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Late Pleistocene and Holocene pollen stratigraphy at Lago di Vico, central Italy

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Abstract. A new pollen record from Lago di Vico (core V1) provides fundamental new information towards reconstruction of flora and vegetation history in central Italy during the last 90 000 years. The chronological framework is secured by seventeen AMS ^{14}C dates, one $^{40}Ar/^{39}Ar$ date and tephra analyses. At the base of the pollen record, i.e. shortly after the $^{40}Ar/^{39}Ar$ date 87 000± 7000 B.P., three phases with significant expansion of trees are recorded in close succession. These forest phases, which stratigraphically correspond to St Germain II (and Ognon?) and precede pleniglacial steppe vegetation, are designated by the local names Etruria I, Etruria II and Etruria III. During the pleniglacial, a number of fluctuations of angiosperm mesophilous trees suggest the presence of tree refugia in the area. The lowest pollen concentration values are recorded at ca. 22 000 B.P. which corresponds with other pollen records from the region. The late-glacial is characterized by an expansion in the arboreal pollen curves that is less pronounced, however, than in other pollen profiles from Italy. The Holocene part of the profile is consistently dominated by deciduous oak pollen. No major changes in arboreal pollen composition are recorded but several marked and sudden declines of the tree pollen concentration suggest that the forest cover underwent dramatic changes. Clear evidence for human impact is recorded only when cultivated crops became important which dates to ca. 2630±95 B.P.

Key words: Crater lake – Pollen analysis – Late Pleistocene – Holocene – Central Italy

Introduction

The present study is part of programme of palynological investigations in central Italy, and particularly of the Lazio region, carried out by the Laboratory of Palaeobotany and Palynology of Rome University "La Sapienza", with the aim of obtaining and integrating palaeoenvironmental data from a region that is rich in Quaternary stratigraphical deposits and at the same time particularly complex and diversified from the environmental viewpoint (Follieri et al. 1993). For this purpose, and following the pilot investigation at Valle di Castiglione (Follieri et al. 1988, 1989), the study of several long pollen records has been undertaken under the supervision of M. Follieri. The sites investigated are as follows (from north to south; Fig. 1): Lago di Mezzano (Sadori, unpublished), Lagaccione near Lago di Bolsena (Magri 1999), Lago Lungo near Rieti (Sadori 1994), Lago di Vico (this paper), Stracciacappa (Giardini 1993, Giardini, unpublished), Valle di Baccano (Ciuffarella 1996) near Lago di Bracciano, Piana del Fucino (Folleri et al. 1986a) and Piana Pontina (Sadori 1999).

The first palynological investigations at Lago di Vico were carried out by Frank (1969) from a core presumably collected at the northern lake border. At the time it was written, that paper represented a significant advance in late Quaternary vegetation studies relating to central Italy. More recently a new core, which does not include the Holocene, was collected outside the lake, about 300 m from the present shoreline (Francus et al. 1993; Leroy et al. 1996; holes 90, Fig. 1). This core was the subject of multidisciplinary investigations, but has only two radiocarbon dates and a detailed pollen profile was not published.

The present paper presents new data and interpretations based on investigations of a new coring, core V1, from within the present-day lake. The core contains Holocene sediments that extend to recent times and the results include an independent chronology constructed on the basis of radiocarbon and $^{40}Ar/^{39}Ar$ dates and tephra analyses.

The site

The Vico volcano is a strato-volcano with a central collapse caldera, at present occupied by the homonymous lake. The activity of the Vico volcanic district occurred in four phases, starting around 900 ka (Sollevanti 1983)

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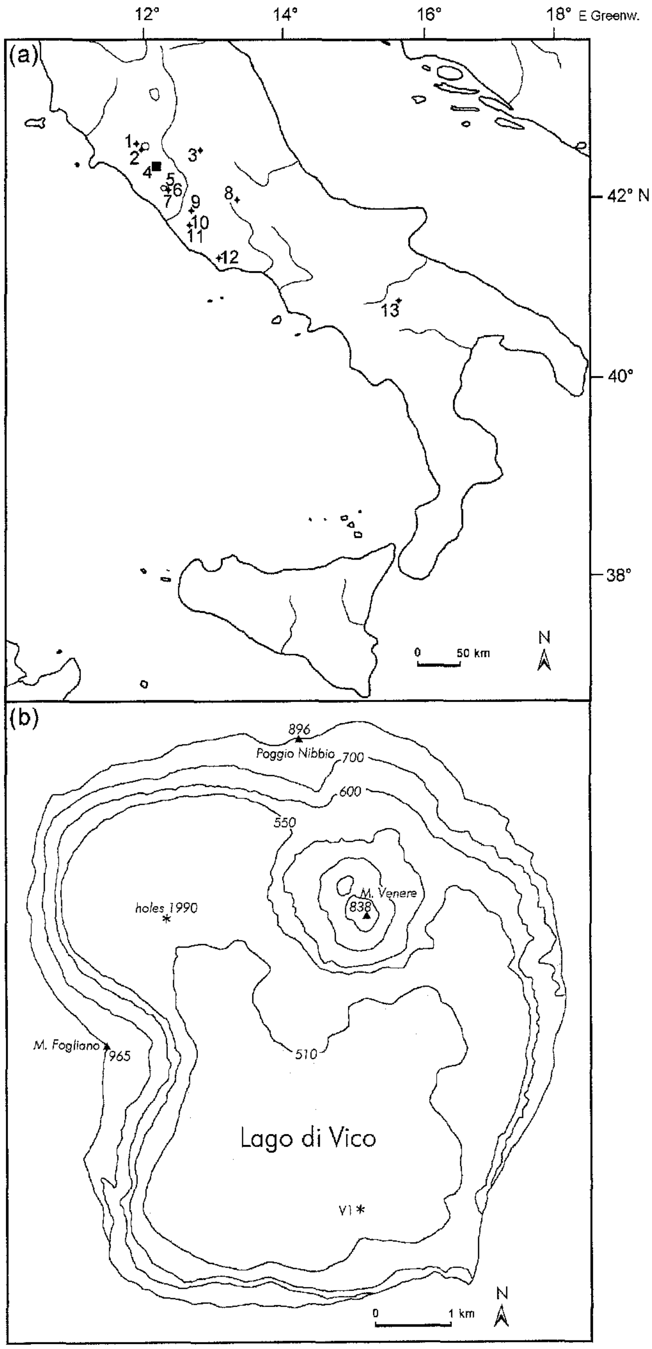


Fig. 1. a Map showing location of the Italian pollen sites mentioned in the text. *1*, Lago di Mezzano; *2*, Lagaccione; *3*, Lago Lungo di Rieti; *4*, Lago di Vico; *5*, Stracciacappa; *6*, Valle di Baccano; *7*, Lago di Martignano; *8*, Piana del Fucino; *9*, Valle di Castiglione; *10*, Lago Albano; *11*, Lago di Nemi; *12*, Piana Pontina – Migliara 47; *13*, Lago Grande di Monticchio.
b Detailed map of Lago di Vico and enclosing crater. The location of core V1 (present paper) and 1990 cores ("holes 1990" in Leroy et al. 1996) are indicated. The shaded area corresponds to the present lake

and ending about 90 ka (Bertagnini et al. 1993), when a cone, Monte Venere, was produced inside the caldera itself. The caldera containing the lake formed during a period of mainly explosive activity, in the period 200-150 ka (Bertagnini and Sbrana 1986). Two K/Ar determinations for the Monte Venere lavas are available. These give dates of 95±10 ka (Laurenzi and Villa 1985) and 85 ka (Palacin 1985), respectively.

Lago di Vico (510 m asl; 42°19'N, 12°10'E) has a maximum depth of about 50 m, a maximum diameter of ca. 5 km, and an area of about 12 km^2. The catchment area (ca. 40 km^2), exclusively formed by volcanic rocks, is delimited by the edge of the caldera which reaches highest elevations at Monte Fogliano (965 m asl) and Poggio Nibbio (896 m asl). The present-day lake level is conditioned by an artificial underground outflow at the south-east lake border. It is not sure if a first lowering of lake levels was achieved by the Romans in connection with the Via Cimina, which runs adjacent to the lake, but it is historically documented that a tunnel was excavated in the second half of the sixteenth century by the Farnese family (Fagliari Zeni Buchicchio 1992). Considerable fluctuations of the lake level are indicated by clear traces of three orders of terraces delimited by falaises at 535-540 m, 525 m and 513 m asl, respectively, that are visible along the inner perimeter of the caldera and on the slopes of Monte Venere (Giraudi and Narcisi 1994). Moreover, a bathymetric survey of the lake has revealed several underwater artificial drainage channels (Barbanti 1969).

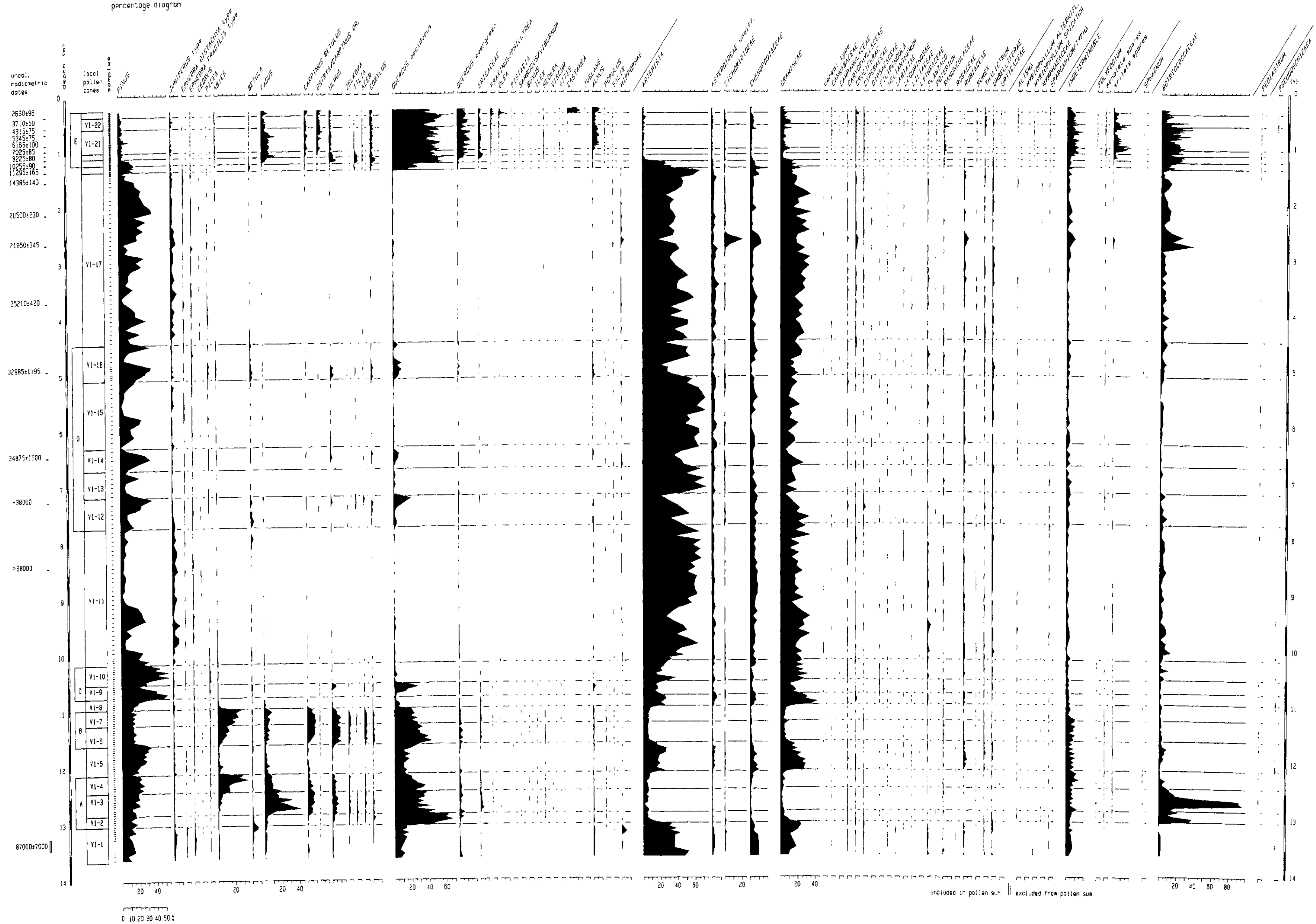
Lago di Vico lies in a region with a complex and varied climate that is determined by the Tyrrhenian Sea to the west (ca. 40 km), the Cimini mountains to the north, the Tiber valley to the east and by the water body of the lake inside the caldera which results in permanently wet conditions and influences both soils and vegetation. The meteorological station nearest to the lake is at Ronciglione, a small town that lies south of the caldera at 441 m asl. Here the mean annual precipitation is ca. 1400 mm (40-year average) and the mean annual temperature is 13.6°C. A linear regression of precipitation versus elevation gives ca. 2000 mm annual precipitation at Monte Fogliano (Raglione 1990). This high precipitation rate prompted Blasi (1994) to classify the Vico caldera as a lower hyperhumid ombrotype and submontane thermotype phytoclimate, which is characterized by high mean annual precipitation (1400-1600 mm), frequent summer showers (170-200 mm), no summer aridity, cold winters, mean minimum temperatures of the coldest month in the range 0.1-1.3°C and mean annual temperature in the range 12-13.6°C.

Andisols are the most frequent soil type on the leucitic lavas of the northern and western slopes of the caldera and on Monte Venere. They have a dark and rather thick epipedon, with high levels of humus and nutrients and a high water retention capacity that assures water availability even in summertime (Lulli et al. 1986). These soils are an important factor influencing the widespread diffusion of forest which cover, even at present, nearly half of the inner slopes of the caldera.

The number of identified plant species in the area exceeds 750 which is largely attributable to the biodiversity of the well preserved forest and aquatic coenoses. The forest vegetation of the caldera can be classified as follows: a) monospecific beechwood on the upper part of Monte Fogliano; b) multistratified thermophilous beech-

LAGO DI VICO (VI) - 510 m

percentage diagram



wood mixed with mesophilous deciduous oakwoods mainly on the southern and western slopes and on Monte Venere; c) mixed oakwood dominated by *Quercus cerris*, mainly on the northern slopes of the caldera; d) chestnut (*Castanea sativa*) coppices on the eastern slopes; e) extrazonal populations of *Quercus ilex* and other Mediterranean elements (Scoppola et al. 1990; Scoppola 1992; Scagliusi 1996). Within these forest types, the intensity of the human impact is strong in the chestnut and oak coppices, while it is low or very low in the remaining areas. In the lowest, flat part of the caldera, near the lake, there are plantations of hazel that date mainly to the last thirty years (Castagnoli 1995). In the travel guide by Abbate (1890), that records 363 species around Lago di Vico, *Corylus* is not mentioned, while a number of evergreen species not found at present, such as *Laurus nobilis*, are listed. Lago di Vico is an area where the best examples of palustrine and aquatic vegetation of the Lazio region occur, with hydrophytic coenoses being numerous and varied even after human impact has strongly influenced the natural dynamic succession characteristic of these habitats (Scoppola and Anitori 1996).

Human activity in the caldera is archaeologically documented from Neolithic times onwards. A series of ten radiocarbon dates, with a range of 8000±160 B.P. to 4390±50 B.P. from a votive cave on Monte Venere indicates that the cave was frequented during much of the Neolithic (Delpino and Fugazzola Delpino 1975-80, 1987; Alessio et al. 1991). Evidence of Bronze Age occupations is found on the northern slope of Monte Venere and on Monte Fogliano (Fugazzola Delpino and Delpino 1979) and remnants of Etruscan and Roman cultures are widespread in the area.

Materials and methods

In April 1992 two pairs of cores were collected from Lago di Vico at water depths of between 19.3 and 22.6 m using a modified Livingstone piston corer (Fig. 1). Core V1, which is the subject matter of this paper, is 15.2-m long and was taken in a depth of 22.6 m in the southern part of the lake. Prior to coring the bathymetry was investigated by R.B. Hansen using sonar scanning. The collected cores, 8 cm in diameter, were split along their length, photographed and visually inspected before subsampling for geochemical, sedimentological, mineralogical and tephrochronological analyses (Giraudi and Narcisi 1994), microstratigraphical investigations (J.F.W. Negendank's team), measurements of magnetic properties (K.M. Creer's team), $^{40}Ar/^{39}Ar$ dating (M. Laurenzi), radiocarbon AMS dating and pollen analysis.

The lithostratigraphy of the sequence, which is based on the macroscopic observation of the sediments, is summarised in Table 1. Organic carbon content was determined by potassium dichromate titration (Giraudi and Narcisi 1994). There are two main peaks with high organic content (up to 8%) between 13-12 m, and 1.3 m and core top, respectively. Lesser peaks occur between 11.75-11.00 m, 9.95-9.55 m, at ca. 9.15 m, between 8.55-8.15 m, and at 7.55 m and 4.95 m (Giraudi and Narcisi 1994). The relatively high values between ca. 10-8 m may be related to the abundance of bryophyte macroremains at the same depths.

Seventeen AMS ^{14}C dates were obtained from bulk sediment, each associated with a specific horizon identified on the basis of the pollen analytical results (Table 2). All dates are

Table 1. Lithostratigraphy of core V1 at Lago di Vico (Giraudi and Narcisi 1994)

Depth (m)	Sediment description
0 - 0.63	Black organic muds with very high water content in the uppermost 0.25 m
0.63 - 0.68	Greyish-brown mud
0.68 - 1.20	Black organic mud
1.20 - 1.35	Dark grey non-calcareous mud
1.35 - 6.05	Grey and brownish non-calcareous mud
6.05 - 7.92	Grey and brownish non-calcareous mud, occasionally with bryophyte remains; at 7.26-7.27 m there is an inversely graded sandy layer
7.92 - 10.95	Grey non-calcareous mud with bryophyte remains, at times with traces of bedding; at 9.60 m there is a sandy mm-thick layer
10.95 - 11.81	Dark organic mud, weakly bedded, at times with bryophyte remains; at 10.77 m and 10.14 m there are sandy mm-thick layers
11.81 - 12.17	Greenish mud
12.17 - 13.01	Black organic mud; at 12.70-12.73 a sandy layer is present
13.01 - 13.24	Finely laminated non-calcareous sediments
13.24 - 13.46	Lapilli tephra
13.46 - 13.65	Finely laminated non-calcareous sediments
13.65 - 15.20	Weakly stratified volcanic sands and sandy silts

internally consistent. A $^{40}Ar/^{39}Ar$ date, obtained from the lapilli-tephra layer at 13.46-13.24 m, gave an age of 87±7 ka (M. Laurenzi, personal communication).

Samples for pollen analysis was carried out at varying sampling intervals (2-cm intervals: 0.28-1.40 m; 4-cm intervals: 4.80-5.04 m, and 10-13.24 m; 8-cm intervals; 1.40-4.80 m and 5.04-10.00 m; between 13.24-15.20 m only three samples of silty sediments, from 13.47 m, 13.53 m and 13.61 m, contained enough pollen for counting purposes). In all, 253 samples were analyzed. Samples of ca. 0.5 g dry sediment was treated with HCl (37%), HF (40%) and hot NaOH (10%). Pollen concentration values were obtained by adding tablets with a known number of *Lycopodium* spores to a specific weight of sediment.

Pollen preservation was generally good. The number of indeterminable (degraded, corroded and broken) grains exceeded 10% of the pollen sum (PS) in only a few samples. A mean PS of 626 and 345 terrestrial pollen were achieved in 150 samples with arboreal pollen (AP) at least 50% and 103 samples with AP less than 50%, respectively. A preliminary pollen diagram, drawn after ca. 300 pollen per sample were counted for the whole sequence, although showing all the main trends, was much more spiky than the final diagram. This suggests that a count of at least 500 AP in forested periods is necessary to reduce statistical errors (Berglund and Ralska-Jasiewiczowa 1986). In all, 80 pollen taxa were identified, excluding spores. The number of pollen taxa per sample is linearly correlated with the AP percentages (correlation coefficient, 0.80), so that in samples with at least 50% AP, the number of pollen taxa is never less than 23, whereas in samples with less than 50% AP, the number of pollen taxa may be as low as 11.

Quercus deciduous includes both *Quercus robur*-type and *Q. cerris*-type pollen. As concerns *Carpinus*, two pollen types have been distinguished, namely *Carpinus betulus* and

Table 2. AMS ^{14}C dates from Lago di Vico (core V1)

Depth (m)	Age (B.P.)	^{14}C Lab. No. (Ua-)
0.36	2630 ± 95	3852
0.56	3710 ± 50	3853
0.66	4315 ± 75	3370
0.86	5345 ± 75	3854
0.96	6165 ± 100	3371
1.03	7025 ± 85	3855
1.11	8225 ± 80	11963
1.21	10 255 ± 90	3856
1.34	11 295 ± 165	3372
1.52	14 385 ± 140	3857
2.10	20 500 ± 230	3858
2.64	21 950 ± 345	3373
3.68	25 210 ± 420	3859
4.90	32 985 + 1195/-1040	3374
6.44	34 875 + 1500/-1265	3375
7.23	>38 000	3860
8.41	>38 000	3861

Ostrya/Carpinus orientalis. *Fraxinus excelsior*, *Fraxinus ornus* and *Phillyrea* have been combined in the *Fraxinus* curve in order to simplify the pollen diagram. Also, the individual curves in question have low values and are broadly similar.

Results

Pollen percentage and concentration diagrams for the whole core and for the last 15 000 years are presented in Figs. 2-4 and Fig. 5, respectively. Local pollen zones are defined on the basis of visual inspection of the diagrams and the numbering system includes the prefix V1 to designate the core. Superzones, defined by Tzedakis (1994) as composed of several stratigraphically contiguous pollen assemblage zones sharing common biostratigraphical features and forming an identifiable cluster, have been used to group zones with similar AP percentages and concentrations. During non-forested periods it is difficult to decide if the fluctuations in *Pinus*, *Artemisia*, *Gramineae* and other herbaceous taxa are significant in terms of vegetation changes. We have chosen not to detail the zonation to that level.

Zone V1-1: 13.61-13.02 m. This zone is characterized by high values of NAP, particularly *Artemisia* (30-50%), Gramineae (15-20%) and *Chenopodiaceae* (5-10%). The representation of *Pinus* and deciduous *Quercus*, the most abundant trees, lie between 7-15%. Towards the top of the zone slight expansions, initially involving *Hippophae* and then *Betula*, both peaking at 7%, are recorded. Other tree pollen, e.g. *Juniperus*, *Fagus*, *Abies*, *Carpinus betulus*, *Ulmus*, *Corylus* and *Alnus*, are present with low frequencies. Total pollen concentrations vary between 6000-100 000 grains/g, with *Artemisia* and Gramineae having the highest values. The mean number of pollen taxa is 27. There are no pollen spectra available in the interval 13.46-13.24 m because of the presence of coarse volcanic sand that was $^{40}Ar/^{39}Ar$ dated.

Superzone V1-A (zones V1-2 to V1-4): 13.02-12.10 m

This superzone is characterized by high AP values (max. 96%). Deciduous *Quercus*, *Fagus* and *Abies* successively dominate or co-dominate and show clear vegetation dynamics. *Pinus* has high percentage and concentration values throughout the zone. Other AP taxa with substantial curves include *Carpinus betulus*, *Ulmus* and *Quercus ilex*-type. All tree taxa are represented, except the most thermophilous, e.g. *Fraxinus/Phillyrea* and *Pistacia*. Total pollen concentration varies between 130 000-430 000 grains/g, excluding the very low value at 12.72 m (13 000 grains/g) where there is a thin tephra layer.

Zone V1-2: 13.02-12.82 m. Deciduous *Quercus*, which achieves overall maximum representation for the profile (exceeding 65%), characterizes the start of this forest period. *Pinus* is at ca. 15-20% while *Fagus*, *Ulmus*, *Corylus*, *Betula* and evergreen *Quercus* are <5%. Other elements of the mixed oak forest (*Zelkova*, *Acer*, *Tilia* and *Carpinus*) have very low representation. The mean number of pollen taxa is 30.

Zone V1-3: 12.82-12.42 m. An expansion of *Fagus* (up to 40%, the highest value of the profile) is recorded, deciduous *Quercus* continues with high values (up to 45%), and *Carpinus betulus* and *Ulmus* are recorded in appreciable amounts although never attaining 10%. Associated with the tephra layer at 12.73-12.70 m, there is a decline in pollen concentration and *Fagus* and Ericaceae peak at the expense of *Quercus* and *Pinus*. In the second half of the zone, *Abies* shows a clearly increasing trend. Botryococcaceae register the highest values for the profile. The mean number of pollen taxa is 29.

Zone V1-4: 12.42-12.10 m. An increase of *Abies* (from 12% to 34%) corresponds to a decrease in deciduous *Quercus* (from 34% to 20%), *Fagus* (from 19% to 8%), *Carpinus betulus*, *Ulmus* and Ericaceae. *Pinus* shows high concentration values and *Tilia* is absent. Pollen concentration curves show similar trends to the percentage curves and the mean number of pollen taxa is 30.

Zone V1-5: 12.10-11.58 m. This zone is characterized by high percentage values of NAP (50-60%) while *Pinus* and deciduous *Quercus* lie in the ranges 15-30% and 10-15%, respectively. Gramineae (up to 30%), *Artemisia* (up to 25%), Chenopodiaceae (<10%), Asteroideae and Rubiaceae (both <5%) are the most abundant NAP taxa. In the uppermost two samples, the percentage representation of deciduous *Quercus* increases considerably (up to 25%) which signals the forest expansion recorded in following zone V1-6. Total pollen concentration is between 45 000 and 170 000 grains/g and the mean number of pollen taxa is 29.

Superzone V1-B (zones V1-6 and V1-7): 11.58-10.94 m

Superzone V1-B is characterized by high frequencies of trees (>80%), particularly deciduous *Quercus*, *Abies*, *Pinus*, *Ulmus*, *Carpinus betulus* and *Fagus*. *C. betulus*,

LAGO DI VICO (VI) - 510 m
concentration diagram
uncal. radiometric dates
depth (m)
local pollen zones
samples
PINUS
JUNIPERUS type
EPHEDRA DISTACHYA type
EPHEDRA FRAGILIS type
CEDRUS
PICEA
ABIES
BETULA
FAGUS
CARPINUS BETULUS
OSTRYA/CARPINUS OR.
ULMUS
ZELKOVA
TILIA
ACER
CORYLUS
QUERCUS deciduous
QUERCUS evergreen
ERICACEAE
FRAXINUS/PHILLYREA
OLEA
PISTACIA
SAMBUCUS/VIBURNUM
BUXUS
ILEX
HEDERA
VITIS
CASTANEA
JUGLANS
ALNUS
POPULUS
SALIX
HIPPOPHAE
ARTEMISIA
ASTEROIDEAE undiff.
CICHORIOIDEAE
CHENOPODIACEAE
GRAMINEAE
RUBIACEAE
RUMEX
THALICTRUM
UMBELLIFERAE
URTICACEAE
ALISMA
MYRIOPHYLLUM ALT.
NYMPHAEACEAE
SPARGANIUM/TYPHA
INDETERMINABLE
POLYPODIUM
monolete spores
trilete spores
2630±95
3710±50
4315±75
5345±75
6165±100
7025±85
8225±80
10255±90
11295±165
14385±140
20500±230
21950±345
25210±420
32685±1135
34875±1500
>38000
>38000
87000±7000
VI-1
VI-2
VI-3
VI-4
VI-5
VI-6
VI-7
VI-8
VI-9
VI-10
VI-11
VI-12
VI-13
VI-14
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VI-16
VI-17
VI-21
VI-22
A
B
C
D
E
0 20 x 10^3 grains/g

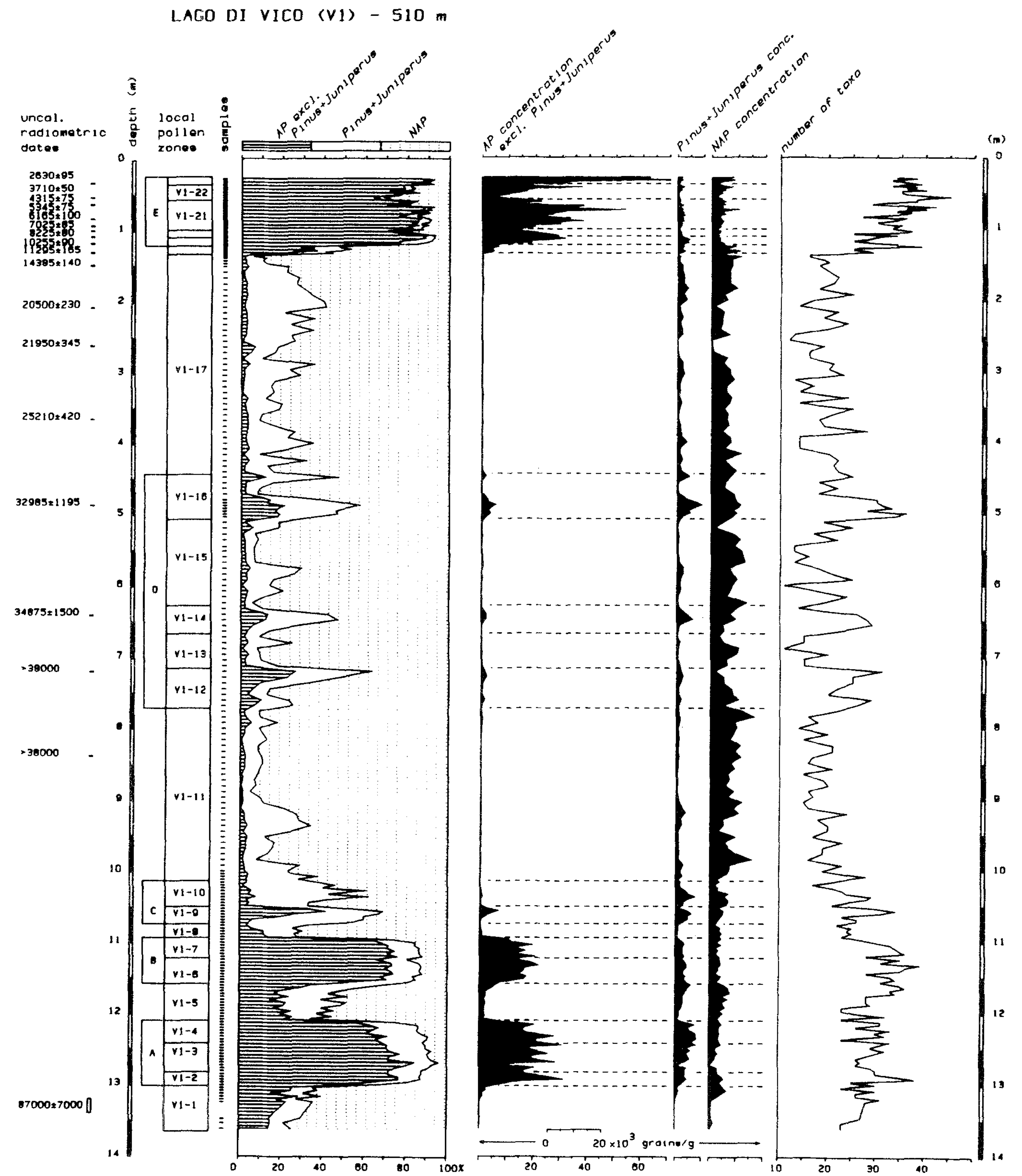


Fig. 2. Summary curves for pollen profile (core V1), Lago di Vico

Ulmus, *Acer* and *Zelkova* achieve their overall maxima for the profile. Throughout the superzone, however, both *Artemisia* and Gramineae are consistently represented at ca. 5%. Total pollen concentrations vary between ca. 150 000-300 000 grains/g.

Zone V1-6: 11.58-11.22 m. Deciduous *Quercus*, rising to a peak of about 40%, is accompanied by *Pinus* at ca. 15%, *Abies*, which increases from ca. 2-13%, *Ulmus*, *C. betulus* and *Fagus*. Several other angiosperm trees and shrubs are recorded but with low percentages. The mean number of pollen taxa is 34.

Zone V1-7: 11.22-10.94 m. Floristically this zone is very similar to the preceding one but there are clear differences in the relative abundance of the dominant taxa. *Quercus* gradually decreases to values of <20%, while *Abies* reaches 27%. These trends are also to be seen in the concentration diagram. The mean number of pollen taxa is 32.

Zone V1-8: 10.94-10.74 m. This zone is characterized by high frequencies of NAP (ca. 70%) which consists mainly of Gramineae and *Artemisia*. Chenopodiaceae and Asteroideae have also substantial curves. *Pinus* shows an increasing trend that preludes a peak of the following zone (V1-9). There are low percentage values for many angiosperm trees and there is a continuous deciduous *Quercus* curve at 2-6%. Total pollen concentration is between ca. 30 000-60 000 grains/g. The mean number of pollen taxa (24) is distinctly lower than in the previous and following zones.

Superzone V1-C (zones V1-9 and V1-10): 10.74-10.14 m

This superzone is characterized by the highest representation of *Pinus* (max. 54%) in the profile. An important peak of deciduous *Quercus* (26%) is found between two peaks of *Pinus*. Total pollen concentration ranges between 35 000-165 000 grains/g.

Zone V1-9: 10.74-10.50 m. This zone is characterized by a peak in *Pinus* (53%) followed by a peak in deciduous *Quercus* (26%) and lower values for *Ulmus* (5%), *Alnus* (2%), *Betula* (<2%) and many other broadleaved trees with very low percentages. Pollen concentration values parallel the percentage curves. NAP (30-50%) consist mainly of *Artemisia* and Gramineae. Total pollen concentration is between ca. 60 000-165 000 grains/g and the mean number of pollen taxa is 29.

Zone V1-10: 10.50-10.14 m. Pinus has high percentage and concentration representations (28%-54% and 15 000-70 000 grains/g, respectively). Deciduous *Quercus* is the only angiosperm tree taxon with a continuous curve, but many other trees are present in low quantities. *Artemisia* (max. 37%) and Gramineae (max. 31%) are the dominant NAP. Pollen concentrations lie between 35 000-135 000 grains/g and the mean number of pollen taxa decreases to 23.

Zone V1-11: 10.14-7.72 m. NAP percentages are very high (70%-90%), mainly as a result of high *Artemisia* (up to 67%) and Gramineae values (15-30%). The occurrence of *Lygeum* confirms the steppe character of the vegetation in this period. Of the woody taxa, only *Pinus* and *Juniperus* show appreciable percentage values, *Pinus* being less abundant and *Juniperus* more abundant than in the preceding zone. Angiosperm tree pollen are sparse or even absent. NAP concentrations are consistently higher than the AP values (45 000-164 000 grains/g versus 4000-38 000 grains/g). The mean number of pollen taxa is 19. In this part of the core bryophyte macroremains are common and include *Brachytecium rivulare* Bruch at 8.16 m and and *Calliergon sarmentosum* Kindb. at 8.16 m and 7.92 m.

Superzone V1-D (zones V1-12 to V1-16): 7.72-4.44 m

This superzone, which has high NAP, shows several weak fluctuations in the curves for broadleaved trees. AP values vary between 5-63%. Even if it is difficult to characterize this superzone, because of rather unstable vegetational features, it is a useful grouping for purposes of description and interpretation, especially in view of the almost complete absence of angiosperm tree pollen in the preceding and following zones (V1-11 and V1-17). Total pollen concentration lies between 18 000-250 000 grains/g.

Zone V1-12: 7.72-7.16 m. Pinus and deciduous *Quercus* show an increasing trend which culminates at the top of the zone with values of 36% and 20%, respectively. Pollen concentration also increases at the end of the zone. Several other tree pollen types are represented, sometimes by single grains, e.g. *Betula*, *Corylus*, *C. betulus*, *Alnus*, *Quercus ilex*-type, *Zelkova*, *Tilia*, *Ulmus*, *Ostrya/Carpinus orientalis* and *Acer*. A sample from 7.23 m gave an AMS ^{14}C date of >38 000 B.P. The average number of pollen taxa is 25.

Zone V1-13: 7.16-6.68 m. Artemisia lies between 50-70% throughout and has high concentration values (up to ca. 80 000 grains/g). *Pinus* is the only tree with appreciable values (mostly <10%). *Quercus*, *Salix* and *Betula* are the only deciduous trees recorded. The absence of many AP taxa results in the lowest mean number of pollen taxa (15) for the whole sequence.

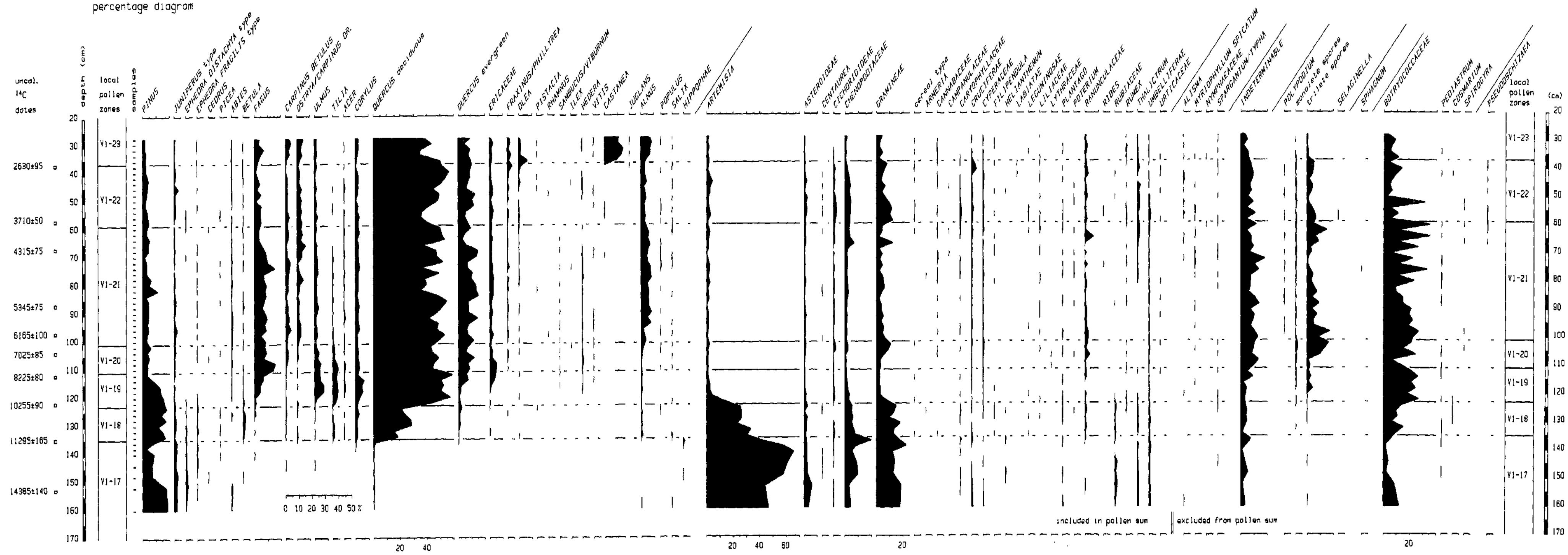
Zone V1-14: 6.68-6.28 m. AP percentages rise to 46% mainly as a result of increases in *Pinus* (30%) and deciduous *Quercus* (6%). There are sporadic records of several broadleaved tree pollen (*Quercus ilex*-type, *Betula*, *Corylus*, *Ulmus*, *Alnus*, *Fagus* and *Tilia*). AP concentrations also increase somewhat. A sample from 6.44 m gave an AMS ^{14}C date of 34 875+1500/-1265 B.P. The mean number of pollen taxa (24) is appreciably higher than in the preceding zone.

Zone V1-15: 6.28-5.08 m. There are high NAP values (70-90%) with *Artemisia* having values of 50-70% throughout. *Pinus* is relatively abundant (up to 25%) in the first half of the zone, where it is the main contributor to the increased AP values. *Juniperus* is consistently recorded at low percentages that rise somewhat towards the top of the zone. Concentration values parallel the percentage values. Leaves of the moss *Isopterygium* cf. *pulchellum* Lindb. were recorded at 5.26 m. The mean number of pollen taxa is 18.

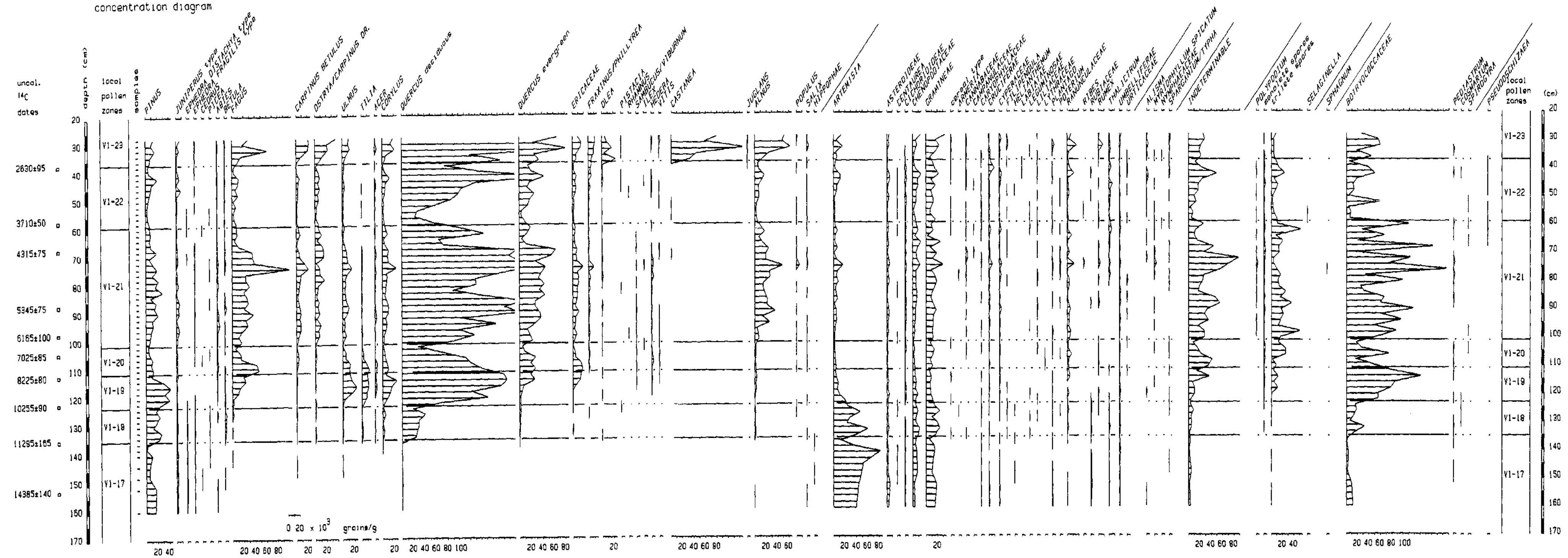
Fig. 3. Pollen percentage diagram, Lago di Vico (core V1)
Fig. 4. Pollen concentration diagram, Lago di Vico (core V1)
Fig. 5. Part of pollen profile (percentage and concentration diagrams) relating to the last 15 000 years, Lago di Vico (core V1)

LAGO DI VICO

percentage diagram



concentration diagram



Zone V1-16: 5.08-4.44 m. AP values rise near the base of the zone to achieve 60%, and then decrease to <10%, and peak again in the last sample (to 45%). These trends are particularly clear in the concentration diagram, while the correspondence between NAP concentration and percentage values is not so good. The first peak in AP includes *Pinus* (35%), deciduous *Quercus* (10%), *Ulmus*, *Betula*, *Corylus*, *Alnus*, evergreen *Quercus*, *Juniperus*, *Picea* and other tree taxa which have sporadic occurrences (AMS ^{14}C date of 32 985 +1195/-1040 B.P.). The final records for *Zelkova* and single grains of *Olea* and *Rhamnus* are recorded in this part of the profile. A second peak in AP is due mainly to an increase in *Pinus*. Deciduous *Quercus* is the only other AP curve that exceeds 5%. The mean number of pollen taxa is 28, which is the highest of superzone V1-D.

Zone V1-17: 4.44-1.35 m. The zone is characterized by very sparse representation of angiosperm tree pollen (max. 2% and none recorded at 2.56 m). The lowest concentration value for the profile is recorded at 2.64 m (1500 grains/g), which corresponds with a peak in the percentages of Cichorioideae and Chenopodiaceae. This episode is AMS ^{14}C dated to 21 950±345 B.P. NAP concentrations are consistently higher than the AP (1300-111 000 grains/g versus 200-41 000 grains/g). *Artemisia* and Gramineae are the dominant taxa at mainly 30-50% and 20-40%, respectively. There is an important change at the end of the zone, between the two AMS ^{14}C dates 14 385±140 and 11 295±165 B.P., when *Artemisia* percentage and concentration values increase. The mean number of pollen taxa is 19.

Zone V1-18: 1.35-1.23 m. This is a transition zone (30% angiosperm trees) between zone V1-17 which is dominated by NAP and *Pinus* (together these constitute up to >95%) to a period in which AP dominate (superzone V1-E; AP values of 70-90%). The transition expresses itself clearly in the deciduous *Quercus* and *Artemisia* curves, the former increasing from 2% to 28% and the latter decreasing from 60% to 25%. *Pinus* (10-15%) and Gramineae (10-15%) do not show appreciable variations compared to the preceding zone, but there is a weak, though significant, increase in several tree taxa, and, in particular, *Betula*, *Corylus*, *Tilia* and evergreen *Quercus*. The mean number of pollen taxa rises to 30. The chronology of this zone is fixed by a ^{14}C date at its beginning (11 295±165 B.P.) and shortly above the end of the zone (10 255±90 B.P.).

Superzone V1-E (zones V1-19 to V1-23): 1.23-0.28 m

AP values are high throughout (70-90%) while the pollen concentrations show considerable variation (65 000-870 000 grains/g). The dominant tree pollen taxon (also the characterising taxon) is deciduous *Quercus* which is never <35%. This superzone includes five zones distinguished on the basis of the fluctuations in the relative abundance of the tree taxa other than deciduous *Quercus*, including evergreen *Quercus*, *Pinus*, *Fagus*, *Ulmus*, *Corylus*, *Tilia*, *Alnus*, *C. betulus*, *Ostrya/Carpinus orientalis*, *Fraxinus/Phillyrea*, *Olea*, *Castanea* and several other taxa with very low values. Eight ^{14}C dates that range between 10 255±90 and 2630±95 B.P. provide the chronological framework for the superzone.

Zone V1-19: 1.23-1.11 m. Deciduous *Quercus* dominates (50%) while *Pinus* shows a slightly decreasing trend in percentage representation (from 16% to 8%) and a moderate increase in concentration values. Several AP taxa, already recorded in the preceding zone, expand in the following order: first *Corylus* and *Tilia*, then *Ulmus* and *Fagus*, and finally evergreen *Quercus* and Ericaceae. This sequence is clearly visible both in the percentage and concentration diagrams. Pollen concentrations rise from ca. 150 000 grains/g at the base of the zone to ca. 370 000 grains/g at the top and, at the same time, *Artemisia* and Gramineae decrease both in the percentage and concentration diagrams. The mean number of pollen taxa is 29.

Zone V1-20: 1.11-1.01 m. Deciduous *Quercus* is always dominant (40-60%). Compared to the underlying zone, *Pinus* (5%), *Ulmus* (2-4%) and *Corylus* (2-3%) have lower percentage representation. The short interval spanned by the zone (10 cm) makes it impractical to split it into smaller units, even though there is a clear expansion of *Fagus* (up to 15%) accompanied by an increase in *Quercus ilex*-type and Ericaceae in the lower part of the zone, while an increase in Gramineae and *C. betulus* (moderate rise) and a dramatic decline in AP concentration characterize the upper part of the zone. ^{14}C dates are available for the beginning (8225±80 B.P. at 1.11 m) and end of the zone (7025±85 B.P. at 1.03 m), the latter providing a date for the sudden drop in total pollen concentration from 158 000 to 66 000 grains/g. The mean number of pollen taxa is 33.

Zone V1-21: 1.01-0.59 m. This is a period with relatively stable deciduous oak-dominated vegetation (40-50%), with appreciable values of *Quercus ilex*-type (5-15%), *Fagus* (5-10%), and *Pinus* (5%). *Tilia*, which had started to decline in zone V1-20, is very reduced, whereas *Alnus* (up to 8%) and *Ostrya/Carpinus orientalis* (up to 7 %) attain greatest representation which values are maintained to the core top. Total pollen concentration values are between ca. 200 000 and 650 000 grains/g except for a single sample from a level dated to 4315±75 B.P. where 120 000 grains/g are recorded (all taxa affected). Another drop in deciduous oaks concentration is recorded at 0.84-0.82 m. Other taxa, however, do not decline but show stable or even increasing concentrations (*Pinus*). From this part of the profile, three dates are available, which are internally consistent, i.e. 6165±100 B.P. at 0.96 m, 5345±75 at 0.86 m and 4315±75 B.P. at 0.66 m. The mean number of pollen taxa is 34.

Zone V1-22: 0.59-0.37 m. The zone is characterized by relatively low values of AP (70-80%) and by a dramatic drop in pollen concentration (65 000 grains/g) which coincides with the ^{14}C date of 3710±50 B.P. (0.56 m). At the same time, the highest overall number of pollen taxa is recorded (45), which is mainly due to increased NAP diversity. *Castanea*, *Olea* and cereal-type, already recorded in various samples within superzone V1-E, occur simultaneously for the first time as the concentration values decline. These taxa are not recorded between 0.48-0.50 m, when a new pronounced recovery of trees, and particularly deciduous *Quercus*, is recorded. Total concentration values reach 480 000 grains/g towards the end of the zone (0.42 m). The mean number of pollen taxa is 38.

Zone V1-23: 0.37-0.28 m. Total pollen concentration achieves the highest overall values of 870 000 grains/g that correspond with AP percentages of ca. 90%. The most important feature is the considerable and sharp expansion of *Castanea* (>10%) and *Olea* (7%) that is accompanied by other cultivated plants such as *Juglans, Vitis* and cereals, curves for which start at the level that is ^{14}C dated to 2630±95 B.P. There appears to be little overall change in forest composition. Only moderate increases in *Alnus*, *Carpinus betulus*, *Fagus* and *Ostrya/Carpinus orientalis* at the expense of deciduous *Quercus* are recorded. The mean number of pollen taxa is 35.

Discussion

The results from Lago di Vico are in agreement, on the one hand, with the results of palaeoecological investigations at the other lakes of the region, especially Valle di Castiglione (Follieri et al. 1988) and Lagaccione (Magri 1999), and, on the other hand, provide new fundamental information on periods, which, until now, there was little information from the Italian peninsula, e.g. the Holocene, St Germain II *sensu lato*.

The forest phase corresponding to superzone V1-A was already recognized in previous works at Lago di Vico and variously interpreted. At first it was correlated with either the Eemian, or St Germain I or II (Francus et al. 1993), and then it was estimated to begin at 95-90 ka, based on tentative, long-distance correlations with other proxy-data curves, without additional tephrochronological, radiometric or pollen stratigraphical data (Leroy 1994; Leroy et al. 1996).

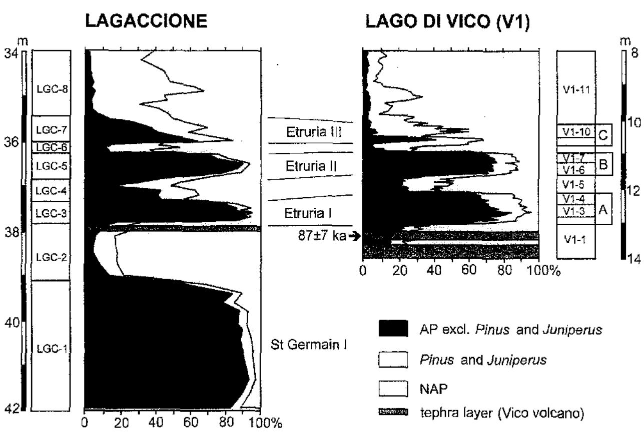


Fig. 6. Correlation of the pollen diagrams from Lago di Vico (core V1) and Lagaccione (Magri 1999) for the Etruria forest phases

The close similarity of the profile from core V1, Lago di Vico, with the recently constructed profile from Lagaccione, a crater lake located ca. 30 km north-west of Lago di Vico (Fig. 1; Magri 1999), as well as the $^{40}Ar/^{39}Ar$ date from the tephra layer at 13.46-13.24 m (87±7 ka), provide important new information for establishing the biostratigraphy and chronology of the Lago di Vico sequence.

Figure 6 shows the correlation of the forest periods from the base of core V1 with the base of the pollen diagram from Lagaccione. At Lagaccione, a long period of dense forest is recorded at the bottom of the sequence (zone LGC-1). On the basis of floristics and vegetation development, this forest period has been correlated with the St Germain I interstadial (Magri 1999). In fact, the Lagaccione sedimentary record starts after the formation of the explosion crater, which followed the emplacement of a lava flow that is K/Ar dated to 145±9 ka (Metzeltin and Vezzoli 1983). On the basis of comparison with the Valle di Castiglione record, the possibility is excluded that the forest period at the base of the Lagaccione profile is of Eemian age, because of the scarcity of Mediterranean evergreen elements and the abundance of *Fagus* (>45%). On the other hand, the forest period LGC-1 cannot be correlated with St Germain II, as it is followed by a tephra layer that relates to the final phases of activity of the Vico volcano (Narcisi and Anselmi 1998), and this volcano was not active after ca. 90 ka.

In the La Grande Pile profile, the interstadial St Germain II, as defined by Woillard (1978), follows the interstadial St Germain I and the stadial Melisey II. At Lagaccione, three successive forest expansions are recorded (see LGC-3, LGC-5 and LGC-7). However, it is uncertain if zone LGC-3, or LGC-3 and LGC-5 together, or even perhaps LGC-7 correspond with St Germain II, and the correspondence with the Ognon AP fluctuations is also uncertain [cf. Woillard (1978); also de Beaulieu and Reille (1992) who question the significance of this feature]. Similarly, correlations with the Oerel interstadial at Oerel (Behre 1989; Behre and van der Plicht 1992), with the third interstadial at Samerberg (Grüger 1979) and Wurzach (Grüger and Schreiner 1993), and with the Dürnten interstadial in Switzerland (Welten 1982; Wegmüller 1992) cannot be established with any degree of certainty. For these reasons, Magri (1999) favoured the use of local names, i.e. Etruria I, Etruria II and Etruria III, in referring to the forest expansions recorded in zones LGC-3, LGC-5 and LGC-7, respectively.

A tephra layer from the final eruptions of the Vico volcano have been recorded at Lagaccione immediately beneath three forest oscillations that have comparable patterns and stratigraphical position to those at Lago di Vico. From this, it is clear that superzones V1-A, V1-B and V1-C correspond to Etruria I, Etruria II and Etruria III, respectively (Fig. 6). The first two oscillations, that correspond to Etruria I and Etruria II, respectively, display similar vegetation dynamics at the two sites. These start with deciduous oaks, then *Fagus* and *Carpinus betulus* expand, and at the end *Abies* increases. The main difference relates to the expansion of *Fagus* during Etruria II at Lagaccione, which is matched by an expansion of *Abies* at Lago di Vico. The third oscillation, i.e. Etruria III, is characterized at both sites by the dominance of deciduous *Quercus* and *Pinus*, and then by a marked expansion of *Pinus*. At Lago di Vico *Quercus* is not as abundant and disappear earlier than at Lagaccione.

The forest periods, Etruria I, Etruria II and Etruria III, that are recorded in core V1 (present paper) are clearly correlated with zones 1, 3 and 5, respectively, in the 1990 cores from Lago di Vico that were studied by Leroy (Fig. 7; Francus et al. 1993; Leroy et al. 1996, in which publication "holes 1990" is used to designate the cores. The main differences between the two records are as follows: (a) in the 1990 cores, Etruria I is much longer than Etruria II, while, in core V1, Etruria I is only somewhat longer than Etruria II, which is the same as at Lagaccione; (b) in the 1990 cores (Francus et al. 1993) *Picea* achieves substantial representation (up to 7%) during zone 5 (Etruria III), which is not matched in core V1 but is recorded at Lagaccione. The contrasting locations of these cores within the Lago di Vico basin may largely account for the differences in the pollen records. The 1990 cores are from outside the present lake while core V1 was collected some 4.5 km distant in a water depth of over 20 m (Fig. 1). The location of the 1990 cores is much more influenced by changes in the lake levels and so there may have been strong variations in sediment accumulation rates that probably resulted in periods of high accumulation as well as low/non-existent accumulation or even erosion. The abundance of *Picea* pollen in the 1990 cores may also have resulted from the marginal position in the basin so that local marginal vegetation can be expected to be strongly represented. *Picea* is invariably under-represented in pollen records due to its poor pollen production (Hicks 1994), so that Huntley and Birks (1983) argue that percentages of *Picea* higher than 5% indicate local presence. Clearly, *Picea* was locally present in central Italy during at least part of the last glacial period (Follieri et al. 1998). This is noteworthy in view of the fact that the present-day distribution of spruce in Italy is limited to the Alps and a few relic stations in the northern Apennines.

The correlation of the Etruria forest periods with vegetational events described in other pollen records from southern Europe is very uncertain, even if only the most continuous sequences are considered. At Ioannina in north-west Greece (Tzedakis 1994), the sampling interval is probably too coarse to detect such minor fluctuations. At Tenaghi Philippon in Macedonia (Wijmstra 1969), during the Elevtheroupolis forest period which is correlated with St Germain II there are two main fluctuations in the AP curve that might also be due to the irregular course of the Gramineae curve. At Kopais in central Greece (Tzedakis 1999), there are mini-phases of expansion and contraction of AP values – though not well characterised – during and after a forest expansion that is correlated with St Germain II (zone KG). At Valle di Castiglione, near Rome (Follieri et al. 1988), the forest vegetation recorded in the stratigraphical position corresponding to St Germain II shows some fluctuations, but due to problems relating to sediment accumulation they cannot be characterized with certainty. The record at

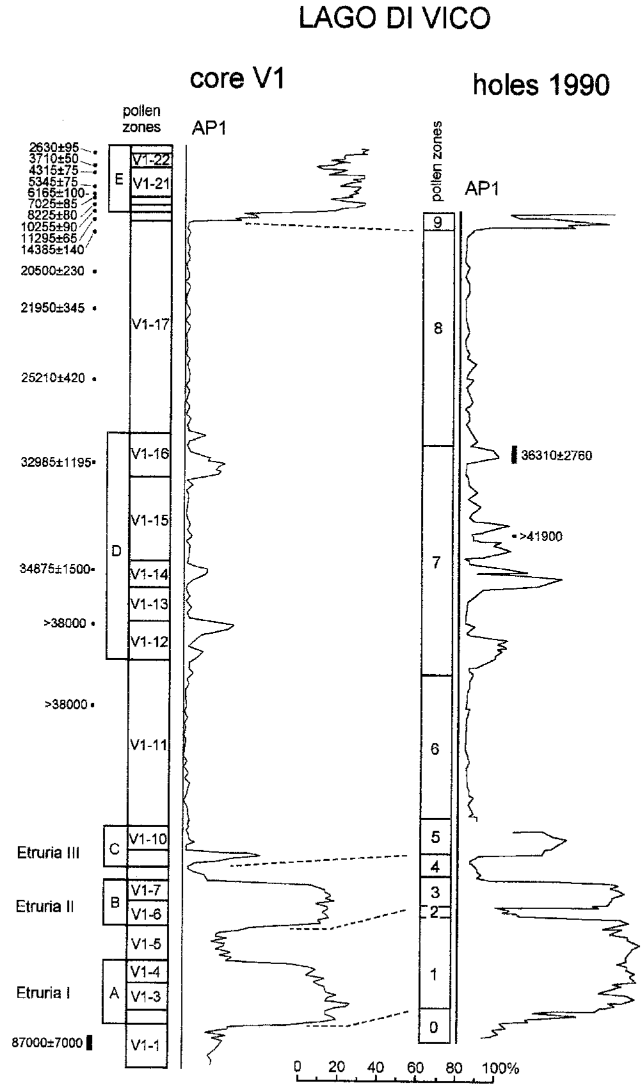


Fig. 7. Correlation of pollen diagrams, core V1 (present paper) and profile from 1990 cores (Leroy et al. 1996), Lago di Vico. AP1, AP less *Pinus*, *Cedrus*, *Juniperus*, *Ephedra*, *Hippophae* and *Arceuthobium*

Lago Grande di Monticchio in southern Italy (Watts et al. 1996a), which dates back to ca. 76 000 B.P., does not span the St Germain II interval. Moreover, the fluctuations recorded at the base of the Lago Grande di Monticchio profile are not comparable, in terms of vegetation dynamics, to any of the Etruria periods recorded at Lagaccione and at Lago di Vico. The fluctuations in oak and pine recorded at the base of the diagram from Abric Romaní in Catalonia (Burjachs and Julià 1994) may resemble those of Etruria III, but lack biostratigraphical units with super-regional significance, e.g. St Germain II, and so it is impossible to establish reliable correlations with Lago di Vico.

A correlation of the Etruria forest periods with palaeoclimatic events recorded by other palaeoenvironmental time-series is intentionally omitted in the present paper, in the absence of a secure chronological and stratigraphical control. The recent paper by Kukla et al. (1997), in which even the well-defined chronostratigraphic position of the last interglacial (Eemian) as recognized in French records appears not to be in agreement with the age of oxygen isotope (OI) substage 5e, its OI stage equivalent, makes it imperative to be cautious when considering periods whose chronostratigraphic position and climatic significance are still very uncertain.

Caution is necessary not only when considering the Etruria periods but also in any evaluation of the subsequent pollen zones of the pleniglacial. While zone V1-11 and superzone V1-D appear to correspond with OI stages 4 and 3, respectively, it is not possible to state whether timing and duration of the stratigraphic units of the continental and ocean records match and whether the oscillations as recorded in the respective records can be correlated. For the same reasons, no correlations are advanced with the Heinrich events as recorded in North Atlantic cores (Bond et al. 1992; Broecker 1994).

As regards the correlation of the records from the 1990 cores with the OI curve from the GRIP ice core as proposed by Leroy et al. (1996), it should be noted that this is supported by only one ^{14}C date (36 310±2760 B.P.) that falls within the time range of radiocarbon. Also, the "ca. 7 pulses" of AP, that are correlated by Leroy et al. (1996) with OI stage 3, differ in number and importance with respect to the fluctuations recorded in the GRIP record (Dansgaard et al. 1993). The inappropriateness of the proposed correlations is also emphasised by the contrasting fluctuations in the pollen curves from the 1990 cores and the present core V1 (Fig. 7). On the basis of the available ^{14}C dates, the final AP expansion of the middle pleniglacial in the 1990 cores, that is dated to 36 310±2760 B.P., may correlate with either the end of zone V1-12 (>38 000 B.P.) or with zone V1-14 (34 875±1500 B.P.) or even with the first AP oscillation in zone V1-16 (32 985±1195 B.P.).

Based on comparisons with the other pollen records from the Lazio region (Valle di Castiglione, Follieri et al. 1988; Lagaccione, Magri 1999; Stracciacappa, Giardini 1993; Valle di Baccano, Ciuffarella 1996), it seems most likely that neither the 1990 cores or core V1 from Lago di Vico provide a continuous record for the pleniglacial. The abundance of moss macroremains in the sediments suggest lowering in the lake levels that probably resulted in interruptions in sediment accumulation. While interruptions in sediment accumulation are quite likely in the 1990 cores, which are from the filled-in area outside the present lake, appreciable hiatuses are less likely in core V1 since this was retrieved from beneath more than 20 m of water. The consistency of the ^{14}C dates in zones V1-14 to V1-17 indicates that the part of the record from ca. 35 000 to 11 000 B.P. is fairly continuous, while comparison with the other records from Lazio shows that part of the middle pleniglacial interstadials older than 35 000 B.P. are probably missing at Lago di Vico. Follieri et al. (1998) introduced the local name 'Lazio Complex' for a series of seven pleni-glacial oscillations recognized in at least three out of four records, i.e. Valle di Castiglione, Lagaccione, Lago di Vico and Stracciacappa. The record from Lago di Vico contributes substantially towards defining episodes V to VII (*sensu* Follieri et al. 1998; 35 ka to 30 ka), but is less helpful with respect to the earlier episodes II to IV, within which interval there is only one pronounced oscillation (zone V1-12).

Interruptions in sediment accumulation during the pleniglacial occur also in the other crater lakes of Lazio, making detailed correlations difficult. At Valle di Castiglione, a palaeosol interrupts the record from the end of St Germain II s.l. forest period to the middle pleniglacial interstadials (Follieri et al. 1988). At Lagaccione, the ^{14}C dates between ca. 30 and 23 ka show inconsistencies (Magri 1999) that again highlight potential problems in sediment deposition and/or in core collection with respect to this period.

The correlation of the records from Lago di Vico with that from Lago Grande di Monticchio (Watts et al. 1996a) is also problematic. Neither the ^{14}C dates nor the sequence of vegetational events are such as to enable reliable reference events to be established that would enable sound correlation of the two sequences. At Lago Grande di Monticchio, even if a continuous and detailed time-scale has been proposed (Zolitschka and Negendank 1996), the cores, collected from a submerged terrace overlain by only 7 m of water, include two considerable slumps that constitute ca. 3 m of sediment, numerous cm-thick turbidites and a hundred discrete tephra layers (Narcisi 1996). There must therefore be some doubt as to the continuity of the pollen record, particularly during the last glacial period.

Even though the Italian peninsula has yielded a number of long pollen sequences from crater lakes that span the last glacial period, none of the records can be regarded with confidence as uninterrupted throughout the whole pleniglacial. However, it is difficult to critically evaluate records relating to periods that are too old to be dated with confidence by the radiocarbon method and are also poorly characterized from the biostratigraphical point of view. It should also be borne in mind that, during the glacial period, all Italian crater lakes appear affected by events and processes that have affected sediment accumulation, e.g. emersion, pedogenesis, erosion, slumps, redeposition, reworking, etc. This may be related to climatic instability over this long period of tens of thousands of years and/or tectonic instability that is generally a feature of areas with volcanic activity during the late-Quaternary.

It is only during the final phase of the last glacial period, that corresponds roughly with OI stage 2, that relatively stable vegetation features are recorded at Lago di Vico as well as in all the pollen records from central and southern Italy, namely, Lagaccione (Magri 1999), Valle di Castiglione (Follieri et al. 1986b), Lago Grande di Monticchio (Watts et al. 1996a) and Lago Albano (Lowe et al. 1996). This phase is characterised by a clear dominance of non-arboreal pollen (NAP), appreciable *Pinus* and *Juniperus* representation and sparse records for deciduous trees, mainly *Quercus*. In the long pollen records from central Italy for which both pollen concentration and radiocarbon dates are available (core V1 from Lago di Vico, Lagaccione and Valle di Castiglione), the lowest pollen concentrations are found at ca. 21-22 ka (non-calibrated ^{14}C years). At the same time, at both Lago di Vico (core V1) and Lagaccione, as well as at Valle di Castiglione, Cichorioideae clearly peak (20%, 5% and 6%, respectively), which suggests that this feature may be of regional significance. It is not possible to verify if this holds true at Lago Grande di Monticchio (Watts et al. 1996a; the pollen diagram does not show a Cichorioideae curve) or at Lago Albano for which there are no ^{14}C dates (Lowe et al. 1996).

The first clear increase of AP (zone V1-18) after the pleniglacial is found just before the ^{14}C date 11 295±165 B.P. This is preceded by low representation of deciduous *Quercus* accompanied by only sporadic records of other deciduous tree taxa (*Betula*, *Carpinus betulus*, *Ulmus*, *Fagus* and *Corylus*). At Lagaccione, on the other hand, a sharp expansion of AP at ca. 11 800 B.P. is preceded by a continuous, even if very subdued, increase in AP starting already at ca. 13 300 B.P. (Magri 1999). At Lago Grande di Monticchio the full-glacial to late-glacial boundary has been placed at ca. 12 500 B.P. (Watts et al. 1996b), but some deciduous tree populations, e.g. birch and oaks, clearly spread somewhat earlier. On the basis of the evidence from other sites, the possibility should therefore be considered that, at Lago di Vico, the beginning of the rise in late-glacial deciduous tree populations is inadequately recorded because of one or more of the following reasons, namely a hiatus, the larger size of Lago di Vico compared with other lakes and/or a lower density of arboreal vegetation in the surrounds of the lake.

During the late-glacial, the AP percentages (max. 52%) suggest a fairly open landscape, while at Lagaccione and at Lago Grande di Monticchio AP attains 80% which suggests a forested landscape. Also noteworthy in core V1 is the fact that *Tilia* achieves only modest values during the late-glacial (<2%) and a small increase during the early Holocene (4%). At Lagaccione and Lago Grande di Monticchio, on the other hand, *Tilia* attains its maximum values (9% and >10%, respectively) during the late-glacial. At Lago di Vico, *Betula* which is invariably <5%, behaves rather differently from Lago Grande di Monticchio, where it had a local presence as indicated by pollen percentages of over 20% and macrofossils. At all sites, including Lago di Vico, Lagaccione, Valle di Castiglione and Lago Grande di Monticchio, deciduous oaks are the most important tree taxa. The situation is similar in the core from Lago Albano that was analysed at the University of Modena (Fig. 2 in Lowe et al. 1996), while the corresponding diagram from the same core that was prepared at Royal Holloway, University of London shows a dominance of evergreen oaks (Fig. 1, Lowe et al. 1996).

As at Lago Grande di Monticchio and Lago Albano, the Younger Dryas at Lago di Vico shows a small increase in NAP (from 48% to 54%; the end of zone V1-18), whereas at Lagaccione there is a pronounced increase in NAP (from 22% to 65%) and there is also a marked decline in AP concentration (from 300 000 to 90 000 grains/g). A hiatus during the Younger Dryas in core V1, Lago di Vico, cannot be excluded.

A sharp increase in AP occurs at 10 255±90 B.P. and high values (70-90%) are maintained up to the present time. A key feature of the Holocene at Lago di Vico is the overwhelming abundance of deciduous *Quercus* which is never lower than 35%, while none of the other arboreal taxa reaches 20%. The Holocene vegetation at Lago di Vico does not undergo any major change in composition or a typical interglacial succession, though a number of dramatic declines in pollen concentration may be indicative of considerable variations in forest density. On the whole, the Holocene record from Lago di Vico is probably the most complete and best dated record in central and southern Italy, even if it is represented by only a 1.23-m-long sediment core. At Lago Grande di Monticchio, the mid-Holocene is either very reduced or incomplete (Watts et al. 1996b), at Lago Albano (Lowe et al. 1996) the record is interrupted between about 7100 B.P. and 3700 B.P., at Lago di Martignano (Kelly and Huntley 1991) there are problematic pollen assemblages and radiocarbon dates, and at Valle di Castiglione (Follieri et al. 1986b) and at Lagaccione (Magri 1999) the top of the core is missing due to reclamation works in the basin. In the 1990 cores from Lago di Vico, the post-glacial is not represented (Leroy et al. 1996), so the present study is of particular importance as regards the Holocene in peninsular Italy.

Between ca. 10 300 and 8200 B.P., the deciduous oaks are accompanied mainly by *Corylus*, which attains overall maximum representation, and *Tilia* and *Ulmus*. Similar features are found at Lagaccione, where *Corylus* is comparatively much more important (30%), and at Lago Grande di Monticchio. At Valle di Castiglione, the plain-like landscape, which was fairly open, was dominated by deciduous *Quercus* and *Corylus*. At Lago Albano, where no dates are available for this period and there is uncertainty regarding the *Quercus* curves (see above), *Corylus*, *Tilia* and *Ulmus* behave in a comparable way to Lago di Vico. Even if with local differences, that part of the Italian peninsula between the latitudes of Lagaccione and Lago Grande di Monticchio seems to be characterized mainly by widespread deciduous oaks, accompanied mainly by *Corylus*, and by many other tree taxa in low abundance, which presumably spread from the occasional refugia. *Fagus*, for example, was present at all sites, but it was nowhere a dominant tree.

Between ca. 8200 and 6800 B.P., deciduous oaks always constitute the most important curve. *Fagus* and *Quercus ilex*-type, which attain up to 15% and 12%, respectively, increase appreciably. The same vegetation trend is recorded at Lagaccione, where *Fagus* is comparatively much more important (>40%). The importance of beech is unexpected, especially since at present beech is abundant on the inner slopes of the Vico volcano, while it is uncommon in the Lagaccione area. On the other hand, *Quercus ilex* is present only in a limited number of stands around Lago di Vico while it is well represented in the crater and in the surroundings of Lagaccione. A moderate increase of beech and evergreen oaks is also recorded at Valle di Castiglione, while at Lago Grande di Monticchio and Lago Albano the profiles are probably incomplete.

In Lago di Vico, at a level dated by an AMS ^{14}C date to 7025±85 B.P., pollen concentration reaches a very low value after a decline that started some hundreds of years earlier. A similarly slow but pronounced decline is recorded also at Lagaccione, where the minimum value is recorded near the AMS ^{14}C date 7035±80 B.P. At Valle di Castiglione, where this interval is not well dated, the woodland was still fairly open, so the decline is less marked. The data so far available for the Lazio region suggest that an opening of the forest, that culminated at ca. 7000 B.P., is of regional significance.

From ca. 6800 to 3900 B.P., the composition of the forest appears fairly stable, with clear dominance of deciduous oaks, accompanied by *Fagus*, *Quercus ilex*-type, *Alnus* and many other tree taxa at low percentage values. However, the pollen concentrations show oscillations, with a pronounced drop around 4300 B.P. Analogous declines are recorded at Lagaccione (4350±75) and at Valle di Castiglione (somewhat after the ^{14}C date 4490±65 B.P.) while at Lago Grande di Monticchio and Lago Albano the data are insufficient to draw any worthwhile conclusions. The spread of *Abies* and *Taxus,* which begin at Lago Grande di Monticchio slightly before the AMS ^{14}C date of 3920±50 B.P., is not matched by similar developments in Lazio.

At a level that gave the ^{14}C AMS date of 3710±50 B.P., the most important decline in pollen concentration values during the post-glacial is recorded. This feature clearly corresponds with the minimum in pollen concentration at Lagaccione that is dated to 3750±80 B.P. At Valle di Castiglione a considerable reduction of AP concentration is dated to 3480±50 B.P. At the three sites, and particularly at Lago di Vico, the decline in pollen concentration corresponds with records for cultivated plants such as *Castanea*, *Olea* and cereals. Significant percentage representation of these cultivated plants and also *Juglans* and *Vitis,* which suggests extensive cultivation, is recorded at Lago di Vico only after the date 2630±95 B.P. This cultivation does not seem, however, to be accompanied by forest clearance. In fact, after the decline at 3700 B.P., the forest progressively recovers, and overall maximum pollen concentrations are attained when *Castanea* achieves maximum representation.

Conclusions

A new pollen diagram from Lago di Vico (core V1) contributes substantially towards the reconstruction of the vegetational history of central Italy over the last 90 000 years as follows:

· Seventeen AMS ^{14}C dates, all internally consistent, provide a sound chronology for most of the sequence;
· An ^{40}Ar/^{39}Ar date indicates the age of the base of the record;
· Three successive forest expansions, that are stratigraphically equivalent to St Germain II (and Ognon?) and referred to by the local names, Etruria I, Etruria II and Etruria III, confirm and help refine the vegetational oscillations at the nearby site of Lagaccione. Correlation of the relevant parts of the cores from these sites is supported by tephrostratigraphy;
· A number of weak expansions of angiosperm tree pollen during the pleniglacial contributes to the recognition and characterization of the "Lazio complex" at Lago di Vico (core V1) and in three other long pollen records from the region. It is concluded that tree refugia were not far away;
· The late-glacial tree expansion recorded in core V1 appears less important than at other sites in the region. This suggests that forest conditions were not attained in the vicinity of Lago di Vico though the possibility of a hiatus cannot be excluded;
· A forested landscape is rapidly established at the beginning of the Holocene and is maintained with no substantial floristic variations until about 2600 B.P. Nevertheless, important environmental changes, clearly signalled by sudden and marked declines in the pollen concentration diagram, occur several times during the Holocene;
· Clear signs of extensive farming activity are recorded only after 2630±95 B.P.; and,
· Core V1 from Lago di Vico has provided one of the best Holocene pollen sequences from Italy. It records, without interruptions, the history of vegetation and environment until at least Roman times.

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