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BIOLOGICAL RECORDS OF LATE PLEISTOCENE AND HOLOCENE ENVIRONMENTAL CHANGES FROM TWO ITALIAN CRATER LAKE SEDIMENTS: RESULTS FROM AN EUROPEAN INTERDISCIPLINARY RESEARCH PROJECT (PALICLAS)

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RIASSUNTO - *Registrazioni biologiche di cambiamenti ambientali tardo pleistocenici ed olocenici nei sedimenti di due laghi craterici italiani: risultati ottenuti nel corso di un progetto europeo di ricerca interdisciplinare* (PALICLAS) - Il Quaternario *Italian Journal of Quaternary Sciences*, **9**(2), 1996, 711-720 - Vengono qui presentati alcuni risultati di un'indagine paleolimnologica condotta su due laghi craterici dell'Italia Centrale (Lago di Nemi e Lago di Albano), utilizzati quali indicatori per lo studio delle variazioni climatiche negli ultimi 30 ka circa. La ricerca è inserita in un progetto multidisciplinare europeo (*Palaeoenvironmental Analysis of Italian Crater Lake and Adriatic Sea Sediments, PALICLAS*) ed ha come scopo principale la distinzione delle variazioni di origine naturale da quelle antropogeniche. Diverse tecniche di datazione (es. AMS ^{14}C calibrato; tefracronologia e diagrammi pollinici) concordano nello stabilire che l'intera sequenza olocenica è rappresentata in dettaglio nella carota PNEM 94-1B (L. Nemi, profondità di prelievo: 30 m) e nei primi 5,60 m della carota PALB 94-1E (L. Albano, profondità di prelievo 70 m). Quest'ultima, lunga circa 14 m, arriva a coprire anche il Pleniglaciale; questo periodo è altresì rappresentato in dettaglio nel Lago di Albano dalla carota PALB 94-6B (profondità di prelievo: 30 m). L'analisi di pigmenti fotosintetici, diatomee, crisoficee, cladoceri, ostracodi consente di individuare fasi ad elevata produttività lacustre anche durante il Pleniglaciale (circa 15-30 ka BP, datazione di tefra mediante Ar/Ar), rilevate anche sui profili litostratigrafici, probabilmente legate a rapide ed intense variazioni climatiche (cicli di 200-500 anni). La presenza di ostracodi è limitata al Pleniglaciale, dove il ritrovamento di abbondanti resti coincide con le fasi ad elevata concentrazione di carbonati. Elevata attività biologica, indicata soprattutto da abbondanti fioriture algali, segna la prima metà dell'Olocene (PALB 94-1E; 4-5 m). L'intensa attività è sottolineata anche dall'accumulo di pigmenti fotosintetici di origine solfobatterica, possibile soltanto in condizioni di spiccata anossia e presenza di H_2S. Modificazioni in diversi parametri interessano il periodo intorno a 3,9 e 8,4 ka BP (PALB 94-1E; datazione mediante ^{14}C), e rappresentano con tutta probabilità i primi importanti segnali di impatto antropico, con la riduzione della foresta nel bacino imbrifero del Lago di Albano, cui seguirà un periodo di intensa erosione del suolo e di declino della produttività lacustre. Nella comunità zooplanctonica a cladoceri la deforestazione è accompagnata dalla sostituzione di *Daphnia* con *Bosmina*. Ulteriori e più dettagliate informazioni sull'Olocene si ottengono dalla carota del Lago di Nemi, nella quale in coincidenza con il miglioramento del clima legato alla transizione dal Pleistocene all'Olocene si osserva un aumento nella produttività; fasi di intensa eutrofizzazione caratterizzarono il periodo 11-5,5 ka, con concentrazioni di pigmenti algali e solfobatterici del tutto paragonabili a quelle misurate negli ultimi decenni.

ABSTRACT - *Biological records of late Pleistocene and Holocene environmental changes from two Italian crater lake sediments: results from an EU Interdisciplinary research project (PALICLAS)* - Il Quaternario *Italian Journal of Quaternary Sciences*, **9**(2), 1996, 711-720 - In the framework of the EU funded research project *Palaeoenvironmental Analysis of Italian Crater Lake and Adriatic Sea Sediments* (PALICLAS), several 8.5 to 14 m long cores were collected from two neighbouring crater lakes, Albano and Nemi (Central Italy) in 1994. The results reported in the present paper refer to three cores: two from Lago di Albano (PALB 94-1E and PALB 94-6B; water depth of 70 m and 30 m, respectively) and one from Lago di Nemi (PNEM 94-1B; water depth of 30 m). This paper summarises the results from the study of algal and sulphur photosynthetic pigments, diatom, chrysophyte cyst, ostracod and cladocera fossil remains. Based on AMS calibrated radiocarbon dates, core correlations, tephrochronology and pollen, the boundaries between Glacial/Late Glacial and Late Glacial/ Holocene were established. The core in Lago di Abano collected at –70 m from the surface, spans the longest record (ca. 30 ka BP). The core from the shallowest site in Lago di Albano is unique because, except for the uppermost ca. 8.5 cm, it represents pre-Holocene deposit only (*i.e.* the isotope stage 2). The core from Lago di Nemi pertains only to the Holocene (except for a few centimetres at the bottom of the core). At the base of the cores from Lago di Albano, a thick volcanoclastic deposit, dated ca. 25±5 ka BP in PALB 94-1E, was present. Two other tephra layers (the Etna and Avellino tephras) were detected within the cores of both lakes. The sediments deposited during the glacial period commonly contain low concentrations of biological remains. However, several periods of relatively high productivity (mesotrophic conditions) were observed from 25-30 ka BP to ca. 17 ka BP (tephrochronology). These rapid, sharp, probably related to climatic fluctuations (cycle of ca. 200-500 years), as observed in all the biological record stratigraphies, are in phase with the physical and chemical trends. Ostracod valves were found only in sediments deposited during the glacial period, when there were high carbonate concentrations and oxygenated bottom conditions. A dramatic, oscillating increase in biological activity occurred in the early, mid-Holocene. High concentrations of carotenoids from sulphur photosynthetic bacteria indicate that these sediments accumulated in anoxic bottom waters. This high level of eutrophication, which is likely to be related to a warmer climate, was also identified by other independent parameters, such as high content of organic matter, diatoms and cladocera concentrations and indicator species (*e.g.* small forms of *Stephanodiscus*). In the mid-Holocene, a sudden increase in minerogenic clastic input, accompanied both by a sharp decline in pigment concentrations in biota densities and by a change in diatom and cladocera assemblages, is here interpreted as the first discernible impact of human activity in the catchment (*i.e.* deforestation). The close link between catchment surface processes and in-lake productivity is shown by the clear relationship between forest clearance and the cladocera assemblages from lakes Albano and Nemi, which shifted from *Daphnia* to *Bosmina*. Taken together, pigments and fossil organisms allow us to make a detailed reconstruction of the palaeoenvironment of Lago di Albano, which includes productivity, variations in the lake water level and climate. Additional detailed information about the Holocene was obtained from Lago di Nemi, where very high and fluctuating concentrations of pigments from algal and sulphur photosynthetic bacteria were detected from near the base of the core to about 5 m (6 ka BP), supporting the palaeoclimatic-related evolution reconstructed for Lago di Albano.

Key words: Palaeolimnology, crater lakes, pigments, diatoms, ostracods, cladocera, Latium, Italy
Parole chiave: Paleolimnologia, laghi craterici, pigmenti, diatomee, cladoceri, Lazio, Italia

1. INTRODUCTION

The present study is part of an EU-funded interdisciplinary project (*Palaeoenvironmental Analysis of Italian Crater Lake Sediments, PALICLAS*) aiming at a better understanding of the response at the aquatic ecosystem to both anthropogenic and natural (climatic) forcing.

Lake sediments, especially for crater and meromictic lakes, can provide high resolution records that allow for the reconstruction of past environmental changes (Sanger, 1988; Negendank & Zolitschka, 1993). In particular, early studies on volcanic lakes of Latium had already ascertained their sensitivity to environmental changes (Niessen *et al.*, 1993; Follieri *et al.*, 1993). This region is located in a transition zone at the Southern margin of the North Atlantic front of Central Europe and the South Europe/North Africa airstream, which is sensitive to different Milankovitch forcing (Imbrie *et al.*, 1984; Kutzbach & Street-Perrot, 1985).

Some of the main objectives of the interdisciplinary project, which are partially discussed in the present paper, are as follows: (i) to provide a detailed resolution of palaeoenvironmental conditions and periods of rapid change, (ii) to reconstruct the ecosystem responses to climatic change, (iii) to obtain fine resolution multi-proxy palaeoclimatic reconstructions for the last 30 ka in Central Italy.

This work focuses on the use of lacustrine, biological remains (diatoms, cladocera, ostracods), as well as of "biochemical fossils" (pigments from algae and photosynthetic bacteria) found in the sediment cores from two neighbouring lakes, Lago di Albano and Nemi (Belis *et al.*, 1996; Guilizzoni *et al.*, 1996a).

The importance of the lacustrine biological remains as valuable indicators of past environment and climate has been emphasized in several publications, such as Smol (1990), Bradbury & Dean (1993).

These biological proxies (especially the pigments) can serve as indices of present and past trophic conditions (Leavitt, 1993), and are useful to identify successional changes in glacial and postglacial ecology, limnology and climate, and especially, changes in postglacial aquatic productivity (Sanger, 1988). In combination with other proxy-records, pigments can provide further information on the balance between allochthonous and autochthonous organic contributions to the sediment, redox conditions, and past periods of meromixis (Lami *et al.*, 1994). The last two aspects can be established from the occurrence of some pigments indicative of sulphur photosynthetic bacteria (Züllig, 1985).

2. MATERIALS AND METHODS

In lakes Albano and Nemi, a seismic survey (3.5 kHz) was carried out to identify a range of sites for coring; 24 long cores were taken in June 1994 using a Kullenberg piston corer (Kelts *et al.*, 1986). In the present work we take into consideration three cores only (Fig. 1).

The content of organic matter and $CaCO_3$ were assessed by loss on ignition (LOI) at 550°C and 950°C, respectively (Dean, 1974).

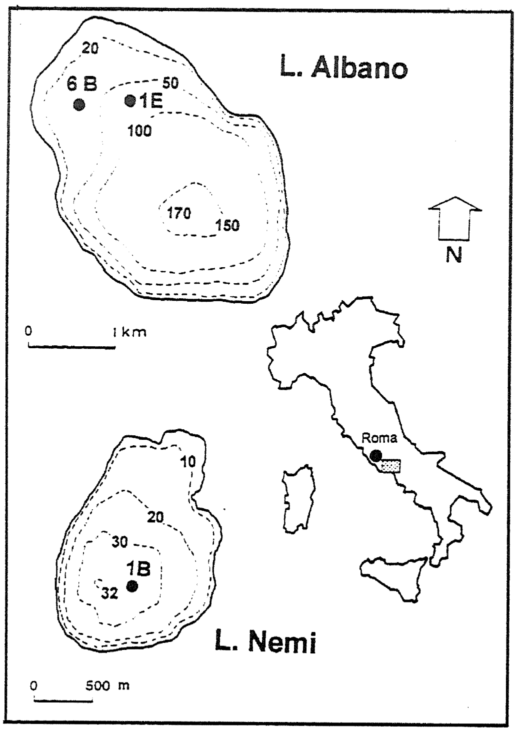

Fig. 1 - Sketch map showing the location of the lakes and the coring positions.

Rappresentazione schematica della localizzazione dei laghi studiati e delle stazioni di prelievo delle carote di sedimento.

Approximately 150 samples from core PALB 94-1E were analysed for organic carbon (OC) by using a CSN analyser after acid digestion (Lami *et al.*, 1996). The OC values proved to be significantly related to LOI (r^2 = 0.91). This regression was then used to calculate the OC from the LOI values for the remaining samples.

Specific algal pigments were determined by ion pairing, reverse-phase HPLC from the aforementioned acetone extract (Lami *et al.*, 1994).

β-carotene (present in all algae and used here as an index of algal productivity), lutein (specific of green algae), the entire collection of prokaryote carotenoids, and the carotenoids of sulphur photosynthetic bacteria (*e.g.* okenone, isorenieratene), were measured and expressed as nMoles /g organic matter.

On selected samples representative of major lithological changes, diatoms and chrysophyte cyst analyses were performed by using standard digestion (Renberg, 1990) and quantification (Battarbee & Kneen, 1982) procedure. Frustules and chrysophyte cysts were classified and enumerated at the optical and scanning electron microscope (SEM) at 1,200 and 10,000x, respectively. Cyst types were classified following Duff *et al.* (1994).

Cladocera analysis was performed following Frey (1986). Up to 200 remains per sample were identified and counted (Hann & Karrow, 1993), through the diagnostic traits reported in Frey (1958).

Ostracod remains were studied on selected samples (6-13 g wet wt.) following Löffler (1986) with some modifications. No pre-treatments were made, because the same sample was also used for the chironomid head capsule analysis. To improve taxonomic determinations

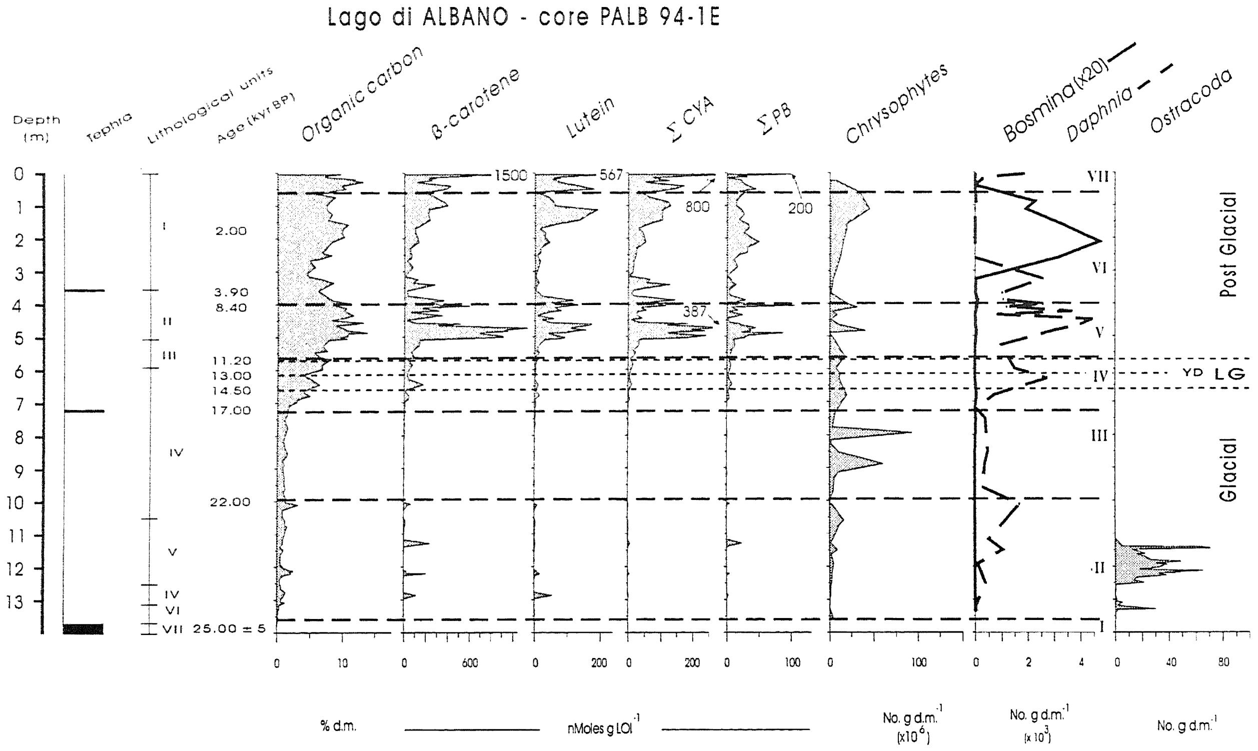

Fig. 2 - Distribution of total organic carbon, pigments, chrysophyte, cladocera and ostracod remains in a pelagic core from Lago di Albano. ΣCYA and ΣPB = sum of the pigments belonging to cyanobacteria and photosynthetic bacteria, respectively. The main lithological units, and the boundary between Pleistocene/Late Glacial, the start of Younger Dryas (YD) and the transition between Late Glacial/Holocene are also shown. Seven biostratigraphic zones are shown, as well as three tephra deposits (Avellino at 354 cm; Etna at 720 cm; coarse non-air-fall tephra at the base of the core, see text). All the ages are given in calibrated years (see text). d.m.= dry mass; LOI = loss on ignition.

Distribuzione di alcuni parametri geochimici, di pigmenti, di resti fossili di crisofite, di cladoceri e di ostracodi in una carota del Lago di Albano. ΣCYA e ΣPB = sommatoria rispettivamente dei pigmenti appartenenti ai cianobatteri e ai batteri fotosintetici. Sono inoltre indicate le principali unità litologiche della carota e i limiti tra Pleniglaciale/Tardiglaciale (LG) e Tardiglaciale/Olocene. Younger Dryas = YD. Sono inoltre indicate sette zone biostratigrafiche e tre livelli di tephra (Avellino a 354cm; Etna a 720cm; tefra alla base della carota). Le età sono in anni calibrati (vedi testo). d.m.= dry mass; *LOI* = loss on ignition.

SEM photographs were analysed.

Palaeo-primary productivity was inferred from a regression curve equation obtained from modern primary productivity measurements and surface sedimentary pigments observed in 12 Italian lakes (Guilizzoni *et al.*, 1983).

3. RESULTS AND DISCUSSION

The results refer to cores PALB94-1E and PALB94-6B, from two sites (sites 1 and 6; water depths of –70 m and –30 m, respectively) of Lago di Albano, and PALB94-1B from Lago di Nemi (water depth of –30 m). A detailed stratigraphy and chronology of the cores is discussed elsewhere (Chondrogianni *et al.*, 1996). The exact location of the coring sites is shown in Figure 1.

3.1 Chronology

Core PALB 94 -1E - At the base of this core there is a 38 cm thick non-air fall tephra layer dated to 25±5 ka BP by $^{40}Ar/^{30}Ar$ (Calanchi *et al.*, 1996b). Based on the correlation of palaeomagnetic directional data with a geomagnetic master curve (Mackereth, 1971) from other dated cores (*e.g.* L. Windermere, England and L. Bouchet, France), this tephra layer can be more precisely dated to 28-30 ka BP (F. Oldfield, pers. comm.). The 1000 cm level of the core was dated (22 ka BP), in the same way.

Two air-fall tephras, one of Campanian origin (Avellino) at 354 cm and the other from Mt. Etna at 720 cm, were dated to 3.9 ka BP and 17 ka BP, respectively (Calanchi *et al.*, 1996a). These ages are calibrated (using the model proposed by Stuiver & Reimer, 1993) and derived from a published ^{14}C analysis of terrestrial material found near the volcanic deposit (Narcisi, 1993).

Due to the lack of any reliable terrestrial macrofossils, which are the best material for ^{14}C dating, no radiocarbon analysis was performed. However, the magnetic susceptibility (van der Post *et al.*, 1995) and pollen profiles (van der Kaars *et al.*, 1995; C.A. Accorsi, 1996, pers. comm.), as well as the lithological correlations of core PALB 94-1E with 7 AMS calibrated radiocarbon-dated core in position 3 (PALB 94-3B; Chondrogianni *et al.*, 1996), were used to date the boundary between Glacial/Late Glacial (14.5 cal. ka BP at 660cm), the onset of the Younger Dryas (13 cal. kyr BP at 630cm) and the Late Glacial/Holocene transition (11.2 cal. ka BP at 560 cm; cf. Fig. 2). Besides, the above core correlations give evidence for major erosion during the deposition of units II

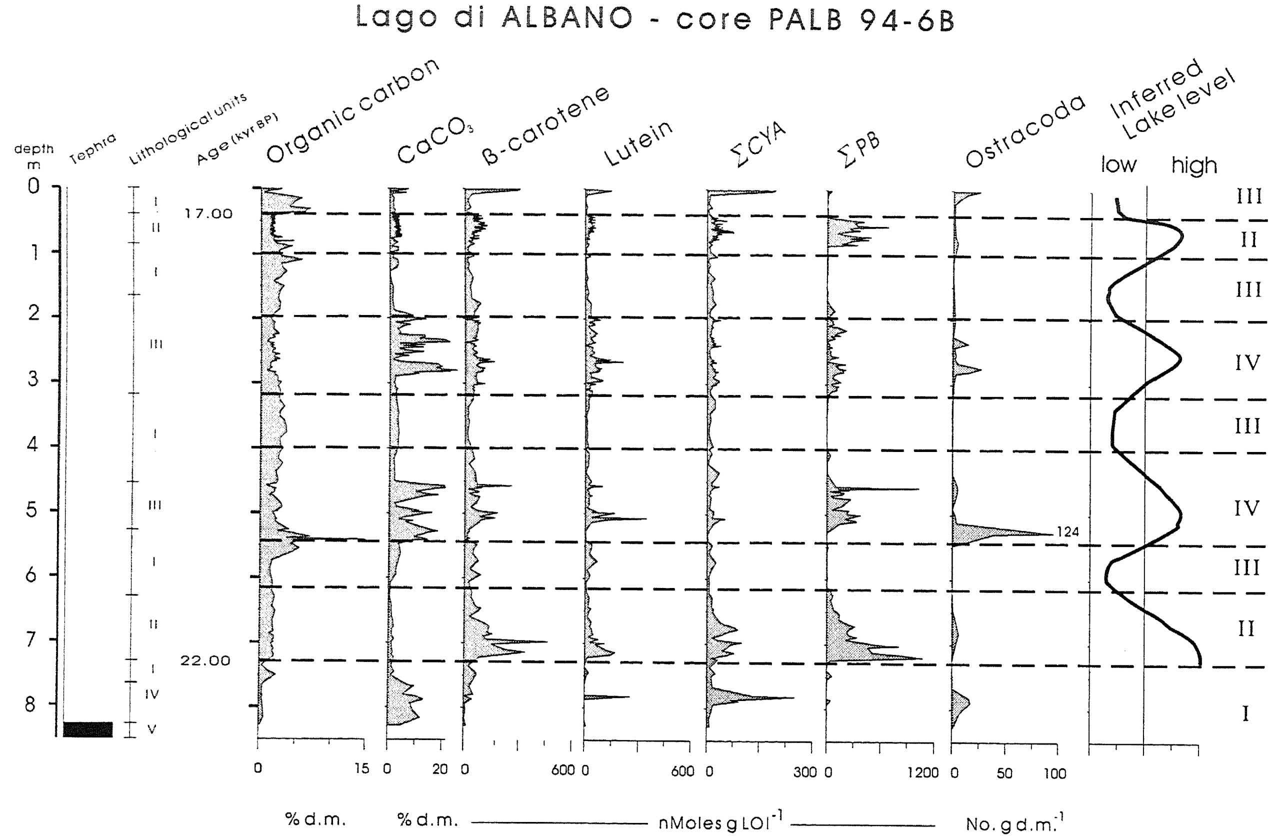

Fig. 3 - Depth profiles of some geochemical parameters, pigments and ostracod remains in a sublittoral core from Lago di Albano. ΣCYA and ΣPB = sum of the pigments belonging to cyanobacteria and photosynthetic bacteria, respectively. The main lithological units, a basal tephra deposit, inferred lake level fluctuations and four biostratigrapic zones are also indicated. All the ages are given in calibrated years (see text). d.m.= dry mass; LOI = loss on ignition.

Distribuzione di alcuni parametri geochimici, di pigmenti e di resti fossili di ostracodi in una carota sublitorale del Lago di Albano. ΣCYA e ΣPB = sommatoria rispettivamente dei pigmenti appartenenti ai cianobatteri e ai batteri fotosintetici. Sono inoltre indicate le principali unità litologiche della carota, il deposito di tefra basale e le quattro zone biostratigrafiche, nonché sono state ricostruite le principali variazioni di livello delle acque lacustri. Le età sono in anni calibrati (vedi testo). d.m.= dry mass; *LOI* = loss on ignition.

(Chondrogianni *et al.*, 1996).

Core PALB 94 -6B - ^{14}C AMS analysis was performed on bulk sediments and aquatic moss remains because of the lack of any terrestrial macrofossil. Nevertheless, no reliable radiometric dating was obtained. The reason for this could be related to volcanic gases and to the well-known hard-water effect, which generally induce dating ageing (Watts, 1985; Alessio *et al.*, 1986; Robinson, 1994).

Two calibrated ages (cf. Fig. 3) were obtained through a correlation with core PALB 94-1E, based on diatom distribution and magnetic susceptibility profiles. Given the similar trends, it was found that top and bottom of PALB 94-6B correspond to the depths of ca. 700 cm and 1000-1050 cm in core PALB 94-1E, respectively. This would mean that 800 cm of core PALB 94-6B are represented by about 300 cm in core PALB 94-1E (cf. Fig. 5), spanning a time interval from ca. 17 cal. ka BP to 23 cal. ka BP. This 6 ka time interval was also present in core PALB 94-6B, as given by the varve counts (see below) (Chondrogianni *et al.*, 1995).

Core PNEM 94 -1B - No ^{14}C dates were available for this core due to the lack of any terrestrial woody remains. However, the calibrated ^{14}C ages reported for this core (cf. Fig. 4) were obtained from a number of realistic estimations on the basis of correlations with (i) whole core magnetic data (Oldfield, 1995), (ii) the Avellino tephra marker, and (iii) pollen diagrams from Lago di Albano (C.A. Accorsi, pers. comm.), Lago di Monticchio (Watts *et al.*, 1996) and Valle di Castiglione (Follieri *et al.*, 1988; 1993).

3.2 Lago di Albano

Core PALB94-1E (core length of 1387.5 cm) - In this core, the following 7 major lithological units were distinguished (Chondrogianni *et al.*, 1996; Fig. 2): (I) olive grey silts, rich in organic matter; (II) dark olive grey silts, interbedded with diatom layers and indistinct laminated intervals, rich in organic matter; (III) dark olive-grey to olive-black muds; (IV), light olive grey spotted muds; (V) yellowish grey spotted muds, rich in calcite and with abundant moss remains; (VI) well-laminated sediments (varves) composed of alternating whitish calcite layers and olive grey detrital silts. The basal tephra layer of this core extended from 1349 cm to 1387.5 cm (unit VII). The aforementioned dating indicates that the Holocene sequence (ca.11.2 ka BP) is contained in the uppermost

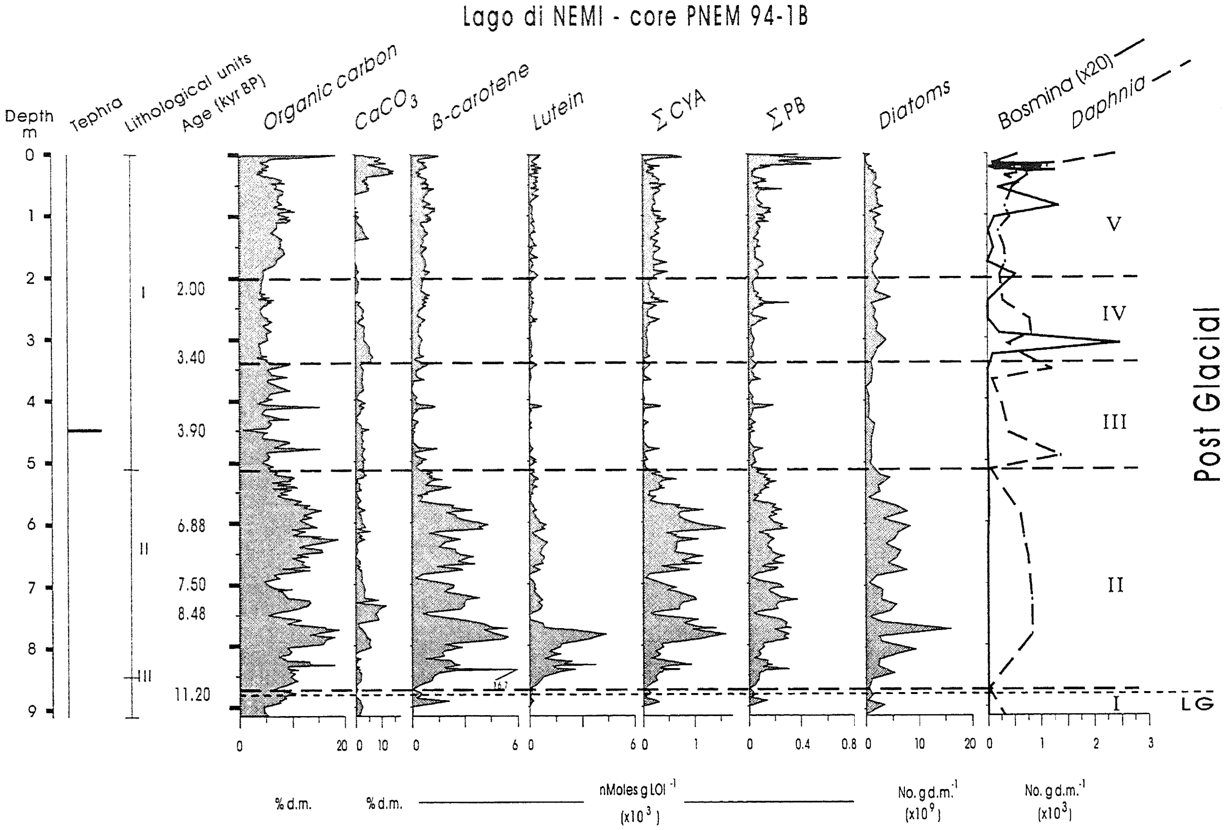

Fig. 4 - Depth profiles of some geochemical parameters, pigments, diatoms and cladocera in a core from Lago di Nemi. ΣCYA and ΣPB = sum of the pigments belonging to cyanobacteria and photosynthetic bacteria, respectively. The main lithological units, Avellino tephra deposit and five biostratigraphic zones are also indicated. All the ages are given in calibrated years (see text). d.m.= dry mass; LOI = loss on ignition.

Distribuzione di alcuni parametri geochimici, di pigmenti e di resti fossili di diatomee e di cladoceri in una carota del Lago di Nemi. ΣCYA e ΣPB = sommatoria rispettivamente dei pigmenti appartenenti ai cianobatteri e ai batteri fotosintetici. Sono inoltre indicate le principali unità litologiche della carota, lo strato di tefra denominato Avellino e le cinque zone biostratigrafiche. Le età sono in anni calibrati (vedi testo). d.m.= dry mass; *LOI* = loss on ignition.

560 cm (Fig. 2).

The sediments accumulated during the glacial period forming the 1387.5 to 720 cm interval generally contain low concentrations of pigments (zones I-III; Fig. 2). This suggests that during this period Lago di Albano remained largely oligotrophic, and that generalised oxic conditions prevailed both in the water column and at the bottom mud surface for much of the time. This is also indicated by the presence of the chironomid *Micropsectra,* a cold, stenotherm, oligotrophic taxon (Lami *et al.*, 1996).

However, a few notable exceptions in the lowest 350 cm of the core were identified (zone II). In this interval, there are occasional intense phytoplankton and sulphur photosynthetic bacteria blooms and all the indicators of lake productivity (*e.g.* β-carotene and ostracods; see Fig. 2; Belis *et al.*, 1996; total carotenoids and chlorophylls, Guilizzoni *et al.*, 1996a; diatoms and chironomids, Lami *et al.*, 1996) show sharp peaks. At least five rapid events can be recognized: from 1297 to 1282 cm; from 1227 to 1216 cm; from 1139 to 1129 cm; from 1079 to 1055 cm; and from 1020 to 1005 cm (cf. Fig. 5). Ostracod remains are abundant in zone II (Fig. 2), with fluctuations mainly associated with the presence of carbonate, oxygenated waters and oscillation in lake water level (Guilizzoni *et al.*, 1996a; Belis *et al.*, 1996). By assuming constant sedimentation rate between 17 ka BP and 25-30 ka BP, we calculated a sedimentation rate of 0.048-0.052 cm yr^{-1} for this glacial period. Consequently, the average duration of these oscillations ranged between ca. 200 and 500 years.

Biological activity began to increase during the Late Glacial with a break which is probably associated with the Younger Dryas (Fig. 2; zone IV).

Intense, fluctuating algal blooms during the Holocene can be identified between the 530 cm and 380 cm stratigraphic intervals (zone V), which represent cycles of ca. 700-200 years (sedimentation rates ranged from 0.050 to 0.091 cm yr^{-1}). From about the Subboreal and, in particular, from 170 cm (Roman period) onward (zone VI; Fig. 2), an increased trophy was also inferred (cf. Fig. 5). A higher primary productivity rate in these periods caused more oxygen-deficient conditions in the bottom waters, leading to pigment preservation. Within these intervals the carotenoids belonging to green (isorenieratene) and purple (okenone) sulphur photosynthetic bacteria are abundant (Lami *et al.*, 1995; Guilizzoni *et al.*, 1996a). These pigments, and especially the green ones, are present in almost all the samples analysed, except in intervals from 1129 to 1197 cm, 1237 to 1267 cm, and from 1297 to 1373 cm. The organisms producing these pigments proliferate under strictly anoxic conditions and with the presence of H_2S in the lake waters.

The most abundant carotenoids in the upper part of the core (from 500 cm to 0 cm) are lutein (Chlorophyceae), zeaxanthin and echinenone (cyanobacteria), and diadinoxanthin (diatoms).

The sharp change of the biological remains at about 400 cm can be interpreted as the first discernable impact of human activity in the catchment. This is shown by an abrupt decline in pigment concentrations (Fig. 2), a sudden increase in erosion (Calanchi *et al.*, 1996b), the end of the predominance of reducing conditions (van der Post *et al.*, 1995), a shift in diatom assemblages (Lami *et al.*, 1996) and an increase in pollen from non-arboreal species (*e.g.* Gramineae; Oldfield, 1995; C.A. Accorsi, 1996, pers. comm.). The marked, persistent decrease in chrysophycean cyst concentrations observed at this depth can also be interpreted as indicative of human disturbance. A sharp decrease in chydorids, *Daphnia* and in the ratio *Daphnia/Daphnia+Bosmina* also occurs. The anthropogenic impact seems to have been particularly important during the Subboreal (ca. 320 cm), when there was a shift in the cladoceran population from a community dominated by *Daphnia* to one dominated by *Bosmina* (Manca *et al.*, 1996). As observed in other lakes, this shift is consistent with the increase in non-arboreal pollen and is related to forest clearance (Kerfoot, 1974). Other signals of human impact (peak of *Bosmina;* generally increased concentration of pigments) on the lake ecosystem are recorded at ca. 170 cm (Roman period), and in the uppermost layers (zone VII).

Core PALB94-6B (core length of 840 cm) - In this core that was collected at the shallowest site (30 m), 5 major lithological units were distinguished (Chondrogianni *et al.*, 1996; Fig. 3): (I) massive olive-grey silts, intercalated with thick beds of well-preserved mosses; (II) olive-grey silts intercalated with brownish coloured laminated muds; (III) yellowish-grey laminated carbonates intercalated with massive olive-grey, organic-rich silts and coloured, laminated muds; (IV) carboniferous detrital sands; (V) a thick (33 cm) volcanoclastic layer (not yet dated), similar to that occurring at the bottom of core PALB 94-1E, which identifies the base of this core. The first three lithological units alternate to form four major cycles with unit (I) overlaying unit (II) or unit (III) down to ca. 760 cm depth. These cycles have a duration of about 500 to 2000 years. Optical microscope analyses of these sediments put to evidence that the laminations are annual varves.

This coring site is peculiar because all the sediments (except the uppermost 8.5 cm) predate the Holocene and identify "glacial" intervals characterized by largely non-forested, steppe-like vegetation (van der Kaars *et al.*, 1995). Throughout the sequence four, cyclic, biozones with high pigment contents (zones II, IV; Fig. 3), which could be related to high primary productivity, are clearly defined at 40 to 100 cm; 195 to 320 cm; 400 to 540 cm; and at 615 to 720cm (Figs. 3 and 5). However, within these major intervals, there are several rapid oscillations in the intensity of the productivity, probably related to unstable conditions.

These peaks in pigments (zones II, IV) do not correlate with the presence of abundant moss remains (see below; zone III) and are probably related to planktonic or benthic algae development as well as to the abundance of endogenic $CaCO_3$ (bio-induced precipitation), the presence of well-laminated sediments, the $\delta^{13}C$ high positive values (Chondrogianni *et al.*, 1995), the magnetic data (Oldfield, 1995), the presence of *Stephanodiscus* spp. (Lami *et al.*, 1996) and to ostracod abundance (Belis *et al.*, 1996). It is probable that zone II corresponds to warmer periods and relatively higher water levels (Chondrogianni *et al.*, 1996).

Both mineralogical (Calanchi, 1996b), and lithological (Chondrogianni *et al.*, 1995) evidence indicate that the calcite present in zone I is of inorganic origin (Fig. 3). The development of mosses (zone III, dominated by *Drepanocladus aduncus* and *Drepanocladus* spp.; C. Andreis and R. Ochyra, pers. comm.) is probably associated with a colder climate and very low water levels.

Because of the shallower site of core PALB 94-6B, it is possible that different factors and processes have tuned pigment deposition and fossil abundance. Amongst these, lowering of the water levels would induce a re-oxygenation of the lake bottom (Sanger, 1988; Leavitt, 1993). In this case, intense pigment destruction could occur at a time when productivity may be high.

With respect to the pigments, the most distinctive feature of this pre-Holocene sedimentary sequence is the presence of a number of cyanobacteria pigments (zones I and II), as well as several groups of purple sulphur and purple non-sulphur photosynthetic bacteria (zones II, IV; Fig. 3) (Guilizzoni *et al.*, 1996b; Lami *et al.*, 1996; Fig. 3). In contrast with the core recovered at –70 m water depth (PALB94-1E), these sediments contain OH-spheroidene and rhodopinal carotenoids (not shown) that belong to the Spirilloxanthin-series (*e.g. Rhodopseudomonas* and *Thiodictyon,* respectively). The carotenoids okenone (*Chromatium* sp.) and isorenieratene (*e.g. Chlorobium* sp.) (not shown) are also present at very high concentrations (much higher than pigments from core PALB 94-1E and cores from Lago di Nemi), and belong to the purple (Chromatiaceae) and green (Chlorobiaceae) sulphur photosynthetic bacteria, respectively (Guilizzoni *et al.*, 1996b).

Strictly anaerobic conditions were found in four major intervals (as shown in Fig. 3 by the sum of photosynthetic bacteria pigments; *i.e.*: 720-615 cm; 540-400 cm; 320-195 cm; 100-40 cm, zones II, IV), whereas the existence of spheroidene (not shown) with no spheroidenone (red carotenoid produced as soon as the smallest amount of O_2 is present) may be presumed to indicate a prolonged period of meromixis in a shallow environment (Guilizzoni *et al.*,1996b; Züllig, 1985).

In addition to the bacteria, the chlorophyceae (lutein) and cyanobacteria (echinenone) are the most important taxa during periods of high productivity levels, and at the bottom of the core (Fig. 3).

In the intervals which record strong anoxia, ostracod remains are less abundant or absent. When present, these

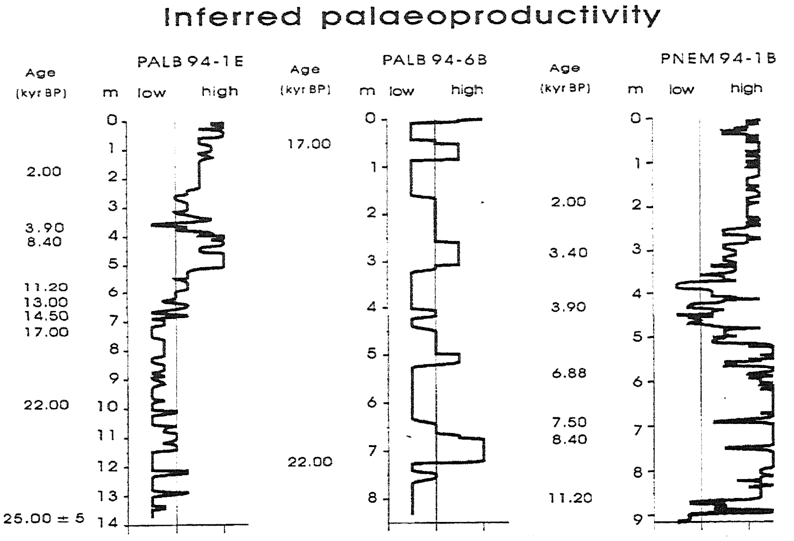

Fig. 5 - Inferred primary productivity in two cores from Lago di Albano (PALB 94-1E and PALB 94-6B) and in a core from Lago di Nemi (PNEM 94-1B). All the ages are given in calibrated years (see text).

Ricostruzione delle fluttuazioni di produttività primaria in due carote di sedimento del Lago di Albano (PALB 94-1E e PALB 94-6B) e in una carota del Lago di Nemi (PNEM 94-1B). Le età sono in anni calibrati (vedi testo).

fossil remains are very decalcified (note that, in general, ostracod peaks do not match bacteria peaks, Fig. 3). The absence of this taxon in certain intervals could be due either to a very low concentration of calcite, or to unfavourable conditions for valve preservation (Belis *et al.*, 1996).

3.3 Lago di Nemi

Core PNEM94-1B (core length of 915 cm) - The following three lithological units were distinguished (Fig. 4): (I) diatom beds and laminae intercalated with massive olive-grey to olive-black muds and sections with greenish-brownish coloured laminated muds; (II) distinctly laminated muds intercalated with diatom beds and laminae and massive olive-black muds; (III) massive olive-black to dusky-brown muds.

The sediment sequence of this core spans the last 11.8 ka, on the basis of pollen stratigraphy (C.A. Accorsi, 1996, pers. comm.) and of the comparison of parallel magnetic susceptibility scans with one of the dated cores from Lago di Albano (Oldfield, 1995). In any case, the ages reported in Figure 4 are reliable because of the strong correlations among cores (cf. chronology section).

From the pigment and diatom analyses, six major biostratigraphic zones of different productivity have been distinguished (Fig. 4).

Zone I - It represents a short pre-Holocene period at the base of the core, with a low level of productivity.

Zone II - Two phases can be recognised: (1) from 870 cm to 785 cm, in which an increasing trend of pigment and diatom remain concentrations, favoured by the ameliorated climatic conditions during the early Holocene, is evident. The calculated sedimentation rate is 0.065 cm yr^{-1}; (2) from 785 cm to 510 cm: this interval is characterized by a high trophic state with cyclic pigment fluctuations. Abundant pigments of cyanobacteria (*e.g.* echinenone, myxoxantophyll, oscillaxanthin), green algae (lutein), and sulphur photosynthetic bacteria (okenone, OH-spheroidene & isorenieratene) are present. A high trophic level during this interval is also indicated by the presence of the eutrophic diatom *Stephanodiscus hantzschii,* with predominance of *Daphnia* (Manca *et al.*, 1996). In this phase, human impact in the catchment seems to be recorded in the pollen diagram (C.A. Accorsi, 1996, pers. comm.). Estimated sedimentation rate is 0.066 cm yr^{-1}.

Zone III (from 510 cm to 330 cm): - It is a period of generally lower productivity, reduced concentrations of pigments, increase of Gramineae (C.A. Accorsi, 1996, pers. comm.). A major change in pigment concentrations occur at ca. 320 cm (human impact during the Subboreal), together with a shift from a *Daphnia*-dominated to a *Bosmina*-dominated zooplankton community (Manca *et al.*, 1996). This interval has an average sedimentation rate of 0.084 cm yr^{-1}.

Zone IV (from 330 cm to 200 cm) - Productivity is low. When compared with the previous zone, an increase in both cyanobacteria and total algal community characterizes this zone. Again a *Bosmina* phase is recognizable (peak at 200 cm with a decrease of trees) at this level. *Cannabis* has been detected (C.A. Accorsi, 1996, pers. comm.). The top of this zone corresponds with the Roman period. Sedimentation rates ranges from 0.060 cm yr^{-1} to 0.120 cm yr^{-1}.

Zone V (from 200 cm to ground surface) - An increase of productivity is observed with predominance of cyanobacteria, *Stephanodiscus* and *Bosmina* in recent times. The average sedimentation rate from an initial value of about 0.100 cm yr^{-1} has increased to 0.38-0.60 cm yr^{-1} during the present century as inferred by varve counting (Masaferro *et al.*, 1993).

In summary, the pigment concentration at Lago di Nemi, particularly in the sediment layers of zone II, is 2 to 5 times higher than that of Lago di Albano.

4. CONCLUSIONS

On the basis of the presented proxy-data, we can attempt to interpret the palaeoenvironmental evolution. However, a more comprehensive reconstruction of environmental changes in these lakes for the late Quaternary in Central Italy will be obtained through the integration of data from the different PALICLAS research groups.

Several warm events seem to have occurred throughout the glacial period, by judging from the Lago di Albano cores. These are identified by a fairly high lake productivity (Fig. 5) characterized by temporarily anoxic phases during the year, alternating with cold periods of low water level, and oligotrophic conditions. These main oscillations had an estimated cycle duration of ca. 200-500 years. Within these major cycles, further distinct fluctuations can be distinguished. As observed in the pollen profiles of cores drilled in Lago di Albano (van der Kaars *et al.*, 1995) and — southwards — in Lago Grande di Monticchio (Huntley *et al.*, 1996), and on the basis of a study on mammal changes in southern Italy (Abbazzi *et al.*,1996), these climatic oscillations occurred in a wide area. According to Huntley *et al.* (1996) and Oldfield (1995), they can be correlated with North Atlantic and Greenland palaeoenvironmental records.

High productivity levels appear during the first half of the Holocene, a period in which inferred primary productivity reached values of very eutrophic lakes (Fig. 5). Oscillations in lake productivity can be compared with the similar, important vegetational changes reported from the Valle di Castiglione and Lagaccione in Central Italy (Magri & Follieri, 1989) and Lago Grande di Monticchio (Huntley *et al.*, 1996). More recent human impact is detected for the Mesolithic, the Suboreal and Roman times. These anthropogenic impacts yielded a lowered productivity in the lake (*e.g.* during the Mesolithic) and when (*e.g.* during Roman times) the lake was subjected to nutrient enrichment, the effect was less marked — except perhaps in very recent times — than that consequent to the natural impact noted during the early Holocene.

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