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Radiocarbon Dating of East African Lake Levels

New observations provide fresh insights into late Quaternary paleoclimates.

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East Africa and, in particular, its lake basins have provided the type area for the sequence of "pluvials" and "interpluvials" once proposed as stratigraphic horizons for sub-Saharan Africa by the first Pan-African Congress on Prehistory (*1*). Of necessity, pioneer research contributions to African paleoclimatology often depended on the compilation of scattered items of stratigraphic evidence correlated by reference to supposed archeological or paleontological equivalences, or in some instances by reference to the paleoclimatic theories themselves. These criteria as well as the stratigraphic validity of the pluvial-interpluvial scheme were subsequently challenged by Cooke (*2*), Flint (*3*), Bishop (*4*), and McCall *et al.* (*5*). Most African geologists have now abandoned the climato-stratigraphic approach, and the concept of early to middle Pleistocene "pluvials" of East Africa has fallen into disuse. The advent of isotopic dating has allowed many former dilemmas to be solved decisively, but there has been ambiguity concerning the apparent evidence for a protracted and significant wet period spanning most of the late Pleistocene (the "Gamblian Pluvial"). Uncertainty also prevails as to the nature and significance of Holocene wet phases (the "Makalian" and "Nakuran"). Clearly, further field studies of an interdisciplinary nature were necessary in order to obtain fresh information from the key lake basins in East Africa.

During the past several years, the writers have, jointly or independently, studied depositional sequences and shorelines at various points, with extensive ^{14}C dating of local successions to permit objective correlation on a regional basis. These areas include the Omo-Rudolf basin (K.W.B.), the Nakuru-Elmenteita basin (G.L.I., C.W.-K., and J.L.R.), and the Naivasha basin (J.L.R.). This work complements Kendall's investigation (*6*) of Lake Victoria and earlier studies by one of us (K.W.B.) along the Nubian Nile. Our results for East Africa provide new insights into late Quaternary paleoclimates. Furthermore, these appear to have some relevance for a better understanding of environmental changes elsewhere in sub-Saharan Africa.

The Omo-Rudolf Basin

Lake Rudolf (*7*), with a contemporary surface area of 7500 square kilometers, is the largest nonoutlet lake in East Africa (Fig. 1). Situated in a downwarped zone adjacent to the Eastern Rift, this alkaline lake is fed primarily (approximately 80 to 90 percent) by the Omo River, which derives its waters from the western Ethiopian Plateau. Studies by Fuchs in 1931 and 1934 (*8*) suggested the presence of four high shorelines between +100 and +27 meters, attributed to successive middle to late Pleistocene "pluvials," the earliest of which led to an overflow of the lake to the adjacent Nile basin. The details of this apparent sequence and the "dating," by scattered artifacts, were already questioned by Cooke (*2*), and, based on work in 1959, Whitworth (*9*) described a more realistic section of high lake beds west of Rudolf, with two transgressions, to a maximum height of +87 m.

A semidetailed study of the lower Omo basin by K.W.B., which included mapping, sedimentological work, and a large suite of ^{14}C dates, has unraveled a more complex picture (*10, 11*). The mid-Pleistocene to mid-Holocene time span is represented by littoral, deltaic, and fluvial beds (*12*) that are tectonically undeformed and designated as the Kibish Formation. Member I, indicating a lake level about 60 m higher than the present level (*13*), has a single Th/U date of 130,000 years ago that is compatible with the geological evidence. Member III lies just beyond the satisfactory range of ^{14}C dating, but a Rudolf level of +60 to +70 m is indicated shortly prior to 35,000 years ago (Table 1). There are no deltaic or littoral sediments from the period 35,000 to 9,500 years ago, so that the lake must have been relatively low; in addition, there are some indications of local aridity such as carbonate horizons and "desert" varnish on lag pebbles. The youngest Kibish units, designated as Members IVa and IVb, preserve considerable surface morphology, are well exposed, and currently have 15 ^{14}C de-

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terminations. The initial transgressive sediments of Member IVa have not been identified, but the maximum level was attained by 9500 years ago and the lake level fluctuated between about +60 and +80 m (*10*) until a little after 7500 years ago (*14*), when Lake Rudolf shrank to about its present dimensions. Member IVb records a transgression of Lake Rudolf that began shortly before 6600 years ago and reached a high level of +65 to +70 m about 6200 years ago (Table 1). This level was maintained until after 4400 years ago (*15*) and was followed by a temporary regression of unknown amplitude and a final transgression to +70 m a little before 3000 years ago. Lake Rudolf has also been relatively low since about 3000 years ago, with the level fluctuating rapidly within a range of over 40 m, and dropping from +15 to −5 m between 1897 and 1955 (*7, 16*).

Beach ridges, cuspate bars, and other shoreline features at +65 to +70 m indicate an interconnection between Lake Rudolf and the vast Lotigipi mud flats to the west through a low-level, swampy divide. The expanded lake must have periodically overflowed to the Lotigipi for much of the time about 6200 to 3250 years ago, with the threshold elevation essentially determining the maximum lake level. Temporary maxima near or above +80 m about 9500 to 7500 years ago probably induced overflow across the flat watershed to the Pibor-Sobat and, ultimately, the Nile River. Such hydrographic links are supported by the molluscan, fish, and reptilian faunas (*17*).

The Nakuru and Naivasha Basins

The floor of the Eastern Rift Valley reaches its highest elevation in the sector just south of the equator where three basins of internal drainage within the valley contain comparatively small lakes (Figs. 1 and 2). Of these, Lake Naivasha is the largest and the most dilute, while Lake Elmenteita and Lake Nakuru are shallow and highly saline; in fact, Nakuru has been dry at least once during the 70 or 80 years for which records exist. During the 1930's Solomon (*18*), Leakey (*19*), and Nilsson (*20*) reported evidence from these basins of major climatic fluctuations during the late Pleistocene and Holocene. The southern portion of the Nakuru basin became the type area for the "Gamblian Pluvial," a climato-stratigraphic entity that has been widely used as a standard of reference in Africa and has often been explicitly or implicitly equated with the last glacial period of high latitudes [that is, the Würm and Wisconsin period, and so forth (*1, 8*)].

Our studies amply confirm earlier observations of successive lake fluctuations, but a partial ^{14}C chronology shows that the most clearly documented episode is a high stand that occurred at the beginning of the Holocene. In fact, the lake basins were filled to their highest possible level about 9000 years ago. Later, Elmenteita and Nakuru merged and had a common outlet northward, while Naivasha overflowed southward. Furthermore, stratigraphy of exposed deposits demonstrates that prior to this high stand there was a moderately prolonged period when the lakes were at least as small as they are now. There is evidence, however, for earlier high stands more than 20,000 years ago. Also, at least in the Nakuru basin, the stratigraphy (*21*) and geomorphology (*22*) indicate a minor episode of lake enlargement more recent than the early Holocene stand, while a sublacustrine core (*23*) indicates that Lake Naivasha dried up almost completely about 3000 years ago. Table 2 is a list of the available ^{14}C determinations.

Geomorphological Evidence

During recent investigations no definite traces have been found in the Nakuru-Elmenteita basin of shorelines at elevations above the modern, potential outlet of the Nakuru basin [1949 m (6390 feet) above sea level or about 185 m (610 feet) above modern lake

Table 1. Carbon-14 ages of high lake levels from the Omo-Rudolf basin (Kibish Formation).

^{14}C age (years ago)	Coordinates	Lab number	Nature of sample	Nature of context	Lake Rudolf level (± 3 m)	Stratigraphic assignment (Kibish Formation Member)
3250 ± 150	5°19′N, 35°57′E	L-1203-H	Mixed shell	Beach ridge	+70	IVb
4400 ± 100	3°08′N, 35°59′E	(No data)	*Etheria*	Littoral	+66 (?)	(?) IVb
5150 ± 350	5°10′N, 35°35′E	L-1303-A	Mixed Shell	Beach ridge	+70	IVb
5450 ± 100	5°19′N, 35°59′E	L-1203-I	Mixed Shell	Littoral	+69	IVb
5700 ± 100	5°18′N, 35°57′E	L-1203-G	Mixed Shell	Littoral	+67	IVb
5750 ± 100	5°22′N, 36°05′E	L-1203-K	Unionidae	Channel fill	+69	IVb
6600 ± 150	4°28′N, 35°57′E	L-1303-D	Mixed Shell	Transgressive sandstone	+15	IVb
7160 ± 80	2°55′N, 36°05′E	UCLA-1247-E	Unionidae	Littoral	+66 (?)	(?) IVa
7900 ± 150	5°05′N, 35°55′E	L-1203-L	*Etheria*	Littoral oyster bank	+80	IVa
8650 ± 150	5°24′N, 35°56′E	L-1203-B	*Corbicula*	Littoral	+72	IVa
8700 ± 200	5°24′N, 35°56′E	L-1203-D	*Corbicula*	Littoral	+72	IVa
8800 ± 200	5°24′N, 35°56′E	L-1203-E	*Corbicula*	Littoral	+72	IVa
8900 ± 300	5°23′N, 35°57′E	L-1303-H	Mixed Shell	Littoral	+59	IVa
9100 ± 300	5°24′N, 35°57′E	L-1203-M	Mixed Shell	Channel fill	+72	IVa
9300 ± 400	5°05′N, 36°02′E	L-1303-C	Unionidae	Littoral	+78	IVa
9500 ± 150	5°24′N, 36°12′E	L-1203-J	Unionidae	Minor channel fill	+80	IVa
9500 ± 150	5°24′N, 35°56′E	L-1203-C	*Corbicula*	Littoral	+67	IVa
26,700 ± 2500*	5°18′N, 35°56′E	L-1203-F	Mixed Shell	Littoral	+58	III
> 35,000	5°09′N, 35°48′E	L-1303-B	Unionidae	Littoral	+55	(?) III
> 37,000	5°24′N, 35°56′E	L-1203-A	*Etheria*	Channel fill	+67	III
> 39,000	5°24′N, 35°57′E	(No data)	*Etheria*	Channel fill	+59	I

* Validity in question [see (*9*)].

level (*22*)]. However, at approximately this critical altitude there are well-developed shoreline notches and littoral deposits along the outer slopes of the Menengai caldera (1943 m or 6370 feet), on the Karterit volcanic cone (1942 m or 6365 feet), and at Gamble's Cave (1934 m or 6344 feet). Concordant ^{14}C dates have been obtained for littoral deposits at the last two of these localities (see Table 2 for Karterit), although L. S. B. Leakey's dates from Gamble's Cave have not been published. It seems virtually certain that these surviving shoreline features all belong to a phase between 10,000 and 8,000 years ago when the lake stood at or intermittently expanded to reach an outlet approximately 180 m above the modern lake level. This beach complex is provisionally termed the "Gamble's Cave shoreline." The lowest point in the rim of the basin now is at a breach in the wall of the Menengai caldera (see Fig. 2), but there is some evidence that Menengai did not experience its final, paroxysmal eruption until the mid-Holocene (*24*), which may explain why no lacustrine or littoral features have yet been recognized inside the caldera. It may be that this particular outlet was not open at the time, but other potential outlets at only slightly higher elevations exist nearby along the eastern, external footslope of the caldera.

At the northern end of the Nakuru basin, another shoreline notch, the "Misonge shoreline," is found at about +49 m (165 feet). This is locally cut into soft pyroclastic deposits apparently derived from the last major eruption of Menengai. It is likely that this shoreline corresponds with the "Nakuran Wet Phase" shoreline of Solomon (*18*) and Leakey (*19*), although these authors give a height of +44 m (145 feet). Erosional traces of shorelines older than the Gamble's Cave stand do not appear to have survived, although littoral deposits belonging to much earlier lake expansions are known (see below).

Stratigraphic Evidence

The Nakuru basin stratigraphy summarized here is derived from the unpublished work of the University of California Archaeological Research Group in Kenya (1969–70) (*21*). Three sets of sedimentary units, separated by conspicuous disconformities, were found in the area south of Lake Nakuru; pending formal definition, these entities are referred to as units A, B, and C (oldest to youngest).

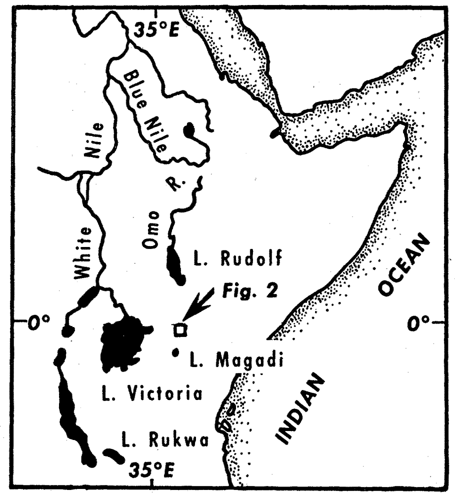


Fig. 1. The East African lakes.

There is a diatomaceous bed in unit C that directly overlies Menengai pyroclastics; this evidence and the altitudinal range of unit C (up to +54 m) suggest a correlation with the Misonge shoreline. Silts overlying the diatomite gave a ^{14}C date of 3540 years ago, so that an age of 4000 to 6000 years ago seems a reasonable estimate for the Misonge stand. On the other hand, unit B can be correlated with the Gamble's Cave shoreline on the basis of its altimetric range (to at least +160 m), its archeological content (backed blade and industries of the "Kenya Capsian"), and the available ^{14}C dates. It is widespread and lithologically varied: in valleys near to the former shorelines, laminated siltstones are exposed to thicknesses of 30 m or more, while eroded meter-thick beds of diatomite may be the only surviving traces in midbasin.

Unit B is separated from the underlying unit A by a widespread disconformity recording a period during which drainage lines were deeply incised into the floor of the basin. This may have been partly due to tilting of the graben floor, but since the weathered alluvial and colluvial deposits of the uppermost part of unit A extend out into the basin to altitudes less than 50 m above the modern lake, it is certain that a long period of low lake level preceded the deposition of unit B. A small ^{14}C sample from fluvial beds in the upper part of unit A has been dated at 19,000 years ago (*25*). The lower strata of unit A indicate alternating enlargements and contractions of the lake. The base of unit A is nowhere exposed satisfactorily, but at the Makalia bend (Fig. 2, site 1) and at Nderit Drift (Fig. 2, site 2) sections include evidence of two lacustrine cycles in this unit. At Prettejohn's Gully (Fig. 2) a long section includes three diatomaceous beds separated by conspicuous weathered alluvial and colluvial strata. The diatomaceous silts of each cycle interdigitate with sands and pumice gravel at heights between +100 and +150 m or more, which suggests repeated limitations of the lake level at an elevation approaching that of the modern potential outlet.

A date of 21,000 years ago has been obtained for carbonate concretions from a clay horizon within the youngest lacustrine bed of unit A, at a site low in its altitudinal range. Since carbonate accumulation may have been wholly or partially secondary, this must be treated as a minimum age. All the archeological material recovered from unit A has been of "Middle Stone Age" or "Kenya Stillbay" character.

Paleolimnologic Evidence

Cores have been lifted from beneath the waters of the three modern lakes (*22*). Study of a 27-m core from beneath Lake Naivasha has largely been completed and the sediments span about 9200 years. A deeper core taken from Lake Naivasha in 1969, which penetrated a coarse pumice deposit at a sediment depth of 50 m, has not yet been studied. Also in 1969, a 23-m core was obtained from Lake Elmenteita, and a sample from the base of this is dated at 29,320 years ago. The study of this core is still in progress.

Discussion

Apart from the probable association of the Misonge shoreline and the unit C sediments with the so-called Nakuran Wet Phase, it is impossible to establish one-to-one relationships between the early Holocene lake fluctuations, as reported here, and climato-stratigraphic entities such as the "Gamblian Pluvial" or the "Makalian Wet Phase" of previous authors. Instead, a new regional nomenclature, tied more closely to formal litho-stratigraphic and bio-stratigraphic entities, is required.

There is widespread evidence that faulting and tectonic deformation continues in the region and that this has certainly influenced aspects of the sedimentary and hydrologic history of the basin. However, it seems equally clear that rapid oscillations of lake levels with amplitudes of 60 to 190 m must have been largely due to changes in the hydrologic balance. Ancient hydrologic budgets can be estimated when present hydrologic parameters are known. Approximate data on modern precipitation, evaporation, and lake size are available for the Nakuru-Elmenteita and Naivasha basins, and two of us (J.L.R. and C.K.-W.) have independently computed hydrologic conditions that could have maintained the high lakes 9000 years ago, by using the graphs of Langbein (*26*) and Schumm (*27*) that relate temperature to evaporation and watershed runoff to precipitation. We have assumed that when a closed lake is in equilibrium with local climatic conditions, inflow plus precipitation on the lake equals evaporation. For simplicity, possible overflow or underground loss of water by seepage has been discounted, and the enlarged lakes are considered as closed bodies of water standing at the outlet lips of their respective basins.

Our results thus provide conservative estimates of the changes in precipitation or evaporation necessary to maintain the +180-m lake in the Nakuru-Elementeita basin (*28*). If substantial overflow or seepage occurred from the lake, more radical changes would have to be assumed. Figure 3 shows several combinations of precipitation, runoff, and evaporation that could support a closed lake 180 m deeper than the present one. Several authors (*29, 30*) have suggested that East African temperatures were lower 9000 years ago. If mean annual temperatures were about 2°C lower than at present, annual evaporation would be reduced by 152 millimeters. Further, runoff under moister conditions was probably closer to 10 percent of precipitation than to the present 3.3 percent, in which case an annual rainfall of about 1470 millimeters (compared to a modern average of 965 millimeters for the basin) would have maintained the enlarged lake at its spillway. Core evidence from the adjacent Naivasha basin, however, suggests that the climate about 9000 to 6000 years ago was somewhat warmer than today's, as well as somewhat more seasonal (*23*). Estimates of necessary precipitation need not be greatly affected by this, since increased evaporation from the lake surface because of higher temperatures may have been offset by higher runoff percentages as a result of greater seasonal concentration of rainfall. If the temperature was indeed 2° to 3°C higher than at present, annual precipitation may have averaged as much as 165 percent of modern rainfall.

In contrast to Lake Nakuru, the potential outlet of the Naivasha basin is only about 60 m above the modern lake, and a rainfall increase of 50 percent would result in a substantial overflow (*23*). The core evidence leaves no doubt that Naivasha did overflow 9000 years ago and points to continued overflow until about 5600 years ago. At the latter time, annual rainfall would have been about 150 millimeters greater than the modern basin average.

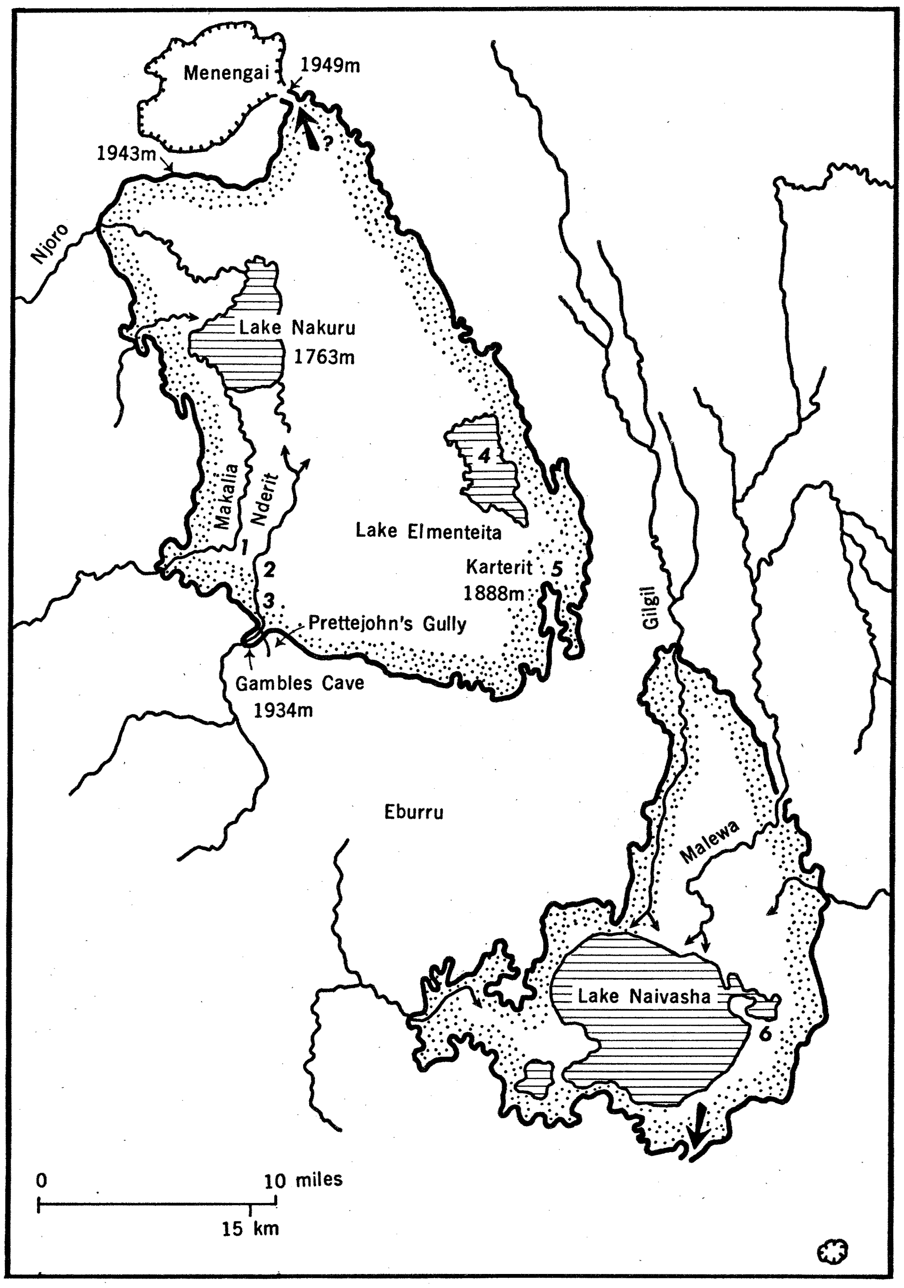


Fig. 2. The Nakuru-Naivasha basin. Expanded early Holocene lakes are indicated by heavy margins, and spillways by arrows. The coordinates for the numbered sites are given in the second column of Table 2.

The Magadi Basin

Lake Magadi lies at the lowest point of the southern part of the Eastern Rift (604 m above sea level). Apart from perennial, spring-fed lagoons, the lake waters are ephemeral and form only a shallow cover on a vast accumulation of trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) up to 30 m thick. A terrace of silts and clays forms a discontinuous shelf 12 m above the modern clays and was deposited at a time when the seasonal water level was higher and somewhat more stable (*31*). A ^{14}C date of 9120 ± 170 years ago (N-862) has been obtained by one of us (G.L.I.) from a sample of the carbonaceous fish fossils that form a band within these "High Magadi Beds," a few meters above modern lake level. Three other ^{14}C measurements have been made by D. L. Thurber for Hay (*32*), with samples of sodium carbonate evaporite from a core in midbasin. These require correction since the surface trona gives an apparent age of 7100 years. The corrected apparent ages are: at 11 m depth, 4600 years ago; at 21.4 m depth, 5750 years ago; and at 47.5 m depth, 10,010 years ago. The section of the core between 48 m and 61 m (its base) is dominated by chert deposits, which are interpreted by Eugster (*33*) as being largely formed from magadiite [$NaSi_7O_{13}(OH)_3 \cdot 3H_2O$] initially precipitated from alkaline brines. From a depth of 34 m to the surface, the deposits are mainly trona, which certainly formed under highly saline conditions. Only the segment between 41 and 34 m, which consists of silty, tuffaceous claystones, is virtually devoid of brine precipitates or their derivatives. By extrapolation, an age of between 9000 and 7000 years ago is likely for this part of the core. The interpretation is complicated by uncertainties about the reliability of the trona dates and by the possibility that there was an influx of volcanic ash in the critical segment of the core. However, the evidence is in accord with that from the dated fish fossils and implies that the phase of greatest known size and dilution of Lake Magadi occurred at the beginning of the Holocene.

Lake Victoria and the Nile River

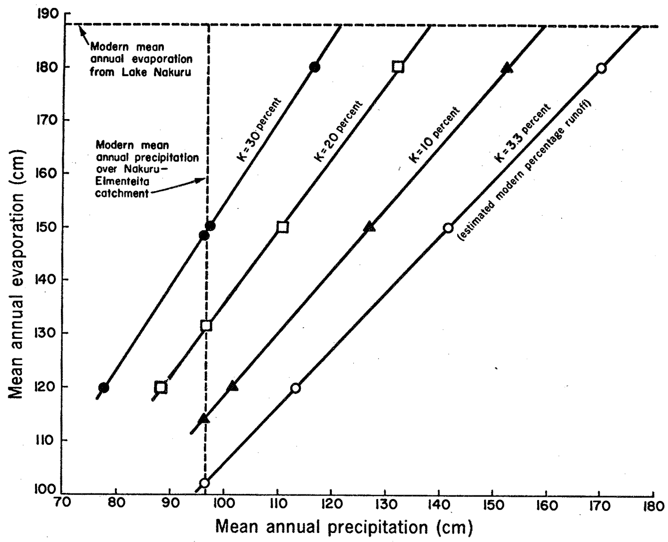
Our own evidence from the Eastern Rift is directly complemented by Kendall's pollen and paleolimnological record of Lake Victoria, a sequence fixed by 28 ^{14}C dates (*6*). The lake was low and without an outlet for a period of undetermined length prior to 14,500 years ago, at which time open savanna vegetation prevailed. The lake began to rise about 12,000 years ago, at which time forest vegetation first appeared around the northern lake margins, but for a short time around 10,000 years ago the level may have fallen to 12 m below the present level. Lake Victoria was particularly full between 9500 and 6500 years ago, with an evergreen forest near its shores. A slightly drier or more seasonal climate is indicated by a shift to semideciduous forest 7000 to 6000 years ago while a reduction of forest cover about 3000 to 2000 years ago may indicate either a drier climate or forest clearance by man. The level of Lake Victoria has in part been affected by incision of its outlet, but the former low lake levels as well as the pollen sequence were certainly independent of this factor (*34*).

The Nile is derived from sources closely connected with the lakes of East Africa. The catchment of the Blue Nile, which now provides the bulk of Nile flood waters, interfingers with the Omo drainage feeding Lake Rudolf, while the White Nile has its source in the outlet from Lake Victoria. A comparison of the late Quaternary record of the Nubian Nile, as intensively studied by one of us (K.W.B.), with that of the East African lakes nevertheless poses certain problems. Before about 27,000 years ago the Nubian

Table 2. Carbon-14 ages relevant for dating fluctuations in lake levels in the Nakuru, Elmenteita, and Naivasha basins. The numerals in parentheses in column 2 refer to numbered sites in Fig. 2.

^{14}C age (years ago)	Coordinates for sites in Fig. 2	Lab number	Nature of sample	Source and context	Indication of lake level or character
3000 ± 60 3040 ± 60	46′S, 36°25′E (6)	Y-1436 Y-1769	Organic mud	Lake Naivasha core (1961)	Above and below stratum showing desiccation
3540 ± 120	29′S, 36°06′E (2)	N-821	Charcoal	Unit C, alluvial silts	Lake Nakuru below +50 m
3400 ± 100* 3810 ± 110*	29′S, 36°05′E (1)	I-5064C I-5064	Carbonate concretions	Unit B, lacustrine deposits (at +90 m)	Lake Nukuru at about +162 m
5650 ± 120	46′S, 36°25′E (6)	Y-1339	Organic mud	Lake Naivasha core (1961)	End of enlarged lake phase
8740 ± 190	25′S, 36°14′E (4)	I-5179	Organic mud	Lake Elmeteita core	Enlarged freshwater lake
9200 ± 160	46′S, 36°25′E (6)	I-1340	Organic mud	Lake Naivasha core (1961)	Greatly enlarged freshwater lake with outlet
9650 ± 250	30′S, 36°15′E (5)	L-1201	Mixed shell	Karterit volcanic cone at +120 m	Probably associated with nearby shoreline at +180 m
12,000 ± 215 12,160 ± 170 12,200 ± 220 12,300 ± 220	31′S, 36°06′E (3)	N-822 (2) I-5062 N-822 (2) N-822 (1)	Charcoal	Unit B, ponded valley and deltaic deposits	Transgressive phase, about +60 m above Lake Nakuru
12,200 ± 180	25′S, 36°14′E (4)	I-5178	Organic mud	Lake Elmenteita core	Near end of a long phase of alkalinity and small size
19,000 ± 400	29′S, 36°14′E (2)	UCLA-1687	Charcoal (small sample)	Unit A, fluvial deposits	Lake Nakuru below +45 m
21,000 ± 420	29′S 36°05′E (1)	I-5063	Carbonate concretions	Unit A, uppermost diatomite beds	Related deposits to or above +150 m
29,320 ± 1100	25′S, 36°14′E (4)	I-5177	Organic mud	Lake Elmenteita core	Small lake

* Dates are inconsistent with their stratigraphic relation to unit C (possibly secondary carbonates).



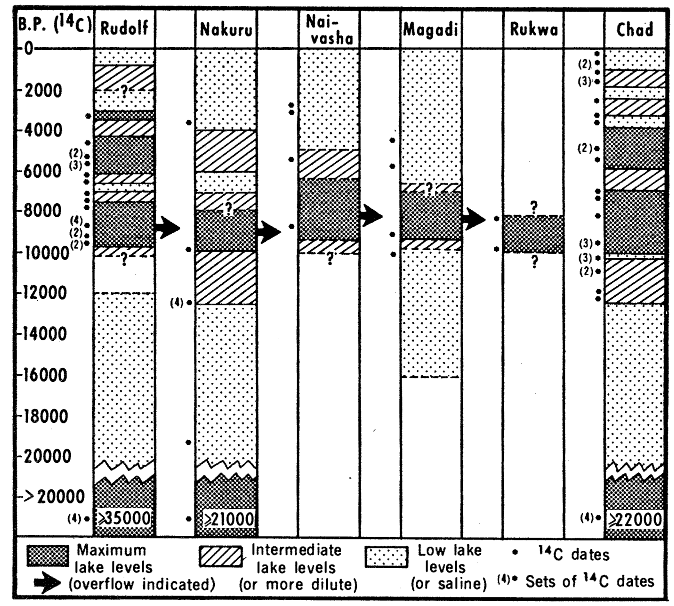


Fig. 3 (left). Hydrological parameters adequate to maintain Lake Nakuru at +180 m. Each line represents balancing covariations of precipitation (over the whole catchment) and evaporation (from the lake surface), with a particular runoff constant *K*. These relationships are limited to deviations that shift equilibrium in the direction of lake expansion. Fig. 4 (right). Fluctuations of lakes that presently lack outlets.

Nile was a high-competence, braided stream. Besides a substantial local tributary influx, it carried appreciable subsaharan waters (*35*), of which a greater than modern proportion derived from the southern Sudan. About 24,000 to 18,000 years ago the Nubian Nile aggraded an exceptionally broad floodplain with discharge and sediment loads only slightly greater than those of the present day (*36*). Before and immediately after this period of flood silt accumulation, the Nile rapidly dissected its old fill to levels below that of the modern floodplain, presumably in response to declining flood discharge. From 17,000 to 5,000 years ago Nile discharge and competence were markedly greater than today, with coarser-grade bed loads and flood silts and a striking incidence of shifting or braided channels suggestive of rapid sedimentation rates. Exceptionally high Nile flood surges appear to have occurred sporadically about 12,000 to 11,000 years ago, with limited flood deposits to a maximum of 9 or 10 m above the general level of the floodplain of that time (*37*). Brief periods of reduced flood discharge and rapid dissection are indicated about 11,500 years ago and on several occasions between 9,000 and 5,600 years ago (*38*). Finally, a number of surviving historical records indicate a downward trend of flood levels after 3000 B.C. (calendar years) that culminated in abnormally low floods 2180 to 2130 B.C. These were followed by unusually high floods about 1840 to 1775 B.C. (*39*) and again in the 9th and 8th centuries B.C. The correspondence with data from the Eastern Rift is good after 12,000 years ago, although relatively high Nile floods from 17,000 to 12,000 years ago find no counterparts in the East African record.

The partial lack of fit between the Nilotic and East African sequence may be more apparent than real and, until pollen cores collected by E. M. van Zinderen Bakker (*40*) from the Ethiopian Plateau have been studied, the response of that critical region to late Pleistocene climates will remain enigmatic. The highest ranges of the Ethiopian Plateau were partially glaciated (*41*), but these glaciers were too small and restricted in occurrence to supply appreciable seasonal meltwaters. However, environmental changes over the little-studied plains of the southern or eastern Sudan may have contributed decisively to the behavior of the Nubian Nile during the late Pleistocene prior to 12,000 years ago.

General Conclusions

The fluctuations of the key East African lakes discussed above are summarized in Fig. 4, which also includes the available evidence from Lake Rukwa (*42*) and Lake Chad (*43*). Except for Lake Victoria, all of these now lack surface outlets and are situated in much drier climates than the major lakes of the Western Rift Valley, which remain filled to their overflow levels. The apparent differences among the fluctuations of the lakes are partly due to differences in the nature of the evidence or the intensity of research, or both, although there must also have been important local differences in the histories of the lakes. Yet the consistencies are far more striking, most notably the coincidence of early Holocene high stands. Between 10,000 and 8,000 years ago, it seems that lakes in many parts of tropical Africa were greatly enlarged. Where evidence for the previous span of time is well resolved, it appears that transgressions leading to this high stand began about 12,000 years ago, and evidence from three basins (Victoria, Nakuru, and Chad) indicates a pause or minor recession just at or before 10,000 years ago. Wherever information is available for the period preceding 12,000 years ago, it can consistently be shown that lakes were much smaller. Several basins (Rudolf, Nakuru, and Chad) also show traces of much earlier phases of lake expansion, which are not yet well dated but which all occurred more than 20,000 years ago. The Holocene record subsequent to the maximum of 10,000 to 8,000 years ago is more complex. Three basins (Rudolf, Nakuru, and Chad) show an apparently concordant, positive oscillation at some point between 6000 and 4000 years ago, but it is uncertain how widely this episode is represented.

Although many of these lakes that are now closed filled to overflowing at least once during the late Quaternary, it is evident from Fig. 4 that the periods of expansion were short-lived compared with phases of contraction to levels near those of today. This pattern may be in accord with fragmentary evidence from lower and middle Pleistocene formations, such as those of Olduvai (*44*) and Peninj (*45*), within which some relatively short-term lake expansions can be documented, but which lack evidence for any marked long-term departure from a balance of evaporation and precipitation similar to the present one. Further, this pattern of brief moist pulsations, with a duration of perhaps 2000 to 5000 years, is also suggested by other late Pleistocene and Holocene sequences (based primarily on geomorphological and palynological evidence) from the Saharan area, Angola, and South Africa (*46*). In default of radiometric dating, such complex successions of relatively brief moist intervals provide few stratigraphic markers of broad applicability. This, together with the fact that vegetation, weathering processes, montane glaciers, lake size, lake salinity, and so forth are all likely to reflect the diverse aspects of climatic change differently, underscores the strictures of Cooke (*2*) and Flint (*3*) against the use of pluvials and interpluvials as a basis for subdividing Quaternary time in Africa.

Positive correlations between high-latitude glacial advances or maxima and intervals of high lake levels have been demonstrated or suggested for many areas of mid-latitude North America and Eurasia (*47*), and similar patterns have often been regarded as probable for tropical Africa as well. However, the evidence summarized above shows a notable lack of such correlations for the tropical lakes considered here. If glaciation and tropical lake levels were connected at all, then a far more complex—delayed, multiple-factor, or inverse—relationship must be sought for the late Quaternary (*48*). This renders the introduction of new climato-stratigraphic terms such as hypothermal and interstadial (*49*) of questionable value in East Africa. Further, whereas the so-called pluvial lakes of higher latitudes were probably due primarily to reduced evaporation (*50*), our computations for the early Holocene lakes Nakuru and Naivasha, as well as for the oscillations of Lake Rudolf and Lake Victoria in recent decades, suggest that many or most of the high tropical lake levels were associated with a modest but significant increase in precipitation.

References and Notes

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13. The present lake level is uncertain but probably lies near +375 m. The relative elevations cited were determined on helicopter runs by using a sensitive altimeter and were corrected by means of synchronous barometric readings made at base camp.
14. Our studies in the Omo region are complemented by recent archeological and paleontological work west of Lake Rudolf, and the youngest date possibly associated with Member IVa comes from the base of a series of littoral deposits at Lothagam [L. H. Robbins, *Azania* **2**, 1 (1967), figure 1; personal communication]. Calibrated to conform with other Lamont dates, in which it is assumed that the Rudolf waters would give an "age" of 400 years [see (*9*)], this would be 7160 years ago [R. Berger, personal communication; ——— and W. F. Libby (UCLA-1247-E), *Radiocarbon* **10**, 402 (1968)]. A further unpublished date of 7650 ± 140 years ago (corrected) (N-813) has been obtained by Robbins from unionids in high lake deposits west of Lothagam Hill (L. H. Robbins, personal communication). Finally, a date of 9360 ± 135 years ago (no lab number given) has been obtained from the shores of Lake Rudolf, from the younger of two units of lacustrine and fluvial-deltaic deposits [C. F. Vondra, G. D. Johnson, B. E. Bowen, A. K. Behrensmeyer, *Nature* **231**, 245 (1971)] that pertain to the Kibish Formation.
15. See K. S. Thomson [*Breviora* **243**, 1 (1966)] for a date of 4800 years ago (no lab number given) from Kangatotha, west of Lake Rudolf. This has been corrected to 4400 years ago in Table 1 to conform with the Lamont series. Other, unpublished dates by L. H. Robbins (personal communication) from Turkana, which document a high lake level at about this time, are 6200 ± 125 years ago, from charcoal (N-812) west of Lothagam (about 2°55′N, 36°02′E), and 5020 ± 220 years ago, from fired clay or silt (N-814) north of Napedet (about 2°56′N, 35°53′E).
16. A rapid rise of 4 m in level from 1962 to 1965 was primarily due to an intensification and prolongation of autumn (equinoctial) rains over most of East Africa (*7*). Fluctuations of lake level from 1949 to 1960, gauged by the Kenya Water Development Department, show no correlation with temperature changes in Turkana; since these temperatures depend largely on variations of cloud cover, evaporation over the immediate lake does not seem important. The 1962 rise was paralleled by Lake Victoria, Lake Baringo, Lake Naivasha, and Lake Manyara.
17. Recent work in the Ethiopian Rift Valley indicates that four of the small lakes here (Zwai, Langanno, Abyata, and Shalla) were united in early Holocene times; this is based on a shoreline at +84 m near Lake Shalla with a date of 9220 ± 190 years ago (GaK-3386). A new, mid-Holocene transgression linked the three southerly lakes, and a shoreline of Shalla at +58 m has a date of 5610 ± 100 years ago (GaK-3387) (A. T. Grove and G. Dekker, "Late Quaternary lake levels in the Rift Valley of southern Ethiopia," paper presented at the 7th Pan-African Congress of Prehistory and Quaternary Studies at Addis Ababa, December 1971). It is estimated that a 15 percent reduction in evaporation with a 30 percent increase in precipitation could support a single lake in the Langanno-Abyata-Shalla basin without an overflow. One of us (K.W.B.) has just examined some of the key sites in the Ethiopian Rift and, although far more extensive field and laboratory study will be necessary here, close similarities with the Kibish III, IVa, and IVb sequence of the Omo-Rudolf basin appear to be indicated. Comparable dates of 8955, 8750, 8715, 7300, 7000, 5840, and 4715 years ago have also been obtained from the last major lacustrine episode in the Afar Depression of eastern Ethiopia (Maurice Taieb, personal communication).
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37. Anomalous flood deposits have ^{14}C dates of 11,720, 12,000, and 12,020 years ago on the Kom Omo plain [(*51*), pp. 115, 129, 278]; of 11,200 and 11,410 years ago at Dibeira East; and of 10,920 and 11,000 years ago at Khor Musa [J. de Heinzelin, in *The Prehistory of Nubia*, F. Wendorf, Ed. (Southern Methodist Univ. Press, Dallas, 1968), pp. 21, 38]; also, H. T. Irwin, J. B. Wheat, L. F. Irwin, *Univ. Utah Anthropol. Pap. 90* (1968), p. 109, for similar evidence from opposite Wadi Halfa.
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42. This basin in southwestern Tanzania shows a high lake level fixed by dates of 9740 ± 130 years ago (A-945) and 8060 ± 120 years ago (A-944) [J. D. Clark, C. V. Haynes, J. E. Mawby, P. Gautier, *Quaternaria* **13**, 305 (1970)].
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48. Several of the high mountains of equatorial East Africa carry small glaciers, and there is clear evidence that these were formerly much more extensive. Regrettably, few ^{14}C dates exist for phases of glacial expansion and retreat; however, a date of 14,750 ± 290 (I-556) for the initial retreat of the Lake Mahoma valley glacier on the Ruwenzori [see Whittow and Osmaston (*30*)] suggests that the expansion and contraction of ice bodies on these mountains may have been more nearly synchronous with high-latitude glaciers than were the fluctuations of lake level. A number of pollen cores provide evidence for marked changes in mountain vegetation during the late Quaternary. J. A. Coetzee [*Palaeoecol. Afr.* **3**, 1 (1967)] has interpreted these as reflecting shifts of the altitudinal vegetation zones controlled largely by temperature, which suggests a close fit with paleotemperature curves constructed for Europe and South America. D. A. Livingstone [*Ecol. Monogr.* **37**, 25 (1967)] argues that in addition to temperature, humidity factors and biogeographic colonization were also involved in the observed vegetation shifts. If these controls apply in significant measure, temperature fluctuations may be less apparent in the pollen records.
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University Affiliation and Recognition: National Academy of Sciences

An analysis of the dominance of disciplinary subsystems in recognition of scientific achievement.

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During the past two decades, sociologists of science have established the importance of recognition accorded scientific achievement as a means of institutionalizing and maintaining norms and values within the social system of science (*1–5*). Such a finding is hardly unexpected, since there appears to be a perceived need within every social institution to evaluate role performance (*6*). Indeed, the ultimate viability of every social institution is apparently related directly to the effectiveness of its evaluation system and, thereby, its reward system. Such systems act as mechanisms of social control, providing sanctions to curb excessively deviant behavior (*7*) and rewards to promote behavior that is in accordance with the norms and values of the particular social institution.

The social system of science incorporates highly visible, institutionalized evaluation and reward systems. Scientists are inducted into a system that allegedly places primary emphasis on the advancement of knowledge. But while ". . . the pursuit of science is culturally defined as being primarily a disinterested search for truth and only secondarily a means of earning a livelihood" (*1*, p. 659), scientists are also taught to expect to be rewarded when they make a contribution to science (*1*, *8*, *9*). In fact, "... the institution of science has developed an elaborate system for allocating rewards to those who variously live up to its norms" (*1*, p. 642). For the most part, these rewards are bestowed in some form of visible honorific recognition. That is, the professional recognition of scientists is stratified, with varying degrees of nonpecuniary recognition presumably corresponding to varying degrees of scientific achievement (*1*).

The range of rewards for scientific achievement is great. B. G. Glaser, for example, lists "eponymy, prizes, awards, fellowships, honorary memberships and

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