Sediments from Lago di Mezzano, central Italy: a record of Lateglacial/Holocene climatic variations and anthropogenic impact

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Abstract: Microscopic, geochemical and pollen analysis of sediment samples of a Lateglacial/Holocene profile from Lago di Mezzano, a maar lake in central Italy, reveals evidence of significant climatic and human-induced environmental changes. Time control is provided by a combination of varve chronology and radiocarbon dating. The well-known Lateglacial climatic variations, a warmer interstadial and the Younger Dryas cold phase are clearly represented in all the parameters. During the interval between 9200 and 5600 cal. BP of the Holocene climatic optimum, annually laminated, organic-rich diatom gyttja was deposited. Two periods of diminished total organic carbon are identified within this interval. The first one (P1) ranges from 8200 to 7800 cal. BP while the second (P2) is centred around 6500 cal. BP. During P1, a predominance of diatoms (*Stephanodiscus parvus* and *S. minutulus*) over other algae (represented by the total organic carbon content) is observed. The timing of this period coincides with the early- to mid-Holocene climatic transition, reported from ice cores and lake sediments (Stager and Mayewski, 1997). P2 is characterized by a decrease in all biogenic parameters including biogenic opal, organic carbon as well as arboreal pollen. From 5000 cal. BP to date, the sediment pattern changes coincide with the mid-Holocene climatic deterioration. In addition to these natural variations, human impact has been recorded and recognized from sedimentological features such as turbidites and charcoal, as well as from reduced arboreal pollen content. Two Middle Bronze Age (3700 cal. BP and 3300 cal. BP), Etruscan/early Roman (2500 cal. BP), Longobardic (AD 900) and 'modern settlements' (since AD 1700) have been distinguished on the basis of these data.

Key words: Laminated sediments, geochemical evidence, pollen analysis, diatoms, climatic change, human impact, Lago di Mezzano, central Italy, Lateglacial, Holocene.

Introduction

It is widely accepted that the Holocene, though relatively stable compared to the fluctuations of the previous glacial, is characterized by several significant variations in climate. These variations have been recorded in oxygen isotope data of ice cores (O'Brien *et al.*, 1995), coral records (Beck *et al.*, 1997), and marine archives (Sirocko *et al.*, 1993; Bond *et al.*, 1997), as well as in high-resolution studies of lacustrine sediments (Ariztegui *et al.*, 1996a; 1996b; Kelts, 1997).

In addition to the advantages of varve dating, lacustrine laminated sediments provide many proxy data that give information about past environmental conditions. These data include organic carbon and biogenic opal that represent the biogenic productivity of the lake, as well as dry density, that represent the input of minerogenic components. The interpretation of such data sets with respect to climate change, however, is restricted by uncertainties such as:

(1) organic carbon as an indicator of temperature, productivity and/or bottom-water conditions: preservation versus production of organic carbon;

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(2) dilution of biogenic matter content by minerogenic influx: biogenic matter flux versus minerogenic accumulation;
(3) the source of the organic matter: aquatic versus terrestrial origin;
(4) the general forcing of the sedimentological system: climatic versus anthropogenic influence.

The aim of this study is to identify climatic changes using different proxy-parameters derived from a lacustrine sediment core from central Italy. The parameters used to assess the lake's principal sedimentation processes and its relationship with changing climatic conditions during the Lateglacial and Holocene include:

- the microscopic investigation of the sediment structure (laminations and their composition);
- the determination of the ratio of organic and inorganic matter;
- information about the source of organic matter (by way of Rock Eval pyrolysis);
- information about changes in the trophic conditions (as indicated by the dominant diatom occurring);
- information about the vegetation in the catchment area (by palynology);
- comparison with other lacustrine archives that will provide evidence of the regional or global significance of the discussed climatic changes.

Setting of the investigated site

Lago di Mezzano (42°37′N, 11°56′E, 452 m a.s.l.) is a small maar lake located in central Italy (Figure 1), west of Lago di Bolsena, 100 km north of Rome. It is 800 m wide and has a maximum water depth of 31 m. The lake surface area is 0.5 km^2, and the catchment area is *c*. 1 km^2 (the catchment to lake surface ratio is 2.03) with no surface inflow and only one outflow of minor importance. It has a U-shaped morphology with a flat central part and steep sidewalls (Figure 1). Situated in the Caldera di Latera, the maar was formed by a phreatomagmatic eruption at the end of the volcanic activity in the Vulsinian mountains 100 kyrs ago (Nappi *et al.*, 1995).

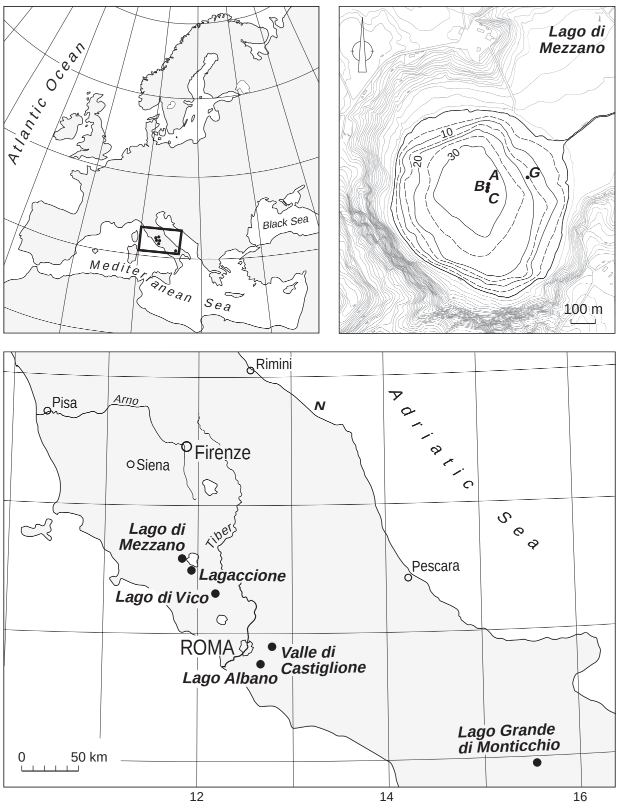

Figure 1 Location of Lago di Mezzano with bathymetric map.

Located between the Mediterranean in the southwest and the Apennine mountains in the northeast, the Latium region has a strong precipitation gradient from northeast to southwest in line with the transition from the temperate to the Mediterranean climatic zone. Mezzano is located in the temperate zone. It has a high mean annual precipitation (1000 mm/a) which falls mainly in early winter (October to December) and dry, warm summers (Blasi, 1994). In Valentano, the closest city to the lake, the mean annual temperature is 13.1°C. Tree vegetation in the Latium region consists of mixed oak woods dominated by *Quercus robur* and *Q. cerris* with hornbeams (*Carpinus betulus*), chestnut (*Castanea*) and beech (*Fagus sylvatica*). Around the lake shore, *Alnus*, *Salix* and *Populus* are the most common trees. Present-day limnology is characterized by mesotrophic to oligotrophic conditions evidenced by a low conductivity (between 204 and 212 mS/cm), very low phosphorous content ($<$0.005 mg/l SRP) in the water, a pH of 8 and a warm-monomictic behavior with one single overturn in autumn. It is assumed that an anoxic hypolimnion is established during summer months, because measurements of dissolved oxygen in the water column in spring show a depletion of oxygen in the bottom water (Ramrath, 1997).

Material, methods and chronology

The sediment cores were recovered from Lago di Mezzano in May 1995 using a modified Livingston piston corer (Usinger corer). Three parallel cores were taken from the centre of the lake, each with a minimum length of 28 m. Two of the parallel cores were investigated petrographically and geochemically (Ramrath, 1997). A series of large-scale thin sections (10 cm in length) was prepared and microscopically analysed. Semi-quantitative analyses of the dominant diatom species, charcoal and siderite were performed by estimating the amount of each component on a scale of 0 (not existent) to 4 (abundant). For benthic and planktonic diatoms these numbers were added up and a ratio was calculated. Volumetric sediment samples covering 1 cm slices were taken every 5 cm and analysed for dry density (DD), total carbon (TC), total sulphur (TS), total inorganic carbon (TIC) and biogenic opal (BiO). TC and TS were measured by standard LECO combustion at 1350°C. The amounts of CO_2 and SO_2 liberated were measured by infrared absorption spectrometry. TIC was analysed by coulometry, which is based on the analysis of the amount of CO_2 produced after sample treatment with 85% phosphoric acid. TOC was calculated by subtraction of TIC from TC. BiO was determined by an XRD-method (Brauer *et al.*, 1999), which is based on the calculation of the amount of amorphous components in a sample that was previously combusted in order to remove any organic matter. Loss-on-ignition (LOI) at 550°C was also determined. Pollen samples were prepared at 32 cm intervals, between 4 m and 7 m at 16 cm intervals. About half a gram of dry sediment was chemically treated with HCl (30%), HF (40%) and hot NaOH (10%). *Lycopodium* spores tablets were added to each sample to calculate the pollen concentration. More than 120 samples were analysed under the microscope, counting 466 terrestrial pollen grains in average. The sediment is very rich in generally well-preserved pollen. An AP/NAP curve obtained by preliminary pollen counts is presented. In addition to these analyses Brandt *et al.* (1999) and Wilkes *et al.* (1999) investigated palaeomagnetism and organic chemistry for this site.

Sedimentation rates (in mm a^{-1}) were obtained from microscopic varve thickness measurements and presented as a mean value for every 1 cm slice of sediment, where each slice corresponds to the dry density sampling depths respectively. The sediment accumulation rate SAR (in mg cm^{-2} a^{-1}) was calculated by multiplication of dry densities and corresponding sedimentation rates. Based on these data, flux rates (in mg cm^{-2} a^{-1}) were calculated.

The amount of total organic matter was calculated by multiplication of TOC with a factor of 1.81, which was previously determined by correlation of LOI and TOC (Ramrath *et al.*, 1999b). Biogenic matter (BiM) is the sum of organic matter and biogenic opal, while minerogenic matter (MiM) is the difference between 100% and BiM (Ramrath, 1997).

The chronology (Figure 2) was established on the basis of varve thickness measurements, interpolated sedimentation rates and several radiocarbon dates (Ramrath *et al.*, 1999a). A total of 5529 layers was measured. Evidence that these layers are annual was derived from the diatom bloom layers and succession and from their similarity with varves described from the Holocene lake sediments from Lake Holzmaar, Germany (Zolitschka, 1990). Radiocarbon ages were measured from the organic fraction of the bulk sediment with the AMS method, carried out by Beta Analytic Inc., Florida, and then were calibrated using the calibration program of Stuiver and Reimer (1993). All ages refer to calendar years and can be compared directly. Between 9010 and 870 cal. BP, ages are based on the floating varve/sedimentation rate chronology. Bioturbated intervals were interpolated using the mean sedimentation rates of the laminated adjacent sections. The top and the lower parts of the profile were dated using calibrated radiocarbon dates (Figure 2). Dating error is likely to be not greater than 5% as it is assumed for other timescales derived from similar methods (Zolitschka and Negendank, 1996; Zolitschka, 1998).

The Lateglacial/Holocene section comprises a total of 14 500 calendar years. An absolute time marker is provided by the tephra layer deposited after the Avellino eruption of the Somma-Vesuvius volcano which has an age of 4020 cal. BP according to this chronology and 4100 cal. BP according to Calanchi *et al.* (1996) and Alessio *et al.* (1974). It is also a major marker layer for the comparison with other lacustrine profiles of the region.

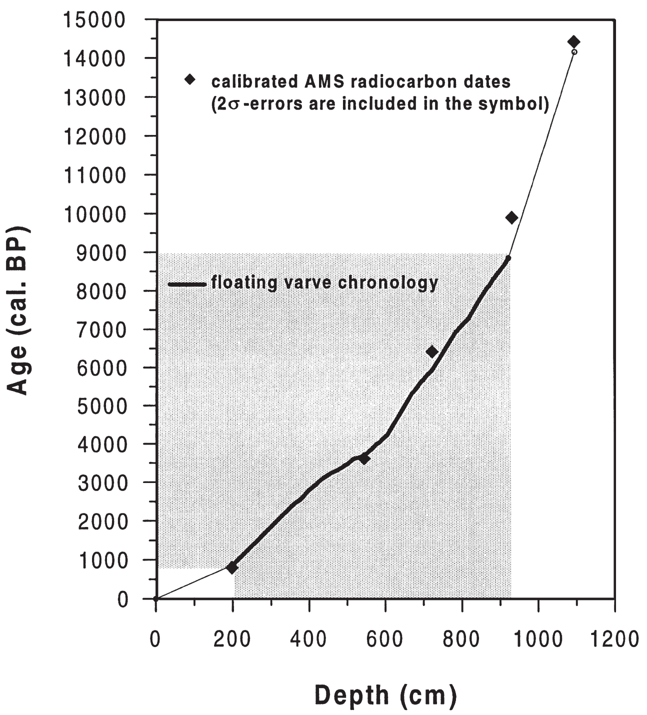

Figure 2 Age-depth diagram. The shaded section is dated by varve counting.

Results and discussion

The Lateglacial/Holocene record is subdivided into three units: A, B and C. Unit C comprises the Lateglacial and is characterized by the change of organic to more minerogenic sediment corresponding to the cooler conditions of the Younger Dryas that extends from 12 600 to 11 400 cal. BP (Ramrath *et al.*, 1999a). Unit B, which dates from 11 400 to 3700 cal. BP, is mainly composed of laminated organic diatomaceous gyttja, whereas unit A, which extends from 3700 cal. BP to present, is dominated by more clastic sediment, containing a substantial amount of turbidites.

Unit C: the Lateglacial (14 500 to 11 400 cal. BP)

Since 14 500 cal. BP the climatic amelioration of the beginning Lateglacial is represented by increased biogenic sedimentation as revealed in high TOC (rising to >11% at 13 500 cal. BP) and BiO values (rising up to 30% at 13 500 cal. BP) and low dry density (<0.4 g cm^{-3} for the whole interval) (Figure 3). Additionally, the AP curve reveals a prominent peak of 75% between 14 000 and 13 000 cal. BP, mainly due to angiosperm trees (up to 70%) indicating wetter and/or warmer climatic conditions (Figure 3). However, flux rates do not show this climatic amelioration clearly. This is partly due to the low sedimentation rates, which diminish the resolution of the samples (Figure 3).

At 12 600 cal. BP, dry density and minerogenic flux increase. The sediment is bioturbated and the lake level was probably low during this time as indicated by a corresponding sediment hiatus in a profile recovered from 17 m water depth (Ramrath, 1997). A drop in TOC and BiO is also seen, beginning at 12 650 cal. BP and ending at 11 400 cal. BP (Ramrath *et al.*, 1999a). In addition the angiosperm trees undergo an important drop from 80% to 20%. These changes are due to the climatic deterioration of the Younger Dryas. The ages correspond well with dates from other European lacustrine archives (Goslar *et al.*, 1995; Brauer *et al.*, 1997; Zolitschka, 1998).

Unit B: the early Holocene (11 400 cal. BP to 3700 cal. BP)

The beginning of the Holocene is characterized by a continuously decreasing flux rate of minerogenic matter (from 7.5 to 3.5 mg cm^{-2} a^{-1} at 9000 cal. BP). AP values increase from 25% to more than 80% and TOC and BiO from 7 to 13% and 25 to 40%, respectively, while TS-content shows large variations of around 0.8% (Figure 3). The sediment is bioturbated.

At 9000 cal. BP a significant change took place. BiM-flux exceeds the MiM-flux and annual layers were deposited, making available a varve chronology as an additional dating method. TOC and BiO are high. Between 9000 and 5000 cal. BP pollen data shows that full forest conditions are achieved with AP values reaching 100% and very high total pollen concentration values (around 1 000 000 grains/gram). Several explanations for this type of development are possible (Ariztegui *et al.*, 1996a; Robinson, 1994; Truze and Kelts, 1993). They include:

(1) climatic amelioration enhanced conditions for aquatic productivity and organic carbon production due to warmer temperatures, as well as enhancing chemical weathering and related nutrient supply into the lake; the lake became eutrophic with an anoxic hypolimnion, which enhanced the preservation of organic matter and the development of annual laminations;
(2) a dense vegetation cover of the catchment area prevented and reduced the allochthonous input to the lake.

Analysis of the Hydrogen index (HI) and Oxygen index (OI) of the sediment samples from Lago di Mezzano (Wilkes *et al.*, 1999) reveal evidence that organic carbon in this sediment unit is derived from planktonic rather than from terrestrial plants indicating a high lacustrine productivity between 9000 and

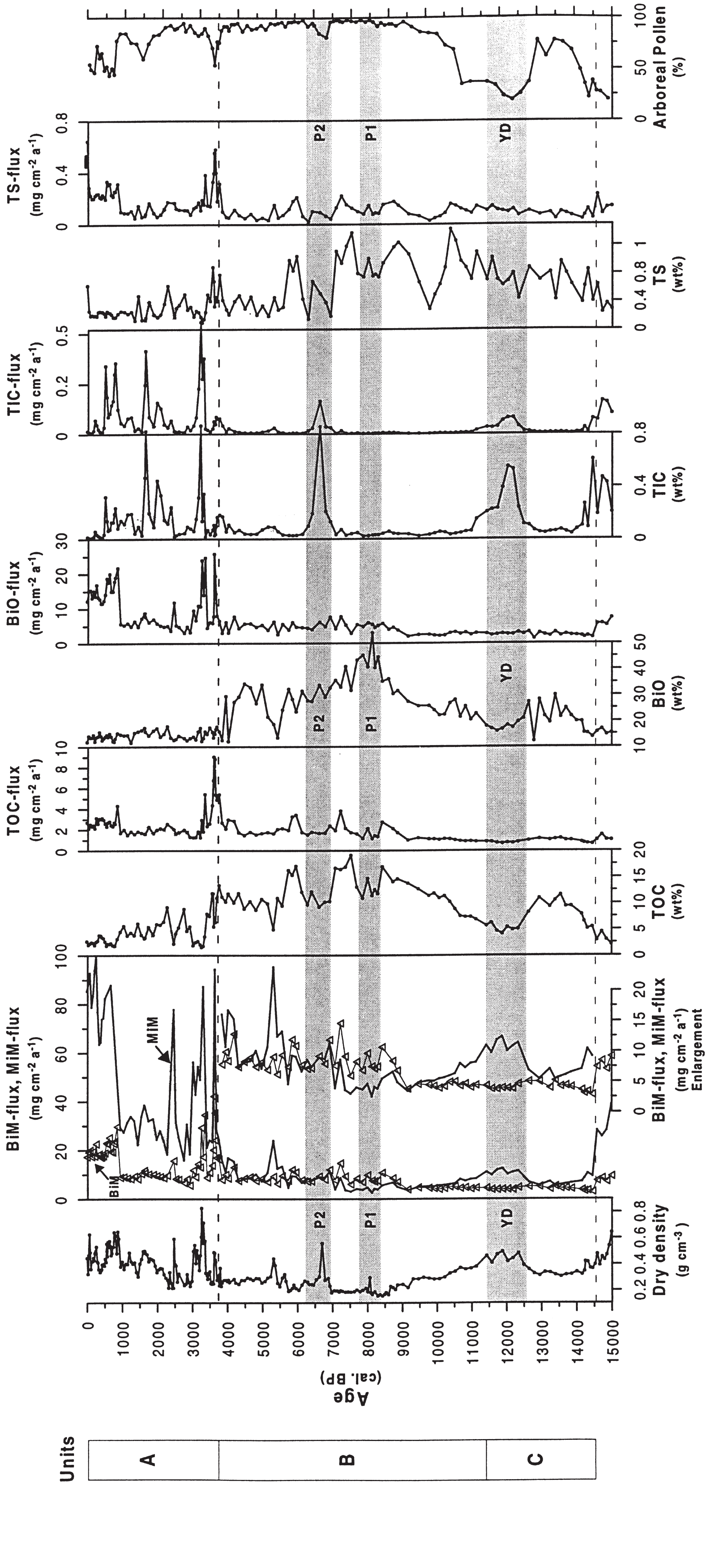

Figure 3 Sedimentological properties of the profile: dry density, biogenic matter (BiM-flux), minerogenic matter (MiM-flux), total organic carbon (TOC), biogenic opal (BiO) total inorganic carbon (TIC), total sulphur (TS) and arboreal pollen concentration plotted versus time. The Younger Dryas, two periods of diminished primary productivity, and the sediment section influenced by anthropogenic activities are highlighted.

5600 cal. BP. This is supported by a higher amount of planktonic diatoms than benthic forms (Figure 4). Changes in the algal assemblage, however, can be identified throughout this interval. Microscopic investigations show that *Stephanodiscus* and *Fragilaria* are the most prominent planktonic diatom genera contributing to summer blooms, but these genera are replaced by *Cyclotella* and *Aulacoseira* species at certain intervals. It is possible, that the changes in diatom genera may be responsible for the fluctuations in BiO concentration. According to the Rock Eval data (Wilkes *et al.*, 1999) blue-green algae seem to be dominant between 7500 and 6800 as well as between 6200 and 5500 cal. BP. The autumn/winter layers are generally composed of epiphytic diatoms and terrestrial plant remains.

TOC is generally high (15–20%) between 9000 and 5600 cal. BP, but two periods of lower values were identified, P1 between 8200 and 7700 cal. BP (mean: 12%) and P2 between 6800 and 6200 cal. BP (mean: 10%).

BiO concentration is the highest in P1, reaching more than 50% of the sample, while the flux rate is moderate due to low sedimentation rates. BiM-flux is still well above MiM-flux which is indicative of high productivity and low minerogenic influx. The varves are easily identified, because diatom bloom layers were deposited during spring and summer. The good preservation of the varves may be used to assume a high lake level, which in turn could be a sign of wet conditions with a high runoff. The TOC minimum suggests that productivity and possibly temperatures were lower.

The diatom layers start to diminish after 7700 cal. BP, when TOC increases to values around 20% (Figure 3). Non-siliceous algae seem to become increasingly important, indicating that conditions were favourable for a high aquatic productivity and good preservation of organic matter at the sediment surface.

Trophic conditions probably changed during the second TOC minimum P2 (6800 to 6200 varve years BP). Here the sediment is bioturbated and laminations are disturbed indicating oxic conditions at the sediment surface. Layers of siderite occur and appear as peaks in TIC content. BiM-flux decreases, but not below the level of MiM-flux (Figure 3). BiO is still relatively high (mean: 30%), but steadily decreasing. In addition, pollen content exhibits a slight decrease (Figure 3) over a short period of time, both for AP percentages (from 95% to 80%) and total pollen concentration (from 900 000 to 300 000 pollen grains/gram). These findings may be indicative of a drop in the mean precipitation that in turn caused decreased runoff and lower lake levels as well as restricted plant growth in the catchment area.

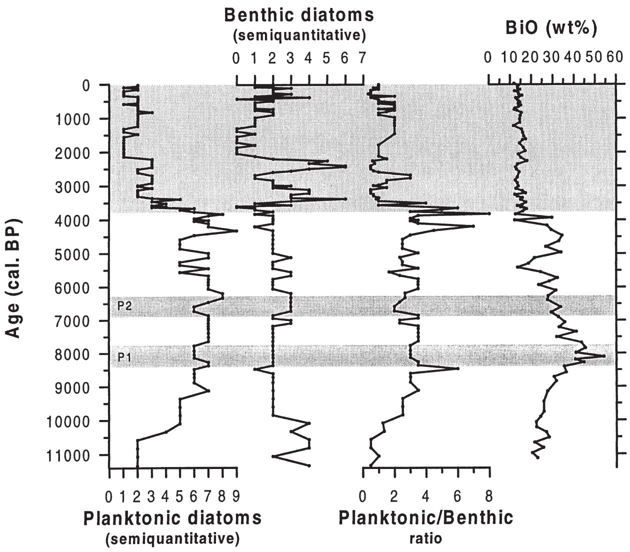

Figure 4 Semiquantitative occurrence of planktonic and benthic diatoms estimated by microscopic analyses. The ratio of planktonic and benthic diatoms is compared with biogenic opal (BiO).

From 6200 to 5200 cal. BP the lake level presumably rose again resulting in a sedimentation pattern similar to the one before 6800 cal. BP with regular organic diatomaceous laminations and both high organic carbon content and flux rate.

From 5000 to 4200 cal. BP the sediment pattern changed. *Stephanodiscus* decreased and the dominant diatom species was *Aulacoseira subarctica*, correlating with a maximum in BiO concentration. As *Stephanodiscus* is generally attributed to more eutrophic waters than *Aulacoseira* (Kilham *et al.*, 1996; Bennion, 1995), this change may indicate a period of more oligotrophic conditions. The sediment structure during this interval is not regularly laminated and certain sections are bioturbated. The re-establishment of benthic fauna suggests an oxic hypolimnion and holomixis providing oxygen. Explanations for this change include a lower lake level as well as a reduced nutrient transport into the lake, due to a low precipitation/evaporation ratio, which reduces the runoff into the lake, and thus the nutrient and water supply. This change could be a result of drier and cooler climatic conditions.

Unit A: late Holocene (from 3700 cal. BP to present)

Since 3700 cal. BP the impact of human presence is recorded in the sediments masking the climate signal. Both the increasingly clastic sediment (high MiM-flux and high dry density) and the occurrence of turbidites are indicative of a disturbance in the catchment area of the lake. Charcoal, which was found in some thin sections, may also be regarded as an indicator of human activity (forest clearance around the lake). Additionally, the deposits consist of redeposited lake sediments caused by lower lake levels as demonstrated by the occurrence of *Campylodiscus hibernicus*, a diatom typical for cold environments (Haworth, personal communication 1997). This diatom is not found in the Holocene record of Mezzano before 3300 cal. BP (Ramrath *et al.*, 1999a). As this diatom species is common in the Lateglacial sediments when the lake was larger than today, its presence in younger sediments may be used as an indicator of both low lake levels and soil erosion processes due to forest clearance in the catchment area. Its presence only in the uppermost part of the profile may be explained by the protection of these old lake sediments by vegetation or overlying soils during the first part of the Holocene.

Five distinct settlement periods were distinguished and compared with independent archaeological information from the region (Figure 5) based on Pettiti and Mitchell (1993).

Middle Bronze Age settlements (pile dwellings) at Lago di Mezzano have been found in present-day water depth of 6 to 12 m (Petitti and Mitchell, 1993). The lake level must have been at least 8 m lower at that time. This period is represented in the sediment profile by a first peak of minerogenic flux at 3700 cal. BP with values 15 times higher than before and is related to increased varve thickness. The increase in TOC-flux (Figure 3) and planktonic diatoms (Figure 4) may be related to human-induced eutrophication, although Rock Eval results show that most of the organic matter is of allochthonous origin (Wilkes *et al.*, 1999). Strongly decreased AP percentages (from 90% to 54%) and dropped concentration values (from 1 500 000 to 70 000 pollen grains/gram of dry sediment) are recorded. During the Middle Bronze Age (around 3300 cal. BP) the settlements were abandoned, due to rising lake levels (Franco, 1982) indicating increased precipitation. The massive occurrence of turbidites at 3300 cal. BP (Figure 5) is indicative of disturbances in the vegetation cover within the catchment area, possibly due to forest clearance, that resulted in an increased availability of minerogenic detritus. Deforestation is also an explanation for the significantly decreased AP concentration values (60 000 pollen grains/gram).

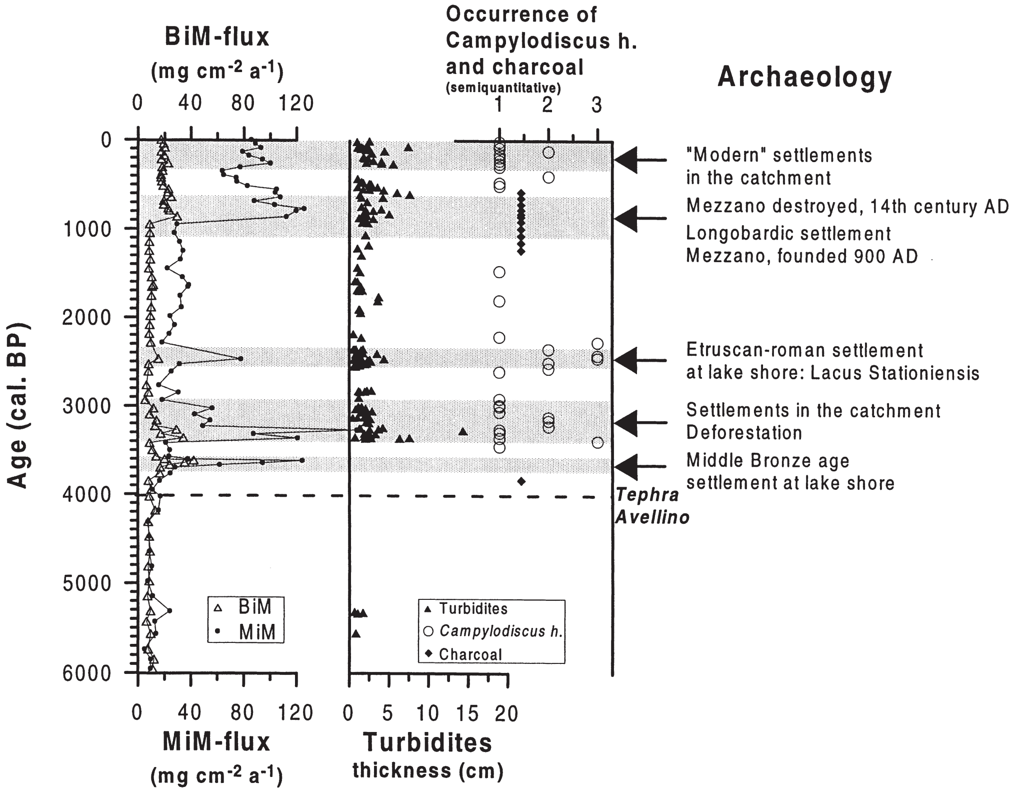

Figure 5 Evidence for human impact on sedimentation recorded in biogenic matter (BiM-flux), minerogenic matter (MiM-flux), the occurrence and thickness of turbidites, the occurrence of *Campylodiscus hibernicus* and charcoal, compared with archaeological data.

Additionally, a low ratio of planktonic and benthic diatoms (Figure 4) shows that influx into the lake from the shores became increasingly important.

At 2500 cal. BP another peak in turbidite occurrence indicates a settlement phase, probably correlating with the Roman village Lacus Stationiensis (Luzi and Scipioni, 1994). The morphological terrace visible around the modern lake (personal observation and survey; Palagiano, 1969) indicates that the lake level was probably 3 m above its present-day level and therefore the surface area of the lake was greater. In time, the outflow, Fosso delle Volpi-Olpeta, was deepened, causing the lake level to decrease and the swamp to drain (Palagiano, 1969). This interference with the natural environment is reflected by the detritic deposition from the shores and the occurrence of benthic diatoms (Figure 4). In addition, the redeposited diatom species *Campylodiscus hibernicus* within the turbidites is also reflected as a peak of BiO-flux (Figures 3 and 4). Furthermore, palynological data show a decrease of arboreal pollen concentration in the sample corresponding to 2500 cal. BP.

The uppermost interval since 1000 cal. BP is characterized by an increase in both biogenic and minerogenic matter as shown by high sedimentation rates and high dry densities. However, the increase of BiM-flux is much lower than MiM-flux. Moreover, the low hydrogen index (Wilkes *et al.*, 1999), suggests that the organic matter is mostly allochthonous.

As far as the settlement history is concerned, charcoal remains detected in the thin sections (Figure 5) provide evidence of human activity in the catchment area. These remains occur abundantly from 1100 to 600 cal. BP. Archaeological data confirm the presence of a longobardic settlement called Mezzano founded AD 900 (1050 cal. BP) which was destroyed in AD 1348 (Luzi, 1990). Human activity in the catchment area would also explain the presence of many turbidites in this segment of the profile, the diminished AP percentages (from 80% to 50%) and pollen concentration reduced to 35 000 pollen grains/gram. The diatom *Campylodiscus* recurs at around 600 cal. BP, becoming more abundantly after 300 cal. BP until present (Figure 5) that indicates lowering of lake levels. This interpretation is again supported by historical data of human activity (drainage) in the eighteenth century and during the beginning of the twentieth century (Palagiano, 1969).

Comparisons with other records

Regional comparisons

For regional comparison of the major changes found in the Mezzano record the following lake-sediment studies have been taken into account: Lago Albano/Lago di Nemi (Guilizzoni and Oldfield, 1996) and Valle di Castiglione (Alessio *et al.*, 1986), all located near Rome in the Alban Hills, Lago Grande di Monticchio (Zolitschka and Negendank, 1996), located in Basilicata, southern Italy, Lagaccione (Magri, 1999), located in the Vulsini volcanic district and Lago di Vico (Magri and Sadori, 1999), located south of Lago di Mezzano in the Vico volcanic district. Table 1 shows the principal corresponding results, on which data they are based, and their references.

The summarized results confirm that the information about climate change during the Holocene derived from different sites seems to be consistent. Taking into account the varying methods of dating and investigating the sediment profiles, the results support the natural variations as well as the human influence on the sedimentation processes found in the Mezzano record. Comparisons of the profiles show that the period P1 between 8200 and 7800 cal. BP is of major importance for the region. In lakes Albano and Nemi a decline in primary productivity (Manca *et al.*, 1996) is recorded along with a dominance of diatoms (Ryves *et al.*, 1996) which is consistent with the results from the Mezzano profile. In the Albano lakes (Lowe *et al.*, 1996) as well as in Lagaccione (Magri, 1999) and Vico (Magri and Sadori, 1999) a reduction in vegetation density in the catchment area is indicative of cooler temperatures. However, apart from the high lake levels

Table 1 Regional comparison of six different lakes with respect to the suggested climatic changes recorded in the sediments of Lago di Mezzano

Name	Mezzano	Albano/Nemi	Monticchio	Castiglione	Lagaccione	Vico
Younger Dryas	12 650 to 11 400 cal. BP	12 500 to 11 480 cal. BP Based on: sedimentology Ref: Chondrogianni *et al.*, 1996	12 830 to 11 590 cal. BP Based on: pollen, sedimentology Ref: Watts *et al.*, 1996, Zolitschka and Negendank, 1996	Ending 10 800 uncal. BP Based on: pollen Ref: Alessio *et al.*, 1986	11 200 to 10 850 uncal. BP Based on: pollen Ref: Magri, 1998, submitted	
Climatic optimum	9000 to 5000 cal. BP	9000 to 6500 cal. BP Based on: TOC, biogenic input Ref: Ariztegui *et al.*, 1996a	7700 to 5500 cal. BP Based on: TOC, pollen Ref: Zolitschka, 1998, Watts *et al.*, 1996			
P1: possibly cool and wet	8200 to 7800 cal. BP	8500 to 7300 cal. BP Based on: diatoms, algal remains, pollen Ref: Manca *et al.*, 1996, Ryves *et al.*, 1996, Lowe *et al.*, 1996			7000 uncal. BP Based on: pollen Ref: Magri, 1998, submitted	7025 uncal. BP Based on: pollen Ref: Magri and Sadori, 1998, submitted
P2: possibly dry	6800 to 6200 cal. BP	6400 cal. BP Based on: diatoms Ref: Ryves *et al.*, 1996				
Mid-Holocene climatic deterioration: dry and cool	5000 to 4000 cal. BP			3900 to 3500 uncal. BP Based on: pollen, $\delta^{18}O$ on mollusc shells Ref: Alessio *et al.*, 1986, Follieri *et al.*, 1988, Bonadonna and Leone, 1995	3750 uncal. BP Based on: pollen Ref: Magri, 1998, submitted	3700 uncal. BP Based on: pollen Ref: Magri and Sadori, 1998, submitted
Human influence	From 3700 cal. BP	From 4000 cal. BP Based on: sedimentology, diatoms, pollen, rock magnetism Ref: Ariztegui *et al.*, 1996, Ryves *et al.*, 1996, Lowe *et al.*, 1996, Rolph *et al.*, 1996		From 3200 uncal. BP Based on: pollen Ref: Follieri *et al.*, 1988		2600 uncal. BP Based on: pollen Ref: Magri and Sadori, 1998, submitted

at Lago di Mezzano, there is not much evidence concerning the postulated increased precipitation.

The period P2 between 6800 and 6200 cal. BP is not as well documented in the other lake profiles. Only the records of Lake Nemi show a reduction of primary productivity around the same time (Ryves *et al.*, 1996).

The identified climatic change between 5000 and 4000 cal. BP (the mid-Holocene climatic deterioration) has been recorded in many different archives and regions all over Europe (Kelts, 1997; Yll *et al.*, 1997; Perez-Obiol and Julia, 1994) as well as on other continents. Results of palaeolimnological studies in the Sahara, for example, provide evidence of a major decline in precipitation at around 4.5 kyrs BP (Ritchie *et al.*, 1985). Additionally, a climatic deterioration is recorded in many archives including archaeological evidence across the Mediterranean region during the third millennium BC (Dalfes *et al.*, 1997). This period possibly correlates with the major social structural changes in the early societies of Greece, Mesopotamia and Egypt. A rapid moisture balance shift around 4000 years BP with impact in the different regions and cultures all over Europe has been also proposed by Kelts (1997). This shift has been observed in many lakes in central Italy as evidenced by widespread lake level lowering in Latium by several metres (Fugazzola Delpino, 1982) prior to the Bronze Age.

There is also a general agreement concerning the onset of detectable human influence in this region. Apparently, the Early Bronze Age was the first period leaving major impact on the environment and sedimentation processes in the lakes as well as on the vegetation in the catchment areas of the lakes. Only Lago Grande di Monticchio does not show major evidence of change at that time. At Lago di Vico, the major forest reduction took place at 3700 uncal. BP, but widespread expansion of cultivated plants is evident only from 2600 uncal. BP (Magri and Sadori, 1999).

Comparison with the oxygen isotope record

The comparison of the oxygen isotope record of the GRIP ice core (Johnsen *et al.*, 1992) with the TOC of the Mezzano profile shows some close similarities (Figure 6). At the beginning of the

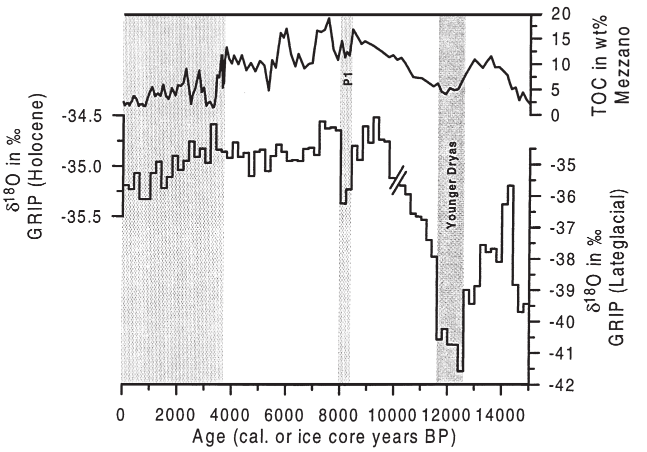

Figure 6 Comparison of the TOC-content of Lago di Mezzano with the oxygen isotope record of the GRIP ice core (Johnsen *et al.*, 1992). The Younger Dryas and the climatic deterioration at 8000 BP are highlighted.

Holocene, the warmer temperatures are reflected in high $\delta^{18}O$ values and high TOC contents. Around 8000 ice core years BP, $\delta^{18}O$ values exhibit a significant minimum which also seems to be a global phenomenon (O'Brien *et al.*, 1995) recorded in both lacustrine (Stager and Mayewski, 1997) and marine archives (Bond *et al.*, 1997). This global climatic transition, that has been referred to as early- to mid-Holocene transition (EMHT; Stager and Mayewski, 1997) may be correlated with the TOC minimum P1. Evidence from marine investigations on ice-rafted debris layers (Bond *et al.*, 1997) as well as on soluble impurities in ice (O'Brien *et al.*, 1995) support that this transition is a result of climatic deterioration, a global cooling event. In earlier discussions (Bond *et al.*, 1997; Watts *et al.*, 1996; Ramrath *et al.*, 1999b) concerning global cooling events during the Pleistocene, these lower temperatures generally correspond with an intensified west wind system bringing precipitation to the Italian peninsula. This might have been the cause for the decline in aquatic productivity recorded in the lakes of central Italy and for the contemporary high lake levels postulated for the Lago di Mezzano.

However, local and regional effects on the sedimentation of the lake must also be taken into account. In general, the TOC record cannot be regarded as a climatic parameter. There are many possible explanations why the carbon accumulation is reduced, the climatic factor being only one of them. Correlation of change for different archival material indicates a common influencing factor, which can only be attributed to climate. This seems to be true for the TOC-minimum P1, but not necessarily for P2. However, documentation indicates that the cooling event at 8000 cal. BP is only one in a series of similar events on a millennial timescale during the Holocene period (Bond *et al.*, 1997). These events result from substantial changes in the North Atlantic's surface circulation which is directly linked with the atmospheric circulation responsible for the general climatic conditions in the western Mediterranean region (Macklin *et al.*, 1995).

Conclusions

The present study was undertaken in order to identify Lateglacial and Holocene environmental changes by the investigation of various proxy data on a sediment profile from Lago di Mezzano, which is reliably dated by a combination of varve chronology and radiocarbon dating.

The Younger Dryas is well recorded as a period of high minerogenic influx. The first part of the Holocene, from 9000 to 5200 cal. BP, is considered as a climatic optimum, recorded by the deposition of annually laminated, organic-rich diatom gyttja. However, two short intervals of diminished organic sedimentation between 8200 and 7800 and between 6800 and 6200 cal. BP are identified. The first one correlates with the early- to mid-Holocene transition. This is a cooling period recorded in many other archives and probably of global importance. Another major change in sedimentation is documented between 5000 and 4000 cal. BP that corresponds with the climatic deterioration in the Mediterranean region.

The impact of human activity on lacustrine sedimentation seems to begin during the Middle Bronze Age (3700 cal. BP), masking the climatic signal in the sediments. Several periods of increased minerogenic input are observed: 3700 cal. BP, 3300 cal. BP (Middle Bronze Age), 2500 (Etruscan/Early Romans), and 800 cal. BP (Longobards), which are all related to archaeological and historically known settlements at the lake shore or in the catchment area (Petitti and Mitchell, 1993; Luzi and Scipioni, 1994; Palagiano, 1969).

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