

## Paleolimnology of mid-elevation lakes in the Kenya Rift Valley

J. L. Richardson & R. A. Dussinger

*Department of Biology, Franklin and Marshall College, Lancaster, PA 17604, USA*

Keywords: diatoms, ostracodes, paleoclimate, Kenya, Pleistocene, Holocene

### Abstract

Three small lakes of the Kenya Highlands have been subject to intermittent paleoenvironmental investigation for more than 50 years. In this report, the stratigraphic, core-based history of Lake Naivasha (elev. 1890 m) is extended backward to 20000 B.P. and is related to less complete 30000-year core stratigraphies from nearby lakes Nakuru and Elmenteita. The paleolimnological reconstructions, primarily diatom-based, include geochemical parameters and the first ostracode stratigraphies from tropical Africa. The analyses from all three lakes converge on a history of low and fluctuating water levels over approximately the past 4500 years, preceded by a major Holocene high stand (ca. 10000–6000 B.P.) and a brief earlier rise centered on 12500 B.P. The lakes were mostly very low during the late Pleistocene (13000–30000 B.P.), though modestly elevated levels may have occurred early in this time period. The ostracode record, comprising at least 15 species, was relatively continuous in the Nakuru core but was restricted to sharply demarcated regions in cores from the other lakes.

### Introduction

The floor of the East African Rift Valley arches broadly upward as it crosses the equator, reaching elevations of 1800–2400 m in the Kenya Highlands (Fig. 1), where the valley is flanked to east and west by the still higher Aberdare Range (3900 m) and Mau Escarpment (3000 m). The three lakes discussed in the present paper occupy this elevated region of the valley and are separated from each other by less than 50 km. At times of high water within the last 8000 years their maximum separation was probably less than 10 km. Because of their proximity to each other, and also because of their limnological contrasts (two are closed, alkaline lakes today, while one is fresh and apparently drained by underground seepage), their paleolimnological records present unusual opportunities for comparison.

Exposed lake sediments and strandlines indicate that the two alkaline lakes, Nakuru and Elmenteita,

once were joined as a single large lake nearly 200 m deep and 800 km<sup>2</sup> in area (Washbourn-Kamau, 1971; Butzer *et al.*, 1972). Today their depths fluctuate between 0 and 5 m, and Nakuru (the larger of the two) covers an area of no more than 40 km<sup>2</sup> – often less. The freshwater Lake Naivasha presently is the largest of the trio, its area in recent decades ranging between about 110 and 175 km<sup>2</sup> and the depth of its main basin between about 3 and 8 m. Naivasha, too, formerly was much larger, though because its basin has a lower surface outlet this lake never became as large or deep as the combined Lake Nakuru-Elmenteita (Washbourn-Kamau, 1975). Naivasha, which lies closer to the eastern wall of the rift than the other lakes, receives considerably less direct rainfall than they but is fed by larger, more reliable streams.

This paper summarizes our core-derived knowledge of water-level and biological change in these lakes since 30000 B.P. A detailed, 9000-year record from Lake Naivasha (Richardson & Richardson,

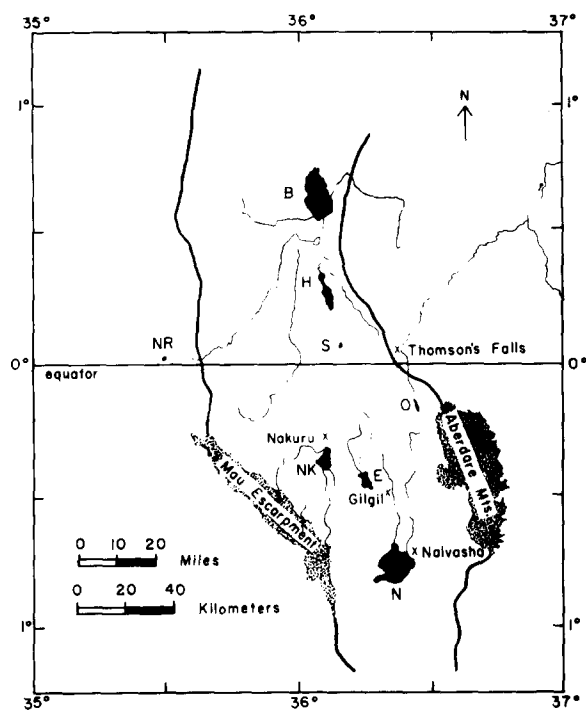


Fig. 1. Location map for Rift Valley lakes in the Kenya Highlands. Main towns and boundaries of the Rift Valley are also shown. Abbreviations for lakes: B = Baringo, E = Elmenteita, H = Hannington (Bogoria), N = Naivasha, NK = Nakuru, NR = Narasha, O = Ol Bolossat, S = Solai.

1972) and an account of the ostracode stratigraphy of Lake Nakuru (Cohen *et al.*, 1983) have appeared already, and additional detailed stratigraphies for all three lakes are in preparation. For more than 50 years the landscapes surrounding the present lakes have attracted the attention of geomorphologists, stratigraphers and paleoclimatologists, because of their abundant evidence of higher lake levels in the past (Nilsson, 1931, 1940; Flint, 1959; Washbourn-Kamau, 1971, 1975). Also, for at least as long a period, archeologists and paleoanthropologists have investigated the rich record of early man in these basins (cf. Leakey, 1931; Posnansky, 1967; Isaac *et al.*, 1972; Ambrose, 1984). One aim of our core-based paleolimnologic studies is to develop sufficiently precise paleoclimatic records to provide a detailed ecological context for prehistoric cultural and habitation changes in this region. We dedicate this paper to the memory of Glynn Isaac; friend, field companion and initiator of this joint endeavor linking paleolimnology and paleoanthropology.

## Materials and methods

A 1960–61 expedition led by D. A. Livingstone of Duke University obtained an initial core from the Crescent Island Crater on the eastern edge of Lake Naivasha, using a lightweight piston sampler. In 1969–70 four additional cores were collected, using heavier piston-coring equipment of Livingstone's from (1) the Crescent Island Crater, (2) the main basin portion of Naivasha, (3) Lake Nakuru and (4) Lake Elmenteita. The present account concentrates on cores 2–4. The Naivasha cores provide more complete continuous records than those from Elmenteita and Nakuru, but the latter extend further back in time.

Laboratory analyses were made of several mineralogic and paleochemical parameters, mostly to be reported elsewhere; of fossil diatoms, on which the paleolimnologic reconstructions are primarily based; and of fossil ostracodes. Diatoms were cleaned by the peroxide-dichromate method of Van der Werff (1953), mounted permanently in Hyrax, and counted at 1000X; except where their densities were very low, at least 300 were counted per level, usually at 20 cm stratigraphic intervals. For ostracode analysis, wet mounts of 0.04 cc sediment samples, for the most part also at 20 cm stratigraphic intervals, were counted at 20–40X using a dissecting microscope.

## Results and interpretation

### 1. Diatoms, inferred chemistry and water levels

Figs. 2 and 3 present summaries of the diatom stratigraphies of Lakes Elmenteita, Nakuru and the main basin of Naivasha, together with interpretations of the diatom zones in terms of changing water chemistry. In Figs. 3 and 4 these inferences are translated into probable water level changes over the periods recorded by these cores; Richardson and Richardson's (1972) record of water level change from Naivasha's Crescent Island Crater is added to Fig. 4.

The first third (30000–20000 B.P.) of the time period for which we have records is represented only by the Nakuru and Elmenteita cores, and there imperfectly, by sediments composed largely of volcanic ash and pumice. The fossil diatoms, though

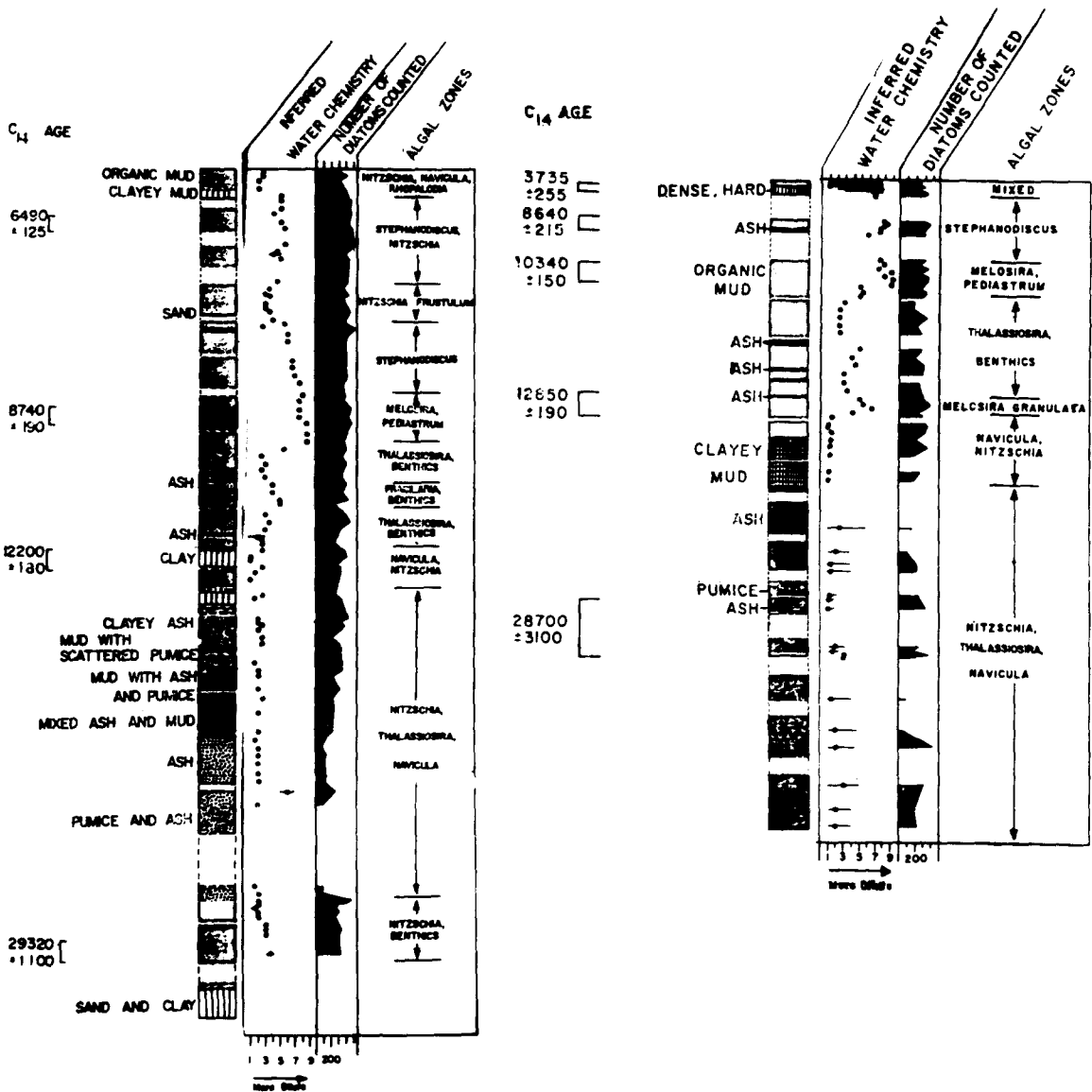


Fig. 2. Core stratigraphies from Lake Elmenteita (left) and Lake Nakuru (right). The diatom records, presented here in terms of zonal dominance patterns, are the basis of the inferred records of total solute content. The dilution scale is relative; both lakes varied over approximately a hundred-fold range of dilution and concentration.

relatively sparse, indicate that these two lakes certainly were separated during the early period, and were low and quite probably intermittently dry. The diatom flora was dominated by *Nitzschia frustulum*, *Nitzschia palea* (?), *Navicula el kab* and *Thalassiosira rudolfi*.

In the second phase of our time sequence (20000–10000 B.P.), the Nakuru and Elmenteita records are joined by that of Naivasha's main lake (Fig. 3). All three lakes remained low through most of this period, but Naivasha was relatively fresh

(alkalinity 1–15 meq/l) whereas the other two lakes were generally highly concentrated (alkalinities 50–150? meq/l). In its most dilute phases Naivasha was apparently a small, weedy pond characterised by *Eunotia* spp., *Pinnularia* spp., *Navicula zanoni* and *Cocconeis placentula* v. *euglypta*; but more characteristically it was a shallow, more open and more alkaline habitat dominated by a variety of planktonic and tychopelagic diatoms.

These conditions terminated between 13000 and 11500 B.P., apparently rather asynchronously

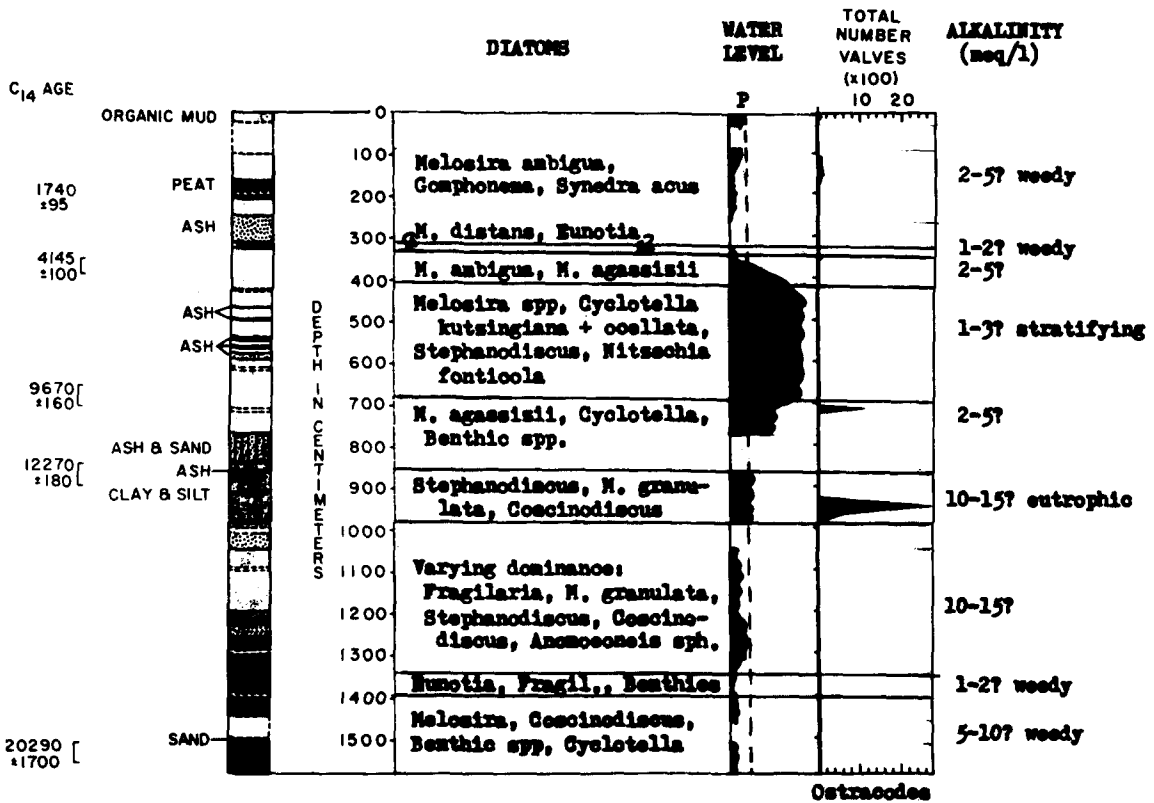


Fig. 3. Core stratigraphy from the main basin of Lake Naivasha, showing diatom zones, regions of ostracode occurrence, and inferred alkalinity and lake level changes.

among the three lakes. The Nakuru core records the earliest (c. 12800 B.P.) and most abrupt move toward a more dilute condition (= a higher water level) in the form of a brief but major pulse of *Melosira granulata* var. *angustissima* and *Fragilaria brevistriata*. Lake Nakuru then apparently receded to a more alkaline condition characterized by *Thalassiosira rudolfi* and/or *Coecinodiscus rothii*, *Rhopalodia gibberula* and several benthic taxa, remaining in this state until the lake's major freshening phase began (c. 10500 B.P.).

The early freshening of Lake Elmenteita was apparently a much weaker episode than that of neighboring Lake Nakuru, and the radiocarbon date suggests that in Elmenteita this freshening occurred closer to 12000 B.P. than to 12800. Elmenteita then receded, acquiring a flora similar to that of Nakuru, until joining its neighbor in the major freshening that began c. 10500 B.P. Lake Naivasha also expanded circa 12500 B.P., to levels probably close to those of the present lake. However, judging

from the character of its sediment and its dominant diatoms (*Stephanodiscus rotula* v. *minutula*, *Melosira granulata*, *Thalassiosira rudolfi*), the Naivasha of 12500 B.P. was quite different ecologically from today — more fertile, more alkaline, and richer in suspended clay and silt. In Naivasha this phase persisted, without the subsequent recession noted for Nakuru and Elmenteita, until all three lakes, apparently contemporaneously, began to expand to maximum size and freshness.

The most recent 10000 years of our combined record is divisible into two major phases of roughly equal duration. As this period began, levels of all three lakes were rising (or had just risen) to high, fresh levels — the greatly expanded lakes alluded to in the introduction. In both Nakuru and Elmenteita, which probably became confluent at about this time, an early dominance of *Melosira agassizii* (accompanied by the chlorophyte *Pediastrum simplex*) gave way to dominance by *Stephanodiscus rotula*. One can interpret this change as a transition from

maximally fresh to somewhat less dilute conditions as the lakes stopped rising; probably, too, Nakuru-Elmenteita now became stratified at least seasonally, with silica depletion in the epilimnion favoring the ascendancy of *Stephanodiscus* (cf. Kilham, 1971). At times during this large-lake phase Elmenteita-Nakuru probably lost water via a surface outlet to the north, but this outflow doubtless was relatively minor. Naivasha, with heavier riverine inflows and a lower overflow channel from its basin, became much more truly an open, through-flow lake during this high-water phase than did the other two lakes, and developed a more varied set of dominant planktonic diatoms.

The Elmenteita core provides a more complete record than does the Nakuru core of the later stages of the large lake in their joint basin. A phase of somewhat lower, more alkaline conditions circa 7500 B.P. is signalled by the emergence of *Nitzschia frustulum* and, briefly, *Thalassiosira rudolfi* as dominants; thereafter, although *Stephanodiscus* returned strongly (probably signalling a rise in water level), *N. frustulum* remained as an important element, suggesting that the lake remained more concentrated ionically than it had been in the period 8000–10000 B.P. Naivasha's core record, by contrast, indicates relatively little limnological change and continued high water levels throughout this time period (circa 10000–5500 B.P.). About 5000 years ago all three lakes apparently began falling rapidly. In Naivasha, where the decline is signalled much more definitely (its core record for this period is much more complete), dominance passed quickly from *Melosira agassizii* (at 4145 B.P.) to *M. ambigua* and then to *M. distans* and *Eunotia* spp. in a peaty layer signalling shallow, weedy, dilute conditions. The lake probably dried completely for a brief time thereafter (the Crescent Island Crater core records 3000 B.P. as being the date of lowest water level), and sometime after 1700 B.P. Naivasha assumed its present character as a shallow, open, relatively fresh lake dominated by *Melosira ambigua* and *Synedra acus* with *Gomphonema* common in the extensive macrophytic growths.

We believe that lakes Nakuru and Elmenteita may have become confined to their own sub-basins even before their precipitous decline circa 5000 years ago. For much of the period since that decline they apparently have been dry. During shallow

phases the upper sediments of the dilute, pre-5000 B.P. lake phase seem to have been mixed with more recent, alkaline-lake sediments. In addition, some sediments probably were removed by deflation when the lakes dried completely. The present highly alkaline lakes Nakuru and Elmenteita are at most times heavily populated by blue-green algae, with *Nitzschia frustulum* and *Navicula el kab* the most characteristic diatom associates.

## 2. Ostracodes

When Dussinger (1973) first determined the ostracode stratigraphy of these cores, too little was known of the ecology of East African species to allow detailed use of ostracodes in our paleolimnological reconstructions. Rather, we envisioned that from the diatom stratigraphy we would be able to make inferences about the ecology of stratigraphically co-occurring ostracodes, thereby building a stronger foundation for the use of African ostracodes as direct paleolimnological indicators in future African studies.

Within the past decade, in fact, studies primarily by other investigators (Peypouquet *et al.*, 1979; Cohen *et al.*, 1983) have begun to use ostracodes directly in paleolimnological reconstructions. Indeed, an interpretation of our Nakuru core record using ostracodes as the primary indicators has now been published, and compared (Cohen *et al.*, 1983) to the diatom-based interpretation presented in this paper. There is very good agreement between the two separately-prepared interpretations, the chief difference being an indication from the ostracodes of a somewhat more dilute (= larger?) Lake Nakuru circa 25000 B.P. than is indicated by the diatoms (cf Fig. 4).

The ostracode taxa identified from the sediment of all three lakes are listed in Table 1. The Nakuru ostracode record (see Cohen *et al.*, 1983) is more extensive than that of Elmenteita and Naivasha, although a rich ostracode fauna (containing all the species found in the Nakuru record) also characterized Elmenteita between 12000 and 7000 B.P. (Ostracodes were absent during this time span only during the *Melosira/Pediastrum* phase.) Elsewhere in the Elmenteita core ostracodes were very scarce; in opposition to Lake Nakuru, they do not seem to have been common in Elmenteita during its low-water phases. In the core from Naivasha's main ba-

Table 1. Occurrence of fossil ostracode taxa in sediments of lakes Nakuru, Elmenteita and Naivasha.

Taxon	Ecological notes
<i>Limnocythere</i> sp. A	Mid- to highly alkaline phases of all three lakes
<i>L.</i> sp. B	Most generally abundant species in Elmenteita and Naivasha, and widely occurring in Nakuru core; tolerant of wide alkalinity range.
<i>L.</i> sp. C	Mid to lower alkalinity phases; scattered occurrence in all lakes.
<i>L. michaelsonii</i>	High to intermediate or quite low alkalinity levels; in all lakes
<i>Gomphocythere obtusata</i>	Scattered in all cores; apparently tolerant of wide alkalinity range
<i>Cypridopsis</i> sp. A	Restricted occurrence in all lakes; mid- to low alkalinities?
<i>C.</i> sp. B	Similar to <i>C.</i> sp. A
<i>C.</i> sp. C	Similar to <i>C.</i> sp. A
<i>C.</i> sp. D	Mid- to high alkalinities in all lakes
<i>Zonocypris calcarata</i>	Restricted occurrence, in Elmenteita & Nakuru only. Low alkalinities.
<i>Oncocypris</i> sp.	Low to mid- high alkalinities; restricted occurrence in all lakes.
<i>Cypria</i> sp.	Intermediate alkalinities; all lakes
<i>Cypretta</i> cf. <i>C. murati</i>	Scattered; rel. dilute phases in Nakuru and Elmenteita; absent from Naivasha.
<i>Mecynocypris</i> cf. <i>M. reniformis</i>	Mid- to mid-low alkalinities, all lakes
<i>Potamocypris arcuata</i>	Only in Naivasha; restricted here to mid-alkalinity, open water conditions.

sin ostracode occurrence was even more sharply restricted (Fig. 3), and although the narrow zones of occurrence were rich in species, ostracodes by themselves yield a very incomplete reconstruction of Naivasha's history.

## Discussion

The striking high stand recorded for all three lakes circa 10000–5000 B.P. represents a major climatic phenomenon already known from other studies in many parts of Africa (cf. Butzer *et al.*, 1972; Street & Grove, 1976). Information that relates to the nature, timing and duration of the drier phases, and to lesser fluctuations of climate and lake conditions within the major wet phase, may be a more significant contribution from these cores. For example, the diatoms in these stratigraphies give only faint, equivocal evidence — and the ostra-

codes none at all — of the higher water levels about 16000–19500 B.P. for which Holdship (1976) found evidence at Lake Manyara, an Eastern Rift Lake some 400 km south of our study area. Harvey, 1976; see Richardson *et al.*, 1978) also found evidence for elevated levels of Lake Mobutu Sese Seko (650 km NW) at about this time. An earlier freshening phase, circa 25000–27000 B.P., that also was recorded by both Holdship and Harvey, seems better supported in our cores by ostracode evidence (Fig. 4) than by diatoms. These early wetter episodes must have been relatively minor at our sites.

The proximity of Lakes Nakuru, Elmenteita and Naivasha to each other makes the contrasts among their core histories (Fig. 4) particularly instructive.

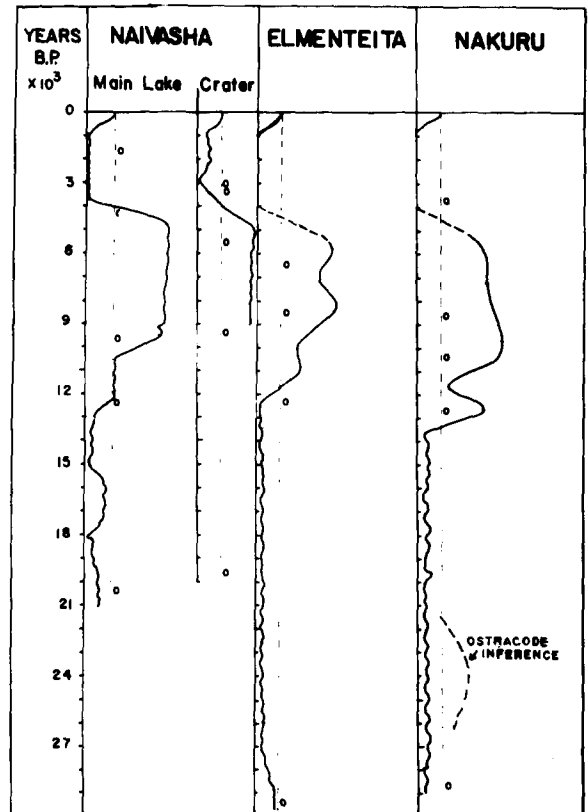


Fig. 4. Inferred water level changes for all lakes, including the crescent Island Crater of Naivasha (analyzed by Richardson & Richardson, 1972). The inferences are diatom-based; an alternative interpretation based on ostracodes is shown for the lower part of the Nakuru core. In other parts of this core diatom- and ostracode-based stratigraphies generally agree closely. Carbon-dated strata are indicated by circles, and average modern water levels by dashed lines.

There are noteworthy differences, such as the fluctuation of Nakuru about 12 800 B.P. that seemingly had no parallel of equivalent magnitude in the other two lakes. Some of these contrasts may be resolved by closer analysis, or may be artifacts of interruptions in the record of one or another of the lakes due to incomplete core recovery. However, it is clear that hydrological differences between Naivasha and the other two lakes underlie some of these contrasts, and these differences have produced records that complement each other in the degree of resolution they provide. When these lakes were high, Naivasha's biota and chemistry seem to have remained relatively stable, owing no doubt to the copious surface inflow and outflow at this time. Conversely, the deep Elmenteita-Nakuru lake of the major high-water period retained much of the ecological climatic sensitivity of a closed-basin lake; its inflow rivers and outflow channel were smaller and the lake only overflowed at times of very highest water. It is in the records from Elmenteita-Nakuru, rather than Naivasha, that biotic changes preserve evidence of a fluctuating water chemistry and climate during the high-water period 5000 to 10000 years ago, rather than uniformly moist conditions. But while the Elmenteita-Nakuru record is more fine-tuned during the high-water portion of the lakes' history, at low-water times Naivasha's record is more sensitive. Since this lake seldom shrank to dryness, its accumulating sediments preserved evidence of limnological and climatic fluctuations at times when the other two lakes were dry. Only from Naivasha, for example, has it been possible to ascertain that the time of *maximum* Holocene aridity occurred about 3000 B.P. in these basins. As we have indicated, ostracodes are a consistent and interpretively valuable component of the stratigraphy of Lake Nakuru, and to a lesser extent of Lake Elmenteita, but in the Naivasha main lake core their occurrence is highly localized. As ecological knowledge of East African ostracodes continues to accumulate, their usefulness (and use) in paleolimnological interpretation will increase but our results suggest that ostracode analysis will be fruitful for only some lake stratigraphies, not all.

A number of workers (Hustedt, 1949; Richardson, 1968, 1969; Hecky & Kilham, 1973; Richardson *et al.*, 1978; Gasse *et al.*, 1983) have directed their attention to the water chemistry relationships of

modern East African diatoms. Consequently, the paleoecological meaning of many diatom species and assemblages is quite well understood, and we believe that the diatom-based interpretations we have made here are sound. But both questions and opportunities remain with respect to the diatom stratigraphies. For example, why have we been unable to infer with greater precision the dilution status of both late and early portions of the Nakuru history (Fig. 2)? Is this uncertainty caused by post-depositional mixing of sediments representing more than one stage of a chemically fluctuating lake? Or, alternatively, did the diatom species recorded together in these regions of the core actually coexist? If the second suggestion is correct their chemical ecology may be more eurytopic than we presently suspect. Other questions relate to the *Melosira agassizii/Pediastrum* zone of Lakes Nakuru and Elmenteita: is this assemblage indicative, as we tend to think, of the phase of maximum dilution in these lakes? And if so, does it represent the time of highest lake level and maximum overflow, or instead, a prior phase of lower but rapidly rising levels? In the case of Naivasha, the diatom record raises similar questions, but also opportunities. Here the stratigraphies seem unusually conducive, for example, to untangling questions about ecological differences within the genus *Melosira*. At least four distinct taxa of *Melosira* alternated and sometimes coexisted as dominant elements in Naivasha through nearly the entire, changing, 20000-year history we now have from this lake. The record is sufficiently detailed to provide strong indications of the conditions favoring each taxon of *Melosira*, and more detailed analysis with this genus as the focus should be fruitful.

### Acknowledgements

We thank all of the following: The Office of the President, the Kenya National Park Service for permission to work in Kenya and in Lake Nakuru National Park; Daniel Livingstone for the loan of coring equipment; Paul Buckland, Thomas Harvey, Glynn Isaac, Peter Kilham, Alice Richardson and Paul Waiswa for assistance in drilling operations; and Andrew Cohen, L. D. Delorme, Linda Dusinger, Timothy Morris, Dean Pappas and George Ruddy for assistance with laboratory analysis or in-

terpretation. This research was supported by grants from the National Science Foundation to J. L. Richardson at Franklin and Marshall College, and to D. A. Livingstone at Duke University.

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Accepted 18 March 1986.