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Interpretation of Holocene lake-level change from diatom assemblages in Lake Sidi Ali, Middle Atlas, Morocco *

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Abstract

While palaeohydrological changes in non-outlet lakes provide a key proxy indicator of past climatic fluctuations, for lake systems which have been chemically insensitive, it is necessary to use indicators of water depth rather than salinity to reconstruct their hydro- climatic histories. A study of diatoms in the modern sediments of Sidi Ali, a non-outlet lake in the Middle Atlas of Morocco, has shown a statistically significant correlation between water depth and the ratio of planktonic to littoral diatoms. This relationship is used to calibrate fossil diatom assemblages from a lake sediment core from the same lake to provide a quantitative index of water levels over the past *c.* 6500 years. Palaeoecological evidence suggests that climatically induced hydrological variations have dominated the bulk of the mid-late Holocene lake sediment record, with significant human-induced catchment disturbance only occurring during the twentieth century. The pattern of water depth fluctuations suggests that the response time of the regional groundwater system to climatic forcing is <100 years.

Introduction

The sedimentary record of water-level fluctuations in non-outlet lakes provides a proxy indicator of past climatic change (Street-Perrott & Roberts, 1983). Lake level in an endorheic basin is controlled directly by changes in the water balance, maintained by the precipitation/evaporation ratio. In many lakes, especially those in karstic areas, this simple relationship is complicated by groundwater flows which may be the dominant hydrological control on water level. Nevertheless, shallow aquifer systems also respond to climatic forcing with time lags of $<10^2$ yr (Almendinger, 1993); thus groundwater-moderated lakes may be regarded as windows in the regional groundwater system. Because changes in groundwater pathways (e.g. the opening and closing of outlets) can also alter lake level, regional climatic reconstruction must be supported by results from several basins.

A critical climatic parameter in lake-level studies is lake area, which can be reconstructed directly using palaeo-shoreline evidence. However, because former shorelines only preserve evidence of lake high-stands and provide a discontinuous time series for past water levels, most studies have concentrated on the continuous stratigraphic record provided by lake bottom sediments. No direct measurement of former water depth or lake area is possible from the diverse biological and chemical data sources contained in the lake sediment archive, and so attention has instead focussed on surrogate indicators of water level, especially salinity. Salinity may show a close but non-linear relationship with lake volume in endorheic systems and can be reconstructed using biological indicators such as diatoms (Fritz *et al.*, 1991) and ostracods (De Deck-

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ker, 1981), and geochemistry (Chivas *et al.*, 1986, Engstrom & Nelson, 1990). The quantitative reconstruction of water depth should none the less remain an important objective of palaeolimnological studies, and in chemically insensitive lakes it may be the only way of gauging the response of the lake hydrosystem to climatic change. In this study we examine the water-level fluctuations in a karstic lake which is known to be hydrologically responsive, but which exchanges water and salts through connection with groundwater. Although surficially closed it does not accumulate salts when water volume contracts, so past variations in lake level have not been matched by corresponding changes in salinity Here we utilise the relationship between diatom distribution and water depth in the present lake, to reconstruct lake-level change during the mid to late Holocene.

Site description

Aguelmam (= lake) Sidi Ali (33 ° 03′ N, 5 ° 00′ W) lies at 2080 masl in the Middle Atlas mountains of Morocco (Fig. 1). The present lake is 2 km long, 0.5 km wide and up to 65 m deep (Maxted, 1989). It comprises two basins which are periodically separated by a basalt ridge, as they were in September 1991 when the present study of the lake was undertaken. The smaller circular basin to the southwest, with which this study is concerned, has a maximum depth of 15 m and an area of 12.6 ha. The lake lies along a fault between Liassic dolomite to the north-west and limestone to the south-east. Sidi Ali is alkaline with a recorded pH of *c.* 9.1, but is relatively dilute with a conductivity of 1200–1400 μScm^{-1}. Alkaline earth carbonates predominate, especially Mg^{2+} ions, giving a Mg^{2+}/Ca^{2+} ratio of 3.4:1. Gayral (1954) monitored Sidi Ali over an annual cycle and found that during the summer the main lake was well stratified with surface temperatures of 20 °C and bottom waters of less than 8 °C, whilst in winter a temperature of less than 6 °C was found at all depths as a result of snowmelt. A similarly stratified dissolved oxygen profile was found by Dumont *et al.*, (1973) who concluded that Sidi Ali was mesotrophic. Water level has fluctuated markedly in recent times, and a shoreline defined by carbonate deposits on basalt was observed 5 m above the lake level at the time of sampling. Cartographic and air-photograph evidence confirms that the lakes were joined as recently as 1974.

The nearby meteorological station (2100 masl) records a mean annual precipitation of 817 mm (Martin, 1981), much of which falls as snow during the cold winter months (November–April) which have mean minimum temperatures of −6 °C. The vegetation of the area has been described by Lecompte (1986). It includes spiny xerophytic matorral, typified by *Erinacea anthyllis* Link, with scattered *Juniperus thurifera* L. An open, heavily degraded forest of *Cedrus atlantica* (Endl.) Carrière occurs on and to the southeast of the limestone scarp bordering the lake. Damp level ground on the southwestern lake margin is occupied by closely grazed herbaceous vegetation, commonly referred to as pelouse.

A number of palaeolimnological studies have been recently undertaken in the Middle Atlas region. Chronologically the longest record comes from Tigalmamine, 45 km southwest of Sidi Ali (Lamb *et al.*, 1989; El Hamouti *et al.*, 1991). This site has revealed water level and vegetation changes during the late Quaternary. The Holocene record is one of relatively high lake levels interrupted by abrupt regressions at 10 200, 7500, 4500, 3500 and 2500 ^{14}C yr BP. Pollen analysis has shown that cedar forests which now cover much of the region only arrived in the area *c.* 4500 ^{14}C years ago. Shorter sequences have demonstrated human impact on soils and lake nutrients during the late Holocene (Lamb *et al.*, 1991; Flower *et al.*, 1989). Twentieth century waterlevel changes at Lake Azigza, a lake also modulated by groundwater flows, have been shown to correlate with rainfall records (Flower & Foster, 1992).

Materials and methods

A 625 cm long core was taken from the smaller southwestern basin at a water depth of 5.65 m using a Livingstone piston corer (Wright *et al.*, 1983). The uppermost 130 cm of the sediment was collected using a piston-equipped perspex® tube and cut into 2 cm slices in the field. Modern diatoms were sampled from surface muds along a transect across the lake bed using a Hongve surface sampler (Wright, 1990).

Diatom samples were prepared from wet sediment containing the equivalent of 0.2 g of dry material when adjusted for water content. Organic material was removed using hot 30% H_2O_2 and carbonates with 10% HCl. The diatom samples were mounted on slides in Naphrax and 500 diatom valves were counted per sample. Identifications were based primarily on Krammer & Lange-Bertalot (1986, 1988, 1991a,

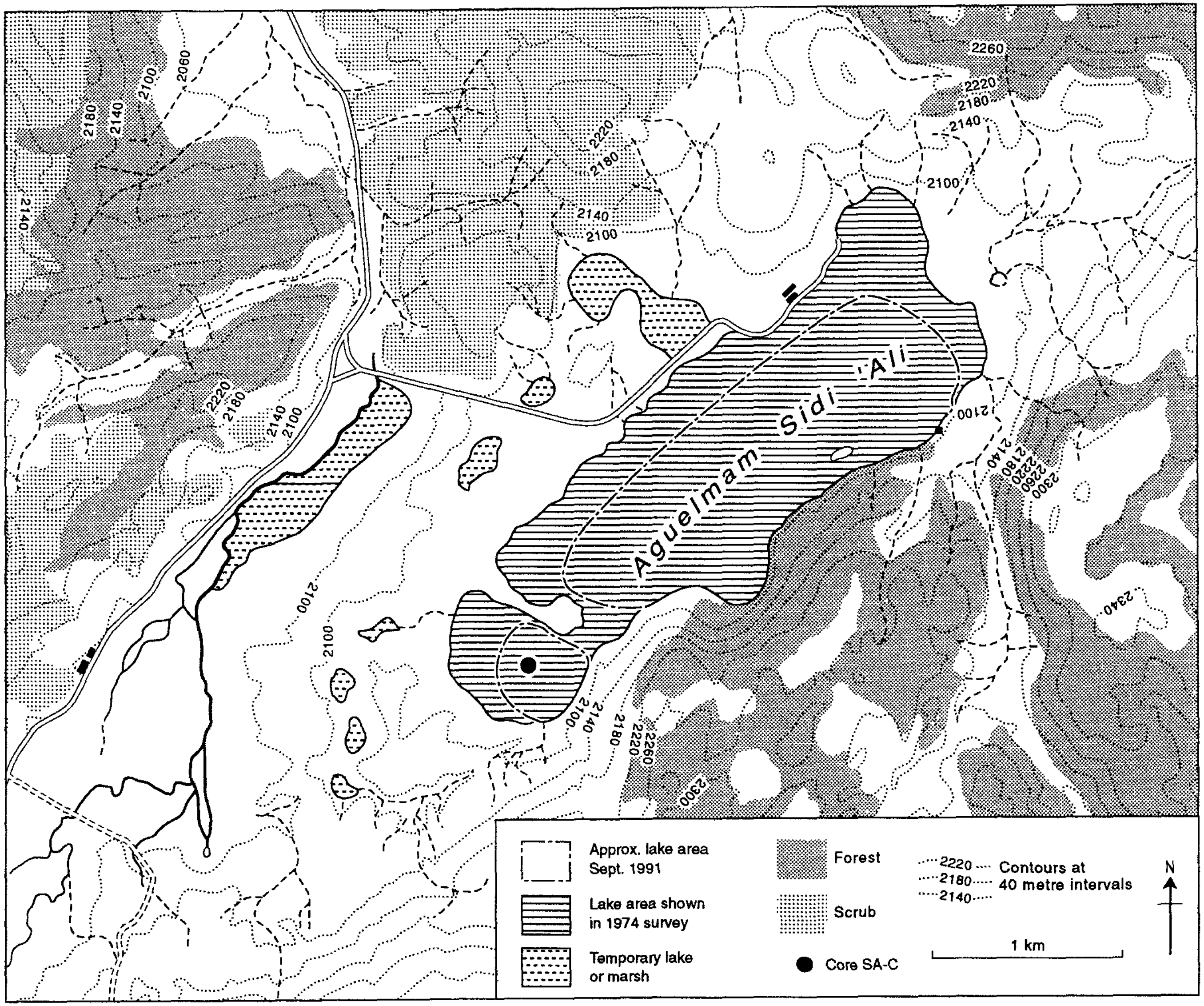

Fig. 1. Lake Sidi Ali. The lake is shown as it was in 1974 during the most recent survey, when the two basins were joined. In September 1991 the two basins were separated and greatly reduced in extent, especially to the north-west. The approximate position of the lake's margin in 1991 is shown.

Table 1. Regression equations describing the relationship between water depth (D) and four versions of $Log_{10}(P/L)$ ratio. Simple linear regression was used such that $Log_{10}(P/L)=a \cdot D-b$. The coefficients for the gradient of the regression line (a) and the intercept (b) are given for each version. The adjusted r^2 value accommodates the small sample size (n=6). An F-test was used to determine the significance of each version and probability that this relationship is a result of chance is given by p

	a	b	r^2	Adjusted r^2	$p =$
1	0.063	0.567	0.9	0.88	0.0039
2	0.085	0.884	0.95	0.94	0.0008
3	0.063	0.464	0.85	0.82	0.0081
4	0.086	0.801	0.91	0.88	0.0031

1991b) and Hustedt (1930). Diatoms were classified according to three habitat groups; planktonic, tychoplanktonic, and littoral using modern ecological data from Morocco (Barker unpublished). Littoral taxa in this study include all epilithic, epipelic, epiphytic, and shallow-water benthic life forms.

The organic and carbonate contents were determined using the weight-loss on ignition method at 550 °C (2 h), and 950 °C (1 hour) respectively.

Results

Modern diatom assemblages

Clear differences in diatom assemblage composition were found in the bottom mud samples taken at different water depths (Fig. 2). The marginal sediments are dominated by a typically diverse diatom flora including *Cocconeis placentula* (Ehr.), *Cymbella rutnerii* (Hust.) and *Amphora pediculus* (Kütz.) Grun. In contrast, the deeper water samples contain a higher proportion of *Cyclotella* af. *comensis* Grun. (*sensu* Krammer & Lange-Bertalot 1991, Fig. 1 p. 334) and *Cyclotella azigzensis* Flower & Håkansson. Total diatom abundance increases exponentially with water depth and both planktonic and littoral forms increased in absolute number (Fig. 3a). The absolute increase in littoral diatom abundance with water depth is paradoxical and presumably reflects either the focussing of fine littoral sediment toward the centre of the basin, or the dilution of the littoral samples by allochthonous materials.

The composition of the modern diatom assemblages is closely related to water depth. Particularly striking is the logarithmic relationship found between depth (D) and the Planktonic/Littoral ratio (P/L). This relationship is driven by the habitat classification allocating diatom species to either littoral or planktonic life-forms. This assumes life forms are well known for all species although, in fact, some uncertainty extends to the classification of members of the *Fragilaria* and *Cyclotella* genera. Our surface samples have helped to resolve the habitat affinities of problematic taxa. *Cyclotella* sp. 1 is found in the greatest relative abundance in the shallow water mudsamples of the littoral zone (Fig. 2). In absolute abundance terms it is evenly distributed across the basin. This distribution is in sharp contrast to the truly planktonic *C.* af. *comensis* and *C. azigzensis* which are more abundant in the deeper waters (Fig. 3b). Furthermore, water samples taken from the centre of both the large and small basins at Sidi Ali contain >90% *C.* af. *comensis*. More problematic is the life-form of *Fragilaria brevistriata* Grun., which is most abundant at intermediate depths in the present lake (Fig. 3c) and appears to be neither truly planktonic nor wholly littoral. *F. brevistriata* is considered here as tychoplanktonic (cf. Flower *et al.*, 1989).

In response to these uncertainties, four versions of the P/L ratio have been constructed:

1. All *Cyclotella* species classed as planktonic, all other species are littoral.
2. *C. azigzensis* and *C.* af. *comensis* only classed as planktonic, all other species are littoral.
3. As for 1 but excluding *Fragilaria* from either group.
4. As for 2 but excluding *Fragilaria* from either group (see Fig. 3d).

Regression equations describing the modern logarithmic distribution of the P/L ratio against water depth for each of these four versions of the P/L model and the statistical significance of these are shown by Table 1. Each of these relationships is significant at the 90% confidence level.

Core SA-C: lithostratigraphy and chronology

The sediments are rich in organic matter, especially at the base of the sequence and are largely brown-black fine gyttja rich in ostracods. Organic matter values in excess of 45% dry weight are found between 473 and 513 cm in a fine, black, organic mud poor in ostracods (Fig. 4). Calcareous material, most of which appears to be biogenic, reaches a maximum between 397 and 421 cm (up to 27% by weight) in a section of silt and sand. Clays are more abundant in the upper 200 cm.

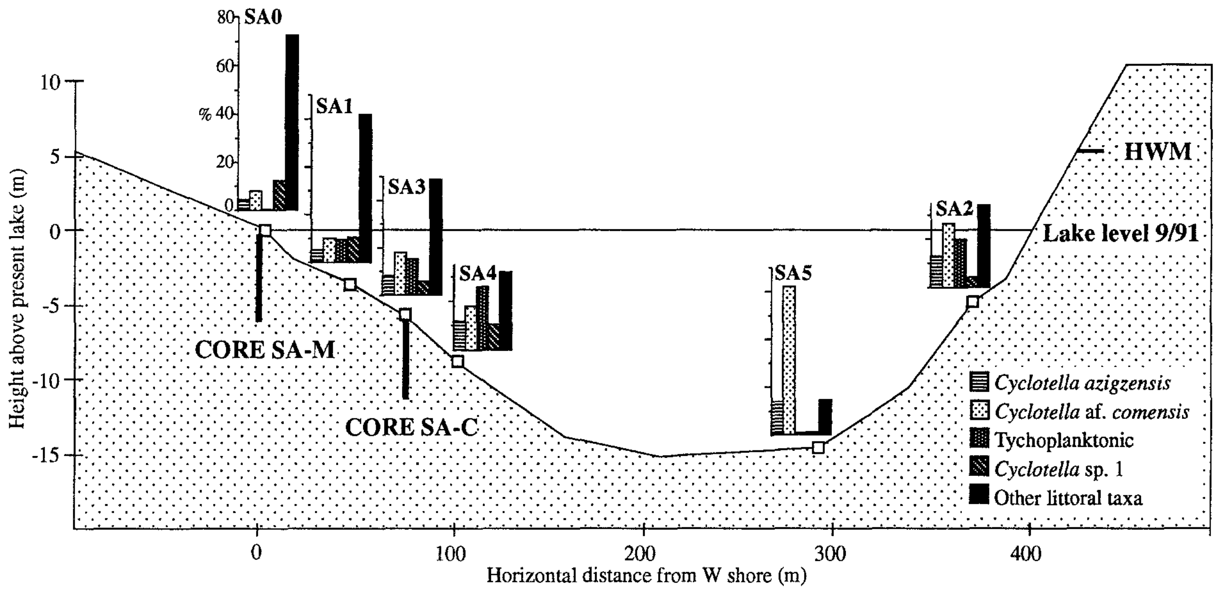

Fig. 2. Position of cores and modern surface sediment diatom samples along a cross-sectional profile of the smaller of the two basins at Sidi Ali. Bathymetry was measured across a transect at the widest point using a weighted tape (note exaggerated vertical scale). The position of a high water mark (HWM) found 5 m above the 1991 water level was located by levelling.

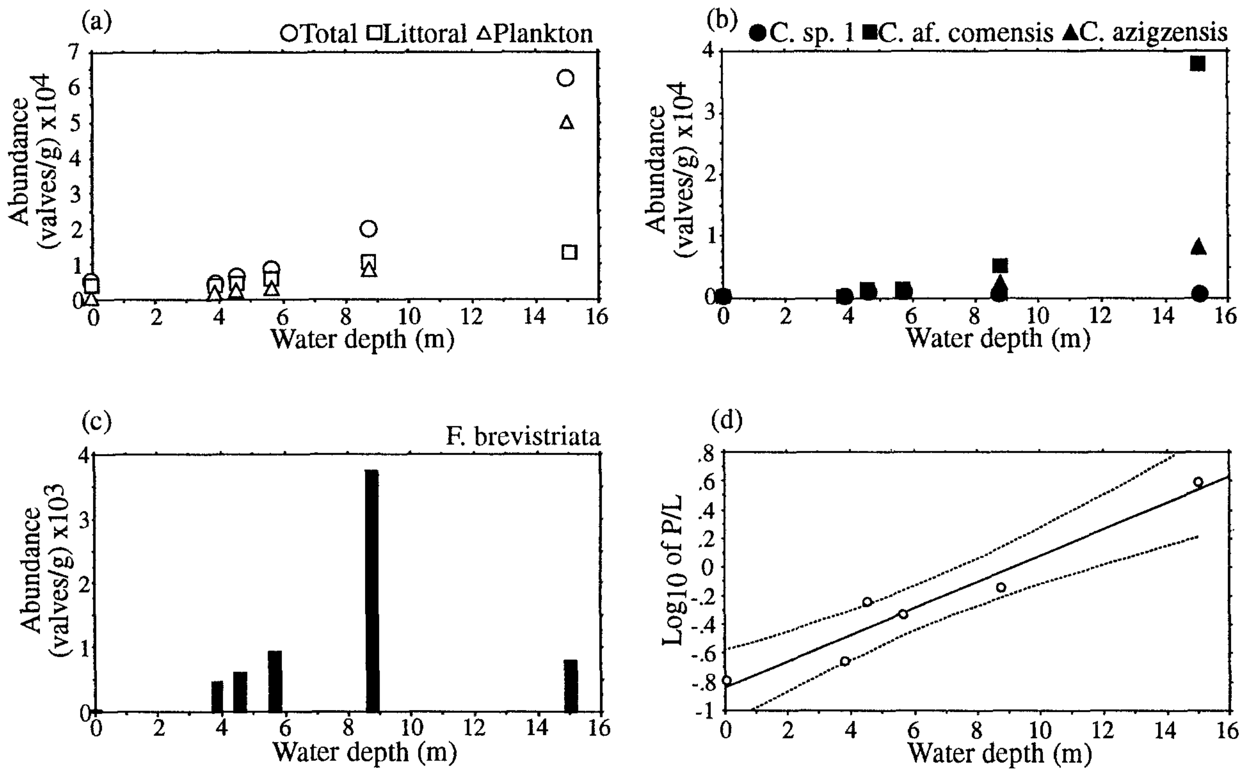

Fig. 3. Diatom assemblages from modern surface sediment. (a) Diatom abundance (valves/g) with water depth of (i) all diatoms, (ii) littoral species, and (iii) planktonic species. The small increase of littoral taxa in the deeper samples suggests sediment focussing. (b) Distribution of three *Cyclotella* species with water depth. The abundance of *C.* af. *comensis* and *C. azigzensis* both increase in the deeper water sediments whilst *C.* sp. 1 is evenly spread indicating a littoral habitat. (c) The abundance of the tychoplanktonic *F. brevistriata* is greatest at intermediate water depths (8–10 m). (d) Regression of Log_{10} (P/L) and water depth for version 4 of the P/L ratio showing 90% confidence limits for the gradient. The adjusted r^2 for this relationship is 0.88.

Table 2. Radiocarbon determinations used to produce chronology for core SA-C. * denotes conventional ^{14}C analysis on total organic matter (TOM). All other dates are made using the AMS technique on the materials specified

Core depth (cm)	Material dated	^{14}C age (yr)	$\rho^{13}C_{PDB}$	Code
45	Ostracod shell	900+55	−0.5	AA12382
96–98	TOM	1450+80	−25.5	Beta-58350*
105	Ostracod shell	1065+50	+0.7	AA12383
213–216	TOM	1840+110	−24.0	Beta-58351*
265	Ostracod shell	2840+55	−2.2	M12384
265	Seed + OM	2940+60	−19.7	AA12386
403	OM	3545+55	−24.3	AA11980
403	Cedar needles	3445+80	−24.6	AA11981
403	Ostracod shell	4120+65	−1.9	AA12385
507	OM	4910+55	−27.9	AA11982
509–511	TOM	5330+190	−23.2	BetaS8352*
625	OM	3060+65	−22.9	AA1983

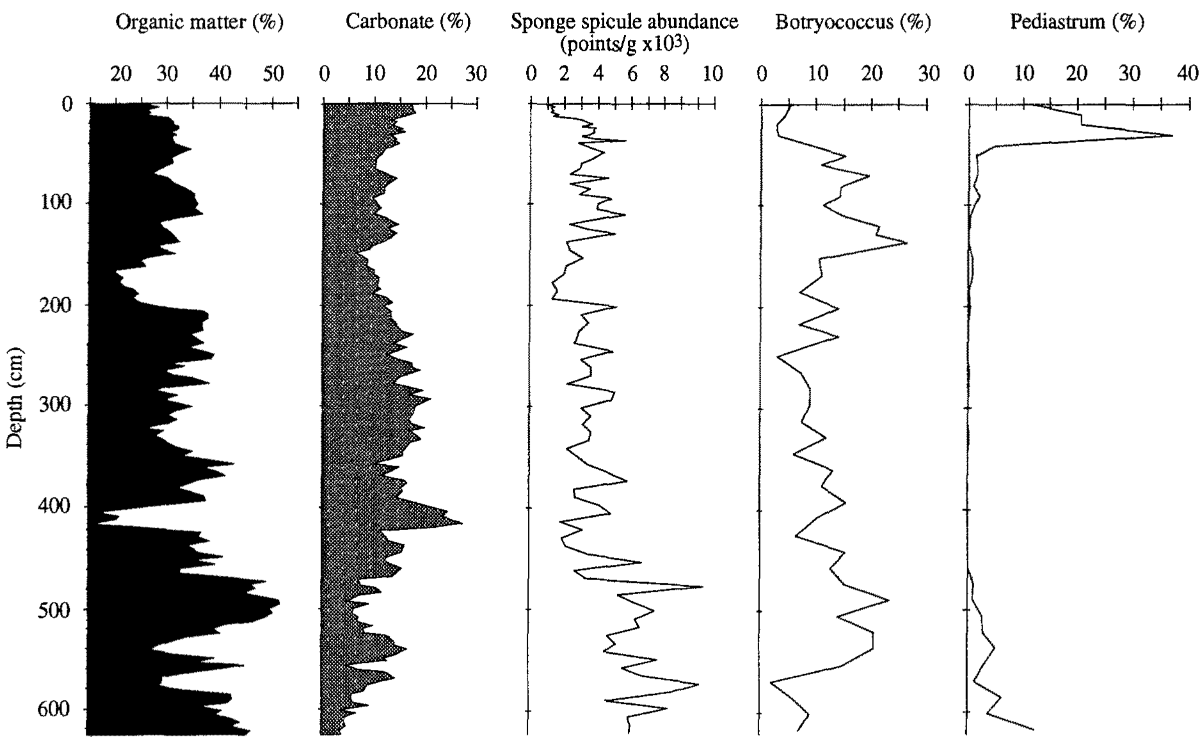

Fig. 4. Organic matter and carbonate content (estimated from loss on ignition), sponge spicule abundance, and preserved remains of the dinoflagellate *Botryococcus* and chlorophyte *Pediastrum* (as % of total pollen, spores and HF-resistant algal remains) from core SA-C.

Nine AMS and three conventional radiocarbon dates, and profiles for ^{210}Pb and ^{137}Cs provide a chronology for SA-C (Table 2 and P. Appleby pers. comm.). Of the radiocarbon dates, the basal sample (AA1983) is clearly out of sequence as too young, while the two uppermost ones (AA12382 and Beta-58350) may be somewhat too old. The AMS-dated ostracod sample from 45 cm depth (900 BP), has a ^{210}Pb age of only 200 BP. One of the other ostracod samples (AA12385) is also older than the other AMS dates from the same level, although not all the ostracod samples seem to be subject to this, presumably old carbon, error. Overall, however, the dates form a coherent chronology, with a mean sediment accumulation rate of 81 cm 1000 y^{-1}, except between 3500–2900 BP where there indications of a slight increase to 128 cm 1000 y^{-1}, and above 40 cm where the ^{210}Pb and ^{137}Cs dates indicate a pronounced acceleration in sedimentation.

CORE SA-C: Diatom stratigraphy

Diatom preservation in the 625 cm core is excellent and 99 samples contained 140 taxa (Fig. 5). The diagram is divided numerically using stratigraphically constrained cluster analysis with Edwards and Cavalli-Sforza chord distance as a dissimilarity measure and based on all taxa over 2% (Grimm, 1987). Five diatom assemblage zones and several sub-zones resulted. Zone 5 (625–561 cm) is dominated by the planktonic taxa *C.* af. *comensis* with *C.* sp. *1* and *Cyclotella krammeri* Håkansson. *C. krammeri* is not found in the modern sediments but has been reported from lakes in the High Atlas mountains where it occupies shallow-littoral habitats (C. A. Duigan pers. comm.). This species is described as cosmopolitan in waters of low conductivity by Håkansson (1990). Littoral and benthic species become important in zone 4 (561–433 cm) and dominate the assemblage until the first rise in *Stephanodiscus parvus* Stoermer and Håkansson at 509 cm. *S. parvus* alternates with *C.* af. *comensis* from zone 4b through to 3a. The abrupt fall in *C. krammeri* at 433 cm marks the boundary between zone 4 and zone 3 (433–173 cm) where it is replaced by *C.* sp. *1*. *C.* af. *comensis*, and *C. azigzensis* contribute most to the planktonic community of zone 2 (173–42 cm). Zone 1 (42–0 cm) is notable for the rise of tychoplanktonic *F. brevistriata*, reaching 80sub-zone 1b. In absolute terms *F. brevistriata* is equally important in 1c where overall valve abundance is very high.

Core SA-C: other biological remains

Sponge spicules are also abundant in the Sidi Ali sediments especially in the lower section (diatom zones 4 and 5) (Fig. 4). Several forms were noted, although these have not been identified. In the modern surface samples the greatest density of sponge spicules occurs in the most marginal sample (SA0) where water depth was only 5 cm. Preserved remains of the chlorophyte *Pediastrum* are found in the lower section of the core beneath 475 cm and again within the uppermost 50 cm (Fig. 4). The dinoflagellate *Botryococcus* is recorded throughout the core with greatest abundance between 565–485 cm and from 145–115 cm. Ostracods are abundant in three sections of the core (607–527 cm; 475–423 cm, 355–255 cm). Gastropods shells are also found between 335 and 255 cm. The pollen stratigraphy has also been analysed and will be presented elsewhere.

Interpretation

Water levels at Sidi Ali are known to have fluctuated during recent decades and are likely also to have done so in the mid-to-late Holocene period covered by the core SA-C. Although surficially a closed basin, lake-level changes at Sidi Ali are not matched by major changes in salinity. The diatom flora contains almost entirely fresh or oligosaline species throughout the mid to late Holocene period represented by the core. This is presumably a result of sub-surface outlets in this karstic area connecting the lake to the regional water table and so preventing an accumulation of salts. Diatom-inferred salinity is therefore precluded as a proxy indicator of lake-level change.

However, an indicator of water depth is provided by down-core variations in diatom habitat groups. A fall in lake level will bring the littoral zone closer to the coring site and hence augment the supply of littoral diatoms. This approach assumes (i) that changes in the nutrient status of the lake have not altered the balance between planktonic and littoral diatom productivity, even if overall abundance has changed markedly, and (ii) that reworking of marginal sediments has not led to an influx of fossil littoral diatoms. The P/L ratio has been applied in many other studies to provide a qualitative index of relative water level change from diatom assemblages (cf. Gasse *et al.*, 1987, 1989; El Hamouti *et al.*, 1991). A more quantitative approach was adopted in an ostracod-based study by Mourguiart & Roux (1990) from lakes in the Bolivian Altiplano. These authors used the modern water depth affinities of benthic ostracod assemblages to quantify the down-core variations of ostracods from Lake Titicaca by means of a transfer function (Mourguiart *et al.*, 1992).

Similarly, down-core variations in the P/L ratio can be quantified in terms of water depth using the four equations describing the diatom-depth relationships calculated from the modern surface samples from Sidi Ali. However, our approach differs from that of Mour-

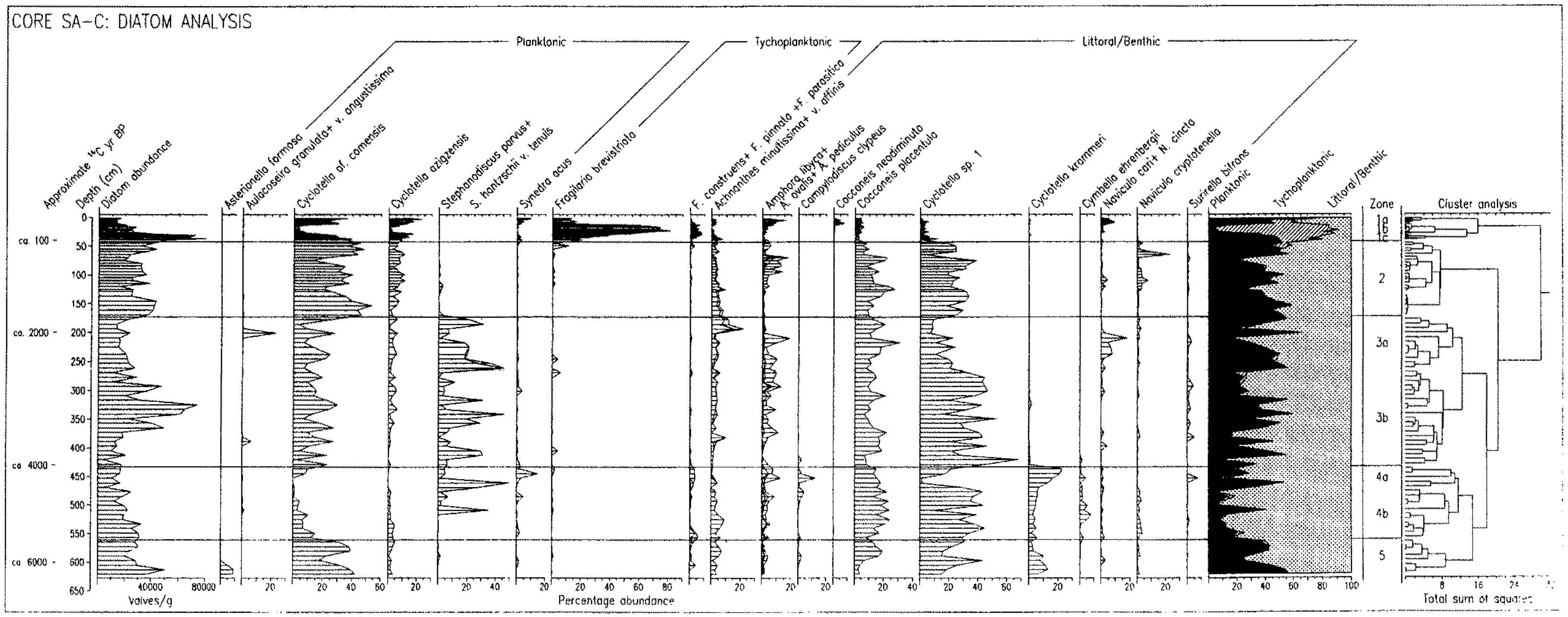

Fig. 5. Diatom stratigraphy of core SA-C showing percentage abundance of principal taxa.

guiart & Roux (1990) who suggest ostracods have clear ecologically-defined water depth affinities, whereas the distribution of diatoms according to water depth results from a combination of ecological and taphonomic factors. One important assumption we make is that the regular zonal patterns of diatom sedimentation with water depth found today also occurred in the past. Other comparable studies by Meriläinen (1971), Bradbury & Winter (1976) and Anderson (1989) indicate that diatoms from different habitats are concentrically distributed in the surface sediments rather than being completely homogenized across the lake bed. However, it is not known how stable this relationship is over time, and how factors other than water depth (e.g. changing wind direction, macrophyte growth) could alter the composition of the diatom assemblage at the coring site. This can only be fully resolved if multiple cores are analysed, as accumulation rates are variable, and different depositional centres may be important at various times in the past (Anderson, 1990).

Reconstruction of lake level using the P/L ratio

The four versions of the P/L ratio constructed from the distribution of diatoms in the surface sediments have been used to calibrate stratigraphic changes in this ratio and to produce an index of changing water depth in Lake Sidi Ali. In a lake with no evidence of past surface outflow, water depth is likely to be as significant hydrologically as lake level per se. Smoothed versions of the P/L-derived water depth index are shown in Fig. 6. It is significant that the models are generally in accord concerning relative changes in water depth, except in zone 1. Water depths become 'negative ' in sub-zone 1b in models 1 and 3, where *Fragilaria* is included in the littoral component, and this is clearly not possible. It is also unlikely that the water levels predicted by models 1 and 2 of between 5 and 10 m deeper than present were sustained throughout the mid-late Holocene. Geomorphological studies in the basin suggest a maximum shoreline of 5 m greater than that at present. Accordingly, we consider version 4 of the P/L ratio to be the most reliable and this will now be considered in more detail.

The unsmoothed water-level curve shown in Fig. 7 is based on numerical calibration of the P/L diatom ratio following version 4. The error bars represent the 90% confidence intervals shown in Fig. 3d. Diatom zone 5 represents a period of declining lake levels at the coring site from an estimated water depth of 9 m at the base of the core to one of less than 4 m at the start

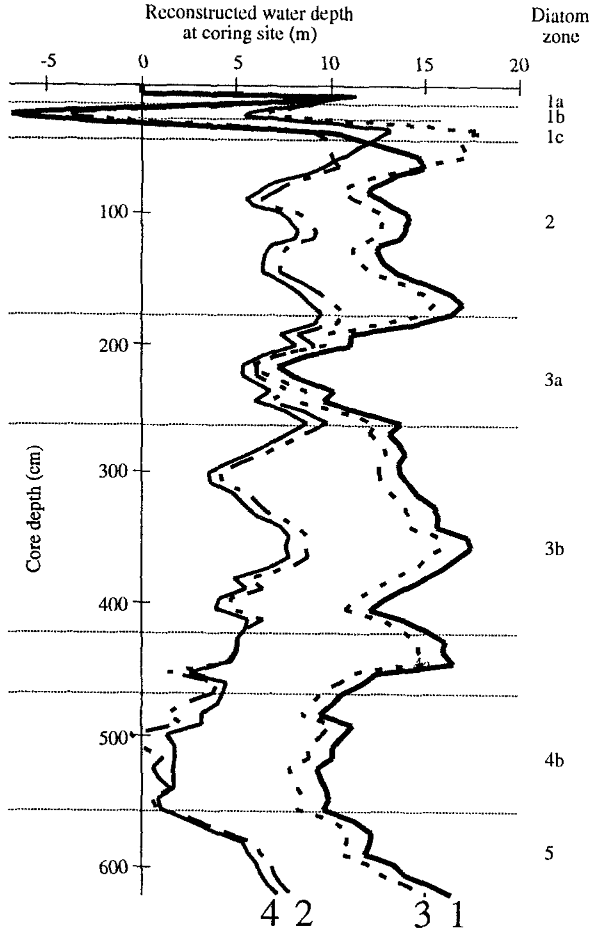

Fig. 6. Mean water depth curves from core SA-C reconstructed from four versions of the P/L ratio. The curves have been smoothed using a 5-sample running mean to facilitate intercomparison.

of sub-zone 4b. Low water levels (<1 m) are suggested for much of sub-zone 4b where littoral diatoms are abundant. There is a high abundance of sponge spicules in this section of core, supporting the presence of low water levels and suggesting that the lake margin was close to the coring site. The lake level rose progressively but erratically during sub-zones 4a and 3b, taking it above that of the present day and reaching a maximum depth at the coring site of *c.* 11 m. During this period *S. parvus* and *C.* af. *comensis* alternate as the dominant planktonic diatoms, probably reflecting differences in nutrient levels. *S. parvus* is typically associated with eutrophic conditions (Anderson, 1990) whereas *C.* af. *comensis* is abundant in the mesotrophic waters of the present lake. Therefore, the P/L ratio in these sections where *S. parvus* is dominant may be biased by productivity changes, leading to an over-representation of the plankton and hence an overestimation of water depth.

A further prolonged regression is suggested by high relative and absolute littoral diatom abundance between 310 and 270 cm. The estimated water level fell to between 3 and 5 m at the coring site during this period. However, sponge spicule abundance does not increase as it did in the earlier regression of sub-zone 4b, probably because water levels were somewhat higher than is suggested for sub-zone 4b. Sponge spicules in the modern samples are largely confined to very shallow water (<0.1 m) close to the lake shore. During much of sub-zone 3a and zone 2 the lake water depth exceeded that of the present day reaching 11 m at the coring site, but short-lived regressions are suggested at 213–191 cm, 125 cm and 75 cm.

Water-level changes in zone 1 must be interpreted with caution as human activities in the catchment appear to have caused marked changes in the nutrient status and turbidity of the lake. This zone is dominated by the facultative planktonic *F. brevistriata*. Elsewhere in the Middle Atlas region at Dayat Affougah, and Dayat-er-Roumi on the western coastal plain, Flower *et al.*, (1989) have suggested that *F. brevistriata* dominated over *Cyclotella* species where human impact has led to erosion of soils, thus, releasing nutrients into the water, increasing turbidity, and possibly suppressing the plankton. The presence of *Pediastrum* also suggests high trophic levels in zone 1 (Happey-Wood, 1988). A better estimate of water depth during zone 1 comes from the modern surface samples in which *F. brevistriata* is found most abundantly at intermediate water depths (8–10 m).

Conclusion

Overall the lake-level record appears to be a sensitive one with several, often abrupt water-level fluctuations taking place, each having durations between <100–<500 yr (Fig. 7). Unlike some other groundwater-fed lakes in the region, there are no periods of stable lake-level recorded during the second half of the Holocene (El Hamouti, 1989, El Hamouti *et al.*, 1991). This indicates that the groundwater system which controls the hydrological flux to the lake must also have a response time to climate of <100 years, confirming twentieth century observations of lake-level change. Moreover, mean lake level at the coring site is estimated to lie within a range between the present water level and the well-defined shoreline (+5 m) for about half the time period covered by the core. The reconstructed water-level curve indicates that lake Sidi Ali probably reached this highwater mark on a number of occasions during the late Holocene. That it does not seem to have exceeded this level suggests a topographic or groundwater control on the maximum extent of Sidi Ali. This agreement between reconstructions based on geomorphological and diatom stratigraphical evidence gives confidence to the range of water-level fluctuations estimated using the P/L index.

Lake water depth fell beneath that of the present-day for only *c.* 40% of the mid-late Holocene period. Three principal regressional phases are suggested. The first occurred during the mid Holocene with an apparent age of 5300 radiocarbon years BP. This followed a gradual reduction in water levels lasting approximately 600 years. A second, less severe regression occurred *c.* 2500 radiocarbon years BP. The third happened *c.* 1800 radiocarbon years BP. The latter two events were more abrupt in nature with water level apparently falling 8 m in <100 years. While the chronology of these events may need some revision, this analysis represents a semi-quantitative attempt to reconstruct water depth using a continuous lake-sediment time series in a climatically sensitive region.

Sidi Ali is an ideal site for applying the P/L model as an indicator of water depth as it has a gently sloping bathymetry and an extensive littoral area lying within the photic zone. In other basins with more complex bathymetry and hydrology this simple approach may not be applicable. The water depth calibration of the P/L curve is site specific as the mixing processes forming the fossil diatom assemblages are unique to each site. The most appropriate modern analogues are from within the basin itself, rather than from samples from many different lakes as employed in the transfer function approach (e.g. Fritz *et al.*, 1991). This study highlights the need for systematic surface sampling of lakes whose limnological histories are under investigation, especially where other commonly-used indicators of water depth, such as salinity, are not available.

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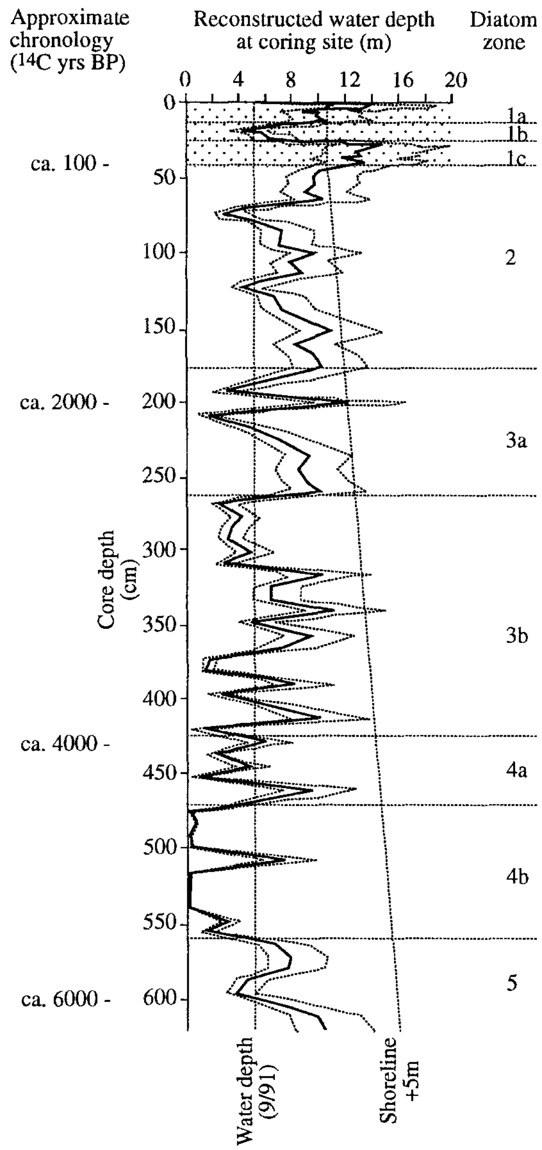

Fig. 7. Reconstructed water depth from core SA-C using the calibrated P/L ratio. Dotted lines give 90% confidence intervals. Estimated water depth in zone 1 (shaded area) is uncertain due to the abundance of tychoplanktonic diatoms. The apparent increase in the elevation in the + 5 m high water mark with depth is to take account of the progressive effect of basin infilling.

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