We anticipate that the 'mantle plane' will be useful as an aid in understanding geochemical aspects of petrogenetic processes in different tectonic settings. As discussed above, specific conditions of mixing are required to generate magmas whose isotopic compositions lie on the plane. Where isotope ratios in volcanic products are observed to deviate significantly from the plane, constraints on the nature of magma generation processes and source materials can be inferred. For example, melting of metasomatically veined mantle may produce magmas with anomalous isotopic compositions. In addition, products of intra-crustal differentiation are not constrained by mantle isotope systematics and may have isotopic compositions which lie far

off the mantle plane. Where crustal materials are involved in igneous processes at volcanic arcs or sites of intra-continental volcanism, the isotopic compositions of resulting magmas are expected to lie off the plane.

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Palaeolimnology and archaeology of Holocene deposits north-east of Lake Turkana, Kenya

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Geological, diatom, pollen and archaeological studies, supported by 24 original radiocarbon dates, provide new evidence to illustrate the Holocene history of Lake Turkana, Kenya. High and intermediate lake levels are recorded between 10,000 and about 3,000 yr BP, with a general regression during the later Holocene. Archaeological finds document the transition from a fishing-based economy to pastoralism.

DURING the past 15 yr, considerable evidence has been presented to illustrate the Holocene limnological histories of many East African lakes[1-6]. Research has demonstrated several former periods when lake levels were higher than today, some of which were broadly synchronous in different basins, and which have generally been attributed to palaeoclimatic variations. We report here the principal results of a multidisciplinary study of the Holocene sediments of Lake Turkana, providing new evidence for lake level fluctuations, and for the palaeoclimatology, palaeoecology and archaeology of East Africa.

Lake Turkana, one of the oldest and largest African lakes (7,500 km², 125 m maximum depth), occupies a predominantly semi-arid basin of internal drainage at the northern end of the Kenya Rift (Fig. 1). Its waters, which are moderately saline and alkaline[7-10], are mostly derived from the Ethiopian Highlands, through the Omo River[11]. Like most non-outlet lakes, Turkana's waters have been subject to climatically-induced fluctuations in level and hydrochemistry of variable magnitude, frequency and duration[8,11,12].

Holocene lacustrine sediments lie around the margins of the lake, up to 80 m above the present (July 1976) lake surface (~375 m OD). Although sediments north of the lake have already been examined[13-16], Holocene deposits from the other shorelines have previously received little attention. North-east of the lake near Koobi Fora (Fig. 1), they are informally termed the 'Galana Boi beds'[17-21].

Geology and lithofacies of Galana Boi beds

The Galana Boi beds are a sequence of predominantly lacustrine and marginal lacustrine, poorly consolidated, diatomaceous silts and sands. They rest unconformably on Plio–Pleistocene sediments over an area of ~2,000 km². Where exposed, they are mostly <10 m thick, but attain an aggregate thickness of 32 m in Area 103 (Fig. 1). The deposits lie up to 80 m above the modern lake and are unaffected by tectonics, except locally near the Kokoi uplands (Fig. 1), where they have been uplifted.

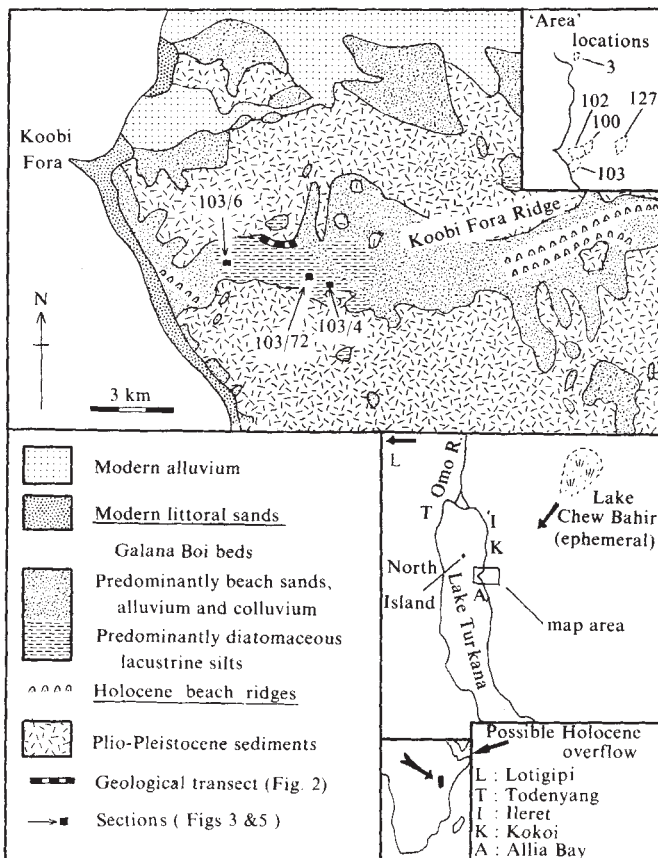Littoral sandy units crop out as discontinuous curvilinear

Fig. 1 Simplified geological map showing the distribution of the Galana Boi beds, east of Koobi Fora. Area numbers shown in the inset refer to fossil-collecting areas as designated by the Koobi Fora Research Project.

bodies parallel to former shorelines, while lacustrine silts have infilled palaeovalleys. Fluctuating lake levels during deposition have contributed to the development of lenticular and interdigitating sedimentary units, displaying vertical and lateral facies variations over short distances. Though commonly horizontal, primary depositional dips of up to 15° have developed where sediments drape over topographic highs.

Nearshore, moderate- to high-energy environments such as beach bars, barriers and sandy littoral shelves, are represented by a sublitharenite-quartz arenite lithofacies[10]. These heterogeneous sediments are typically well sorted (locally with distinct heavy mineral laminae) and although commonly massive due to bioturbation, many kinds of stratification are present. Typically they form linear bodies <2 m thick. Molluscs are common and include *Mutela emini*, *Etheria elliptica* and *Pila ovata*. Calcified root-tubules[22] and fish bones are locally numerous.

Distal alluvial and delta plain environments, and parts of shorelines adjacent to river mouths, are associated with a litharenite-arkosic arenite lithofacies[10]. This encompasses various sublithofacies that are moderately to poorly sorted. Stratification is generally poor and units are usually <2 m thick. $CaCO_3$ concretions, rhizoliths, root-marked palaeosols, molluscs, fish and other vertebrates are locally present.

Low energy lacustrine environments are represented by a diatomaceous silt, clay and fine sand lithofacies. The sediments are commonly well laminated (up to 1 cm), locally fissile and attain a maximum thickness of about 20 m. Diatom content ranges up to 10^8 individuals per g of sediment. Nitratine ($NaNO_3$) locally forms up to 8% of the deposits in Area 103. Molluscs are common and are dominated by *Melanoides tuberculata*, *Corbicula africana*, *Cleopatra pirothii* and *Bellamya unicolor*. Carbonaceous root-marks, calcite-cemented siltstone nodules, fish bones, pollen, sponge spicules and ostracods also occur.

There are three important biogenic lithofacies. In the first, *Etheria elliptica* forms reefs up to 4 m thick. Their relationship to other facies indicates a high-energy environment. In the second, *Melanoides tuberculata* and *Corbicula africana* variously dominate in silty sand units <10 cm thick. The degree of shell wear shows that both *in situ* and reworked assemblages are present. Third, a few outcrops of impure diatomite record former lagoons and areas of low clastic input.

Stratigraphy and chronology

Much of the data presented here originate in Areas 102 and 103 (Fig. 1). The stratigraphy of Area 102 is summarized by the transect in Fig. 2. The stratigraphies of Area 103 and other localities are shown in Fig. 3. Many new radiocarbon dates have been obtained[23] from the region and are listed in Table 1. The time-spans represented by the sections (Figs 2, 3) are shown in Fig. 4, together with a generalized plot of former lake levels against time. For descriptive purposes, three high level phases are recognized. These 'phases' do not represent continuously stable levels, but periods of varying duration in which the lake was high and fluctuating between +50 and +80 m.

Early Holocene sedimentation (phase 1): The diatomaceous silts of section C in Area 102 (Fig. 2) record a period of high lake levels (+75 to +80 m). They thicken to the east and south, and probably represent a large part of the early and middle Holocene. To the south-east, the basal units have been dated at 9,880±670 yr BP (ref. 24) (section 103/4, Fig. 3).

South of the Kokoi uplands (Fig. 1), dates of 9,540±260 and 9,260±235 yr BP have been obtained from molluscs in high level spits (uplifted to +95 m). In the same area, mammal bones from littoral deposits have yielded ages of 8,395±270 and 8,355±235 yr BP.

Shells from littoral sands (+70 to +80 m) near Ileret (Fig. 1) have been dated at 9,360±135 yr BP (ref. 17). Locally, these sands contain abundant stromatolites[10,25,26] (section 3/42, Fig. 3). In Area 127 (Fig. 1), subarkosic sands, silts, clays and impure diatomites represent former littoral and lagoonal environments. Shells from these deposits (+73 to +75 m) have yielded ages of 8,710±130 and 8,520±130 yr BP, while fish bone has given a date of 7,855±160 yr BP. Locally, these sediments are overlain by reefs of *Etheria elliptica* (section 127/52, Fig. 3), which have given erroneous modern ^{14}C ages.

The dates reported above show that phase 1 (Fig. 4) accords with the high lake levels widely recorded in East Africa[1-6] for the early Holocene (~10,000–7,500 yr BP).

Middle Holocene sedimentation (phase 2): Following the early Holocene lake maxima, Butzer[16] found evidence in the Omo region (Fig. 1) for a fall to modern levels at 6,600 yr BP. Although the diaton record from section103/72 (Fig. 5) does suggest a regression that could relate to such an event, we lack evidence for a drop of such magnitude. This regression (Fig. 4) was followed by the higher, fluctuating levels of phase 2.

Phase 2 littoral deposits lie at ~+70 m in Area 103 (5,060± 245 yr BP)[24] and +67 m, 5 km north-east of Koobi Fora (4,540±230 yr BP)[27]. Several dates (3,960±60, 3,945±135 and 4,100±125 yr BP) have been recorded from littoral sands at +45 to +47 m (GaJi 4, Fig. 2). These units overlie diatomaceous clayey silts and silts (with *Stephanodiscus* and *Melosira* dominated diatom floras, Fig. 2) that formed under an expanded lake whose shoreline (~+55 m) may be marked by the planar cross-stratified sands of section B (Fig. 2).

Phase 2 represents a middle Holocene period of high (up to ~+75 m) fluctuating lake levels. However, the later stages were characterized by lower elevations of ~+50 to +55 m (Fig. 4).

Late Holocene sedimentation (phase 3): Phase 3 (Fig. 4) is recorded by 6 m of white, highly diatomaceous, laminated silts (section 103/6, Fig. 3), 5 km south-east of Koobi Fora. The base of this sequence lies at ~+35 to +40 m. Its stratigraphical relationship to sediments dated further east indicates a late Holocene age. An interbedded white vitric tuff (8 cm thick) probably represents a contemporary ashfall into the former

Fig. 2 Geological transect and representative microfossil spectra from Area 102. The location of the transect is shown in Fig. 1. The three sections were accurately levelled relative to one another and then related to the height of the lake surface (in July 1976) by using a barometric altimeter.
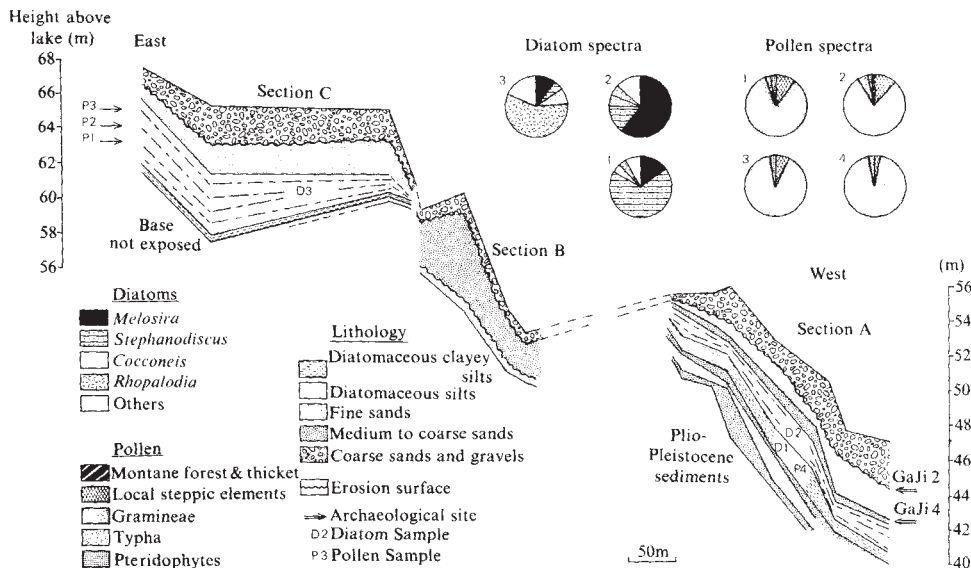
lake. One possible source may be the North Island volcano (Fig. 1), where trachytic lavas[28] overstep high-level, wave-cut platforms of probable early or middle Holocene age. An ill-defined series of beach ridges and regressive littoral sands record lower, fluctuating lake levels for the past two millennia.

Although the third phase remains to be dated radiometrically, it may be of broadly similar age to a late Holocene high stand recognized in the Omo region at 3,250 yr BP (ref. 14).

Other confirmed and probable Holocene lake sediments at +75 to +80 m have been reported from the southeastern[29], southwestern[30] and western[31-33] lake margins.
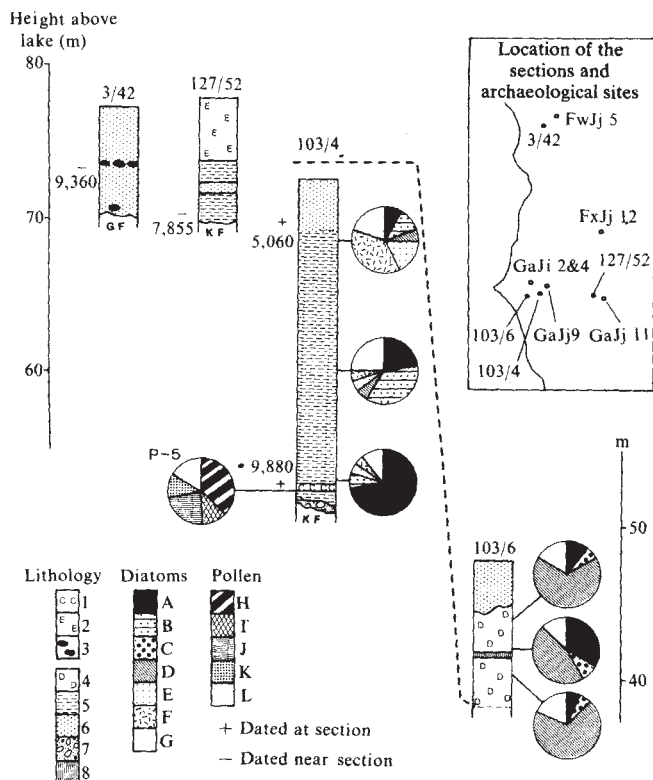

Fig. 3 Simplified litho- and microfossil stratigraphy of the Galana Boi beds. Lithologies: 1, coquina; 2, *Etheria* reef; 3, stromatolites; 4, impure diatomites; 5, diatomaceous silts; 6, sands; 7, orthoconglomerates; 8, tuff. The base of section 103/6 is not exposed. GF, Guomde Formation; KF, Koobi Fora Formation. Diatoms: *a, Melosira; b, Stephanodiscus; c, Cyclotella* and *Thalassiosira; d, Fragilaria; e, Cocconeis; f, Rhopalodia; g,* others. Pollen: *h,* montane forest and thicket; *i,* local steppic elements; *j,* Gramineae; *k,* Typha; *l,* Pteridophytes; *m,* others.

Diatom stratigraphy and lake palaeoecology

Figure 5 shows the diatom stratigraphy of section 103/72, which lies 9 km south-east of Koobi Fora (Fig. 1). Its base lies at ~+50 m and lateral tracing to locally dated units (section 103/4, Fig. 3) brackets it between ~9,880 and 5,060 yr BP (ref. 24).

Abundant planktonic diatoms in the lower 3.8 m of section 103/72, combined with a scarcity of benthic and epiphytic species, suggest a period of deep water and high lake level (phase 1). Lower levels are indicated by a dramatic decline in the planktonic species *Melosira agassizi* and *M. granulata-agassizi,* and by an increase in shallow water forms such as *Rhopalodia vermicularis* and *Cocconeis placentula.*

An increase in the planktonic component (dominated by *Stephanodiscus*) between 6 and 6.5 m reflects a second high level period, after which the lake was generally lower, but still covering the section site. Two, probably short-lived, transgressions can be inferred from increases in *Stephanodiscus minutula* (formerly *S. astraea v. minutula*) at 7.9 m and *Melosira nyassensis v. victoriae* at 7.2 m. At the top of the section, a decrease in diatom abundance, increasing grain size and littoral sands all indicate a fluctuating, regressing lake.

Although the basal silts of section 103/72 are certainly early Holocene, a lack of datable material at the top of the silts (10 m) has left the section open to two possible interpretations. First, the silts could be entirely of early Holocene age, the decline in *Melosira* at 3.8 m recording an early Holocene regression. This implies a very high average sedimentation rate of at least ~1 m 300 yr^{-1}, with even higher rates to the south and west where the silts thicken to ~20 m. Alternatively, the *Melosira* decline could reflect the fall in lake levels between phase 1 and phase 2 recorded elsewhere (Fig. 4). The subsequent transgression would then be of middle Holocene age, the record ending at ~5,000 yr BP. If the latter interpretation is correct, then the altimetric data, diatom stratigraphy and continuity of silt sedimentation would indicate that the lake did not fall below about +50 m for any extended period between ~10,000 and 5,000 yr BP.

The youngest diatomaceous units (phase 3 in Fig. 4; section 103/6 in Fig. 3) contain a flora dominated by *Fragilaria* spp. and *Melosira granulata,* but significantly include a few *Thalassiosira rudolfii* and *Cyclotella meneghiniana* for the first time. The latter diatoms occur in the modern saline, alkaline lake[10].

Ecological studies of modern East African diatoms[34-38] allow several inferences to be made concerning the former hydrochemistry. Today, Lake Turkana is saline (2.5 g l^{-1}) and alkaline (19-25 mequiv. l^{-1}) with a pH of ~9.2 and a SiO_2 concentration

of ~ 18 mg l^{-1} (refs 7–9). The early and middle Holocene diatoms imply alkalinities ($HCO_3^- + CO_3^{2-}$) of $\leqslant 10$ mequiv. l^{-1}, salinities below 2 g l^{-1}, a pH of ~ 7–8.5 and fluctuating SiO_2 concentrations of from ~ 1 to 10 mg l^{-1}.

Pollen of the Galana Boi beds

Figures 2 and 3 give the locations of five samples from which pollen was obtained. Sample P-5 is of early Holocene age, while the younger P-1 to P-4 material extends into the middle Holocene.

The oldest pollen spectrum was extracted from the base of a coquina dated at $9,880 \pm 670$ yr BP (section 103/4, Fig. 3). It is characterized by abundant regional elements—montane forest and thicket taxa (36.8%), which do not occur in modern lake samples[39]. The pollen grains were probably transported to the lake by rivers originating in the Ethiopian Highlands. They suggest both increased runoff and an extension of the

highland forests. This, together with a high percentage of *Pteridophytes* (14.7%), suggests increased rainfall over the catchment. Arboreal forms are uncommon (3.2%) among local elements, which are dominated by herbaceous types, notably *Gramineae* (21.2%) and *Compositae* (7.4%). The *Chenopodiaceae/Amaranthaceae*, which indicate saline soils, occur in low percentages (2.2%).

Samples P-1 to P-4 (sections A and C, Fig. 2) are younger and very different. They are dominated exclusively by taxa that typically inhabit lake margins in sub-desert zones[40]. Regional elements are absent or rare (0.4% in P-2) with only two taxa, *Juniperus* and *Myrica*, being represented. The occurrence of *Typha* and *Pteridophytes* in percentages >1% suggests the presence of rivers, although runoff was probably less than in the early Holocene. Local arboreal elements are rare (0.2–0.4%). Among local herbaceous forms, *Gramineae* are very abundant (77–99%). The *Chenopodiaceae/Amaranthaceae* again occur in low percentages (2.7% maximum). In two samples *Tribulus* constitutes 8.4–10.1% of the total pollen sum (P-2 and P-4, Fig. 2). This herbaceous taxon is today associated with refuse tips and is widely distributed in sub-desert zones[41]. Its occurrence may reflect the presence of local human encampments.

The early and middle Holocene lake margins were covered by a sub-desert steppe with well developed, herbaceous vegetation similar to that of today, although arboreal forms were more common at 9,880 yr BP. The poor representation of *Chenopodiaceae/Amaranthaceae* and the occurrence of *Typha* and *Pteridophytes* indicates the presence of freshwater rivers, supporting the other evidence for a lake less saline than today. The distribution of regional pollen suggests a more humid environment at 9,880 yr BP, but by the middle Holocene, climatic conditions had become more comparable with those of the present.

Archaeology

Two principal human economic adaptations are represented in the Holocene deposits. First, associated with early Holocene beaches, and continuing through into the middle Holocene deposits, are a distinctive set of lacustrine based occupations. Faunal refuse consists primarily of fish bones, while cultural materials include barbed bone harpoons and, at some sites, decorated and undecorated pottery. Seven large occupations are situated on the +75 to +80 m shoreline. Dates of $8,710 \pm 130$ yr BP (GaJi 11, Fig. 3) and $8,395 \pm 270$ yr BP (FxJj 12, Fig. 3) have been obtained from two of the sites. Importantly, ^{14}C ages of $9,540 \pm 260$ and $9,260 \pm 235$ yr BP were obtained from a basal *Melanoides* coquina at FxJj 12. This horizon contains a low density scatter of microlithic artefacts and fish-bone refuse. While the small excavation did not yield barbed bone harpoons, the lithic material indicates that by 9,500 yr BP, human groups with characteristic Later Stone Age lithic artefacts, were camping adjacent to the +75 to +80 m shoreline.

The lacustrine based sites exhibit broadly similar technological and economic features. The lithic assemblages are primarily composed of microlithic elements (especially crescents and curved backed blades), morphologically unstandardized scrapers, *outils écaillés* and core tools. Barbed bone harpoons, including uniserial, biserial and triserial examples, have been recovered. Two sites (FxJj 12 and GaJi 11) lack pottery remains suggesting a possible aceramic occupation phase. Decorated and undecorated pottery is represented at the remaining five shoreline sites. Numerous sherds similar to the well known 'wavy-line' pottery from the Sudan[42] are present at FxJj 12-North[43]. Fish remains, primarily several species of catfish and Nile Perch, constitute the major proportion of faunal refuse. Hippopotamus and crocodile, in addition to a wide variety of land mammals, are also represented. While freshwater molluscs, including such edible species as *Pila ovata* and *Etheria elliptica*, are commonly associated with the lacustrine sites, direct evidence for their consumption is lacking. Archaeological sites with similar lacus-
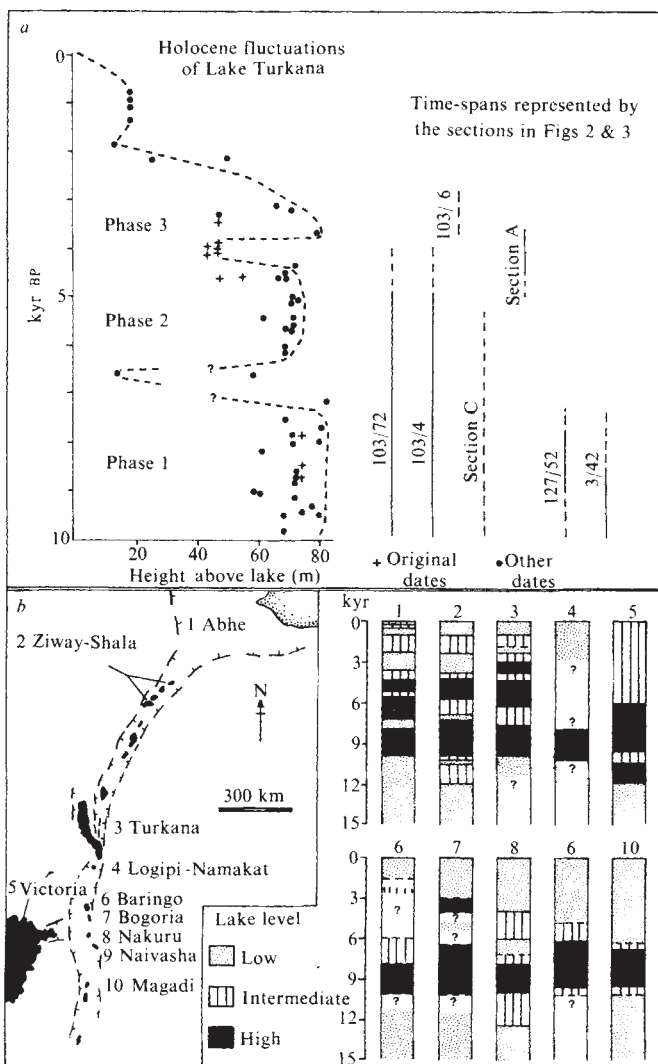

Fig. 4 Holocene fluctuations in the level of Lake Turkana and other East African lakes. *a*, The Holocene fluctuations of Lake Turkana, based on original (+) and previously published (●) dates (refs 16, 17, 24, 27, 29, 30, 47) from shoreline deposits of known height. Individual data points have not been joined together as this process can introduce a false sense of accuracy. The dates themselves commonly have error ranges of ±100–200 yr. Several dates from a single unit at the same level may give a wide variation. Dates from archaeological site GaJi 4 for example, range from 3,405 to 4,580 yr BP, with an exceptional date of 10,320 yr BP (probably from reworked material). As more dates become available so problems of scatter become apparent. For these reasons, we have traced only the general trends based on clusters of dates. *b*, Lake level trends for other East African lakes during the past 20,000 yr (includes original data for lakes Turkana, Baringo and Bogoria. Other sources: refs 1, 5, 49 and 56).

Fig. 5 Lithofacies, diatom stratigraphy and interpretation of section 103/72, north-east Turkana. The section site is shown in Fig. 1. Many species are present (96) but only the most impo tant are included. The first five are planktonic types, whereas the remainder tend to be associated with shallow waters in East Africa. The lake level interpretation is relevant to the section site only, the base of which lies at about +50 m (barometric determination). The minimum and maximum levels of the fluctuation curve are provided by the known height of the section and the overflow level of Lake Turkana respectively. Within these limits the curve is generalized from the diatom data.
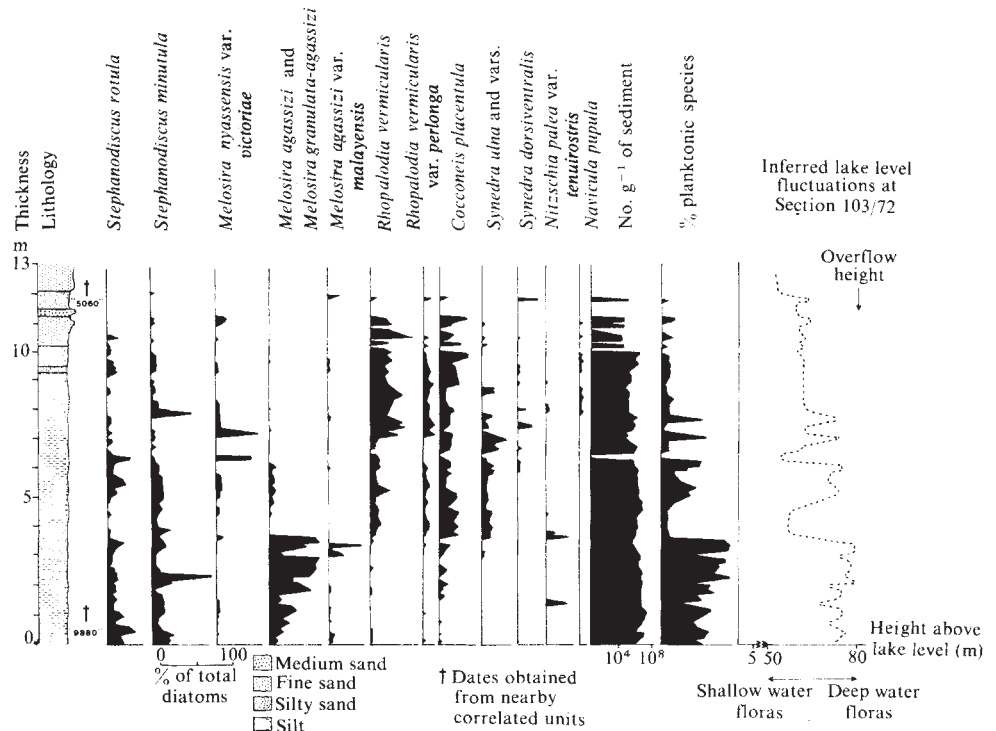
trine adaptation are known from the northern[16,44], southwestern[30] and southeastern[29] margins of the basin.

The second principal economic tradition, the Pastoral Neolithic, is associated with the second phase of high lake levels. Domestic stock, including ovicaprids and probably cattle, are present at sites GaJi 2 and GaJi 4 (Fig. 3). A suite of ^{14}C determinations (Table 1) date the occupations to ~4,000 yr BP. These dates currently represent, along with preliminary dating results from North Horr[45], the earliest securely dated evidence for domestic animals in Eastern Africa[46]. At two sites, anomalously old shell dates of 8,915 ± 140 yr BP and 10,320 ± 150 yr BP have been recorded. These probably represent reworked debris and in both cases are associated with suites of younger dates from various materials.

Both pastoralist settlements lie within middle Holocene beach sands at +43 to +47 m. Stone artefact assemblages consist of typical Later Stone Age microliths and debitage. Several distinctive pottery types, including Nderit Ware, are represented. While fishing continued to play an important subsistence role, barbed bone harpoons are absent. The early pastoralists had apparently devised an alternative, as yet unidentified fishing strategy. Faunal remains of wild animals are noticeably scarce. A third pastoralist settlement, the Ileret Stone Bowl Site, yielded a single ^{14}C date of 4,000 ± 140 yr BP. Domestic cattle and ovicaprids are present in apparent association with stone bowls.

While little archaeological material is associated with the third phase, recent fieldwork to the south-west[47] suggests that human groups were pursuing a combination of aquatic and pastoral economic adaptations.

Discussion

Late Pleistocene high-stands are recorded for several East African lakes[1-5]. None has yet been recognized at Lake Turkana for the period 35,000–10,000 yr BP. This may reflect either a continuously low status or the erosion of any high-lake sediments that were deposited.

Lake Turkana expanded during the early Holocene, periodically reaching +80 m. Contemporary local hunter–gatherer groups camped adjacent to its fluctuating shorelines and increased their reliance on fishing.

Sandy silts at Todenyang (Fig. 1) that dip below the modern lake surface, have yielded a single mixed shell date of 6,600 ±

150 yr BP (ref. 14), which indicates a fall to modern levels during the middle Holocene. Although we do not reject this possibility, our experience of shells in the Turkana basin has shown that they may be reworked with little damage and should be interpreted with caution. If valid, the date implies major desiccation of a large lake at a time when the great majority of intertropical African lakes were at high or intermediate status[2,48]. No evidence has been found for significant contemporary erosion of the unconsolidated sediments in area 103 which span this period. Similarly, evidence is lacking for a fall of such magnitude to the south-east of the lake[29]. While accepting a possible drop to intermediate levels at this time, we lack evidence to confirm a fall to modern levels.

During the remainder of the middle Holocene the lake was fresh and fluctuated between high and intermediate levels. The local vegetation was dominated by *Gramineae* and by 4,500 yr BP, human groups with domestic animals were present.

Lake Turkana contracted during the late Holocene and became significantly more alkaline. While we have evidence for a lake standing at about +50 m, we lack data to confirm the rise to +75 m at 3,250 yr BP suggested by Butzer[16]. The lake level oscillated below about +50 m after 3,000 yr BP (refs 16, 30) (Fig. 4).

The lake demonstrates hydrological variability both in time and space. Hydrodynamic variations and consequent differences in the nature of the surface level record around the lake, partly reflect the influence of prevailing easterly winds. High energy shorelines predominate to the west, whereas more mixed energy environments occur to the east. The diatom record suggests that many minor oscillations were superimposed on the major fluctuations. In addition, alternating light and dark laminae in silts may reflect a cyclic input of flood waters, similar to those from the modern Omo River.

The lake level fluctuations can be mostly attributed to variations in the water balance caused by climatic change. The lake may have increased its catchment for periods during the early and middle Holocene by receiving overflows from Lake Chew Bahir[49] (Fig. 1) and a former lake in the Suguta Valley to the south[50,51]. At its maximum level (+80 m), Lake Turkana overflowed into the Lotigipi Plain (Fig. 1) and thence to the River Nile[16,52].

The archaeological data may provide a geographical and chronological link between the early food-producing traditions

Table 1 Radiocarbon dates from Lake Turkana

Site	Lithology/ environment of dated unit	Material dated	Laboratory	Laboratory date no.	Date (yr BP)	Elevation of dated unit above lake level (m)
Fishing settlements						
GaJi 3	Beach sands	Bone apatite (M)	Geochron	Gx-5475-A	4,560±185	55–56
GaJi 11	*Etheria* reef	*Etheria* shell	Geochron	Gx-5477-A	Modern	75
GaJi 11	*Etheria* reef	*Etheria* shell	Helsinki	Hel-1275	Modern	75
GaJi 11	Sand bar	Shell	Helsinki	Hel-1276	8,520±130	73–75
GaJi 11	Sand bar	*Etheria* shell	Helsinki	Hel-1277	8,710±130	73–75
GaJi 11	Sand bar	Bone apatite (F)	Geochron	Gx-5476-A	7,855±160	73–75
FxJj 12	Sand spits	Shell	Geochron	Gx-5479	9,260±235	95 (uplifted)
FxJj 12	Sand spits	Shell	Radiocarbon Ltd.	R1-954	9,540±260	95 (uplifted)
FxJj 12	Sand spits	Bone apatite (M)	Geochron	Gx-5481-A	8,395±270	95 (uplifted)
FxJj 12	Sand spits	Bone apatite (M & F)	Geochron	Gx-5480-A	8,355±235	95 (uplifted)
FxJj 12-N	Beach sands	Bone apatite (H)	Geochron	Gx-4733-A	3,215±155	100 (uplifted)
Pastoral Neolithic						
GaJi 2	Beach sands	Charcoal	Un. Penn.	P-2609	3,970±60	43–46
GaJi 2	Beach sands	Charcoal	Un. Sydney	SUA-634	4,160±110	43–46
GaJi 2	Beach sands	Shell	Un. Sydney	SUA-635	8,915±140	43–46
GaJi 4	Beach sands	Charcoal	Un. Sydney	SUA-637	3,945±135	45–47
GaJi 4	Beach sands	Humic acid from SUA-637	Un. Sydney	SUA-637-B	4,100±125	45–47
GaJi 4	Beach sands	Charcoal	Un. Penn.	P-2610	3,960±60	45–47
GaJi 4	Beach sands	Bone apatite (M)	Geochron	Gx-4642-I-A	3,405±130	45–47
GaJi 4	Beach sands	Bone apatite (F)	Geochron	Gx-4642-II-A	4,580±170	45–47
GaJi 4	Beach sands	Shell	Un. Sydney	SUA-638	10,320±150	45–47
FwJj 5	Fluvial sands	Bone apatite (M)	Geochron	Gx-4643-A	4,000±140	–
Other sites						
Nderati	Sandy silts	Shell	Geochron	Gx-5478	13,040±640	–
GaJj 9	Burial site 1	Bone apatite (H)	Geochron	Gx-4641-A	Modern	–
GaJj 9	Burial site 2	Bone apatite (H)	Geochron	Gx-6400-A	3,125±210	–
Previously obtained dates						
Ileret*[17]	Sands	Shell	—	—	9,360±135	70–75?
Area 103*[24]	Coquina	Shell	—	—	9,880±670	52–55?
Area 103*[24]	Sandy silts	Shell	—	—	5,060±245	70–73?
Area 103*[24]	Silts	Charcoal	—	—	4,390±235	65–68?
Area 102*[27]	Beach sands	Shell	Un. Birm.	Birm-540	4,540±230	67

M, Mammal bone; F, fish bone; H, human bone; Un., university. Heights quoted are based on barometric determinations. Site locations shown in Figs 1 and 3. For consistency with previous research, all shell dates are recalibrated to give an age 400 yr younger than that obtained by ^{14}C assay (for explanation, see ref. 14). The Ileret date of 9,360 yr BP is quoted as published as we have not been able to confirm any recalibration.

* Reference number.

in the Sudan and later pastoralist occupations in the central Kenya Rift. The appearance of early pastoralism in the Turkana basin may have been the result of small-scale population movements caused by middle Holocene climatic deterioration in the Sahel and Savannah zones, or the diffusion of pastoralist tradition[4]. Ehret[53] indicated that the linguistic evidence supports an ancestral Southern Cushitic identity for these early pastoralists. While this evidence is being evaluated[54], the archaeological data from the Turkana basin seem to support the Cushitic model[23,30].

An alternative model for the beginnings of pastoralism in East Africa has been proposed by Nelson (ref. 55 and unpublished data). He has uncovered evidence of domestic cattle some 40 km to the south of Nairobi, reported to date between 14,000 and 15,000 yr BP. This date would require rewriting of the history of animal domestication worldwide. However, it is based on a single ^{14}C determination on bone apatite (from our experience, a sometimes unreliable dating material) and faunal elements studied only in preliminary form. While a challenge to other models of early domestication in East Africa, including that presented here, more ^{14}C dates and extensive comparative examination of the fauna are needed before the far reaching implications of Nelson's work can be accepted.

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Expression of murine H–2Kᵇ histocompatibility antigen in cells transformed with cloned *H–2* genes

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Cosmids containing H–2 *histocompatibility antigen genes of the* H–2ᵇ *haplotype have been isolated. One of these genes expresses a 45,000 molecular weight protein, indistinguishable from* H–2Kᵇ *when introduced into mouse L cells. These* H–2Kᵇ *transformed L cells can be killed by allospecific anti-*H–2Kᵇ *cytotoxic T cells. Moreover, when infected with influenza virus, they can be killed by an* H–2Kᵇ*-restricted, influenza virus–specific cytotoxic T cell line. These results show that expression of the* H–2Kᵇ *gene product on the L-cell surface is sufficient to make it a target for specific T-cell killing.*

CELL-surface glycoproteins encoded by the genes of the major histocompatibility complex (MHC), *H–2* in mouse, *HLA* in man, are important in regulating cell–cell interactions, especially those governing the functions of the immune system[1]. Class I molecules, of which the best characterized are encoded by genes on the H–2K, D and L regions (Fig. 1a) act as guides for presenting extrinsic antigen (for example viruses) to cytotoxic T cells, whilst class II molecules encoded by genes in the I–region perform a comparable function for T helper cells[1]. How extrinsic antigens are presented in association with self-MHC molecules is still very poorly understood, partly because the structure of the T-cell receptor is unknown. However the problem can be approached by study of MHC molecules themselves. Knowledge of the amino acid sequence and three-dimensional structure of these molecules has progressed very rapidly over the past few years (see, for example, ref. 2). The *H–2K* and *H–2D* gene products are highly polymorphic, which may reflect the importance of genetic variation of MHC molecules in overcoming virus infections. The mutation rate, particularly of class I H–2 molecules is extremely high[3] and of all of the *H–2* haplotypes studied, that of *H–2ᵇ* is the highest. Within this haplotype it is the *H–2Kᵇ* molecule which undergoes mutational change most frequently. Nathenson *et al.*[4] have determined the complete polypeptide sequence of the H–2Kᵇ molecule of C57BL/10 mice and have also determined portions of the sequence of several mutants[5] which express an altered H–2Kᵇ molecule. Information about the DNA coding for these molecules is thus of great interest, and may give insight into the mechanism of mutation and generation of new haplotypes.

Several groups have isolated cDNA[6,7] and genomic DNA clones[8–10] containing class I *H–2* or *H–2* related DNA sequences from BALB/c mice (*H–2ᵈ* haplotype). We have isolated ~100 different cosmid clones, containing sequences mapping to the *H–2* and associated regions (Fig. 1a) of chromosome

17 from a cosmid library constructed using spleen DNA from C57BL/10 mice (*H–2ᵇ* haplotype). A full description of the construction and screening of these libraries together with chromosomal mapping data for all the *H–2*-related cosmid clusters, will be given elsewhere. Here we describe a cluster of five overlapping cosmids (the H8 cluster) and show that one of the two *H–2* gene sequences cloned in this cluster encodes a cell-surface antigen which is recognised by *H–2Kᵇ* restricted T cells. It therefore appears identical to the *H–2Kᵇ* polypeptide found on cells derived from C57BL/10 mice.

Restriction map of the H8 cosmid cluster

The H8 cluster of cosmids consists of five overlapping cosmids containing two class I *H–2* related genes, approximately 15 kilobases (kb) apart, which hybridize to human genomic[11] and *H–2* cDNA class I gene probes[6] (Fig. 1b). The DNA cloned in this cluster spans about 65 (kb) of the C57BL/10 genome and the two *H–2* class I gene-related sequences are arranged in a head to tail configuration, as determined by hybridization to 5' and 3' probes obtained from the *HLA* or *H–2* probes. The left-hand gene (*H–2* genes are defined here as DNA sequences which hybridize to *HLA* and *H–2* class I probes) is present in cosmids H8, H25, H24 and H39 (A gene), whereas the right-hand gene sequence (B gene) is present only in H8 and H21. As polymorphic restriction site mapping of this cosmid cluster shows that the cloned region is derived from the *H–2K* (Fig. 1a) end of the *H–2* complex (manuscript in preparation), we investigated whether one (or both) of the two gene regions in the H8 cluster encoded an *H–2Kᵇ* cell-surface antigen. Thus, we have introduced each cosmid into mouse Ltk⁻ (of *H–2ᵏ* haplotype) cells using CaPO₄–mediated DNA transfer and tested the resulting tk⁺ clones for expression of new H–2ᵇ cell-surface antigens using (1) direct monoclonal and allo-antibody binding (2) antibody-dependent complement-mediated lysis and (3) alloreactive anti-H–2Kᵇ T-cell mediated lysis (CML) and (4) H–2Kᵇ-restricted virus specific T-cell killing.