The Holocene Lake Plain of North Rudolph, East Africa

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Abstract: During most of the early and middle Holocene, Lake Rudolf was 75m deeper than today, flooding the Kibish Lake Plain as much as 60-100km north and northwest of the modern shore, with periodic overflow across the White Nile watershed. The landforms and sediment sequences of this lake plain are mapped or profiled, described, and integrated into a regional geomorphologic framework, controlled by a suite of ^{14}C dates. High lake stands are dated 10,000-7,000, 6500-4000 and about 3250 years ago (uncalibrated), with levels fluctuating around that of the present 7000-6500 and since 2500 years. Environmental changes of such magnitude reflect long-term changes of East African climate, so that the Rudolf Basin provides a well-documented index of regional climatic trends for the last 10 millenia. Since shortly after 10,000 years, prehistoric fishing and hunting settlements dotted the rivers and shorelines, favored by optimal aquatic resources but inhibited by a higher incidence of malaria. Aquatic subsistence patterns survived severe but temporary lake shrinkage 7000 years ago; during the last 5 millennia they have gradually given way to pastoral cultures. The Kibish Lake Plain serves to illustrate that geographic landscape analysis can rarely afford to be ahistorical.

INTRODUCTION

A century ago Gilbert (1881) described the lacustrine features of former Lake Bonneville, interpreting the beaches of this ancestral Great Salt Lake. Subsequently, geomorphologists have analyzed other fossil lakes, emphasizing shoreline sequences, so for example, Nilsson (1931) and Washbourn (1971) in East Africa. The advent of radiocarbon dating favored increasing emphasis on ^{14}C dates, with several synopses of African lake level changes appearing during the 1970s. Such date lists or time slices are poorly suited to discuss the complex problems of shore forms and sedimentary development. There also is a tendency to accept ^{14}C assays literally, ignoring geochemical contamination problems and even to contruct lake level curves form such "dates" rather than from a proper geomorphological framework.

The extensive lacustrine plain north and northwest of Lake Rudolf is ideally suited for a more comprehensive study that links landforms, stratigraphic sequences, and evidence of human settlement. This multiple record is preserved in a sedimentary basin where the Omo River leaves the Ethiopian high country to enter non-outlet Lake Rudolf (Fig. 1; for a description of the catchment and its hydrology, see Butzer, 1971a, Chap. 1). A base of Pliocene and Early Pleistocene beds (Butzer, 1976a; Brown and Nash, 1976; Brown and Shuey, 1976; DeHeinzelin, Haesaerts and Howell, 1976) supports a thick mantle of alluvial, deltaic and lacustrine sediments known as the Kibish Formation (Butzer, Brown and Thurber, 1969; Butzer, 1971b). This Formation has four members: Members (Mbs.) I to III are Upper Pleistocene and older than 37,000 ^{14}C years; Mbs. IVa and IVb are of early to mid-Holocene age and date 10,000 to 3,000 years ago (B.P.). Member IV deposits are exposed over almost 3,000km^2 and form the Kibish Lake Plain that is the subject of this paper. This surface grades into piedmont alluvia along the basin margins, and is cut by the prominent flood and delta plains of the Omo and Kibish rivers.

Field mapping of the Kibish Lake Plain (Fig. 2) was carried out by helicopter, mainly to the base of 1:100,000 outline maps, and revised and refined with British and U.S. aerial photography (see Butzer, 1971a, 9-10, for maps and photo resources). Regional correlation of shorelines or beach facies was impeded by a lack of map contours for this quasi-level and very extensive plain, and even the few mountain peak elevations are unreliable. Consequently, spot elevations were obtained by multiple aneroid readings, using the helicopter altimeter and a second engineering aneroid to cross check, while a control aneroid was read at regular intervals in the base camp. Elevations cited here

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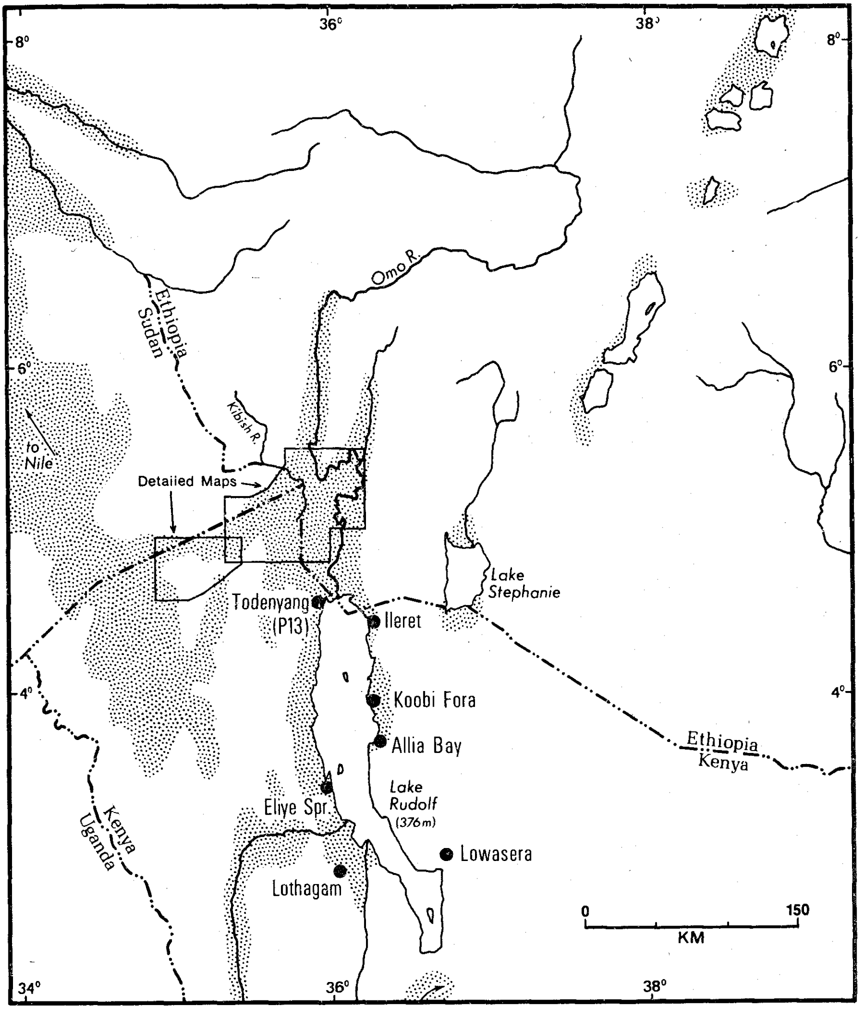

Fig. 1. Lake Rudolf and adjacent depositional plains, shown in gray. Note position of detailed maps (Fig. 2). Lake Rudolf has been renamed Turkana by the Kenyan government, a change not recognized by Ethiopia.

are accurate to ±2m and are given with reference to the (somewhat arbitrary) 376m level of Lake Rudolf in 1968.

BEACH RIDGES

The most striking landforms of the Kibish Lake Plain are beach ridges (Fig. 2 and 3). These have very gentle slopes, with a typical relief of 5 to 10m, and a width of several hundred meters (Fig. 4). Ridges as mapped are generally composed of multiple, partly coalescent crests, and commonly occur in sets. Chimney termitaria (Fig. 5) favor these beach ridges because of good drainage, and the vegetation is a distinctive grassland with scattered trees (Type AI of Carr, 1977, 31–40).

Most of the ridges run subcontinuously over stretches of 10–20km, and one attains 48 km in length. They are conspicuous on LANDSAT imagery. Several ridges feather out in large spits (Fig. 5),

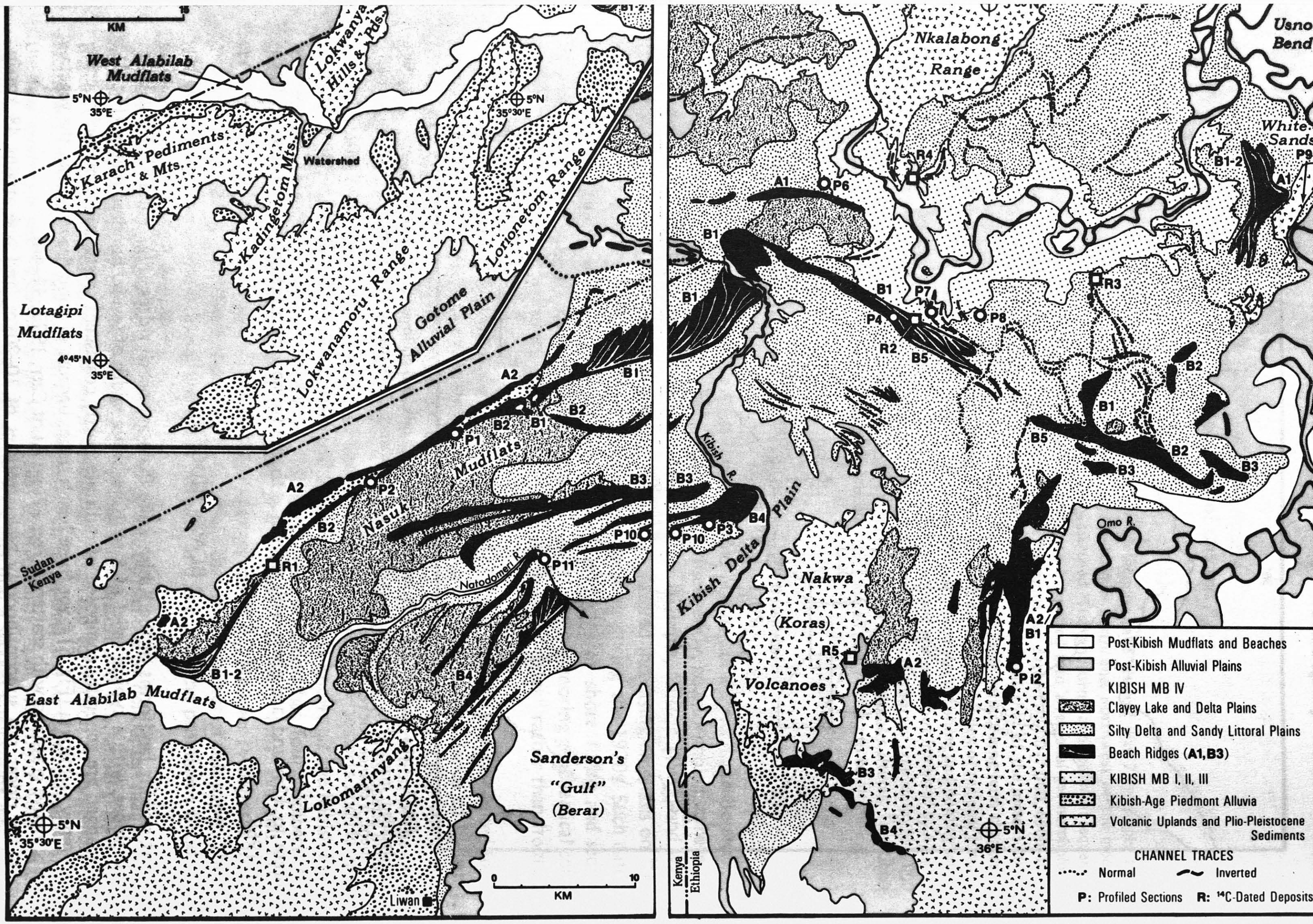

Fig. 2. The Kibish Lake Plain north and northwest of Lake Rudolf. The western sector (inset) is at reduced scale.

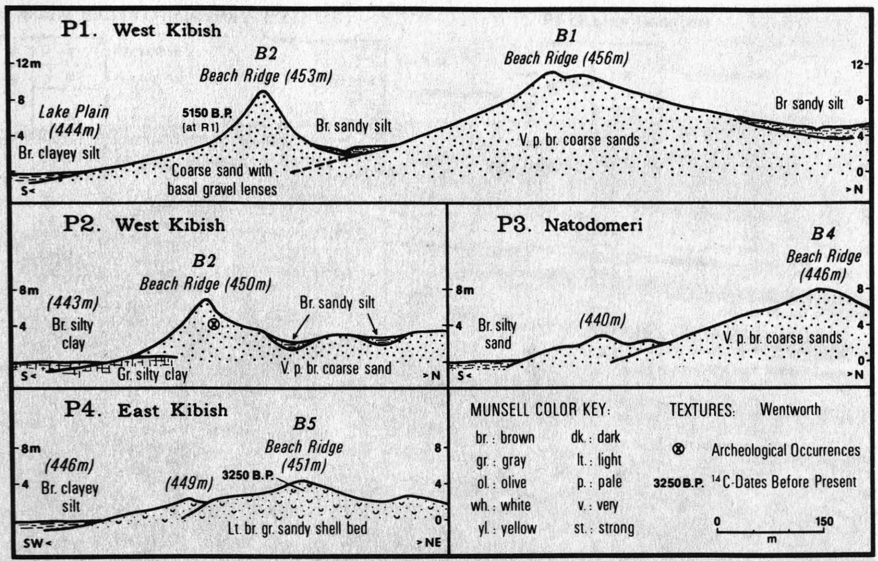

Fig. 3. Cross sections of selected beach ridges, Kibish Lake Plain. Vertical exaggeration 12.5:1.

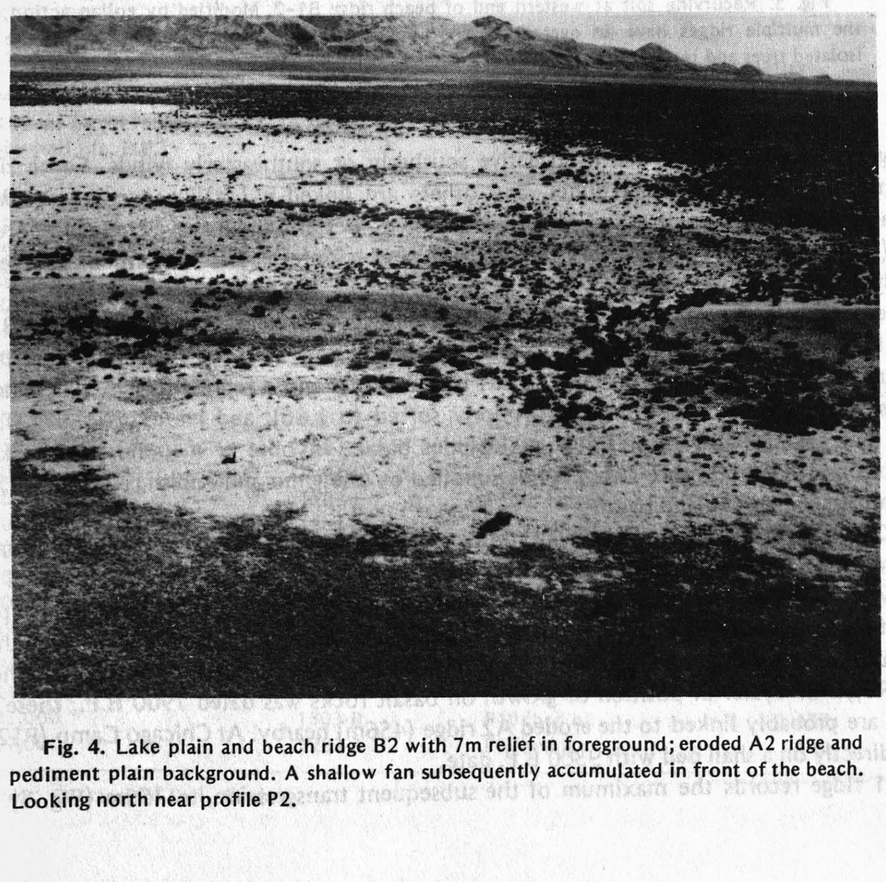

Fig. 4. Lake plain and beach ridge B2 with 7m relief in foreground; eroded A2 ridge and pediment plain background. A shallow fan subsequently accumulated in front of the beach. Looking north near profile P2.

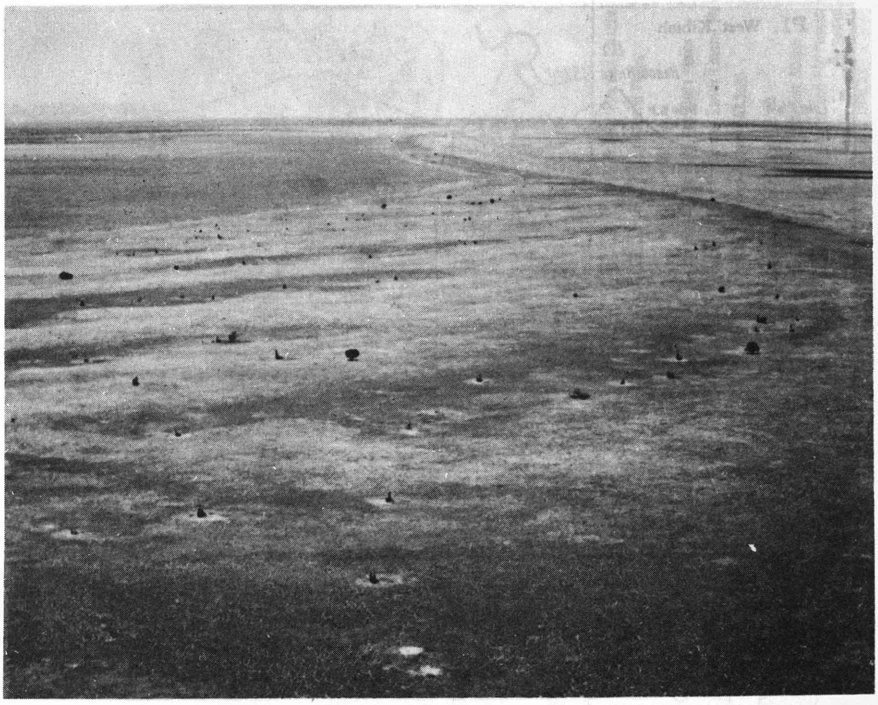

Fig. 5. Recurving spit at western end of beach ridge B1-2. Modified by eolian action, the multiple ridges have an overall relief of 7m and maximum elevation of 449m; the isolated trees and termitaria average 3m high. Looking northeast.

recurving northwards in response to effective southerly or southeasterly winds. Some ridges have been remodelled as longitudinal dunes, and others are linked by shallow transverse (W-) dunes. Comparable forms can be observed along the modern, western (high wave-energy) shore of Lake Rudolf (see Butzer, 1971a, Figs. 2-37 to 40, 42), and counterparts of intermediate age are symmetrically arranged around the recent Omo Delta (see Butzer, 1971a, Figs. 2-2, 21, 41).

Coarse sands are the rule and one typical beach ridge matrix has a median *phi* of 2.30, good sorting (Folk σ 0.87), a fine tail (Folk Ski 0.24), and average kurtosis (Folk Kg 1.02). However, grit or gravel is present where coarse detritus is abundant, and a representative matrix to a beach shingle is very coarse (median *phi* 1.22), poorly sorted (σ 1.86), and leptokurtic (Kg 0.69), with a coarse tail (Ski 0.17). Gravel lithology includes basalt, rhyolite or metamorphic rocks derived from outcrops 10km and more away. Sands supplied by the Omo and Kibish rivers are rich in hornblende and augite from upland basalts.

The Kibish-age shorelines span an elevation range of 430-460 m, and record a fluctuating lake level between +55 and +85m. The ridges have been numbered in Figure 2 on the basis of preservation, elevation, and arrangement. The "A" ridges are strongly eroded and fragmentarily preserved; they are found between 454 and 462m elevation. At Rhino Canyon (P6, Fig. 6), ridge A1, the highest (462m) and most northerly, has a direct date of 8800 B.P. (see date list, Table 1). At the foot of Nakwa (R5), Nile oyster in position of growth on basalt rocks was dated 7900 B.P.; these shell bed remnants are probably linked to the eroded A2 ridge (456m) nearby. At Chicago Camp (P12, Fig. 7), A2 rests directly on a shall bed with 9300 B.P. date.

The B1 ridge records the maximum of the subsequent transgression, to 456m (Fig. 3). Directly

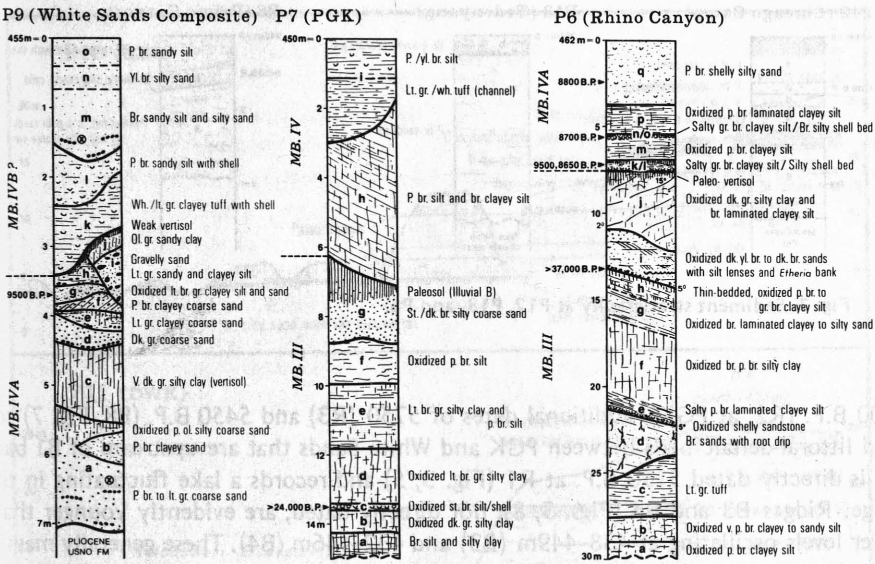

Fig. 6. Sediment stratigraphy at P9, P7, and P6. All textures in the profiles of Figs. 6 to 9 were determined by hydrometer analyses and wet sieving.

Table 1. Radiocarbon Dates on Freshwater Shell from the Kibish Formation

Apparent age (error range) (Libby half-life, B.P.)	Lamont No. L–	Site and stratigraphy	Sample elevation
Member IV B			
3250 (150)	1203-H	P4, Ridge B5	450 m
5150 (350)	1303-A	R1, Ridge B2	448
5450 (100)	1203-I	P8, rear of B1	441
5700 (100)	1203-G	R2, Ridge B1	452
5750 (100)	1203-K	R3, rear of B1	444
6600 (150)	1303-D	P13, near modern shore	378
Member IV A			
7900 (150)	1203-L	R5, near A2	455
8650 (150)	1203-B	P6, predates A1	454
8700 (200)	1203-D	P6, predates A1	456
8800 (200)	1203-E	P6, Ridge A1	459
8900 (300)	1303-H	R4, predates A1	428
9100 (300)	1203-H	P5, predates A1	445
9300 (400)	1303-C	P12, base of A2	453
9500 (150)	1203-J	P9, predates A1	452
9500 (150)	1203-C	P6, predates A1	454
Member III			
>24,000	1203-F	P7 (bed c)	437
>35,000	1303-B	P10 (bed h)	432
>37,000	1203-A	P6 (bed i)	450

Source: Courtesy of D. L. Thurber.

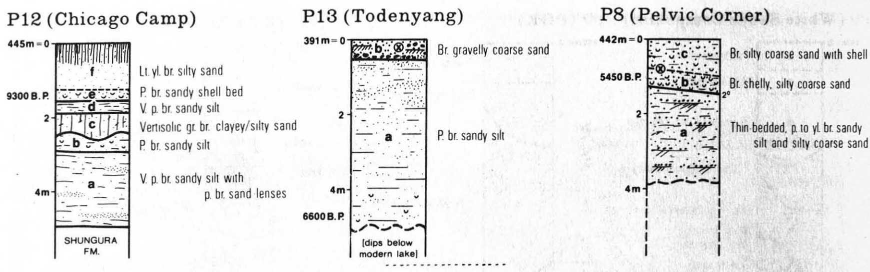

Fig. 7. Sediment stratigraphy at P12, P13, and P8.

dated 5700 B.P. (R2, at PGK), additional dates of 5750 (R3) and 5450 B.P. (P8, Fig. 7) come from widespread littoral-deltaic beds between PGK and White Sands that are upstream of B1 barrier bars. Ridge B2 is directly dated 5150 B.P. at R1 (Fig. 3, 5) and records a lake fluctuating in the 440 to 450m range. Ridges B3 and B4 (Figs. 3, 8), not directly dated, are evidently younger than B2 and verify lower levels oscillating at 438-449m (B3) and 432-446m (B4). These generally massive, sandy ridges (Fig. 3) are almost certainly older than the low and loose sandy, B5 shell ridges that record a brief 450m shoreline ca. 3250 B.P. (Table 1) and represent the youngest tangible deposits of the Kibish Formation.

Molluscan samples were studied from 20 sites or levels of Kibish Mb. IV. Of these, 19 are dominated by either *Corbicula africana*, a pelecypod, or *Melanoides tuberculata*, a herbivorous gastropod; one collection, at R3, was dominated by two species of *Cleopatra*, also a herbivorous gastropod; the usual subdominants are *Melanoides* or *Corbicula*, in reversed order. These mollusca define the overall ecology as that of a fresh-water lake or delta, with *Corbicula* most common over sandy substrates, and *Melanoides* more common with clayey substrates or in less well-aerated waters.

All of the Kibish beach ridges show little soil development. Complete profiles have a slightly humic, pale brown A-horizon over a lightly rooted, light yellowish brown, loamy B, with a total thickness of 1 to 1.5m. Structure is weak, and textural and geochemical horizonation are minimal in these non-calcic brown soils, typical of Holocene pedogenesis on sandy substrates in the study area (see also Butzer, 1971a, 19). No systematic difference in depth of weathering was apparent among the several generations of beach ridges.

LAKE, DELTA AND LITTORAL PLAINS

Whereas beach ridges form conspicuous landforms, flat depositional surfaces are the most extensive elements of the Kibish Lake Plain.

Cracking clay plains are common in the western and northern sectors. Totally featureless, the surface constitutes a gray to dark grayish brown vertisol with an active profile of at least 1.5m. Clay fractions range from 30 to over 60%, with expandables (smectite) dominant. Wet for long periods after rains, these clay plains represent pedogenetically altered mudflats of several origins. The Nasuk clay plain in the west was originally lacustrine, but is similar to the lower and functional, seasonally flooded mudflats of post-Kibish age, i.e., the Alabilab, Lotagipi, and Sanderson's Gulf mudflats (Fig. 2). Vegetation is grassland (type BI of Carr, 1977, 49-55). The clay plain in the north was once an old delta plain and is less clayey, with a shrub cover (type BII, Carr, 1977, 54-57). The giant crack networks of the several Kibish clay plains have modern counterparts in the Omo delta fringe (Butzer, 1971a, Figs. 2-15, 31) and argue for both synchronous and post-depositional development.

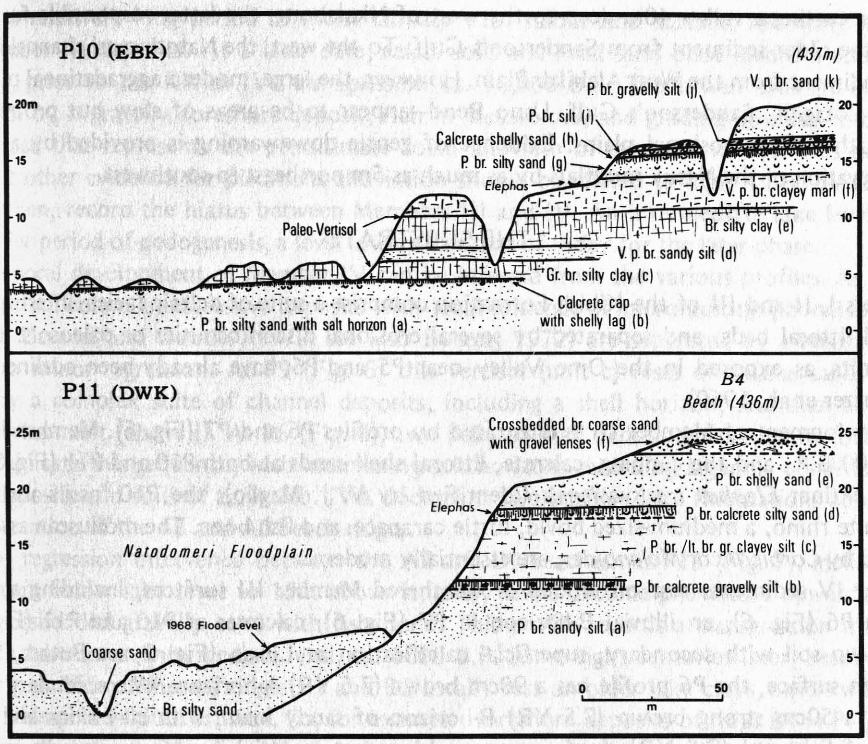

Fig. 8. Cross sections at P10 and P11. Vertical exaggeration 4:1.

Silt plains are widespread in the central sector and associated with gently undulating relief. Textures vary from silty sands to clayey silts, and cracking, vertisolic features are less common and less developed. The coarse grained facies generally represent littoral, foreshore deposits (P8, P12, Fig. 7; P10, P11, Fig. 8) or flat-lying areas linking successive beach ridges (P1, P2, Fig. 3). Soils here tend to be brownish loams. The finer grained deposits are deltaic, with extensive, interbedded volcanic tuffs that were swept into the fluvio-lacustrine transition zone by the Omo River from higher up in the Ethiopian watershed. The deltaic silt, loam, and clay loam soils also have poorly differentiated, 70-130cm brownish profiles (P7, P9, Fig. 6). In general, the silt plains have a complex vegetation of thornbush and steppe (type BIII, Carr, 1977, 58-61).

Of particular interest on the silt plains are relict traces of multiple Omo channels (Fig. 2). Many of these now form ridges of light gray silt (P7, Fig. 6), representing durable tuff plugs choking former meander trains. Subsequent erosion has attacked less permeable levee beds of mixed texture, creating an inverted relief of 3 to 5m. These "inverted" channels frequently run parallel to or lead into other, "normal" channels, where the original banks rise a few meters above partially-filled channels, comparable in size and form to atrophied channels of the modern delta (see Butzer, 1971a, Figs. 2-8, 9B, 17, 32, 33). The fossil channel traces form an intricate network in a triangular area south and southeast of Nkalabong. Location with respect to the "B" beach ridges as well as links with Kibish Mb. IVB tuffs (P7, P9, Fig. 6) suggest the distributaries of a mid-Holocene delta. The "normal" channel traces are found near the distal end of this delta and disappear on the adjacent, lower-lying plains; channel cutting began during final emergence of the Kibish Lake Plain, apparently with shoreline retreat from ridge B3.

The Kibish Lake Plain was subsequently dissected on a large scale by the Omo and Kibish rivers, the former cutting a valley 40m deep to the west of Nkalabong, the latter responsible for removing much of the older sediment from Sanderson's Gulf. To the west, the Natodomeri channel has served to flush sediment from the West Alabilab Plain. However, the large, modern aggradational plains—East Alabilab, Lotagipi, Sanderson's Gulf, Usno Bend—appear to be areas of slow but protracted subsidence, rather than erosional plains. Evidence of gentle downwarping is provided by a decline in median elevation of the Nasuk mudflats by as much as 5m northeast to southwest.

THE SUBSTRATE

Members I, II and III of the Kibish Formation comprise a suite of deltaic facies, interbedded with occasional littoral beds, and separated by several erosional disconformities or paleosols. The stratigraphic units, as exposed in the Omo Valley near P5 and P6, have already been outlined (Butzer, 1976a; Butzer et al., 1969).

The development of Member III is illustrated by profiles P6 and P7 (Fig. 6). Member III is older than 37,000 B.P., and the capping, calcrete, littoral shell sands at both P10 and P11 (Fig. 8) include fossils of extinct *Elephas transvaalensis* (identified by V. J. Maglio); the P10 fossils also comprise hippo, white rhino, a medium-sized bovid, turtle carapace, and fish bone. The molluscan assemblages, dominated by *Corbicula* or *Melanoides*, are essentially modern.

Member IV sediments rest on eroded or weathered Member III surfaces, including a truncated vertisol in P6 (Fig. 6), an illuvial B-horizon in P7 (Fig. 6), calcretes at P10 and P11 (Fig. 8), and another deep soil with secondary, superficial calcification at Liwan (Fig. 2; see Butzer, 1976). At the modern surface, the P6 profile has a 90cm brown (7.5 YR) A-horizon, with secondary humification, over a 50cm strong brown (7.5 YR) B-horizon of sandy loam, with clay skins and powdery void fills of light red (2.5 YR), ferric compounds; parent material is a coarse quartz sand rich in opaque minerals. More representative is the 2.5 to 4m B-horizon at Liwan, composed of strong brown (7.5 YR) loam and clayey loam, developed in a piedmont alluvium rich in basalt, rhyolite and chert gravel. Here the 5cm Ca-horizon is developed at 25 to 30cm depth within the older B-horizon; pebbles in and above the Ca have been partly split *in situ* by salt hydration, while surface lag gravel is patinated, with occasional facets caused by sand blast (ventifacts). The initial deep soil

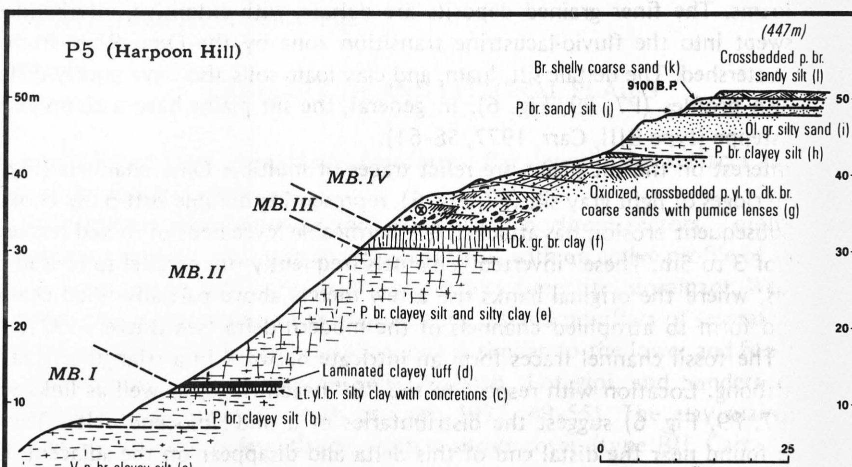

Fig. 9. Cross section at P5 (Harpoon Hill). No vertical exaggeration.

argues for a relatively long period of moist climate with stable land surface, following emergence of the Member III deposits. At a later date, calcic soils and local sand blast record a drier climate than today, prior to the Kibish IVa transgression ca. 10,000 B.P. The Liwan soils are overlapped up to 425m by a gravelly foreshore deposit, rich in *Melanoides*, and grading upvalley into a +12m stream terrace that represents the penultimate fossil alluvium of the local valleys. This association implies that other evidence for piedmont alluviation should be related to high Kibish IV lake levels. The soils, then, record the hiatus between Members III and IV. An intermediate lake level is likely for the earlier period of pedogenesis, a level lower than that of today for the later phase.

The temporal development of Member IV can be inferred from the various profiles. At P12 (Fig. 7) two 10th millenium transgressive deposits with local evidence of microfaulting (faunal assemblage A1 of Van Damme and Gautier, 1972; see also Butzer, 1972) are separated by a vertisol (unit c) suggesting a minor regression. At P9 (Fig. 6) this vertisol (unit c) rests on coarse sands and was followed by a complex suite of channel deposits, including a shell horizon, and then by renewed vertisol development (above j). At P6 (Fig. 6), two pairs of shell beds and clayey units (beds k to p) probably replicate this sequence, with intervening salt horizons recording lagoonal conditions. Overall, these deposits and soils of early Mb. IVA document two positive lake fluctuations above 450m, prior to formation of the A1 and A2 beach ridges.

A major regression intervened between the A2 and B1 beaches. At P13 (Fig. 7), inclined sandy silts rise from below lake level to 15m above it; gritty levels become prominent upwards, and the top is a crossbedded gravelly sand with fish bone. This profile records a transgression from below the modern lake to an intermediate level, ca. 6600 B.P. Some eight centuries later, beach ridge B1 was forming at 455m. Whereas ridges B1 and B2 locally rest on older lake clays, others were associated with widespread initial erosion. So, for example, foreshore deposits of ridge B4 at P10 and P11 (Fig. 8) rest directly on Member III, and they incorporate reworked shell from the calcrete shell bed that caps this unit.

THE NILE-RUDOLF DIVIDE

The faunal linkage of Lake Rudolf with the Nile system, and the implicit paleogeographic pattern, was first argued by Höhnel, Rosiwal, Toula and Suess (1891, 130–134). Detailed molluscan studies of late Kibish assemblages by Roger (1943) and by Van Damme and Gautier (1972) clearly document a Rudolf-Nile connection of Holocene age. Demonstration of this link in the field, beginning with the first topographic survey of R. C. Wakefield in 1938 (East Africa 1:250,000 topographic map series Y 501, sheet 58-L, 1941), has proven difficult. My own survey was able to show that the Lokwanya "pass" (Fig. 2, inset) now forms a 450m watershed for floodwaters draining either southeast to Sanderson's Gulf (see Butzer, 1971a, 98–101) or westward to the West Alabilab which also receives drainage from the Ethiopian highlands to the north and the Lotagipi Plain to the south (see Champion, 1937). LANDSAT imagery shows a distinct line of winding depressions, averaging 2 to 5 km in width, extending 90 km westward to the upper Pibor-Sobat catchment. Beach ridges are absent in this zone of internal drainage, and I did not locate fossil lake beds in the area covered by the western sector of Figure 2.

The complex recurved spit at the western end of the Nasuk mudflats (Fig. 5) provides direct evidence that an open Lake Rudolf extended to near Lokwanya during the 6th millenium B.P. Indirectly, the elevations of ridges A1, A2, B1, and B5 argue for lake levels that periodically spilled across the Lokwanya watershed. However, the absence of recognizable beaches further west (see Butzer, 1976b, Fig. 8-8, looking south across the East Alabilab) suggests shallow waters, with insufficient depth to generate wave action, or heavily vegetated terrain even on windward shores. In either case, shallow, seasonal, and marshy water bodies are more probable than true lakes in the West Alabilab and the shallow basins farther west.

It appears that the Rudolf-Nile connection was tenuous, with seasonal overflow of Rudolf waters into the poorly-defined drainage channels of the southeastern Sudan during particularly wet decades. Such hydrographic links to the Pibor-Sobat and White Nile can be dated during parts of the 10th, 9th, 8th, and 6th millennia B.P., with a last stand near the critical threshold about 3250 B.P.

SHORELINES WEST AND EAST OF LAKE RUDOLF

Observations on high beaches of Lake Rudolf were made during the 1930s by Fuchs (1939) and Arambourg (1943, 206). Fuchs in particular claimed the existence of four widespread shorelines at +330, 220, and 90 feet (99, 90, 66 and 27m), the first two with "Chellean" and "Acheulian" artifacts respectively. No sections or details were provided and no such sequence has been substantiated by more exacting studies.

Archeological work by Robbins (1972, 1974, 1979) in West Rudolf, around Lothagam and Eliye Springs (Fig. 1), suggests two high lake phases of Holocene age. The older deposits range from below 425 to about 458m elevation, and have shell dates of 8600, 8420, 8230, 7960, 7160 and 7000 B.P. The younger deposits, best exposed at 422 to 435m, have shell dates of 6010, 5420, 5020, 4800, 3720, 2560 and 1640 B.P., as well as a charcoal date of 6200 B.P.

Another intensive study in East Rudolf near Koobi Fora and Allia Bay, nearing completion by J. W. Barthelme, verifies two similar lacustrine sequences that form part of what is there defined as the Galana Boi Formation (Vondra, Johnson, Bowen and Behrensmeyer, 1971). Unpublished dates from Koobi Fora and Ileret range between 9880 and 4390 B.P. (Barthelme, pers. comm.; Vondra and Bowen, 1976). Particularly informative is Phillipson's (1977) work at Lowasera, where diatomites drage upward into a shell horizon that marks a lake level of at least 452m, about 9420 B.P. Subsequent, detrital beach deposits have a bone apatite date of 7735 B.P., while later, high lake stands of less certain elevation are broadly related to apatite dates of 4410, 3920, 3580 and 3070 B.P. Since ^{14}C apatite assays are somewhat unpredictable, and inconsistent with shell dates (Barthelme, pers. comm.), the latter values should be regarded as general approximations only.

The information from west and east of Lake Rudolf serves to show that Lake Rudolf rose rapidly shortly after 10,000 B.P. and remained generally high until 7000 B.P. A second high lake, mainly at intermediate levels, dates roughly 6200 to 3900 B.P., with Lowasera suggesting another high stand a few centuries later, Robbins' (1979) dates of 3720 and 2560 B.P. relate to lake levels cresting at 422 to 426m, well below that of Kibish beach ridge B4 and more compatible with the 400 to 410m median elevation of the post-Kibish, Murle lake beds of the Omo delta (Butzer, 1971a, 93-98). Robbins (1979) also has an array of well-dated archeological sites that argue for maximum lake levels of only 380 to 390m from before 2210 to after 870 B.P. These strictures show that Robbins' 1640 B.P. date on a 435m beach is spurious. Further, my earlier geomorphic estimates for rates of Omo Delta evolution were too high (see Butzer, 1971a, 129-130): The post-Murle stages (0 to 4) span almost 2500 years, rather than a millenium or so. This revision of the Omo Delta chronometry agrees well with Robbins' (1979) reconstruction of maximum Rudolf levels for the same period.

Most of the West Rudolf lacustrine beds that preserve their original form pertain to Kibish Mb. IV, but some shallow exposures appear to be older, even if difficult to distinguish from younger deposits. Shell from one such beach of potentially greater age, at Eliye Springs, was dated "greater than 40,000 years" (Robbins, 1979) and may pertain to Member III. Comparable units appear to be absent in East Rudolf: There are no dates greater than 10,000 B.P. and my 1973 examination of the Galana Boi outcrops at Koobi Fora failed to identify older, i.e., Upper Pleistocene, lake beds.

The available evidence from West Rudolf and the Omo Basin is both compatible and complementary. The ^{14}C dates are comparable in using a standard correction factor of –400 years, assuming that lake water would give an "age" 400 years too old (see Butzer et al., 1969), and not applying corrections for $\delta^{13}C$ (a desirable but expensive procedure). No systematic errors are anticipated

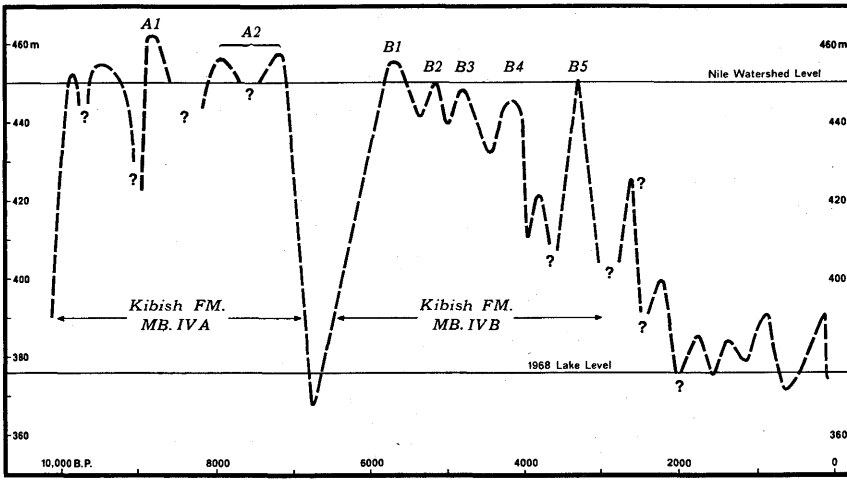

Fig. 10. Provisional trace of Rudolf lake levels during the last 10,000 years based on all sources. Average "high" positions are shown, and levels fluctuated in a range of 5m or so below the generalized trace on a shorter term basis.

since the mollusca assayed come from expanded, freshwater lakes, with a stronger Omo influx, deriving its carbonates from fresh weathering of alkaline volcanics. Good aeration and thus equilibrium of atmospheric versus aquatic CO_2 is furthermore assured, both in the delta region and along the high wave-energy shores of West Rudolf. The Rudolf dates are in fact generated on identical assumptions to those obtained from the Nile system in Sudan and Egypt. Nonetheless the dates display inconsistencies, e.g., within profile P6 (probably due to a saline soil environment) and possibly between P9 and P12.

The composite results synthesized in Figure 10 consequently provide a provisional, rather than definitive, lake level trace. It is compatible with the available data from East Rudolf and Lowasera, but will require revision in the light of further field investigation and more exacting chronometric controls. This trace has also not been calibrated for atmospheric ^{14}C flux, so that the span between 2500 and 5000 B.P. appears too compressed, being at least five centuries longer in terms of true calendar years (see Damon, Ferguson, Long and Wallick, 1974).

PREHISTORIC SETTLEMENT

The Holocene archeological record of the Rudolf Basin has assumed great interest with its profusion of fishing settlements and its earliest evidence for subsaharan pottery (Robbins, 1972).

Already in 1933, Arambourg (1943, 207) recovered a uniserial bone harpoon from profile P13 (Fig. 7), bed b. At Lothagam, Robbins (1974) has documented a bona fide fishing site directly above a beach dated 7160 B.P. There are over 280 uniserial barbed harpoons and other, barbless bone points, together with 734 undecorated potsherds. Over 95% of the identifiable bones are fish, mainly Nile perch and catfish. The oldest pottery site, with a "stamped" ware, is dated 8420 B.P., and pottery sites that include "wavy line" sherds range in age from 7960 to 6200 B.P. These last pottery styles are widespread at Saharan fisher sites and the former has a maximum date of 8200 B.P. (Wendorf, Schild, Said, Haynes, Gautier and Kobusiewicz, 1976). So-called Nderit (or Gumban A) pottery and ground stone bowls or platters appear by 4100 B.P. in East Rudolf, together with domesticated cattle and sheep/goat (Barthelme, 1977, and pers. comm.); similar pottery is already

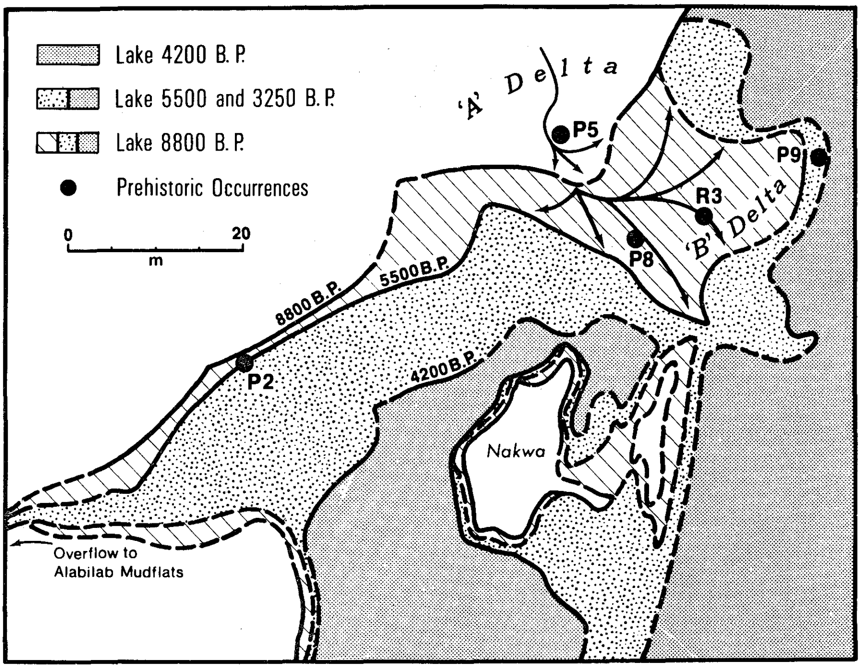

Fig. 11. Paleogeography of the Kibish Lake Plain during early and middle Holocene times.

verified 5020 B.P. west of the lake (Robbins, 1972, 1979). In East Rudolf some harpoon sites were strictly fish-oriented while others include a substantial component of land mammals; there is at least a partial temporal overlap between harpoon fishers and Nderit cattle herders (Barthelme, 1977; Phillipson, 1977).

The Holocene distribution of land and water on the Kibish Lake Plain is outlined in Figure 11, selecting the A1, B1 and B4 beach stages for most useful reference. Shoreline positions east of Nakwa are problematic, and numerous islands and shallow inlets evidently complicated the topography both here and around the various delta margins. Positions of the A1/2 and B1/4 deltas are shown in a schematic way only.

Except for the systematic 1967 excavations of R. E. F. Leakey at and near Harpoon Hill (P5, see Fig. 9), archeological work in the Omo Basin was incidental in view of the time constraints and a general focus on fossiliferous Pliocene strata. The archeological occurrences that were identified nevertheless suggest a basic picture of human occupance as well as strategies for future research.

The oldest archeological materials from the Kibish Formation are two specimens of a primitive *Homo sapiens* from Member I, found near P5, and approximately dated at 130,000 B.P. on the basis of uranium isotopes and a tentative magneto-stratigraphy (Leakey, Butzer and Day, 1969; Butzer et al., 1969; F. H. Brown, pers. comm.). Richard and Margaret Leakey surface-collected or excavated 69 artifacts from the former land surface related to one of these sites, representing a former delta distributary levee. These artifacts remain unpublished, but my preliminary inventory, kindly made possible by the National Museum of Kenya, shows a reasonably homogeneous assemblage, with 47 items similarly weathered and only 6 slightly waterworn. Raw material is overwhelmingly basalt, chert and rhyolite. Although basically undiagnostic, with 29 pieces of lithic waste, there are 5 retouched or utilized Levallois flakes. The presence of a complete buffalo skeleton and fragmented bovid bone (see Leakey et al., 1969) suggests a possible occupation site. Other nearby surface collections by the Leakeys include a typical, bifacial "Stillbay" point (10.4 by 5.1cm) and a bifacial Levallois point (7.1 by 6.3cm), both in mint condition. These pieces support a Middle Stone Age identification. Unfortunately the other *Homo sapiens* remains from Member I lack archeological associations.

Levallois flakes and points, Acheulian hand axes, or undiagnostic, miscellaneous artifacts were also found—reworked and in secondary context—in the much younger strata of Member IV. All three categories were found in bed m of profile P9 (Fig. 6), with scattered flakes in bed a. Two waterworn, ovate handaxes were recovered from unit g, not far from profile P5 (Fig. 9). This problem of derived, Pleistocene artifacts in Holocene deposits is a common one in West Rudolf (Whitworth, 1965; Robbins, 1972), and can be attributed to stream or wave reworking of older objects.

Primary artifactual associations in Member IVA were found by the Leakeys at Harpoon Hill (Fig. 9). These include eight broken, barbed harpoon tips or bases weathering out of the base of bed g, three of these with matrix still attached. Three are biserial, five uniserial. Varying degrees of patination and water polish suggest derivation from one or more adjacent occupation sites. There also is a 16.3cm uniserial harpoon, embedded in a fine conglomerate representing an Omo bedload deposit. Coming from somewhat below bed 1, directly dated 9100 B.P., the P5 harpoons are the oldest yet known from Africa. Together with the early fishing site from Ishango, on the Zaire-Uganda border (De Heinzelin, 1962), the Omo harpoons lend support to the hypothesis that early Holocene fishing cultures first developed in the lake basins of East Africa and diffused from here into the Nile system and the Saharan wadis. In any event, the earliest date on a Saharan harpoon site is 8130 B.P. (see Adamson, Clark and Williams, 1974).

Another site, with six uniserial harpoon fragments, has been reported by Brown (1975). These specimens were found at site R3 on the surface of fluvio-lacustrine tuffs directly dated 5750 B.P. (Table 1).

A different but mixed collection was made at Pelvic Corner (P8, Fig. 7), where a partial human skeleton was found in an erosional area together with remains of buffalo, hippo, and equid and a small bovid (L. S. Fichter, pers. comm.), all mineralized. Associated lithic artifacts include a crescent, a small adze, some scrapers and blades, and abundant waste in chert, as well as some modified basalt pebbles. There are two types of coarse pottery, with different thicknesses and decorations; most abundant is an incised type with deep, parallel grooves (identified by J. W. Barthelme), a sherd class no older than 1500 years in West Rudolf (Robbins, 1972, 1979); the less common, impressed sherds are compatible with the 5450 B.P. age of the shell beds from which the bone was evidently eroded. Most of the sherds and some of the lithics are younger and derived from the surface above bed c. The human cranial and long bones are strongly fragmented, like the animal bone, suggesting possible cannibalism (J. De Heinzelin, pers. comm.). Whatever its ambiguities, Pelvic Corner documents a mammal butchery site along a sandy delta shoreline or barrier bar coeval with beach ridge B1.

Another site was found eroding out of the B2 ridge at P2. Here there are crescents, bladelets and blades in chert and chalcedony, together with rare sherds of fine, brown impressed pottery. No bone is preserved.

The limited Holocene archeological information from the Kibish Lake Plain serves to document barbed harpoon cultures from before 9100 (P5) to after 6600 B.P. (P13), and pottery since about 5500 B.P. Sites appear to be concentrated along stream banks or beach ridges, ideal locations for future archeological survey. So far there is no record of Nderit ware or domesticated animals, although the tribes encountered here during the 19th century were pastoralists with supplementary sorghum planting (see Butzer, 1971a, 132-139). However, aquatic cultures have survived around the Rudolf shores until recently, and Robbins (1979) reports a late site of 950 B.P. with barbed points, abundant fish, and rare domesticated sheep/goat near Eliye Springs. The implications are that several distinct cultural traditions, some with multiple subsistence options, characterized the past settlement record, much as they have recent ethnographic configurations.

THE PALEO-ENVIRONMENTAL ENSEMBLE

The Kibish Lake Plain formed an extension of Lake Rudolf during 6 of the last 10 millennia. Related landforms and surficial deposits remain largely intact over an area of almost 3000 km^2 north and northwest of the present lake. The resulting relict landscape is one of the more impressive examples of its kind.

During these high stands, Lake Rudolf expanded 60-100km north of its modern shores. The lake averaged about 75m deeper, whereas the known maximum depth today is 73m, so inferring a volume more than twice as great. Furthermore, this expanded lake stood 5m or more above the watershed level for brief periods, arguing for repeated seasonal overflow westwards into the poorly defined White Nile drainage.

Some 80 to 90% of the annual Rudolf influx now comes from the highlands of western Ethiopia via the Omo River (Butzer, 1971a, 37), and short-term 20th century lake fluctuations appear to respond primarily to the intensity and duration of the rainy season over the upper Omo catchment (Butzer, 1971a, Chap. 5). Nonetheless a rapid rise in lake levels during the early 1960s was synchronous throughout the Kenyan and Ethiopian rift system. The regional nature of major long-term climatic anomalies is demonstrated for the last 10 millennia by the same rift lake basins (Butzer, Isaac, Richardon and Washbourn-Kamau, 1972; Gasse, 1975; Butzer, 1978; Street, 1979). The lake level trace presented in Figure 10 consequently reflects the broad trends of Holocene climate in Kenya and Ethiopia. Based on the largest array of ^{14}C dates from any East African basin, and grounded both in study of regional geomorphology and of site-specific microstratigraphy, the essential outlines of this paleo-environmental trace are now reasonably well established.

Long-term positive hydrological trends or stable, wet anomalies are indicated for most of the period 10,000 to 7,000 B.P., again 6500 to 4000 B.P., and briefly about 3250 B.P., with conditions fluctuating around the modern mean 7000 to 6500 B.P., and again during the last 2500 years. Prior to 10,000 B.P. Lake Rudolf has no finite ^{14}C dates, arguing for low or intermediate levels during at least the last 30 millennia of the Pleistocene. This general impression is borne out by the development of arid, calcic coils and desert pavement during part of this time span. But earlier, undated evidence of humid soil development matches several indicators for wetter conditions in upland Ethiopia (Gasse, 1975; Butzer, 1978, 1979). Also, other East African lakes began to rise, fitfully, to intermediate levels, two millennia or so prior to 10,000 B.P. (Butzer et al., 1972; Degens and Hecky, 1974; Butzer, 1978).

Although some will be tempted to see a direct correlation between high latitude glacier fluctuations (Grove, 1979) and East African precipitation, such comparisons do not stand up well to detailed scrutiny. More significant is the rapid development of aquatic cultures in East Africa ca. 10,000 B.P. and their diffusion into the Nile Valley and the Sahara, where conditions were also wetter. Far-flung external contacts may also be reflected in the first appearance of pottery in the Rudolf Basin 8500 B.P. Despite ideal subsistence potentials, skeletal material from West Rudolf indicates an adult longevity of only 30 years, and porotic hyperostosis of the skull vaults suggests chronic anemia (Angel, Phenice, Robbins and Lynch, 1979). Since there is no schistosomiasis in Lake Rudolf, endemic malaria—today rare in West Rudolf but commonplace in the Omo Delta—must have been a major health hazard. Luxuriant vegetation grew along the now barren shores of the lake (Robbins, 1974). Rapid shrinkage and fragmentation of the aquatic resource base 7000 to 6500 B.P. did not eliminate the mixed fishing and hunting cultures, but the first pastoralists penetrated the area by 5000 B.P. and have competed with dwindling fisher populations ever since.

The Kibish Lake Plain illustrates an assemblage of relict landforms that record a different climatic equilibrium level in the Rudolf Basin between 10 and 3 millennia ago. Identical landforms developed then as are still actively forming now, except that base level was some 75 m higher. Today beach ridges and lake plains of early to mid-Holocene age dominate the landscape, with very little modification. A basic continuity of human utilization is similarly apparent, from 10 millennia until a few centuries ago, with the hydrological threshold of 2500 years ago also shifting the equilibrium "level" of prehistoric settlement in favor of pastoral economies. This essential continuity of historical and contemporary landscapes, in both the physical and cultural dimension, is not necessarily unique to the Kibish Lake Plain. But it serves to illustrate that geographical landscape analysis can rarely afford to be ahistorical.

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BIBLIOGRAPHY

Adamson, D., Clark, J. D. and Williams, M. A. J. (1974) Barbed bone points from Central Sudan and the age of the "Early Khartoum" tradition. *Nature*, 249, 120-123.

Angel, J. L., Phenice, T. W., Robbins, L. H. and Lynch, B. M. (1979) Late Stone Age fishermen of Lothagam, Kenya. *Michigan State University Museum Anthropol. Series*, 2(2), in press.

Arambourg, Camille (1943) *Mission scientifique de l'Omo 1932-1933. Mus. Nat. Hist. Naturelle, Paris*, Vol. 1(2), 61-230.

Barthelme, J. W. (1977) Holocene sites northeast of Lake Turkana: A preliminary report. *Azania*, Vol. 12, 33-41.

Brown, F. H. (1975) Barbed bone points from the Lower Omo Valley, Ethiopia. *Azania*, Vol. 10, 144-149.

Brown, F. H. and Nash, W. P. (1976) Radiometric dating and tuff mineralogy of Omo Group deposits. In Coppens et al., op. cit., 50-63.

Brown, F. H. and Shuey, R. T. (1976) Magnetostratigraphy of the Shungura and Usno formations, Lower Omo Valley, Ethiopia. In Coppens et al., op. cit., 64-78.

Butzer, K. W. (1971a) Recent history of an Ethiopian Delta. *Univ. Chicago Dept. of Geography Res. Paper*, 136, 1-184.

Butzer, K. W. (1971b) The Lower Omo Basin: Geology, fauna and hominids of the Plio-Pleistocene formations. *Naturwissenschaften*, Vol. 58, 7-16.

Butzer, K. W. (1972) Molluscan assemblages from the Late Cenozoic of the Lower Omo Basin, Ethiopia: Comments. *Quat. Res.*, Vol. 2, 591.

Butzer, K. W. (1976a) The Mursi, Nkalabong, and Kibish formations, Lower Omo Basin, Ethiopia. In Coppens, et al., op. cit., 12-23.

Butzer, K. W. (1976b) *Geomorphology from the Earth.* New York: Harper & Row.

Butzer, K. W. (1978) Climate patterns in an un-glaciated continent. *Geog. Mag.*, Vol. 51(3), 201-208.

Butzer, K. W. (1979) Pleistocene history of the Nile Valley in Egypt and Lower Nubia. In M. A. J. Williams and H. Faure, eds., *The Sahara and the Nile.* Rotterdam: Balkema, pp. 248-276.

Butzer, K. W., Brown, F. H. and Thurber, D. L. (1969) Horizontal sediments of the Lower Omo Valley: The Kibish Formation. *Quaternaria*, Vol. 11, 15-30.

Butzer, K. W., Isaac, G. L., Richardson, R. L. and Washbourn-Kamau, C. K. (1972) Radiocarbon dating of East African lake levels. *Science*, Vol. 175, 1069-1076.

Champion, A. M. (1937) Physiography of the region to the west and southwest of Lake Rudolf. *Geog. Jour.*, Vol. 89, 97-118.

Coppens, Y., Howell, F. C., Isaac, G. L. and Leakey, R. E. F., eds. (1976) *Earliest Man and Environments in the Lake Rudolf Basin.* Chicago: University of Chicago Press.

Damon, P. E., Ferguson, C. W., Long, A. and Wallick, E. I. (1974) Dendrochronologic calibration of the radiocarbon time scale. *American Antiquity*, Vol. 39, 350-366.

Degens, E. T. and Hecky, R. E. (1974) Paleoclimatic reconstruction of Late Pleistocene and Holocene based on biogenic sediments from the Black Sea and a tropical African lake. *Colloques Internationaux du C.N.R.S.* (Paris), No. 219, 13-24.

De Heinzelin, Jean (1962) Ishango. *Scient. Amer.*, Vol. 206, 105-118.

De Heinzelin, J., Haesaerts, J. P. and Howell, F. C. (1976) Plio-Pleistocene formations of the Lower Omo Basin with particular reference to the Shungura Formation. In Coppens et al., op. cit., 24-49.

Fuchs, V. E. (1939) The geological history of the Lake Rudolf Basin, Kenya Colony. *Phil. Trans. Roy. Soc. London*, Vol. 229B, 219-274.

Gasse, Françoise (1975) *L'évolution des lacs de l'Afar Central (Ethiopie et T.F.A.I.) du Plio-Pleistocene a l'Actuel.* Thèse, Université de Paris VI, 3 vol.

Gilbert, G. K. (1881) Contributions to the history of Lake Bonneville. *U.S. Geol. Surv. 2nd Ann. Rept. (1880-81)*, 167-200.

Grove, J. M. (1979) The glacial history of the Holocene. *Progress in Physical Geography*, Vol. 3, 1-54.

Höhnel, L. R. V., Rosiwal, A., Toula, F. and Suess, E. (1891) Beiträge zur geologischen Kentniss des östlichen Afrika. *Denkschr. k. Akad. Wiss. (Vienna), Math.-naturw. Kl.*, Vol. 58, 99-140.

Leakey, R. E. F., Butzer, K. W. and Day, M. H. (1969) Early *Homo sapiens* remains from the Omo River region of southwest Ethiopia. *Nature*, Vol. 222, 1132-1143.

Phillipson, D. W. (1977) Lowasera. *Azania*, Vol. 12, 1-32.

Robbins, L. H. (1972) Archeology in the Turkana District, Kenya. *Science*, Vol. 176, 359-366.

Robbins, L. H. (1974) The Lothagam site: A Late Stone Age fishing settlement in the Lake Rudolf Basin, Kenya. *Michigan State Univ. Museum Anthropol. Series*, Vol. 1(2), 149-216.

Robbins, L. H. (1979) Lopoy: A Late Stone Age fishing and pastoralist settlement west of Lake Turkana, Kenya. *Michigan State Univ. Museum Anthropol. Series*, Vol. 2(1), in press.

Roger, Jean (1943) Mollusques fossiles et subfossiles du Bassin du Lac Rodolphe. In C. Arambourg, op. cit., pp. 119-155.

Street, F. A. (1979) Chronology of Late Pleistocene and Holocene lake level fluctuations, Ziway-Shala Basin, Ethiopia. *Proceedings, VIII Pan African Congress of Prehistory and Quaternary Studies*, Nairobi, in press.

Van Damme, D. and Gautier, A. (1972) Molluscan assemblages from the Late Cenozoic of the Lower Omo Basin, Ethiopia, *Quat. Res.*, Vol. 2, 25-37.

Vondra, C. F. and Bowen, B. E. (1976) Plio-Pleistocene deposits and environments, East Rudolf, Kenya. In Coppens et al., op. cit., 79-93.

Vondra, C. F., Johnson, G. D., Bown, B. E. and Behrensmeyer, A. K. (1971) Preliminary stratigraphical studies of the East Rudolf Basin, Kenya. *Nature*, Vol. 231, 245-248.

Washbourn, C. K. (1971) Late Quaternary lakes in the Nakuru-Elementeita Basin, Kenya. *Geog. Jour.*, Vol. 137, 522-534.

Wendorf, F., Schild, R., Said, R., Haynes, C. V., Gautier, A., and Kobusiewicz, M. (1976) The prehistory of the Egyptian Sahara. *Science*, Vol. 193, 103-114.

Whitworth, T. (1965) Artifacts from Turkana, northern Kenya. *South African Arch. Bull.*, Vol. 20, 75-78.