Lake Turkana and Its Link to the Nile

Thomas C. Johnson and John O. Malala

Abstract Lake Turkana is a large, closed-basin lake in the northern Kenyan rift that occasionally overflowed first to the Indian Ocean and then, after about 1.3 million years ago, into the Nile drainage basin. The lake lies in a broad, arid depression surrounded by late Cenozoic fluvial, lacustrine, and volcanic sequences. The climate of the Turkana basin is hot and arid, with extended periods of unusually intense diurnal winds. Seasonal variability in air temperature and rainfall is much subdued compared to the other great lakes of East Africa. Lake temperatures range between 24.5°C and 30°C, the salinity is about 2,500 mg/l, and the entire water column is oxygenated throughout most years. The lake's hydrological budget is dominated by Omo River input and by evaporation. Primary production in the lake is about 700–800 gC/m^{2}y, and is typically limited to the upper 6 m of the turbid water column. Lake level has fluctuated more than 100 m in response to climate change. Analyses of sediment cores from within the modern lake and of lake deposits exposed onshore indicate that Lake Turkana overflowed into the Nile in the early Holocene (11.5–7.8 and 7.4–4.3 kyr), at 102 kyr, and at 195 kyr, with possible links at 123 and 172 kyr as well. Geochemical composition of much older (2.8–0.7 Ma) lacustrine sediments exposed to the east of the lake also suggest periodic overflow to the Nile, but the exact timing of these events are yet to be worked out. Additionally, Lake Turkana very likely was much lower than its present level during the last ice age and at other times of weakened African monsoon, perhaps even completely desiccated.

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1 Introduction

Lake Turkana is a large, closed-basin lake in the northern Kenyan rift that in wetter times overflowed periodically, first to the southeast into the Indian Ocean prior to 1.9 million years ago (Ma) and then to the northwest into the Nile drainage basin. Turkana is the most remote of the great lakes of the East African Rift Valley, occupying a desert setting and offering little to attract the population densities that have enveloped the great rift valley lakes to the south. The lake's water is slightly saline, making it unsuitable for agriculture or human consumption. Nevertheless, the lake is home to a rich aquatic ecosystem that reflects earlier communication with the Nile Basin and subsequent evolution to the arid conditions of today. This chapter summarizes the geological setting and limnology of Lake Turkana with emphasis on its periodic linkage to the Nile River system.

2 The Turkana Basin

Turkana lies in a broad, arid depression between the Ethiopian Rift to the northeast and the Kenyan Rift to the south. It is the largest lake in the eastern arm of the Rift Valley, with a length of about 250 km and average width of 30 km. The drainage basin occupies 146,000 km^2 and extends from the Kenyan highlands near the equator on the south to a broad expanse on the Ethiopian Plateau north of the lake (Fig. 1) (Butzer, 1971). Most of the western shore and the northern half of the eastern shore of the lake is draped with Pliocene and Quaternary fluvial sands and gravels with interbedded lake deposits, while much of the remaining shoreline comprises Miocene – Pliocene volcanic sequences (Morley et al., 1999).

A multi-channel seismic survey conducted on the lake by Project PROBE (Duke University, USA) in the early 1980's revealed a series of six half grabens underlying the lake floor, exhibiting roughly north–south orientations and alternating directions of dip, or "polarity," away from their respective arcuate border faults (Dunkelman et al., 1988). More than 3 km of sediment fill these grabens, displaced locally by four Pliocene to Recent volcanic centers that are equally spaced along the lake axis. These are the "barrier" at the south end of the lake and the three small islands (South, Central and North) within the lake (Dunkelman et al., 1988). Acoustic basement consists of Miocene – Pliocene volcanic sequences similar to those exposed across much of the surrounding landscape.

Lake Turkana has a mean depth of 35 m and a maximum depth of about 120 m. The lake floor slopes gradually from the shoreline towards the offshore basins throughout most of the lake, with bathymetric contours rather evenly spaced towards the deeps (Fig. 2). High resolution seismic profiles display evidence for erosion or non deposition where the water is shallower than 35 m due to surface wave activity, with the exception of the Omo River delta where the high sediment influx overwhelms the erosional impact of wind-generated waves (Johnson et al., 1987). The seismic profiles display abundant evidence for normal faulting, even in the most recent sediments (Johnson et al., 1987; Dunkelman et al., 1988), indicating that the Turkana basin remains tectonically active

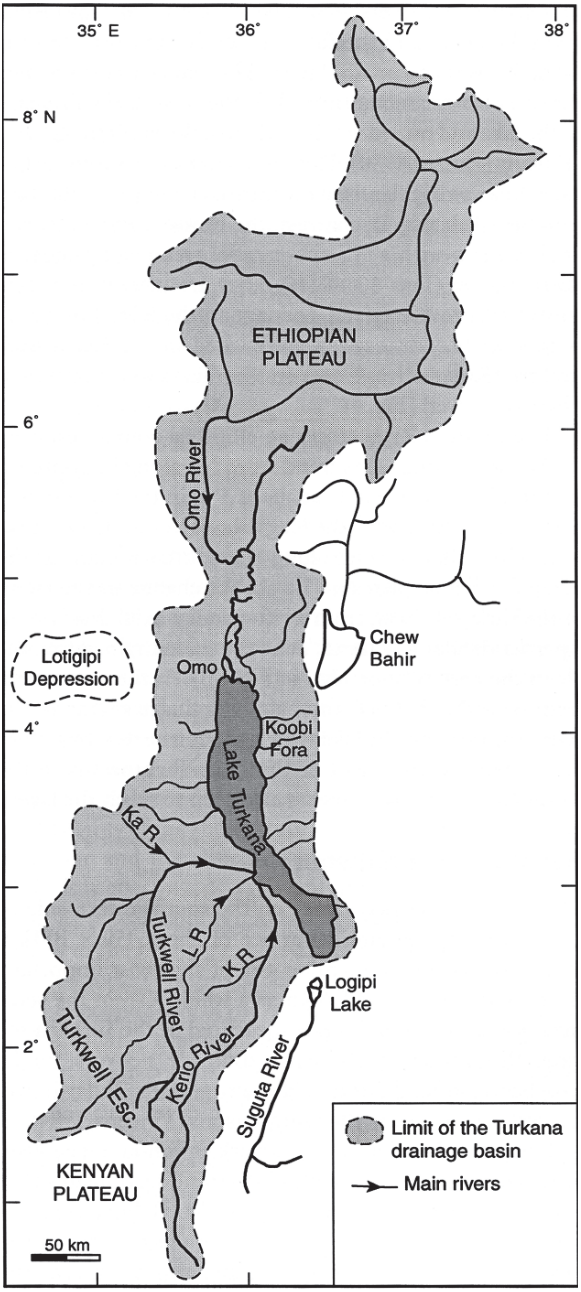

Fig. 1 The drainage basin of Lake Turkana (from Vetel et al., 2004)

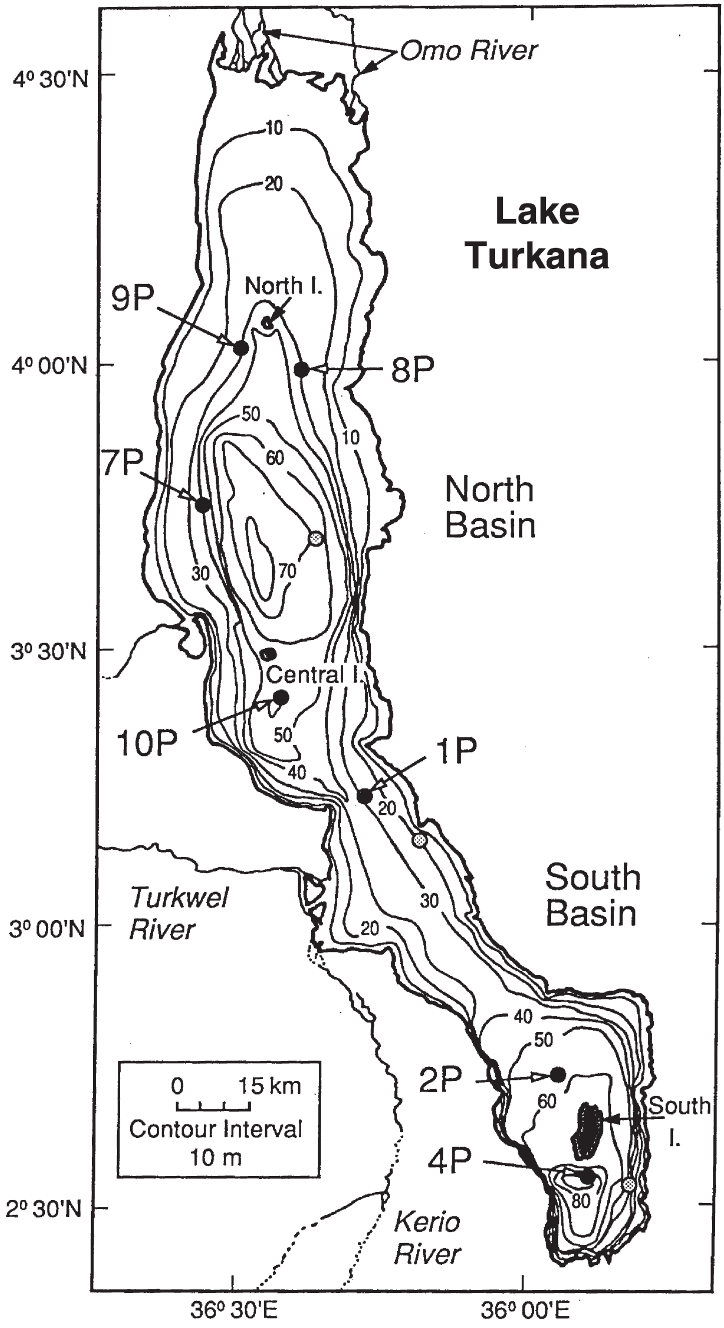

Fig. 2 Bathymetric map of Lake Turkana, depicting sediment core locations. Bathymetric contours are in meters below lake surface in 1984. Reprinted from Halfman et al. (1994) with permission from Elsevier

today. An analysis of river drainage network anomalies, coupled with seismic reflection data from west of the south and central basins of the lake, revealed recent faulting across a 60 km – wide zone onshore as well (Vetel et al., 2004).

3 Climatic Setting

The climate of the Turkana basin is characterized by hot, arid conditions, with extended periods of unusually intense diurnal winds. Seasonal variability in air temperature and rainfall is much subdued compared to the other great lakes of East Africa. Mean maximum and minimum air temperatures recorded in 1973–1975 at Ferguson's Gulf were 32.5°C and 26.0°C, respectively (Ferguson & Harbott, 1982). Air temperatures are slightly warmer in the winter months than in the summer, presumably due to the cooling influence of occasional rains and clouds when the Intertropical Convergence Zone (ITCZ) passes overhead. Mean annual rainfall in the Turkana Depression is about 200 mm/y (Nicholson et al., 1988), while the annual evaporation rate is about 2,300 mm/y (Ferguson & Harbott, 1982). The lake survives only because of the fresh water delivered by the Omo River from the Ethiopian Highlands, where annual rainfall is in the range of 800 to 1,200 mm/y. The Omo River accounts for 80–90% of freshwater input to the lake (Yuretich & Cerling, 1983), with the remainder derived primarily from the seasonal input of the Turkwell and Kerio Rivers that drain the Kenyan highlands and enter the lake midway along its western shore (Fig. 1). The rains on the surrounding highlands are highly seasonal, and reflect the dynamics of the ITCZ, which migrates to the north over the Ethiopian Highlands during boreal summer and to the south of Lake Malawi during boreal winter. Most of the Ethiopian Plateau experiences one rainy season a year centered on July-August, while the Kenyan highlands to the south of Turkana, and the lower elevations to the east of the Ethiopian Plateau, have two rainy seasons centered on April and September (Nicholson et al., 1988). So freshwater input from the major rivers is highly seasonal and impacts the lake's ecosystem dramatically even though the local climate shows little seasonality.

The winds over Lake Turkana are unforgettable. When we were conducting field work on the lake in 1984, the air was calm in the late morning hours and into the afternoon. The wind would begin to blow around sundown and by midnight was blowing steadily at 80 km/h and gusting to 110 km/h. The winds would continue, often peaking at sunrise before dissipating abruptly to the calm conditions of the daylight hours. When I revisited the lake in 1992 the diurnal winds were not as intense, and they were strongest in the late morning and early afternoon rather than during the night. Ferguson & Harbott (1982) reported mean wind speeds in 1973–1975 of about 295 km/24 h near Ferguson's Gulf on the west central shore of the lake, and 760 km/24 h at Loiengalani on the eastern side of the south basin, almost always out of the south and east. They noted the tendency for strong daily winds to last for 9 or 10 h, and over the roughly 2 years of measurements found the timing of intense winds to vary, but most often center around the late morning hours. The pronounced diurnal pattern of winds likely arises from interactions between local thermal circulation patterns and the prevailing trade winds over the region.

4 Limnological Considerations

The limnology of Lake Turkana has rarely been investigated due to the lake's harsh and remote setting and a lack of local infrastructure to support the logistical needs of a scientific field program. E. B. Worthington led the first limnological survey of the lake as part of the Cambridge Expedition to the East African lakes in 1930–1931. Their focus was on the lake fisheries, which showed close similarity to the fauna of Lake Albert, but with significant divergences from Nilotic fauna (Worthington, 1996). The team was surprised by the unusual immensity of Nile perch recovered from the lake. The only other extensive limnological surveys to be conducted on the lake were the Lake Turkana Project 1972–1975 (Ferguson & Harbott, 1982; Hopson, 1982) and a limnological study carried out as part of a fisheries project in 1985–1988 (Liti et al., 1991). Most of the discussion of the limnology of the lake presented here is derived from the latter two expeditions.

Surface water temperatures in Lake Turkana ranged from about 27°C to 30°C throughout the years in 1973–1975, while bottom water temperatures exhibited only minor seasonal fluctuations between 24.5°C and 26.5°C (Ferguson & Harbott, 1982). The lake was about 1°C warmer in 1987–1988 (Liti et al., 1991). The lake exhibits weak thermal stratification during the spring months, followed by more uniform temperature structure due to wind mixing at other times of the year (Fig. 3). The south basin of the lake is typically 1°C–2°C cooler than the north basin, due to upwelling in the south driven by the southerly winds, and northward transport of the warm surface waters.

The lake's hydrological budget is dominated by Omo River input and by evaporation. The seasonal drop in lake level when river input is at a minimum implies an annual evaporation rate of about 2,300 mm, or 17.5×10^9 m^3/y (Yuretich & Cerling, 1983). Total river inflow to the lake, derived from mass balance assuming direct rainfall on the lake surface of 180 mm/y and negligible exchange of lake water with ground water, is estimated at 16×10^9 m^3/y (Yuretich & Cerling, 1983).

While the lake circulation has not been measured directly with current meters, the horizontal and vertical distribution of conductivity clearly indicate a prevailing counterclockwise pattern of circulation, at least in the north basin, as well as substantial vertical mixing of the water column in the south basin (Fig. 4). Ferguson and Harbott (1982) speculated that surface waters flow primarily in a northwesterly direction over most of the lake, with the exception of southwards flow along the eastern and western shores of the north basin, balanced by counter currents in the opposite direction at depth. This has not been verified by direct observation.

A unique aspect of Lake Turkana among the great lakes of the Rift Valley is that its waters are usually well oxygenated at all depths. Throughout the 1973–1975 years of measurement, near-surface waters typically contained 7.5–8 mg/l O_2 and

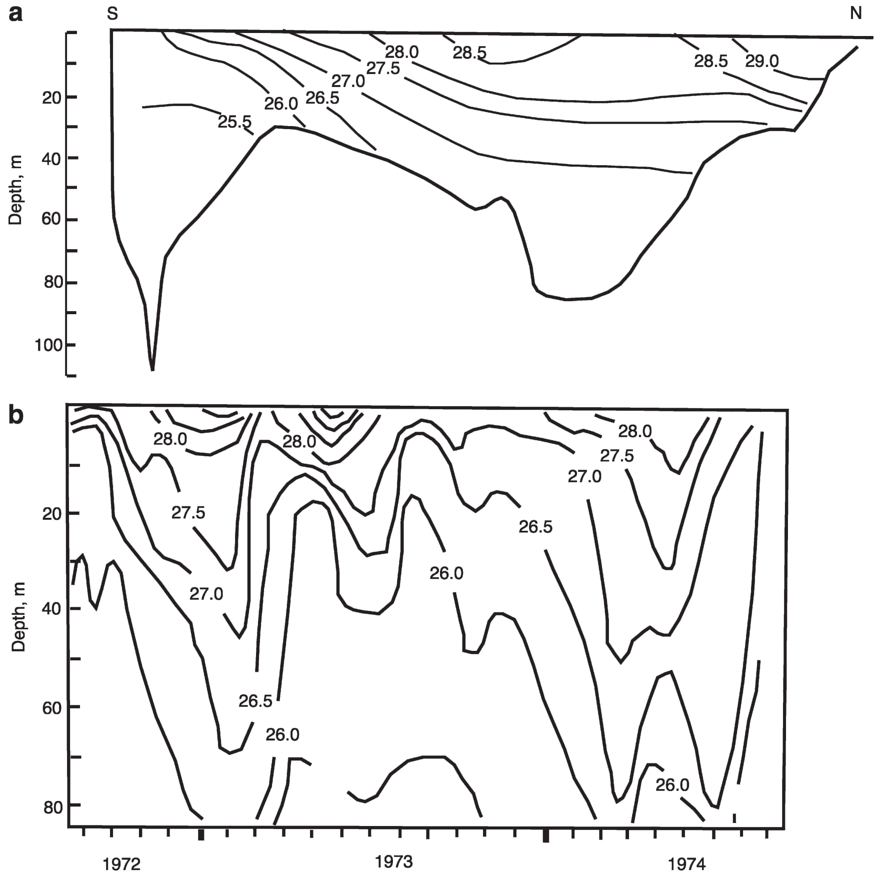

Fig. 3 (**a**) Temperature structure along the north–south axis of Lake Turkana in March 1975. (**b**) Temporal variability in the thermal structure at a station just north of Central Island from August 1972 to August 1974 (both figures modified from Ferguson & Harbott, 1982, with permission of the UK Department of International Development)

bottom water concentrations varied between 4 and 5.5 mg/l (Ferguson & Harbott, 1982). The absence of anoxia in the deeper reaches of the water column was likely due to effective mixing by the intense wind field and the relatively shallow mean depth of the lake. However in 1987–1988, dissolved oxygen concentrations at 70 m depth dropped briefly to 2.4 mg/l in June 1987 and to 0.2 mg/l in May 1988 during periods of thermal stratification (Liti et al., 1991).

Lake Turkana is a brackish Na-HCO_3 lake with a salinity of about 2,500 mg/l, dominated by Na^+, HCO_3^-, and Cl^- ions, and a pH averaging 9.1 (Cerling, 1979; Yuretich & Cerling, 1983). The salinity is much lower than might be expected, given the lake's closed-basin status for roughly the past 4,000 years (discussed below). Yuretich & Cerling (1983) attribute the relatively low salinity of Turkana waters to cation removal by sediment–water reactions, such as Na^+ uptake by

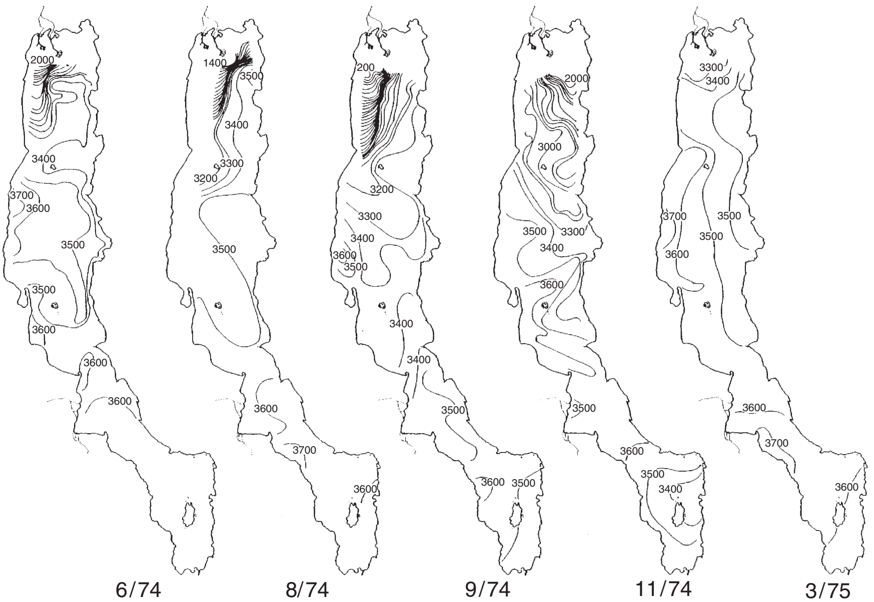

Fig. 4 Surface water conductivity on five occasions between June 1974 and March 1975. Reprinted from Ferguson and Harbott (1982) with permission of the UK Department of International Development

smectite, Mg^{++} incorporation into a silicate phase, and Ca^{++} precipitation in calcite, as well as by burial of solutes in pore water. The few measurements of dissolved nutrients that have been made in the lake show it to be a N-limited system, with dissolved NO_3^- concentrations much less than 1 mg/l and dissolved PO_4^{3-} of about 2 mg/l (Ferguson & Harbott, 1982; Liti et al., 1991).

The phytoplankton of Lake Turkana are dominated by the blue-green alga *Microcystis aeruginosa* and the green alga *Botryococcus braunii*, with occasional high concentrations of the diatom genus *Surirella* (Harbott, 1982; Liti et al., 1991). Lake Turkana waters are highly turbid due to wind turbulence and substantial sediment input from the Omo River, and frequent aeolian depositional events. The photic zone is consequently restricted to the upper 6 m of the water column. During the months of high river input, phytoplankton concentrations are higher in the northern part of the lake than in the south, presumably due to river-supplied nitrate. Despite evidence for upwelling in the south basin, algal concentrations were always found to be much lower than in the central and north basins, and algal blooms were never observed in the southern part of the lake (Harbott, 1982). Primary production in the lake, based on very few measurements of oxygen production, is estimated to be about 700–800 gC/m^2y (Liti et al., 1991).

The zooplankton community is dominated by protozoan *Heliozoa* and *Ciliata* in terms of numbers of individuals, and by carnivorous and omnivorous crustaceans, primarily the Calanoid, *Tropodiaptomus banforanus*, and the Cyclopoid, *Mesocyclops leuckarti* (Beadle, 1981). The identities of both taxa were later revised and changed to *Tropodiaptomus turkanae*, an apparent endemic of the lake (Maas et al., 1995), and *Mesocyclops ogunnus* Onamabiro. *Mesocyclops leuckarti* does not occur in Africa, and is replaced in the Nile basin by about seven species, of which at least *M. ogunnus* and *M. salinus* occur in Turkana (Dumont, 2009). Small, detritus-feeding prawns dominate the benthos and provide an important food source for the lake's fish population. Of the 48 species of fish identified in Lake Turkana by Hopson and Hopson (1982), 30 are found throughout the soudanian region, 22 of which are also found in Lake Albert and 8 in the Nile (Beadle, 1981). Ten species are endemic to Lake Turkana, a relatively small number when compared to Lakes Victoria, Malawi and Tanganyika to the south that are each home to hundreds of endemic species of fish (Beadle, 1981). The low degree of endemism and the prevailing soudanian character of Turkana fish populations reflects the relatively recent hydrological tie to the Nile flowage. The fisheries of Lake Turkana has undergone dramatic and unpredicted change in recent decades, a reflection of a highly variable system responding to both fishing pressure and a fluctuating lake level that impacted nearshore nurseries and other environmental factors (Kolding, 1992).

5 Turkana's Past Connection to the Nile

Lake Turkana, like other closed basin lakes in arid regions, is considered an "amplifier lake" in terms of its dramatic response to climate variability (Street-Perrott and Roberts, 1983). Relatively minor swings in rates of evaporation and rainfall can generate substantial rise or fall in lake level and in water chemistry. Such changes can lead to dramatic shifts in lake biota, as well as in the composition of sediments accumulating on the lake floor.

The most recent fluctuations in the hydrological budget of Lake Turkana are apparent from radar altimetry measurements of the lake elevation, monitored at least bi-monthly since 1992 from Topex/Poseidon and Jason satellite systems (Fig. 5). Over this time period lake level has fluctuated by over 5 m, from its lowest level in 1996 to its highest level in 1999. The level of Lake Turkana closely parallels the levels of Lakes Victoria and Tanganyika over the same time interval. All three lakes rose dramatically in the 1998 El Nino year when heavy rains fell throughout tropical East Africa, responding primarily to the sea surface temperature (SST) field in the Indian Ocean (Goddard & Graham, 1999). SST's in the west central Indian Ocean tend to be relatively warm compared to the eastern equatorial region during El Nino years (Goddard & Graham, 1999), leading to enhanced advection of moisture over tropical East Africa and relatively intense rainfall.

A hydrological history of the Turkana basin is derived, at least qualitatively, from the composition of sediments recovered in cores from the offshore basins of the modern lake. These sediments consist of laminated to thinly bedded, calcareous silty clay (Yuretich, 1979). The laminae are typically 0.3–0.5 cm thick and are defined by calcite-rich light layers between calcite-poor dark layers. These couplets are not varves, but rather represent on average 1.5–2 years duration, and perhaps reflect the influence of the biennial oscillation on rainfall on the Ethiopian Plateau (Halfman

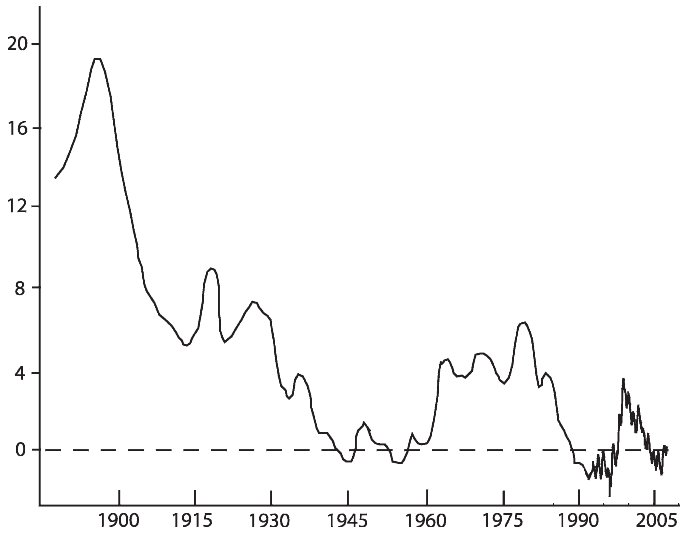

Fig. 5 The history of lake level fluctuations from 1893 to 2006, based on historical ground survey to 1990 (from Kallqvist et al., 1988; measurements by the Kenya Marine Fisheries Institute (1988–1994); and on TOPEX/Poseidon satellite radar altimetry, from Global Reservoir and Lake Elevation Data Base, Eastern Africa, U.S. Department of Agriculture Foreign Agricultural Service web site (http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/gr_regional_chart.cfm?regionid=eafrica&region=&reservoir_name=Turkana). Lake level is in meters, based on an arbitrary datum of about 361 m asl

et al., 1994). Laminations are preserved in the sediment, despite the oxygenated bottom waters, because of the unusually high sedimentation rates and the prevalence of epifaunal detritovores living on the lake floor rather than infaunal invertebrates that would more effectively destroy sedimentary structures (Cohen, 1984).

The sedimentary calcite consists of ostracod shells and endogenic, arrowhead-shaped crystals of low-Mg calcite about 2–5 μm in length. The profiles of carbonate content in Turkana sediment cores reflect dilution by varying input of detrital siliciclastic sediment derived primarily from the Omo River, and is a rough measure of rainfall on the Ethiopian Plateau (Fig. 6) (Halfman et al., 1994). The 12 m long piston cores from Turkana span at most only 5,400 years, due to the high sedimentation rate in the lake. A stacked carbonate record bears crude resemblance to the Nile discharge record of Hassan (1981) that spans the past 1,500 years (Fig. 6), and displays significant periodicity of 76, 32, 22, 18.6 and 11 years (Halfman et al., 1994).

Diatoms are not well preserved in the upper few meters of Turkana sediment cores due to the high pH of the lake waters and its impact on the preservation of biogenic silica (Johnson, 2002). However Core LT84-2P recovered from the south basin of the lake displays increasing abundance of diatoms with depth, and a major shift in diatom species abundances 7.6 m below the lake floor. Below this level, the diatom assemblage is dominated by *Aulacoseira* (formerly *Melosira*) species indicating freshwater conditions, and above, dominance of salt tolerant genera *Thalassiosira* and *Surirella* (Fig. 7) (Halfman et al., 1992). The age of this transition

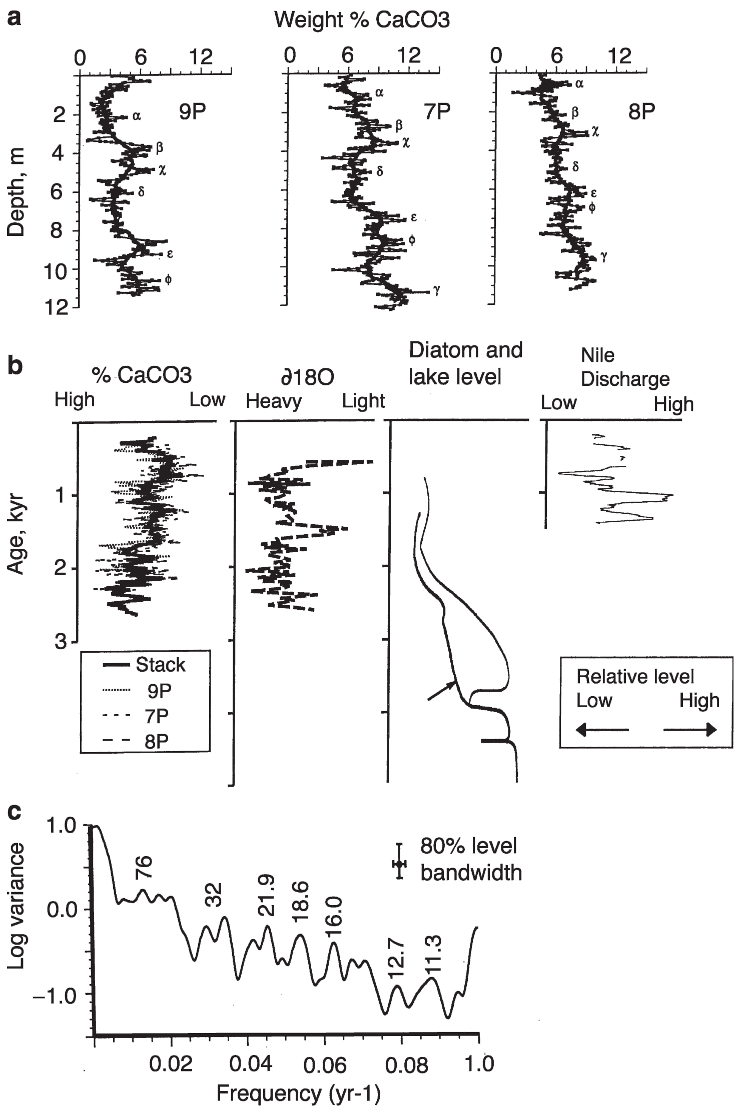

Fig. 6 Abundance of calcite in sediment cores from Lake Turkana reflect past changes in river input to the lake, with high calcite abundance reflecting low river input. (**a**) Weight % calcite versus depth in cores from the northern basin. Core locations are depicted in Fig. 2. (**b**) Various measures of hydrologic change vs. radiocarbon age from Lake Turkana and the Nile River: calcite abundance, δ18O of calcite, and diatom indicators of salinity in the south basin core 2P (see text and Fig. 7), and dated beach ridges (see text and Fig. 8). Nile River discharge data are from (Hassan, 1981). (**c**) Power spectra of stacked %$CaCO_3$ profiles plotted against age in Turkana cores, showing decadal scale cyclicity in the lake's hydrological regime. Modified from Halfman et al. (1994) with permission from Elsevier

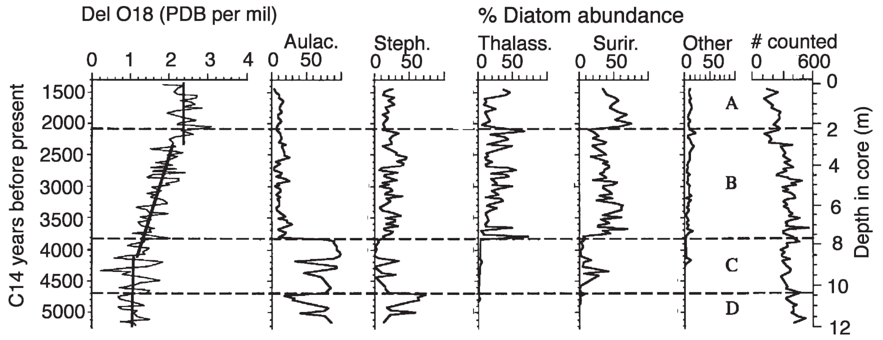

Fig. 7 δ18O of endogenic calcite and the relative abundances of the major diatom genera versus age in core LT84-2P (location in Fig. 2). Reprinted from Halfman et al. (1994) with permission from Elsevier

is 3,900 ^{14}C ybp, or 4,320 Cal ybp, and it signals the last time that Lake Turkana was an open basin lake, with outflow to the Nile.

The oxygen isotopic composition of the $CaCO_3$ in micrite and ostracodes has been analyzed in Turkana sediment cores, as further evidence of the hydrological history of the lake. $\delta^{18}O$ of lacustrine calcite varies with temperature and with the isotopic composition of the lake water. Temperature variability in tropical lakes has relatively minor impact on oxygen isotopic composition compared to the effect of shifts in lake water isotopic composition that result from either evaporative fractionation or to changes in the composition of source water through time. The relationship between the isotopic composition of calcite and lake level history is not simple (Ricketts & Johnson, 1996), but with appropriate modeling a reasonable estimate of past lake level can be derived (Ricketts & Anderson, 1998). The $\delta^{18}O$ profile of micrite in the same piston core analyzed for diatoms, described in the previous paragraph, is quite variable throughout the core, and undergoes a pronounced shift to heavier values over the span from 3,900 to 2,200 ^{14}C ybp (4,320–2,320 Cal ybp) (Fig. 7) (Ricketts & Johnson, 1996). This prolonged shift to heavier values cannot be explained by the abrupt drop in lake level at 4,320 Cal ybp, but must indicate a 2,000 year long adjustment in climate over the Ethiopian Plateau that was manifested in part by a corresponding shift in the isotopic composition of rainfall in the region (Ricketts & Johnson, 1996).

The most accurate history of lake level fluctuations is derived from a series of radiocarbon dates on mollusk shells recovered from shoreline deposits exposed in the basin above present lake level, especially to the north and east of the lake. These beach strandlines with early to mid Holocene ages lie as high as 460 m above sea level, or 10 m higher than the sill that would allow Turkana water to drain westward into the Sobat catchment and the Nile (Butzer, 1980). The elevation of Lake Turkana today is about 360 m asl. There is considerable variability in radiocarbon dates from the relict shoreline deposits but, when taken together, appear to cluster into two, possibly three, phases of lake high stands in the Holocene (Butzer

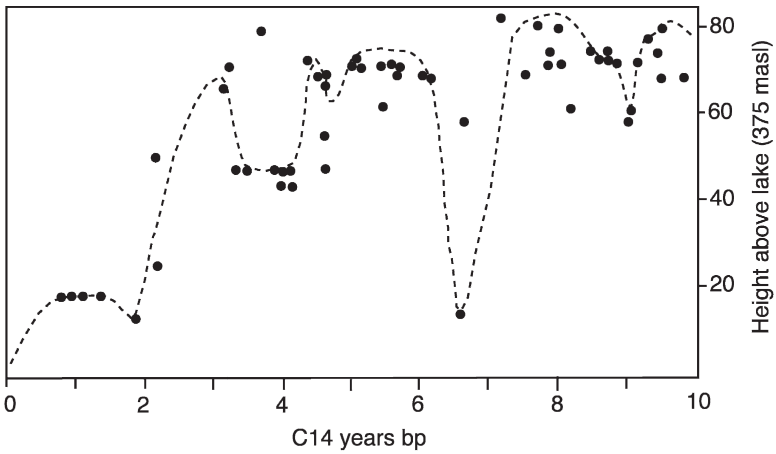

Fig. 8 A curve of Lake Turkana level versus radiocarbon age for the past 10,000 years, based on radiocarbon dates on relict shoreline deposits. Modified from Owen et al. (1982) with permission from the Nature Publishing Group

et al., 1972; Owen et al., 1982). The first, lasting from 10,000 to 7,000 ^{14}C ybp (11,500–7,800 Cal ybp), includes several dates from beach ridges at elevations corresponding to overflow conditions (Fig. 8). A brief low stand, defined by only one date at 380 m asl, is identified at 6,600 ^{14}C ybp (7,500 Cal ybp). This precedes the second phase of high lake level that spans the interval of 6,500–4,200 ^{14}C ybp (7,400–4,700 Cal ybp). Lake level then dropped to about 420 m asl. There is one radiocarbon date of 3,250 ^{14}C ybp suggesting a final brief period of overflow into the Nile (Fig. 7) (Butzer et al., 1972; Owen et al., 1982), but this is not compatible with the diatom data from Core LT84-2P (Fig. 7), nor with core data reported by Barton and Torgersen (1988). This suggests that the date is erroneous, and that the last time of Turkana overflow to the Nile was around 4,300 to 4,700 Cal ybp, based on the diatom record in LT84-2P and dated beach deposits, respectively.

The history of lake level fluctuations in the Turkana basin prior to 11,500 Cal ybp is not as well known as it is for the Holocene. No lake high stands have been identified for Turkana for the period 35,000–10,000 ^{14}C ybp (Owen et al., 1982). However the Kibish Formation includes some older, flat lying deltaic deposits and interbedded tuffs at the drainage divide between the Turkana and Nile catchments (Fig. 9). The formation has been divided into four members, each representing at least one interval when Lake Turkana was high enough to contribute outflow to the Nile. The uppermost Member IV has been radiocarbon dated and included with the early Holocene deposits described previously. Alkali feldspars extracted from pumice clasts from tuffs in Members I and II have been dated by ^{40}Ar/^{39}Ar, at 196 ± 2 and 104 ± 1 kyr, respectively (McDougall et al., 2005), which coincide with ages of sapropels S7 (195 kyr) and S4 (102 kyr) in the eastern Mediterranean Sea. The sapropels are distinct, organic-rich horizons with an absence of benthic faunal remains that have been attributed to high Nile discharge to the Mediterranean, which

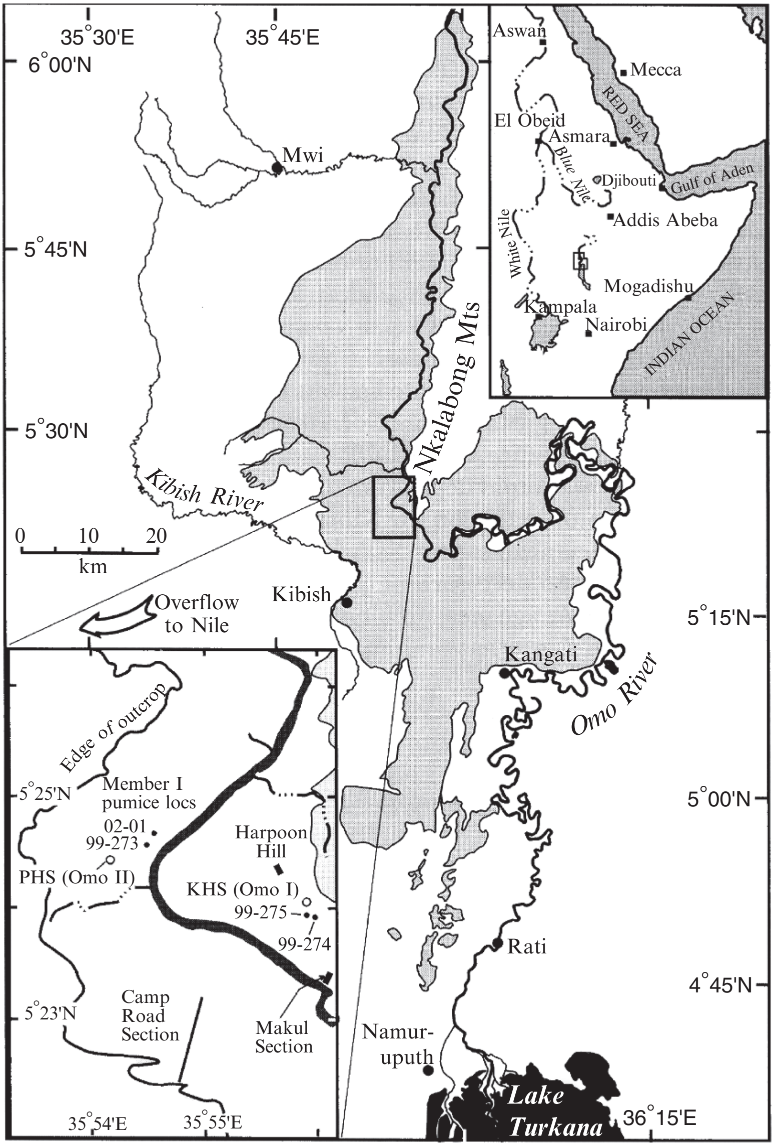

Fig. 9 A map of the Kibish Formation (shaded area) north of Lake Turkana. Reprinted from McDougall et al. (2005) with permission from the Nature Publishing Group

caused intense stratification in the upper water column and suboxic conditions on the sea floor (Rossignol-Strick et al., 1982). Member II of the Kibish Formation has two siltstone sequences separated by a disconformity. These likely coincide with S5 (119–123 kyr) and S6 (172 kyr), or with two phases of S5 (McDougall et al., 2005). The tie between sapropel formation in the Mediterranean and the high stands of Lake Turkana lead to speculation that there are more high stand deposits in the Turkana basin to be found and dated, but at present we can only be sure of Turkana links to the Nile in the early Holocene, at 102 kyr, and at 195 kyr, with possible links at 123 and 172 kyr as well.

Plio-Pleistocene lake deposits are also exposed to the east and west of the present lake. The lacustrine clays are interbedded with conglomerates, sands and silts of alluvial and fluvial origin. Stratigraphic correlations have been drawn across the Turkana basin based on interbedded tephras of distinct composition, many of which have been dated by the $^{40}Ar/^{39}Ar$ method (Feibel et al., 1989; McDougall & Brown, 2006). Cerling (1979) analyzed lacustrine clays and silts in the Koobi Fora Formation east of the lake to determine the paleochemistry of past lake high stands, based on fossil assemblages, exchangeable cations on clay minerals, and presence or absence of certain authigenic minerals. At the time of his analysis the age of the deposits was not well known, but they are now dated at about 4.2–0.7 Ma (Feibel et al., 1989). Cerling determined that the presence of molluscs in lacustrine deposits indicates relatively freshwater conditions, with alkalinity in the range of 0.5–16 meq/l (Cerling, 1979). Under these circumstances, Lake Turkana was likely overflowing. Feibel (1994) concluded that the lake overflowed to the southeast to the Indian Ocean from the late Miocene until at least 1.9 Ma, based primarily on an abundance of fossil stingray spines in lacustrine and fluvial deposits that are of early Pleistocene age (1.9–1.3 Ma). Subsequent tectonics in the basin shifted the direction of Turkana outflow during humid times from a corridor to the Indian Ocean to the Nile drainage system.

We have no record of how much lower Lake Turkana may have stood than at its present level. It is likely that it was reduced to a much smaller body of water during the last ice age and in earlier times of weakened summer monsoons, and perhaps was completely desiccated. New results from the Lake Malawi and Lake Bosumtwi Drilling Projects, and from a core from Lake Tanganyika, indicate widespread megadrought conditions in tropical Africa prior to 75 kyr – far drier than during the last glacial maximum at 21 kyr (Scholz et al., 2007). Lake Malawi was about 500 m lower than today around 110 and 130 kyr, and 350 m lower than present around 75 and 100 kyr. Such extreme aridity during precessional minima in summer insolation may have extended as far north as the Ethiopian Plateau. If so, Turkana may have completely dried out. This could mean that the soudanian biota that are found in Turkana today are the remnants of only the most recent flooding of the Turkana basin between 10,000 and 4,000 years ago.

6 Conclusions

Lake Turkana is a closed-basin lake that relies primarily on inflow from the Omo River for its existence in the hot, arid depression of northern Kenya. It is a slightly saline lake that has a well-mixed water column and an oxygenated lake floor. Sedimentation rates are high in the lake, typically on the order of 0.2–0.5 cm/y, due to high river discharge of sediments from the extensive drainage basin. The lake has stood 100 m higher than present under wetter conditions in the past, at which times the water was of low salinity and the lake spilled into the Nile River catchment, at least in the last 1.3 million years. The most recent outflow from Turkana to the Nile occurred in the early Holocene, from about 11,500 to 7,800 Cal ybp, and again from about 7,400 to 4,300 Cal ybp. At present we have no evidence for Turkana outflow to the Nile between 11,500 ybp and 104,000 years ago. High stand deposits in this age range may become revealed with further field work in the region. Prior to 104 kyr, a few high stand deposits have been dated that appear to coincide with Mediterranean sapropels, dating as far back as 195 kyr. The history of lake level fluctuation prior to this time is unknown. There are thick sequences of lacustrine shale that have been imaged seismically and sampled in oil exploration wells in the Lokichar Basin southwest of the lake, and the lake itself overlies 3.5 km of sediment up to 4.3 million years old. There is still much to be learned about the hydrological history of the Turkana basin and its past tie to the Nile River.

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