.

sion 4.1.2, for mixed marine and atmospheric samples. The stratigraphic position of the ^{14}C samples is indicated in Fig. 3a. For sediment properties of the entire samples compare Fig. 2. The results of dating are summarised in Tab. 1.

5. DISCUSSION

Because only two bulk dates were available, dating based on pollenstratigrahic relations is tentative.

Core section 800 - 700 cm (PZ 1)

The change in the pollen assemblage from pollen spectra rich in *P. mugo*-types at the core basin towards *Picea*, followed by broadleafed deciduous trees (*Quercus, Tilia, Ulmus, Fraxinus excelsior*), indicate a gradual climate amelioration. PZ1 differs from the late glacial period at Valun by the finding that *Tilia* was more abundant than *Ulmus*, and by higher percentages of spruce. With respect to *Tilia*, the interstadial of Valun PZ1, however, is more similar to the *Tilia*-rich late Lateglacial observed by Huntley *et al.* (1999)

at Lago di Monticchio, central Italy. With respect to the lack of *Fagus* and *Abies*, this interstadial section is comparable with pollen spectra known from the middle Würmian period (isotope stages 3 and 4) at sites south of the Alps (Sercelj, 1966; Alessio *et al.*, 1986; Watts *et al.*, 1996b; Follieri *et al.*, 1998; Allen *et al.*, 1999; Magri, 1999). If there is no sediment gap between PZ1 and PZ2 (see below), however, the stratigraphic position supports a relation with isotope stage 3.

This sediment unit is characterized by its high amount of calcite. Ratios of calcite/dolomite fluctuate around 3. It can thus be assumed that a good portion of the calcite present in this unit can be attributed to autochthonous sources in a freshwater environment; the upper part of this unit was characterized by indications of a deepening of the freshwater lake (onset of *Daphnia* followed by *Bosmina*) and by a high diversity of the cladoceran fauna. In the section 700 until 800 cm *Herpetocypris reptans* was the dominant ostracode associated with other freshwater taxa. Currently, this species occurs in Western and Central Europe. Females and males, however, were found in the fossil material, whereas today only females are known in Europe (Gonzalez *et al.*, 1996). Low numbers of *Cyprideis torosa* and *Cytheromorpha fuscata* indicate a temporyry, slightly brackish influence.

Core section 700 - 635 cm (PZ2)

Pinus percentages are the highest and *vice versa* pollen concentrations are low. Low pollen concentrations can be due to enhanced sediment accumulation, low pollen production, or a combination of both processes. The high pine pollen abundances of Valun during upper Pleniglacial correspond with observations made from Adriatic cores (Lowe *et al.* 1996; Combourieu-Nebout *et al.,* 1998). Lowe *et al.* (1996) suggested that pine pollen might be over represented in the open sea Adriatic cores when compared with herbs-dominated Late Pleistocen pollen assemblages from Italian crater lake sediments (Watts *et al.*, 1996a).

The sudden increase of *P. mugo*-types at the lower boundary of PZ1 is either the result of a rapid climate change or indicates a sediment gap between PZ1 and PZ2. The pollen composition of lower PZ2 dominated by *P. mugo*-types is comparable with modern pollen accumulation in lakes of the Dolomites, situated in the present subalpine *P. mugo* belt (Schmidt *et al.*, submitted). Pollen from *Quercus* and other deciduous broad-leaved trees during PZ2 only occurred in low values (1-3%). NAP are dominated by Poaceae and various herb types. The lower PZ2 indicates the coldest section throughout the core. Hence, it might correlate with the last glacial maximum (LGM). The dominance of *P. mugo*-types indicates sufficient winter snow-cover, which is necessary to protect the dwarfed pine against frost damage. The section rich in *P. mugo*-types was followed by an increase in *P. Haploxylon*-type, which indicates rise in timberline.

The high content of clay, quartz and dolomite indicates allochthonous catchment influx. The peak in organic matter at lower part may originate from allochthonous sources. Increase in precipitation and/or meltwater discharge may have been responsible for soil erosion and freshwater pulses.

In the ostracode assemblage *C. torosa* in the lower part formed a peak together with *Cytheromorpha fuscata*. Tuberculated carapaces occurred in *C. torosa.* Such an assemblage was observed by Galoukas *et al.* (1995) in oligohaline waters (salinity: 0.5 – 1.5%). According to Ascoli (1966-67), however, *C. fuscata* is able to tolerate a salinity range of 1 – 18%. At present this species is distributed in Central and Northern Europe (Wagner, 1957; Colalongo, 1965; Ascoli, 1966-67; Galoukas *et al.*, 1995). In the Adriatic it is only known from fossils. Whereas *C. fuscata* persisted in the following sections, *C. torosa* disappeared. Whereas *H. reptans* disappeared, *L. mirabilis* expanded. The latter, according to Galoukas *et al.* (1995) is a cold freshwater form. It was mentioned, however, from the Baltic area (Danielopol *et al.*, 1989) from slightly saline waters. The good preservation of carapaces from *C. torosa* and *C. fuscata* indicates *in situ* deposition within a lake which probably was close to the sea. Ostracod-inferred palaeosalinity for lower PZ2 (ostracode zone 2/1), however, contrasts with the pollen assemblage rich in *P. mugo*-types and with results from geochemistry. A time lag in the onset of LGM sea-level lowering, preserving lake salinity, was considered to explain the discrepancy between the cold and wet climate conditions and the ostracod-inferred palaeosalinity. The possible broader range of salinity tolerance allowed *C. fuscata* to survive during LGM periods of temporarily enhanced freshwater incursions, whereas *C. torosa* disappeared.

In respect to the cladocerans, only *A. affinis* could survive during maximum of the cold phase. It was found in high alpine lakes (Lotter *et al.*, 1997) as well as Lateglacial time. Most of the chydorids, however, present during the former interstadial, were lacking. Temperature decline is thought to be responsible.

Core section 635 - 470 cm (PZ3)

During this zone, pollen of the *P. sylvestris*-types increased, although pollen abundances from deciduous trees remained low. The content of pre-Quaternary sporomorphs, low pollen concentrations, and a prevailing high content of clay minerals during the whole section indicate increased sediment accumulation rates, probably by erosion.

The pollen zone 3 was divided into three subzones. The subzone 3/1 at lower part probably characterises a temporarly wetter period as indicated by the expansion of Cyperaceae at the expense of *Artemisia* and Chenopodiaceae. A short, but marked peak of organic carbon, may be due to influx of organic matter, probably by running water. The lack of most of the chydorids, present during the interstadial Valun 1, and the increase of *B. longirostris* indicate high water level. The following peak of *C. fuscata* indicates increasing salinity. Since this finding corresponds with the increase of *P. sylvestris*-types, summer evaporation may have increased. Cladocerans during PZ3 were only found in a few exemplars which were badly preserved and hence could not be identified with accuracy (aff. *Alona salina*). At 600 cm foraminifers occurred for the first time. The assemblage consists of brackish-water species, such as *Ammonia* gr. *tepida*, together with other marine species (*Asterigerinata adriatica, Cassidulina carinata, Elphidium spp.).* Because of their bad preservation, they were considered as allochthonous and displaced. Lower PZ3/1 might be synchronous with a period of enhanced sediment redeposition, as observed at Längsee preceding the Längsee interstadial. The sediments rich in spruce probably originated from interstadial deposits. Ramrath *et al.* (1999) relate, in Lago Mezzano and Monticchio, peaks of increased minerogenic depositions with an Heinrich event and with a slight decrease of the oxygen isotope curve of GISP2 greenland ice core (Grootes *et al.*, 1993; Meese *et al.*, 1994; Stuiver *et al.*, 1995) during 21,000 to 22,000 years.

The subzone 3/2 differ from the former by a slight increase of *Quercus* and the *P. nigra*-type which indicates progressing vegetation development. The increase of *Artemisia* and Chenopodiaceae may indicate a trend to more dry summer, and/or brackish influence. It correlates with the onset of the ostracode *Sylvestra* sp. 2 when *C. fuscata* decreased. They indicate the increase in brackish conditions and water temperature. The *Sylvestra* taxa are representatives for shallow-warm waters (Bonaduce *et al.*, 1990). They occurr in deltaic environments strongly influenced by freshwater (Pugliese & Stanley, 1991). Summer warming potential during this subzone have been sufficient for *Sylvestra* occurrence. The increase in salinity at upper 3/1 might be due to increased summer evaporation rather than impacts from the Adriatic Sea. This is supported by the depth of the lower boundary (600 cm) of the *Cytheromorpha fuscata*-rich ostracode zone 3 at 57 m below the present sea level. According to Bard *et al.* (1990) a corresponding sea level depletion relates to an ^{14}C age of about 12,000 BP. This is distinctly younger than was expected. Since occurrences of pre-Quaternary sporomorphs continued and pollen concentrations remained low, wet winter seasons with meltwater catchment erosion are thought to have contrasted dry and warm summer seasons. The climate amelioration of PZ3/2 was compared with a pollen sequence from Längsee, Carinthia, indicating the expansion of alpine shrubs and trees. The upper boundary of the Längsee oscillation (Fig. 8) dated at 15,535 ± 160 ^{14}C BP (Schmidt *et al.*, 1998). Using CALIB (1999, version 4.1.2), the calibrated age ranges between 17,917 to 19,261 cal. BP. Diatom-inferred summer surface-water temperatures during this interstadial period at Längsee approached values obtained for older Lateglacial. At Valun PZ3/2, *P. sylvestris*-types occurred together with low abundances of oak. If both sections from the two sites are synchronous, the difference might be due to a location nearer to the Alpine ice-margins in the former, and of closer glacial refuges in the latter.

The uppermost subzone (PZ 3/3) shows a shift from *P. mugo*-types at the transition to the former subzone to highest values of *P. Haploxylon*-type in the core at upper part, accompanied by a slight increase of *Picea*. It indicates that the timberline in the Dinarids during the latter was formed by a *Pinus* of the subgenus *Haploxylon*. At present there is a gap between the Alpine areal of *P. cembra* and that *of P. peuce*, the latter being restricted to the southern Dinarids (Fukarek, 1970). Pollen concentration was the lowest during PZ3/3. The transition to the former subzone is coupled with peaks of prequartenary sporomorphes and quartz, followed at upper part by a peak in dolomite. Sediment erosion and transport by running water temporarly may have increased sedimentation rates. The latter and/or less pollen influx are thought to be responsible for low pollen concentrations. The origin of the prequaternary sporomorphes is questionable; possibly they originated from fossil karst fillings and/or flysch. *C. fuscata* and *Sylvestra* sp. 2 were the only two ostracode species which occurred in low numbers. Their tolerance of freshwater incursions may explain their persistence.

LÄNGSEE (Carinthia)		regional pollen zones and fluctuations	VALUN (Cres) regional pollen zones	PZ	LAKE VRANA (Cres)	PZ	Climate S=summer
LATEGLACIAL	Younger Dryas	YD2 Pinus spp. YD1		4/2	*Pinus* spp. (*Quercus*)	2/2	cold+drier warmer cold+wet
	Lateglacial Interstadial (approx. ^{14}C ky BP)	Lg-FL3 (deciduous trees) Lg-FL2	? *Pinus* spp. *P. nigra*-T., *Quercus* mixed oak forest taxa	4/1	sediment gap ?		warm S-dry
		P. sylvestris-T.					
	12.0	Lg-FL1	12,160 ± 125 BP		*Pinus* spp. *Betula*	2/1	wet
	NYT12.3 12.6	*Betula*-expansion transition zone	*P. sylvestris-T.*				increasing temp.
PLENIGLACIAL	Längsee cold period (Oldest Dryas Ia)	NAP, *Juniperus*	*P. Haploxylon*-T. *P. mugo*-T.	3/3	*Pinus* spp. 14,445 ± 45 BP	1	cold drier / wet
	15,535 ± 160 BP Längsee oscillation ?	*Juniperus, Pinus*	(*Quercus*) *P. sylvestris*-T.	3/2			warmer S-dry
		NAP (redeposition)	*Pinus* spp.	3/1			wet
		NAP	*P. Haploxylon*-T. *P. mugo*-T.	2			cold+drier cold+wet

Fig. 8. Pollen stratigraphic relations between Valun, Lake Vrana (Schmidt *et al.*, 2000), and Längsee (Schmidt *et al.*, 1998, and submitted). NYT=Naples Yellow Tuff; Lg-FL1-3=Lateglacial climate fluctuations.

Relazioni stratigrafici a pollini fra Valun, Lago di Vrana (Schmidt et al., 2000), e Längsee (Schmidt et al., 1998, and submitted). NYT=Naples Yellow Tuff; Lg-FL1-3=Fluctuazioni climatici tardi-glaciali.

Corresponding with the development at Längsee, and hence supporting the chronostratigraphic interpretation, the climate amelioration at Valun was followed again by a period of deterioration. At Valun, results indicate a bipartition of PZ 3/3; the lower part shows evidence of having been wetter than the younger part. In Lake Vrana, which is close to Valun, a pine pollen-rich section was dated at 14,445 ± 145 ^{14}C BP (Schmidt *et al.*, 2000). Using CALIB (1999), the age ranges between 16,824 and 17,830 cal. BP. The ^{14}C age supports the correlation with the Längsee cold period. The pine dominated period at Valun indicates increased catchment erosion and sediment redeposition, and hence comparable environmental conditions as were observed for lower PZ3/3 at Valun. The findings of an interstadial period with alpine tree expansion followed by a wet period which started at about 15.5 ky ^{14}C BP, as observed at Lake Vrana and Valun are in concordance with the finding of a flooded *Larix* forest at Revine (Belluno).

^{14}C measurements ranged between 15.2 and 14.3 ky ^{14}C BP (Casadoro *et al.*, 1976; Friederich *et al.*, 1999). The pollen curves indicate an open lerch-pine forest (Paganelli & Moretti, 1976).

Oxygen isotope variations of *Globigerina bulloides* in central Adriatic cores, according to Combourieu-Nebout *et al.* (1998), showed slightly increased values between 16.8 to 15.7 (reservoir corrected ^{14}C), coupled with pollen indicative of drier conditions. It was followed at 15.7 ky BP by a period with an isotope minimum and with low pollen concentrations.

PZ3/3 of Valun was related to the Oldest Dryas Ia of Längsee according to Schmidt *et al.* (1998). This time interval overlaps with glacier readvances in the Alps and Apennine. Surface exposure dating of moraines from the type locality of Gschnitz in the Central Alps, according to Kerschner *et al.* (1999), provided a preliminary age of about 15,000 years. The Fontari Stade complex of the Apennine dated at about 16 to 14 ^{14}C ky BP (Giraudi & Frezzotti, 1997). At least temporarly cold and wet climate conditions might correlate with high lake levels and indications of catchment erosion in central Italian maar lakes (Zolitschka & Ramrath, 1998).

Core section 470 – 330 cm (PZ 4)

The change in vegetation from the dominant alpine pines towards *P. sylvestris,* associated to a small extent with elements of the mixed-oak forest (dominance of *Quercus* followed by *Ulmus* and *Fraxinus excelsior*), indicates late glacial climate amelioration. Temperature progress is also indicated by the increase of *P. nigra*-types. The Poaceae reached the highest numbers within NAP, at the expense of *Artemisia* and Chenopodiaceae. Since Cyperaceae values are similar to the former sections, increase in Poaceae may not only have originated from littoral vegetation, but gramineae-rich mountain steppes. At present, rocky pastures on carbonaceous bedrock are dominated by *Chrysopogon gryllus*, *Festuca* spp., *Koeleria* spp. and *Stipa* spp. (Mavrovič, 1994).

Three phases of temporary increase of *P. mugo*-types, however, indicate climate fluctuations within this section. In Figure 8 suggested correlations between Valun, Lake Vrana, and Längsee are illustrated. At Valun, the expansion of deciduous trees started below a phase of temporarily increased pollen of *P. mugo*-types. The ^{14}C sample (Ua-13656) located below the beginning of this *P. mugo*-rich phase was dated at 12,160 ± 155 BP. With the use of CALIB (1999) for mixed marine and atmospheric samples (sediment from a slightly brackish environment), the calibrated age ranges between 13,061 and 14,252 cal. BP (see Tab. 1). In this case the beginning of the climate fluctuation is within the range of Lg-FL1 of Längsee (see Fig. 8). At least the subsequent phase, with higher values of oak and submediterranean pine, was related to the *Pinus*-biozone. At Lake Vrana, a *Betula*-rich period was compared by Schmidt *et al.* (2000) with an early Lateglacial birch-dominated period in Lago di Monticchio (Huntley *et al.*, 1999). At Valun, however, the pine pollen dominance continued. A more regional pollen catchment at Valun coupled with a possible pine pollen over representation, and *Betula* which has dominated the shoreline vegetation in the Vrana basin, may explain the discrepancy of the pollen assemblages at the two neighbouring sites.

Fluctuations in quartz during this section may indicate short-term influence of running water. At 470 cm, expansion of foraminifers indicate the marine ingression into Valun lake. The depth of this layer is about minus 55 m below the present sea-level. Age and depth are in concordance with the sea-level curve presented by Bard *et al.* (1990). The threshold of the basin, however, is not known. Whereas the ostracod genus *Sylvestra* persisted at low numbers, *C. fuscata* disappeared when marine ingression took place. According to Albani & Serandrei Barbero (1990) and Serandrei Barbero *et al.* (1999), the dominance of the foraminifer *Ammonia* gr. *tepida*, and subdominant *Haynesina depressula* indicates an environment comparable with inner-lagoon conditions. Probably precipitation and salinity, coupled with temperature, affected the growth of these foraminifers in the lagoon. During PZ4/3, the onset of the curve of Hystrichosphaeridae, together with a slight increase of *Cribroelphidium decipiens,* indicate that the marine influence probably progressed. During PZ 4/2, foraminifers were at their lowest. The dominant marine ostracods which were present during this time were *Leptocythere bacescoi, Cytherois uffenordei, Semicytherura masolii,* and *Leptocythere ramosa*. These species are more salinity tolerant, and hence they presently occur in northern Adriatic lagoons (Marano and Grado) up to 15 – 20 % salinity (Montenegro & Pugliese, 1996; Montenegro *et al.*, 1998).

With respect to the beginning of the distinct decline of the foraminifers, the upper two climate fluctuations indicated by increasing values of the *P. mugo*-types were related to the biozone of Younger Dryas (YD). The upper boundary of the younger subsection rich in *P. mugo*-types was dated at 10,600 ± 125 BP. The calibrated age (Tab. 1) ranges between 10,862 and 12,346 cal. BP. In this case, the YD phases of climate regressions are divided by a warmer interphase. This finding correlates with results obtained from Längsee (Schmidt *et al.*, submitted). A probably slightly warmer interphase separates the lower part with a stronger impact by running water from the upper part. Signals of a temporarly slight increase in temperature within Younger Dryas provide oxygen isotope records from Swiss lake sediments (Lotter *et al.*, 1992). For the northern Apeninne, Lowe (1992) and Lowe & Watson (1993) assumed for the Younger Dryas a distinct snow-line depression. The late glacial phases rich in *P. mugo*-types at Valun may indicate decline of timber and snow-line. An increase in precipitation, and possibly less summer evaporation, were assumed to be responsible for lake level increase in Lake Vrana, dated at 10,620 ± 125 BP (Schmidt *et al.*, 2000) (calibrated age range 12,116 – 12,970). Kerschner *et al.* (in press) have shown for the northern slopes of the Alps that areas at present influenced by Atlantic circulations, have received, during Younger Dryas, the same or even slightly higher precipitation than today.

Core section 340 - 200 cm (PZ5)

During early PZ5/1 Hystrichospaeridae suddenly increased to high abundances. This distribution corresponds with those of Dinoflagellate cysts during early

Holocene observed by Zonneveld (1996) from a southern Adriatic core. High abundances of Hystrichosphaeridae correlate with peaks of of the dominant foraminifers (*Ammonia inflata, A. perlucida, Aubignayna perlucida, Cribroelphidium decipiens, Ammonia inflata),* and first ocurrences of typical marine species such as *Elphidium* ssp., *Quinqueloculina* spp. Together with the same ostracods found in the upper part of the previous section, additional marine species (*Cytheridea neapolitana* and *Sagmatocythere versicolor*) occurred. Both foraminifers and ostracods indicate progressing marine influence. A distinct peak in organic carbon indicates increasing marine productivity. According to observations by Montenegro and Pugliese (1996), the environment is comparable to outer-lagoon conditions. The marine influence culminated at lower foraminifer zone 3/1, where species diversity and abundances (peak of *Ammonia inflata)* were the highest. This period might be related with lake level lowering in Vrana during early Holocene, as was observed by Schmidt *et al.* (2000). Mineral proportions during this period at Valun are characterized by a distinct lowering of the quartz content which suggests that transport by running surface water was less important.

During PZ5/2 the expansion of *Fagus*, *Abies*, *Picea*, which were present in low numbers during the whole core section, and ferns, indicate an increase in humidity. Probably during this time the forests rich in beech of the mountain belts in the Velebit (see Culiberg & Sercelj, 1994) and in Istria established. The expansion of a vegetation favoured by increased humidity, and corresponding environmental changes in the bay of Valun and neighbouring Lake Vrana, were related with the onset of an Adriatic pluvial period. The latter, according to Wunsam *et al.* (1999) lasted from 8.4 to 6 ky ^{14}C BP. This pluvial caused water level increase in the nearby Lake Vrana. According to Schmidt *et al.* (2000), the lake at about 8.5 ^{14}C BP reached its present depth. In the Valun bay, enhanced freshwater influx, and hence salinity decline, is thought to be responsible for the distinct decrease of foraminifers and Hystrichosphaeridae during this time. Marked peaks of quartz were assumed to indicate local erosion processes delivering their respective freight by running waters to the sea. Mg-calcite and aragonite, present within this uppermost unit, are most likely due to marine organisms (biogenic skeletal debris).

6. CONCLUSIONS

An 8 m long sediment core was obtained from the present 51 m deep marine bay of Valun, Island of Cres. Since the whole core section is dominated by pine pollen, the differentiation of *Pinus* pollen-types improved information about climate changes. Their dating, at the present stage of investigations, however, is tentative; possible chronostratigraphic relations were discussed.

The change from alpine pines to spruce and broadleafed trees (*Tilia*) during PZ1 indicated a gradual climate amelioration. The overall picture of this interstadial section is the shift from cold to moderate warm, however humid conditions. Because of the lack of *Fagus* and *Abies* in vegetation, and the pollen assemblage mentioned, this section was compared with vegetation development of the middle Würmian period (isotope stages 3 and 4) south of the Alps. Freshwater conditions with slightly brackish influence, probably due to a location of the lake close to the sea, towards the top of the section are indicated.

The sudden increase of *P. mugo*-types at lower boundary of PZ1 is either the result of rapid climate change or indicates a sediment gap between PZ1 and PZ2. The high abundances of *P. mugo*-types during lower PZ2 indicates a situation being comparable with the subalpine *P. mugo* belt. Because of the lowest inferred temperatures throughout the core, PZ2 was related to the last glacial maximum (LGM). A time lag in the onset of LGM sea-level lowering, preserving lake salinity, was considered to explain the discrepancy between the cold and wet climate conditions and the ostracod-inferred palaeosalinity. During LGM, cladoceran and ostracod freshwater taxa of cold habitats occurred together with ostracods tolerating salinity fluctuations from fresh to slightly brackish conditions. At present among the latter, some species are distributed in central or northern Europe, and in the Adriatic region are only known from fossils. The increase of *P. Haploxylon*-type towards top of PZ2 indicates rise in timberline. It was followed by an at least temporarly wet period with fluctuating timberlines (3/1). The subsequent phase (3/2) dominated by *P. sylvestris*-types, together with low pollen abundances of oak, indicate climate amelioration. Ostracods such as *Sylvestra* indicate lake salinity and water temperature increase. This development was related to an interstadial period with the expansion of alpine shrubs and trees at Längsee, Carinthia (Längsee oscillation, Prä-Bölling?), with an upper boundary of about 15.5 ky ^{14}C BP. At Valun it was followed by a pine-rich period of climate regression (Oldest Dryas Ia). The lower part rich in *P. mugo-types,* and with catchment erosion, was thought to have been more wet than the younger one with highest pollen abundances of *Haploxylon* pine throughout the core.

The palynological results of Valun support the suggestion of refuges at least for the dwarfed and *Haploxylon* pines in the northern Dinarides during the time of last glaciation; at locally favourable places, sparse refuges may also have occurred for *P. sylvestris*, spruce and oak. Cold periods coupled with extensive snow-cover have favoured the dwarfed pine in the calcareous areas of the Dinarides. Pine refuges, high pine pollen production superimposing pollen deposition from herbs, and generally less dry conditions in the mountain ranges of the Dinarides, may explain the difference to *Artemisia* and Chenopodiaceae dominated Late Pleistocene formations in the present Mediterranean, e.g. in central Italy.

The change from pollen of alpine pines towards dominating *P. sylvestris*-types, and to a lesser extent of *P. nigra*-type and elements of the mixed oak forest, indicates late glacial climate amelioration. At places where birch was able to compete with pines (e.g. shores of Lake Vrana), initially *Betula* expanded. Subsequent to a phase of Lateglacial climate fluctuation, higher pollen abundances of oak and the *P. nigra*-type indicate that summer probably became warmer and drier. The marine ingression into the karstic basin took place during the early late glacial period. The lower boundary of the Younger Dryas biozone was drawn according to the distinct decline of foraminifer abundances concurrent with again increasing values of the *P. mugo*-types. The foraminifer decrease probably was affected by both temperature decline and freshwater incursions.The YD biozone appeared as a multiphase period; a warmer interphase divides two phases of regression and timberline decline. Increased precipitation during an early Holocene Adriatic pluvial period has probably lowered salinity in the Valun bay. This may explain that foraminifer abundances and species diversity which increased during early Holocene were as low as during Younger Dryas biozone.

In summary, the results support the suggestion of gradients in vegetation development along a north to south transect due to temperature and the location of refuges. Generally, the lower parts of the cold periods, LGM, Oldest Dryas Ia, and Younger Dryas, have been more wet than the drier upper parts. Additionally, a post-LGM section (possibly related to an Heinrich event), and Lateglacial climate fluctuations, have been wet. Winters during these periods of climate oscillation in the Dinarides appeared to have been rich in snowcover. A warm and dry summer developed during the period related to the Längsee oscillation and during Alleröd. The Holocene progress of summer drought, however, was interrupted by an early Holocene pluvial period.

The multiproxy approach and land/sea-correlations improved climate interpretations and intercorrelations between the PAGES sites.

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REFERENCES

Albani D.A. & Serandrei Barbero, R. (1990) - *I foraminiferi della Laguna di Venezia.* Mem. Sci. Geol., **42**, 271-341.

Allen, J.R.M., Brandt, U., Brauer, A., Hubbertens, H.-W., Huntley, B., Keller, J., Kraml, M., Mackensen, A., Mingram, J., Negendank, J.F.W., Nowaczyk, N.R., Oberhänsli, H., Watts, W.A., Wulf, S. & Zolitschka, B. (1999) - *Rapid environmental changes in southern Europe during the last glacial period.* Nature, **400**, 740-743.

Alessio, M., Allegri, L., Bella, F., Calderoni, G., Cortesi, C., Daipra, G., De Rita, D., Esu, D., Follieri, M., Improta, S., Magri, D., Narcisi, M.B., Petrone, V. & Sadori (1986). – *^{14}C dating, geochemical features, faunistic and pollen analyses of the uppermost 10 m core from Valle di Castiglione (Rome, Italy).* Geologica Romana, **25**, 287-308.

Alessio, M., Bella, F., Cortesi, C. & Turi, B. 1973. *University of Rome carbon-14 dates XII.* Radiokarbon ,**15**, 165-178.

Alonso, M. (1996). – *Fauna Iberica: Branchiopoda. Museo de Ciencias Naturales.* C.S.I.C. Madrid, 486 pp.

Ariztegui, D., Asioli, A., Lowe, J.J., Trincardi, F., Vigliotti, F., Tamburini, F., Chondrogianni, C., Accorsi, C.A., Bandini Mazzanti, M., Mercuri, A.M., Van der Kaars, S., McKenzie, J.A. & F. Oldfield (2000). - *Palaeoclimate and the formation of sapropel S1: inferences from Late Quaternary lacustrine and marine sequences in the central Mediterranean region.* Palaeogeography, Palaeoclimatology, Palaeoecology, **158**, 215-240.

Ascoli, P. (1966-67) - *Ostracodi olocenici continentali e salmastri di un pozzo perforato nella laguna di Venezia.* Mem. Biogeografia Adriatica, **7**, 53-149.

Bard, E., Hamelin, B., Fairbanks, R.G. & Zindler, A. (1990). – *Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals.* Nature, **343**, 405-410.

Beug, H.J. (1967). – *On the forest history of the Dalmatian coast.* Review of Paleobotany and Palynology, **2**, 271-279.

Beug, H.J. (1977). - *Vegetationsgeschichtliche Untersuchungen im Küstenbereich von Istrien (Jugoslawien).* Flora, **166**, 357-381.

Biondič, B., Ivicič, D. & Preglovič, E. (1992) - *The hydrogeology of the Lake Vrana, The Cres Island.* Proceedings of the International Symposium „Geomorphology and Sea“ and the meeting of the Geomorphological Commission of the Carpatho-Balcan countries, Mali Losinj, September 22-26, 1992. Department of Geography, Faculty of Science, University Zagreb, 25-36.

Biondič, B., Kapelj, S. & Mesič, S. (1997) - *Natural tracers – Indicators of the origin of the water of the Vrana Lake on Cres Island, Croatia.* Tracer Hydrology, **97**, 113-120.

Bonacci, O. (1993) - *The Vrana lake hydrology (Island of Cres – Croatia).* Water Resources Bulletin, **29**/2, 407-414.

Bonaduce G., Russo A. & Barra D. (1990) - *The ostracode genus* Sylvestra *Doruk, 1973: systematics, ecology and distribution.* Bull. Soc. Pal. It., **29** (3), 279-288.

Bottema, S. (1974). – *Late Quaternary vegetation history of north-western Greece.* Thesis, University of Groningen, 190pp.

CALIB (1999). – *Radiocarbon Calibration Program,* Quaternary Isotope Lab University of Washington.

Casadoro, G., Castiglioni, G.B., Corona, E., Massari, F., Moretti, M.G., Paganelli, A., Terenziani, F. & Toniello, V. (1976). - *Un deposito tardowürmiano con tronchi subfossili alle Fornace dei Revine (Treviso).* Boll. Comit. Glac. It., **24,** 22-63.

Colalongo, M.L. (1965) - *Gli Ostracodi della serie de Le Castella (Calabria).* Giorn. Geol., **33** (1), 83-130.

Combourieu-Nebout, N., Paterne, M., Turon, J.-L., Siani, G. (1998). - *A high-resolution record of the last deglaciation in the central Mediterranean sea: Palaeovegetation and Palaeohydrological evolution.* Quaternary Science Reviews, **17**, 303-317.

Correggiari, A., Roveri, M. & Trincardi, F. (1996) - *Late Pleistocene and Holocene Evolution of the North Adriatic Sea.* Il Quaternario, **9** (2), 697-704.

Culiberg, M. (1991). – *Late Glacial vegetation in Slovenia.* Academia Scientiarum at Artium Slovenia, Classis IV: Historia Naturalis, **29**, 52 pp.

Culiberg, M. & Sercelj, A. (1994). - *Palynological research in the Plitvice National Park.* Razprave IV. Razreda Sazu, **35**(10), 177-185.

Danielopol, D. L., Martens K. & Casale L. M. (1989) - *Revision of the genus* Leucocythere *KAUFMANN, 1892 (Crustacea, Ostracoda, Limnocytheridae), with the description of a new species and two new tribes.* Bull. Inst. Royal Sci. Nat. Belgique. Biologie, **59**, 63-94.

Eicher, U. (1980). – *Pollen- und Sauerstoffisotopenanalysen an spätglazialen Profilen vom Gerzensee, Faulenseemoos und vom Regenmoos bei Boltigen.* Mitt. Naturforsch. Ges. Bern, N.F., **37**,65-80.

Follieri, M., Giardini, M., Magri, M. & Sadori, L. (1998). – *Palynostratigraphy of the last Glacial Period in the Volcanic Region of Central Italy.* Quaternary International, **47**/48, 3-20.

Fontugne, M. R., Paterne, M., Calvert, S. E., Murat, A., Guichard, F. & Arnold, M. (1989) - *Adriatic deep water formation during the Holocene: Implication for the reoxygenation of the deep Eastern Mediterranean Sea.* Paleooceanograpy, **4** (2), 199-206.

Frey, D.G. (1986) - *Cladocera analysis.* In: Berglund, B.E. (Ed.), *Handbook of Holocene palaeoecology and palaeohydrology.* J. Wiley & Sons, Chichester, 667-692.

Friederich, M., Kromer, B., Spurk, M., Hofmann, J. & Kaiser, K.F. (1999). – *Paleoinvironment and radiocarbon calibration as derived from Late Glacial/Early Holocene tree-ring chronologies.* Quaternary International, **61**, 27-40.

Fritz, A. (1972) - *Das Spätglazial in Kärnten.* Ber. Deutsch. Bot. Ges., **85**, 1-4, 93-99.

Fukarek, P. (1970) - *Beitrag zur Kenntnis der oberen Waldgrenze in einigen Gebirgszügen der südlichen Dinariden.* In Waldforschung und Vegetationsgrenzen im Hochgebirge. Mittl. Ostalp.-din. Ges. f. Vegetkde., **11**, 45-54.

Galoukas S.F., Hajek-Tadesse V. & Danielopol D.L. (1995) - Cytherissa lacustris *(Ostracoda, Cytherideidae) in the Pleistocene of Levsos island (Greece, Aegean Sea): its paleoecological interest.* N. Jb. Geol. Paläont. Mh., **2**, 105-110.

Giraudi, C. & Frezzotti, M. (1997) - *Late Pleistocene glacial events in the central Apennines, Italy,* Quaternary Research, **48**, 280-290.

Gonzalez, M.E., Martens K. & Baltanas A. (1996) - *A taxonomic revision of European Herpetocypris BRADY and NORMAN, 1889 (Crustacea, Ostracoda).* Bull. Inst. Royal Sc. Nat. de Bélgique, Biologie, **66**, 93-132.

Grootes, P.M., Stuiver, M., White, J.W.C., Johnsen, S. & Jouzel, J. (1993). – *Comparison of oxygen isotope records from the GISP2 and GRIP Greenland ice cores.* Nature, **366**, 525-554.

Grüger, E. (1975). – *Pollenanalyse spätpleistozäner und holozäner Sedimente aus der Adria.* Geol. Jb., A **29**, 3-32.

Huntley, B., Watts, W. A., Allen, J.R.M. & Zolitschka, B. (1999) - *Palaeoclimate, chronology and vegetation history of the Weichselian Lateglacial: comparative analysis of data from three cores at Lago Grande di Monticchio, southern Italy.* Quaternary Science Reviews, **18**, 945-960.

Indinger, P. (1999). - *Pigmentanalytische Untersuchungen der Sedimente eines fakultativ meromiktischen Küstensees: Malo Jezero, Insel Mljet, Kroatien.* – Diplomarbeit Univ. Wien, 65pp.

Jäger, S. (1975) - *Saccusdifferenzierungen an rezenten* Pinus-*Arten.* Diss. Universität Wien, 139 pp.

Jahns, S. (1991). - *Untersuchungen über die holozäne Vegetationsgeschichte von Süddalmatien und Südgriechenland.* Diss. Cuvilier Verlag, ISBN 3-928815-06-7, Georg August Univ. Göttingen, 144pp.

Jahns, S. & van den Bogaard, C. (1998). - *New palynological and tephrostratigraphical investigations of two salt lagoons on the island of Mljet, south Dalmatia, Croatia.* Veget. Hist. Archaeobot., **7**, 219-234.

Kallel, N., Paterne, M., Duplessy, J.-C., Vergnaud-Grazzini, C., Pujol, C., Labeyrie, L., Arnold, M., Fontugne, M. & Pierre, C. (1997) - *Enhanced rainfall in the mediterranean region during the last sapropel event.* Oceanologica Acta, **20** (5), 697-712.

Kerschner, H., Ivy-Ochs, S. & Schlüchter, C. (1999) *Paleoclimatic interpretation of the early Lateglacial glacier in the Gschnitz valley, central Alps, Austria.* Annals of Glaciology, **28**, 135-140.

Kerschner, H., Kaser & Sailer, R. - *Alpine Younger Dryas glaciers as palaeo-precipitation gauges.* Annals of Glaciology (in press).

Klaus, W. (1972) - *Saccusdifferenzierungen an Pollenkörnern ostalpiner* Pinus-*Arten.* Österr. Bot. Z., **120**, 93-116.

Klaus, W. (1975) - *Über bemerkenswerte morphologische Bestimmungsmerkmale an Pollenkörnern der Gattung* Pinus *L.* Linzer biol. Beitr., **7**/3, 329-369.

Klaus, W. (1977a) - Zur Bestimmung und Interpretation der Pollendichte in Sedimenten. Jahrb. O.Ö. Mus.-Ver., **120**, 315-344.

Klaus, W. (1977b) - *Zur Pollendiagnose der Rot-Kiefer (*Pinus sylvestris *L.).* Sitz.-Ber. Österr. Akademie der Wissenschaften, math.-nat. Kl., Abt. I, **186**/44-5, 1-218.

Lotter, A.F., Eicher, U. & Siegenthaler, U. (1992) - *Late-Glacial climatic oscillations as recorded in Swiss lake sediments.* Journal of Quaternary Science, **7**, 187-204.

Lotter A.F., Birks, H.J., Hofmann, W. & Marchetto, A. (1997) - *Modern diatom, cladocera, chironomid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of past environmental conditions in the Alps. I. Climate.* Journal of Paleolimnology, **18**, 395-420.

Lowe, J. J. (1992) - *Lateglacial and early Holocene lake sediments from the northern Apennines, Italy* *pollen stratigraphy and radiocarbon dating.* Boreas, **21**, 193-208.

Lowe, J. J. & Watson, C. (1993) - *Lateglacial and early Holocene pollen stratigraphy of the northern Apennines, Italy.* Quaternary Science Reviews, **12**, 727-738.

Lowe, J.J., Accorsi, C. A., Bandini Mazzanti, M., Bishop, A., Van der Kaars, S., Forlani, L., Mercuri, A. M. Rivalenti, C., Torri, P. & Watson, C. (1996) - *Pollen stratigraphy of sediment sequences from lakes Albano and Nemi (near Rome) and from the central Adriatic, spanning the interval from oxygen isotope Stage 2 to the present day.* In: Gulizzoni, P., Oldfield, F. (Eds), *Palaeoenvironmental Analysis of Italian crater lake and Adriatic sediments.* Mem. Ist. ital. Idrobiol., **55**, 71-98.

Magri, D. (1999). – *Late-Quaternary vegetation history at Lagaccione near Lago di Bolsena (central Italy).* Review of Palaeobotany and Palynology, **106**, 171-208.

Mavrovič N. (1994) - *Cres und Losinj, Art Studio Azinovic d.o.o.* Azinovic, M. (Ed.), 178 pp.

Meese, D., Alley, R., Gow, T., Grootes, P.M., Mayewski, P., Ram, M., Taylor, K., Waddington, E. & Zielinski, G. (1994). - *Preliminary depth-age scale of the GISP2 ice-core.* CRREL Special Report.

Montenegro M.E. & Pugliese N. (1996) - *Autecological remarks on the ostracod distribution in the Marano and Grado Lagoons (Northern Adriatic Sea, Italy).* Bull. Soc. Paleont. It., Spec. Vol. **3**, 123-132.

Montenegro M.E., Pugliese N. & Bonaduce G. (1998) - *Shelf ostracods distribution in the Italian seas.* Bull. Centre Rech. Elf Explor. Prod., Mém., **20**, 1-101.

Orsi, G., Dàntonio, M., de Vita, S. & Gallo, G. (1992). - *The Neapolitan Yellow Tuff, a large magnitude trachytic phreatoplinian eruption: Eruptive dynamics, magma withdrawal and caldera collapse.* Journal of Volcanology and Geothermal Research, **53**, 275-287.

Paganelli, A. & Moretti, M.G. (1976). – *Analisi polliniche del deposito di Revine. In:* Casadoro, G., Castiglioni, G.B., Corona, E., Massari, F., Moretti, M.G., Paganelli, A., Terenziani, F. & Toniello, V. (1976) – *Un deposito tardowürmiano con tronchi subfossili alle Fornace dei Revine (Treviso).* Boll. Comit. Glac. It., **24**, 54-60.

Pugliese N. & Stanley J. D. (1991) - *Ostracoda, depositional environments and late Quaternary evolution of the eastern Nile Delta, Egypt.* Il Quaternario, **4** (2), 275-302.

Ramrath, A., Zolitschka, B., Wulf, S. & Negendank J. F.W. (1999) - *Late Pleistocene climatic variations as recorded in two Italian maar lakes (Lago di Mezzano, Lago Grande di Monticchio).* Quaternary Science Reviews, **18**, 977-992.

Randič, A., Abramič, A., Balenovič, D., Biondič, B., Cimerman, R., Dorčič, G., Draganovič, E., Gašparovič, F., Karajič, N., Kozelički, N., Mastrovič, M., Pandčič, K., Rukavina, M., Smodlaka, N., & Vidič, S. (1996) – *Implications of Expected Climatic Changes for the Cres-Losinj Islands.* In: Jeftič, L., Keškeš, S. & Pernetta, J.C. (Eds), Climate Change and the Mediterranean, Vol. 2, 431-548.

Schmidt, R. (1975) - *Pollenanalytische Untersuchungen zur spätglazialen bis mittelpostglazialen Vegetationsgeschichte im Raume Bozen.* Linzer biol. Beitr., **7**/2, 225-247.

Schmidt, R., Wunsam, S., Brosch, U., Fott, J., Lami, A., Löffler, H., Marchetto, A., Müller., H.W., Prazakova, M. & Schwaighofer, B. (1998) - *Late and post-glacial history of meromictic Längsee (Austria), in respect to climate change and anthropogenic impact.* Aquat.sci., **60**, 56-88.

Schmidt, R., Drescher, R., Krisai, R., Müller, J., Szeroczynska, K. (2000). - *Lake level changes in respect to palaeoclimate since Lateglacial, and anthropogenic impact in the northern Adriatic large karstic Lake Vrana (Isle of Cres, Croatia).* Journal of Limnology, **59**, 113-130.

Schmidt, R., van den Bogaard, C. & Merkt, J. (2001) – *A new Lateglacial chronostratigraphic tephra marker for the south-eastern Alps: The Naples Yellow Tuff (NYT) in Längsee (Austria) in the context of pollen and microstratigraphic records.* Quaternary International (submitted).

Schneider, R. (1978) - *Pollenanalytische Untersuchungen zur Kenntnis der spät- und postglazialen Vegetationsgeschichte am Südrand der Alpen zwischen Turin und Varese (Italien).* Bot. Jahrb. Syst., **100**/1, 26-109.

Schultze, E. (1979) – *Die Bedeutung eines Pollenprofils aus dem Haidensee (486 m NN) in Kärnten für die spät- und frühpostglaziale Vegetationsentwicklung im nördlichen Klagenfurter Becken.* Linzer biol. Beitr., **11**/1, 21-31.

Schultze, E. (1984) - *Neue Erkenntnisse zur spät- und frühpostglazialen Vegetations- und Klimaentwicklung im Klagenfurter Becken.* Carinthia II, **174**/94, 261-266.

Schultze, E. & Niederreiter, R. (1990) - *Paläolimnologische Untersuchungen an einem Bohrkern aus dem Profundal des Mondsees (Oberösterreich).* Linzer Biol. Beitr., **22**, 231-235.

Serandrei Barbero R., Carbognin L., Taroni G. & Cova E. (1999) - *Distribution of recent benthic foraminifera in the southern basin of the Venice lagoon (Italy): Statistical evaluation of taxa significance.* Micropaleontology, **45**, 99-111.

Šercelj, A. (1966) – *Pollenanalytische Untersuchungen der pleistozänen und holozänen Ablagerungen von Ljublianso Barje (deutsche Zusammenfassung).* Razprave, **9**, 431-472.

Šercelj, A. (1970). – *Würmzeitliche Vegetation und Klima in Slovenien (deutsche Zusammenfassung).* Academia Scientiarum et Artium Slovenica. Dissertationes, **13**, 209-249.

Šercelj, A. (1978). - *Zur Vegetationsgeschichte des slowenischen Raumes.* Poroc. Vzhodnoalp.-dinar. Dr. preuc. Veget., **14**, 81-83.

Šercelj, A. (1996). – *The origins and developments of forests in Slovenia.* Academia Scientiarum et Artium Slovenia, Classis IV: Historia Naturalis, **35**, 152pp.

Šercelj, A. & Culiberg, M. (1984). – *Vicende floristiche nei territori delle Alpi Sud-orientali e dellÀdriatico Nord-Orientale.* Giornale Botanicoi Italiano, **118**, 283-288.

Stuiver, M., Grootes, P.M. & Braziunas, T.F. (1995) - *The GISP2 delta ^{18}O climate record of the past 16,500 years and the role of the sun, ocean, and volcanoes.* Quaternary Research, **44**, 341-354.

Trinajstić, I. (1970) - *Höhengürtel der Vegetation und die Vegetationsprofile im Velebit-Gebirge.* Mittl. Ostalp.-din. Ges. f. Vegetkde., **11**, 219-224.

Tzedakis, P.C. (1993). - *Long-term tree populations in northwest Greece through multiple Quaternary climatic cycles.* Nature, **364,** 437-440.

Van Husen, D. (1976). *Zur quartären Entwicklung des Krappfeldes und des Berglandes um St. Veit an der Glan.* – Mitt. Ges. Geol. Bergbaustud. Österr., **23**, 55-68.

Van Husen, D. (1997). – *LGM and late-glacial fluctuations in the Eastern Alps.* Quaternary International, **38**/39: 109-118.

Wagner, C.W. (1957) - *Sur les Ostracodes du Quaternaire récent des Pays-bas et sur leur utilisation dans l'étude géologiques des dépôts holocènes.* Diss. Univ. Paris, 259 pp.

Walter, H. & Lieth, H. (1964) - *Klimadiagramm Weltatlas.* Jena.

Watts, W.A., Allen, J.R.M., Huntley, B. & Fritz, S.C. (1996) - *Vegetation History and Climate of the Last 15,000 Years at Laghi di Monticchio, Southern Italy.* Quaternary Science Reviews, **15**, 113-132.

Watts, W.A., Allen, J.R.M. & Huntley, B. (1996). – *Vegetation History and Palaeoclimate of Last Glacial Period at Lago Grande di Monticchio, Southern Italy.* Quaternary Science Reviews, **15**, 133-153.

Wick, L. (1996) - *Late-glacial and early-Holocene palaeoenvironments in Brianza, N Italy.* Il Quaternario, **9**, 653-660.

Wijmstra, T.A. 1969. - *Palynology of the first 30 meters of a 120 meter deep section in northern Greece.* Acta Botanica Nederlandica, **18**, 511-528.

Willis, K.J. 1994. - *The vegetation history of the Balkans.* Quaternary Science Reviews, **13**, 769-788.

Wunsam, S., Schmidt, R. & Müller, 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.

Zolitschka, B. & Ramrath, A. (1998) - *Glacial events in Italy: dating moraines with lacustrine records?* Terra Nostra, Schriften der Alfred Wegener Stiftung, **98**/6, 138-142.

Zonneveld, K.A.F. (1996) - Palaeoclimatic reconstruction of the last deglaciation (18 ka BP – 8 ka BP) in the Adriatic Sea region; a land-sea correlation based on palynological evidence. Palaeogeograpy, Palaeoclimatology, Palaeoecology, **122**, 89-106.

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