

Ostracodes as Indicators of Paleohydrochemistry in Lakes: A Late Quaternary Example from Lake Elmenteita, Kenya

ANDREW S. COHEN
*Department of Geosciences
University of Arizona
Tucson, AZ 85721*

CHRIS NIELSEN
*2535 S. Lowell Blvd.
Denver, CO 80219*

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Fossil ostracodes provide a useful way of interpreting the hydrochemical history of lakes. The tolerances of many ostracode species to particular hydrochemical parameters are known based upon studies of living taxa by Cohen et al. (1983) from eastern and southern Africa range assemblages.

A hydrochemical analysis of ostracodes applied to fossils from a radiocarbon-dated core from Lake Elmenteita, a small rift-valley lake of central Kenya, suggests that about 12,000 years B.P., Elmenteita was a small, closed lake of Range IV salinity and alkalinity. It underwent a period of decreasing salinity and alkalinity, passing through Range III to a Range II, high-water phase, about 10,000 years B.P. The lake remained in Range II or fluctuated slightly, prior to its rapid return to a Range IV, highly alkaline and saline, small-lake condition about 8,000 years B.P.

The results of this study are compatible with other studies of Lake Elmenteita's Quaternary history, as well as regional studies dealing with lake levels and paleoclimate in East Africa. More broadly, these results demonstrate the great potential for recognizing regional paleohydrologic and paleoclimatic trends from tropical lacustrine ostracodes derived from cores.

INTRODUCTION

The interpretation of paleoenvironments in lacustrine settings is a rapidly

blossoming field of research, due to the needs of such disparate fields as climatology and petroleum exploration. Lacustrine ostracodes are proving to be a very useful tool for paleoenvironmental, and, in particular, paleochemical, reconstructions. Their environmental sensitivity is indicated by recent studies in North America (Delorme et al., 1977; Forester, 1983), Australia (De-Deckker, 1983), and Africa (Carbonel and Peypouquet, 1983; Carbonel et al., 1983; Peypouquet et al., 1983; Cohen, 1982; Cohen et al., 1983). Whereas all of these authors utilize slightly different approaches, their work indicates that ostracodes are extremely sensitive to minute differences in water chemistry in lakes, and that this sensitivity can be put to use by the paleoecologist in the reconstruction of water-chemistry trends through time in ancient lakes. The great variability of solutes and solute evolutionary pathways encountered in the nonmarine environment, relative to the ocean, makes this a factor of first-order interest in lacustrine paleoecology (Eugster and Jones, 1979).

LOCATION AND CHARACTERISTICS OF STUDY SITE

Lake Elmenteita (0°25'S, 36°15'E) lies near the summit of the Central Kenyan Dome, within the Eastern or Gregory Rift Valley, at an elevation of 1,776 m (Fig. 1). The lake occupies the central portion of a topographically closed basin bounded by numerous Quaternary normal faults. The surficial geology throughout the entire basin consists of Plio-Pleistocene volcanics and Pleistocene fluvio-lacustrine sediments.

Lake Elmenteita receives an average of about 900 mm rainfall per year at present. Rainfall is seasonally distributed with April-May and July-August maxima (100-150 mm/month).

During the driest period of the year, December to February, the lake basin normally receives less than 50 mm rainfall per month. The rainy months have slightly less extreme temperature ranges than during the dry period. For example, during May, the wettest month, the daily mean minimum and maximum temperatures are 11° and 25°C respectively, whereas the January range is from 9° to 29°C. Total insolation is highest during February, with average daylight cloud cover lasting less than three hours, and lowest during April and November, when daylight cloud cover exceeds six hours on average. High rates of evaporation from the lake's surface result in a precipitation-evaporation deficit for the lake of approximately -600 mm per year (Hastenrath and Kutzbach, 1983). The deficit is balanced by runoff from a number of small streams, the Karian-dusi River, and the Mbaruk River. No specific evidence is currently available regarding subsurface discharge, although such discharges have been documented in the highly fractured, volcanic terrains found in adjacent Lake Naivasha (Gaudet and Melack, 1981). Outflow seepage from the lake probably maintains Elmenteita as a large evaporative lens (R. Forester, 1986, pers. comm.).

Lake Elmenteita covered an area of 15 km², with a maximum depth of 2.25 m, at the time the core described here was extracted in 1969. By 1978, the most recent date for which accurate morphometric data are available, the lake had expanded to cover 18 km² with a maximum depth of approximately 2.5 m, indicative of its extremely low-gradient shoreface. Elmenteita at present has no surficial outlet, and is highly alkaline and saline. Water chemistry parameters for Lake Elmenteita are given in Table 1. Total ionic concentration in the modern lake is subject to considerable fluctuation as is indicated by the two "Modern Lake" analyses.

MATERIALS AND METHODS

The ostracode samples studied in this report were obtained from a 22.5 m core taken in late 1969 by Dr. Jonathan Richardson of Franklin and Marshall College, in the central part of Lake

Table 1—Modern water-chemical determinations for Lake Elmenteita and some paleochemical estimates for critical late Pleistocene–early Holocene intervals.

Sampling Interval	Sample Date or ^{14}C Interpolated Estimated Age	Na^+ (mg/l)	Ca^{+2} (mg/l)	$\text{HCO}_3^- + \text{CO}_3^{-2}$ (meq/l)	Cl^- (mg/l)	K_{20}
Modern Lake	Feb. 1961	9,450	<10	289	5,200	43,750
Modern Lake	Dec. 1952	—	1.1	146.5	4,000	22,500
320 cm	~7,400 y. BP	900–4,000	<4	30–80	500–1,500	3,500–10,000
600 cm	~8,600 y. BP	75–125	5–15	5–10	20–30	500–1,000
920 cm	~11,200 y. BP	500?–900	5–10	20–30	300–500	2,500–4,000

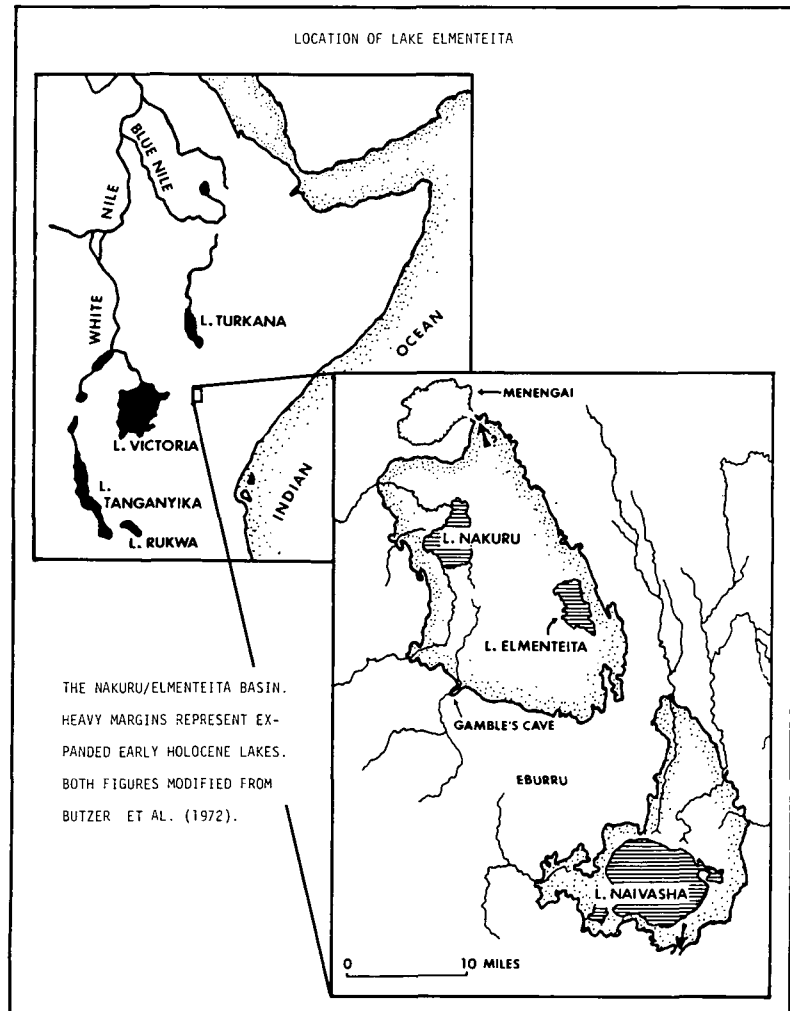
Elmenteita at 1.87 m water depth. Details of the core stratigraphy are given in Dussinger (1973) (see Fig. 2). The lower 12.5 m of the core is almost entirely composed of volcanic ash and pumice, with total organic carbon content less than 6%. Above this point in the core the lithology changes drastically to an organic-rich mud with organic carbon ranging from 10–25%.

Radiocarbon dates (^{14}C) were obtained by Richardson for 4 horizons in the Elmenteita core: $29,320 \pm 110$ years B.P. at 21 m downcore; $12,200 \pm 180$ years B.P. at 10.5 m; $8,740 \pm 190$ years B.P. at 6.25–6.5 m; and $6,490 \pm 125$ years B.P. at 1.25–1.5 m (Dussinger, 1973). Only the last 3 of these are directly pertinent to this study and are illustrated in Figures 2 and 3. Preliminary studies by Dussinger (1973) and Nielsen (1984) showed that ostracodes are almost entirely restricted to the upper 10 m of the core, the lower 12.5 m of ash being essentially barren except for a minor occurrence near the base of the core. Our study deals with 19 out of 50 samples taken at 20 cm intervals from approximately the upper 10 m. The remaining 31 samples were either barren of ostracodes or could not be disaggregated without damaging ostracodes and thereby invalidating our quantitative approach.

Moist sample splits of 1–2 gm were taken from scraped core interiors and disaggregated with a mild detergent. Samples were then carefully washed in a #200 (.075 mm) stainless-steel sieve. Between 100–200 valves were counted for each sample, except for the upper 5 samples, which were nearly barren (yielding only 20–50 valves each). For this study valve counts include both

adult and juvenile ostracodes. Ratios of the adults/juveniles have not yet been obtained. Such ratios are often consid-

ered significant by ostracode workers, as a sample consisting entirely of juveniles of a species might indicate that the

**FIGURE 1—A)** Location of Lake Elmenteita, Kenya. Arrow indicates possible ancient outlet to the Menengai Crater. Elevations are in meters above sea level.

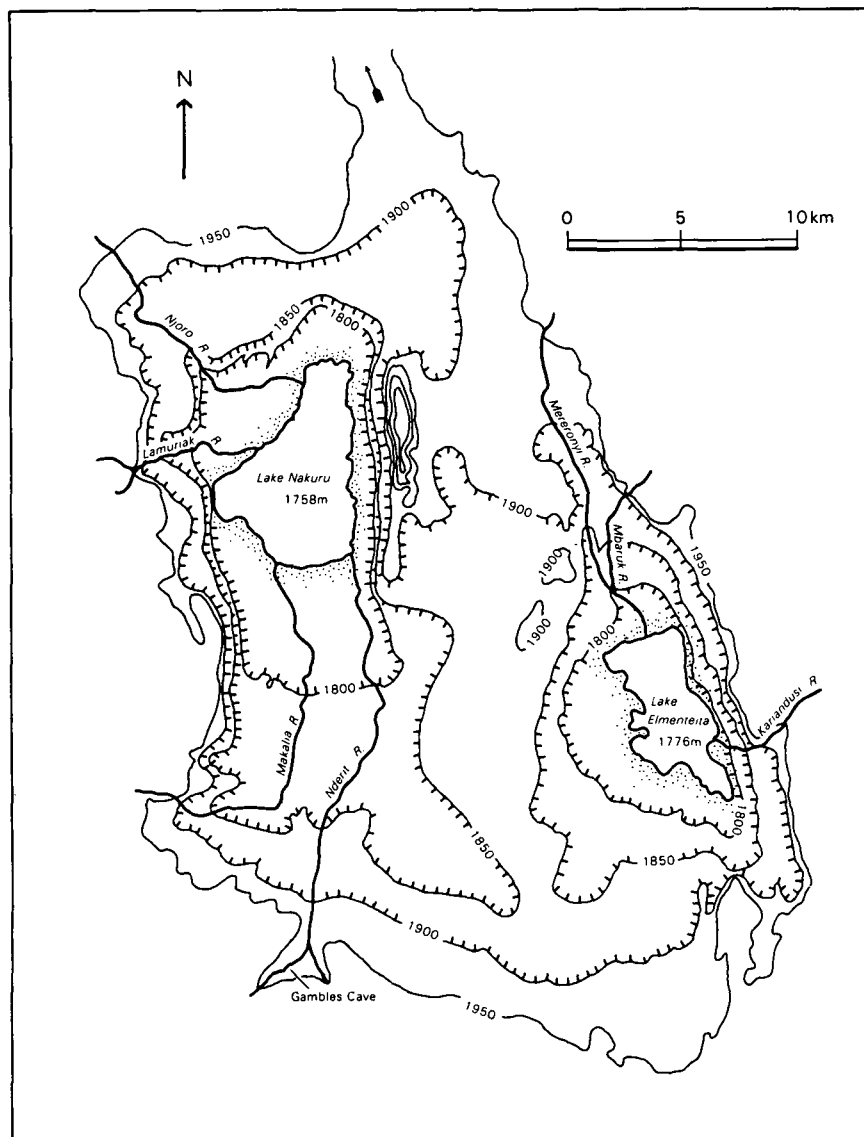


FIGURE 1—B) Details of the Nakuru-Elmenteita Basin physiography. Arrow indicates possible ancient outlet to the Menegai Crater. Elevations are in meters above sea level.

habitat is unsuitable for it throughout its life cycle. However, all samples examined consisted of mixed adult-juvenile populations.

RESULTS

A relatively low diversity ostracode fauna comprising a variety of cosmopolitan African taxa was recovered from the Elmenteita core. Three species, *Limnocythere michaelsoni* Daday, *Gom-*

phocythere obtusata Sars, and *Sclerocypris jenkiniae* Klie dominate most of the assemblages through the fossiliferous sections of the core (Fig. 3).

L. michaelsoni occurs in great abundance in the lower interval of the core, below 850 cm. From 850–720 cm its frequency declines rapidly and the species is absent or very rare from 720–510 cm. Above 510 cm its frequency rises rapidly and it

is the only ostracode present above 430 cm.

G. obtusata frequencies present almost a mirror image to those of *L. michaelsoni*. *G. obtusata* is relatively uncommon or absent in the lower interval of the core. Its abundance rises rapidly above 850 cm. At 510 cm it reaches its maximum abundance (in both total numbers of valves and percentage), and then its abundance rapidly declines to zero at 450 cm.

S. jenkiniae shows a much more erratic pattern of abundance through the core. The species is absent below 930 cm and then becomes relatively abundant up to 830 cm. Above this point, up to 450 cm, the species occurs in relatively low (always less than 25% of the total fauna) but fluctuating frequencies. Like *G. obtusata*, *S. jenkiniae* is entirely absent in the core above this point.

Two additional taxa, *Mecynocypris/Alloocypris* Rome cf. *A. reniformis* Rome and *Oncocypris* Muller sp., also occur frequently, but only at restricted intervals within the core. *Mecynocypris/Alloocypris* sp. constitutes as much as 60% of the ostracode fauna at 590 cm, and is quite common throughout the interval from 720–530 cm. Elsewhere in the core it is rare or absent. *Oncocypris* sp. occurs abundantly over a similar, but more restricted, interval, from 600–700 cm only.

Two additional taxa, *Darwinula stevensoni* Brady and Robertson, and *Plesiocypridopsis* Rome sp., occur sporadically in the mid-levels of the core between 540–720 cm.

In addition to the taxa reported here, Dussinger (1973) found *Zonocypris calcarata* Klie, rare at 310 cm; *Cyprina* sp.?, rare at 450 cm and 310 cm; *Cyprina* cf. *C. murati* Gauthier, very abundant at 700 cm and rare between 600–500 cm; and *Sclerocypris venusta* Sars, moderately abundant at 930 cm. Dussinger's (1973) findings and frequencies for the major ostracode taxa, discussed earlier, are in good agreement with ours.

Ostracode frequencies are shown on Figure 3 in number of valves ($\times 100$) per gram of sediment (dry mass). A small peak at 940–960 cm and two strong frequency peaks at 700–720 cm and 510–540 cm are apparent. Whereas the

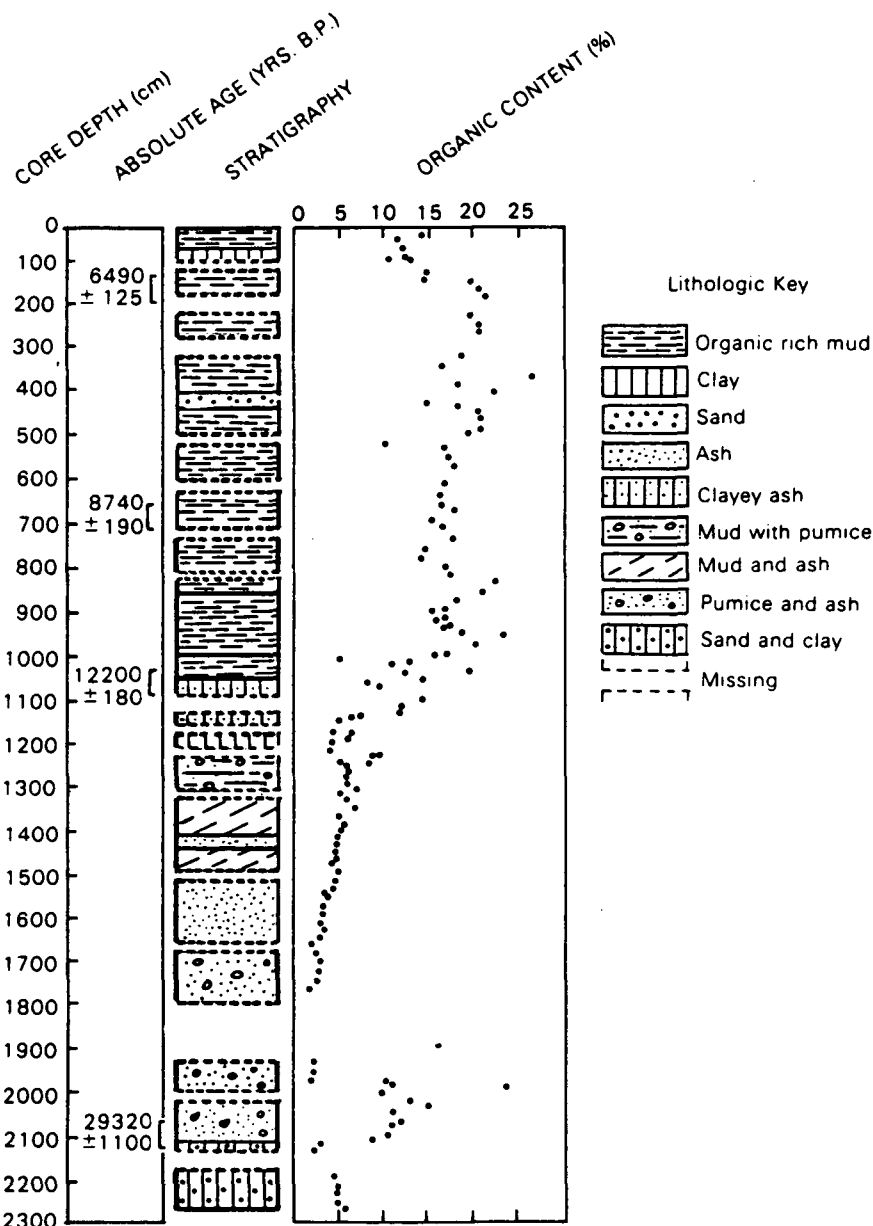


FIGURE 2—Stratigraphy of the Lake Elmenteita core analyzed in this study. Modified from Dussinger (1973).

two major peaks are dominated by *Gomphocythere obtusata*, the lower peak is almost entirely due to an abundance of

Limnocythere michaelsoni. The transition to the low-frequency ostracode zone above 420 cm corresponds with a

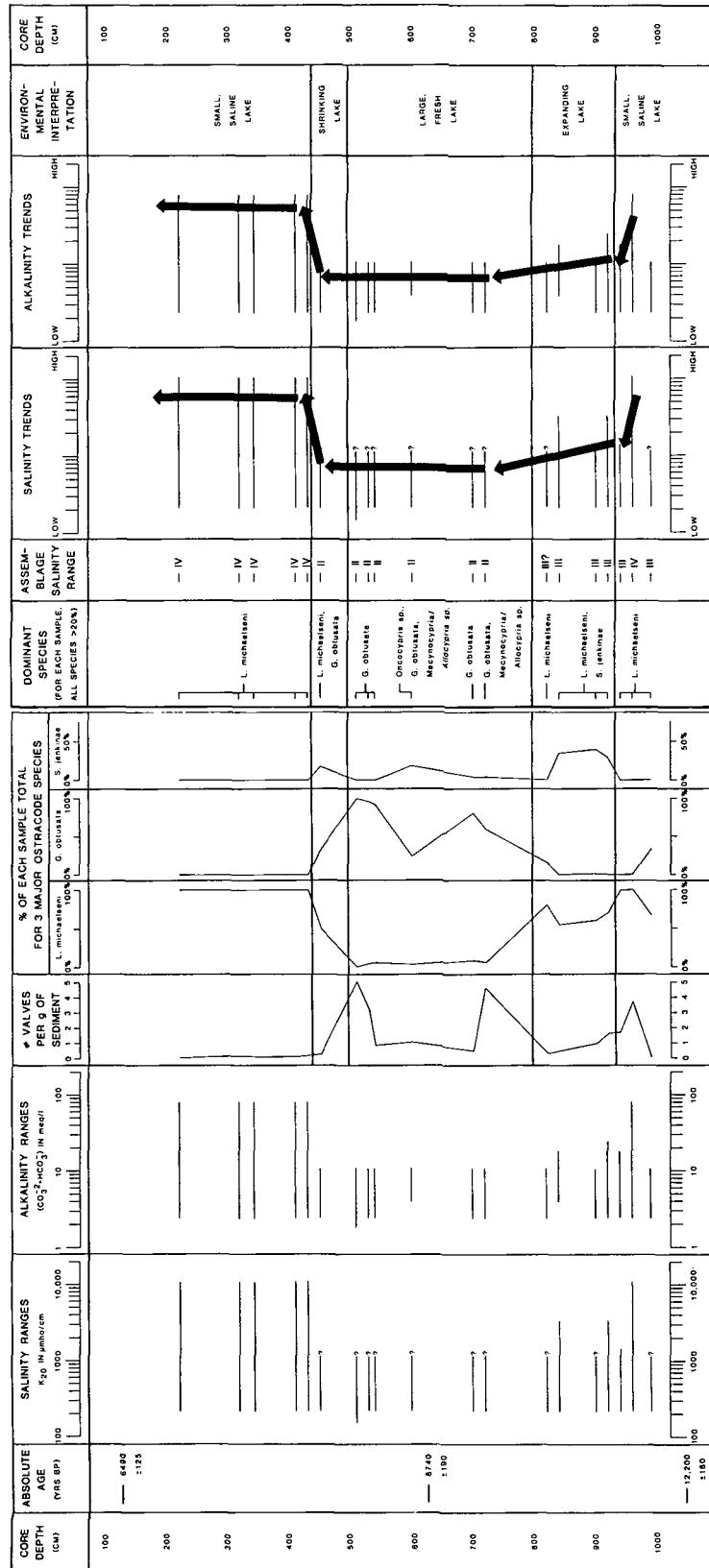
rapid decline in *G. obtusata* and a concomitant increase (in % of total fauna) in *L. michaelsoni*.

PALEOCHEMICAL INTERPRETATIONS

Cohen et al. (1983) defined four Ostracode Assemblage Ranges, identifying characteristic genera for various ranges of select dissolved major ions in eastern and southern African nonmarine waters (Fig. 4). The assemblage range names do not indicate that the typical genus is restricted to that range, only that it is characteristic of it. Cohen et al. (1983) gave detailed water-chemistry ranges for the wide variety of species that form the basis of the analysis presented here, but these range analyses are too lengthy to duplicate fully in this paper. Earlier work by Cohen (1982) has demonstrated that water chemistry (including dissolved O_2 concentration) is by far the most critical environmental parameter in controlling the occurrence of cosmopolitan, tropical ostracodes in Africa. Temperature variations, which are often important in regulating temperate ostracode distribution patterns, play only a minor role in the tropics, where temperature seasonality is minimal. Cohen (1982) has also shown that within the clay to medium sand grain size range, substrate variations are not important in regulating the distribution patterns of nonmarine African ostracodes.

The technique followed here and in the earlier contribution by Cohen et al. (1983) involves the analysis of overlapping water-chemistry ranges for co-occurring taxa (see Fig. 5 for an example). In the earlier study by Cohen et al. (1983, p. 144–147) occurrence frequencies were explicitly ignored, as we felt it was inappropriate to incorporate such data in our preliminary use of this technique. In the present study, we have decided to try to incorporate this type of data, albeit in a qualitative way only. Thus, as illustrated in Figure 5, the much greater frequency of the high-alkalinity-tolerant species *Limnocythere*

FIGURE 3—Ostracode stratigraphy and paleochemical interpretations from the Lake Elmenteita core. The upper 10 m of the 22.5 m core were analyzed in this study. Three ^{14}C dates obtained from the upper portion of the core provide age control for the events discussed, and are shown on the left side of the diagram. "Salinity" ranges are actually shown as electrical conductivity (K_{20}). The conversion rate is $K_{20} \sim \text{salinity (p.p.t.)} \times 10^3$. Salinity and alkalinity ranges are absolute ranges based upon presence/absence data only. See Table 1 for representative water-chemistry estimates based upon taxa frequencies. Uncommon ostracode taxa are discussed in the text but not figured on this diagram. Numbers of valves per gram of sediment are $\times 100$.



OSTRACODE ASSEMBLAGE RANGES						
RANGE #	NAME	Na ⁺	Cl ⁻	Alkalinity	K ₂₀	Comparison with Talling and Talling's (1965) classification
I	<i>Stenocypris</i> Assemblage	<75	<20	<5.0	<500	Class 1 (<600)
II	<i>Mecynocypria</i> Assemblage	75-150	20-50	5-15	500-1500	Class 2 (600-6000)
III	<i>Gomphocythere</i> Assemblage	150-900	50-500	15-30	1500-4000	
IV	<i>Limnocythere</i> Assemblage	>900	>500	>30(-80?)	>4000	Class 3 (>6000)

FIGURE 4—Ostracode Assemblage Ranges. The Range number is followed by the most distinctive or commonplace genus of that range. Na⁺ and Cl⁻ values are in mg/l, alkalinity (CO₃⁻² + HCO₃⁻) in meq/l, and K₂₀ (conductivity) in μmho/cm. Talling and Talling's (1965) classification scheme (values are K₂₀) is included for comparison. From Cohen et al. (1983).

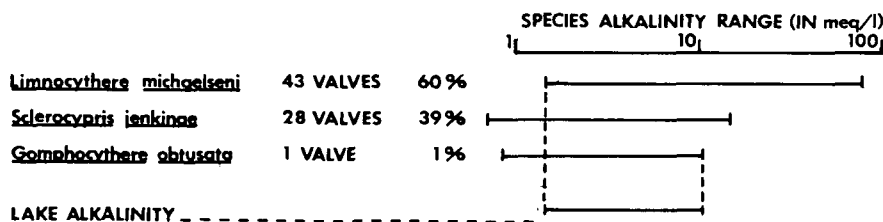


FIGURE 5—Sample analysis of a paleochemical determination from an ostracode fauna. The ostracode taxa contained in a lacustrine sediment sample are identified and their water-chemistry (in this example, alkalinity) tolerance ranges, if known, are "overlapped." The sample shown is from the 903 cm level of the Elmenteita core. The resultant range represents the only alkalinities at which all three species can coexist and thus the alkalinity range of the lake at the time of deposition.

In some cases, the range can be effectively weighted by considering the relative abundances of the range-determining taxa. Since 60% of the ostracodes at 903 cm are *L. michaelseni* and only 1% *G. obtusata*, the lake during deposition had an alkalinity more likely towards the high end of this range than the low end.

michaelseni as compared with *Gomphocythere obtusata*, a species found normally in much fresher waters, can be taken to suggest that the actual alkalinity of the core site at the time of deposition was closer to the higher end of the overlapping range (10 meq/l total alkalinity), than to the lower end (1.4 meq/l). At present we have no empirical data to suggest how this qualitative,

frequency-derived estimate might be transformed into a more firmly quantitative estimate.

L. michaelseni previously was shown to be a highly euryhaline and euryalkaline species. However, Cohen et al. (1983) demonstrated that monospecific assemblages of this species are only known to occur in highly alkaline, Range IV conditions. In this study we have utilized

this observation in our interpretations of the 940–980 cm and 430–200 cm core intervals, where the assemblage is monospecific for this taxa. *G. obtusata* appears to be indicative of Range I to mid-Range II conditions, and its common occurrence in the mid-sections of the analyzed core suggests these conditions for the 810–450 cm interval. Finally, *Mecynocypria/Alloocypria* sp., also common in the mid-levels of the core, is indicative of Range II conditions.

Our interpretations of Assemblage Ranges and resultant salinity and alkalinity trends are shown in Figure 3. The picture that emerges is one in which a highly saline/alkaline Range III–IV lake existed when the lowermost core interval (below 940 cm) was being deposited. By interpolating constant sediment accumulation rates between the radiometrically dated horizons we propose an approximate age range of 12,000–11,500 years B.P. for this interval. Somewhat less saline/alkaline, Range III conditions apparently followed this in the lake, documented between 940–820 cm. By interpolation, the approximate time period when these conditions existed would have been 11,500–10,000 years B.P. The lowest salinity and alkalinity conditions of the documented interval (Range II) occurred during the deposition of sediments from 820–450 cm. This section was deposited between approximately 10,000–8,000 years B.P. Following this interval, there was a rapid return to highly saline/alkaline Range IV conditions for the remainder of the sampled core interval (8,000–6,700 years B.P.). It is important to note that the uppermost 200 cm of the core is barren of ostracodes and that no modern African ostracodes are known from waters with alkalinities higher than 80 meq/l CO₃⁻² + HCO₃⁻ alkalinity. The possibility that ostracodes were eliminated due to ectogenic meromixis (stratification-induced anoxia) can be eliminated given the declining organic-carbon content found in the upper core segment. The 200 cm core level, deposited approximately 6,700 years B.P., may well represent the last time in the recorded sedimentary history of Lake Elmenteita that water chemistry conditions were hospitable to an ostracode fauna.

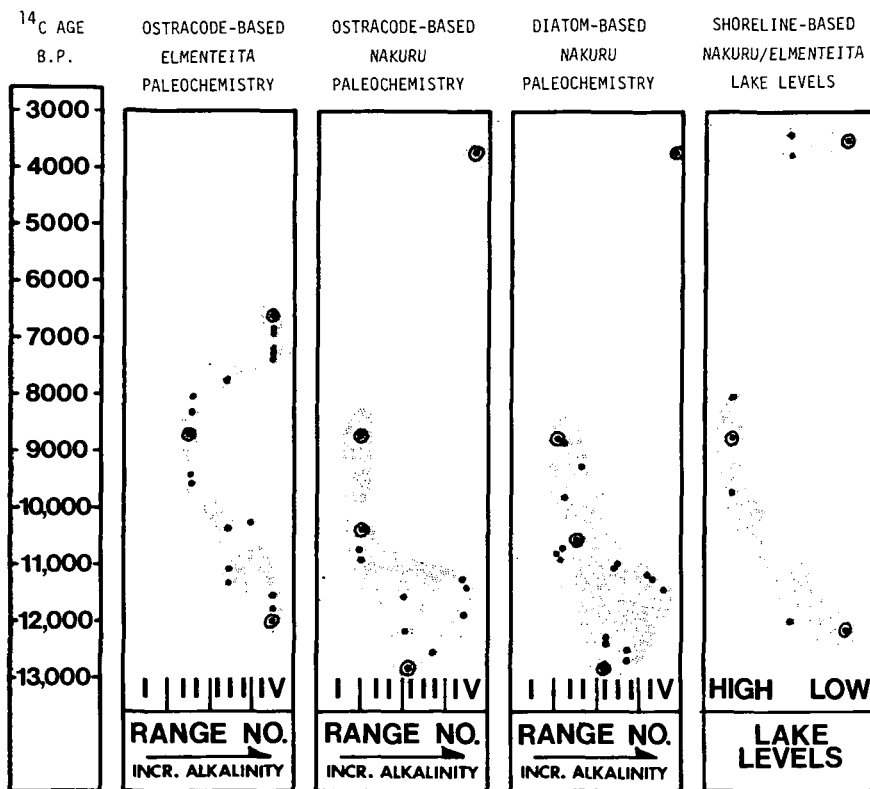


FIGURE 6—A comparison of various paleochemical and paleo-lake-level interpretations for the Nakuru-Elmenteita Basin. The ostracode-based paleochemical interpretation shows a broad correlation with independent paleochemical and lake-level studies. The age of each sample represented by a noncircled data point is interpolated from ^{14}C dates and is thus approximate. Nakuru data after Cohen et al. (1983); shore-line data after Butzer et al. (1972).

QUATERNARY LAKE-LEVEL FLUCTUATIONS IN LAKE ELMENTEITA: BIOGEOGRAPHIC AND CLIMATIC IMPLICATIONS

Fluctuations in lake level in the Lake Nakuru-Lake Elmenteita Basin have been previously described by Washbourn-Kamau (1970), Butzer et al. (1972), and Hamilton (1982). Our results are compatible with these earlier studies, because changes in water chemistry may be correlated with shrinking or expanding lake phases. Butzer et al. (1972) described an elevated shore line around the combined Nakuru-Elmenteita Basin (illustrated in Fig. 1) that gave ^{14}C dates of 10,000–8,000 years B.P. They proposed that the two lakes were connected at that time at a common lake level of as high as 1,934 m,

158 m above present day Elmenteita. This maximum elevation shoreline at Gamble's cave was about 10 m below the modern potential outlet, although seepage may have occurred between the lake and the adjacent Menengai Crater (Fig. 1). This corresponds precisely with our minimum salinity/alkalinity Range II phase for the Lake Elmenteita core.

In Figure 6 we compare water-chemistry and lake-level trends through time for lakes Elmenteita and Nakuru, based on three distinct lines of evidence: ostracode fauna, diatom flora, and shore-line dating. All of these independently point towards a period of lowered lake levels and concomitant high alkalinities throughout the two basins prior to 10,000–10,500 years B.P. The fossil data suggest that this phase may have ended slightly earlier in Nakuru

than in Elmenteita. A phase of high lake stands and reduced alkalinities is consistently documented between 10,000–8,000 years B.P. After 8,000 years B.P. there is no directly comparable data to our Elmenteita ostracode record. Earlier studies of ostracodes and diatoms from near the top of a core from Lake Nakuru suggested highly alkaline conditions approximately 3,800 years B.P. However, the Nakuru sedimentation record consists of a major hiatus between about 8,600–3,800 years B.P., most likely due to an erosional discontinuity that developed during a period of declining lake level. Thus, for Lake Nakuru, it is not possible to accurately date the time at which these alkaline conditions resumed. Our evidence from Elmenteita suggests that the transition back to highly alkaline conditions occurred very rapidly following the high lake stand between 10,000–8,000 years B.P.

The 10,000–8,000 year B.P. high lake stand has been widely recognized throughout east and central Africa, and more recently in other parts of the globe (Street and Grove, 1979). In Figure 7 we illustrate our interpretations from Lake Elmenteita against related interpretations from other African lakes. To explain the major changes in lake levels inferred in Central Kenya during the early Holocene from strand-line data, Hastenrath and Kutzbach (1983) proposed a 260–300 m/yr increase in rainfall for the Nakuru Elmenteita Basin for the period 10,000–8,000 years B.P., based upon sensitivity-analysis models.

The 500–800 cm (Early Holocene) ostracode fauna is indicative of an important biogeographic event with profound paleoclimatic implications. Several taxa found at this level, including *Alloocyprina reniformis*, *Gomphocythere obtusata*, and *Zonocypris calcarata* are not found today east of 32°E, being primarily restricted to the moister regions of central and western equatorial Africa. The closely related genera *Alloocyprina* and *Mecynocypris* occur in relict distributions in the Lake Tanganyika Basin and portions of Zaire and northernmost Zambia. *Gomphocythere obtusata* is found in extremely disjunct regions at present (coastal South Africa and around the south end of Lake Victoria), while *Zonocypris calcarata* only

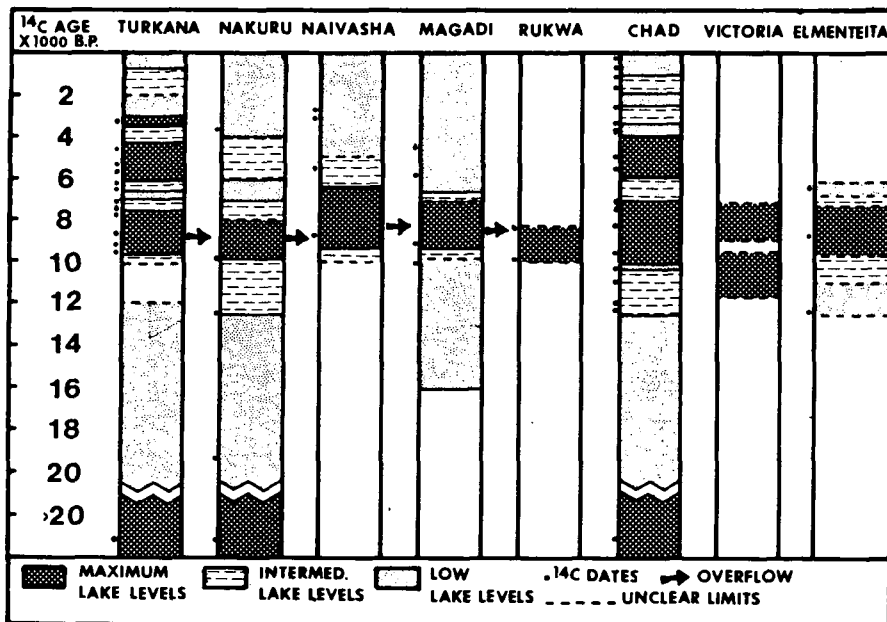


FIGURE 7—Elmenteita and regional lake-level data. The lake-level interpretations derived for Elmenteita by ostracode typology agree broadly with regional lake-level interpretations derived by other techniques. Most noteworthy is the occurrence of maximum lake stands approximately 10,000–8,000 years B.P. throughout East Africa and as far west as Lake Chad. While the regional climatic explanation is unclear, for many of these lakes, including Elmenteita, increased precipitation is probably the cause of the early Holocene high lake levels.

Except for Victoria and Elmenteita, the figure is modified from Butzer et al. (1972). Lake Victoria data is from Kendall (1969).

occurs today in Cameroon, in West Africa. All are restricted to regions of high annual rainfall, generally greater than 1,500 mm/yr, with pronounced wet/dry seasonality.

These three taxa have now been documented in Early Holocene lacustrine sediments from a number of lake basins in Kenya. Aside from Elmenteita, *A. reniformis* and *G. obtusata* have been recovered from cores or exposed strata of the L. Nakuru, L. Naivasha, and L. Turkana basins. *Z. calcarata* is known from a Lake Nakuru core.

These fossil and recent distributions suggest a reduction in suitable habitat for wet-tropical ostracodes during the progressive drying of East Africa following the end of the Early Holocene. These conclusions are consistent with the previously mentioned 300 mm/yr decline in rainfall for the central Kenyan Rift based upon shore-line and sensitivity-analysis studies. These are particularly interesting, however, given the implications of rainfall seasonality, which *cannot* be

demonstrated by previously employed methods.

In situations where strand lines cannot be located or adequately age dated, ostracode-based hydroclimatic analyses provide an alternative to more traditional methods. Other studies have previously shown that ostracode faunal changes can be related both directly and indirectly to climatic change in North America (Carter et al., 1984; Forester and Markgraf, 1984; Delorme et al., 1977; Delorme and Zoltai, 1984). The congruence between earlier shore-zone studies and our results from L. Elmenteita demonstrates the value of ostracode-based hydrochemical analyses for unravelling details of the paleoclimatic evolution of tropical Africa.

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REFERENCES

- BUTZER, K. W., ISAAC, G. L., RICHARDSON, J. L., and WASHBOURN-KAMAU, C. K., 1972, Radiocarbon dating of East African lake levels: *Science*, v. 175, p. 1069–1076.
- CARBONEL, P., GROSDIDIER, E., PEYPOUQUET, J. P., and TIERCELIN, J. J., 1983, Les ostracodes, temoins de l'evolution hydrologique d'un lac de rift. Exemple du Lac Bogoria, Rift Gregory, Kenya: *Bulletin Centres des Recherches Exploration-Production Elf-Aquitaine*, v. 7, p. 301–313.
- CARBONEL, P., and PEYPOUQUET, J. P., 1983, Ostracoda as indicators of ionic concentrations and dynamic variations: methodology (Lake Bogoria, Kenya), in MADDOCKS, R. F., ed., *Applications of Ostracoda to economic and scientific problems: Proceedings of the 8th International Symposium on Ostracoda*, Houston, p. 264–276.
- CARTER, L. D., FORESTER, R. M., and NELSON, R. E., 1984, Mid Wisconsin through early Holocene changes in seasonal climate in Northern Alaska: *American Quaternary Association, 8th biennial meeting, abstracts with programs*, p. 20–23.
- COHEN, A. S., 1982, *Ecological and paleoecological aspects of the Rift Lakes of East Africa* [unpubl. Ph.D. dissert.]: University of California-Davis, 314 p.
- COHEN, A. S., DUSSINGER, R., and RICHARDSON, J., 1983, Lacustrine paleochemical interpretations based on eastern and southern African ostracodes: *Paleogeography, Paleoclimatology, Paleoecology*, v. 43, p. 129–151.
- DE DECKKER, P., 1983, The limnological and climatic environment of modern halobiont ostracodes in Australia. A basis for paleoenvironmental reconstruction, in MADDOCKS, R., ed., *Applications of Ostracoda to Economic and Scientific Problems: Proceedings of the 8th International Symposium on Ostracoda*, Houston, p. 250–254.
- DELORME, D., and ZOLTAI, S. C., 1984, Distribution of an arctic ostracod fauna in space and time: *Quaternary Research*, v. 21, p. 65–73.
- DELORME, D., ZOLTAI, S. C., and KALAS, L. L., 1977, Freshwater shelled invertebrate indicators of paleoclimate in Northwestern Canada during the late glacial: *Canadian Journal of Earth Sciences*, v. 14, p. 2029–2046.
- DUSSINGER, R., 1973, The environmental reconstruction of African Rift Lakes using ostracodes as paleoecological indicators [Thesis]: Lancaster, PA, Franklin and Marshall College, 37 p.
- EUGSTER, H. P., and JONES, B. F., 1979, Behavior of major solutes during closed basin

- brine evolution: *American Journal of Science*, v. 279, p. 609–631.
- FORESTER, R., 1983, Relationship of two lacustrine ostracode species to solute composition and salinity: Implications for paleohydrochemistry: *Geology*, v. 11, p. 435–438.
- FORESTER, R., and MARKGRAF, V., 1984, Late Pleistocene and Holocene seasonal climatic records from lacustrine ostracode assemblages and regional (pollen) vegetational patterns in southwestern U.S.A.: *American Quaternary Association, 8th biennial meeting, abstracts with programs*, p. 43–45.
- GAUDET, J. J., and MELACK, J. M., 1981, Major ion chemistry in a tropical African lake basin: *Freshwater Biology*, v. 11, p. 311–333.
- HAMILTON, A. C., 1982, *Environmental History of East Africa*: New York, Academic Press, 328 p.
- HASTENRATH, S., and KUTZBACH, J. E., 1983, Paleoclimatic estimates from water and energy budgets of East African lakes: *Quaternary Research*, v. 19, p. 141–153.
- KENDALL, R. L., 1969, An ecological history of the Lake Victoria Basin: *Ecological Monographs*, v. 39, p. 121–176.
- NIELSEN, C., 1984, Ostracodes as paleochemical indicators at Lake Elmenteita, Kenya: *American Quaternary Association, 8th biennial meeting, abstracts with programs*, p. 94.
- PEYPOUQUET, J. P., CARBONEL, P., TAIEB, M., TIERCELIN, J. J., and PERINET, G., 1983, Ostracoda and evolution process of paleohydrologic environments in the Hadar Formation (the Afar Depression, Ethiopia), in MADDOCKS, R. F., ed., *Applications of Ostracoda to Economic and Scientific Problems: 8th International Symposium on Ostracoda*, Houston, p. 277–285.
- STREET, F. A., and GROVE, A. T., 1979, Global maps of lake-level fluctuations since 30,000 yr B.P.: *Quaternary Research*, v. 12, p. 83–118.
- TALLING, J. F., and TALLING, I. B., 1965, The chemical composition of African lake waters: *Internationale Revue der Gesamten Hydrobiologie*, v. 50, p. 421–463.
- WASHBOURN-KAMAU, C. K., 1970, Late Quaternary chronology of the Nakuru-Elmenteita basin: *Nature*, v. 226, p. 253–254.



In the early nineteenth century, geology was a new, exciting, and fashionable science. It was experiencing its first and greatest boom in conceptual innovation, empirical expansion, and public approval and interest. It attracted some of the most talented in the scientific world, particularly those with a taste for travel and the outdoor life rather than for mathematics. But those with lesser talents or more limited opportunities could also hope to gain recognition and respect, for it was felt that any worthwhile grand conclusions in geology had to rest on the foundations of local details that required much time and patience to acquire. The empiricism esteemed by geologists bound leaders and locals into a symbiotic partnership that was seen as a model of the ideal community of science.

—Martin J. S. Rudwick