

Taphonomy and diagenesis in diatom assemblages; a Late Pleistocene palaeoecological study from Lake Magadi, Kenya

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Abstract

Many fossil diatom assemblages do not possess a direct modern analogue as a result of taphonomic processes and diagenesis within the assemblage. Some of these problems are illustrated with reference to core material collected from hypersaline Lake Magadi, Kenya, which during the Late Pleistocene experienced major fluctuations in water chemistry and depth. Competing multiple hypotheses are proposed for no analogue assemblages, with selection between these hypotheses being based on the results of interdisciplinary research.

Introduction

The study of fossil diatom assemblages provides a powerful means of reconstructing the palaeolimnology of closed basin, saline lakes (e.g. Holdship, 1976; Gasse, 1977; Bradbury, 1989). The interpretation of these depends on modern aut- and syn-ecological studies of diatoms from the investigated region (e.g. Gasse *et al.*, 1983; Gasse, 1986a; Fritz & Battarbee, 1986). But, despite the increasing amount of modern ecological data by no means all fossil assemblages have modern analogues at the regional scale.

The search for suitable analogues is further hindered by taphonomic processes which can mix diatoms from different habitats or from different periods in time. These processes are particularly important in tropical lakes where seasonal differences in the hydrological regime are often very pronounced and recharge by the river system occurs ephemerally. Fluvial influx of dilute water

may produce a periodically stratified lake thus increasing the heterogeneity of lake habitats and/or introduce assemblages that were living within the river system. Death assemblages will be subject to mixing by limnological processes, involving not only the incorporation of planktonic and periphytic species but also the dispersal of diatoms from micro habitats such as hot springs. Once the sediment is deposited it becomes liable to physical mixing processes and bioturbation often resulting in breakage and/or dissolution of diatom frustules. Thus the fossil assemblage represents a combination of environmental conditions occurring spatially in the lake catchment as well as those operating temporally during distinct hydrological seasons (Gasse, 1988).

In highly saline environments diatom frustules are liable to be dissolved (e.g. Badaut & Risacher, 1983) and can even be diagenetically transformed into zeolites (e.g. Stoffers & Holdship, 1976; Gasse & Seyve in Tiercelin *et al.*, 1987). Dissolu-

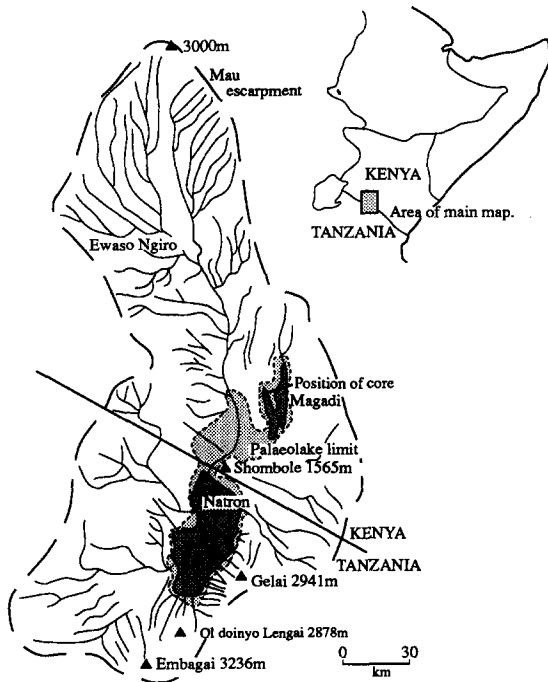


Fig. 1. The Magadi-Natron catchment (after Hillaire-Marcel and Casanova, 1987).

tion of frustules can occur either during deposition or much later as a result of the circulation of concentrated groundwater circulation. Such chemical dissolution could preferentially dissolve weakly silicified forms (Shemesh *et al.*, 1989) and can therefore lead to biased palaeoecological data. These problems are present in all lake-based diatom studies but take a different and more complex form in the context of saline tropical lakes.

Some of these problems will be illustrated here with reference to a new diatom sequence from Lake Magadi, Kenya. Permanent water in Magadi only occupies 40% of the lake area, the remainder being covered by a thick deposit of trona (sodium carbonate). Water levels are maintained from a groundwater reservoir that discharges through a series of hot springs. Magadi has no perennial inflowing streams at present, the Ewaso Ngiro drainage system entering the Magadi-Natron catchment but passing to the west of Magadi (Fig. 1).

Materials and methods

A 9 m core was taken from a mudflat on the north western edge of Lake Magadi named Flamingo Nursery. This was collected in 1987 as part of the EQUARIFT programme coordinated by the CNRS, Laboratoire de Géologie du Quaternaire, Marseille. A wide range of analyses have been undertaken on this core including sedimentology, mineralogy, palynology, and palaeomagnetism (Taieb *et al.*, 1989). Five radiocarbon dates have been obtained, placing the sequence in the Late Pleistocene period (Fig. 2). These have been made on organic matter from the upper and lower sections of the core using both conventional and accelerator mass-spectrometer dating methods.

Fifty five samples were taken from the core for diatom analysis and 500 valves were counted where possible. Standard treatments with 10% HCl and 30% H₂O₂ to remove the carbonates and the organic matter respectively were used to prepare the samples for observation. Routine counting was made with a light microscope ($\times 1250$) whilst evidence for dissolution was studied using scanning electron microscopy.

A tripartite zonation of the core is indicated by many of the analyses which have been undertaken and the diatom stratigraphy will be treated accordingly. The fossil data have been compared to modern assemblages included in a database incorporating diatom and environmental information from 210 sites in East Africa (Gasse *et al.*, 1983). Transfer functions for pH (Gasse & Tekaiia, 1983; Gasse, 1986b) and conductivity (Gasse, in prep.) have been used to reconstruct palaeoenvironmental conditions.

Zone 3; 18000–17000 BP (870–760 cm)

This lowest section of the core is characterized by the abundance of *Anomoeoneis sphaerophora*, with *Rhopalodia gibberula*, *Hantzschia amphioxys*, *Nitzschia 'groups latens'*, *N. frustulum* and *Navicula* spp. (including *N. mutica*, *N. tenella* and *N. sp. af. jakhalsensis*). The sample analysed at the very base of the core (869 cm) differs from the rest of

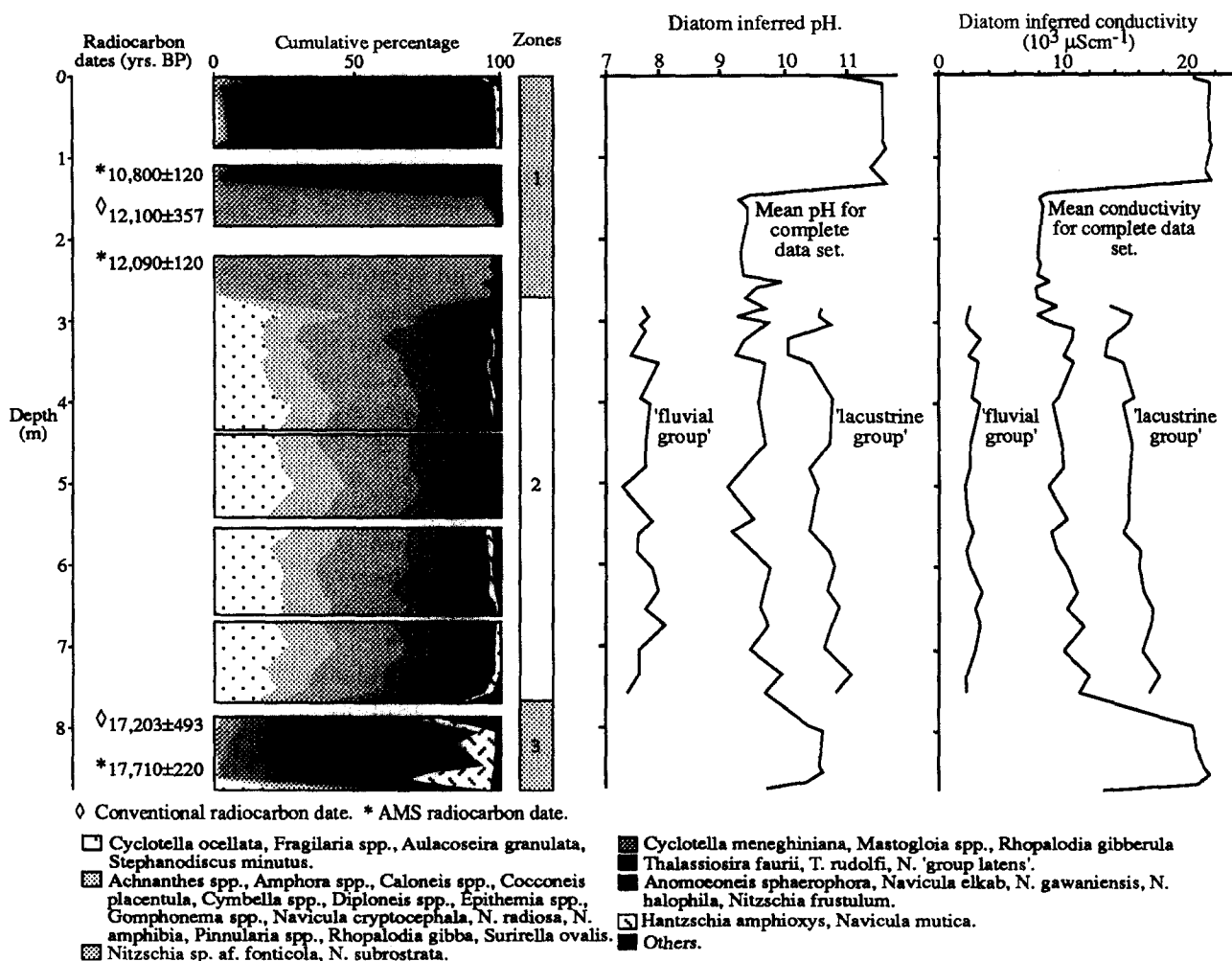


Fig. 2. Summary of diatom analysis of the Flamingo Nursery core, Lake Magadi, Kenya (left) with estimates for pH and conductivity (right).

the zone as it contains a more diverse diatom flora including several oligosaline species, it is therefore considered as a sub-zone (B) of zone 3. The dominance of the assemblage by *A. sphaerophora* makes it comparable to mud samples collected from Embagai Crater Lake (pH 10.1, conductivity $13\,500 \mu\text{S cm}^{-1}$, Gasse *et al.*, 1983), and in surface mud samples collected from the Magadi hot springs (pH > 9 , conductivity $> 20\,000 \mu\text{S cm}^{-1}$). These analogues are all from shallow lakes or hot springs where the living assemblage is periphytic. Sub-zone 3B has a more diverse flora and includes many species with greater affinity to water of moderate or low salinity alongside the more saline elements characteristic of sub-zone 3A.

The autecological attributes of species in this zone suggest an environmental interpretation similar to that indicated by the synecology. The mean conductivity of zone 3A is $20\,800 \mu\text{S cm}^{-1}$ whilst mean pH is estimated at 9.6 (Fig. 2). Zone 3A is largely comprised of species classified as littoral epipellic-epilithic ($> 72\%$ excluding aerophilous species). Very few epiphytic or planktonic species were found, which is taken to indicate shallow water conditions with little fringing vegetation close to the coring site. A significant number of species encountered are often, although not exclusively, found in aerophilous habitats. This could suggest that the lake virtually dried up or was merely moist periodically during this interval.

Zone 2.: 17000–? 12500 (750 cm–280 cm)

Zone 2 incorporates diatoms typical of saline environments (e.g. *Navicula elkab*, *Thalassiosira faurii*, *Rhopalodia gibberula*, *Cyclotella meneghiniana*) alongside those usually found in more dilute conditions (*Aulacoseira granulata*, *Epithemia sorex*, *E. zebra*, *Fragilaria* spp. and *Stephanodiscus minutus*). This situation is unusual although similar mixed assemblages have been found elsewhere, for example in the Guidimouni salt pond, Niger (Gasse, 1987). For lake Magadi three alternative hypotheses will be discussed below for this conjunction of species, although several combinations of these hypotheses may also be envisaged.

The combination of high diversity within, but close similarity between samples, is difficult to explain unless either the environment was very stable or the sediment accumulated very quickly. The sediment appears to include volcanic glass at certain parts of this zone and it could be that there was an increase in volcanism within the area which contributed greatly to the rate of accumulation via an aeolian deposition of ash. Organic matter and diatom abundance are both quite low throughout this zone (although the number of diatoms/g does increase above 4 m). This could be a result of the 'diluting' effect of an allochthonous input into the lake. Zone 2 finishes as suddenly as it begins with a striking change in the fossil diatom assemblage taking place, only *Nitzschia subrostrata* and *N. sp. af. fonticola* continuing to be present in zone 1C. The sediment stratigraphy again mirrors this change with the fine homogenous clay changing to laminated sediments via an intervening sandy horizon. Other analyses including mineralogy, sedimentology and magnetics also show marked changes close to this point, perhaps indicating an hiatus in deposition.

Zone 1: 12500–10000 BP (270 cm–0 cm)

This zone is divided into three sub-zones, 1C from 270 cm–139 cm, 1B from 130 cm–6 cm, 1A a single sample at the surface. Sub-zone 1C com-

prises almost entirely *N. sp. af. fonticola* which accounts for over 69% of the diatom assemblage, although *N. subrostrata* is significant in the lower part of this zone. Assemblage 1B begins at 130 cm, where the diatom flora becomes almost entirely comprised of *Nitzschia 'group latens'* (>90%). Problems of the taxonomy of *N. sp. af. fonticola* and *Nitzschia 'group latens'* have been discussed by Gasse (1986a) and environmental interpretation using these species is difficult. The core top sample shows another change in the diatom stratigraphy with a return of *A. sphaerophora* and *Navicula gawaniensis* which correspond well to other modern samples collected from around the Magadi area today.

The water chemistry of the lake during the deposition of sub-zone 1C is difficult to estimate because of the variance of the morphology of *N. sp. af. fonticola* which may include taxa of different autecology. The calculation here is based on a weighting derived from an average of all the morphological types within this species. The estimated mean pH and conductivity for this zone is 9.3 and 8 150 $\mu\text{S cm}^{-1}$. A further problem occurs in trying to categorise the life-form of this species as it can occur in both the periphyton and the plankton of lakes. The dominance of *N. sp. af. fonticola* suggests it was living planktonically as fewer niches are available to competitors in the plankton than the periphyton. The interpretation of sub-zone 1B is also difficult because of the taxonomy of *N. 'group latens'*. By making the assumption that the autecology of *N. latens sensu stricto* is representative of the various morphological types within this group it is possible to estimate mean pH at 11.2 whilst average conductivity is 21 500 $\mu\text{S cm}^{-1}$. These values should be treated with caution given that they are based largely on the autecology of a single taxon. *N. 'group latens'* can live in planktonic or periphytic life-forms in lakes, swamps and hot springs. The morphological type which dominates here is very similar to that living today in the chemically concentrated, yet moderate to very deep lakes Elmenteita and Shala (Gasse, 1986a). This sub-zone therefore would seem to represent an increase in chemical concentration following sub-zone 1C.

Discussion

The importance of taphonomic processes in palaeoenvironmental interpretation is well illustrated by zone 2, where the conjunction of diatoms is indicative of different habitats. One hypothesis to explain this juxtaposition of species is that the lake was stratified seasonally and that a freshwater lens developed during the wet season over a more saline brine; indeed Eugster (1986) has reported periodic stratification in Magadi today. If this were the case it would be expected that the freshwater species were largely planktonic, but as 30–40% are in fact periphytic, this casts doubt on this hypothesis. What seems to be a more likely explanation is that the (relatively saline) lake received periodic inputs of freshwater from a river entering the lake close to the coring site. This would explain both the different life-forms and an increase in sediment accumulation rate as is suggested by the various analyses. A third hypothesis is that the mixture of species is due to the erosion of older sediments from elsewhere in the catchment. However, the preservation of diatoms within this zone is good which would not seem to indicate reworked material.

Adopting as a working hypothesis the second explanation (ie. a river entered close to the site) the data have been tentatively split into freshwater 'fluvial' and saline-alkaline 'lacustrine' components and an environmental interpretation is attempted accordingly. The autecology of the complete data set produces estimates of pH and conductivity with a large degree of variance, the calculation was therefore repeated using the split data (Fig. 2). Statistically these represent respectively minimum and maximum values since the division into the two groups was based largely on chemical preferences. The life-forms of the species in the lacustrine group are divided quite evenly between the three categories of littoral epipelagic- epilithic, facultative planktonic and euplanktonic. In contrast the species thought to have been brought to the site by a river include many epiphytic forms as would be expected if this hypothesis were correct.

The problem of diatom frustule dissolution is

crucial to the reliability of the environmental interpretation given for Zone 1. An indication that some dissolution has taken place comes from the poor preservation of valves and the low abundance of diatoms within this zone. Indirect evidence of silica dissolution and subsequent diagenesis is provided by the mineralogy of this zone. Magadiite (Eugster, 1967) was noted in varying amounts on the diatom slides and was found to entirely comprise the samples where diatoms were absent, a similar situation was found north of Lake Chad by Maglione (1970) where saline diatoms were dissolved and their silica diagenetically transformed into magadiite. It is possible that the diatom frustule silica has been dissolved and has contributed along with non-biogenic silica to the formation of magadiite and other zeolites (eg. erionite, analcime, Nicolas Quash, pers. comm.). Similar observations of frustule diagenesis in hyperalkaline Lake Bogoria have been made by Gasse & Seyve (1987). If dissolution and diagenesis occurs differentially with respect to different species then the percentage calculations upon which the transfer functions are based become unreliable.

Conclusions

The precise taxonomy of diatoms in living communities and in fossil assemblages is essential to any palaeoenvironmental interpretations based on fossil diatom assemblages. Problems are often exacerbated in saline lakes where the taxonomy may be poorly known and the species diversity is often rather low. Taphonomic processes can contribute to the problems of interpretation and may bring together assemblages from different environments. However, within the context of a multidisciplinary study it may be possible to distinguish these assemblages if support is available from other analyses. Dissolution of diatom frustules is also a common problem in saline lakes but this can be detected from the preservation of the remaining frustules and supporting mineralogical analysis, therefore avoiding erroneous palaeoenvironmental interpretations being made.

The processes discussed here must be taken into account when reconstructing palaeoenvironments generally but especially when using transfer functions to give quantitative estimates for environmental variables. The apparent precision derived from these may mask underlying inaccuracies. It is only when these issues are fully addressed that the potential of diatoms in reconstructing palaeoenvironments of salt lakes will be fully realised.

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