Statement of Originality

This thesis is based on my own research work and personal field observations in East Africa and England. Acknowledgements are made in the text to the published sources on which I have drawn and to certain personal communications relevant to my investigations. I have not submitted the thesis for any qualification at any other university.

Celia Washbourn
19-12-67.

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INTRODUCTION

For more than 20 years, the sequence of lake level fluctuations in the Nakuru-Elmenteita basin of the Eastern Rift Valley, Kenya, has been taken as the basis of the Upper Pleistocene and Holocene chronology in East Africa. The climatic and geological units for this period were named after high lake shorelines in the basin.

The shorelines and lacustrine sediments in the Nakuru-Elmenteita basin were originally studied by L. S. B. Leakey and E. Nilsson in the years 1926-33. These investigators did a great deal of valuable work but their studies were inevitably hampered by the lack of accurate maps and height data and the difficulty of access to much of the area. It also appears (i) that the evidence of former lakes was perhaps too readily interpreted in terms of a sequence of climatic fluctuations which could be correlated with the fluctuations of East African glaciers and with the late-glacial and post-glacial climatic phases of Europe. (ii) That in working out some aspects of the chronology, too great reliance was placed on archaeological data and correlations at a stage when in fact understanding of the prehistoric industries of East Africa was still embryonic.

Since the 1930s there has been a tendency to accept the sequence of Gamblian, Makalian and Nakuran wet phases as adequately supported by the geological and geomorphological evidence in the Nakuru-Elmenteita basin, and as a valid basis for correlation with other parts of Africa.

In the late 1950s, criticisms began to be made of the earlier (pre-Gamblian) "pluvials" which had been recognized in East Africa, the Kageran, Kamasian and Kanjeran. The criticisms concerned (i) the desirability of basing a geological and stratigraphical sequence on essentially climatic units; (ii) the value of the evidence for moist conditions during the postulated Kageran, Kamasian and Kanjeran phases. It is now generally accepted that much of the evidence for these "pluvials" can be explained without invoking climatic change and that a geological sequence for this period (the Quaternary) in East Africa should be established which is based on conventional units.

There has however been no detailed re-appraisal of the evidence in the Nakuru-Elmenteita basin for the later (Gamblian, Makalian and Nakuran) wet phases. The authors of the criticisms of the earlier "pluvials" were unable to spend long in this area and restricted themselves to general comments on the value of the evidence. It has generally been accepted that in this closed basin the fluctuations of the lakes have been uninterrupted by major volcanic or tectonic events since before the Upper Pleistocene and thus provide a good index of the changes of climate that have taken place. It has also been believed that the lake did actually fluctuate as has been described, with major peaks at about 510', 375' and 145' above the present level of Lake Nakuru. However since the original research was done by Leakey and Nilsson, there has been no detailed re-examination of the geological and geomorphological evidence for high lake levels in this basin.

It seemed that at this stage, with (i) increasing doubt being thrown on the theoretical basis of East African Quaternary geological chronology; (ii) the availability of air photographs and greatly improved maps of the Nakuru-Elmenteita basin, and (iii) the possibility of finding samples for carbon-14 dating, it was worth while making a re-examination of this evidence. As a geographer, I have been particularly concerned with geomorphological aspects of the evidence for the high lake levels; the shoreline cliffs, surface accumulations of beach pebbles, anomalies of drainage patterns, etc. It has been necessary to include some investigation of the lake sediments, in particular of their relationship to the shorelines. I have concentrated on describing and mapping the various shoreline features and shallow-water sediments, and on measuring their altitudes precisely. I have been able to draw on the results of recent purely geological research that has been done in the Nakuru-Elmenteita basin. Neither in the shorelines or the sediments can evidence of a distinct, climatically-controlled, three-fold fluctuation of the lake be distinguished, and it appears that the accepted picture of Upper Pleistocene and Holocene conditions in this area needs revision in the light of these results.

CHAPTER ONE

THE REGIONAL SETTING: THE NAKURU-ELMENTEITA BASIN

The Nakuru-Elmenteita lake basin lies just south of the Equator at almost the highest part of the Eastern Rift Valley, Kenya. Its location in East Africa and the topography and drainage of the basin and catchment area are shown on maps 1, 2 and 3. The surface of Lake Nakuru is at about 5780' S.D., of Lake Elmenteita at about 5830' S.D.;[1,2] along the main line of the Rift only Lake Naivasha to the south, at about 6200', is higher. The basin is closed to the south by Eburu, a dissected volcanic massif rising to about 9365', and to the north by the volcano Menengai (highest point about 7475'). The lowest part of the basin rim is the Bahati plain to the north-east, where overflow into Menengai caldera could take place at about 6390' S.D., not, as Leakey (1931a and b) and Nilsson (1931) believed, the Gilgil divide at about 6600'. The sides of the basin are defined by the Rift Valley scarps, Mau escarpment to the west and the Bahati-Mbaruk-Gilgil scarps to the east; on either side there are a number of

1. From information given me by the Water Development Department in Nakuru, Level of Lake Nakuru on 16th March 1966 = 5779,10' S.D. and Level of Lake Elmenteita 5829,41' S.D.
2. The use of the abbreviations S.D. and R.D. to indicate Survey of Kenya datum and East African Railways and Harbours datum respectively is explained in Appendix A.

steps at different levels from the crest of the escarpment to the valley floor. There is also much evidence of recent small-scale faulting in the basin, such as the fragmented topography west of Lake Nakuru, the ridge of Lion Hill and the faults cutting the small volcanoes south of Lake Elmenteita. The pattern of faulting, though locally variable, shows a broadly north-south trend.

None of the volcanoes in this area are at present active, but there is evidence of several phases of recent volcanic activity continuing probably until the last few hundred years. There are almost unvegetated lava flows and small fresh-looking ash cones within Menengai caldera, and a young lava flow has spilled down the outer slope of the caldera on its southern side and across the Menengai shoreline cliff (Map 4). The youngest volcanoes in the south of the basin seem to be Cedar Hill on Eburu and a cone just north of the former Eburu station. Hydrothermal activity continues in Menengai caldera and near Eburu station, in particular on the slope known as 'Steamjet Hill'. These steamjets are mentioned by Thomson (1885) and Gregory counted them and drew a plan (1921 p. 117). Condensers have been fitted to some of them to provide water for stock. (Photograph in Thompson and Dodson (1963 p. 38).)

In 1928 there was an earthquake of catastrophic magnitude with epicentre at Subukia, about 25 miles north of the Nakuru-Elmenteita basin, and newspaper reports of earth tremors in the Nakuru and Naivasha areas are not infrequent. (File G44, Department of Mines and Geology, East African Standard reports of earth tremors, 4th April 1951, 14th July 1960, 7th May 1964.) Temperley (1966 p. 28) suggested that the 20 mile long, 12' deep fissure which formed near the base of the Laikipia escarpment during the 1928 earthquake can be considered as an increase in the height of the escarpment there and a continuation of the Rift Valley formation processes. At any rate it is clear that even now this area is far from being tectonically stable, and that volcanic and tectonic porcesses have been active in the very recent geological past.

The scenery in the basin is very varied. Lake Nakuru is bounded on its east and west sides by faulted zones with steep rocky scarps, thickly forested. On the east and west shores of Lake Elmenteita the faults are not so clear, and the slopes to that lake are not so steep. Between the lakes, and across much of the central part of the basin, is a gently sloping area with no marked relief; this stretches south of Lake Nakuru up to the lower slopes of Eburu, and north-east of the lake onto the Bahati plain. It is broken in the north by some eroded volcanic cones, Honeymoon and Crescent Hill, and by some small ridges of volcanic rock defined by faults (Hyrax Hill and others). To the south of Lake Elmenteita lies the area known as the Badlands, with recent volcanic cones and lava flows. These were studied in some detail by McCall who concluded that there had been three stages of volcanic activity, of which the oldest was contemporaneous with the Kariandusi diatomites and tuffs. Some of the more recent lava flows and cones post-date some of the Upper Pleistocene lake sediments, and the possible disruptive effect of this recent activity on a simple relationship of climate and lake level cannot be ignored.

The rocks exposed in the basin include a number of lavas and volcanic tuffs and pumice beds, as well as the sediments of lacustrine origin. Particularly striking are the white and pale grey diatomites and diatomaceous silts which are typical of this area and of the Pleistocene lacustrine sedimentation in the Rift Valley. The superficial deposits and soils vary considerably within the basin. In the north recent ash and pumice from Menengai covers much of the land and the soils tend to be immature and show compound profiles, where soil formation was interrupted by the superimposition of a further layer of volcanic material. Light grey dusty soils on the flat central area (e.g. at Soysambu and Elmenteita) have developed on the diatomaceous silts of this part. The lower slopes of Eburu are covered with coarse reddish-orange silts which seem to have been formed by the weathering of older volcanic material, pumice and tuffs. Over much of the basin, especially on the steeper slopes and fault scarps, the bedrock is close to the surface with lava and tuff slabs and boulders outcropping and there is no true soil. Rocky screes have developed at the foot of some of the fault scarps, e.g. on the west side of lake Nakuru.

The vegetation and land use of the area ranges from the forests of Eburu and the Mau escarpment to the open grassland scattered with thorntrees and used for cattle ranching (on the central lowlands) and the more intensive (mostly wheat and maize) farms of the Bahati plain and near Nakuru town. Access to most of the basin is relatively easy; there are few parts, except in the west and south-west, which are not within reasonable walking distance of a track suitable for a Land-Rover. Although, as is discussed below, the actual shoreline features and breaks of slope are not easy to find, there are a reasonable number of good sediment exposures, in quarries, silage pits, river sections and road and railway cuttings, so that evidence of the nature and distribution of sediments is not too hard to find.

The basin is crossed by a number of streams, draining towards Lakes Nakuru and Elmenteita; most of their water does not reach the lakes by surface flow, but passes underground to the water bodies underlying the lakes. These streams are:

To Lake Nakuru: Ngosur, Nderit, Makalia, Njoro, Lamuriak.

To Lake Elmenteita: Meroroni, Mbaruk, Kariandusi, Kekopey.

The catchment area of the basin is relatively small, limited on the north and south by the mountains Eburu and Menengai. On the east side, most of the drainage from Ol Kalou and Kinangop is to the Naivasha basin via the Gilgil and other rivers. The Nakuru-Elmenteita basin catchment extends furthest to the south-west, on the slopes of Mau forest, where the head waters of the rivers Makalia and Nderit extend for several miles at over 9000' altitude. Even these streams, however, tend to be dry along much of their lengths towards the end of the dry season in February and March. The Kariandusi river, which gets part of its water supply from a hot spring, has perhaps the most regular flow of the Nakuru-Elmenteita basin streams. In the north of the area a small stream, Crater stream, flows into Menengai caldera on the east side; although this stream carries water for much of the year, the water is lost underground beneath the broken lava surface of the caldera floor and there is very rarely any standing water in the caldera. The caldera would appear to have a considerable capacity to absorb water. It seems probable that a fair amount of water could be supplied to the caldera by overflow from the Nakuru-Elmenteita basin without causing more than locally swampy conditions on its floor.

Climatic records have been kept for several stations within the basin and around it, in some cases for over 30 years. The higher land bordering the basin receives a fair amount of rainfall, averaging 40" a year and more on the Mau escarpment and up towards Bahati forest. The amount drops off rapidly towards the lower land, in particular around Lake Elmenteita (average about 20-25" p.a.) and it is common to see rain storms over the higher land and the foothills while the central parts of the basin remain dry. The amount and season of the rainfall also appears to be very variable from year to year. Past and present climatic conditions in the basin are discussed in more detail in Chapter 7.

Lakes Nakuru and Elmenteita are shallow and highly alkaline. According to the soundings carried out by Leakey in 1929, Lake Nakuru was everywhere less than 10' deep, and the depth of Lake Elmenteita never exceeded 6' 3". There was a general fall in lake levels from the early years of this century to about 1960; for some years in the 1950's both lakes were reduced to a few small puddles on a saline crust. They rose sharply after the heavy rains in 1961-2. Since then the lakes have fallen slightly, but are still at a relatively high level for this century. It appears that at present they contain no fish and no mollusca, although they do contain an algal flora, including diatoms. These provide the food for the flamingoes which live on the lake shores. Lake Nakuru also supports a small population of hippopotamuses in a pool at its north-east corner. The present appearance of the lakes is a clear indication of their 'relict' character as the dwindled remnants of a much larger body of water.

From the middle Pleistocene to the present the Nakuru-Elmenteita basin appears to have provided a very favourable environment for human settlement. There are a number of rich archaeological sites: Kariandusi, Gamble's Cave and Hyrax Hill are preserved as museums by the Museum Trustees of Kenya, and recent excavations have been carried out at an important site on Prospect Farm. Much of the research which has contributed to our knowledge of the former extent of the lakes in the basin has been done in connection with archaeological investigations. The archaeology of the sites in the basin is discussed in Appendix C.

CHAPTER TWO

GENERAL SUMMARY OF PREVIOUS WORK IN THE NAKURU-ELMENTEITA BASIN

The Nakuru-Elmenteita basin is shown on maps 2 and 3. The first European to visit the basin seems to have been Joseph Thomson, who went through the area and into Baringo in 1883. He described the landscape briefly and mentioned Lakes "Elmeteita and Nakuro". (Thomson 1885 p. 340)

Important early work on East African geology was done by J. W. Gregory, starting in 1892-93. From the time of his first visit to the Rift Valley he noticed evidence of a former larger extent of the lakes and believed that these lakes had existed contemporaneous with the former larger glaciers on Mount Kenya, of which he had seen the moraines. (Gregory 1894 p. 521) In his second major work (1921) he described lake sediments from several parts of the Rift Valley and fitted them into the geological sequence which he established for East Africa. He suggested that there had been at least two important periods of lacustrine sedimentation in the Rift Valley, separated by a major episode of faulting and vulcanicity. The earlier of these, the "Nyasan series", which he believed to be of lower Miocene age, included the Kamasia beds in the Baringo basin, the Kariandusi sediments in the Nakuru-Elmenteita basin, and sediments exposed in the Njorowa gorge south of Lake Naivasha. These were said to have been laid down in larger lakes within a rift valley, the Baringo basin sediments in "Lake Kamasia", and the Njorowa gorge sediments "either in the southern part of Lake Kamasia or in a contemporary independent lake" (1921 p. 199). These lake sediments were faulted by major rift valley faulting and overrun by lava flows during the succeeding "Laikipian" (Miocene) and "Naivashan" (Pliocene) periods. A later period of high lake levels was suggested: "The Lower Pleistocene was characterised by the climatic change which increased the rainfall and led to the great development of the glaciers of Kenya and Kilima Njaro, and to the great extension of the lakes, such as the greater Baringo, the greater Naivasha, and to the formation of Lake Suess, a former lake which once covered the plains around Suswa and Longonot" (1921 p. 207). Gregory established the idea that there had been two main periods of large lakes in the Rift Valley, separated by a period of great faulting and much vulcanicity. Although the dating of his sediments was soon revised, and they were found to be considerably younger than he had thought, the idea of a major break between two main periods of lake sedimentation in the Nakuru-Elmenteita basin has remained current until the last few years and is still accepted by some.

Early travellers in East Africa also noticed features which seemed to suggest more recent climatic change; Thomson in his visit to the Nakuru-Elmenteita basin in 1883 saw many dead trees on the plain north of Eburu, "probably the strange effect is due either to a change of temperature or alteration of the rainfall" (1885 p. 347), while Gregory said of Lake Elmenteita "its level is being lowered by evaporation, and it is now much smaller than it once was" (1896 p. 108).

The work of E. J. Wayland in Uganda from 1919 onwards (e.g. Wayland 1934), although not directly concerned with events in the Eastern Rift and the Nakuru-Elmenteita basin, is of significance in containing the most explicit and important early statements of the "pluvial" hypothesis. This idea of a series of wetter and drier climatic phases during the Pleistocene in East Africa which could be correlated with the European glacial and post-glacial events, was to influence studies in East African Quaternary geology for the next 30 years, not always beneficially. Wayland worked for a short time in the Nakuru-Elmenteita basin during the first season of the East African Archaeological Expedition in 1926 and his advice may well have encouraged the interpretation of the evidence in this area according to the pluvial theory.

The work of the East African Archaeological Expedition, which began in 1926 under the leadership of L. S. B. Leakey, included studies of the sediments and shorelines of the former lakes of the Nakuru-Elmenteita and Naivasha basins as well as archaeological investigations. Even in the earliest brief accounts of the work of the expedition (in The Times 1928,29 and Nature 1929) the high-level shorelines were seen as evidence of climatic fluctuations which might be correlated with fluctuations in Europe. A note of caution was sounded by Wayland "the correlation of Kenya pluvials with definite periods of the Pleistocene, as recently set forth, is purely hypothetical" (Wayland 1929 p. 607). Despite this expressed caution, the correlations, summarized briefly below, were given with very little reservation in Leakey 1931b; the climatic sequence in East Africa was worked out by Leakey and Solomon (p. 12 and Appendix A in that volume) and the correlations with Europe were discussed by C. E. P. Brooks (Appendix B).

Shorelines and climatic fluctuations in the Nakuru and Naivasha basins correlated with those in Europe.

(Leakey 1931b pp. 245 and 270)

5. Nakuran post-pluvial wet phase - equivalent to Sub-Atlantic in Europe. Lake Nakuru at 145'A.L. No shoreline mentioned for Lake Naivasha except the possible 'Neolithic' 50' beach described by Gregory (1921 p. 220).

   Dry period - equivalent to Sub-Boreal in Europe.

4. Makalian post-pluvial wet phase - equivalent to Bühl Stadium in Europe. Lake Nakuru at 375'A.L., Lake Naivasha at 100'A.L.

   Dry period - equivalent to Achen oscillation, Gothiglacial retreat.

3. Upper Gamblian pluvial[1] - equivalent to Würm glaciation. Lake Nakuru at 510'A.L., Lake Naivasha at 180'A.L.

   Pause - Lake Nakuru at circa 600'A.L. (Riss-Würm interglacial).

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1. In Leakey's more recent terminology the whole of the Gamblian pluvial has been correlated with the Würm glaciation, the pluvial before it (now known as the Kanjeran) with the Riss glaciation.

2. Lower Gamblian pluvial - equivalent to Riss glaciation.

   Lake Nakuru at 775'A.L., Lake Naivasha at 380'A.L.

   Dry period, volcanic activity, rift valley faulting.

   (Mindel-Riss interglacial)

1. Kamasian pluvial - equivalent to Mindel and Günz glaciations.

At first Leakey and Solomon accepted Gregory's correlation of the Baringo, Kariandusi and Njorowa gorge sediments as lake sediments of the Kamasian pluvial. They said: "The Kamasian beds were not laid down in lake basins with a similar configuration to those of today, but rather in one enormous lake which stretched in any case from Baringo to the Kedong Valley, and probably still farther" (1931b p. 246). Then Acheulian implements were found in these beds at Kariandusi and the Miocene age suggested by Gregory was rejected in favour of a Lower Pleistocene date, at least for the upper part of these beds. After the last major faulting of the Rift Valley were believed to follow the Gamblian and later pluvial episodes, "from the beginning of the second part of the Pleistocene" (1931a p. 501), whose deposits were said to be unfaulted (1931b p. 246). Further evidence for this break in sedimentation was put forward by Leakey in 1936 (pp. 49-50). He found hand-axe industries, apparently slightly younger than those of Kariandusi, in what he described as 'old swamp beds' on top of the Kinangop plateau. These he believed to indicate the last stages in the drying up of the great Kamasian lakes and to be approximately equivalent to the lake sediments at Kariandusi, 2000' lower. Faulting of this order, i.e. the last major faulting of the Rift Valley, was believed to post-date the deposition of these Kamasian beds. In a diagram (1936 p. 50) Leakey showed a section across this part of the Rift Valley and the supposed great height range of the Kamasian deposits from the floor of the Rift Valley up onto the Kinangop plateau.

At a later stage (1950 pp. 62-3) Leakey slightly altered his sequence by splitting the Kamasian pluvial into two; the Kariandusi sediments were correlated with sediments at Kanjera on Lake Victoria which contained rather similar Acheulian implements and put into the "Kanjeran" pluvial. The revised sequence is shown below:

Post-pluvial wet phases - Makalian and Nakuran.

4th Pluvial - Gamblian (3 peaks separated by recessions)

3rd Pluvial - Kanjeran (2 peaks separated by a recession)

2nd Pluvial - Kamasian

1st Pluvial - Kageran.

The most recent expression of Leakey's opinion on the climatic sequence in East Africa is to be found in Chapter

VII of his volume on Olduvai Gorge 1951-61 (published 1965). In this he was concerned with the earlier climatic fluctuations rather than the most recent ones which have been traced in the Nakuru-Elmenteita basin. He referred very briefly to the Makalian and Nakuran phases, and in a little more detail to the Gamblian pluvial: "there can be no doubt that there was a pluvial period during the Upper Pleistocene. This has been termed the Gamblian" (p. 84). He repeated the old opinion on the break between the Kanjeran and Gamblian pluvials: "There is considerable evidence that towards the close of the Middle Pleistocene, at the end of the Kanjeran pluvial, there were major tectonic movements resulting in faulting and warping on a big scale" (p. 83). Although Leakey mentioned the danger of using the climatic episodes as stratigraphic units, and the care with which correlations between climatic changes in different parts of Africa should be made, his opinions on the reality of all the pluvials and the soundness of the geological evidence which has been cited for them show little sign of having changed. The Olduvai sequence was interpreted in terms of pluvial-interpluvial fluctuations, and the greater part of the chapter was in fact a summary of the evidence for the Kageran, Kamasian and Kanjeran pluvials on which Cooke (1957) and Flint (1959) among others have thrown so much doubt.

Erik Nilsson spent two seasons in East Africa, 1927-8 and 1932-3; during the first of these he worked for some time at Leakey's East African Archaeological Expedition camp near Elmenteita. From the results of this fieldwork he wrote a number of papers; the most important are probably those in Geografiska Annaler of 1931 and 1940, and his most recent paper in Stockholm Contributions in Geology, 1963. His work can perhaps be best considered in four parts - (i) the shoreline features (ii) the sediment sections (iii) the glaciers and moraines (iv) the climatic sequences and correlations.

(i) Nilsson spent much time looking for evidence of former higher lakes in the Nakuru-Elmenteita and Naivasha basins (also in the Baringo-Hannington and Ethiopian lake basins). In his 1931 and 1940 papers he listed a great number of shoreline features (mostly 'cut terraces', i.e. small concave breaks of slope) at heights of up to over 800' above the present level of Lake Nakuru. In 1931 (pp. 342-3) he listed 57 shoreline features in the Nakuru basin; in 1940 (pp. 75-7) he listed about 140. The 1940 shoreline heights are summarized in my figure 4, from which some comparison can be made with the results of Leakey's and my levelling. In most cases there is little grouping of Nilsson's shoreline fragments at heights where Leakey or I have identified lake shorelines. The only map of the shorelines that he gave is at a scale of about 1 to 0·4 million, and the list of shorelines gives only imprecise locations such as "5km SW of Elmenteita". Later research workers in this area (including myself) have failed to find more than a small fraction of the features that Nilsson identified as shorelines.

In some cases I have succeeded in identifying features which seem to correspond with those described and located by Nilsson; where I have levelled the heights of these I often found Nilsson's height figures to be quite close to mine. Of course it is not possible to be sure that even if I referred to the same feature as Nilsson, I levelled to the same part of it.

Flint suggested that the tilting of the shorelines shown by Nilsson "might result from some systematic instrumental error". (Flint 1959a p. 355) I find this rather hard to follow, since Nilsson probably did his levelling from a number of different points along the railway, which at that time ran right through the centre of the Nakuru-Elmenteita basin, and the length of the lines of levelling to the shoreline features (to which a systematic instrumental error should be proportional) would not increase from one end of the basin to the other. I would think that the tilting obtained could be a result of the great number of supposed shorelines identified by Nilsson. These were put in groups according to height, each group spanning a considerable height range and some overlapping with the groups above and below (see the list, from Nilsson 1931 pp. 342-3):

Nakuru basin shorelines, Nilsson 1931

Lake No.		Shoreline fragments		Height above Lake Nakuru
I	(later B)	12	between	634-877'
II	C	5		634-690'
III	D	11		358-601'
IV	E	11		332-443'
V	F	11		243-358'
VI	G	5		164-177'
VII		1	at	43'

I suggest that the pattern of tilting shown by Nilsson might appear by chance from this haphazard collection of many features at different heights. It should be noted that the tilting described by Nilsson is not along one axis only, nor does the amount of tilt of the shorelines decrease steadily from the oldest to the youngest. (The tilting is shown in many diagrams, e.g. 1931 pp. 300, 301; 1963 p. 35.)

I concluded that it was of little use to spend much time analysing Nilsson's complex tilting sequence. It may be adequate as a mathematical scheme to explain his data but the validity of the data, the identification and grouping of the shorelines, is doubtful and impossible to check.

Criticism of this aspect of Nilsson's work has been expressed by a number of other people. Solomon, who had spent some time working on these shorelines himself, said: "The writer has never been able to follow Dr Nilsson's work on the ancient beaches around these lakes; their identification has always seemed to him to be speculative and of doubtful validity" (in O'Brien 1939 p. 41). Kent gave a brief account of Nilsson's work and considered that "the levels of shorelines shown in Nilsson's diagrams (1940 figs. 18 and 19) appear capable of correlation in many ways other than that shown, and do not seem clearly to establish evidence of tilting" (Kent 1942 p. 736). He also suggested that the correlation of climatic fluctuations from Kenya to Ethiopian and the Faiyum which Nilsson had put forward should be based on something more than just number and intensity of wet periods, for example archaeological or palaeontological evidence. According to E. S. Deevey (in Shapley 1953), in the Nakuru-Elmenteita and Naivasha basins "Neither the stratigraphic nor the geomorphic evidence is notably enriched by Nilsson's confusing account . . . Nilsson's descriptions inspire no confidence that the features measured are really strand lines, let alone that they can be correlated from one transect to the next" (p. 299).

(ii) Nilsson described sediment sections from both the Nakuru-Elmenteita and Naivasha basins and attempted to attribute particular layers of sediment to lakes at particular levels. These correlations, based on the sequences of lake deposits and discontinuities within the sections, and on the altitudes of the various sediments, are not very firmly based. Nilsson did not describe sequences where a pebble-sand-lake silt exposure occurs below the actual shoreline notch, which seems to be the best evidence to connect a sediment and an actual shoreline level. In particular, Nilsson concentrated on the complex river sections, such as Nderit drift and the Melawa river, attempting to interpret them in terms of his sequence of lake level fluctuations. Although I have not myself studied these sections in detail, it is clear that more work needs to be done on them, and I feel that it is very risky at this stage to try to interpret them entirely in terms of a basin-wide chronology. Some of the sediments in these valleys may represent relatively short and local phases of deposition within that valley, and not have a real equivalent in the rest of the basin; thus an interpretation of the sequence in the valley may be difficult to verify from evidence from other areas in the basin.

(iii) The glaciers; Nilsson described moraines of various ages, resulting from a number of different periods of larger glaciers, on mounts Elgon, Kilimanjaro, Kenya and Ruwenzori in East Africa, and mounts Simien and Kaka in Ethiopia. I have not myself examined any of these moraines and therefore cannot make a personal evaluation of Nilsson's work on them. From some of the comments of people who have worked on these mountains it would seem that Nilsson's work on the moraines is perhaps more accurate and easier to substantiate than his work on the shorelines of the Nakuru-Elmenteita basin. Osmaston (1965 and pers. comm.) was able to use some of Nilsson's data in compiling a table of the stages in the glaciation of the East African and Ethiopian mountains, and confirmed Nilsson's belief in a good correlation between the glacial stages on the various mountains. (Table 6.11 in Osmaston's thesis, 1965.) Mohr (1963) discussed conflicting opinions on the glaciation of the Simien mountains and suggested that, "Considering the extent of the glaciations on the peaks of East Africa, and making allowances for the lower elevation and higher latitude of Simien, the estimates of Nilsson would seem the most accurate though somewhat exaggerated" (p. 199).

(iv) From the evidence of the larger glaciers and lakes Nilsson established a sequence of climatic fluctuations. Like Leakey, he assumed a close correlation between the pluvial-interpluvial changes in East Africa and the glacial-interglacial changes in Europe; he has said: "From the beginning of his investigation of the former greater African lakes and glaciers, the author was convinced that nothing but the general Pleistocene climatic changes could offer a really sufficient and plausible explanation for their occurrences" (1963 p. 23). There are a number of tables in Nilsson's papers which show the correlations he made between the climatic fluctuations in East Africa, Ethiopia, Egypt, Europe and North America, for example in 1931 (p. 338), 1940 (pp. 207 and 210) and 1963 (p. 53). Some of these correlations were based in part on carbon-14 dates and varve counting, but most often the assumption seems to have been that where a general similarity of rhythm of wet-dry or cold-warm fluctuations could be traced, with the same pattern of peaks, these peaks must necessarily be contemporaneous. The theoretical basis for such correlations over wide distances is unconvincing, and in East Africa at least the sequence itself is far from being well enough established for such correlations to be based on it.

Despite the fact that Nilsson worked for some time in the Nakuru-Elmenteita basin with Leakey and Solomon, and that they started with a similar assumption, that the climatic fluctuations that they traced in East Africa could be correlated with those which had been established in Europe, there is no very obvious agreement between their results on the sequence of lake levels in the basin. Nilsson did attempt to include Leakey's terminology of Gamblian, Makalian and Nakuran phases in his table of lake and glacier fluctuations, as shown in the accompanying table (No. I). However any comparison of their results on the basis of shoreline altitude is almost meaningless, since Nilsson postulated tilting and a great range of heights for each shoreline group. Matters are also complicated by the fact that the terminology of the sequences of both Leakey and Nilsson, and the relative importance accorded to certain of the phases, have changed since the early 1930s.

The theories outlined above, and the use of essentially palaeoclimatological and archaeological material as the basis for geological correlations, were almost unchallenged until the 1950s. The pluvial period terminology was formally adopted as the basis for stratigraphical work in East Africa at the First Pan-African Congress on Prehistory at Nairobi, January 1947:

Resolution no. 14:

"(2) The established succession of deposits and faunas in East Africa should be used as a basis for the development of the African terminology.

(3) Certain stratigraphic units should be recognised in East Africa from now onwards. They are:

Nakuran
Makalian
Gamblian
Kamasian
Kageran."

Table I

Nilsson-Leakey correlation

Nilsson 1931 Table I (p. 326)

Nakuru-Elmenteita	Naivasha	Baringo-Hannington	Mt Kenya	Kilimanjaro	Ruwenzori	Mt Elgon	Climat and su
VII VI V	? VI V	?		Several small moraines			Altern wet an dry ph
Lake IV dried completely				Glacier IV melted completely			Arid sub-ep
IV	IV	?		Small moraines			Wet
Lake III dried completely				Glacier III melted completely			Arid
III	III	III	III	III	III	III	Wet
Regression of lake II				Recession of glacier II			Dry
II	II	II	II	II	II	II	Wet
Regression of lake I				Recession of glacier I			Dry
I	I	I	I	I	I	I	Wet
Kamasia lake dried completely				Glacier melted completely			Last or in epoch
Kamasia lake (or lakes)			Remains of old mor-aines	Glacio-fluvial materials covered with lavas	?	?	Great or gl epoch

Table I

Nilsson-Leakey correlation

Nilsson 1931 Table II (p. 328)

limanjaro	Ruwenzori	Mt Elgon	Climatic epochs and sub-epochs		Climatic phases according to L. S. B. Leakey 1931b	
veral small moraines			Alternating wet and dry phases	Post pluvial or post-glacial epoch	Nakuran	Wet period c 850 B.C.
er IV melted completely			Arid sub-epoch		Dry	Climatic optimum
Small moraines			Wet		Makalian	Bühl stadium etc.
er III melted completely			Arid		Dry	Achen retreat etc.
III	III	III	Wet	Last pluvial or glacial epoch	Upper Gamblian	Würm glacial
cession of glacier II			Dry		Mid-Gamblian pause	Riss-Würm interglacial
II	II	II	Wet			
cession of glacier I			Dry			
I	I	I	Wet		Lower Gamblian	Riss glacial
er melted completely			Last interpluvial or interglacial epoch		Long break, volcanic activity	Mindel-Riss interglacial
lacio-luvial aterials overed ith avas	?	?	Great pluvial or glacial epoch		Kamasian pluvial subdivisions unknown	Mindel glacial Gunz-Mindel interglacial Gunz glacial

The use of this terminology was confirmed, with the introduction of the term Kanjeran at the Third Pan-African Congress on Prehistory at Livingstone in 1955, although a slight reservation was entered.

Resolution no. 1:

"(4) It is recommended that Kageran, Kamasian, Kanjeran, Gamblian, Makalian and Nakuran should be recognized as stratigraphic climatic divisions only in the East African region, and that these terms should not be applied in other parts of Africa except where correlation is firmly attested by at least two of the three lines of evidence: palaeontological, archaeological or the geological setting."

These resolutions mark the heyday of the pluvial theory and its importance in East African Quaternary stratigraphy. Since the 1950s increasing doubt has been cast on the validity of the theoretical basis of much of the earlier work. Already in 1930 Bailey Willis doubted that a huge Baringo-Magadi "Lake Kamasia" could have existed and suggested: "An alternative explanation is that the rift valley, when man of the stone age occupied it, had already acquired a form approaching that which we now see, and that similar deposits . . . were laid down on benches at different levels, whether in separate ponds or in swamps" (p. 280). Criticisms were also made by Solomon (in O'Brien 1939, ch. III); he was chiefly concerned with criticism of the pluvial hypothesis as used by Wayland as a basis for the geological and archaeological successions in Uganda, but also included some reservations on his own work in the Nakuru-Elmenteita basin with Leakey. In particular, he believed that the possibility of post-Gamblian movements in the Nakuru-Elmenteita basin may have been underestimated by himself and Leakey in 1931. Solomon appears not to have done any more fieldwork in the Nakuru-Elmenteita basin at this stage but to have based his suggestions on a general re-appraisal of the geological and archaeological sequence.

On his return to South Africa from the Pan-African Congress on Prehistory at Nairobi, Du Toit (1947) gave an account of some of the evidence for Pleistocene climatic change in East and South Africa, and stressed the need for caution in the interpretation of the geological evidence of climatic change and in the correlation of the assumed pluvial periods between widely-separated localities. He pointed out that between large areas, inverse climatic trends may be noted for several years at a time, and the danger of assuming "that the conditions deduced from one or two spots must prove representative of the country, or even be applicable to half a continent" (1947 p. 30). About the new terminology which had been introduced at the Congress, he remarked sensibly: "It might incidentally prove an advantage if such terms as "Kamasian Pluvial", "Third Interpluvial", etc. could, for a while at least, be replaced by less committal expressions, and the undoubtedly intricate question of climatic oscillations restudied from a more detached angle . . ." (p. 38).

Shackleton (1955) gave an account of some of the Middle Pleistocene ('Kanjeran') sediments in the Rift Valley (at Olorgesailie, Kunyu wa Gicheru in the Kedong basin, Kariandusi and on the Kinangop plateau), and concluded that although they were faulted, these lake beds had not been affected by the major faulting which formed the Rift Valley. He re-examined the Kariandusi and Kinangop sites which Leakey had studied and decided that the implement-bearing laterites from the Kinangop plateau were formed when the main scarp was already in existence and were unconformable on the greatly faulted tuffs and lavas forming the top of the plateau. It appeared that the sedimentation of the "Kanjeran pluvial" post-dated the last major faulting in this part of the Rift Valley; this opinion has since been accepted by most of the geologists who have studied this area (e.g. McCall, Baker and Walsh, 1967).

Cooke (1957) gave a useful critical account of the evidence for the Quaternary climatic fluctuations in East Africa. He warned, "We must, I think, distinguish sharply between a climatic interpretation which could fit the observations and which is demanded by the evidence" (p. 13) and concluded "the only well documented evidence for climatic changes in East Africa is that for the Gamblian Pluvial, the two later wet phases (Makalian and Nakuran) and the intervening dry period, as shown in the Nakuru-Naivasha basin" (p. 61). He suggested also that there was a certain amount of evidence for wetter conditions in pre-Gamblian times. Cooke demonstrated that a Lower Pleistocene "Lake Kamasia" stretching from Baringo to Magadi was unlikely to have existed, since the warping of the lava floor underlying these lake deposits is not enough to explain the 3000' difference in height between the "Kamasian" deposits in the Nakuru-Naivasha basin and those of Magadi and Baringo.

The value of Cooke's comments on the Nakuru-Naivasha basin sediments and shorelines is limited by the fact that he did little fieldwork there and thus, understandably, accepted the basic data, height information and sections of the earlier workers with little question. Thus, although he considered Nilsson's tilting sequence "not convincing", he accepted his "undoubtedly accurate data" (p. 43). Cooke was aware of the problems that the existence of an outlet may cause in interpreting a climatically-controlled sequence of lake levels, and said, "In the Naivasha basin interpretation of the lake terraces is complicated by the Njorowa gorge but in the area to the north this factor does not affect the lake once its level is below the Gilgil barrier (6,600 feet)" (p. 44). Unfortunately here he accepted the height figures for the Nakuru-Elmenteita basin given by Leakey and Nilsson, in which the presence of the Bahati overflow, over 200' lower than the Gilgil divide, is ignored. In fact the primary problem in the Nakuru-Elmenteita basin is not whether the suggested sequence is adequately supported by the reported data, but concerns the quality of this data, and this one cannot judge without spending some time in the field. Cooke also examined the basis for recognition of parallel Gamblian and later phases in the Baringo-Hannington and Ethiopian lake basins, and concluded: "There is thus only circumstantial evidence suggesting that the pluvial conditions considered necessary in the Nakuru-Naivasha basin to account for the Gamblian deposits there may perhaps be paralleled in other areas" (p. 55).

In his paper in the Geological Magazine of 1959 (referred to henceforth as Flint 1959b) Flint gave a detailed and critical account of the evidence for each of the wet and dry periods suggested by Leakey and others in the East African Pleistocene sequence. He rejected the kind of evidence and correlations on which the older (Kageran and Kamasian) pluvials were founded and included a full criticism of the use of inferred climatic phases as the basis for stratigraphical units. Flint visited, though only briefly, several of the Nakuru-Elmenteita basin sites and accepted the general idea of the higher lake shorelines as evidence of the Gamblian and later wet phases, and, though less certainly, the reddish, so-called "wind-blown" sand as evidence of drier conditions. However he was not certain of the exact number of fluctuations to be deduced from this evidence in the Nakuru-Elmenteita basin, and said: "Published data on the Gamblian and later climatic evidence are, however, so inadequate that the number of climatic fluctuations to be read from them is uncertain", (p. 277) and "Whether all the 'wet' and 'dry' phases (five in the Gamblian and five more in the post-Gamblian) . . . are admissible on the evidence published so far is less clear" (p. 277). Of the older climatic phases, Flint doubted the value of the evidence of the Kanjeran pluvial at Olduvai and suggested that although larger lakes probably existed in which these sediments were laid down, the possibility of tectonic control of the change in sedimentation environment cannot be excluded. Only the Olorgesailie lacustrine sediments were accepted as reasonable evidence of a moister climate during the "pre-Gamblian" (1959b pp. 270-1).

A shorter paper (Flint 1959a) included more general discussion of the concept of pluvial-interpluvial fluctuations and the kinds of evidence for climatic changes during the Pleistocene in Eastern and Southern Africa. Concerning the Nakuru-Naivasha basin shorelines, Flint said that they "although discontinuous, actually are more nearly continuous than is shown on sketch maps made before 1935" (p. 355). (He is presumably referring to maps such as Leakey 1931a p. 499 and Nilsson 1931 p. 291.) Concerning this comment of Flint's, I would say that although the actual shoreline cliffs in the Nakuru-Elmenteita basin seem to be no more continuous than they are shown on Leakey's or Nilsson's maps, there is certainly quite a lot of sedimentary evidence of lake shorelines which is missing from these maps.

Recent detailed geological mapping has been done in the Naivasha basin by Thompson and Dodson (1963) and in the Nakuru-Elmenteita basin by McCall (1957a and b, 1967). Unfortunately the degree sheet boundary (latitude 0° 30'S) runs across the southern part of the Nakuru-Elmenteita basin, so that important sections on the River Nderit and on Eburu are cut off from the rest of the basin and included in the area covered by the Naivasha report. The writers of this report, which was actually completed by 1958, seem to have done little fieldwork on the recent lacustrine sediments and former shorelines, and accepted much of the earlier work on this topic rather uncritically. According to the Foreword: "The mapping was greatly assisted by the large amount of work done previously by archaeologists, with whose results the authors are in general agreement." Thus they accepted Nilsson's evidence for tilting of the shorelines in the Nakuru-Naivasha basin, and made Leakey's Gamblian-Makalian-Nakuran sequence the basis of their chronology of the Upper Pleistocene in the Naivasha basin. Their report contains little useful criticism or evaluation of the earlier work in this area, and almost no new information about actual evidence of the former higher lake levels.

The papers by McCall contain much useful material on the geology of the Nakuru-Elmenteita basin, and I refer to them often in the chapters that follow. Although he was not primarily concerned with the evolution of the lakes, his work on the younger sediments and their relationship to episodes of faulting and vulcanicity is of great relevance to a study of the former lake levels. McCall believed that the last major faulting of the Rift Valley is Middle Pleistocene and pre-dates the "Kanjeran" sediments such as those at Kariandusi: "There is every reason to believe these sediments were deposited in the basin of Nakuru-Elmenteita as we know it today" (McCall 1967 p. 67). Later sedimentation took place in rather shallow basins delimited by two phases of minor faulting; there are believed to be only minor unconformities between all these Nakuru-Elmenteita basin sediments. However McCall doubted the suitability of the Nakuru-Elmenteita basin for a study of climatic fluctuations from the evidence of changes in lake level, "since tectonic movements and volcanic eruption altering the shape of the land surface certainly occurred there up to the end of the Pleistocene and are still continuing on a very minor scale. From this fact it is clear that factors other than climatic exerted a control on the extent of the lakes in this basin at any time" (1967 p. 64). His classification of the Upper Pleistocene sediments, with a threefold subdivision, is discussed in detail below (Chapter 3); from it he concluded: "While climatic fluctuations have a bearing on the extent of the lakes the three subdivisions appear to owe their existence primarily to factors other than climatic, and at present the writer can see no real validity in correlation with the European glaciation" (1967 p. 72). Another account of the Nakuru-Elmenteita basin stratigraphy, based on virtually the same material as McCall (1967) is in the paper by McCall, Baker and Walsh in the volume edited by Bishop and Clark (1967).

In a recent paper (1966) Temperley discussed features he named 'faced scarps' in the Kenya Rift Valley as evidence of rejuvenation along an older line of faulting and suggested that the major Rift Valley faulting might be much younger than has been suggested by McCall and others, i.e. Upper Pleistocene, and post-dating episodes of grid-faulting. He did not discuss the implications of this theory in terms of the sedimentation history of the area.

A symposium on systematic investigation of the African later Tertiary and Quaternary was held at Burg Wartenstein, Austria, in July 1965. The papers presented at the symposium were published in the volume edited by Bishop and Clark (1967). The symposium reviewed the work done by scientists working on late Tertiary and Quaternary problems in Africa over the past ten years in many disciplines, including stratigraphical geology, palaeontology, palynology, archaeology etc. Recommendations were made concerning the existing sequences and terminologies; among these were recommendations on the principles of stratigraphic nomenclature to be used in the study of the African later Tertiary and Quaternary. It was pointed out that "It is necessary, at least at the moment, to disallow palaeoclimatic-stratigraphic units for the African Quaternary" (p. 906), and was recommended that stratigraphical schemes adopted for Africa should follow similar lines to the stratigraphic codes in use in North America, Australia and New Zealand (pp. 890-1). Concerning the general principles of nomenclature it was said: "Stratigraphic units can be created by naming and defining them in print. Geographical names should be used, thus permitting the continued use of the name even if the geology should be reinterpreted at a later date. Climatic phases which are correctly defined may also be regarded as useful units but should not be confused with rock units, time units, or faunal units" (p. 397). It was stressed that the approved stratigraphic code should "make clear the distinction between rock units, time-stratigraphic units, time units, biostratigraphic units, and other units" (p. 890).

These recommendations are of relevance to the study of the late Quaternary in the Nakuru-Elmenteita basin, in connection with the use of the terms Gamblian, Makalian and Nakuran. This terminology is one in which the distinctions between the different kinds of units have become blurred, and the need for revision is apparent. My comments on the continued use of these terms are given in Chapter 8.

CHAPTER THREE

THE GEOLOGY OF THE NAKURU-ELMENTEITA BASIN

The landscape of the Nakuru-Elmenteita basin (see map 3) includes features resulting from volcanic activity, faulting and lacustrine sedimentation. The greater part of the centre of the basin (an area about 20 miles long and 10 miles wide) is covered by lake beds, and the faulted topography (e.g. Lion Hill and the area west of Lake Nakuru) and volcanoes and lava flows (e.g. the Elmenteita Badlands) only take up a relatively small area. However episodes of faulting and vulcanicity have had a strong influence on the pattern of sedimentation in the basin, and knowledge of when and where they occurred is essential to an understanding of the history of the lakes.

Table II shows the suggested sequence of events in this area since the Lower Pleistocene. The table is based on McCall (1967 Table I); I have omitted the references to rocks from outside the Nakuru-Elmenteita basin and inserted a note on the possible date of the 600 foot lake in the basin. Some aspects of the sequence are discussed in detail below:

1. <u>The faulting and vulcanicity</u>

(i) It is now believed that the last (third) major Rift Valley faulting pre-dated the deposition of almost all the

Table II

Late Quaternary Events in the Nakuru-Elmenteita Basin

(From McCall 1967 table I)

Recent	Superficial deposits etc. Volcanics: Menengai trachytes, lava and scoria cones. Elmenteita basalts, lava and scoria cones. Sediments: Makalia sediments (deltaic?) ~~~~ weak unconformity "Gamblian" sediments of Nderit and Makalia. [Probable age of shorelines of 600 foot lake in Nakuru-Elmenteita basin]
~~	Minor faulting: new fractures and renewals on older fracture lines. E.g. west of Lake Nakuru.
Upper Pleisto-cene	Sediments: tuffs and lacustrine sediments of Nakuru basin. Larmudiac sediments. Volcanics: pumice mantle from Menengai is not later than this, possible much older.
~~	Minor faulting: new fractures and renewals on older fracture lines. Nakuru and Elmenteita basin.
Upper Middle Pleisto-cene	Volcanics: Elmenteita older basalts, tuffs and agglomerate tuffs. (tuff cones e.g. Karterit) Honeymoon Hill. Soysambu olivine basalts. Sediments: Kariandusi lake beds ("Kanjeran").
~~	Third major faulting of Rift valley. Volcanics: possible date of formation of Menengai caldera.
Lower/ lower Middle Pleistocene	Volcanics: Gilgil trachyte; lava flows. Sediments: Enigma Cove lacustrine sediments.

lacustrine sediments now exposed in the basin: this includes the Kariandusi diatomites as well as the younger "Gamblian" lacustrine silts. It is suggested that all this sedimentation has taken place in a basin essentially similar to that of the present day. There was no major break with great faulting, vulcanicity and an arid climate between the deposition of the Kariandusi sediments and the later sedimentation in this basin.

(ii) The later (post-Kariandusi) sediments in the basin are not entirely unfaulted, but have been affected by possibly two episodes of minor tectonic activity. Such faulting appears to have consisted often of renewals of movement along older fracture lines, and in some areas produced a very fine grid pattern. Examples of this fine grid faulting are seen to the west of Lake Nakuru, where there are many small parallel rocky scarps, and also in the faults cutting the tuff cones south of Lake Elmenteita. Of the faults west of Lake Nakuru, McCall said, "These faults displace the sediments and tuffs of the Upper Pleistocene (Gamblian) succession and effect an apparent lowering of the floor of the Rift Valley in the Nakuru basin by up to 100 feet" (1967 p. 101).

(iii) Menengai caldera; it appears that the formation of the caldera took place at quite an early stage in the Pleistocene history of this area. This episode is likely to have caused major topographical changes at the northern end of the basin and the scattering of a great deal of volcanic debris nearby. It would seem that these events pre-dated even the Kariandusi sedimentation, and are certainly considerably older than the 600 foot lake and associated sediments. The 600 foot shoreline on Menengai is cut into thick beds of pumice which are believed to have been produced during the caldera eruption.

McCall did a considerable amount of research on Menengai and in his earlier papers (1957a and b) he put the age of the caldera formation as late as about 10,000 years B.P. Certain glassy tuffs (Solai and Mbaruk tuffs) believed to have been emitted early in the explosions of the caldera formation, were correlated with the 'Makalian' ash. The putative age for this ash was based on palaeoclimatic and archaeological correlations (Leakey 1931b). In his later paper (1967) McCall rejected this correlation and suggested that the thick pumice mantle is "from the structural evidence" possibly as old as Lower Pleistocene. (1967 p. 63) The caldera formation is thus attributed to about that date. If the caldera is as old as this, then any changes in the basin associated with its formation are not likely to have had any effect on the recent sedimentation, i.e. in the 600 foot and later lakes.

(iv) The Bahati overflow area: the level of the 600 foot lake appears to have been stabilized at the level of the east side of the rim of Menengai caldera, at the point OF on map 3 (see also map 5). The possibility that changes in the level of the rim might have occurred at a late date must be considered in connection with the history of this lake.

The outlet area is in fact a subsided part of the caldera rim; similar subsidence structures exist round other parts of the caldera and indicate that it was formed by subsidence of the superstructure into the underlying magma chamber rather than by catastrophic explosion. (McCall 1957a pp. 14-15). It is possible that since the original formation of the caldera, changes on this rim have taken place which altered the overflow level of the basin and thus the height to which lakes in the basin could rise. However McCall does not mention the possibility of a later renewal of faulting or subsidence around the caldera rim and it may be that after the initial catastrophic activity which shaped it, the outline of the caldera remained stable. The Bahati area does not seem to be one where the most recent episodes of faulting, which might have caused changes around the caldera rim, have been active. The Bahati plain is a smooth open expanse not crossed by the fine grid faults typical of the latest faulting episodes. On McCall's structural map of this area (1967 p. 94) no faults younger than the Lower/lower Middle Pleistocene are shown anywhere in this vicinity. The overflow area is marked as a 'lateral graben' and although no age is given for the faults defining it, other faults round the crater rim are marked 3a, presumably belonging to the third major faulting episode which is the Lower/lower Middle Pleistocene one.

It is possible that the level of the outlet has been slightly raised since it was formed, and since the lake stood at this level, by volcanic debris from the recent small-scale activity within the caldera. This possibility is discussed in more detail in Chapter 5.

(v) Other vulcanicity has occurred in the Nakuru-Elmenteita basin during the period of sedimentation in the most recent lakes. Products of this activity, in the form of narrow layers of ash and tuff, are seen in some of the sections in the basin, often between layers of diatomaceous silt. Often it is not easy to tell whether such material was laid down directly into water (straight from the eruption) or had undergone a certain amount of transportation beforehand. Most of this vulcanicity was centred in the 'Badlands' south of Lake Elmenteita, but eroded remnants of tuff cones also exist north of Lake Nakuru, Honeymoon Hill and Crescent Hill. Some of these volcanoes are older than the 600 foot stage of the lake, since probable shoreline features of this level are cut into them and lacustrine sediments occur around their lower slopes.

Other cones and lava flows are certainly younger than some of the recent lake sediments. McCall studied the Elmenteita Badlands and distinguished three phases of vulcanicity (1957a pp. 21-4):

Phase one; buff and grey tuff cones and associated lava flows. The central parts of the cones are downthrown by north-south faults, for example Karterit and Split Hill. The tuffs which form these cones are believed to be equivalent to the Kariandusi lake sediments. McCall mentioned lake shorelines, identified as "Gamblian", on these cones. Honeymoon and Crescent Hill are probably also of this phase.

Phase two; red basalt cinder cones and associated lava flows; these are unfaulted. They are said to cover the earlier lake deposits but to be overlain in parts by a thin layer of more recent deposits.

Phase three; the most recent vulcanicity produced a steep red cindery basalt cone 1 mile north of the former Eburu station, and some lavas.

This vulcanicity, although it covered part of the south-east corner of the basin and may have spread fine volcanic debris over a wider area, does not seem to have been a major disruptive force in the sedimentation history of the basin. The material produced, even to make up the larger cones, has not drastically changed the basin shape or volume and thus has probably not had a great influence on the conditions under which the lakes existed in the basin.

C. Lacustrine and other sediments

(i) Enigma Cove sediments: a layer of diatomite is exposed at "Enigma Cove" in the steep face of the Gilgil escarpment (Temperley 1966). It is faulted and overlain by lava and is believed to pre-date the third major Rift Valley faulting, i.e. to be Lower/lower Middle Pleistocene in age. Since it is a diatomite, it is almost certainly of lacustrine origin, but was deposited in a basin that has since been disrupted by faulting and flow of lava. This sediment cannot therefore be fitted into any sequence of lake level fluctuations or related to any lake shorelines in this basin.

(ii) Kariandusi diatomites: these were originally exposed along the Kariandusi river valley and are now visible to a depth of over 100' in the mine close to the main Nakuru-Nairobi road at the point KA on map 3. A more detailed discussion of the Kariandusi mine and the Nakuru-Elmenteita basin diatomites is given in Appendix D. The position of the Kariandusi sediments in the history of faulting and lake deposition in the basin has been the subject of some controversy. They were first attributed to the Miocene by Gregory and then transferred to the Pleistocene by

Leakey and attributed first to the "Kamasian", later to the "Kanjeran" pluvial phases. Acheulian handaxes overlie the diatomites at Kariandusi in a rich site and by correlation with similar industries elsewhere in Kenya Leakey therefore suggested (i) that these lake beds were contemporaneous with deposits at Kanjera in West Kenya (hence the "Kanjeran" pluvial), (ii) these lake beds were contemporaneous with swamp beds 2000ft higher, on the Kinangop plateau just east of the Rift Valley; hence there had been faulting of this order since this sedimentation, i.e. the last major Rift Valley faulting.

McCall, Baker and Walsh (1967 p. 196) rejected this correlation and said, "It is this conclusion that may well have resulted in a major mis-correlation in this part of the Rift Valley". The work of Shackleton (1955) and McCall (1957, 1967) has shown that the Kariandusi sediments were deposited on a strongly faulted trachyte surface, but are themselves only affected by minor faulting; i.e. they clearly post-date the last major faulting in this part of the Rift and are possibly of upper Middle Pleistocene age. These sediments are well stratified and show a marked westwards dip (into the valley); this is believed to result from slight downwarping of the Rift Valley floor continuing after their deposition. According to McCall, these sediments pass laterally into the graded tuffs of the older cones of the Elmenteita Badlands, for example Karterit. These cones are faulted, so some faulting has taken place in this part of the basin since the Kariandusi sediments were deposited. McCall suggests that despite this later minor faulting "there is every reason to believe these sediments were deposited in the basin of Nakuru-Elmenteita as we know it today" (1967 p. 67). I see no reason to disagree with this opinion; however the assumption of an essentially similar basin does not preclude the possibility (a) of a change in the outlet level at the rim of the basin since the sediments were laid down, (b) that the shoreline features of the lake in which these sediments were laid down have been disrupted by later minor faulting and so can no longer be recognized or correlated by height.

There are, in the southern part of the basin, other small diatomite exposures which seem faulted, some also overlain by lavas, and all a lot harder and whiter than the later diatomaceous silts, (described below). These include sections 8/4, 8/5, 8/9 and 8E/2 (map 3), at altitudes between 6400-6650' S.D., all considerably above the Kariandusi deposits which are not exposed much above 6150' S.D. These sediments are likely to be of lacustrine origin but are above the level at which a lake could exist in the basin today. The implications of this are discussed in Chapter 5.

More diatomite is exposed at Soysambu, on the ridge between Lakes Elmenteita and Nakuru, and in 1965 was being worked in an open pit. It has been suggested that this sediment is contemporaneous with that of Kariandusi, and it is so marked on McCall's geological map (1967). From a brief study of this deposit and other diatomites in the south of the basin, I decided that it might in fact be younger than the Kariandusi sediments and the same age as the diatomites at SE/3 and 10/18. This appeared likely because of the youthful and unfaulted appearance of the diatomites at Soysambu, which are overlain only by a narrow layer of soil. This correlation is discussed in more detail in Appendix D. The Kariandusi diatomites are overlain unconformably by horizontally bedded sediments. They include gravels and impure diatomaceous silts and have been suggested as being of "Gamblian" age (McCall 1967 p. 67), and to be fluviatile deposits. In the area of the mine itself, these sediments are now hard to trace, but probably equivalent beds overlie the older diatomites slightly higher up the River Kariandusi.

(iii) Upper Pleistocene and Holocene sediments: these deposits cover a large part of the centre of the basin, but they are best exposed in sections in the Nderit and Makalia valleys and to the west of Lake Nakuru along the River Lamuriak. They include quite pure, light grey diatomites, some with regular banding, and softer grey-brown diatomaceous silts. There are also deposits which are probably of terrestrial origin, in particular bright orange and reddish coarse, usually unstratified silts. There are some layers of volcanic material, including the coarse pumiceous debris which is found in sections 3/3,4,5 on the Bahati plain, and fine dark grey ash which occurs near the River Makalia, in particular outcropping above bright red silts in the Magharibi cliff (see plate 22).

The complex sections in the Nderit and Makalia valleys were studied in detail by Leakey, Solomon and Nilsson (Leakey 1931b, Nilsson 1931). Their interpretations are based on the Gamblian-Makalian-Nakuran lake level sequence; the various diatomaceous silts are attributed to deposition at periods of high lake levels, the breaks between them and terrestrial deposits to the intervening periods of low lake levels. They assumed:

(i) the essentially climatic control of the pattern of lake level fluctuations.

(ii) that no faulting had affected the Gamblian and later sedimentation.

(iii) the validity of the archaeological sequence as worked out in this part of the Rift Valley (from Gamble's Cave in particular) and the definite association of different industries with particular lake levels.

Since it is no longer accepted that no faulting took place in the "post-Kanjeran" in this basin, the theoretical basis of the interpretation of these sections is seriously weakened. It is possible that changes in sedimentation conditions in an area resulted from tectonics rather than climatic change. The likelihood of valid correlations between different parts of the basin is lessened, since the highly localized small scale faulting that appears to have been typical of this period could cause considerable changes in sedimentation in one area and leave others relatively unaffected. The value of the detailed archaeological sequence established for this area, and of the correlations which were based on it, is also now doubted; this is discussed in more detail in Appendix C.

It seems of little value to include an account of these sediments as interpreted by the earlier authorities, or a detailed criticism of their conclusions, since the basis of the interpretations is now so uncertain. McCall himself, who made a more detailed study of the sediments in other parts of the basin, reproduced some of the earlier material of Solomon and Nilsson on the Nderit and Makalia sections without further comment (McCall 1967 pp. 68-70). The geological report covering most of the important sections along the River Nderit is that by Thompson and Dodson (1963) on the Naivasha area. Unfortunately this too contained little original material on the lake shorelines and sediments and did little more than repeat the interpretations of Leakey, Solomon and Nilsson.

McCall distinguished three series of Upper Pleistocene to Holocene sediments in the basin; these, however, definitely do not correspond with the Gamblian-Makalian-Nakuran divisions, and he stressed "the three subdivisions appear to owe their existence primarily to factors other than climatic . . ." (1967 p. 72). On his map, the sediments were shown in two subdivisions only:

$Pl1_3$ - Upper Pleistocene, "Gamblian" and Larmudiac beds

Q1 - Recent, "Makalia River Beds".

These include gravels, silts, diatomaceous silts, pumiceous beds and graded tuffs, and were said to be of part lacustrine, part fluviatile origin.

It is clear from the text, and from my subsequent discussion with McCall, that the heading $Pl1_3$ as used on the map covers sediments of a considerable age range, from Upper Pleistocene probably into the Holocene. The older group of these may be referred to by the name given them by McCall (1967 p. 71), the Larmudiac Beds. They are best exposed in the highly faulted topography west and north-west of Lake Nakuru, where they have clearly been influenced by minor faulting. They include lake deposits, diatomaceous silts and clays and stratified graded tuffs and thus are evidence of former larger lakes in the basin. However since they are faulted, it is dangerous to try to correlate them on a basis of altitude, or to link them with a particular shoreline level. None seem to occur much above the present overflow level of the basin, so that it is unlikely that they pre-date any major changes in the topography of the Bahati or Gilgil areas. In the text (1967 pp. 71,72) McCall stated that these Larmudiac beds only occur below the high level shoreline on Menengai (base of shoreline cliff at circa 6370') and it was implied that the sediments are thus of the same age as this "Gamblian" shoreline. In a later discussion, McCall suggested that this height relationship is almost certainly a coincidence and that the Larmudiac sediments are clearly much older than the shoreline. This agreed well with the conclusions I had made while doing my fieldwork about the comparative youth of this shoreline and the sediments associated with it.

Younger than the Larmudiac beds and probably post-Pleistocene in age are the "Gamblian" and "Makalian" beds, which McCall considers to have been deposited in a trough formed within the Larmudiac sediments by later minor faults. According to McCall there is evidence in some places of a very weak unconformity, perhaps due to minor faulting or a period of aridity, between two sets of sediments in the

Makalia and Nderit sections; at this stage, however, this cannot be considered as conclusive evidence of a Gamblian-Makalian "interpluvial". On McCall's map the "Makalian" sediments (Ql) are limited to parts of the lower courses of the Rivers Makalia and Nderit, the area north of Lake Nakuru below the area 5950' Misonge shoreline, and a small strip east of Lake Nakuru at the foot of Lion Hill. The distinction within the Upper Pleistocene between "Gamblian" and Larmudiac beds is not made clear.

It is unfortunate that the names "Gamblian" and "Makalian" have been retained, however incidentally, in this classification of McCall's. It implies that the deposits can be fitted into the established sequence of climatic-controlled lake level fluctuations, and are equivalent to the "Gamblian" and "Makalian" sediments described in the earlier work on the geology of this basin. The results of McCall's and my work on the sediments and shorelines indicate that this is not the case. It would be wise, when further work is done on the sediments, to use new names which are free of the palaeoclimatic implications associated with the names "Gamblian" and "Makalian".

CHAPTER FOUR

EVIDENCE FOR PAST MORE HUMID CONDITIONS AND HIGHER LAKE LEVELS IN THE NAKURU-ELMENTEITA BASIN

1. The Drainage System

A number of small water-courses drain towards Lakes Nakuru and Elmenteita (see maps 2 and 3). Most of them contain very little flow of water in the lower parts of their courses, since it is lost in the permeable silts bordering the lakes. For part of the year the upper courses also seem to contain very little water. The valleys of the streams are often deeply cut and in parts the stream beds are littered with large water-worn boulders. I noticed this in particular on the Rivers Nderit and Makalia, which I examined at the end of the dry season, March 1967. The river beds were filled with loose dust and sand, and large boulders of dark lava, some several feet in diameter; the only water visible was in a few small stagnant pools. It is true that the Nderit and Makalia headwaters are in the best watered part of the Nakuru-Elmenteita catchment; when the rains come the rivers seem to fill up very quickly, and after a particularly heavy storm a considerable spate might develop. However even after nearly two months of heavy rains in April-May 1967, the volume of water in the Nderit and Makalia rivers seemed small, compared to the depth of their valleys. Much of the upper Nderit valley is a rather narrow steep-sided V over 50' deep, while the upper gorge of the Makalia (at 11/3 on map 3), cut in a lava scarp, is over 100' deep. The lower parts of their valleys are cut in rather soft material, including diatomaceous silts, but the higher deep valleys are cut in light grey volcanic tuffs which are quite hard, and in the lavas of the scarps bounding the basin.

I would suggest that the misfit appearance of these and other Nakuru-Elmenteita basin streams may not simply be a result of the highly seasonal nature of their flow and of the soft and porous rocks of the lower parts of the basin, but could indicate an actual decrease in volume of water since the greater part of the erosion of the stream valleys was done. In the absence of river capture or tilting of the land causing a reduction of catchment area and in the amount of water reaching the river, it is reasonable to assume that there has been a climatic change, probably a slight decrease in rainfall. In a few cases man, in diverting water for farming purposes, has reduced the amount of water in the drainage channels; this is true of the Ngosur stream on the Bahati Plain and of a spring on Eburu now piped to provide water for Prospect Farm. Dams have also been built, e.g. across the River Lamuriak and at the top of Prettejohn Gully. Such activities do not, however, seem to have influenced the major drainage lines; most of the water for farming appears to be taken from boreholes rather than from the rivers.

Many other valleys in the Nakuru-Elmenteita basin appear to be completely dry for almost all the year. Occasionally, after an exceptionally heavy rainstorm, they may support a brief rush of surface flow, but for most of the year their floors are dry and dusty or closely vegetated and show no sign of erosion by running water. Examples of these in the south of the basin are Aspinal and Prettejohn Gullies, south-bank tributaries of the River Nderit (map 3). These valleys are rather straight and bounded by steep cliffs, up to 40' high. The walls of Prettejohn Gully are cut in a variety of rather soft sediments, coarse red silts, pumice pebble beds and diatomaceous silts; Aspinal Gully is cut in the harder grey tuffs which are widespread in this part of the basin. A few acres of the upper "catchment" of Prettejohn Gully have been converted into a dam which collects water during the rains. This, however, is simply a small collecting hollow for rainfall; it does not contain any springs or lead upstream to a further source of water. The gullies may have been cut along lines of weakness caused by the approximately north-south faults of this district (a small fault block of lava stands in the middle of Prettejohn Gully), but they are erosion valleys and not miniature rift valleys. It seems hard to explain the existence of these two quite large valleys which now contain no water at all for almost the whole year without suggesting that they once contained more water. Large trees grow on the floor and sides of both valleys, and in Aspinal Gully a thick mat of grass covered the floor even at the end of a long dry season; they are not completely waterless, but the amount of water that passes down these valleys at present would seem inadequate to account for their size and depth. On the other hand it is possible that these valleys are generally in equilibrium with present day climatic and erosional conditions, but that a great amount of erosion in them is done under exceptional conditions which recur at intervals of several years. In this context it would be interesting to know the amount of erosion that took place in Prettejohn Gully in very wet years such as 1951 and 1961-2.

Smaller dry valleys are found on Menengai; their distribution above the Menengai shoreline shows well on the air photograph, plate A 21 (in back pocket). There appear also to be a number of rather deeper gullies, dry for most of the year, cutting the slopes of Eburu; these however are in thickly forested country, mostly above 7000', and are not easily accessible. They do not continue down onto the flatter land below Eburu, and their lower ends appear to be considerably higher than the lower ends of the Menengai valleys. For example, one of the lowest of these Eburu gullies ends at about EP_1 (map 3); this is almost certainly at a height of above 6450', judging by the altitude of a borehole (number C.533) not far above the lower end of the gully. The borehole, according to McCall's aneroid measurements (1957a p. 54) is at a height of 6497'.

The Menengai dry valleys are best seen where the shoreline cliff is best developed, see map 4. They are cut in the thick pumice mantling the outer slopes of the volcano; the pumice is exposed in small sections towards the lower ends of the valleys. The valleys have a rounded cross-section, with gently sloping "interfluves" and in some cases interlocking spurs. Some of them end a few hundred yards above the shoreline; others, as is seen on the air photograph, continue right up towards the rim of the crater. In most cases they do not continue below the shoreline, but end abruptly with little sign of a deltaic fan at their "mouth" or of a possible continuation of the drainage line below this, at an altitude of about 6370'. However some, such as the large valley which reaches the golf course above 2/11, can be traced as a definite hollow for several hundred yards below the shoreline, towards the buildings of Nakuru town. Below some other valleys I noticed a slight hollow, which when it crossed farm land tended to be left uncultivated and contained rather rough, long grass.

These valleys seem to be former drainage lines. Today there is no sign of erosion by surface running water in them, except after a very heavy storm when I have seen the grass flattened and some pumice fragments washed out over it. The valley floors are covered with thick grass and there are small thorn trees and bushes in them. The only signs of the processes that may have formed them are a few small circular hollows (circa 4' deep) with bare walls and a slight appearance of damp; small grassy runnels lead downstream from these along the valley floor. These small central hollows suggest that subsidence might have been operative to some extent in forming the valleys. Such a process does appear to have formed fissures, steep-sided gullies cut in fine silts at a lower altitude to the west of Nakuru town. Subsidences have taken place there in the last few years and I heard rumours that there was an 'underground river' below the town. The fissures were discussed by Pulfrey (1950), who concluded that the fissures ". . . are erosional features and in no way connected with earthquakes. They all lie in shallow valleys that will be stream courses when sufficient rain is precipitated". He suggested that the fissures are formed by 'subterranean denudation' - rain sinks in and removes salts and solid particles from certain horizons (probably of fine silt or ash), forming subterranean cavities and eventually causing collapse of the surface. This process is easy enough to appreciate when one looks at the almost vertical walls of these lower fissures; there is one just beside the Eldoret road near 1/21 (map 3), and another a few miles up the road near 4/8. The first of these lacks any continuous long-profile and in fact the floor of the gully is divided into a number of steps and actually rises in level for some distance 'downstream' away from the road. The valleys above the Menengai shoreline, on the other hand, have continuous, gently sloping long-profiles and they show other features, such as the tributaries and interlocking spurs, suggestive of erosion by surface running water. It would seem that their appearance and the lack of surface erosion happening there now cannot be explained by assuming that they are formed by the same process of 'subterranean denudation'.

In considering the significance of these Menengai shoreline dry valleys, I should like to give here in full a quotation from Nilsson (1940 p. 9) concerning the Naivasha basin, but relevant also to the Nakuru basin; "On the higher slopes of this basin there are numerous ravines going down to a certain level up to which the lake sediments of the Last Pluvial are deposited. Some of the ravines have not carried water of any importance since the last lake of this epoch stood at this level, because there is no continuation of the ravines in the sediments which were deposited as deltas in front of the mouths of the ravines. . . . There are also, however, several ravines of this kind which have a continuation in more or less deep canyons through the lake sediments, indicating that brooks have passed the ravines since the highest lake sank away from its uppermost shoreline." Nilsson went on to relate the 'canyons' also to lower lake terraces and suggested that, "The diminishing numbers of these ravines, counted from higher to lower levels within the basin down to the few ones which now carry water to lake Naivasha, give a clear idea of the close relation between the amount of precipitation and the levels of the ancient lakes of the Last Pluvial."

I have not examined the evidence of drainage lines in the Naivasha basin on which Nilsson based these suggestions. It is possible that in this case a study of the air photographs might be of value. In the Nakuru-Elmenteita basin the air photographs are only useful in some parts, such as on Menengai. In the thickly forested, faulted topography of the east and west sides of the basin, and on Eburu and

Lion Hill, it is hard to distinguish from the photographs such small ravines and gullies, or to note their exact beginning and end. I have noticed, in my field work, that there tend to be a lot of steep 'notches' or small V-shaped valleys cut in the rocky scarps of the Mau and Bahati-Mbaruk escarpments and Lion Hill, which run downslope at right angles to the fault lines and would seem to have been cut by running water. I did not notice any signs of waterfalls or active flow in them, and usually no continuation of a drainage line can be seen on the flatter land below the slopes. These might be equivalent to the Menengai shoreline valleys; the height of the lower end of these notches (in particular on the east side of Lion Hill, above a gently sloping terrain of diatomaceous silts) is some distance above 6300' and comparable to the height of the Menengai shoreline.

It is, I think, possible to suggest that the Menengai dry valleys and perhaps the small steep valleys described above were formed during a period of higher rainfall and consequent higher lake level. Their lower limit does suggest a definite relationship with the lake at the 600 foot Menengai shoreline level. They may, as is suggested by the absence of delta fans beneath them, pre-date the highest level of the lake, and have been truncated by the erosion of the pumice into which they were cut, or they may have been formed at the time of the maximum lake, and never have been any longer than they are today. Under present day climatic conditions erosion of these valleys is clearly proceeding very slowly, if at all. It is not really possible to suggest a definite figure as to how much more rain would have been needed to form these valleys. However it does appear that rainfall at the time when they were formed was definitely rather higher than it is today. A decrease in evaporation resulting from a fall in temperature, such as might explain some rise in the lake level, would probably not suffice to explain this more active stream erosion.

2. The Lacustrine Sediments

(i) The diatomites and diatomaceous silts. These have been discussed above (Chapter 3) and are described in more detail in Appendix D. In general I have accepted diatomaceous deposits, even quite narrow layers, as evidence of lacustrine sedimentation. It is possible that a few small deposits of very impure diatomaceous silts may have formed in swampy pools at altitudes above the lake shoreline. The majority of the diatomaceous deposits that I studied were probably laid down within the lake or in swampy areas close to the shoreline; their altitude (in the case of the unfaulted deposits) will thus be lower than that of the lake level at the time that they were deposited.

(ii) Beach and shallow water deposits. (a) The surface pebbles: in several parts of the basin, very striking concentrations of smoothly spherical or ovoid pebbles of rather hard, dense rock are found, at considerable heights above the present lake level. (see plates 4,5,6,7) Where they occur one can usually see rocky slopes and outcrops which would provide not-too-distant sources of stones as material for a shingle beach; I have not so far found accumulations of these pebbles far from any such sources of hard rock. It seems to me likely that these are beach pebbles and not from a river valley or deltaic fan, for the following reasons: (I) In the case of the Menengai shoreline (see map 4), pebbles can be traced for over 4½ miles along the side of the mountain at a fairly constant altitude; it seems impossible that such a spread of pebbles could have been produced by small streams draining from the rim of the crater. (II) The main deposit of pebbles on Lion Hill (at 5/16) lies on a level stretch of land high on the hill with no sign of any possible water course that might have flowed to bring the pebbles there. (III) The pebbles of north-east Elmenteita (at 8/1) are spread across spurs and hollows on the hillside; there is no concentration along possible former drainage lines. The same is true of the other occurrences of these pebbles; it seems impossible to relate their distribution to the modern rivers or to drainage lines which might in the past have held water. Their wide horizontal spread and similarity of altitude suggests an origin on a lake shoreline.

Since these pebbles lie on the surface, often on quite steep slopes, and are generally mixed with soil and unrolled stones, it is clear that in most cases some sorting has taken place since they were on the lake shore. This sorting will have involved a certain amount of downward movement under the influence of gravity and rainfall on the slopes. When they were actually on a lake beach, the pebbles were probably in most cases restricted to a fairly narrow vertical range; since then, during the retreat of the lake and the subsequent period of sub-aerial erosion, they are likely to have spread over a considerable vertical range. In many places the highest pebbles which can be traced are thus probably some distance below the original level of the beach. Occasionally deposits in a cave or rock shelter may have been preserved at their original highest altitude or even slightly above the general level of the shoreline. It is possible that some 'storm beaches' were thrown up on exposed situation and remained above the lake; however it is likely that in most cases subsequent downwashing will have eliminated them.

The amount of downwashing that has taken place will vary according to the situation of the pebbles and the slope of the land on which they lie. The pebbles at 5/16 (map 3 and plate 5) are thickly spread over a flat part of Lion Hill and it appears that most of them have hardly moved downslope at all. In contrast, the pebbles at 12/3, below the rocky face of the Gilgil escarpment, and at 8/1 (plate 6) may have moved down 50' or more. The pebbles on the Menengai shoreline (map 4) include some (e.g. those along Maragoli Avenue, plate 4) which are close to the original lake shore and others which may have been washed down over 100'. The pebbles are spread over a considerable height range but there is no indication of a lower concentration of pebbles which might have resulted from a stillstand of the lake between 6250-6370'.

(b) The pebble and sand sections: in several sections exposed quite high above the present lake (above 6300') I found stratified layers of pebbles, sands and diatomaceous silts. In these sections the pebbles are usually of light grey pumice which has been worn into very smooth ovoid shapes. They vary in size from less than ½ cm. to 2-3 cms, rather smaller than some of the lava pebbles which are up to about 6 cms in diameter. They occur in regular horizontal or slightly dipping layers; the pebbles are usually stratified according to size and with some parallel alignment of their long axes. A medium-textured sand of light crystalline material with darker grains, possibly obsidian, occurs in layers in some of these sections.

It is possible that in some cases these deposits accumulated under 'estuarine' or deltaic conditions slightly below the surface of the lake, i.e. that the actual sorting of the material was done by a stream flowing into the lake. This appears to be true of the thick beds of pumice pebbles exposed in Prettejohn Gully (plate 8) and possibly of the smaller sections at 2/11 below the Menengai shoreline, on the line of one of the longest gullies in this area. The beds in Prettejohn Gully extend several hundred feet along the gully and are over 10' thick in parts, showing very regular layering and size-stratification in dipping beds; the influence of a directed flow of water in sorting them seems clear.

In other cases (e.g. 3/6 at Bahati and 8E/3 at Eburu) the topography does not seem suitable for a stream to have reached the lake at that point, and the sediments probably accumulated in shallow water moving up and down a beach shoreline. In such circumstances a sequence (upwards) of pebbles to sand to diatomaceous silt, as appears at 3/6 (plates 12,13) could indicate a progressive deepening of the lake at that point, resulting from a rise in water level or possibly subsidence of the lake floor. The Eburu section (8E/3, plate 11) in which the sequence (upwards) is diatomite to sand to fine pebbles to coarser pebbles, should indicate shallowing of the lake.

(iii) Trona: McCall's geological map (1967) marks "Rt' - Trona-impregnated silts bordering soda-lakes" around parts of the shorelines of Lakes Nakuru and Elmenteita. The trona (hydrous sodium carbonate) forms as thin crusts on the flats bordering the lake. During the early 1950s, after some exceptionally dry years, the "soda dust" blew from the lake and caused irritation to people's throats and eyes in Nakuru town. Since then, with the advance of the lake waters, much less trona is exposed and the dust does not blow about much. The deposits visible today are clearly related to the present shallow, saline lake and to the evaporation of highly saline water from the damp surface of the flats as the lake retreats in dry periods. They are not, however, preserved at any altitude above the lake and it would not be expected for such highly soluble salts to be preserved for long unless conditions were extremely dry. Under moister conditions than today, with larger lakes, the concentration of salts would presumably have been less and saline crusts would not have formed. I have noticed indications of possible salinity in some of the diatomaceous silts; sometimes I have seen a whitish efflorescence on the surface of an exposure. Often also, the teethmarks of cattle and buck are visible on the surface of small cliffs of the silts; it would seem possible that the animals gnaw the rock for the salts it contains.

(iv) Coarse tuffs of the Bahati plain: one of the geological problems of the Nakuru-Elmenteita basin is that of the sediments of the Bahati plain, east of Menengai. I had expected to find on it sediments of clearly lacustrine origin, possibly fine silts, for the following reasons: (a) much of the plain lies between 6150-6350', altitudes between which I have found many exposures of lake sediments in other areas; the well-marked Menengai shoreline at 6370' is less than 4 miles west of the southern part of the Bahati plain. (b) With a lake at about 6370', the plain would seem to have been a rather sheltered inlet, suitable conditions for orderly deposition of fine material. It is relatively far removed from the most recent faults of the Nakuru basin (i.e. probably those on the west of Lake Nakuru), and does not appear to have been crossed by major drainage lines which might have brought down great masses of coarse material to disrupt lacustrine sedimentation. (c) On the western border of the plain, towards the lower slopes of Menengai, are three deposits of unmistakably lacustrine material. Sections 3/1 (at 6253') and 3/2 (at 6259' S.D.) showed regular layers of pumice pebbles and quite pale, pure diatomaceous silt in pits about 6' deep, below a shallow soil horizon. Section 3/6 (just above 6343' S.D.) showed a smooth lava surface overlain by a regularly stratified sequence of pebbles, sands and a narrow band of diatomaceous silt. The nature of these sediments, and their altitude, suggests strongly that they are deposits from the same lake that cut the Menengai shoreline cliff and in which very similar sediments were laid down at around 6340'.

However I could find no comparable lacustrine deposits elsewhere on the Bahati plain; most of the area is cultivated and exposures are few, except in silage pits or small farm quarries. In these coarse volcanic material is exposed in a variety of different sections. The material is of two kinds; light angular pumice with no signs of size stratification, and "tuffs" with a mixture of fine and coarse, scoriaceous pieces, in one case with a rough horizontal stratification. In almost all of these sections layers of light-grey, rather fresh-looking pumice lie uppermost, below a narrow soil horizon. That a certain amount of weathering of this pumice has taken place is suggested by the narrow zones of reddish staining that can be traced horizontally in the sections. In several of the pits two layers, each at least 2' thick, of rather similar looking pumice are separated by a narrow band of orangeish grit and silt; this possibly indicates a later deposition of pumice on top of an immature soil developed on the older pumice. In these sediments there appears to be no sign of any rounded or size stratified material to suggest lacustrine sedimentation. It would seem from their appearance that these layers of pumice were deposited straight from a volcanic eruption, and have not been washed downslope from material fallen higher on Menengai. They would indicate a number of showers of pumice separated by relatively short periods of weathering and soil formation. There is a slight suggestion that the number and thickness of these layers increases from south-east to north-west, towards the low point of the caldera wall. Thus there is little sign of such material on the main Nakuru-Nairobi and Thomson's Falls roads; at 3/3 and 3/16 there is one layer only; at 3/13, 3/19 and 3/8 there are two layers, while at 3/9 facing down into the caldera at the low point of the wall (at the point OF on map 3), there are several layers of pumice and darker, more 'welded' looking bands. This might suggest that these pumice layers were erupted over the low point of the rim at some date since the caldera was formed. However the distribution of this pumice, and the correlation of the different layers, has not yet been precisely worked out, and the above suggestions are only tentative.

In section 3/3a a layer of this pumice, circa 5' thick, overlies about 14' of other volcanic material, coarse (some blocks over 6" long) scoriaceous dark fragments in a finer matrix. In this pit it is unstratified, and appears homogeneous from top to bottom, with about 1' of pinkish brown silt merging into it at the top, below the light grey pumice. In pits 3/4 and 3/5, a few hundred yards to the west, the upper layers of pumice and silt are missing. (This might possibly be explained by their having been completely removed in the farming of the land and digging of the pit, although it does not seem very likely.) The sections here are both of over 18' of volcanic material of mixed sizes, rather paler in colour and finer than in 3/3. In 3/5a, there are clear signs of parallel, approximately horizontal banding, zones of between 15 cms - 30 cms wide of 'coarser' (not usually more than 3 cms diameter) and 'finer' (about ½ cm or slightly less) fragments; these bands appear to be visible throughout the section.

The only other sections which show any definite stratification are the two rather anomalous exposures at 3/10 and 3/15. There, below a narrow layer of dusty soil, over 10' of 'sand' is exposed; narrow dipping layers of small grey rounded pumice fragments alternate with layers of darker, denser material. The deposits seem very restricted in extent; 3/10 is close to the River Ngosur where it is still a flowing stream while 3/15 appears to lie in the hollow indicating its former course, lower down on the plain. It is possible that these are coarse riverine or estuarine sands dating from a relatively recent time when there was a greater flow in the Ngosur, and possibly a higher lake standing some way up on the plain.

The above sections, 3/3, 3/10 and 3/15 are the only ones I could find in the central part of the plain that suggested sedimentation in water. This difference from what I had expected might be explained in one of three ways: (i) that lake sediments were once deposited on top of the volcanics in the plain and have since been eroded away from on top of them; this seems very unlikely as it is hard to imagine an agent for such erosion on this gently sloping area and the profiles show no sign of such a truncation. (ii) That the volcanic material post-dates the lacustrine sediments and has covered them up; this is possible although the deepest pits I saw were over 20' deep and there seemed no sign of fine lake silts in them. Boreholes to a depth of several hundreds of feet have been drilled on the plain and their records give no indication at all of any silts, sands or rounded pebbles below the surface; this however is not very conclusive evidence as fine lake silts, especially if in rather thin layers, might easily be missing from the record though present in the borehole. (iii) Some of this volcanic material might be the equivalent of the silts laid down elsewhere in the lake, and have been deposited here in a larger Lake Nakuru. This might be true of the lower strata in pits 3/3,4,5. This question cannot be answered at present from the character of the deposits. Certainly there appears to be no sign at all of rounding of the fragments by water, and as McCall said in referring to some older 'graded tuffs' ". . . deposition directly into a lake from air-borne showers seems indicated, rather than reworking by rivers and transport into a lake" (1967 p. 51). It is possible that this, and the later material, originated from within the crater of Menengai, and that the sections of fine lacustrine material and beach pebbles at 3/1,2 and 6, were protected by the shoulder of the mountain from the fall of volcanic material which covered the central part of the plain.

3. The Shorelines

The central part of my work in the Nakuru-Elmenteita basin has been the identification and study of the former shorelines of the lake. As a geomorphologist I was particularly interested in relief features that might have been formed along the lake shores. Many of these were recognized and surveyed by Nilsson and Leakey, but the information they give about these features is rather scanty. I was unable to find the majority of Nilsson's 'wave cut-terraces' and have been forced to conclude that in many cases he probably identified breaks of slope which are of quite different origin, such as small fault scarps. Leakey described rather fewer shorelines and I have been able to identify the majority of these, although it is not clear to which parts of them he levelled and my height figures are not always the same as those he obtained. Details on the identification and levelling of the shoreline features by Nilsson, Leakey and myself are given in Appendix A.

It is clear from even a brief visit to the Nakuru-Elmenteita basin that the shoreline features are not an obtrusive element in the landscape. There is no suggestion of a series of terraces at different levels cut into the slopes or of cliff lines that can be traced for miles along the contours above the present small lake. The dominant element in the landscape is faulting, which has produced the many rocky scarps and slopes with an approximate north-south alignment. Sediments of the former lakes are found all over the basin, but the actual shorelines are not so easy to find. I found evidence of four 'shorelines' each indicating a stillstand of the lake level long enough to produce a fairly well-marked shoreline cliff; Table III shows the approximate circumference of the lake at each of those levels, and the actual length of shoreline that I have identified with any certainty.

Table III

	Approximate circumference of lake		Length of shoreline cliffs (i.e. distinct relief features)
Lake at 6400 ft	77 miles		2½ miles (Menengai) ½ mile (Karterit)
Lake at 6120 ft	60 miles		1 mile (Magharibi)
Lake at 5950 ft	43 miles		3½ miles (Misonge)
Lake at 5790 ft	16 miles		½ mile (Kiboko)
Present circumference of lakes.	Lk Nakuru Lk Elmenteita	15 miles 13 miles	Almost none; present shorelines are very gently sloping, saline flats.

The evidence is not quite as fragmentary as appears from the list, since shallow water and deltaic sediments are found in fair numbers and can be related to the shoreline level to provide an indication of its position in areas where the actual cliff is absent. However it is as well to stress at this point that this basin is not one in which the evidence of former shorelines is well preserved; however hard one were to look, there are large areas where no significant relief or sedimentary evidence would be found.

Various reasons may be suggested for this lack of evidence of what are, it seems, quite recent lakes. Although I agree with Leakey's general comments about the difficulty of tracing former shoreline features, I cannot agree with his statement that, "In places, especially to the north-west end of the basin, the old beaches are nearly all obliterated by more recent deposits of volcanic ash from Menengai . . ." (1931a p. 500). The major eruptions of pumice from Menengai appear to have pre-dated the high lake levels; the best-marked cliff line is actually cut in the thick pumice mantle on the side of the volcano. I did not find any beaches or shorelines higher than that on Menengai in the south of the basin, where little if any Menengai material would have fallen.

The present day conditions of the lake shore are not favourable to the development of marked or permanent relief features. In the past few years the lake shoreline has fluctuated widely over very gently sloping flats, which are particularly wide on the north and south shores; even below the steeper east and west shores the lake fluctuates over a strip of flat land several yards wide at the base of the steeper slopes. The result of this wide fluctuation over an almost flat shore is that at present no features appear to be forming which could be compared with any of the higher supposed shoreline features. The lake is surrounded in parts by swampy vegetation, in parts by saline flats; the only relief features I have seen on these were some very small ridges, less than 1' high, which were formed of loose pumice pebbles close to the waterline. They were clearly very impermanent features formed by a few days of gentle wave action at one level. In contrast, the waves of a lake 600' deep and of the order of 20 miles long would no doubt have had considerable erosive power. The increased length and depth of the lake would allow the generation of greater waves, and the surface of a larger lake would be more exposed to the wind than is the present lake, sheltered right at the bottom of the basin. Wave erosion would also be more concentrated in its effect on the steeper slopes of the basin sides than on the flats surrounding the present lake. The power of the waves produced marked shoreline cliffs in some parts of the basin; it remains to be explained why none are visible along the greater part of the former lake shorelines.

It is likely that even when the lake was actually at a high level, the form and size of the shoreline features varied considerably from one part of the shoreline to the next. The erosive power of the waves would be greatest on an exposed shore, one open to the waves of longest fetch or those generated by the dominant winds. It is not certain what would have been the dominant winds during these earlier periods of rather different climatic conditions; however the biggest waves would probably have been generated along the length of the lake and beaten on its northern or southern shores. The power of the waves would also tend to be greater and more concentrated on a steeper shore than on a very flat one. This is probably one explanation why so little in the way of shoreline features has been preserved on the Bahati plain and on the plain south of Lake Nakuru where the land surface slopes very gently; the shoreline would have been fluctuating widely and little concentrated erosion would have taken place. The character of the rock would also be very important to both the original form of the shoreline and to the extent to which it has been preserved today. It seems that recognizable shoreline features, are not found in the highly faulted topography of harder lavas. It may well be that the lake surface stood along some of the fault scarps without a great deal of erosion of the lava taking place. This is probably true of the Gilgil scarp which in parts extends above and below the 6370' level of the highest shoreline. From the height evidence it is likely that the water level did come up onto this Gilgil scarp, but the slope itself is definitely not a lakeshore cliff and gives no supporting evidence of the height of the shoreline. Similarly, the water level on Menengai was, in the Maragoli Avenue area and further east (see map 4), against the rocky slopes (Pliocene ignimbrites and welded tuffs) of the mountain, but there is nothing there that can be recognized as a wave-cut shoreline feature. The shoreline appears most clearly in the softer volcanic rocks, pumice, ash and tuff; it seems that these were susceptible to wave erosion and undercutting. Most of them, however, are rather permeable and later sub-aerial degradation by surface water would take place slowly. The shoreline cliffs thus tend to be better preserved than one might expect in this relatively unconsolidated rock.

Since the shoreline features are so fragmentary and of such variety, it is hard to be certain of their origin and that they were in fact formed by wave erosion. From a morphological point of view, the theoretical minimum requirement to indicate wave-erosion would be some kind of a concave break of slope. Figures 5 and 6 show the probable relationship of the 'cliff' and the 'wave cut terrace'. In the Nakuru-Elmenteita basin, however, there are many small cliffs and concave breaks of slope which were not formed by wave erosion. Even among those for which such an origin is likely, no real comparison of profile shape is possible since the rock type and general slope of the land vary so between different parts of the basin. The height and steepness of the slope facets above and below the concave breaks of slope are very variable, and it is not possible to distinguish a shoreline cliff from a fault scarp on the basis of profile alone. The plan view of the feature is more useful in this respect. In the Nakuru-Elmenteita basin the fault scarps are, almost without exception, aligned close to north-south. It is easy to identify the shorelines which curve around in an approximately east-west direction at the northern end of the lake, i.e. the Menengai and Misonge shorelines. It is less easy to be certain about shoreline cliffs along the eastern and western shores of the lake, where fault lines and contours all run approximately north-south. However a shoreline cliff will tend to curve round following the contours; i.e. when it reaches a river valley it will tend to curve upstream for some distance around what was an inlet when the lake was at that level. Fault scarps are more likely to run right across the valley and produce rapids or a waterfall on the river.

At the same time the shoreline features that I have been studying appear all of them to be close to horizontal and the height of the cliff is fairly constant along the short lengths which are preserved. This is not so of the fault scarps which often vary in size considerably along one scarp and are not always horizontal.

None of these morphological characteristics, however, provide a very firm basis for identification of a break in slope as a shoreline, if it cannot be traced for a considerable distance round the lake at a constant level. With the small, isolated shoreline cliffs in the Nakuru-Elmenteita basin, it is often necessary to use sedimentary evidence as further proof of their origin. The best proof is obtained from the presence of rounded pebbles on the terrace below the cliff, close to their original position on the lake beach. In this basin such clear deposits are not often found, as many of the beach pebbles have been washed down and covered with soil and vegetation. However there are a number of sections of stratified lacustrine material, pebbles, sand and silt, at various heights below the Menengai shoreline. In the case of the high level (600 foot) shoreline the sedimentary evidence is quite complete, and the height correlations between the various sections in the different parts of the basin are good. The sediments occur in quite simple sections and with these high level deposits there is usually little uncertainty about the level of the lake in which they were laid down. In the lower parts of the basin the history of lacustrine sedimentation is more complex and it is not so easy to relate a particular sediment to a definite shoreline.

I have recognized several features in the Nakuru-Elmenteita basin which may be shoreline cliffs formed by wave erosion when the lakes stood at higher levels. In most cases these had already been identified by Leakey or Nilsson or by both; in their accounts the actual shoreline features are usually very briefly described. I have therefore given a description of each of the possible cliffs that I recognized and discussed my reasons for identifying it as a shoreline. In this chapter I describe:

(i) the Menengai shoreline
(ii) the notch behind Gamble's Cave
(iii) the notches on the Elmenteita volcanoes and on Honeymoon Hill.

At this stage I concentrate on the characteristics of these features as possible shoreline cliffs, rather than on their altitudes and the correlations that may be made to indicate the main stillstand levels of the lakes in the basin. This aspect of the shorelines is discussed in Chapter 5, and I also discuss the identification of the lower shorelines, the Magharibi cliff near the River Makalia, the Misonge shoreline and the Kiboko shoreline.

(i) The Menengai shoreline: this feature, on the southern slopes of Menengai above and to the west of Nakuru town, was referred to several times by Nilsson. He mentioned ". . . a cut-terrace, near Nakuru Junction. This terrace could be followed without any great difficulty for a long distance along the southern slope of Menengai." (1931 p. 293) It was said to be eroded in layers of volcanic material from

Menengai, described as showing "an upper dark layer, a brown middle layer, and a lower light-grey layer" (p. 296). The terrace was said to be at an altitude of 6415' R.D. shortly east of Nakuru Junction, and at 6425' R.D. about 4½ miles further east. No reference to a feature that might be this shoreline was made in Leakey's work, in fact he said, "Especially to the north-west end of the basin, the old beaches are nearly all obliterated by more recent deposits of volcanic ash from Menengai" (1931a p. 500). McCall (1957a and 1967) referred briefly to this shoreline and attributed it to the "Gamblian" period (1957 p. 25), correlated with the shorelines on the Elmenteita tuff cones. On his new geological map (1967) it is badly drawn, crossing the contours at a considerable angle.

The cliff-line is shown on map 4, in the photographs (plates A1, 1,2) and in the profiles (fig. 1). It is a striking feature, especially in the west, between profiles 1 and 9, although it can also be traced for some distance east from there. The cliff is about 40' high and cut into by the mouths of the gullies described in section 1 of this chapter; below it is an even gentle slope southwards. The cliff is cut into the thick pumice mantle; the light grey rock is exposed above it and in the cliff-line itself, but does not seem to occur in such thick, fresh-looking sections anywhere below the shoreline. At a lower level this pumice is found in small, rather silty beds and as weathered fragments in the surface soil over a wide area. There is not much sign of a break of slope continuing westwards from Nakuru Junction, although there is possibly a continuation of the cliff across the Njoro Road. I levelled a profile there (above 4/3 on map 3) and found there was a break of slope, although not nearly so marked as that on Menengai, at about 6360' S.D.

The best development of the shoreline seems to be in the area where it is cut in the thick beds of unconsolidated pumice. This material would be susceptible to erosion by waves along a cliff-line but since it is very permeable later degradation of the cliffs by sub-aerial erosion would not be too rapid. To the east (beyond about 2/11), the older rocks of the fabric of Menengai volcano, (marked Pliocene welded vitreous tuffs and ignimbrites by McCall in 1967) are more in evidence on the surface, forming rounded and rocky ridges and spurs. It appears from their altitude that the water level did stand up against some of these slopes, but no obvious cliffs have been formed on them. The shape and distribution of the slopes on these rocks is probably related to the original volcanic events rather than to erosion by the lake.

The altitude of the base of the cliff is about 6370' S.D.; it does not appear to be tilted.

(ii) The notch behind Gamble's Cave: I am uncertain as to whether or not this is a shoreline cliff. It was so described by Nilsson, as a 'cut-terrace' at 6383' R.D.* (1931). It was mentioned again by him in 1940, "In accordance with its free exposure, which can be seen from the few figures of elevation, this beach is well developed" (p. 23). Its height in Nilsson's 1940 paper was given as 6393' R.D.*. It is not always exactly clear to what feature Nilsson referred, and there seems to be confusion here in his use of the words 'beach' and 'terrace'; however, it does seem that he referred to a feature behind and immediately east (i.e. 'downstream') of Gamble's Cave. Leakey was more explicit, and said, "A little to the east of the caves is a terrace and a small cliff" (1931b p. 92), and also showed a photograph of the feature, but he did not state its altitude. There is a further discussion of the features identified by Leakey and Nilsson in the Gamble's Cave area and the heights given for them in Appendix A.

Surface features in this area, on the upper slopes of the Nderit Valley and above Aspinal Gully, are very hard to see clearly, as the vegetation is thick and tangled. However there does seem to be a small bench with a cliff

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* Nilsson's heights: 1944 metres (1931); 1947 metres (1940).

above it running round the hillside from the cave onto the slope above the western wall of Aspinal Gully. The cliff is cut in pale grey tuffs and is usually a steep slope (more than 45°) about 20' high. It shows from the opposite bank of Aspinal Gully as an approximately horizontal line marked by a change in vegetation; above it grow fairly small thorn trees and bushes; below it is thicker vegetation with a lot of euphorbia and larger thorn trees. I traced it about 100 yards round the slope from the cave; some distance beyond this it fades out and is not seen clearly further up Aspinal Gully. There is a possible continuation of the cliff on the other side of Gamble's Cave, upstream along the Nderit Valley.

I measured to the estimated base of the cliff in two places just east of the cave; it was not easy to find the exact base of the cliff as much soil and vegetable matter has collected on the terrace and the heights I obtained may be too high, although the agreement with Nilsson's heights is good. It would have been best to level and pace a profile, as was done along the Menengai shoreline, but the thickness of the vegetation and the steepness of the slopes made this impossible.

Height of estimated base of cliff:

Close behind Gamble's Cave - 6394' R.D. i.e. 6388±3' S.D.

About 5 yards further east - 6404' R.D. i.e. 6398±3' S.D.

The terrace does not appear to be systematically tilted; this height difference probably results from the different estimations of the base of slope.

It is possible that this notch is a former shoreline cliff of Lake Nakuru. It is meaningless to compare its shape with that of the Menengai cliff, as the rock in which it is cut is considerably harder and a steeper slope might be expected. Similarly it is cut on a steeper hillside and the narrower 'terrace' might also be expected. On the other hand there are a lot of small fault scarps in the tuffs on these hillsides, of very similar appearance, and it could be one of these. The cliff line curves around the hillside, from an approximate east-west alignment above Gamble's Cave to one close to north-south above Aspinal Gully. This could be typical of a shoreline feature rather than a fault scarp. The cliff appears not to continue far up Aspinal Gully, nor did I see any sign of an equivalent feature on the north side of the Nderit valley, opposite Gamble's Cave. This might be because the cliff formed along a small local fracture line. On the other hand it would be reasonable to expect the best developed shoreline cliffs in this area to be on the north-facing slopes, such as the slopes around Gamble's Cave on which the cliff actually occurs, since they would be most exposed to the waves of a high-level lake. Slopes with southerly or south-easterly aspects might be more sheltered from the waves and less striking erosion features would develop.

(iii) Shorelines on the Elmenteita volcanoes and Honeymoon Hill: the oldest phase of vulcanicity south of Lake Elmenteita is believed to be contemporaneous with the "Kanjeran" sedimentation at Kariandusi. Some of the tuff-cones and lavas therefore pre-date the "Gamblian" and later lakes. The older lavas are covered by lake sediments and the lake shoreline would have stood on the slopes of some of the older cones. Wave erosion could well have been effective on the exposed slopes of these steep-sided islands of relatively unconsolidated tuffs. The accounts of previous workers in the area contain various general references to shorelines on these cones, but there is no specific information as to what they are like, which volcanoes they are on, or at what altitude. Nilsson's maps and instructions on location are not precise enough for one to work out where he found shorelines, but he seems to have identified 'terraces' and 'gravel' at different heights on several cones. McCall said, "These cones show lake-shore lines identified as Gamblian midway up their slopes . . ." (1957a p. 23) and correlated them with the Menengai shoreline (1957a p. 25), presumably on the basis of altitude. He did not, however, specify the altitudes of the shorelines or the cones on which he found them.

An air photograph of the volcanoes (plate A2) shows clearly on several of them a series of what appear to be horizontal terraces running round the outer slopes of the cones. These are particularly clear along the western slope of the volcano Karterit, where as many as three terraces seem visible. When the volcanoes are looked at in the field, these features are much less striking than one would expect from the air photographs. They are best seen from several miles away. Their visibility depends partly on light conditions; they are also best seen when shadows are rather long. The state of the vegetation may also be important; they seem to be clearest after a long dry season, when most of the grass on the slopes is dead. The growth of fresh grass during the rains makes them less visible. I noticed this particularly in the case of the lower notch on the north-east slope of Karterit, which was quite clear in March 1967 (when I took plate 14), but by the time I tried to rephotograph it and level to it in May and June was virtually invisible. The closer one approaches to the volcanoes, the less obvious most of these features appear. The western slope of Karterit, when seen from a few miles away on the Gilgil-Elmenteita road, shows only a faint horizontal banding, and I spent several hours walking up and down the slope without recognizing anything that might account for its appearance on the air photograph.

It was equally hard to distinguish any horizontal feature on Split Hill, and the cone when seen in profile showed no marked break in slope that might account for the shadow on the air photograph.

This is not to say, of course, that these features do not exist, but merely to show the difficulty of actually finding them on the ground and hence of mapping them and measuring their altitude. The best-marked of them (on the ground) is the higher one on the north-east slope of Karterit. This is not especially striking on the air photograph, but it is in fact a cliff up to about 5' high in parts, running across the hillside (plate 15) an equivalent feature also appears on the opposite, north-west spur of the divided volcano. The other features, which show up clearly on the photographs and not when one walks across the slope, are presumably slight concave breaks of slope. These would show in the exaggerated relief of a stereoscopic view, but might well be undetectable to someone actually on the slope. The older volcanoes are covered with tangled vegetation; on the west slope of Karterit this was often above head height and movement and visibility were not easy. The slopes tend to be uneven, with rocky boulders and slabs outcropping in places, and on the west slope of Karterit I could follow no apparent 'terrace' for more than a few yards along the slope before it changed level. I found no possible beach pebbles there either, and consider it unlikely that they would have been preserved in situ on such a steep slope.

It is possible that these features are not lake shorelines; two other possible origins might be: (i) The notches might result from subaerial erosion, picking out harder and softer bands in the tuffs which form the cones. However this does seem to have happened in parts on the inner slopes of some of the cones and the features which result are less clear cut and not as straight as the possible shorelines. (ii) They might have been formed by faulting of the cones, and subsequent erosion along the lines of weakness. However the faults which have broken the cones in this area seem to have slashed straight through them, rather than curving round their slopes as the terraces so clearly do. (See especially the north-west spur of Karterit on the air photograph, plate A2.)

Most of the features which show on the air photographs and at a distance appear to be close to horizontal; this is not true of the cliff on the northern end of Karterit. From a distance I could see an upper and (in March) a lower line on the hillside; the upper one has a slight dip outwards (downwards to the east) from the central valley through the cone. On the opposite spur of the cone a similar line at about the same height dips in the opposite direction. The upper notch on the north-east spur is the most striking of these features and is a rocky scar running across the hillside. In parts it forms an overhanging cliff over 4' high, cut in the slabby steeply dipping tuffs (plate 15). Sometimes it is less distinct and looks only like a jumble of slabs of this rock, but its line can be traced clearly right across the hill. The lower notch could be seen from a distance in March; later when I looked for it, it was not clearly visible. On the slope itself there was only a rather indeterminate rocky belt and no distinct cliff as existed higher up.

It is hard to be certain about the origin of these features. The upper notch, at least, appears to have been formed by erosion; the lake shoreline probably did stand against the cone at about this height and it is not easy in this case to imagine another agent than waves along a lake shoreline producing such a feature. Although I could find no pebbles or beach gravel immediately below the upper Karterit notch, there are sediments of definitely lacustrine origin along the east slope of the volcano (at 8V/4) and in the hollow at its northern end (at and above 8V/8). These include diatomaceous silts (some containing fresh-water mollusca) and pebble-beds, and the correlation in height with similar sediments below the Menengai shoreline is quite good. (See Chapter 5.)

I measured the height of the upper Karterit notch in two ways, firstly by levelling up to its eastern, lower end, and secondly by taking a horizontal sight from a point on the Gilgil-Elmenteita road, whose height I then determined. In the second case I sighted onto the notch at its central height about half-way across the hillside. I also tried to sight onto the lower notch in the same way, but left it too late in the year and the notch became almost indistinguishable, probably because of the growth of vegetation over the rock. The results of my levelling are given in Chapter 5.

If the features on the Elmenteita volcanoes are lake shorelines, it appears (i) in the history of the lakes in the Nakuru-Elmenteita basin there has been more than one stillstand level long enough to erode some kind of a feature on the cones. It is difficult to estimate how long such a stillstand would have to be, particularly in the case of the features which show up on the air photograph and from a distance but can hardly be seen on the actual slope. (ii) In the case of Karterit it would seem there has been a tilting of the body of the volcano, away from the central fault line on either side, since the notches (or at any rate the higher one) were cut.

Honeymoon Hill; this is a much eroded volcanic cone north of Lake Nakuru. It is believed by McCall to be of the same age as the older cones south of Lake Elmenteita and is made of a similar yellowish tuff. On its northern side one can in some lights distinguish a horizontal line rather similar in appearance to some of the fainter lines on the Elmenteita cones; this cannot be traced on the ground surface. The altitude of this line is probably below 6100', i.e. if it is a shoreline feature, it was formed during a lower stillstand of the lake than were the best marked cliffs on the Elmenteita volcanoes.

CHAPTER FIVE

THE MAJOR STILLSTAND LEVELS IN THE NAKURU-ELMENTEITA BASIN

1. Evidence of Lakes above about 6400'

It should be stressed that as the basin is today, no lake could be contained in it above an altitude of about 6390' S.D., which is slightly more than 600' above the present day level of Lake Nakuru. I have verified this by careful levelling (map 5) and the height of the present overflow level, according to my measurements, is between 6391-6392' S.D. At this level, water would begin to flow into Menengai caldera. The height of the caldera rim is such that in theory the water would flow out again at a still lower point on its north-east corner. However it seems unlikely that any such overflow occurred. The caldera floor appears highly permeable and at present there is no surface water there, apart from a few damp patches which sometimes form close under the walls. I would suggest that even under considerably moister conditions, with a higher rainfall and larger streams flowing into the caldera, it would have been able to absorb a reasonable amount of overflow from the lake. The caldera would certainly have been damper, possibly rather swampy in parts, but I do not think there was ever a large lake in it. The volcanic activity within the caldera since the time of the possible lake overflow has produced quite a large volume of lava and some small ash cones. This may have changed the level of the overflow slightly (see below, page 128) but has certainly changed the inside of the caldera and obliterated any signs there might have been of the earlier presence of standing water within.

Earlier workers in this area appear not to have recognized the existence of such a low outlet from the basin. Leakey categorically stated: "We have surveyed very carefully indeed, and there is a definite basin in the Nakuru district which is everywhere shut in and where it is possible to have a lake 300 feet above the present level" (1931a p. 513). This would be at a level of about 6577' R.D. Nilsson said: "If one follows the beach on Menengai further eastwards, one finds that it does not here reach so high that the corresponding lake could have found an outlet into the caldera of Menengai and from there northwards" (1931 p. 296). The shoreline referred to is the high one which I have called the Menengai shoreline and which towards its eastern end is said by Nilsson to be at an altitude of about 6425' R.D. All Nilsson's maps of the basin show the highest lake definitely enclosed below 6600' on the Bahati plain, but extending across the divide at Gilgil. This with present day relief is a physical impossibility; McCall said of the Gilgil divide: "It is important to note however that this divide is at a level higher than the lowest point in the margin of the Nakuru-Elmenteita basin, the Nakuru-Solai divide situated to the east of Menengai, at an altitude of just over 6500 feet" (1967 p. 66). This does appear to be the approximate height of the saddle between the Nakuru-Elmenteita and Solai basins, but it seems that McCall did not realize fully the implications of the low point on the caldera rim and its possible role as an outlet from the lake.

It is not clear to me how such a large error (of 200') can have entered into the earlier estimations of the height of the lowest point on the rim of the Nakuru-Elmenteita basin. It is true that many of the older maps have very inaccurate formlines, particularly in the Bahati area, showing the basin closed at over 6600'. On the other hand by the 1920s the railway had been built through Nakuru and more precise and accurate height control was available from there, only a few miles south of the Bahati plain. It may be that the whole possibility of overflow into Menengai caldera was overlooked; even so, the Nakuru-Solai divide is lower than the Gilgil divide and less than 800' above the present lake. The most recent map (no.119/1 of the 1:50,000 series) is a great improvement on the early ones; it has formlines at 50' vertical intervals which show the level of the low point of the crater rim to be between 6350-6400'.

At present, given a sufficiently high rainfall, the level of the lake would rise until it reached the Bahati outlet and overflow would then take place into the caldera. No shoreline features would be formed and no lake sediments deposited above a level of about 6390'. However one can find, in the literature and in the field, evidence for lake shorelines and lake sediments at altitudes well over 6400'.

Nilsson mentioned a number of very high shoreline terraces. In his 1940 shoreline list (pp. 75-7); he quoted 9 terraces said to be higher than his height for the Gilgil pass (6612') and about 34 whose heights were above the Bahati overflow level (see fig. 4). All of these were described as terraces, i.e. small concave breaks of slope, and not as beach deposits. Their positions are shown only on a very small scale map (1940 p. 25) and it is impossible to locate them very precisely. However it appears that most of the highest of them are in the southern part of the basin. According to Nilsson, there was contact between the Nakuru-Elmenteita and Naivasha basins over the Gilgil divide, and there has since been uplift of this area, centred on Eburu; this is believed to explain the presence of these extremely high shorelines in the southern part of the basin and the fact that the equivalent high level shorelines towards the north of the basin are not at such high altitudes.

I investigated carefully the higher slopes in the south-eastern part of the basin, in particular around the divide at Gilgil, for any trace of the terraces described by Nilsson. The map in the 1931 paper gave rather more detailed information than did the 1940 one. It showed the 'lake I' shoreline, at over 2000 metres (close to 6600') on the spur north of Gilgil town and also to the south of the town. Nilsson also showed a shoreline which was given in the list as being at 6659' R.D., 0.62 miles north of Gilgil railway station. I was not able to identify any of these terraces, or find any other signs of a former lake at this level on the Gilgil divide. The slopes tend to be rocky, with a thin reddish-brown soil over volcanic rock, and although there are often quite a lot of small stones in patches on the surface, I could find no rounded pebbles at all. Nor did it seem possible to identify any of the small breaks of slope as being shoreline terraces. It seems clear that any such breaks in slope, on the mainly north-south aligned sides of the spurs, are likely to be formed by small faults. There does seem to be a fairly marked division, at slightly above 6600', between the gently sloping area of the divide and the rocky slopes surrounding it. However this division is not everywhere at the same height and cannot really be said to resemble a shoreline feature in any way. Nor was the topographical discontinuity paralleled by any sedimentary discontinuity. The soil on the flat part of the divide might be a bit deeper than that on the surrounding slopes, but basically it seemed to be similar; rather dusty, brownish, with a few small stones but no pebbles nor any sign of lacustrine sedimentation.

I also looked for Nilsson's higher altitude shorelines elsewhere, such as on Lion Hill and on the slopes of Eburu. Several groups of terraces over 6400' were listed for these areas. I was not able to find any cliff or terrace that I could say had been formed by wave erosion high up on these slopes. There are small rocky cliffs, almost certainly fault scarps, running approximately north-south on Lion Hill. On Eburu I found erosion scars, small 'cliffs' and gullies cut in the coarse red silts. Some of these may have been mistaken for shoreline cliffs by Nilsson; see discussion in Appendix A.

On his map (1931a p. 499) Leakey showed the following shorelines as being above 6400' in the Nakuru-Elmenteita basin:

Southern part of Lion Hill - shoreline at 775' A.L. (=6552' R.D.)

South of Gamble's Cave - shoreline at 690' A.L. (=6467' R.D.)

In the text, he referred to "a high-level lake, which left a clear terrace at 775 feet above the present level of Lake Nakuru. This lake seems to have fallen gradually leaving a well-marked rest-level at a point some 600±feet" (1931a p. 500). The 775' terrace was attributed to the Lower Gamblian pluvial period, which according to Leakey came soon after the close of the last major episode of faulting and vulcanicity in this part of the Rift Valley. Leakey was definite (1931a p. 513) that this 775' lake was contained in a basin similar to that of the present day, and that the beaches were only very slightly tilted and had not been brought to their present high altitude in the basin by uplift through faulting.

In the second main account of Leakey's work (1931b) it was said of the Nakuru basin, "The topography of this basin suggests the presence of three principal rest levels of the lake; but no widespread beach has as yet been found to correspond to the highest of these, although various high-level terraces and beaches have been found, notably on Lion Hill in the centre of the basin, where the highest terrace stands 750 feet above lake level" (p. 247).

There was no mention of any other shorelines at above 700' A.L., beside those near Gamble's Cave and on Lion Hill. It appears that both of these are terraces and that no beach sediments were found associated with either of them.

Again, I can only say that I have failed to find these features, although I would not therefore claim that they do not exist. The southern part of Lion Hill, on which the 775' shoreline is marked, is particularly broken and thickly vegetated country; although I spent several days cutting my way through the forest and scrambling up the slopes, I found nothing that I could identify as a shoreline terrace. The area above and south of Gamble's Cave is rather more open country. Dr Leakey pointed out to me the spur above the cave as being the higher terrace; when I examined it, however, there did not seem to be any feature there as high as 690' A.L. (6467') and it might be that this is a misprint for 590' A.L. (6367'). This would be closer to the height of the slope outside the cave and also agree better with Leakey's suggestion of an approximately 600' A.L. stillstand; there is no other feature mentioned at a height anywhere near 690' A.L.

Leakey also described a beach at about 6600' (its height is not very precisely given) close to the Gilgil Railway Station and 'Gilgil Hotel'. It is attributed to the high (approximately 380' A.L. Naivasha) shoreline of the Naivasha basin and is shown as being definitely on the Naivasha side of the divide (section of basin in Leakey 1931a p. 504). It is not presented as evidence of contact between lakes in the Nakuru-Elmenteita and Naivasha basin at Gilgil; Leakey did not believe that such contact had taken place between the "Gamblian" or later lakes. If the beach was actually at 6600' it would be very close to (according to my levelling actually above) the height of the divide. However the most recent height information and my own levelling show that the Gilgil Railway Station and former hotel are at about 6580' S.D. and below, definitely on the Naivasha side of the divide. Unfortunately I was unable to find the beach itself, and so confirm its height beyond doubt. It was apparently found in the foundations of the hotel, and so would not be easily located today. If it is in fact in the hotel foundations, it is almost certainly not above 6580', and would not indicate any high level lake contact between the Nakuru-Elmenteita and Naivasha basins.

Thompson and Dodson (1963) tend to follow the opinions of Leakey and Nilsson concerning the history of former lakes in the basin, and appear to have done little further fieldwork of their own to check or add to the earlier work on the shorelines and sediments. They said that, "During the course of the present survey, the maximum extent of the Gamblian I lakes was found to be approximately at the 6550 foot contour throughout the area, both in the Naivasha and Nakuru basins" (p. 47). On their map, the "Ql -

Quaternary lacustrine deposits" were shown over a wide area between the 6400' and 6600' formlines on the northern slopes of Eburu and near the River Nderit. They did not, however, give any further details of these high lacustrine sediments or the sections in which they were found. I tried to confirm the existence of lacustrine deposits in this area at such high altitudes. It is clear that somewhere here to the north of Eburu there is a transition from fine greyish soil (apparently derived from diatomaceous silts of lacustrine origin) to the higher slopes which are covered with coarse reddish-brown silts, presumably derived from volcanic material and of terrestrial origin. I concluded that Thompson and Dodson probably overestimated the altitude at which this change in sediments takes place on Eburu; their suggested value of 6600' may have been influenced by the fact that Leakey mentioned the highest Lower Gamblian lake shorelines as being at over 6550'. The exposures of sediment in most of this area are rather few, but I got information from various small sections and pits on the farms and from borehole records. This area is not crossed by deep valleys, so there is no hope of seeing a sedimentary sequence comparable to that exposed in Prettejohn Gully.

The highest exposures of definitely lacustrine material on Eburu are listed below, in the section on the 600' shoreline. Apart from a small faulted patch of diatomite at SE/2, all of them are well below 6400' and do not seem to have originated in any lake which was above the present Bahati overflow level. I looked hard for higher exposures of diatomaceous silts or of lake pebbles, especially across Prospect Farm, but was not able to find any. A pit about 10' deep (9/7) showed coarse orange-brown silt overlying angular, grey volcanic material (pumiceous) with no sign of any stratified material or lacustrine sediments. A certain amount of grey and light brown or yellowish tuff with pumice fragments in it is visible in small outcrops on the lower part of Prospect Farm. Higher up thick beds of the coarse reddish-orange silt are exposed. The bore-hole records contain occasional references to 'lake beds' and 'water rounded sediments' at various depths, including a few which would probably be above 6400', judging by the altitudes of the boreholes and the depths from which this material was reported. However these borehole records are kept very roughly by the foremen, who are not geologists, and it is quite likely that any light coloured, rather fine material might be described as a 'lake sediment'. I was able to examine the samples of material from these bore-holes, kept at the Water Development Department (Ministry of Works) in Nairobi, and found the greater part of the material to be volcanic, lava and pumice and yellowish tuff.

There was nothing that could be described as a lacustrine silt or as rounded beach pebbles. It is possible that any really fine sediment would not be preserved in the samples, or even recognized during the drilling, if it were only a narrow layer. However it seems likely that the light-brown lake beds that are described in the borehole records may be fine tuffs and ash rather than diatomaceous silts. Boreholes c 533 and c 1877 (see map 3) were both shown on Thompson and Dodson's map as being within the area marked Ql, at over 6400'. I walked around and between these boreholes and could find nothing that looked like a lake sediment; the area was covered by coarse red silts on the surface and exposed in sections over 10' deep in erosion scars and gullies.

In brief, I found none of the recent lacustrine sediments on Eburu above about 6300-6350', nor was I able to see any sign of an actual shoreline there. I found two quite small sections, possibly slightly above 6400', of stratified fine rather rounded pumice fragments (see map 3, EP_1 and EP_2). One of these lies in a gully and may be a stream or deltaic deposit from a moister period; the other appears to be on a slight ridge rather than in a valley and is not quite so easily explained. These two small isolated deposits of stratified material surrounded by the coarse reddish silts do not by themselves seem strong evidence of widespread lake sedimentation.

McCall mentioned virtually no evidence of recent lacustrine sedimentation above the 6400' level in the Nakuru-Elmenteita basin. His map unfortunately does not cover the southern part of the basin as far as the slopes of Eburu. There is only one outcrop of Middle Pleistocene or younger sediment shown above the 6400' contour on that map, and that is the patch of Pl1$_3$ (Upper Pleistocene Larmudiac and Gamblian beds) which lies on the 6600' formline north of the River Makalia. I attempted to locate this outcrop, but was unable to do so in the short time I had to spare, especially as this was during the rainy season when this area is not easily reached. It is possible that this exposure is of volcanic rather than lacustrine material; it might even be some distance below 6600', since the formlines in this part of the map are not very accurate. If it is a lacustrine deposit at 6600' feet or above, it would appear to have undergone some movement relative to the divides at Bahati and possibly also at Gilgil, since it was laid down in a lake in this basin. The sediment might be comparable with the sediment exposures listed below which are small faulted deposits and appear to be older than the 600 foot shoreline and associated sediments.

8E/2 is a small deposit originally described by Saggerson (1950). He gave its altitude as 6600'; I levelled from Eburu Station and found it to be at 6512' R.D. (=6506±3' S.D.). It lies on top of a steep scarp of volcanic rock; the deposit includes circa 2' of a rather impure diatomite with a lot of grey pumice pieces in it and with bands of fine light grey and grey-brown material of volcanic origin. It is a small, horizontal exposure with the different layers weathered into a slabby surface. The exposure is quite isolated at the top of the nearly 200' scarp and there is no sign of any similar rock nearby. It seems clear that this diatomite is a considerably older deposit than those not far from it at 8E/3 and 4 (see below) and that its deposition predated a period of a certain amount of faulting and erosion in the Nakuru-Elmenteita basin.

8/9 is an exposure of what seems to be a rather pure diatomite which lies isolated above the Gilgil divide. I have not found it referred to in any of the published or unpublished literature on Kenya diatomites or on the geology of this area, although the pit has apparently been worked to a small extent. Its altitude is between 6643-6650' S.D., which is higher than the Bahati overflow and possibly also than the top of the barrier to the south of the Naivasha basin before Njorowa Gorge was cut. The diatomite is at least 6' thick and is quite pure and soft and white, like some of the purer beds at Kariandusi. It occurs in a saddle on top of a steep narrow ridge of faulted volcanic rock, and I could find no sign of similar deposits nearby or on other parts of the divide.

8/4 and 8/5 are exposures along the main Gilgil-Nakuru road; the sediments are very clearly visible and it seems strange that no mention is made of them by McCall in his text or on the map. The section at 8/4 is about the highest point at which these sediments are exposed; its altitude is about 6430-6440' S.D. The exposure is about 3' high and extends for several yards along the road. It consists of even layers of whitish silt, fine grey volcanic ash, slightly coarser orange material and very smooth round pumice pebbles. The pebble beds are slightly cemented and reddish stained. The beds have a slight southwards dip and are crossed by transverse cracks and narrow veins containing a light coloured material. These sediments, which include pure diatomaceous silts and well sorted beds of pumice pebbles, are clearly of lacustrine origin. The silts are quite firm and sometimes there are many small cracks and fissures on their surface. Similar layers can be traced northwards down the main road and also down the road to Elmenteita, whose junction with the main road is just opposite 8/4. Westwards, down the Elmenteita road, the fine white silts occur with a particularly well-developed 'pebble conglomerate' of very rounded pumice pebbles, well-consolidated and outcropping in slabs and blocks. It is not clear exactly where the westward limit of this exposure is, but it does not seem to extend more than a hundred yards or so west of the main road.

The exposures of lacustrine sediment north along the main road from 8/4 seem almost to alternate with volcanic rocks in a series of small cuttings. The volcanic rock is blocky, rather light grey with a yellowish tinge, with rather large distorted vesicles showing flow structure. The exposures are not continuous, so that it is hard always to work out the exact relation between the volcanics and the sediments. However it seems clear that the sediments form a narrow strip, not extending far west or east of the road. They occur in small faulted blocks or enclaves within the volcanics along this line. The volcanics and white silts are juxtaposed in section 8/5, almost at the lowest end of these exposures towards the north; its altitude is probably some way below 6400'. The relationship between the silt and lava is shown in plate 17. The silt here has a contorted appearance, with haphazard inclusions of grey pebbles and pebble conglomerate; this might suggest that it was included in a moving lava flow, although there seems to be no sign of baking of the silt by the heat of the lava. The contact between silt and lava here does not seem to be a faulted contact.

It is not certain that all of these diatomites are of the same age, or that all or any of them can be correlated with the Kariandusi diatomites which are nearby, although at a rather lower altitude. In the case of the exposures at 8/4 and 8/5, it seems unlikely that they are the same age as the Kariandusi sediments. The Kariandusi silts are said to overlie a faulted surface of volcanic rocks, and to be only slightly faulted themselves; the silts at 8/4 and 8/5 seem to lie within and in parts perhaps under volcanic rock and to predate a fair amount of faulting and perhaps the emission of lava flows in this area. It is clear that each of these deposits (including 8E/2 and 8/9) were laid down in lake basins rather different from those of the present day. In the case of 8E/2, the difference may not have been very great, and the deposit may owe its present height to having been pushed up on the scarp in a localized episode of faulting, while other areas remained relatively stable, including perhaps the divides at Bahati and Gilgil. The layers of fine volcanic ash and pumice in the deposits at 8E/2 and 8/4 suggest that they were being deposited while there was some volcanic activity occurring in this region. The position of the diatomite at 8/9 high up on the divide suggests possible more serious faulting since it was laid down. It has probably been thrust up some distance from the lake floor on which it was laid down. If it is assumed that the sediment was deposited at anything near this altitude (well over 6600') one is faced with the problem of explaining how such a high-level lake was contained in this part of the basin, and where its northern and southern shores were.

I made a brief microscopic examination of these silts to check that they were in fact diatomaceous, but did not study them in detail and have not attempted to work out in detail the relationship of the silts to each other and to the episodes of faulting and vulcanicity in the basin. This study, although of great interest, would not be directly relevant to my investigation into the younger lakes whose shorelines are preserved in the basin. The distinction between these small deposits of quite hard white silt and the softer light brownish or greyish silts and pebble beds found below 6400' is clear. These small deposits may contain silts the same age as those at Kariandusi, post-dating the last major faulting of the Rift Valley, or possibly in some cases rather older. At any rate it is certain that all of them predate at least some faulting which has lifted them from their original position on a lake floor or shoreline. This faulting may not have changed the topography of this area very much, but it was enough to disrupt the lake sediments and also the shorelines of these older lakes. It is thus of no value to correlate these sediments by altitude or to attempt to trace a shoreline from their altitude within the basin. They seem to belong to a sedimentary episode which is quite sharply delimited from that of the 600 foot and later lakes. The break in lacustrine sedimentation between these episodes can be explained as resulting from a period of faulting and possibly also vulcanicity; it does not provide evidence of an arid "interpluvial" phase.

There is a small deposit of stratified volcanic material (grey pumice 'pebbles', rather small and rounded, and darker fragments of heavy minerals) rather similar to those described above on Eburu, towards the north-east corner of the Bahati plain, at 3/10. It appears to be some distance above 6400' and thus considerably higher than the widespread beach deposits of the 600 foot level. It is an isolated deposit and lies close to the Ngosur stream; a rather similar deposit (3/15) occurs some distance downstream, at about 6200'. These deposits may be fine river gravels laid down along a larger stream under moister climatic conditions; they do not seem to be lake beach deposits such as are at 3/6 on the Bahati plain.

I have failed to find in the Nakuru-Elmenteita basin convincing evidence of a recent lake shoreline at above 6400'. There are faulted lacustrine sediments above that altitude which indicate that the relationship between the height of the Bahati overflow and other parts of the basin must have changed at some time since those sediments were laid down. This might have taken place through changes on the Bahati plain and at the rim of the caldera to lower the outlet from an altitude of rather over 6500' to its present level. However, the most recent faulting does not appear to have affected this part of the basin and the rim of the caldera may have remained quite stable since the original collapse associated with the actual caldera formation. According to McCall: "The grid-faulting tends to be concentrated in the basins, and to die out on the volcanic massifs such as Menengai and Eburu" (1967 p. 14). The position of the diatomaceous silts in the south of the basin at altitudes above the Bahati overflow may thus be due to their having been thrust up on fault blocks rather than to an absolute lowering of the overflow. An estimate of the necessary amount of movement can be obtained by comparing the heights of these diatomaceous silts with those of the divides at either end of the basin. The heights are these:

Diatomaceous silt	8/9	6650' S.D.
	8/4	6440' S.D.
	8E/2	6506' S.D.
Gilgil divide		6597-98' S.D.
Bahati overflow		6391-92' S.D.

The sediments at 8/4 and 8E/2 are below the Gilgil divide, and would only need a relative movement of about 120' to be below the Bahati overflow also. The diatomite at 8/9 is over 100' higher, and its position, clearly on a faulted block, on the crest of the Gilgil divide would require rather greater movement. Its possible connection with the Naivasha basin makes the 8/9 diatomite difficult to interpret. However the total faulting implied by these sediments is only of the order of 200' or 300', which is relatively little when compared with some of the major Rift Valley faulting (throws of several thousands of feet) which has taken place in this area. (McCall 1967 pp. 99-100)

No comparable outcrops of older faulted diatomaceous silts are recorded from the northern end of the basin, in the area near the Menengai shoreline. This may be because these older silts were laid down in a lake predating the caldera eruption and have been covered by the thick pumice mantle which was produced in this eruption. Alternatively, the older silts may also post-date the caldera formation and be separated from the younger sediments by a period of minor faulting only. In this case their non-appearance above 6400' in the northern end of the basin would be merely a matter of chance.

It does seem that in the northern part of the basin pumice falls have blanketed the topography in some parts and may also have covered some older lacustrine sediments. In the south there was probably no bulk production of volcanic debris on the scale of the Menengai eruption. The lavas and tuff cones of the Elmenteita badlands are low down in the basin and the coarse material produced seems to have been rather restricted in its distribution. The sedimentary record was not interrupted by thick pumice falls as it appears to have been on the slope above the Menengai shoreline, and some older lacustrine deposits remain visible.

2. Evidence of the 600 foot Lake Level

During my fieldwork in the Nakuru-Elmenteita basin I found a considerable amount of evidence for an important shoreline at about 600' above the present lake level, that is, at about 6370' S.D. This includes the following: (i) The shoreline cliff and terrace on Menengai. (ii) The sequence of sediments below this shoreline. (iii) The Bahati overflow and the sediments at 3/6. (iv) The Eburu diatomites. (v) The sediments and possible shoreline at Gamble's Cave. (vi) Other sediments in various parts of the basin including Lion Hill, Njoro Road, Karterit. This evidence is summarized in Table IV.

I have discussed the nature of the different kinds of evidence (e.g. the shoreline cliffs, the beach pebbles, the silts) in detail in Chapter 4. Here I shall summarize the evidence and discuss the height correlations between sediments and shorelines in the different parts of the basin, their relationship to the height of the overflow, and the question of tilting of this shoreline.

Table IV

Summary of evidence for the 600 foot shoreline

Locality	Base of cliff	Highest lava pebbles	Pebbles and sand (highest)	Highest diatomaceous silts
Menengai	6370'	6381'	6357' 6341-43'	6303'
Bahati	overflow 6391-92'		6343-44'	
Njoro Road	c 6360'		6303'	
Lion Hill		6383'		6331'
North-East Elmenteita		*6368'		6243'
Kariandusi		*6378' 6338'		6338' *6329'
Kekopey		6364'		6311' *6345'
Gilgil Escarpment		6318'		6313'
Karterit	c 6365'	6293'		6320'
Adjusted from railway datum+				
Eburu		6360'		6338'
Nderit-Gamble's Cave	*6388-6398'		6347'	6286'
Makalia				6314'

\+ 6 Foot adjustment from railway datum to survey datum.
* The lacustrine origin of these features is not certain.

A. The results of earlier work

The importance of this circa 600' A.L. shoreline does not appear to have been generally recognized by earlier workers in the basin, although they did describe a number of shoreline features from about this altitude. Leakey (1931a p. 499) showed beaches on Lion Hill at 608' A.L. (=6385' R.D.) and at 590' (=6367' R.D.) and possibly another at 590' south of Gamble's Cave. These were believed to indicate a "well-marked rest level" in the fall from the Lower Gamblian high lake at 775' A.L. Solomon (in Leakey 1931b) mentioned a terrace at about 600' A.L. (=6376' R.D.) and beach gravel in the cave on Lion Hill, said to be at 620' A.L. (=6396' R.D.). There is no mention in either of these works of the cliff and terrace on Menengai (at 6370' S.D.). This seems strange, since it is a very well marked feature and easily accessible (even in the 1920s and 1930s it was close to the railway line and not far from Nakuru town) and is described fully by Nilsson, who was working in the area at the same time as, and partly in collaboration with, Leakey and Solomon.

According to Leakey, the circa 600' A.L. 'rest level' was not as important as the next below it; "The most widespread rest level is that represented by the beach in Gamble's Cave and dated as Upper Gamblian in age" (Leakey 1931b p. 247). Leakey listed the evidence for this shoreline as:

Gamble's Cave	500' A.L.
Above the precipice west of Lake Nakuru	490' A.L.
Terrace at foot of Lion Hill	510' A.L.
Beach and terrace on Gilgil Escarpment	530'(?)A.L.

(from Leakey 1931b p. 247; height of lake is given as 5776', presumably R.D.). On the map in Leakey 1931a, the Gamble's Cave height is given as 503' A.L., the Lion Hill height as 506' A.L.

The height of this "Upper Gamblian" shoreline is most generally quoted as 510' A.L. It is suggested from the height evidence quoted above that there has been slight tilting (downwards to the west) subsequent to the formation of the beach. From my fieldwork I was unable to confirm that an important shoreline exists at about 510' A.L. (i.e. at circa 6286' R.D. or 6280$\pm$3' S.D.). The results of my fieldwork at the different localities are summarized below; here I shall comment briefly on the evidence for the 510' level as it is listed above. At Gamble's Cave the beach sand is at 6347$\pm$3' S.D., i.e. at least 567' A.L. Nakuru. The beach gravel at the base of the Gilgil escarpment is at 6318' S.D., circa 538' A.L. Nakuru; it lies at the base of a steep cliff and does not seem likely to be at its original level on the lake shoreline. I could find no sign of a terrace at the foot of Lion Hill that indicated a stillstand of the lake at about 6286'. I was not able to locate the shoreline described as being "above the precipice west of Lake Nakuru" at 490' A.L. (circa 6260' R.D.).

I cannot, from these results, accept that there was an important stillstand of the lake at about 510' A.L., whether or not a small amount of tilting is admitted. It is true that the most widespread shoreline does appear to be that represented by the beach in Gamble's Cave, but this is considerably above the 510' level.

Nilsson did not place his shorelines in groups with a small height range. Because of his theory of tilting, each of his higher groups included terraces of very different heights. The full sequence, as correlated with Leakey's sequence, is shown in Table I. The suggested "Gamblian" shorelines were these:

Lake I shorelines at circa 634-877' A.L. (=6415-6659' R.D.)
Lake II shorelines at circa 634-690' A.L. (=6415-6471' R.D.)
Lake III shorelines at circa 358-601' A.L. (=6139-6383' R.D.)

None of these groups can be said to be equivalent to Leakey's 600' or 500' A.L. rest levels, or to the approximately 600' A.L. shoreline which I have found. Nilsson did recognize and level several of the important features of the 600' shoreline level, including the cliff and terrace on Menengai and the beach and possible cliff at Gamble's Cave. However the heights of his terraces and beaches in the Nakuru-Elmenteita basin (listed 1940 pp. 75-7) do not show any concentration at either 600' or 500' A.L. Nakuru, although some terraces from approximately these altitudes are listed (see fig. 4).

McCall's map (1967) showed the shoreline on Menengai, crossing the 6400' formline at rather a steep angle and clearly very roughly drawn. He showed almost no lake sediments above 6400' in the Nakuru-Elmenteita basin and suggested that the Larmudiac sediments only occur below the high-level shoreline on Menengai. Later when we discussed the sediments in more detail he suggested that this height relationship is almost certainly a coincidence and that the Larmudiac sediments, which are slightly faulted, are considerably older than this shoreline. It would thus be the younger "Gamblian" sediments which are related to this shoreline.

3. <u>The evidence for the circa 600 foot stillstand of the lake Menengai</u>

On the southern slope of the volcano the evidence includes: (i) The shoreline cliff, best developed over a distance of about 3 miles between profiles 1 and 9 on map 4. The height of the base of the cliff is close to 6370' S.D. and the cliff does not appear to be tilted. It is discussed in more detail in Chapter 4 above; see also the profiles (fig. 1).

(ii) Lava pebbles outcrop on the surface below the cliff and also eastwards where the cliff line itself is not visible. Some of the highest outcrops, shown on map 4, are listed here with their altitudes.

1/23 below the cliff, pebbles up to 6330' S.D.

2/2 over lava surface below the cliff, 6332-6341' S.D.

Below profile 14, on surface up to about 6366' S.D.

Maragoli Avenue, central part on surface, highest pebbles at about 6381' S.D.

Maragoli Avenue, eastern part on surface, highest pebbles at about 6357' S.D. (plate 6)

Along Crater Road, pebbles at 6361-6378' S.D.

These are only a few of the points at which these pebbles occur. They can be traced between the points to which I levelled and for some distance further east around the side of Menengai, at a rather lower altitude. In all they occur on or near the surface between the altitudes of circa 6230-6380' S.D. over a distance of at least 4½ miles. There are rather more pebbles to be found towards the eastern end of this zone, possibly because the pebble beaches there were originally larger than those further west. This could be because there was a greater supply of material for the pebbles from the lava, welded tuff and ignimbrite exposures along this part of the shoreline. Towards the west, where such exposures are not found, I could not find many rounded lava pebbles.

(iii) Sections with layers of pumice pebbles, sand and diatomaceous silt are found along the shoreline at a generally slightly lower altitude than the coarser lava pebbles. The highest section to show any sign of stratification and water-rounded material is at 1/5, close to Nakuru Junction signal box. Its altitude is 6357' S.D. A better developed section (1/7) with well-stratified layers of pale crystalline sand and rounded pumice pebbles is exposed close to it at an altitude of 6340-43' S.D. (plate 10). Another small section which includes a layer of pale grey diatomaceous silt as well as sand and pebbles is visible close to the main Nakuru-Eldoret road, at 1/31; its altitude is 6303' S.D. Further east are a number of similar deposits with layers of pebbles and sand and diatomaceous silt, between the altitudes of about 6173-6332' S.D. They are particularly clear in the gully at 2/11, where outcrops show on either side of the gully wall and there is a progression upslope from exposures mainly of fine diatomaceous silt to exposures containing mostly pumice pebbles and coarse sand. The outcrops at 2/11 lie between heights of 6255-6275' S.D.

The altitude of the base of the shoreline cliff (6370' S.D.) indicates the height at which wave erosion was concentrated and thus the approximate average water level of the 600 foot lake. The highest beach pebbles on Menengai and Lion Hill are at slightly over 6380' S.D. This is about 10' higher than the base of the cliff. They are found at this altitude in areas where the cliff itself is not visible. The occurrence of beach pebbles at this altitude (which is still below the level of the Bahati overflow) is not unexpected. They might result from (1) storm waves building up a shingle beach slightly above the mean lake level; (2) periods of a few years during which the lake level was unusually high. In this case it would appear that the lake remained high long enough for beaches to form at about 6380' but not long enough for a higher cliff to be cut above the one at 6370'.

Bahati

I could only find sediments of undoubted lacustrine origin on the western edge of the Bahati plain, below the slopes of Menengai. I dug two small pits close to the main road Nakuru-Solai (3/1 and 3/2) and found in them even layers of diatomaceous silts and pumice pebbles, at altitudes of 6253' S.D. and 6259' S.D. The section at 3/6 (plates 12 and 13) showed well-stratified layers of pebbles, sand and a narrow layer of diatomaceous silt over a gently sloping rock surface at an altitude of 6343' S.D. Overflow of water would take place from the Bahati plain into Menengai caldera when the level of the lake reached about 6391' S.D. The overflow would occur at the point OF on map 3, shown in detail in map 5, and also in plate 3. The correlation in altitude between the overflow and the base of the cliff on Menengai (6370' S.D.) is not perfect; if the water level actually stood close to the level of the base of the cliff, as is probable, it would be about 20' below the actual rim of the outlet. It is possible that a tilt of the order of 20' has occurred between the Menengai shoreline cliff and the area of the overflow, over a distance of about 6 miles, but I can find no other evidence that such a tilt has taken place in this area. Any change in the rim of the caldera due to faulting or subsidence would be likely to lower its level and not raise it; it is suggested earlier (Chapter 3) that such a change seems unlikely to have taken place during the period since the 600 foot lake existed. The level of the rim may have been slightly raised since the lake stood there, by accumulation of debris washed down from the slopes of Menengai, and, more important, by volcanic products from within the caldera. There has been quite recent small-scale volcanic activity inside the caldera and this might have deposited pumice and ash on the rim and raised its level by several feet. In sections 3/7 and 3/9, on the slope of the overflow (close to OF on map 3), there are several different layers of fresh-looking pumice and ash. This would help to explain why there is at present no sign of any channel out by water across the outlet. It is also possible that the lake level did not need to rise to the actual rim before the effect of the existence of the outlet would make itself felt in halting or at least slowing down a further rise of the lake. This might be through percolation taking place through the permeable pumice and lava which underlie this area, so that water would be lost from the lake and its underlying water table into the crater before the level of the lake reached the height of the surface overflow.

Over the rest of the plain the sediments were not of obviously lacustrine origin but this cannot be taken as proof that the area had never been under water, as already discussed in Chapter 4.

Njoro Road

(i) A faint break in slope, possibly a westward continuation of the Menengai shoreline cliff, can be traced across from the Nakuru Junction area towards the main Nakuru-Njoro road. I levelled this break in slope where it crossed the road; the profile is much longer and more gently sloping than those of the Menengai shoreline cliff, and this is not due to the road building. The base of the 'cliff' on the Njoro road does appear to be between about 6355-6365' S.D., which agrees quite well with the altitude of the Menengai shoreline.

(ii) A small section with stratified layers of pebbles and impure diatomaceous silts is exposed below this slope at 6303' S.D. (4/3).

(iii) The lower part of this area, between the two main roads to Njoro and Eldoret, is crossed by a number of quite steep-sided gullies. They do not appear to contain running water often, and their sides are grassy along most of their lengths in this part. There are a few small exposures of diatomaceous silts, sand and pebble beds, and these can be traced upslope towards the similar exposures around Nakuru Junction. The highest altitude at which the pebble and silt beds are found in these gullies below the Eldoret road is about 6329' S.D. (4/8). It would appear that these sediments are related to the Menengai shoreline level and are of the same age as those that are found below the shoreline further along to the east. They do not appear to be faulted; i.e. they are probably not the same as McCall's Larmudiac beds which he described from this vicinity. (McCall 1967) The Larmudiac beds are exposed in the river sections south of the Njoro road, along the western shore of the lake. It would appear that somewhere in this area, either north or south of the Njoro road, it should be possible to trace a discontinuity between the sediments which are unfaulted and appear to be contemporaneous with the 600 foot shoreline, and the Larmudiac beds which are faulted and possibly considerably older, but also contain diatomaceous silts and pebble beds. McCall suggested (in loq.) that he thought it unlikely that the Larmudiac beds, as he described them, were in fact contemporaneous with the Menengai shoreline, as he had stated in his report on the geology of this area. (1967) Further study in this area would no doubt provide more information on this aspect of the sedimentary history of the basin.

Lion Hill

This is an elongated ridge running approximately north-south in the centre of the basin, defined by quite steep slopes, fault scarps in volcanic rock. When the lake was at the 600 foot level, the hill would have been an island, and sediments from that lake would be deposited around the slopes of the hill. There is plenty of evidence of such sediments round much of the hill:

(i) On the west side of the hill the slopes are often particularly steep and thickly vegetated, so that evidence of the lake at a high altitude is rather hard to find. There is a thick exposure of fine diatomaceous silt and coarse sand and pebbles in a gully and what appears to have been a quarry (5/1) at an altitude of 6027' S.D., and lava pebbles in quite large quantities are scattered widely over the slope from there up to about 6322' S.D.

(ii) At the northern end of the hill in a small longitudinal hollow is a patch of sediments marked F11$_3$ on McCall's map (1967). I found these to be impure diatomaceous silts and some rounded lava pebbles; the silts I traced up to 6318' S.D., the pebbles up to 6359' S.D. (5/10). It would seem that these silts and pebbles, lying in a small hollow, had been protected from the erosion and downwashing which removed much of the lake sediments from their original positions on the exposed slopes of the hill.

(iii) Similar diatomaceous silts occur along the eastern side of Lion Hill forming a gently sloping rather pitted surface beneath the rocky slopes. I found the upper limits of such silts at 6254' S.D., 6245' S.D., 6331' S.D., and 6319' S.D. (at 5/15, 5/12, 5/14), from north to south along the slope. Pebbles occur rather higher up the slopes, at 6348' S.D., 6313' S.D., 6328' S.D. and 6340' S.D.

(iv) There is a small clear exposure of pumice pebbles over diatomaceous silt at the bottom of the slope below Lion Hill Cave (section no. 5/4) which is at 6331' S.D. and thus agrees well in height with similar exposures below the Menengai shoreline.

(v) Lion Hill Cave was said by Leakey (1931b p. 247) to contain a beach gravel underlying archaeological horizons at an altitude of 620' A.L. (=6396' S.D.). From my levelling I found the floor of the cave to be 6387' S.D. (this was the upper part of the floor towards the back of the cave).

At present the cave floor is rocky and there appears to be no sediment in it except for some fine dust. I saw no sign of any beach gravel in the cave or outside it; the nearest rounded pebbles were a considerable distance below the cave. It is possible, as Leakey has suggested, that the beach gravel has been completely removed from this locality during and since his excavations there. In its original position on the cave floor it would have been at about 6387' S.D. and thus correlate quite well in height with the highest pebbles on Menengai and elsewhere on Lion Hill. The slightly greater height of the possible Lion Hill Cave beach gravel can be explained by the sheltered position of the pebbles in the cave, protected from downwashing. It is possible that Lion Hill Cave may owe its existence, at least in part, to erosion by the waves of the 600 foot lake. It is hard to be certain about this from the appearance of the cave, which is an overhanging arch over 20' high and at least 10' deep cut in the jointed lava which makes up the hill. It would seem, however that the cave is at rather too high an altitude to have been formed in this way, since even its floor is at over 6380' S.D.

Leakey mentioned a beach at 510' A.L. (=6286' R.D.) which was said to be immediately below Lion Hill Cave. I could find no evidence of such a beach or of anything that would suggest a separate lake stillstand at about that altitude. There is a small terrace on the hillside slightly below the cave, but it cannot be traced far around the slope and I did not notice any particular concentration of pebbles at that level.

(vi) South of this area there is a saddle across the hill (5/16), a gently sloping area on which there are a lot of rounded lava pebbles which seem to be close to their original position as a lake beach, since they are in parts very concentrated and almost form a low relief feature on the flat saddle. They occur up to 6383' S.D. (plate 5).

North East Elmenteita

This is the name I have given to an area to the north-east of Lake Elmenteita, just to the east of the main Gilgil-Nakuru road at 8/1 on map 3. Here a great number of rounded lava pebbles are scattered on the rather steep, broken slopes of the wall of the Elmenteita basin. Some of the pebbles are shown in plate 6. They occur from the level of the main road (at circa 6140' S.D.) in great quantities up to about 6260', and more sparsely up as high as about 6368' S.D. They are spread across spurs and hollows on the slopes, and do not appear related in their distribution to any particular hollow that might be a drainage line; they are not a river gravel. It does appear that many of the pebbles have been washed down some distance on this steep, bare slope. I found a patch of quite pure diatomaceous silt at 6243' S.D. on the slope, with pebbles around and on top of it. If the pebbles and silt were laid down in the same lake, as seems quite likely, then most of the pebbles have probably been washed down from some distance above the silts.

On a separate faulted block just to the west, on the other side of the main road from the slope with all the pebbles, I could find no pebbles at all, though I looked carefully over the whole slope. This was unexpected, as the height of this block was between circa 6160-6270' S.D., and its eastern slope was not particularly steep and was scattered with a lot of small weathered (but quite unrounded) stones and pieces of rock. It thus appeared just as favourable an environment for the deposition and preservation of beach pebbles as the slopes opposite. The absence of beach pebbles on this western slope would suggest that either they have been completely removed by subaerial erosion since they were on the beach, or that there were never any pebbles on this slope. I find the first suggestion rather hard to accept, since so many pebbles remain on the opposite slope. The second would imply that there was no stillstand of the lake level sufficient to produce a pebble beach between about 6160' and 6270', which is the height of the top of this small separate block. If this is so, the many pebbles below 6270' on the slopes opposite have been washed down from a beach at a higher altitude.

Kariandusi and Kekopey

These are two streams flowing from the eastern edge of the Elmenteita basin towards the lake. I investigated the parts of their courses east of the main road Nakuru-Gilgil.

(i) Along the Kariandusi the diatomites and fine bands of volcanic ash (exposed in the mine further downstream) are overlain by younger pale grey and brown diatomaceous silts. I traced these silts up to an altitude of 6260' S.D. west of the road to Kariandusi station, and as high as 6338' S.D. on the west bank of the stream itself.

(ii) Lava pebbles were scattered rather sparsely on the surface at the base of the rocky slope west of the station road; I traced them to a highest level of about 6316' S.D. Along the river I found a patch of rounded pebbles at 6378' S.D.; it is possible, of course, that this may be a river gravel, although I did not find much in the way of similar pebble deposits downstream from there.

(iii) Along the Kekopey there is a clear section of diatomaceous silts overlying a thick layer of coarse, reddish-orange unstratified silts. The diatomaceous silts taper out and are not visible above an altitude of 6311' S.D. (8/3). Further upstream I found some more outcrops of impure diatomaceous material, small patches on the stream bank at 6336' S.D. and 6345' S.D.

(iv) There were no exposures of beach pebbles or stratified pebble and sand sections in this area near the river Kekopey. I found a few pebbles at the foot of the rocky slope that runs approximately north-south between the two streams, forming the boundary of the basin. The highest were at about 6364' S.D. but there were long stretches of the slope along which I could find no pebbles at all.

This area, in fact, was rather lacking in any definite evidence of the high lake level. Such evidence as there is does agree in altitude with that I found elsewhere, so that these pebbles and diatomaceous silts might well be attributed to the 600 foot lake. However, the distribution of both pebbles and silts along the stream lines gives rise to some uncertainty about their origin. It is clear that the diatomaceous silts were laid down in relatively still water, and in a fair body of water such as is not provided along the present courses of the streams, so, to some extent, they do indicate a former moister climate and higher lake level. It is possible, however, that they were laid down in an estuary or swamp along the rivers at a time when the lake was higher than it is now, but not necessarily right up to the 600 foot level. On the other hand the heights of these silts do agree well with those below the Menengai shoreline and at Eburu (8E/3 and 8E/4) which were most probably not laid down along a stream course, and which can be attributed to the 600 foot lake.

Gilgil Escarpment

This escarpment forms the south-eastern boundary of the Nakuru-Elmenteita basin. It is a striking feature, in parts made up of several steps and ledges, in parts by a vertical rocky cliff over 100' high. The expected shoreline level between 6350-6400' runs across these steep slopes and it is unlikely that anything in the way of a shoreline terrace or beach sediment would be preserved on them in situ. According to Solomon (Leakey 1931b p. 257), "Patches of Gamblian deposits occur to the south of the Kariandusi River, and their final disappearance, at the Gilgil scarp, coincides with a lake-beach and terrace the level of which corresponds well with that of Gamble's Cave and elsewhere". The "Gamblian" deposits to which he referred are presumably the diatomaceous silts which cover the flat land between the Gilgil escarpment and Karterit volcano. They can be seen in small pits and in ant-bear holes, and outcropping at the foot of small scarps which cross this plain. The "lake-beach and terrace" referred to by Solomon are said to be at "530'(?) A.L. Nakuru" (=circa 6306' R.D.) and the question mark is also shown on the map (Leakey 1931a) where the shoreline is shown crossing the main road south of the Kariandusi river. The position of the beach on this map is rather too far to the north, as the beach is in fact certainly closer to Gilgil than it is to the Kariandusi river. The road has now been realigned and the present main road does not run close to this shoreline. The line of the former main road can be traced across the fields a few hundred yards west of the present road (north of the main scarp) and across the present Gilgil-Elmenteita road where there is a small station on the low-tension electric line. South of this it can be traced up across the escarpment at almost its steepest part. Diatomaceous silts outcrop along the line of the road up to a height of 6313' S.D. (12/3) at the base of the scarp. At that point they form a small outcrop unconformably overlain by rounded pebbles. Pebbles occur also a few yards up the road to a highest level of 6318' S.D. (12/3).

This is presumably at, or very close to, the beach and terrace that Leakey described as being at 530'(?) A.L. Leakey told me that the reason for the question mark was that at the time of their fieldwork they were uncertain as to whether the pebbles, to which they levelled, represented the actual height of the original shoreline. He suggested that this height might actually be too high for the lake level itself, as the pebbles could have been thrown up by storm waves to a height above the normal water level. This seems to me rather unlikely; the pebbles are found near the base of a scree over 50' high, which in turn is at the base of a rocky cliff over 100' high, and are probably not in situ. I looked over the scree for any sign of higher pebbles but could find none. Downward movement of material appears to be rapid on these slopes; there are already quite a number of stones fallen on the old road, which was abandoned only about 20 years ago. The section, as it is exposed on the roadside, suggests that the pebbles have been washed down onto the eroded diatomaceous silt; there is no smooth silt-sand-pebbles transition or conformable contact visible. The diatomaceous silt may be close to its original highest altitude, but the pebbles have probably been washed down from a rather higher level. The silts, at 6313' S.D., agree quite well in height with the higher diatomaceous silts from other parts of the basin, as having been laid down in the 600 foot lake. It is not possible to be certain about the level of the lake in which the pebbles originated, but they do not seem adequate evidence of a lower lake stillstand around the 530' level as Leakey suggested.

Karterit

The shoreline features on the Elmenteita volcanoes have been described in more detail in Chapter 4.

(i) On the north-eastern slope of Karterit the cliff runs between about 6355-6380' S.D.; the height correlation with the Menengai shoreline cliff is not bad, allowing for the tilting of the Karterit cliff.

(ii) Over most of the slope below this cliff I could find nothing in the way of pebbles or lake sediments; the slope is rather bare, with slabs of the yellowish tuff of the volcano outcropping.

(iii) Sediments have been preserved in a small hollow, bounded on one side by a fault scarp, which runs down below the possible shoreline cliff. Here I found pebbles on the surface up to about 6293' S.D. and in a section with layers of light silt at 6279' S.D. Diatomaceous silts containing mollusca (8V/3) are exposed at an altitude of 6192' S.D. (plate 16). (For more detailed discussion of the mollusca see Appendix B.) These sediments and pebbles are at a rather lower altitude than the highest ones exposed below the Menengai shoreline and in some other parts of the basin, but they are still within the height range of similar exposures in other areas; there is no reason to suggest that they were deposited in a lake with its shoreline much below the 600 foot level.

(iv) Along the outer eastern wall of Karterit I could find no pebbles at all, but diatomaceous silts outcrop on the flat land a few hundred yards east of the slope of the volcano. The highest of these outcrops were close to 6320' S.D. (8V/4).

Eburu

Close to the former Eburu station there are some outcrops of diatomaceous silt and pebbles which can probably be attributed to the 600 foot lake. The country here is broken and much affected by recent volcanic activity, which had produced small volcanic cones and lava flows, and these exposures occur in a small enclave which was not covered by the products of this vulcanicity.

(i) Rounded lava pebbles are exposed on the surface and in small sections close to 8E/3. The pebbles shown in plate 7 are at an altitude of 6356' R.D. (=6350±3' S.D.). At 9/1 a section is exposed in an old railway cutting in which a fine reddish sand overlies layers of rounded pebbles and a narrow band of impure but definitely diatomaceous silt. (Plate 9) The pebbles in this section are at 6361' R.D. (=6356±3' S.D.).

(ii) The diatomaceous silts exposed in some of the Eburu sections are quite pure and white, and were once prospected with a view to possible commercial exploitation. (Saggerson 1950) At 8E/3 (plates 11 and 18) they underlie layers of sand and pebbles at an altitude of about 6302' R.D. (=6296±3' S.D.) in the main section; a small patch of diatomaceous silt was exposed at 6323' R.D. (=6317±3' S.D.). At 8E/4 there is a small eroded volcanic cone, probably dating from the first phase of volcanic activity in the Badlands and thus predating the deposition of these lake sediments. The diatomaceous silts outcrop around the sides of the cone underlying pebble layers. Their altitudes there are between 6315-6344' R.D. (=6309-6338±3' S.D.).

The heights of these exposures correlate quite well with those of similar exposures in the northern end of the basin. Although no exact comparison can be made, since there is no trace of a shoreline cliff in this area, the relative altitudes of these sediments do not seem to suggest that there has been any tilting between the north and south ends of the basin since they were laid down.

Nderit-Gamble's Cave

The lacustrine deposits in the extreme south-western part of the basin can be considered in two groups; (i) the Prettejohn Gully exposures, and (ii) the exposures near Gamble's Cave and along the Nderit valley.

(i) The Prettejohn Gully exposures; moving down from the head of the gully, these are as follows:

(a) The uppermost part of the gully, where it is a narrow hollow not more than about 6' deep, is cut in weathered orange material that seems to be of volcanic origin, i.e. a fine pumiceous or tuffaceous sediment.

(b) A short distance downstream the exposures in the gully and in the surrounding countryside are of coarse reddish-orange silts, over 20' thick, largely unstratified, but containing some horizontal bands of whitish nodules, possibly calcareous concretions.

(c) Pebble beds; further down are beds of very smooth, well-rounded pebbles of grey pumice. (Plate 8) They occur in well stratified layers with a slight dip in parts; they can be over 5' thick.

(d) Lower down are exposures of grey diatomaceous silts and quite pure white diatomite with very regular banding of fine brown sand. (Plate 19) The silts appear to enter at the top of the cliffs, above the pebble beds. The thickness of diatomaceous silt exposed in the lower part of the gully is over 40' in places.

The altitudes of these sediments along the gully are:

Highest exposure of pebble beds: 6338' R.D. (=6332$\pm$3' S.D.)

Highest grey diatomaceous silts: 6283' R.D. (=6277$\pm$3' S.D.)

Highest white silts (diatomites): 6271' R.D. (=6265$\pm$3' S.D.)

The sequence of sediments suggests deposition in shallow water close to the lake shoreline at the upper end of the gully, and at rather greater depth further downstream, where the diatomites were laid down. The deposits are possibly partly of deltaic origin. Layers of coarse reddish silt appear to interdigitate between the pebble beds and diatomaceous silts, and may indicate temporary falls in lake level when the reddish material, of terrestrial origin, accumulated on top of the lacustrine or deltaic sediments. The altitudes of these sediments are rather lower than the highest similar deposits in the northern part of the basin, but are still well within their height range. This would agree quite well with the suggestion that the Prettejohn Gully sediments are deltaic deposits from the lake when it stood close to the 600 foot level.

(ii) The Gamble's Cave and Nderit valley exposures: in this area I have concentrated on the possible lake shoreline and sediments in the immediate vicinity of Gamble's Cave and the nearby exposures on either side of the Nderit valley. In this work I have been greatly helped by the results of some research done by G. Isaac when he was excavating a section in Gamble's Cave in 1964-5. He has kindly allowed me to see some of the notes and sections he made. My own work has mainly consisted in levelling to the various outcrops of diatomaceous silts and, by establishing accurate absolute heights for them and for Gamble's Cave, making it possible to compare their altitudes with those of comparable deposits in other parts of the basin. I discussed in Chapter 4 the possibility of the terrace and cliff behind the cave being lake shoreline features. It is possible that the two caves themselves,[1] which in fact were originally not more

1. Leakey originally excavated at Gamble's Cave I and Gamble's Cave II, which were close beside each other on the slope; the references in the early literature are usually to Gamble's Caves. Little interesting archaeological material was found at Gamble's Cave I and in most later sources the form used is Gamble's Cave, by which is meant the original Gamble's Cave II.

than shallow rock shelters in an overhanging cliff of light grey tuff, were cut by the waves of the approximately 600 foot deep Lake Nakuru. This was suggested by Nilsson (1931 p. 297). It is impossible to be certain about this from the morphological evidence, since the rock shelters do not show any obvious signs of having been formed by wave erosion. The altitude of the floor of the shelters (below the beach sand) would be at about 6347' S.D.; the back wall goes up over 30' from there. The shelters would thus be within the range of wave erosion by a lake standing at about 6370'.

The heights I obtained for the base of the cliff behind the cave were 6394' R.D. (=6388±3' S.D.), and, slightly to the east, 6404' R.D. (=6398 S.D.), but it is quite possible that these are rather high, because of the accumulation of debris at the base of the cliff, and that if the lake waters ever eroded this cliffline, it was at a level several feet lower than this. The beach sand in the cave is at 6353' R.D. (=6347±3' S.D.); its height agrees well with the heights of apparently similar sands at 1/7 and 3/6 on the northern side of the basin. (The methods by which I measured the height of the sand, and the discrepancy with earlier results, are discussed in Appendix A.)

On the hillside opposite Gamble's Cave, on the north bank of the River Nderit, are some small isolated patches of diatomaceous silt. (10/5, 10/6, 10/7) These appear to be the remnants of a layer of diatomaceous silt which extended from here eastwards towards the centre of the basin. These outcrops are between 6280-6290' R.D. (=6274-6284' S.D.) on the slope opposite Gamble's Cave. Similar outcrops (10/13, 10/14, 10/15) lie between 6256-6260' R.D. (=6250-54' S.D.) slightly further east, again on the north bank of the river. The most striking of these is the residual shown in plate 20; the contact between the overlying diatomaceous silts and rather coarse, orange silts is particularly clear. In the other sections, and also in the sides of the Nderit valley itself, comparable contacts between the rather narrow layers of diatomaceous silt and coarser orange weathered silts are visible.

Isaac has suggested (pers. comm. and in van Zinderen Bakker 1967a p. 30) that the diatomites and fine silts which occur high up in the sedimentary sequences in this area may be of the same age as the beach sand in Gamble's Cave, i.e. were laid down in the 600 foot lake. His Nderit valley sections show that "no important occurrence of deep water sediments was found at a lower stratigraphic level"; this period of lake sedimentation was apparently preceded by a period of lower lakes.

It is impossible to confirm that these diatomaceous silts, the beach sand and the possible shoreline terrace are all associated with the 600 foot lake, since each of these features is isolated from the other. However their altitudes can be compared with those of similar features in other parts of the basin whose relationship to each other and to the 600 foot lake level is better established. The beach sand in Gamble's Cave is quite likely, by comparison with similar sands in other areas (see above) to have been laid down in the 600 foot lake. The diatomaceous silt outcrops between 6250-6284' S.D. are well within the height range of similar outcrops in other parts of the basin. The higher exposures (up to 6320' or more) found elsewhere in the basin are missing in this area, but this is understandable, considering the amount of erosion that these diatomaceous silts have undergone. The evidence of altitude is thus in favour of the suggestion that these sediments above the Nderit valley are the equivalent of those laid down in the 600 foot lake elsewhere in the basin, and are of the same age as the beach sand in Gamble's Cave. More research, in particular on the Nderit valley sections, will need to be done before the sequence of events in this area is fully worked out.

Makalia

I was able to spend little time at work in this area and concentrated on following the course of the river and examining the outcrops along it, in particular in the section up to and slightly above 6400'. Most of this was between the Upper and Lower Makalia gorges, shown on McCall's map (1967), where the river crosses two of the north-south trending faults which make up the bounding wall of the basin. There is little sedimentary material exposed along the river for most of the distance between the waterfalls, and the river flows over rapids and stony stretches where volcanic rock is exposed. There was nothing comparable to the Nderit river valley exposures, nor could I find any isolated residuals of diatomaceous silts in the area south of the river; the soils are reddish and there was no sign of any material of lacustrine origin. The second gorge and waterfall occur where the river crosses a steep lava scarp. There is not much accurate height information available for this area; however from my levelling I found that the base of the scarp near the river is at about 6230', and its top would probably be at about 6370' or even slightly above. Under these conditions it would be unlikely that evidence of a 600 foot lake shoreline would be well preserved, and in fact I found very little such evidence.

(i) At the base of the scarp, near the river, there were quite a lot of well-rounded stones and pebbles, but these seemed more likely to have been brought down by the stream than to be a beach deposit. On the top of the scarp I had only time to examine the area close to the gorge, and there

I found no signs of a pebble beach or of lacustrine sediments.

(ii) There was an exposure of what could be rather older lacustrine silts some distance above the gorge, close below the ford where the track crossed the Makalia. About 10' of pale coloured silts are exposed in a river cliff, apparently overlain by a narrow layer of lava (11/5). These are likely to be some distance above 6400'.

(iii) Younger-looking, softer silts are exposed in the Upper Makalia gorge and just below it. They are preserved against the rocky walls of the gorge and are possibly of lacustrine or deltaic origin. They occur at 6225' R.D. (=6219±3' S.D.) below the gorge and up to 6320' R.D. (=6314±3' S.D.) on the walls of the lower part of the gorge (11/3). They are pale brownish fine silts with regular parallel laminations of sandier material; at the top are some particularly conspicuous layers of sand and rounded pebbles. I cannot at this stage be certain about the origin of these silts or their correlation with other lacustrine deposits in the basin, but their height agrees well with that of the diatomaceous silts along the River Kekopey and in the Nakuru Junction area.

(iv) Isolated exposures of diatomaceous silts occur downstream towards the lower Makalia gorge. The largest exposures of lacustrine material in this area are below the lower gorge and probably result from deposition in a lake whose level had fallen below 6200'.

Conclusion

The greater part of the evidence for a lake stillstand that I have found in the Nakuru-Elmenteita basin points to the existence of an important shoreline at about 600 feet above the present lake. The evidence for this shoreline includes several of the features which have been attributed to the "Gamblian" stillstands by Leakey. I have avoided the use of the word "Gamblian" in this context as it is now associated not only with the actual shoreline but also with the "Gamblian pluvial" which has been correlated with the Würm glaciation. Elsewhere (Chapter 7 and below) I discuss the reasons why all the shorelines in the Nakuru-Elmenteita basin should be considered as definitely younger than the period of the Würm glaciation.

In referring to the highest shoreline in the Nakuru-Elmenteita basin I have used the term "600 foot shoreline" or "600 foot lake" as a convenient, if approximate designation which does not make any assumption of age or correlation. The actual evidence for the shoreline is at the following heights:

1. Wave-cut notches at about 6370' S.D.
2. Lava pebbles up to about 6383' S.D., and scattered widely for more than 100' below this.

3. Sand and pebble sections at slightly above 6340' S.D.
4. Diatomaceous silts up to a highest level of slightly above 6330' S.D.

The lake appears to have been prevented from rising any further by the presence of the Bahati-Menengai divide at 6391-92' S.D. The shoreline does not appear to be tilted and there is no sign of faulting in any of the sediments laid down below the shoreline that I examined.

I have inserted a note in Table II to indicate where, in my opinion, this lake is likely to belong in the sequence of volcanic and tectonic events described by McCall. Mollusca from the diatomaceous silt at 8V/3 (altitude about 6200' S.D.) are less than 10,000 years old (see Chapter 7 and Appendix B). The lake is thus (partially at least) of Holocene rather than Upper Pleistocene age.

At the same time it appears that the sediments which were laid down in this lake are not the very youngest in the Nakuru-Elmenteita basin, but are overlain by some even younger, including diatomaceous silts which indicate a later stage of lake sedimentation at a lower altitude in the basin. The sediments laid down in the 600 foot lake are possibly the older of the recent sediments that McCall defined, i.e. the "Gamblian" sediments of Nderit and Makalia.

Even if slight faulting or warping has taken place to produce the weak unconformity which McCall put between these

"Gamblian" and the later "Makalian" sediments, it seems not to have had a serious effect on the "Gamblian" sediments or on the shoreline of the lake in which they were laid down.

3. Evidence of the 'Makalian' (375' A.L.) Lake Level

It was believed that after the "post-Gamblian" desiccation the lake rose to a new high level, at about 375' A.L. Nakuru, during the "Makalian post-pluvial wet phase" at a date of between 9000-3000 B.C. (Leakey 1931b p. 269) The following evidence for a shoreline at this level was given by Leakey, on the map (1931a p. 499) and in the text (1931b p. 247):

A. A shoreline is shown crossing the River Makalia at its main northwards bend, at a height of 379' A.L. (=6155' R.D. or 6149' S.D.). It is presumably the feature referred to as being "near Elmenteita camp" (1931b).

B. A shoreline is shown on the map north of the River Kariandusi, east of the main road, at a height of 373' A.L. (=6149' R.D. or 6145' S.D.). It is described as being "at the Kariandusi River".

C. Two shorelines are shown on the map a short distance east of Nakuru, just north of the main Nakuru-Nairobi road and railway line, at heights of 374' and 375' A.L. (=6150', 6151' R.D. or 6144', 6145' S.D.). They are presumably those described as being "at Nakuru on the slopes of Menengai".

Little further description of these features was given in Leakey's work. Concerning the age of the shoreline it was said, "Its Makalian date is established by the absence of Makalian deposits above this level; in any event, it clearly represents the most important post-Gamblian wet period" (1931b p. 247). The Makalian deposits were said to be notably diatomaceous and to rest, sometimes unconformably, upon a red, weathered surface of Gamblian beds.

Nilsson did not mention a close equivalent to the "Makalian" shoreline at 375' A.L. Nakuru. The features described by Leakey at this level were presumably included in Nilsson's "Group IV" (1931 p. 327) which included features at heights 332-443' A.L. (=6113-6226' R.D. or 6107-6220' S.D.). Some of these features agree in altitude and location with those described by Leakey but in most cases there is not a good agreement between their results.

The possible shoreline features that I found at about this altitude are summarized in Table V and discussed below. In most cases I was unable to confirm the existence or the altitude of the features described by the earlier workers in this area.

Table V

Evidence for shorelines below the 600 foot shoreline in the Nakuru-Elmenteita basin

Locality	Base of cliff	Beach pebbles
"Makalian" shoreline		
Magharibi	6122' S.D.[1]	
North-East Elmenteita		6140-6260' S.D.
Hyrax Hill		6180-6194' S.D.
Lanet Lodge Hill		circa 6100-6200' S.D.
"Nakuran" shoreline		
Misonge	5944' S.D.	

1. Height converted from value of 6128' R.D.

A. The Magharibi cliff at the River Makalia

This cliff (see map 3, figure 2 and plate 22) appears to be Leakey's 379' A.L. "Makalian" shoreline. Its position is close to that of the feature shown on Leakey's map (1931a p. 499) and its appearance agrees well with the descriptions of this "Makalian" cliff in Leakey 1931b (p. 247). The altitude of the feature that I levelled is not, however, exactly the altitude given by Leakey (see below). I have named this feature the Magharibi cliff (Magharibi means 'west' in Kiswahili) in order to avoid the term "Makalian" and the implied date and correlations with other shorelines and sediments.

The cliff lies near the base of the Mau escarpment and faces east over the southern part of the Nakuru-Elmenteita basin. It can be traced for about ½ mile, north and south of the River Makalia, and at its greatest development is a striking feature over 20' high. The slopes above and below it are gentle and grassy; the cliff itself is made up of fine, dark grey ash overlying coarse bright red silts. There is a marked horizontal contact between the two strata which can be traced all along the lower part of the cliff. Above the cliff I found some small exposures of pale grey diatomaceous silt in animal holes. Below it, underlying the bright red silt, are white diatomaceous silts. These do not seem to be the "Makalian" silts mentioned by Leakey as having been laid down in the lake which stood at the level of this cliff. Such lake sediments would probably only be traceable today at a lower altitude. Thick exposures of white, orange and laminated silts occur downstream from the Magharibi cliff in the area around the northwards bend of the River Makalia, and the "Makalian" silts as defined by Leakey may be among these.

The cliff is most conspicuous south of the River Makalia, although a definite break of slope exposing the grey ash and red silt extends for some distance north of the river also. A few hundred yards south of the river the cliff becomes smaller, splits into two small steps, and then dies out completely. Beyond this is a fairly thickly vegetated area in which red-brown silts are exposed in small bare patches and erosion scars 1-2' high.

Some doubt attends the identification of this feature as a lake shoreline cliff. There is a distinct possibility that it might in fact be a fault scarp. Its alignment is approximately north-south, similar to that of many small fault scarps in this part of the basin. One of these scarps, slightly east of (i.e. below) the Magharibi cliff, is crossed by the River Makalia in a waterfall; there is another waterfall slightly upstream (near 11/3) where the river has cut a gorge in a rather larger scarp. However there is no sign of waterfall or rapids where the Magharibi cliff might be expected to cross the river; instead the cliff appears to curve upstream on the south bank, following the contours along the valley side. It is possible that this is indicative of an origin as a shoreline cliff rather than as a fault scarp. The rapid diminuition of the cliff to the south might result from the fading out of a small north-south fault scarp; this appears to occur in the case of several scarps in this area. On the other hand it might be that the formation and preservation of the cliff have been best in the area where the dark grey ash caps it; this might be equally suggestive of an origin by faulting or by wave erosion.

Leakey (1931b p. 254) said of this cliff, "This latter [the grey ash] forms in places a little cliff, which often has a small gravel deposit at its foot, and was probably formed during the maximum of the Makalian lake . . .". It would appear from this remark that the "small gravel deposit" was believed to be a beach gravel. I am not convinced of this identification. The stones are not nearly as round and smooth as those generally seen in the higher beach gravels, and many have highly weathered surfaces. Quite a large part of the "gravel" consists of the white nodular concretions which occur widely in the south-west of the basin and in this case are being washed out from the coarse red silts at the base of the cliff. The general appearance of the stones below the cliff suggests a haphazard collection of weathered and residual material, not a beach gravel. The altitude of the stones (not above about 6120' R.D. or 6114±3' S.D.) is considerably lower than that of beach pebbles that have been attributed to the "Makalian" shoreline in other parts of the basin.

On the available topographical and geological evidence it does not seem possible to come to a conclusion about the origin of the Magharibi cliff. A good correlation in height with other possible shoreline features would provide corroborative evidence of it being a shoreline cliff; unfortunately such evidence is at present lacking (see Table V). Investigation of the sediments which lie below the cliff in the Makalia valley and of the range of altitude of similar sediments elsewhere in the basin might indicate whether an important phase of sedimentation took place in a lake whose shoreline was at about the level of the Magharibi cliff. At present there is no evidence to link any particular series of sediments with a possible lake shoreline near this level.

The following heights have been quoted for what appears to be the Magharibi cliff:

1. Leakey 1931a 379' A.L. Nakuru ; 6155' R.D. (=6149±3' S.D.)
2. Nilsson 1931, cut-terrace; 6109' R.D. (=6103±3' S.D.)
   barrier; 6091' R.D. (=6085±3' S.D.)

Describing these, Nilsson said, "The beaches just mentioned as belonging to lake No. V lie on the River Makalia about 5 km NW of the Enderit Drift. Immediately S of the river there is a cut-terrace, and about 2 km north of that lies a barrier" (1931 p. 305).

3. My levelling (see figure 2),

base of cliff; 6128' R.D. (=6122±3' S.D.)

top of cliff circa; 6150' R.D. (=6144±3' S.D.)

The Magharibi cliff south of the river is about 4 km NW of Nderit Drift.

I cannot explain the discrepancies in these measurements, which seem too large to be accounted for by differences in the datum used in our levelling. It seems likely that I identified and levelled to the same feature as Leakey. I am less certain that the terrace referred to by Nilsson is in fact the Magharibi cliff, but he mentioned no other features in this area which correspond more closely in height with Leakey's or my results and it is not likely that Nilsson can have completely omitted any reference to this well marked feature.

B. <u>The shoreline north of the River Kariandusi</u>

From Leakey's published work it is not easy to be certain of the exact position of this shoreline, or even whether it was a beach or terrace. Dr Leakey pointed out to me a pebble covered hillside which, although it is a couple of miles north of the River Kariandusi, agrees quite well in location with the northern part of the 'beach' shown on the map (1931a p. 499). According to the text this beach was at 6150' R.D.; on this hillside (8/1) I found a large number of pebbles from 6140' up to at least 6260' S.D., with no special concentration at the lower end. (See above, Chapter 4, North East Elmenteita.) Nilsson (map 1931 p. 291) showed a group IV shoreline (in approximately the same position as the one on Leakey's map), which might be the beach referred to in his list as being "3·10 miles NW of Gilgil Railway Station", at an altitude of 6180' R.D. The pebbles at 8/1 are in fact rather further from the station than this (over 5 miles) and there appears to be another group IV shoreline on the map which is closer to the right position. However, two of Nilsson's shorelines of the same group within 2 miles of each other might be assumed to be at about the same height (i.e. 6180' R.D.) even allowing for some tilting.

I have not found an actual shoreline at Kariandusi; much of the land has of course been affected by the mining work and the buildings associated with it. A section at 8/12 shows diatomaceous silt overlying a coarse reddish-orange silt. It is possible that this section shows "Makalian" silts overlying the reddened surface of "Gamblian" silts as Leakey described them from other parts of the basin

(1931b p. 246). However 8/12 is almost certainly about 6150' (i.e. above the suggested level of the "Makalian" lake) and in the juxtaposition of red and white silts appears comparable to the section at 8/3 which is above 6300'. The diatomaceous silts at 8/12 would appear to be older than "Makalian" and laid down in a lake whose shoreline was higher than the "Makalian" level. It is possible that pebbles exist along the foot of the steep south-west facing slope, as one travels along the main road north from the River Kariandusi. I did not look along the whole of this ridge, but at the parts I did study in detail (above 8/12 and around 8/1), there was certainly not a definite concentration of pebbles around 6150'.

C. <u>The shorelines east of Nakuru</u>

These appear to be on two small isolated hills which are defined by faults and stand at the southern end of the Bahati plain (map 3). Hyrax Hill is a narrow rocky ridge which reaches a height of about 6260'. Another hill, a mile or so to the east, which has a flat top rising to over 6250', does not seem to have a generally recognized name; I called it Lanet Lodge Hill, from the nearby hotel, while it is probably referred to as Plaat Hill by McCall (1967 p. 45). Hyrax Hill is particularly interesting, as there are a number of archaeological sites of different ages on its slopes. Several of these have been excavated and are now kept open as a museum. Even the oldest of these sites, said to be 'Neolithic' and to contain stone bowls, pottery and obsidian tools, appears to be younger than the pebble beach found on the lower slopes of the hill. No material suitable for absolute dating has yet been found but the youngest of the sites on the hill are possibly within the last few hundred years. The sites were originally excavated by M. D. Leakey in 1937-8; further work was done when the open sites and museum were prepared by Ron Clarke in 1965-6; I am grateful to him for his help to me when he was excavating on the hill. The archaeology of these sites is discussed in more detail in Appendix C.

According to M. D. Leakey, beach pebbles were found on Hyrax Hill at 375' A.L. and also at 335' A.L., the lower beach indicating "a rest level or slight oscillation during the recession of the Makalian lake" (1945 p. 275). I consider it unlikely that one would be able to distinguish pebble deposits within 40' of each other in height as being due to distinct oscillations in the lake level; they might easily be spread over such a height range by later downwashing or as the lake level fell steadily. The 335' beach (altitude circa 6112' R.D., 6106' S.D.) was apparently found beneath Site I, the Neolithic burial and occupation on the south-east side of the hill. There were very few pebbles on the surface in this area, and none were visible in the one burial that is now kept open. I found pebbles on the surface at a higher altitude, close to the house (now the museum) and in the section of a latrine pit when it was being dug. (This was only a narrow layer of rather rounded material in the upper part of the section.) The clearest pebble sections I found, - clean layers of light-grey rounded pumice pebbles - were in some of the pits excavated by Ron Clarke on the northern end of the hill. These pit-dwellings are part of M. D. Leakey's 'North-east village'. She mentioned sections there containing "grey pumice material, water sorted and stratified, with bands of coarse gravel and thin layers of fine sands or pisolithic material, the whole overlain by a more consolidated yellowish-white pumice" (1945 pp. 359-60). This description agrees quite well with what I saw in some of the pits, although I did not notice a layer of more consolidated material overlying the rounded pumice pebbles. It appeared to me that these pebbles were a recent beach deposit, preserved on the gentler northern slopes of the hill, while they may have been lost from the steep rocky slopes to the south. The pebbles were clearly exposed in sections at 6180-6185' S.D., and a few lava pebbles on the surface up to about 6194' S.D. This is considerably higher than the circa 6150' level suggested by Leakey.

Nilsson worked in this area before the Hyrax Hill sites were excavated, although a nearby site, the Nakuru Burial site, had already been studied. It seems that the 'Site' shown on the 1931 map (p. 291) in approximately this area close to a group III shoreline, is this Nakuru Burial site rather than any of those on Hyrax Hill. On the same map slightly to the east (close to 'Macdonald's Farm') is another group III shoreline; this may be the same as the eastern one of Leakey's, which was probably on Lanet Lodge Hill (Plaat Hill). These shorelines are apparently those given in Nilsson's 1931 list as "0·93 mi. N of Macdonald's Farm" at 6139' R.D. and "0·31 mi. SE of Macdonald's Farm" at 6159' R.D. Both of these are described as terraces, i.e. relief features, although Nilsson also mentioned beach gravels found at various places in this area.

I was not able to locate the 'Nakuru Burial Site'; it is not preserved as an open-air museum, and since it was excavated nearly 40 years ago, it is hard to find its exact position. It was apparently at the foot of a small rocky spur which lies between Hyrax Hill and Lanet Lodge Hill. This I called 'Water Tank Hill' as in the 1960s it had two large round water tanks on it. When I studied the area in June 1967 maize was being cultivated all round the hill, and the higher slopes were rather rocky and covered with long rough grass. The site was apparently below a large pile of rocks (Leakey 1931b p. 200) on the west facing side of the hill. I walked over and around much of the hill, but was unable to find any sign of possible beach material on the surface. The Nakuru Burial site was said to lie on a Makalian beach (Leakey 1931b p. 32) but to be considerably younger than it, and in fact contemporaneous with the Nakuran high level of the lake at 145' A.L. (See below, Appendix C) However I was unable to confirm the existence of a beach here, or to check its altitude.

On Lanet Lodge Hill (Plaat Hill) I found lava pebbles covering a good part of the south-eastern slopes of the hill. The pebbles extend over a considerable vertical range with no definite concentration to indicate a beach level. There appears to be rounded and stratified material in a small section near the top of the hill, as well as the pebbles spread over the eastern slope. The highest section is probably over 6200' and the pebbles extend down the slope almost as far as the road at about 6100'.

It can be seen from the above results that I have not been able to confirm the existence of a "Makalian" shoreline at about 375' A.L. Nakuru. Only four features in the Nakuru-Elmenteita basin were originally listed as evidence for this shoreline (Leakey 1931a and b) and this seems rather a small number on which to establish a major lake stillstand and a "post-pluvial wet phase". I found beach pebbles and a possible shoreline cliff at altitudes between about 343 to 404' A.L. Nakuru, with no sign of a concentration at

375' A.L. Even if beach pebbles do exist at 375' A.L., the fact that they are also spread over a considerable range above and below this height considerably lessens the significance of pebbles at 375' A.L. as evidence of a major lake stillstand at that level.

The evidence summarized in this section appears to indicate the lake level falling, possibly with halts and small readvances, from over 400' above the present level to about 340' A.L. (approximately 6280-6120'). If any marked pause occurred, it was at about 6122' S.D., (i.e. circa 342' A.L. Nakuru) when the Magharibi cliff near the River Makalia may have been cut. I do not think that this evidence is enough to confirm the existence of a distinct "Makalian post-pluvial wet phase".

4. Evidence of the 'Nakuran' (145' A.L.) Lake Level

There is some evidence for a stillstand of the lake at about 145' A.L. Nakuru. This was believed by Leakey to represent the 'Nakuran post-pluvial wet phase' at about 850 B.C. He mentioned two fragments of this shoreline, north and south of Lake Nakuru:

(i) A shoreline curving round the northern end of the lake, south of the main road and railway line; this was shown on the map (1931a) and referred to in Leakey 1931b: "A terrace and beach at a height of 145 feet above present lake level is known near Major Macdonald's farm, Nakuru" (p. 247). The height of 145' A.L. is about 5921' R.D. (=5915±3' S.D.), assuming the level of 5776' R.D. for Lake Nakuru as given in Leakey 1931a.

(ii) A shoreline marked on the 1931a map as crossing the River Nderit some distance north (i.e. downstream) of Nderit Drift. Describing certain 'Gumban A' pottery found at "Stable's Drift on the Enderit River" it was said, ". . . the pottery was found in a bank of stratified mud which, to judge by its level seems to represent the upper limit of the lake during the Nakuran wet phase" (1931b p. 199).

Nilsson's equivalent to the Nakuran was said (1931 p. 327) to be shoreline group no. V, with terraces at heights from 243-358' A.L. (=6024-6139' R.D.) but this is considerably higher than Leakey's suggested altitude. Nilsson's shoreline group no. VI, ranging from 164-177' A.L. (=5946-5960' R.D.) seems closer to the Nakuran level. Nilsson did not show any low altitude shorelines crossing the River Nderit which might correspond to the feature referred to by Leakey at 'Stable's Drift', or mention any sections there containing stratified material. He did show a group VI shoreline terrace north of Lake Nakuru "1·55 mi. NW of mouth of River Njoro" at 5955' R.D. (=5949±3' S.D.) which is likely to be the shoreline north of the lake described by Leakey, although on the map (1931 p. 291)

Nilsson did not show it extending nearly as far east as Leakey had.

Nilsson's list of shorelines (1940 pp. 75-7; see also my figure 4) includes a number of 'terraces' at or slightly above 5950' R.D. (=5944' S.D.). This does not agree with Leakey's height of about 5920' R.D., but is close to the height that I have obtained for the Misonge shoreline (see below). It is possible that these terraces may be further evidence of a stillstand of the lake at this level. However I have not succeeded in finding these other features described by Nilsson or in confirming that they are in fact shoreline terraces.

The shoreline north of Lake Nakuru is shown on McCall's map (1967) forming the upper boundary of the Q1 sediments (recent gravels, tuffs and diatomaceous silts) at an altitude rather below 6000'.

In my fieldwork I was able to identify the shoreline north of the lake quite easily. I have called this feature the Misonge shoreline, after a local name for a group of huts at its western end, in order to avoid the implications of correlation and dating that now attach to the term 'Nakuran'. Its identification as a former lake shore depends at the moment entirely on its shape. I have not yet found any beach or shallow water sediments near it, or been able to confirm that the Q1 sediments shown by McCall are in fact a lacustrine or deltaic deposit laid down only below this shoreline in a lake which stood at this level. However I am reasonably confident that it is in fact a lake shoreline cliff. Its origin is especially clear when it is seen in plan, for instance on the air photograph, plate A1 and on map 3. It curves round in an alignment similar to that of the present northern lake shore and is most unlike any of the fault lines or subsidence features in the Nakuru-, Elmenteita basin.

The cliff is best developed at its western end in the town of Nakuru, above Landies road; its shape there is shown by the profile which I levelled (figure 3). Towards its eastern end the actual cliff is rather longer and not so steep, although the break of slope is still clear and is at about the same altitude. The cliff is cut in coarse yellowish tuff which appears on brief examination to be rather similar to the rock of Honeymoon Hill and Karterit. Most of the cliff line is vegetated but this rock outcrops at intervals on and above the slope.

The profile I levelled shows the base of the cliff to be at a height of about 5944' S.D. This agrees well with Nilsson's value (5949' S.D.) but is rather higher than Leakey's (5915' S.D.). I looked below the Nisonge cliff for any lower break of slope which might be the one levelled by Leakey, but could find none. Much of the land below the western end of the cliff is built on, but I could see no further break of slope until below 5900', and there is certainly nothing comparable to the Misonge cliff line.

I was not able to find evidence of this lake shoreline in the area south of Lake Nakuru. "Stable's Drift"[1] was presumably a crossing point on the River Nderit where good exposures of sediments were visible in the valley walls, as at Nderit Drift. It must have lain somewhere along the river between Nderit Drift and Lake Nakuru. This land was in 1965-7 part of Nderit Estate, owned by Mr R. Long. Mr Long had no knowledge of any drift that had ever been called Stable's Drift. In walking along this part of the River Nderit I found no sign of a beach gravel or unconformity in the sections north of Nderit Drift that would be worth levelling as evidence of a former lake shoreline. On the plain south of Lake Nakuru the land rises from about 5780' near the lake to about 6070' on the Elmenteita-Mau Narok road. However it is quite likely that no marked relief feature to correspond with the 5944' Misonge shoreline north of the lake would be found. The land here is underlain by fine lacustrine and deltaic sediments and is extremely flat; a small vertical change in lake level would result in a large

1. "Drift" is an originally South African term for a ford. (Concise Oxford Dictionary)

horizontal movement of the water line, and on such a flat shoreline the erosive power of the waves would be small.

Although I did not succeed in finding a shoreline cliff or beach gravel south of Lake Nakuru that might be correlated with the Kisonge shoreline, I would think it likely that a fairly prolonged stillstand of the lake at about 5944' S.D. did take place. It should however be stressed:

(i) There is not yet adequate proof that this shoreline represents a distinct 'Nakuran wet phase' during which the lake rose to a maximum after having been at a lower level during a dry interval. It could be that the shoreline indicates a pause in a fairly steady fall of the lake from its highest level, without major reverse fluctuations.

(ii) There is no evidence that the shoreline can be dated to about 850 B.C., as Leakey suggested. (Leakey 1931b p. 270).

(iii) Therefore I suggest that the term 'Nakuran' which implies that the shoreline represents a 'Nakuran wet phase' at about 850 B.C. be no longer used as the name for this shoreline.

(iv) The cliff north of Lake Nakuru can be referred to as the Kisonge shoreline, which is a purely locational name with no implications of age or correlation. If the shoreline is to be referred to in terms of its height above Lake Nakuru, it should be called the 165 foot shoreline. This is relating it to the level of the lake in 1967, 5779' S.D.

(See Appendix A for discussion of the expression "A.L. Nakuru".)

5. The Kiboko Shoreline

This is a low grassy slope which can be traced for several hundred yards around the north-eastern corner of Lake Nakuru. It is not more than 50 yards from the water line, and when I saw it in June 1967 the base of the slope was not more than 10' above the water surface. It is a gentle grassy slope about 5' high, thickly vegetated with coarse grass and thorn trees. I could not distinguish any vegetation discontinuity across the slope, or any dead trees near it. Quite large trees, several feet in circumference, grow below, on and above the slope. Pale grey dusty silts can be seen in small bare patches above the slope.

It seems quite likely that this slope is a small cliff formed by the lake when it stood at a slightly higher level than it does now. It is probably not of very great age, since it is so close to the present lake level and also because it is cut in a soft material which would not be likely to preserve a cliff line for very long after the water had fallen below it. On the other hand the shoreline is not so recent that it is still visible as a vegetation discontinuity; it is older than the oldest trees growing on it or below it.

I am not certain of the age of the thorn trees growing near the shoreline, but would estimate them to be at least thirty years old, and probably more. It therefore seems possible that the shoreline was formed at the time of higher lake levels in the early 20th or late 19th centuries.

Unfortunately almost no systematic records of the levels of Lakes Nakuru and Elmenteita exist from before 1951. There were a few measurements of Lake Nakuru made in the 1930s, and Leakey and Nilsson quoted heights for the lake levels from the late 1920s. (See Appendix A) Some general indication of the earlier fluctuations of the lakes can also be obtained from travellers' diaries and descriptions of the area, and from assuming a rough similarity with the fluctuations of Lake Naivasha, which have been traced further back (Sikes, 1936). It is necessary to be cautious in assuming that a rise in Lake Naivasha was immediately and completely paralleled by a rise in Lakes Nakuru and Elmenteita, as the basins and catchment areas are not the same size and do not experience exactly the same climatic conditions. However it seems likely that during the period under consideration the fluctuations of the lakes, in particular their response to groups of exceptionally wet years, were roughly similar in the Naivasha and Nakuru-Elmenteita basins.

The projected curve of the level of Lake Naivasha (Kenya Ministry of Works, Hydraulic Branch, drawing no. L2/5) shows the lake at a low level between about 1860-1882, rising to peaks in 1893-5, 1905-7 and 1917. After 1917 the lake fell fairly steadily until the 1950s. Assuming roughly similar fluctuations for Lake Nakuru, it would seem that the Kiboko shoreline might have been formed between about the years 1893-1917.

Nilsson described two young, low level shorelines from both the Nakuru-Elmenteita and Naivasha basins, calling them G5 and G6 (the fullest discussion of these is in his latest paper, 1963). He attributed G5 to the 1893-5 peak in the lakes, G6 to the 1905-7 and possibly also 1917 peaks. (1963 p. 32). It is not clear exactly where Nilsson found the G5 and G6 shorelines in the Nakuru basin. In an earlier paper he showed a shoreline of lake no. VII on the west side of the lake, just to the north of a river that may be the Lamuriak. None of the shorelines he listed are at quite the same height as the Kiboko shoreline:

Nilsson 1931; shoreline no. VII
(1776 metres) - 5832' R.D. (=5826±3' S.D.)

Nilsson 1963; shoreline G6
(1762 metres) - 5785' R.D. (=5779±3' S.D.)

shoreline G5
(1775 metres) - 5828' R.D. (=5822±3' S.D.)

Lake Nakuru level in 1967 - 5780' S.D.

Kiboko shoreline, circa 10' higher - 5790' S.D.

I have not examined the evidence for shorelines G5 and G6 in the Naivasha basin, but around Lake Nakuru at any rate there does not seem to be more than one low shoreline. Nilsson's interpretation of the features he described is not altogether convincing; it seems unlikely that two shoreline terraces only 43' different in height (as his G5 and G6 were said to be) could have been formed during these short term peaks in the lake level only 10 or 20 years apart. The Kiboko shoreline may have been formed at about this time, but I hesitate to attribute it to the high lake levels of one or two years only. It is more likely to have been forming over several decades, interrupted by periods when the lake fell below this level; it seems wisest to attribute the shoreline to lake levels of the late 19th century without attempting any greater precision in dating it. It might even be older, but it is not likely to be younger than this.

CHAPTER SIX

CLIMATOLOGICAL IMPLICATIONS OF THE 600 FOOT DEEP LAKE IN THE NAKURU-ELMENTEITA BASIN

The geological and geomorphological evidence outlined in the preceding chapters seems to give fairly conclusive proof that a lake about 600 feet deep existed for some time in the Nakuru-Elmenteita basin during the late Quaternary. The existence of such a large body of water in a basin which today contains two saline lakes less than 10 feet deep implies that the hydrological conditions at the time of the 600 foot lake were markedly different from those of today. It seems that this difference can be explained almost entirely in terms of climatic change. Other reasons for the change from a 600 foot deep lake to a 10 foot lake can, in the case of this basin, be eliminated:

(i) River capture might be capable of substantially reducing the amount of water supplied by stream flow to the lake basin, but there are no signs that any such capture has taken place from the Nakuru-Elmenteita catchment area during the period under consideration.

(ii) The rim of the basin does not show any signs of having been lowered at any point by faulting or volcanic activity, within the period under consideration, to allow the lake to be drained in that way. The 600 foot shoreline appears closely related to the present lowest overflow level and it seems unlikely that the overflow level could have been lowered and then, when the lake waters had drained out, rebuilt to a level so close to that of the most widespread lake shoreline.

(iii) In a discussion of the raised beaches of Lake Victoria, Temple considered the possibility that "the lake floor experienced depression, bringing about symmetrical shrinking of the water body away from the margins without measurable deformation" (1967 p. 46). He concluded that in the case of Lake Victoria, which of course is a much larger body of water than even the 600 foot deep Lake Nakuru and exerts a considerable load on the crust, such effects (elastic compression of the crust or isostatic effects) cannot explain the existence of the strandlines. The Nakuru-Elmenteita basin is very much smaller than the Victoria basin and it seems even less likely that differential adjustment could have taken place here between the basin floor and its walls sufficient to explain the existence of an untilted 600 foot shoreline.

(iv) More possible in the case of the Nakuru-Elmenteita basin is Temple's suggestion, that "sinking of water levels might conceivably result from local faulting enlarging the capacity of the basin" (1967 p. 47). It does appear that small-scale faulting has altered the shape of the

Nakuru-Elmenteita basin in relatively recent times, involving an apparent lowering of the basin floor by up to 100' (McCall 1967 p. 101). I suggest, however that this faulting is likely to have predated the 600 foot lake, which appears to be of Holocene age. (Chapter 5) Even faulting causing a change of the order of 100' in the basin floor would probably not by itself be enough to cause the lake to decrease in depth from 600 feet to less than 10 feet. It is possible, but unlikely, that faulting could have initiated an underground outlet from the basin which would greatly increase water losses from the lake.

If this change in the lakes is attributed to climatic and hydrologic influences alone, there is a possibility of using the amount of change in the lakes to obtain an approximation of the magnitude of climatic change that has taken place. Such approximations have been made for a number of lake basins in the western United States. Examples are shown in the work of Antevs (1935, 1954), Leopold (1951), Eardley (1957), Broecker and Orr (1958), Reeves (1965, 1966) and Jones (1925). In this work the exact formulae and methods used in the calculations vary slightly, as does the data on which they are based, but the basic reasoning is this:

(a) Present day conditions of the lake and climatic and hydrologic characteristics of its basin are known from field observations and measurements.

(b) The past size (depth and surface area) of the lake is worked out from geological and topographical observations.

(c) Certain independent indications of past climatic conditions in the area may be obtainable; e.g. estimates of temperature changes from the size of former glaciers compared with those of today.

(d) The past climate (usually precipitation) is obtained from an estimate of the water balance conditions of the former larger lake.

The value of such calculations depends on the amount and reliability of the data available, and on the appropriateness of the formulae used. Most of the authors mentioned above as working in America have made use of rather more information on present and past climatic and hydrologic conditions than was available to me for the Nakuru-Elmenteita basin. However it did seem that there was sufficient data for me to make some calculations of past climate which would be of interest for comparison with other estimates of the rainfall and temperature during the late Pleistocene and Holocene in East Africa. It should of course be stressed that the calculations and estimates that I have made are tentative and very approximate. In many cases I have had to rely on data collected over only a few years and to make assumptions which, although likely, cannot be justified by strict hydrological or climatological criteria.

In the Nakuru-Elmenteita basin calculations I have assumed that the amount of water which fed the lake was just enough to maintain it at its 600 foot level without any overflow taking place. It appears that the lake was stabilized at this level by the presence of the Bahati-Menengai divide; there are therefore likely to have been times when an excess of water entered the lake and outflow took place into Menengai caldera. It is impossible to know how much this excess water supply might have been. It is in theory possible that at the peak of cool wet conditions the water supplied to the lake may actually have been enough to raise the lake say to an approximately 700 foot level, had it not been for the presence of the lower outlet. The topography of this area does not indicate that a great deal of overflow, with consequent erosion and downcutting, has taken place. However this evidence is not conclusive, as the products of recent small scale volcanic activity appear to have blanketed this area to some extent. Since it is impossible to make any estimate of this extra water supply, it seemed wisest to work out the conditions needed to maintain the lake at 600 feet. It should be borne in mind that this will be a conservative estimate of the climatic change; i.e. conditions may actually have been somewhat cooler and/or wetter than is indicated by a calculation made on the basis of the 600 foot lake.

The equation which I have used in my calculations is a simple water balance equation for a lake basin. Assuming that the lake volume remains constant, the equation is, in full:

(1) $$R + P = E + O + G$$

R runoff, defined as "the total recoverable portion of precipitation water received on a drainage basin, whether it moves on the surface or by subsurface flow" (Kittredge 1948 p. 230).

P rainfall on the lake surface

E evaporation from the lake surface

O outflow from the lake in surface channels

G deep underground seepage from the watertable below the lake.

In the form in which I use it for this basin the equation becomes:

(2) $$A_B.P_B.K + A_L.P_L = A_L.E$$

A_B catchment area

P_B precipitation on catchment

K runoff constant; percentage of precipitation on the catchment that reaches lake

A_L area of lake surface

P_L precipitation on lake

E evaporation from lake

The terms in this equation are discussed in detail below.

It will be seen from this equation that an increase in the volume of the lake might result from (i) an increase in precipitation over the catchment area, resulting in an increase in the amount of water supplied to the lake; (ii) an increase in the runoff constant, so that a greater proportion of the rain that falls reaches the lake; (iii) a fall in temperature, resulting in lower evaporation and thus in a decrease in the amount of water lost by evaporation from the lake surface and by evapotranspiration from the catchment. Changes in these factors will not occur entirely independently of each other; the percentage runoff is influenced by the conditions of the soil and vegetation on the catchment, and these in turn will be influenced by changes in precipitation and temperature. An increase in precipitation may cause the rate of evaporation to decrease even if no actual temperature change occurs, as it is likely to be accompanied by cloudier and more humid conditions over the catchment. This was shown to occur in the Naivasha basin; Sikes mentioned "the close connection between rainfall and evaporation. During years of low rainfall, the number of hours sunshine in the year would ordinarily be higher and the mean humidity lower than normal, resulting in greater loss by evaporation. In years of high rainfall the reverse would prevail" (1936 p. 30).

It is not easy to be sure of the relative importance of differences in precipitation, evaporation and runoff to account for the existence of the 600 foot lake in the Nakuru-Elmenteita basin. In my calculations I have worked out a number of precipitation-evaporation-runoff situations under which a 600 foot lake could, theoretically, exist in the basin. It is possible to eliminate some of the more extreme of these as being inherently unlikely on climatological grounds and because they are too much at variance with results obtained from calculations based for example on the extent of former glaciers or on fluctuations of vegetation zones. Most such calculations (e.g. van Zinderen Bakker 1962, 1964, 1967a and b, Osmaston 1965) express their estimates of climatic change during the late Quaternary in East and Central Africa in terms of lower temperatures. According to van Zinderen Bakker, during the hypothermal periods in East Africa "the rainfall would, in general, have been higher although the difference was probably not considerable. The most important ecological factor has, however, been the decrease in temperature and consequently the decrease in evaporation. This very important change raised the water level of lakes and swamps" (1967b p. 143).

From this it would appear that temperature changes are likely to have been most important in controlling the levels of the lakes in East Africa. On the other hand there is a certain amount of information from present day conditions of the lakes to show how rapidly they respond to even small changes in precipitation. An increase in precipitation, such as occurred in 1961-2 and in the following years, caused immediate and striking rises in Lakes Nakuru, Elmenteita, Naivasha and Victoria, among others. The level of Lake Naivasha fell from about 1917 to the 1950s (with some reverse movements) and this can perhaps be linked with a slight negative trend of rainfall on part of the Naivasha catchment which was distinguished between 1920-49 (Sansom 1952). In the case of Lake Victoria, Nörth found a good correlation between monthly mean rainfall over the catchment and the change in lake level between the mean of the first ten days of a month and that of the following month. (Unpublished report, July 1965, East African Meteorological Department.) A correlation coefficient of 0.961 was found between these variables for the years 1938-64, showing that the lake level fluctuations could be accounted for almost entirely by the variations in rainfall on the catchment area.

In the Nakuru-Elmenteita and Naivasha basins the rates of evaporation are very high (the order of 70" p.a. compared with about 50" p.a. for Lake Victoria), so that loss of water by evaporation from the lake surface and by evapotranspiration are important factors in the water-balance equation. Richardson said of Lake Naivasha that, since the rainfall on the lake is only about one third of evaporation (the same is true of Lake Nakuru), changes in lake level will depend to a large extent on changes in evaporation (1965 p. 318). I would suggest that although the rate of evaporation from these lakes is very high, it is not automatically the most important control of fluctuations in lake level. The response of the lake to changes in precipitation is likely to be more rapid; Richardson said, "As a rule, closed lakes are able to rise more rapidly than they can fall. This is because increases in precipitation anywhere in the lake's drainage area will be funnelled into the lake and cause it to rise, but the evaporation which causes a lake to fall takes place only from the lake surface itself" (1965 pp. 319-20).

The terms in the equation $A_B.P_B.K + A_L.P_L = A_L.E$.

(I) The terms O and G in equation (1) have been taken as zero and hence omitted completely from equation (2). The Nakuru-Elmenteita basin is a closed basin and, as already discussed, I disregard possible overflow (O) into Menengai caldera from the 600 foot lake. In the case of underground seepage, the amount of water lost will depend on geological conditions and on the area of the lake bed. It appears that in the Nakuru-Elmenteita basin today such losses are virtually zero; McCall's studies (1957a) of the height of the water table and the hydraulic gradients in the basin do not indicate any major loss by seepage from the lake. It is possible that seepage may have taken place, perhaps northwards, when the lake was at the 600 foot level and covered a much greater area, of diverse geology. As it is impossible to be certain of this or to estimate the amount of water that might have been lost in this way, I decided it was best to take this term as zero. The effect of this approximation will be the same as that of assuming the surface overflow to be zero, i.e. it will result in conservative estimates being made for the terms on the other side of the equation, of the amount of water being supplied to the lake to keep it at this level.

(II) Precipitation: rainfall records have been kept for several years for a number of stations in the Nakuru-Elmenteita and Naivasha catchment areas. The mean annual rainfall clearly varies between different parts of these catchments, which range from the well-watered slopes of Mau escarpment and the Kinangop plateau to hot and dry central parts of the lake basins. I have based my calculations on the mean annual precipitation for the whole catchments, whose figures for the years 1938-66 were given me by the East African Meteorological Department in Nairobi. It would be ideal to have values for (a) the precipitation on the lake surfaces, likely to be the lowest in the whole catchment,

(b) the precipitation on the higher slopes of the catchment, which contributes an important part of the water supplying the lakes, (c) a mean value for the whole basin. For present day conditions, even with a lack of measuring stations through much of the relevant areas, it is possible to arrive at appromimate values for each of these; for past conditions this is not easily done and in my calculations I have had to be content with obtaining an average value for precipitation over the whole basin.

(a) The rainfall on the lake surface today:

(i) Lake Naivasha; mean annual rainfall on the lake measured between 1910-1936 was 21.7" (Sikes 1936 fig. 2).

(ii) Lake Nakuru; mean annual rainfall on the lake is between 31-33" (McCall 1957a p. 31, measured over the years 1943-1952), or 30-35" (McCall 1967 p. 2).

(iii) Lake Elmenteita; mean annual rainfall on the lake is between 21-25" (McCall 1957a p. 31), or 25-30" (McCall 1967 p. 2).

In my calculations for the Nakuru-Elmenteita basin, I have assumed the mean annual rainfall on both lakes to be 25".

(b) The rainfall on the higher slopes of the Nakuru-Elmenteita catchment; according to McCall (1957a p. 33) this is about 40-50" p.a.

(c) The mean precipitation for the whole catchment:

(i) Naivasha basin; mean annual rainfall on drainage area 1910-1936 was 32.5" (Sikes 1936 fig. 2). From the figures supplied to me by the East African Meteorological Department, the mean rainfall between the years 1938-1964 was 35.10" p.a.

(ii) Nakuru-Elmenteita catchment; mean rainfall between the years 1938-1964 was 38.32" p.a. (E.A.M.D. figures).

I have taken the value of 38" p.a. as being the mean value for the whole Nakuru-Elmenteita catchment.

(III) Evaporation: (a) The present-day evaporation from the lake surfaces in the Nakuru-Elmenteita and Naivasha basins is high, and exceeds precipitation by a considerable amount. In the case of Lakes Nakuru and Elmenteita there is a net movement of water from the watertable to the lake to the atmosphere, so that the high salinity of the lakes is maintained. Measurements of evaporation made in these basins include:

(i) For Nakuru, over the years 1959-63 in a 15" pan

Average:	74" p.a.	
Highest year:	82"	
Lowest year:	70"	(East African Meteorological Dept, letter of 10.10.67)

(ii) For Naivasha, over 14 years before 1936, in a 36" pan

Average:	74" p.a.	
Highest year:	90"	
Lowest year:	61.6"	(Sikes 1936)

Sikes suggested that the value as obtained from the measurements at Naivasha could be taken as representing the evaporation from the open water surface of the lake without applying a pan correction factor. Such a factor, possibly of 0.8 or 0.9, is used to bring the evaporation as measured in a pan on dry land to the slightly lower value that is likely from a surface of water surrounded by a further area of water. According to Sikes the evaporation from Lake Naivasha is exceptionally high, as it is an open shallow lake and subject to strong drying winds (1936 pp. 77-8); the evaporation can therefore be taken directly as the value measured at the pan. It seems possible that similar conditions apply in the Nakuru-Elmenteita basin, where the lakes are even shallower, and I have therefore used the value of 74" p.a. as representing the mean evaporation from the lake at the present day.

(b) Estimates of past evaporation rates in the Nakuru-Elmenteita basin during the period under consideration must be based on estimates of the former lower temperatures. At present the mean annual temperature of the Nakuru area is 16.9°C (=62.4°F). (East African Meteorological Department letter of 10.10.67.) According to Whittow and Osmaston (1966) who based their estimates on the past levels of the firn lines on the East African mountains, the mean annual temperatures in late Quaternary times in East Africa have varied thus:

100-300 years ago	- circa 0.5°C lower than present
10,000 years ago	- circa 1-3°C lower
15-20,000 years ago	- circa 3-4°C lower

According to Coetzee (1964) the mean annual temperature about 16,000 years ago was about 8°C lower than it is now. This estimate was based on a study of changes in the vegetation zones on Mt. Kenya. A fall of mean annual temperature of the order of 11-12°C for the last glaciation on the East African mountains has been suggested by van Zinderen Bakker (1967b p. 147). The 600 foot lake, however, appears to have post-dated the maximum of glacial conditions in East Africa, and it seems most realistic to assume that it existed during a time when the fall in temperature was rather less than the maximum values suggested by Coetzee and van Zinderen Bakker. In my estimates of possible past evaporation rates in the Nakuru-Elmenteita basin (see below) I have therefore assumed the lowest possible temperature as being 8°C below the present mean annual value.

In calculating past evaporation rates, I first attempted to use the tables of Thornthwaite and Mather (1957) for computing potential evapotranspiration. The result I obtained for annual evapotranspiration, using the present day values of temperature, was less than half the figure of 74" p.a. which was measured for the evaporation at Nakuru.

The main reason for such a discrepancy is perhaps that the humidity at Nakuru for most of the year is much lower than it is for most of the American stations on which Thornthwaite and Mather's tables were based. According to these tables, for a fall in mean annual temperature from 16.9°C to 12.9°C the annual potential evapotranspiration would fall by only about 4½". The changes in evaporation resulting from temperature change during the last 10-15,000 years in the Nakuru-Elmenteita basin would thus seem to be very small.

Possibly a more realistic estimate of evaporation from a closed lake can be obtained from the figures drawn by Langbein (1961). Langbein was concerned with the hydrology and salinity of lakes in closed basins, mostly in the semi-arid areas of western U.S.A., under conditions not too far removed from those of the Nakuru-Elmenteita basin. These figures show values for net evaporation (i.e. evaporation from lake - precipitation on lake) for different values of annual precipitation and temperature. Applying the Nakuru-Elmenteita precipitation and temperature figures for the present day, the value for net evaporation obtained is about 32" p.a. This is still rather lower than the value as measured (74-25=49" p.a.) but an improvement on the results obtained from Thornthwaite and Mather's tables. Results obtained from Langbein's figure 3, assuming a precipitation on the lake of 25" p.a., are as follows:

Mean Annual Temp.	Net evaporation	Total evaporation
16.9°C (62.4°F)	49" p.a.	74" p.a. (1)
16.9°C (62.4°F)	32" p.a.	57" p.a. (2)
14.9°C (58.8°F)	26" p.a.	51" p.a. (3)
12.9°C (55.2°F)	20" p.a.	45" p.a. (3)
8.9°C (48.0°F)	10" p.a.	35" p.a. (4)

Notes on table

1. Present day figures as measured in the Nakuru-Elmenteita basin.
2. Present day temperature, net evaporation calculated from Langbein's graph.
3. Temperatures as suggested by Whittow and Osmaston, net evaporation calculated from Langbein's graph.
4. Temperature as suggested by Coetzee, net evaporation calculated from Langbein's graph.

These figures indicate that, for example, a fall in mean annual temperature of 4°C would result in a drop in net evaporation of 12" p.a., without considering the effect of any increase in rainfall. The change in evaporation with change in temperature is considerably larger than is obtained from Thornthwaite and Mather's tables. It would appear that a marked change in the amount of water lost from the lake would be produced by quite a small change in mean annual temperature.

(IV) Runoff: it is necessary for these calculations to make an estimate of the percentage of precipitation on the catchment area that reaches the lake. In most cases this factor would be expressed as runoff; i.e. how much of the rain on the catchment reaches the streams and eventually feeds the lake. Conditions in the Nakuru-Elmenteita basin are, however, rather unusual. By far the greater part of the recharge to the lakes passes for some distance through the basin sediments to the bodies of groundwater below the lakes. Some of this water may have moved for a short distance as surface flow in a stream channel, but in this basin even streams which contain a fair volume of water in their upper courses tend to lose almost all of it lower down and the actual surface flow into the lake is almost nil. This situation results from (i) the fault zones and jointed and fissured lavas which admit water readily, (ii) the high porosity and water-transmitting powers of the unconsolidated recent sediments. Usually, therefore, there is almost nothing that can be measured as stream discharge in the Nakuru-Elmenteita basin, but there is a steady flow of groundwater towards the lakes, and groundwater ridges can be distinguished along some of the influent streams. (McCall 1957a p. 38)

The geological conditions described above for the Nakuru-Elmenteita basin are similar to those that Sikes described for the Naivasha basin (1936 p. 76). According to Sikes, however, the hydrological conditions in the Naivasha basin were rather different. He made discharge measurements for streams flowing into the lake (see below) and decided that "sub-surface percolation to the lake may be disregarded as a contribution to inflow" (p. 77).

It seems unlikely, in areas with geological conditions such as those of the Naivasha and Nakuru-Elmenteita basins, that the only water reaching the lakes from the catchments should be that which can be measured as discharge in the stream channels. In the Nakuru-Elmenteita basin, at any rate, this appears not to be the case. There seems to be virtually no runoff or stream discharge that can be gauged as it feeds the lakes. I have, however, been able to calculate the percentage of the precipitation on the catchment area that actually contributes to the recharge of the lakes. This will include the water that reaches the lakes by sub-surface percolation and the small amount that travels as surface flow in the stream channels. This percentage I have called K. Using the known values for present day precipitation, evaporation, and lake surface area (calculation 1 in Appendix E) I obtained a value for K of 3.26%. This means that of the rain falling on the catchment, only about 3" in every 100" reaches the lakes or the watertables below them.

This percentage, although it concerns mainly water that reaches the lake by sub-surface rather than stream flow, is in a sense comparable with the runoff figures given by Sikes for the Naivasha basin. This is because both figures do in fact define the percentage of rainfall that recharges the lake, and in this context, exactly by what paths the water reaches the lake is immaterial. According to Sikes "the average annual discharge from the drainage area of the lake to the lake is of the order of 9% of the rainfall" (1936 p. 76). The actual measurements, made between April 1935 and March 1936, that he quoted for the Naivasha basin were:

River	Discharge as % of rainfall
Melawa	7.65
Gilgil	4.25
Karati	2.81

My estimated value of K for the Nakuru-Elmenteita basin is thus of the same order of magnitude as Sides' measurements of discharge as percentage of rainfall in the Naivasha basin. Bennett (1955 p. 89) gave figures for "water loss" (i.e. runoff) from woodland areas in the United States, ranging from 0,3-3.2% of precipitation, and from undisturbed grassland ranging from 1,0-5,42% of precipitation.

It is likely that under generally wetter conditions, with a moister atmosphere, lower evaporation, and rocks and soil containing more water, the value of K for the Nakuru-Elmenteita basin would be higher; a greater percentage of the precipitation would eventually reach the lake. Changes in vegetation might also have some effect and have probably occurred in the Nakuru-Elmenteita basin during the last 10,000 years, due to climatic change and later human influences. It is hard to know what the values of K are likely to have been during past rather wetter conditions, possibly with some kind of forest vegetation covering a greater proportion of the catchment. Jones (1925) quoted a value of 22% for present day runoff in the Lahontan basin (Nevada, U.S.A.) and in his estimates of the conditions necessary to support the former large lake there included possible percentage runoffs of up to 40% of rainfall. Present day evaporation in the basin is 50" p.a., rainfall 10" p.a.; Jones concluded that "if the percentage of run off increased to 30 per cent and the evaporation decreased to 45 inches, only 2½ times as much rainfall would be needed to support Lake Lahontan at the high-water mark" (1925 p. 49). The runoff values quoted by Jones seem rather high when compared with the figures of Sikes and Bennett. I have, however, included in my figure and table the results of calculations based on the assumption that the runoff that fed the former lakes in the Nakuru-Elmenteita basin was 10,20 and 30% of rainfall, as well as the present day value of 3.26%.

(7) The area measurements: for these measurements I used the 1 : 250,000 maps of East Africa, G.S.G.S. 4801. The Nakuru-Elmenteita basin was covered by the Nyeri sheet (edition 1, 1955) and the Kisumu-Nakuru sheet (edition 2, 1957). Map 2 in the thesis is traced from these maps. The maps show the drainage channels in considerable detail, so that I was able to draw in the Nakuru-Elmenteita catchment area quite easily. The contours on the 1 : 250,000 maps at 200' vertical intervals were based on information from the recent series of 1 : 50,000 maps and seem to be quite accurate. I used a compensating polar planimeter and obtained the various areas in square inches; these could then easily be converted into square miles. The precision necessary for these calculations was not very great, but I measured each area two or more times to check that the results were reasonably accurate.

The areas which I measured were:

(a) the catchment area of Lakes Nakuru and Elmenteita. This was obtained by following the watersheds around the streams draining into the basin. The catchment area is not very large, and on the north, south and east sides it barely extends beyond the actual basin walls. In the north I omitted the caldera of Menengai from my measurement of the catchment area; under present conditions it does not seem that any water falling in the caldera would reach the lake or the watertable in the basin. (This explains a slight discrepancy between my figure for the catchment area and that given me by the East African Meteorological Department, which included the area of Menengai caldera within the catchment; see below.)

(b) the surface area of the 600 foot lake; this I took to be indicated by the 6400' contour around the basin. From my knowledge of the area and the larger scale maps, this contour on the 1 : 250,000 maps appeared to be quite accurately drawn. It is true that the area of a lake at 6400' is slightly larger than that of the lake whose level was between 6370-6390', as is indicated by the shoreline in the basin. Under the conditions of these calculations, however, I decided that this approximation was close enough. It would have been hard, from the available height information, to have made it any closer.

(c) the areas of Lakes Nakuru and Elmenteita as shown on the 1 : 250,000 maps. There is no indication on these maps of a date for the level of the lake shown; the Nyeri map shows part of Lake Naivasha, said to be at the 1948 level, so it is possible that Lakes Nakuru and Elmenteita were also shown at the 1948 levels. The shape of the lakes appears the same as that on the recent (1960 and later)

1 : 50,000 maps and considerably smaller than is shown on the small-scale maps of the early years of the century.

The results of the area measurements:

(a) Total catchment area of Nakuru-Elmenteita basin:

According to E.A.M.D. (letter of 10.10.67), 840 sq. miles (including Menengai crater, circa 30 sq. mi.)

According to my measurement, 810 square miles (excluding Menengai crater)

These areas include the area of the lake surfaces.

(b) Surface area of the 6400' lake (omitting the highest parts of Lion Hill and Karterit, which would have stood above this lake as islands)

288 square miles

(c) Surface area of Lakes Nakuru and Elmenteita:

Nakuru	12 square miles
Elmenteita	$8\frac{1}{2}$ square miles

Thus the areas used in the calculations are:

A_B (area of land catchment)

For present day lakes - 790 square miles
For 600 foot lake - 522 square miles

A_L (area of lake surface)

For present day lakes - 20 square miles
For 600 foot lake - 288 square miles.

Table VI

Summary of results of calculations

Evaporation	K:3.26%	K:10%	K:20%	K:30%
70" p.a.	P_B 66"	P_B 59"	P_B 51"	P_B 45"
60" p.a.	P_B 57"	P_B 51"	P_B 44"	P_B 39"
50" p.a.	P_B 47"	P_B 42"	P_B 37"	P_B 32"
Precipitation				
38" p.a.	E 40"	E 45"	E 52"	E 59"

Conclusion

The results of my calculations of the precipitation, evaporation and runoff conditions under which a 600 foot deep lake might exist in the Nakuru-Elmenteita basin are summarized in the graph (fig. 7) and in Table VI. Concerning a choice between the possible situations, the following comments might be made:

1. Temperatures may have been at least 4°C lower in about 10,000 B.P. This appears likely to have been capable of causing a fall in evaporation of 12" p.a., according to Langbein's figures.

2. Rainfall as much as 160% of present day values has been suggested for parts of Southern Africa during the late Quaternary. Such estimates, based on sediment studies and on geological observations, have been made by Brain (1958),

Bond (1957, 1965) and Cooke (1964). Bond has given the following table of inferred past rainfall at Khami and Lochard, in the Bulawayo area, Southern Africa.

Inferred past rainfall at Khami and Lochard, Bulawayo area, Southern Africa. (Bond 1965 p. 334)

Cultural stage	Type of evidence	Suggested absolute rainfall inches/year	Per cent of present rainfall
Iron Age	Feldspar colluvium	25	100
Later Stone Age	Feldspar colluvium	20	80
Middle Stone Age	Feldspar colluvium	35	140
Sangoan	Ferricrete	40	160
Later Acheulean	Calcification	18	72
Alluvium I	Fossil dambo	40	160

3. The range of annual rainfall values shown in the Nakuru-Elmenteita catchment records even since 1938 is considerable. The mean value is 38" p.a.; of the 29 years 1938-1966, 4 have had less than 30" rain (79% of mean); the lowest was 24.7" in 1965. 6 years have had more than 45" rain (118% of mean); the highest was 53" in 1951.

4. Changes in the value of K, the percentage of rainfall that reached the lake, are likely to have occurred in connection with precipitation and evaporation changes

during the period under consideration. I would estimate that a value of K in the range of 10-20% is most likely, but this is merely a tentative suggestion.

Assuming that K is 20%, evaporation 62" p.a., the rainfall necessary to maintain the 600 foot lake in the Nakuru-Elmenteita basin would (from figure 7) be about 45.5" p.a., 120% of the present annual mean. If K is taken as only 10%, evaporation again 62" p.a., the necessary rainfall would be 52.5" p.a. (138% of present annual mean). I suggest that conditions might have fallen within this range of values. It is possible that evaporation was lower than 62" p.a., in which case a lower precipitation would be needed to maintain the 600 foot lake. At any rate it seems unlikely that precipitation need have risen much about 50" p.a. during the time that this lake existed, and it may well have been lower than this.

It should also be pointed out what a small increase in net evaporation (of the order of 3" p.a., from calculation 6, Appendix E) would be necessary to cause Lakes Nakuru and Elmenteita to dry out completely. An annual rainfall of about 80% of the present value, as suggested by Bond for the Later Stone Age at Bulawayo, maintained for even a few years, would cause the complete desiccation of Lakes Nakuru and Elmenteita.

CHAPTER SEVEN

EVIDENCE OF LATE QUATERNARY CLIMATIC FLUCTUATIONS IN AFRICA

Indications of Quaternary climatic fluctuations in Africa have been obtained from different kinds of evidence, including:

(i) Former higher lake levels of many lakes, including Lakes Nakuru and Elmenteita,[1] Lake Naivasha,[2] Lakes Baringo and Hannington,[3] Lake Rudolf,[4] Lake Victoria,[5] Lake Magadi,[6] all in East Africa; Lakes Zwai and Shala[7] in Ethiopia; Lake Chad.[8]

(ii) Former larger glaciers on mountains that now have small glaciers or are unglaciated; Ruwenzori,[9] Mount Kenya,[10] Kilimanjaro,[11] Mount Elgon;[12] Mounts Simien and Kaka[13] in Ethiopia.

(iii) River gravels, silts, and terraces, resulting from changes in conditions of erosion and sedimentation, have been

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1. Nilsson 1931 etc., Leakey 1931a and b.
2. Nilsson 1931 etc., Leakey 1931a and b, Richardson 1965, 1966.
3. Nilsson 1931 etc., Fuchs 1934, 1950.
4. Fuchs 1935, 1939, Whitworth 1965.
5. Temple 1965, 1967.
6. Baker 1958.
7. Nilsson 1931 etc., Mohr 1963.
8. Grove and Pullan 1964.
9. Nilsson 1931 etc., Osmaston 1965.
10. Nilsson 1931 etc.
11. Downie 1964.
12. Nilsson 1931 etc.
13. Nilsson 1931 etc., Mohr 1963.

attributed to climatic causes. Climatic fluctuations have been worked out on this basis in Somaliland (Parkinson 1932, Clark 1952, 1954), Angola (Leakey 1949) and the Nile Valley (Butzer 1966, de Heinzelin 1967).

(iv) There is evidence, usually from the pollen content of sediments, that the vegetation patterns in parts of Africa have changed during the Quaternary. These changes have been studied in particular in connection with the shifts of montane vegetation belts on the highlands of East Africa. (van Zinderen Bakker 1962,63,64 and Coetzee 1964)

(v) There is a certain amount of faunal evidence; changes in the fauna of an area, such as the extinction of moisture loving species, might be the result of climatic change. Moreau (1964 etc.) studied the birds of tropical Africa (in particular the montane communities) with a view to working out climatic changes during the latter half of the Pleistocene. At present montane forest exists as isolated patches and its avifauna differs greatly from that of the lowland forest and savanna, but shows certain similarities between "islands". At times in the past, the isolation of the montane forests must have broken down and colonization by different bird species took place. The waves of colonization have been interpreted in terms of the periods of expansion of montane forests and the possible underlying climatic changes.

(vi) Evidence of past, more arid conditions has been obtained from areas of dunes and aeolian sands which are now colonized by vegetation. Clark (1963) mentioned at least three phases of deflation by 'Kalahari sands' in North-East Angola since Acheulian times. Grove and Pullan (1964) mentioned ancient sand dunes in Hausaland, Northern Nigeria, in an area now several hundred miles south of the desert margin.

(vii) There is evidence in parts of Africa that at times during the Quaternary, soil formation and weathering processes were not the same as in the same localities today. This has been taken in some cases as indicating climatic changes. Bond (1965) summarized some of the deductions that have been made from such evidence. For instance, in the Bulawayo area, Southern Rhodesia (present rainfall about 25" p.a.) calcretes (kunkar and 'vlei limestone') have been taken as indicating past more arid climates, ferricretes (lateritic ironstone), as indicating past more humid climates.

From such evidence, sequences of climatic fluctuations have been worked out and equivalents of the Gamblian, Makalian and Nakuran wet phases of the Nakuru-Elmenteita basin have been recognized in other parts of Africa; one finds references to these phases in the literature on African archaeology and Quaternary geology. Clark's discussion of the prehistory of Somaliland (1954) included a complete correlation of suggested Somaliland climatic phases with the East African sequence from Kageran to Nakuran wet phases. A similar table was prepared by Leakey (1949 p. 73) for North-East Angola, and equivalents of the Kanjeran, Gamblian and Makalian wet phases in Angola were also recognized by Clark (1963).

For these correlations it was assumed that the "Gamblian" pluvial in East Africa was approximately contemporaneous with the Würm glaciation in Europe and was followed by the later wet phases at the dates which had been attributed to them by Leakey and Brooks as a result of the original work in the Nakuru-Elmenteita basin, i.e.:

Makalian	9000 to 3000 B.C.	(Leakey 1931b p. 269)
	10,000 to 2500 B.C.	(ibid p. 270)
Nakuran	850 to 0 B.C.	(ibid p. 269)

It now appears that such correlations were made before enough was known about the geology, archaeology and palaeoclimatology of Africa. There are the following reasons for doubting their validity:

(i) The climatic sequence in East Africa with which phases in other areas were correlated is now shown to have been based on inadequate geological evidence. For several years, since the criticisms of Cooke (1957) and Flint (1959a) were published, it has been recognized that the evidence quoted for the earlier pluvial periods in East Africa (Kageran, Kamasian and Kanjeran) can be explained in other ways than by climatic change, and that there is insufficient evidence of pluvial conditions in the type areas for any correlations with other areas on a climatic basis to be attempted. The later phases (Gamblian, Makalian, Nakuran) have up to now been accepted as being based on sound evidence in the type area and thus as suitable for correlation with other areas. As the result of my fieldwork in the Nakuru-Elmenteita basin, I have decided that the geological and geomorphological evidence for these phases, too, is not good enough for them to be correlated with suggested climatic fluctuations in other parts of Africa.

(ii) The climatic changes that can be traced from the sequence of lake level fluctuations in the Nakuru-Elmenteita basin appear to be rather younger than has been believed; any correlation based on the age of the Gamblian, Makalian and Nakuran as given above is likely to be wrong. Thus the "Gamblian wet phase" as evidenced from the 600 foot lake shoreline and sediments is in fact probably post-Pleistocene and can not be correlated with a "Gamblian" recognized in another area and thought to be contemporaneous with the Würm glaciation. The time available for the suggested Makalian and Nakuran phases is also considerably reduced.

(iii) Many of these correlations were suggested before radio-isotopic dates became available for any relevant material; they are thus often based on archaeological data and on comparisons between industries at sites which appear to have palaeoclimatic implications, for example a site on a former lake shoreline or within a lake sediment. It now appears that not enough is known about the industries, particularly of the later Stone Age in East Africa, for any except very general geological or palaeoclimatic correlations to be made from archaeological evidence, unless absolute dates are available. No precise correlations can be made simply on the basis of archaeological material and implement assemblages, for not enough is known about these aspects of, for example, the Capsian and later industries in the Nakuru-Elmenteita basin. The fragment of the bone harpoon, found at Gamble's Cave (see Appendix C) is about the only example of material for which a fairly precise correlation with another site is possible.

(iv) It is possible, although not certain, that broadly similar climatic fluctuations have taken place all over the world during the Quaternary. Van Zinderen Bakker (1967b) has suggested for the Upper Pleistocene that "the temperature chronology in Africa is broadly parallel with that of the Northern Hemisphere in time and variation" (p. 371). This however refers to broad temperature fluctuations only, and he went on to say, "'Pluvials' certainly existed but were not coeval all over Africa" (ibid). It is recognized that fluctuations in temperature, which are the result of changes in the amount of radiation reaching the earth, are more fundamental aspects of climatic change than are rainfall fluctuations, which result from the shift of climatic belts. Generally synchronous temperature fluctuations over a period of the order of several tens of thousands of years may have occurred, and yet within this period, shorter-term rainfall fluctuations might not be synchronous in all areas of one continent. Sansom (1952) found that different parts of East Africa showed positive and negative trends in rainfall between the years 1920 and 1949, and it is possible that divergent trends could be recognized between wider areas (for example between East Africa and Somaliland or Angola) over a longer period of time. Even if the likelihood of a general world-wide parallelism of temperature fluctuations in the Upper Pleistocene is accepted, it does not therefore follow that over periods of a few thousand years (the suggested lengths of the "Makalian" and "Nakuran" wet phases) synchronous wet and dry phases are likely to have occurred even in most parts of Africa; it is even less likely that such phases might be correlated with climatic fluctuations on other continents.

It thus appears that at this stage it would be wrong to attempt to establish a sequence of climatic fluctuations in the form of a series of wet and dry phases which should be recognized all over Africa. At the same time an increasing number of absolute dates are becoming available for the late Quaternary in Africa. In several cases the material from which the dates were obtained has a definite palaeoclimatic implication, or at any rate indicates sedimentation in an environment different from that now prevailing at the locality. I have summarized briefly below some of the evidence of late Quaternary climatic fluctuations in Africa, with particular emphasis on phases for which absolute dates are available.

Far from the Nakuru-Elmenteita basin being considered as the type area for a sequence of late Quaternary climatic fluctuations, it now appears that, by comparison with some other parts of Africa, there is relatively little firm information about climatic change in this area, and what there is goes back only as far as about 10,000 years B.P. Cores from the sediments beneath Lakes Nakuru and Elmenteita might provide evidence of climatic fluctuations comparable to those that Richardson has traced from a core from Lake Naivasha, but no such cores have yet been studied from the Nakuru-Elmenteita basin. The diatomaceous and other silts exposed in the basin appear to be too highly oxidised for any pollen to have been preserved in them. Palynological studies have so far made no direct contribution to our knowledge of the climatic fluctuations in the Nakuru-Elmenteita basin.

There is thus little that can be used for correlation with other areas, and I have tried to avoid making such correlations at this stage. In this basin, the available evidence suggests:

(i) The lake was over 420' above its present level not more than 9650 years ago. Mollusca of this age were found in the basin at an altitude of about 6200' S.D. They are fresh-water forms and lie in a matrix of fine diatomaceous silt (see Appendix B); it is likely that they were not living right on the lake shoreline but in some depth of water, so the lake was probably not far from its maximum level of 6370' S.D. (about 600 feet above present level) at that time.

(ii) It is not certain for how long before about 10,000 years B.P. the lake had been at this high level. The evidence from the Nderit Valley sections and from exposures such as 10/13, also from sections 8/3 and 8/12, where a fairly narrow layer of diatomaceous silt overlies layers of material which was probably not laid down in a lake, indicates that it is possible that deposition at altitudes over about 400 or 500' above the present level of Lake Nakuru had not gone on for very long before 10,000 B.P. It is not possible to be certain about this point until further work is done in the Nakuru-Elmenteita basin.

(iii) The stages in the fall of the lake from its 600 foot level cannot at present be dated precisely. There is no indication of a marked pause at 375' A.L. (the 'Makalian' shoreline level), but a shoreline can be traced at 165' A.L. (approximately the 'Nakuran' level) which does indicate a later period when wave erosion was concentrated for some time at one height. Archaeological evidence from sites associated with the lower levels of the lake (see Appendix C) is at present insufficient to date these levels more precisely than to within the last few thousand years. It is not clear whether the 165' shoreline represents a stage in a fairly steady fall from the 600 foot level or a reversal and rise to 165' A.L. from an even lower lake.

1. The Naivasha basin. Shorelines above the present level of Lake Naivasha were described by Leakey (1931a and b) and Nilsson (1931, 1940 etc.). Nilsson listed groups of tilted shorelines; several of the highest lakes were said to have been in contact with the lake in the Nakuru-Elmenteita basin over the pass at Gilgil. Leakey correlated the shorelines with those in the Nakuru-Elmenteita basin although he did not believe that (during the Gamblian and later periods at least) there had been any overflow at Gilgil. Both authors stressed the importance of the

Njorowa Gorge, south of the lake, as an outlet which was eroded by the lake waters.

Leakey's sequence of shorelines for the Naivasha basin was this:

Lower Gamblian - circa 380' A.L. shoreline
(approx. 6584' R.D.)

Upper Gamblian - circa 180' A.L. shoreline
(approx. 6384' R.D.)

Makalian - circa 100' A.L. shoreline
(approx. 6304' R.D.)

Nakuran - Leakey himself does not appear to have found a 'Nakuran' shoreline but suggested the 'Neolithic' beach mentioned by Gregory (1921 p. 220) may belong to this stage of the lake.

I have not myself done any fieldwork in the Naivasha basin, beyond making some brief visits to Njorowa gorge. To make any valuable contribution to the knowledge of the area, it would have been necessary to investigate the shorelines and sediments in the same detail as in the Nakuru-Elmenteita basin, and there was not enough time for this. On the basis of my results from the Nakuru-Elmenteita basin, I can make the following general comments on certain aspects of the earlier work:

(1) It appears most unlikely that any contact between the lakes in the Naivasha and Nakuru-Elmenteita basins has

taken place, at any rate since the last major faulting of the Rift Valley. Lake Nakuru could not rise to the level of the Gilgil divide in the basin as it is today, but would remain at a level about 200 feet below it. In the case of Lake Naivasha, although it is hard to tell the original relative heights of the rim of the basin at Gilgil and at the Njorowa gorge, since so much erosion has taken place at the latter site, it appears most likely that the southern rim of the basin, at Njorowa gorge, was always lower than the Gilgil divide. Overflow would have started there and then become concentrated, and the lake would never have risen to the height of the Gilgil divide. I can find none of the shoreline terraces at and above the Gilgil divide that Nilsson quoted in support of his theory of contact between the lakes. The only lacustrine sediment on the divide is the faulted diatomite at 8/9, which appears to predate a certain amount of faulting. It is certainly older than the lake shorelines preserved in the Nakuru-Elmenteita basin.

(2) The Njorowa gorge outlet spans a height range of about 6375-6600', that is circa 171-396' above Lake Naivasha, accepting Leakey's 1931a value for the level of the lake. There is no reason to assume that if parallel climatic fluctuations took place in the Naivasha and Nakuru-Elmenteita basins, exactly equivalent strandlines

would be formed while Lake Naivasha was cutting down its outlet. A rise in lake level to a 'pluvial peak' is likely to have resulted in increased discharge and thus increased downcutting of the outlet, but would not necessarily result in a stable lake level at which a shoreline feature might be formed. While the downcutting was proceeding, a stable lake level and resulting shoreline would only be likely to result from a feature such as a band of hard rock which held up the incision of the gorge. (Cf. Temple 1967 on the lower Lake Victoria shorelines.) It would not be reasonable to expect a strict correlation between the Naivasha basin shorelines and other lake shorelines in basins which had no outlets or an outlet at a different level.

(3) The basis of Leakey's correlation of Naivasha and Nakuru-Elmenteita basin shorelines was explained thus; "By studying the many tools found in the deposits corresponding to the different lake beaches and by comparing these finds with those from the Nakuru-Elmenteita basin we were able to arrive at the conclusion that the 370± feet terrace represented the Lower Gamblian and the 180± feet terrace the Upper Gamblian" (1931a p. 503). Such correlations might be questioned for several reasons: (i) it is uncertain that a particular shoreline level can be definitely established as being of the same age as a

particular industry, by finding implements of that industry in a deposit which appears to have been laid down when the lake stood at that level. For a firm connection to be established, it is necessary for the implements to be found actually overlying the lake beach or terrace, with no sign of a long gap between the fall of the lake and the settlement on its beach. Such sites have not so far been described from the Naivasha basin. (ii) Not enough seems known about the sequence of industries in these basins for precise correlations of sediments or shorelines on an archaeological basis to be made.

(4) In the Nakuru-Elmenteita basin I was unable to confirm the existence of several of the shoreline levels that had been described by earlier writers. It is possible that the position in the Naivasha basin might be comparable, especially as it appears that they spent rather less time doing fieldwork there (Leakey 1931a p. 502). I thus hesitate to discuss possible correlations of the Naivasha basin sequence until I know that the different shorelines which make up this sequence actually exist.

The most recent information on past conditions in the Naivasha basin comes from the core raised from within the rim of Crescent Island and analysed by J. L. Richardson and others. (Richardson 1965, 1966) Studies were made of the diatoms, chemistry and mineralogy of the core, and carbon-14 dates were obtained for various parts of it. The core was 28 metres long and about 9200 years old at its base; this indicates a rather rapid rate of sedimentation. The following zones were distinguished in the core:

Uppermost part - marked banding indicating a rapidly fluctuating lake, often more saline and smaller than it is today.

Metre 8 - date of 3000 ± 60 B.P. (just above the dry zone)

Metres 8.20-7.80 - a partially weathered, impermeable, sandy layer indicating a complete drying of the crater basin.

Metres 14-8.20 - period of shrinking lake.

Metre 14 - date of 5650 ± 120 B.P.

Below this, to bottom of core - a more homogeneous core with a considerable proportion of planktonic diatoms, indicating a stable lake rather larger than the present one.

Metre 28 - date of 9200 ± 160 B.P.

Richardson suggested that the changes in lake level reflected in this core might be explained by rather small climatic changes, possibly slight variations in precipitation or evaporation operative over a period of several thousand years. At the same time he thought it unlikely that the changes in size of Lake Naivasha were the result of local climatic variations alone, but that equivalent fluctuations might be recognized from other parts of Africa. If this is so, it appears that for at least the last 3000 years conditions in the Eastern Rift Valley have been no moister than they are today; i.e.there was no 'Nakuran wet phase' at 850 B.C. (2800 B.P.) or later.

Richardson mentioned terraces at 23 metres (75.5 feet) and 39 metres (128 feet) above Lake Naivasha, and at 51 metres (167 feet) and 112 metres (368 feet) above Lake Nakuru. These heights were referred to the 1960 levels of the lakes; in the case of Lake Naivasha this was 14 or 15' lower than the 1929 level that Leakey took as his datum for the 'Above Lake' heights. There may well have been a difference of the same order in the level of Lake Nakuru. It would appear therefore that these figures for the terraces were based on Leakey's heights and adjusted for the change in level of the lakes between 1929 and 1960, rather than on any further fieldwork or levelling of these terraces.

Richardson attributed the lowest terrace in each basin (the 23 metre and 51 metre terraces) to the lakes as they stood before 3000 B.P. He assumed there were similar fluctuations in both the Naivasha and Nakuru-Elmenteita basins during the period of the core and suggested that if the period of the small, fluctuating lake (after 3000 B.P.) be called the 'Nakuran', then the higher lake, which produced the lowest terraces might be called the 'Makalian'. According to this scheme there would thus be no 'Nakuran' shoreline in either of the basins. The period of the 'Makalian' lake in the Naivasha basin would thus be between about 5600 to 9200 years B.P.

2. Lakes Baringo and Hannington: lake beaches and lake sediments of various ages are found around Lake Baringo; they were first described by Gregory (1896, 1921). Lake Hannington is a long narrow lake bounded by recent faults; on its east side in particular a scarp drops steeply to the lake shore and evidence of higher levels of the lake is likely to be hard to find. According to McCall, "The two lakes are remnants of a once continuous lake, and are separated by the Loboi plain, a wide extent of silt laid down by the original lake" (1967 p. 8). Nilsson (1931, 1940) described shorelines in the Baringo basin at three different levels above the lake and correlated them with certain of the shorelines in the Nakuru-Elmenteita and Naivasha basins. However it appears that a simple correlation of shorelines and climatic fluctuations between these areas is not possible; "it is clear that the Baringo basin is not a good index of pluvial fluctuation. Indeed, it is hard to show whether any particular rise or fall of the lake was due to climatic change, faulting, volcanic barrier building, or a

combination of one or more of these factors" (Fuchs 1950 pp. 170-1). In the most recent work on the geology of the Baringo basin (McCall, Baker and Walsh 1967, Martyn 1967) the sediments in the 'Kamasian' type area west of Lake Baringo are divided into two successions of widely differing ages, the Chemeron and Kapthurin sediments. Both of these contain lacustrine deposits, diatomites and stratified tuffs. The Chemeron beds are strongly faulted; the Kapthurin beds are only slightly faulted and it has been suggested (McCall 1967 p. 11) that the Kapthurin beds are equivalent to the Larmudiac beds of the Nakuru-Elmenteita basin. Still younger, unfaulted sediments (the Kampi-ya-Samaki and Logumkum beds and Loboi silts) were deposited in the Baringo basin; no further mention of the shorelines of the lakes in which these were laid down is made by McCall or others. They may be equivalent to the Holocene "Makalian" beds of the Nakuru-Elmenteita basin as described by McCall (1967).

The evidence from the Baringo-Hannington basin indicates that during the late Quaternary larger lakes than the present ones have existed there; to a certain extent this is evidence of a past more humid climate. On the other hand, although geological correlations between the Baringo-Hannington and Nakuru-Elmenteita basins may successfully be made, it seems unlikely that any precise correlation of shoreline features, even of the most recent lakes, could be made between these basins. This is particularly so because at present no absolute dates have been obtained for any late Quaternary material in the Baringo basin.

3. Lake Rudolf: there is evidence from the area round Lake Rudolf that during the Quaternary it has stood at a considerably higher level than it does now. The present level of the surface is about 1230', and shorelines ranging from over 300' A.L. to only a few feet above the present level were described by Fuchs (1935, 1939), Cooke (1957) and Whitworth (1965). Fuchs assumed that the fluctuations of the lake were climatically controlled and could be correlated with those from other parts of East Africa; for instance, he attributed the 220' shoreline to the "Gamblian", the 90' shoreline to the "Makalian", wet phases. (Fuchs 1939 pp. 251-3). These correlations seem based on little firm evidence and according to Cooke (1957 p. 46) Fuchs' interpretation of the Quaternary geological history of this area is difficult to substantiate fully. It seems likely that tectonic and volcanic events (there is an active volcano, Teleki's, at the extreme southern end of the lake) have interrupted the climatic-controlled sequence of lake level fluctuations. Dodson concluded of the southern part of the lake basin that "the history of the area during the Pleistocene is characterized by almost

continuous slight tectonic movment, volcanism and sedimentation, with peak phases of fracturing and lava outpourings, not necessarily coincidental with sedimentary beach-level deposition" (1963 p. 31). Similarly, Whitworth said: "In fact, present knowledge of the Quaternary history of the Rudolf basin is insufficiently precise to determine conclusively whether widely correlatable climatic changes or more local tectonic, erosional and volcanic factors played the major role in the fluctuations of the lake" (1965 p. 91).

There is evidence to suggest that the lake was at a high level quite late in the post-Pleistocene. Shells of _Aetheria elliptica_ were collected from lake sediments near the 220' beach at Kangatotha to the west of the lake and have been dated to 4800±100 B.P. (Thomson 1966). A fragment of a bone harpoon was found near Kabua water hole, also west of the lake, associated with the approximately 140' beach. Whitworth suggested that this might be of comparable age to the harpoons from Ishango and Gamble's Cave (see Appendix C) and thus of definitely post-Pleistocene age. It is not certain, however, that these high levels were entirely the result of climatic fluctuations. Dodson described the Barrier, a composite volcanic ridge that cuts off Lake Rudolf from the Suguta valley to the south and was built during at least four phases of volcanic activity. He suggested, "It seems likely that the emplacement of the Barrier contributed to the rise of lake level that led to deposition of the '220-ft' sediments" (p. 36).

The rise of a body of water as large as Lake Rudolf (at present it is 180 miles long and has a maximum width of 35 miles) by over 200' would involve a very large volume of water. It seems unlikely that a change of this magnitude since the end of the Pleistocene could have resulted entirely from volcanic and tectonic events, without at least some contribution from more humid climatic conditions. Although it is not likely that close synchroneity between the fluctuations of Lake Rudolf and those of other East African lakes can be traced, the evidence from the Rudolf basin does suggest that conditions there remained relatively humid until quite late in the Holocene, and is thus in accordance with the most recent evidence from other lake basins.

4. Lake Magadi: this highly saline lake lies in a trough in the Rift Valley which today experiences a very arid climate. There is evidence of at least two series of lake sediments in the Magadi trough, separated by minor faulting. These would indicate past more humid conditions in this area. The younger deposits, the "High Magadi Beds" can be

linked to a horizontal shoreline about 40' above the present lake. In the report by Baker (1958) on the geology of this area no attempt was made to attribute these sediments to a particular phase in the climatic sequence. Later (McCall, Baker and Walsh, 1967) it was suggested they might be equivalents of "Gamblian" deposits of the Nakuru-Elmenteita and Naivasha basins. The most recent stage of sedimentation in the Magadi trough is the Evaporite Series, which is still accumulating today, and is the result of more arid conditions than those during which the High Magadi Beds were laid down.

Climatic fluctuations rather similar to those in the Nakuru-Elmenteita basin appear to have taken place in the Magadi trough during the late Quaternary, but close synchroneity between the two areas cannot at the present stage be established.

5. Lake Victoria: five major strandline levels have been recognized (Bishop 1962 p. 211); the highest of these is at about 200' above the present lake. The upper levels are affected by gentle westerly upwarping, probably of Upper Pleistocene date; the shorelines less than about 80' above the present lake are said to be untilted. These shorelines, however, cannot be interpreted as the result of climatic fluctuations; according to Temple (1967) there

has been during the last thousands of years a gradual fall in lake level as a result of the phased incision of the lake outlet down the River Nile. The cutting of shorelines around the basin would result from pauses in the down-cutting of the outlet, which would be controlled mainly by geological factors. Variations in discharge at the outlet (due to precipitation or evaporation changes over the lake) may have occurred and would have influenced the amount of erosion that was taking place at the outlet, but, as Temple said: "Major climatic variations from this period are . . . not evidenced by the strandlines" (1967 p. 61).

Kendall (1965) studied pollen, microfossils and chemistry of a core from Pilkington Bay, Lake Victoria, and found evidence that the bay had been dry at about 15,000 years B.P. but that since then the lake had almost always been at or above its present level. On the other hand the evidence from Hippo Bay Cave, Entebbe, indicated that in 1965 (after the rapid rise of 1961-2 and following years) the lake was higher than it had been for the past 3700 years. (Bishop 1965 p. 318) The evidence from these sources seems to some extent conflicting. If the Hippo Bay Cave evidence is accepted, it may be that the relatively low level of Lake Victoria during the last 3700 years is a parallel to the small lake that appears to have existed during about the last 3000 years in the Naivasha basin. No more precise correlation between lake level fluctions of Lake Victoria and the lakes in the Kenya Rift Valley is likely to be possible.

5. <u>Glaciers on the East African and European mountains</u>: Workers in East Africa and Ethiopia have recognized several moraines of different ages on the high mountains, indicating that a number of glacial advances have taken place, separated in some cases by long periods of time. At present several of these mountains (Elgon, Aberdares, Simien, Kaka) are unglaciated, and the others (Ruwenzori, Mount Kenya, Kilimanjaro) bear small glaciers which during this century have retreated rapidly. According to Osmaston (1965) the lowering of the firnline on Ruwenzori during the glacial maxima could be accounted for by a decrease of about 4°C in the mean temperature, and possibly by a rather smaller change if an increase in precipitation had also occurred.

Nilsson (1931) recognized fluctuations of the glaciers on Mount Kenya, Ruwenzori, Mount Elgon and in Ethiopia which he correlated with his suggested fluctuations of the Rift Valley lakes. It seems unlikely that a close parallelism between lakes and glaciers can be recognized to the extent where one can state that a particular shoreline is exactly equivalent to a particular moraine. In East Africa even a broad synchroneity between the high levels of lakes and the maximum extent of glaciers has yet to be proved. Downie, in his discussion of the glaciations of Kilimanjaro (1964) pointed out that "so far no direct evidence linking the events on the plains with those on the mountains has been found" (p. 2).

The earlier glaciations which have been recognized on the East African mountains are several hundred thousand years old and thus outside the scope of this discussion. For the late Pleistocene and Holocene, Osmaston recognized the following stages on Ruwenzori:

Glaciation	Moraines	Probable Age
	Lac Gris	100-300 years[1]
	Omurubaho	10,000 years[2]
Lake Mahoma	Lake Mahoma	15-20,000 years[3]

Notes on dates

1. Estimated by vegetation and soil development and lack of erosion (de Heinzelin).
2. Estimated from size of moraines, date of 7000 years B.P. for bottom of Lake Kitandara (Livingstone).
3. Date of 15,000 years B.P. for bottom of Lake Mahoma (Livingstone).

Osmaston commented "comparisons between all the glaciated African and Ethiopian mountains show good correlations. There is no evidence to oppose, and some to support, the hypothesis that glaciations in the tropics were contemporaneous with those elsewhere" (1967a p. 28). Elsewhere he stressed "I think that speculations about the correlations between glaciations and pluvial periods, and between tropical and temperate glaciations, are premature" (1965, p. 144).

Downie suggested that during the post-Pleistocene there had been two small glacial advances on Kilimanjaro, the Little Glaciation and Recent Glaciation, which he correlated with the Makalian and Nakuran wet phases respectively (1964 p. 14). The Recent Glaciation was said to end at about 200 years B.P.

6. The Western Rift Valley: according to Bishop (1962) there is evidence from the sediments of the Western Rift Valley Valley (area of Lakes Albert, Edward and George) that climatic conditions have varied during the Pleistocene. However this is an area where the influence of tectonic movements and volcanic activity on sedimentation has been great, and it is difficult to isolate the effects of climate on sedimentation with any certainty.

In Western Uganda the Katwe and Bunyaruguru volcanoes have been active within the last 10,000 years, and tuffs from them cover palaeosols and contain plant fossils. Bishop and Posnansky suggested that, "It is also possible that the climate in this part of the rift valley was a little wetter some 10,000 and more years ago than it is now, as red palaeosols occur within and beneath the volcanic ashes while grey to brown soils are forming at the surface at the present day" (1960 p. 52). Osmaston obtained a date of 4070 years B.P. for material underlying tuffs at Fort Portal. Plant fossils from these tuffs indicated vegetation, and hence climate, similar to that in this area today. (Osmaston 1967b pp. 25-6)

7. Sahara: there is evidence that conditions in parts of the Sahara during some of the late Quaternary were considerably moister than those of today. This includes archaeological material and floral and faunal remains indicative of sub-humid climates in areas that are now extremely arid. A shoreline of Lake Chad, the Bama Ridge at about 175-190' above the present lake, was described by Grove and Pullan (1964). When the lake stood at this level it must have covered an area of about 120,000 square miles. Carbon-14 dates have been obtained for material from old lake beds to the north-west of the present lake indicating stages in the drying up of the lake during the Holocene. Faure, Manguin and Nydal (1963) quoted several dates for calcareous material found with diatomites, of between about 9200-7000 years B.P. A possible date for an early stage in the existence of the lake, slightly over 21,300 years B.P., was obtained, but there is as yet no confirmation

as to the date when this large lake was initiated. Some dates for material from within the former lake, i.e. below the 175-190' (absolute altitude circa 320-325 metres) shoreline, indicate stages in the fall of the lake from its highest level, viz:

(i) Koulinga at 315 metres; shells dated 5400 B.P.
(ii) Dik at 305 metres; shells dated 4350 B.P.
(iii) Bochianga at 265 metres; shells dated 3160 B.P.

These dates were given by Schneider (1967). They indicate that even as late as 3160 years ago, the lake in the depression north-west of present Lake Chad was over 100 metres deep.

According to Butzer (1966) conditions in the Sahara were quite moist between about 7450 to 4300 years B.P., and possibly earlier. He suggested that a very arid period between 4300-2820 B.P. could be recognized in Egypt, Ethiopia, Fezzan and possibly also in the Hoggar and Tibesti.

8. Pollen studies in East and Central Africa: studies of pollen from sediments in East and Central Africa have been made, in particular by van Zinderen Bakker, and have been interpreted as showing the variation in temperature during the late Pleistocene and Holocene. It has been suggested that the temperatures of East and Central Africa varied approximately synchronously with those of Europe and

America. The position with regard to precipitation is less clear, and it appears that even within Africa, fluctuations were not everywhere synchronous during the late Pleistocene and Holocene. From the pollen analyses, the following results have been obtained:

(i) Cherangani, Kenya (van Zinderen Bakker 1962). The only carbon-14 date from this core which has been published is from the lower part; an age of 12,650 B.P. was obtained for a segment in which the pollen appeared to indicate relatively cold, dry conditions. Dates for the higher parts of the core were estimated and it was suggested that conditions became warmer and more humid from about 11,500 B.P. The forest maximum appears to have been between 5000 and 6800 B.P.; since then conditions have been slightly cooler.

(ii) Sacred Lake, Mount Kenya (Coetzee 1964). A date of 15,862 B.P. was obtained for part of the core, with pollen indicating lower temperatures (possibly by as much as 8°C) than at present. At metre 10,10 in the core a clear increase in forest pollen occurred, possibly indicative of a rise in temperature. By extrapolation, the age of this part of the core was found to be about 10,600 years. The forest increased to a maximum at 5100 B.P.

(iii) Kalambo (Clark and van Zinderen Bakker 1964). Much of the dated evidence from this site is outside the range of time with which I am concerned. There is evidence of warmer, probably wetter conditions at about 27,000 B.P., and of cool, moist conditions at 9550 B.P.

(iv) North-east Angola (van Zinderen Bakker in Clark 1963): There is evidence of warm, moist conditions at 6830 B.P. This does not, however, indicate a great difference from present day conditions in the area.

Morrison (1966) expressed reservations on the deductions of past temperature and precipitation from pollen assemblages. He suggested that it is impossible to be certain what climatic conditions are implied by a particular kind of vegetation, particularly on the East African mountains, since so little is known about the present temperatures and precipitation in the different vegetation zones.

However it appears that broadly synchronous fluctuations of temperature can be traced in East and Central Africa during the late Pleistocene and Holocene. A cold period, contemporaneous with the maximum of the Last Glaciation, has been called the "Mount Kenya Hypothermal", and is believed to have lasted from about 27,000-10,000 B.P. (Bishop and Clark 1967 p. 402). There is also evidence for the hypsithermal (post-Pleistocene warm period) between about 6800-5000 B.P. (van Zinderen Bakker 1967b pp. 371-2), approximately contemporaneous with the climatic optimum in Europe.

9. The Nile Valley: de Heinzelin (1967 p. 322) showed an interpolated high-water curve for the Nile during the last 25,000 years. This was based on a study of the Nile valley silts and terraces over a distance of about 150 km along the river upstream and downstream of Wadi Halfa. Carbon-14 dates were obtained for mollusca from silts and for charcoal from archaeological sites along the valley. The curve showed:

(i) Low-water stage at circa 18-19,000 B.P.; then a small rise.

(ii) Low-water stage at circa 15,500 B.P., followed by a rise.

(iii) A striking fall from about 12,000 B.P., evidenced by the Birbet Formation. According to de Heinzelin, "Evidence of a short recession of the Nile is shown by small disconformities and the encroaching of wind-blown sands; the river dropped to less than 130-129 m around 11,000 B.P." (1967 p. 323).

(iv) After a brief rise of about 5 m, the river fell again. This was the period of the Arkin Formation; a date for a site at 135 m is 9360±180 B.P., then "the Arkin Formation receded progressively with the water level during approximately 4000 years" (ibid).

(v) This steady fall was followed by a more sudden drop of the Nile at around 5300 B.P., evidenced by development of soils over large surfaces of the former river bed, the Qadrus Formation.

(vi) Since then the river has fluctuated around a generally slightly higher level than the lowest reached during (v) above.

De Heinzelin suggested correlations with late Pleistocene and Holocene climatic fluctuations in East and Central Africa (e.g. Kalambo Falls, Cherangani, Ruwenzori) and concluded (1) "The Nile high-water curve reflects a succession of palaeoclimatic events which occurred in the higher basin of the White Nile-Blue Nile-Atbara, the contribution of the two last rivers being emphasized" (i.e. the area on the western slopes of the Ethiopian mountains); (2) "Peaks of high-water correspond to colder phases of the late Upper Pleistocene-Holocene (stadials). Depletions of high-water correspond to warmer phases of the late Upper Pleistocene-Holocene (interstadials)" (1967 p. 326).

Conclusion

The evidence from the Nakuru-Elmenteita basin indicates that the lake in the basin was at a high level at 9600 B.P. This agrees with the evidence from the Naivasha basin. It is possible that the fall of the lakes in the two basins was approximately synchronous and may have taken place from about 5600 B.P. It may have been associated with the rise in temperature during the hypsithermal period in East Africa. On evidence from the Naivasha basin, the lakes would have reached their lowest levels at about 3000 B.P. This is at about the same time as the onset of the arid phase in parts of the Sahara and the drying up of the large lake in the Chad basin. It is not yet clear whether the fluctuation of the lakes in the Nakuru-Elmenteita and Naivasha basins during the Holocene was synchronous with that of the glaciers on the mountains of East Africa.

There is no certain evidence in the Nakuru-Elmenteita basin for the short dry period which Clark (1967 pp. 602-3) believed to have accompanied the close of the Pleistocene in Africa and dated to between 14,000-10,000 B.P. It is possible that the non-lacustrine deposits below the diatomaceous silts at 8/3, 8/12 and in the Nderit valley might have been deposited at a time of lower lake levels during this period.

CHAPTER EIGHT

SUMMARY AND RECOMMENDATIONS

Summary of results

(i) In the Nakuru-Elmenteita basin there is evidence of an important lake shoreline at about 600 feet above the present lake level (i.e. at circa 6370' S.D.). The shoreline, which is best developed on the slopes of Menengai volcano at the northern end of the basin, does not appear to be tilted. Beach pebbles, scattered over the surface and in sections with sand and diatomaceous silt, can be traced around the basin, in particular at altitudes of 6340-6380' S.D., and appear to have been laid down on the shoreline of the 600 foot lake. Grey-brown and white diatomaceous silts have also been laid down in this lake and can be traced up to about 6343' S.D. and widely at lower altitudes. These silts do not appear to have been faulted.

(ii) Mollusca have been found in a silt which can probably be attributed to a date near the maximum of the 600 foot lake. The shells are all of fresh-water snails indicating a habitat in a lake of appreciable size. The age of these mollusca is not more than 9650±250 years. The lake was over 400 feet above its present level at that date. The high level lake in the Nakuru-Elmenteita basin thus persisted for some time into the Holocene; this agrees with evidence of the relatively late persistence of humid conditions in other parts of Africa.

(iii) There is a fairly well-marked shoreline cliff, indicating a lower stillstand of the lake, at about 5944' S.D. White diatomaceous silts which appear distinct from the silts below the 600 foot shoreline outcrop below about 6000' in parts of the basin, but their relationship to this lower shoreline has not yet been investigated. It is not possible to estimate precisely the age of this shoreline, but it was probably formed within the last few thousand years.

(iv) The existence of a 600 foot deep lake in this basin within the last 10,000 years appears to have been the result of a combination of cooler and wetter climatic conditions. It is unlikely that volcanic or tectonic factors have had a significant effect on changes in lake level during this time.

(v) It is suggested tentatively that an increase in mean annual rainfall to about 120% of the present value, with a fall in evaporation by 16% and an increase in the percentage of precipitation that reached the lake, would be enough to have maintained the lake at the 600 foot level.

(vi) The lake appears to have been prevented from rising any higher by the presence of the lowest outlet from the basin (the Bahati-Menengai caldera divide) at an altitude of 6391-92' S.D. Lacustrine deposits above this altitude in the basin date from an earlier period of sedimentation, separated from the sedimentation in the 600 foot lake by an episode of minor faulting. Since the 600 foot shoreline seems to have been controlled by the overflow level it is not in itself strictly representative of a "Pluvial maximum" climatic peak.

(vii) There is evidence that the phase of lacustrine sedimentation in the 600 foot lake was of a relatively short duration and was preceded by a period during which coarse red and orange silts were laid down in several localities at fairly high altitudes (e.g. in the Nderit valley and at 8/3 and 8/12). There is at present no evidence as to whether this change in sedimentation was the result of climatic change or tectonic events.

Recommendations on terminology

For some time it has been realized that the use of palaeoclimatic divisions in defining stratigraphical units in geological sequences is undesirable. It has recently been stressed that, "It is necessary, at least at the moment, to disallow palaeoclimatic-stratigraphic units for the African Quaternary" (F. C. Howell in Bishop and Clark 1967 p. 906). The existing sequence, for the East African Upper Pleistocene and Holocene, based on the evidence of the fluctuations of the lakes in the Nakuru-Elmenteita basin, is an example of a sequence where the distinction between rock units, time-stratigraphic units, and time units is far from clear. The terminology was based primarily on the lake shorelines and sediments of the basin and thus extended to describe the wet phases during which the lakes stood at the various shoreline levels. From there it was further extended to cover climatic fluctuations in other parts of Africa which were thought to be synchronous with those in the Nakuru-Elmenteita basin. The sequence was dated by correlation with the late-glacial and post-glacial climatic phases in Europe; see Table VII.

The terms "Gamblian", "Makalian" and "Nakuran" have been used to describe (i) shoreline features in the Nakuru-Elmenteita basin; (ii) lake sediments in the Nakuru-Elmenteita basin, believed to be contemporaneous with particular shorelines; (iii) Upper Pleistocene and Holocene "pluvial phases" in East and Central Africa; (iv) the actual features (lake shorelines and sediments, river terraces, etc.) which were believed to represent these "pluvial phases" in parts of Africa outside the Nakuru-Elmenteita basin.

The nomenclature has thus become extremely confused. In many cases the basis of correlation of lake shorelines or sediments between areas several hundreds of miles apart seems to have been merely that they appear to be evidence

Table VII

Existing climatic sequence for the East African Upper Pleistocene and Holocene

Phase	Evidence in Nakuru-Elmenteita basin	Correlation with Europe	Date (references to Leakey 1931b)
Gamblian pluvial	Lower 750' A.L. shoreline	Riss	
	Middle 600' A.L.	Würm	
	Upper 510' A.L.	Würm	Ending circa 13,000 B.C. (p. 269)
Dry interval	'Aeolian sand', reddening of sediments	Achen oscillation Gothiglacial retreat	
Makalian post-pluvial wet phase	375' A.L.	Bühl stadium	10,000-2500 B.C. (p. 270)
			9000-3000 B.C. (p. 269)
Dry interval	'Aeolian sand'	Sub-boreal	2500-850 B.C. (p. 270)
Nakuran post-pluvial wet phase	145' A.L.	Sub-atlantic	850-0 B.C. (p. 270)
			1000-850 B.C. (p. 243)

of rather wetter conditions at approximately similar dates; for most of these correlations, absolute dates have not been available. Thus almost any evidence of an Upper Pleistocene wet phase in East or Central Africa has tended to be labelled "Gamblian", of a Holocene wet phase, "Makalian".

Recent research in the Nakuru-Elmenteita basin suggests that the pattern of Upper Pleistocene and Holocene lake level fluctuations does not show the distinct Gamblian, Makalian and Nakuran peaks representing distinct "pluvial phases" on which correlations with other areas were based:

(i) The "Gamblian" deposits sensu stricto in the Nakuru-Elmenteita basin are probably of the order of 10,000 rather than 15,000 years old and cannot be correlated with the Würm glaciation. The general use of the term "Gamblian" to refer to a late Pleistocene pluvial phase in Africa (e.g. Clark 1962 p. 7) is not in agreement with the most recent knowledge of the type area of the "Gamblian" in the Nakuru-Elmenteita basin. There does not seem to be, in the Nakuru-Elmenteita basin, evidence for a threefold division of the "Gamblian"; at any rate, I have found no evidence of lake shorelines at the 750' A.L. and 510' A.L. levels.

(ii) There is not sufficient evidence of a stillstand of the lake at 375' A.L. on which to postulate a distinct "Makalian post-pluvial wet phase". There is a possible shoreline cliff at 6122' S.D. (about 343' A.L. Nakuru) and pebbles are found in various places in the basin over a height range of about 6140-6260'.

(iii) There is a single shoreline cliff at 5944' S.D. (circa 165' A.L. Nakuru) which might qualify to be called the "Nakuran shoreline". However there is no evidence (a) that it represents a distinct rise of the lake to the peak of a "Nakuran post-pluvial wet phase" or (b) that it is the age which has been attributed to this phase, i.e. circa 2800 years B.P. (850 B.C.).

(iv) Concerning these recent "post-pluvial wet phases", the Makalian and the Nakuran, it may be said (a) the time available for these "post-Gamblian" fluctuations of Lakes Nakuru and Elmenteita now appears to be considerably shorter than was thought. If such fluctuations have taken place, they are younger than the dates attributed to them in Table VII. (b) It is not at all certain that minor fluctuations of this kind in lakes in East Africa can be correlated rigorously with phases in the post-glacial climatic evolution in Europe and dated on that basis. Until more detailed information and absolute dates are available for the African sequence, it is best to be extremely cautious about any such correlations.

(v) Dry phases in the "post-Gamblian" in the Nakuru-Elmenteita basin have been correlated with the warmer, drier phases in the post-glacial in Europe. The geological evidence for these dry phases appears to be rather tenuous; minor unconformities in recent sediment sections may, in some cases, be explained by late small-scale tectonic activity (McCall 1967), while the evidence of the "red beds" and "wind-blown sands" (discussed in Appendix C), appears on a re-examination to be insufficient to suggest arid conditions. It would seem likely that the "Makalian" and "Nakuran", in so far as they can be said to exist, were not distinct peaks of wetness separated by marked arid intervals, but pauses in the fall of the lake from its 600 foot level.

It is clear that much of the evidence of Upper Pleistocene and Holocene climatic fluctuations in the Nakuru-Elmenteita basin on which the original sequence and correlations were based needs reappraisal. The theoretical basis of the correlations of climatic phases with other parts of Africa and other continents is also open to doubt (see Chapter 7). At this stage, therefore, it appears that the time has come for the development of a new geological terminology which will avoid the existing confusion of geological and climatic units and the tenuous long-range correlations which have grown up around the old sequence. It seems best that the terms Gamblian, Makalian and Nakuran should be dropped; they have been used in too many different ways and have come to have definite palaeoclimatic implications which cannot now be accepted. It is suggested:

(i) In the Nakuru-Elmenteita basin, new names should be adopted for the shoreline features and for the rock units. The recognizable lake shoreline remnants should each be referred to by a separate name, based on its location, e.g. Menengai, Misonge, etc. In general discussion of particular stillstands of the lake, reference can be made to the approximate height above the 1966 lake level (5779' S.D.), for instance "the 600 foot shoreline". In discussion of the geology of the basin, reference to "Gamblian" and "Makalian" beds should be avoided, as it implies that the sediments can be fitted into the old sequence of climatic-controlled lake level fluctuations. New terms for the Upper Pleistocene and Holocene sediments of the Nakuru-Elmenteita basin should be brought into use which do not imply any connections with particular lake levels or climatic phases, comparable with McCall's "Larmudiac Beds".

(ii) The terms Gamblian, Makalian and Nakuran should not be used to refer to postulated cool, moist phases in the African Upper Pleistocene and Holocene.

(iii) The terms Gamblian, Makalian and Nakuran should not be used in referring to evidence (lake shorelines, sediments or other evidence) of Upper Pleistocene or Holocene climatic fluctuations in other parts of Africa.

APPENDIX A

THE SURVEY WORK: METHODS AND DEFINITIONS

The survey work, consisting of the measurement of the altitudes of shoreline features and exposures of beach and lacustrine deposits, was an important part of the research. I have included a full account of the techniques used, the height control and other relevant details.

1. Units: all my height measurements were made in feet. This was the easiest system to use, since all the Survey of Kenya maps, bench marks and trigonometrical points have heights in feet. It would have been possible once the survey was done for me to convert my heights into metres. This would fit in with the modern trend towards use of the metric system which appears in some of the recent work on East Africa, in particular by Americans. Richardson (1965) used the metric system in his discussion of the Naivasha and Nakuru-Elmenteita basin lake shorelines. He referred to the 51 metre and 112 metre shorelines (above Lake Nakuru). It seemed to me wiser to keep to the established usage for this area, particularly for comparison with Leakey's well-known height figures. The "510'", "375'" and "145'" shorelines have been referred to widely in the literature for many years and the metric equivalents would not have the same meaning for most people. Nilsson's

height figures, which are in metres, are not so widely quoted, and cannot be used directly with the Survey of Kenya maps of the area. I therefore converted Nilsson's metric heights and distances into feet and miles, using the following formulae:

1 km = 0.62 miles

1 metre = 39.4"

I include a list of some of the more important heights in the literature on the Nakuru-Elmenteita basin, converted into metres.

Leakey's shorelines:

A.L. Nakuru		A.L. Metres
750'	=	228.4
600'	=	182.8
510'	=	155.3
375'	=	114.2
145'	=	44.17

Results of my levelling:

	Metres S.D.
Menengai shoreline (6370')	1940
Bahati overflow (6392')	1946
Gilgil divide (6598')	2009

Level of Lake Nakuru March 1966 (5779') = 1760 metres S.D.

2. Datum: the height information in the Nakuru-Elmenteita basin today (1965-7) includes (i) the Survey of Kenya trigonometrical points and bench marks, based on the datum

'Mean Sea Level Kilindini'. There are a number of trigonometrical beacons on prominent points in the basin, and also Survey of Kenya benchmarks at quite small intervals all along the railway line from Gilgil to Nakuru. West of Nakuru this line of benchmarks continues along the main road towards Eldoret. I found the benchmarks along the railway particularly useful for my height control, despite their being on the extreme eastern and northern side of the basin. (ii) East African Railways and Harbours heights are based on the datum 'Low Water Ordinary Spring Tides Kilindini'. Profiles of the railway line, which I got from the E.A.R. & H. office in Nakuru, show the height at frequent intervals along the line and the gradients and distances between these points, so that in theory it should be possible to determine the altitude of any point along the line. This proved not to be possible along the stretch of line in which I was interested (between Nakuru and Nakuru Junction) and in the end I did not make use of this railway height information. Along parts of the line the half-furlong posts have been moved from their original positions whose altitudes were given on the profile diagrams, so that this height information is unreliable.

In most of the basin I was able to use the Survey of Kenya height control; however in the southern and south-western parts there was none within reasonable distance of the features in which I was interested. Here I had to use height information from the old alignment of the railway line, which until the late 1940s went from Gilgil to Lanet via the former Eburu and Elmenteita stations. There was also a fuel siding from Elmenteita to Nderit Drift. Although the actual track has long been removed, the alignment of the railway is followed by a road and some of the station buildings, water tanks and cuttings remain. At Eburu the old benchmark is still in place on the station building and I used this as the basis for my levelling in this area. At Elmenteita the water tanks opposite the police post remain from the old station and I was able to make a close estimate of their height from the old plans; this was used as the basis for the levelling of Gamble's Cave, Nderit and Makalia. (See below for more detailed discussion of this.)

The earlier levelling in this area, by both Leakey and Nilsson, was based on the railway height information which was probably all that was available in this area at that time (1926-30). Nilsson said: "All my height figures within the Nakuru-Naivasha basin have been determined in relation to the levellings along the Kenya-Uganda railway" (1931 p. 293, footnote). Leakey's levelling, by his brother, D. G. B. Leakey, was also done from points of known height along the railway line. (1931a pp. 498-9 and p. 507)

The levelling in the Nakuru-Elmenteita basin has thus been based on two different data; where I quote a height figure in the text, whether one of my own or from the earlier work, I have included a note on the datum, thus:

6370' S.D. i.e. Survey of Kenya datum

6600' R.D. i.e. East African Railways and Harbours datum.

I attempted to obtain a value for the relationship between the two data, so that the heights could be converted to a single datum; the Survey of Kenya datum seemed the most suitable as it is now the more widely used and certainly the more reliable one. However this was not very easily done. The difference between M.S.L. and L.W.O.S.T. Kilindini is known; unfortunately the railway heights are not always given with respect to the formal railway datum, and various corrections have to be added to bring these heights to this datum. This appears to have happened because the railway line was surveyed and built in a number of different sections, and overall consistency of datum was not achieved. Even within the Nakuru-Elmenteita basin there is possibly a variation in the relationship of the railway heights to the L.W.O.S.T. Kilindini datum and hence also to the Survey of Kenya datum. I was not able to draw a definite conclusion about this relationship but made a tentative decision for the purposes of this work, based on the following information:

(i) The difference between M.S.L. and L.W.O.S.T. at Kilindini, according to the E.A.R. & H. head office in Nairobi, is 6.23'. Thus if no further adjustments had to be made, this should be the relationship between all heights on the Survey of Kenya and railway data. Since the Survey of Kenya datum (M.S.L.) is the higher of these, it should only be necessary to subtract 6.23' from heights on the railway datum to bring them to the Survey of Kenya datum.

(ii) According to the Survey of Kenya and E.A.R. & H. offices in Nakuru, the actual difference between the two data there (at Nakuru) is 8.98' or 9.02'. I checked this by levelling between a railway and a Survey benchmark in Nakuru town and found a discrepancy of exactly 9.02' to be explained by the datum difference.

(iii) I carried out similar levelling at Gilgil station, where the railway benchmark remains in position on the station building with a Survey of Kenya benchmark nearby. There was a height discrepancy of 9.89' to be explained by the datum difference.

(iv) On the railway profile sheets of the lines west of Nakuru (possibly for other sections of the line also) there is a note "add 1.05' to conform to L.W.O.S.T. datum at Kilindini". This correction, taken together with the 6.23' datum difference, does not account for the whole of the 9' discrepancy in the heights at Nakuru.

(v) There is no mention at all of datum on the old plans of Elmenteita fuel siding or Eburu station. I was sent these plans from the survey department of the E.A.R. & H. head office in Nairobi and with them a letter in which it was said that the datum for all levels was L.W.O.S.T. and that the minus 6.23' correction should be made to convert the heights to the Survey of Kenya datum. I feel that this suggestion may have been based on a general knowledge of the datum relationship in Kenya rather than on particular knowledge about this area. I also have a note from another source at railway headquarters that for the Elmenteita section of the line, and as far as Kisumu, 3.22' should be added to all levels to bring them to L.W.O.S.T. The net correction to the Survey of Kenya datum would be +3.22' and -6.23' i.e. a net subtraction of 3.01'.

It is not clear, from the above information, exactly how the heights of the control points at Eburu and Elmenteita should be related to the L.W.O.S.T. datum and hence to the Survey of Kenya datum. The relationship could be established by levelling from Survey of Kenya height points to the benchmark at Eburu and to the water tank at Elmenteita. This however would have involved several miles of levelling, as the nearest Survey of Kenya points are over 5 miles away from the Eburu and Elmenteita points. I decided that the total amount of levelling involved (over 20 miles in order to check both these points and control them by levelling both ways) would have taken too much time. The uncertainty is of the order of 3' (see below) and this is relatively unimportant when dealing with features such as shoreline cliffs and exposures of pebbles and silts, whose altitude cannot be defined very precisely and often extends over a height range of more than 3'.

As measured, the difference between railway and Survey of Kenya data is nearly 10' at Gilgil, 9' at Nakuru. The information from plans and notes on the old line between Gilgil and Nakuru suggests that the relationship there might be about 6½' or 3'. However I am not certain about the validity of the extra 3.22' correction (see (v) above) which was to have been applied on the Eburu and Elmenteita section of the line; it seems to me rather incompletely documented and it is possible that some further adjustment of the plans might have taken place since the original survey was made. It also seems to me possible that the old railway benchmarks on Gilgil and Eburu stations, which are on adjacent stations, probably built within a few years of each other, were heighted on the same datum. At Gilgil, this datum is 9.89' below the Survey of Kenya datum.

From the available information, I could find no conclusive indication as to which of the corrections should be applied. I finally decided to take the central one, 6.23', which is the formal relationship between the railway and Survey of Kenya data and was given me by one source in the E.A.R. & H. head office (see (v) above). There seems to me a finite possibility that the correction might in fact be of the order of 9-10', or 3', or possibly even another figure which I have failed to discover, but a 6' correction seems to give a reasonable mean value. An unavoidable uncertainty of ±3' will thus attach to all conversions of heights from railway to Survey of Kenya datum, but in this work this does not seem excessive. It will not, for instance, introduce problems into the determination of possible tilt of the lake shorelines, since the features which I have measured cannot be defined so precisely that a tilt of 3' or so could be distinguished from one end to the other of this basin. In my conversions from R.D. to S.D. heights I have therefore subtracted 6' in each case.

3. <u>The use of the expression 'A.L. Nakuru'</u>: in Leakey's work, almost all the shoreline heights are given in the form "above Lake Nakuru"; absolute altitudes are hardly ever mentioned. This usage has the advantage of being quickly comprehended; the distribution of shorelines at various heights can be more readily pictured than if the

more cumbersome 4-figure numbers of the absolute altitudes are used. The disadvantages are (a) it may tend to encourage generalization and selection of information since the heights are already one degree removed from the original values as measured. (b) The heights are related to a variable datum: the level of Lake Nakuru has fluctuated over a range of several feet since the years when Leakey's survey was done. If this usage is retained, it is essential to define the level of the lake surface which is being used as datum for the shoreline heights. For instance Richardson (1965) described the shorelines in the Nakuru-Elmenteita and Naivasha basins by their height above the 1960 levels of the respective lakes.

Leakey's two main papers (1931a and b) quoted different heights for Lake Nakuru. In 1931a the height was given as 5776.8' (presumably R.D.) as measured on 10th April 1929; on the map (p. 499) this was corrected to 5777'. In 1931b the height was given as 5776' (p. 246). There is a similar disagreement between the two heights given for Lake Naivasha. Although not serious, this difference is slightly irritating. Nilsson (1931 p. 291) gave the height of Lake Nakuru as 1761 metres, i.e. 5781' R.D. This was based on fieldwork done in 1927, so the difference between his and Leakey's figures could be due in part to an actual fall of the lake. Lake Naivasha fell over 5' between 1927 and 1929, so that it is possible that a similar change occurred in the level of Lake Nakuru. There do not appear to be any other records of the levels of Lakes Nakuru or Elmenteita at this time.

Recently the gauges on Lakes Nakuru and Elmenteita were tied in to the Survey of Kenya datum, and I was supplied with information about the 1966 and 1967 levels of the lakes by the Water Development Department office in Nakuru.

Lake Nakuru - zero of gauge = 5771.00' S.D.
lake on 16 March 1966 at 8.10' on gauge
i.e. 5779.10' S.D.
lake on 11 January 1967 at 7.55' on
gauge i.e. 5778.65' S.D.

Lake Elmenteita - zero of gauge = 5822.01' S.D.
lake on 16 March 1966 at 7.40' on gauge
i.e. 5829.41' S.D.

The lakes seem to be slightly higher now than they were in the late 1920s, although the change in the datum makes it impossible to be certain about the exact amount of the variation in level.

I have not used the 'above Lake Nakuru' heights very much in describing the results of my own survey work in the basin (except in referring to the "600 foot" shoreline) and have generally converted Leakey's heights into absolute figures by adding the "above Lake Nakuru" figure to 5776'.

In cases where I do refer to an 'A.L. Nakuru' height based on the results of my own levelling, the level of the lake has been taken as 5779'. This, being determined on the Survey of Kenya datum, is more strictly comparable with my height figures, than using any figure of Leakey's, based on the railway datum. However it must be remembered that these 'A.L. Nakuru' heights are really only approximate and give no more than a general idea of the altitudes of the different shorelines.

4. <u>The survey equipment used</u>: for almost all my levelling I used a Zeiss Koni 025 self-adjusting level and a 14' levelling staff. I found the level to be an excellent instrument, light to carry and very quick to adjust. Its only disadvantage was that when there was a gusty wind the line of sight became rather unsteady. Conditions for levelling were best early in the morning, although it was often possible to continue past midday without the effects of wind and heat shimmer making it impossible to continue work. In most of my levelling I did not make any accurate distance measurements, merely counting the number of paces I took so that backsight and foresight should be about the same lengths.

For the earlier and more important part of the levelling, I controlled all my results by levelling in both directions, to and from the benchmark or trigonometrical point. This was done for all the Menengai shoreline levelling, Bahati, Hyrax Hill, Lion Hill and Gamble's Cave. The results were in every case well within the limits of accuracy that I had set myself, bearing in mind the lack of precision with which most of the features that I was studying could be defined. An example of some of these results, the figures for the Gamble's Cave levelling, is given in the attached table. The net height difference between the two ends of the line of levelling was over 340', although the actual range of height covered was considerably greater. The difference between the two lines, out and back, was 0.39'. This is an error of about 0.11%.

In the later levelling, at Gilgil, Eburu, Nderit and Makalia, I did not have time to level both ways, so the accuracy of the work is unconfirmed. However there seemed no reason why the same standards of accuracy as I had achieved for the earlier levelling should not have been achieved here; the conditions were not more difficult and as time passed my assistant and I became more skilled in the use of the equipment. I think that even these later results should be accurate to within a foot or less, and certainly adequate for the purposes of this research.

Table VIII

Gamble's Cave Levelling

Line	Westwards		Eastwards	
$E_7 - E_6$	0.92	fall	0.97	
$E_6 - E_5$	21.34	fall	21.44	
$E_5 - E_4$	5.08	rise	5.14	
$E_4 - E_3$	31.46	rise	31.36	
$E_3 - E_2$	42.51	rise	42.45	
$E_2 - E_1$	11.25	rise	11.26	
$E_1 - S_2$	79.40	fall	79.45	
$S_2 - S_3$	3.44	fall	3.44	
$S_3 - S_1$	41.59	rise	41.57	
$S_1 - MM_1$	160.54	rise	160.46	
$MM_1 - MM_2$	109.00	rise	108.94	
$MM_2 - 7$	65.95	rise	65.86	
7 - 4	77.17	fall	76.89	
4 - N.B.	116.57	fall	116.62	
N.B. - 6	185.97	rise	185.92	
6 - sand	12.89	fall	12.92	
Net; E_7 - sand	341.62	rise	341.23	Feet

5. Comparison with the results of other levelling in the basin: the results of my levelling are only occasionally truly comparable with those of Leakey and Nilsson. In many cases it is impossible to be certain that we were levelling to the same shoreline 'terrace' or 'beach' as the accounts of their fieldwork do not usually include much detail about the features to which they measured. There are some instances where I am fairly certain that I have identified the features described by Leakey or Nilsson; these are listed below, with the different height figures obtained. It will be noticed that even in these cases there is not unanimous agreement about the heights. In most cases this can probably be explained by the difference in datum and, more important, by the lack of agreement as to exactly what part of the feature was defined and levelled as the 'shoreline' or 'lake level'. It seems more likely that such lack of consistency in usage, rather than major mistakes in the levelling, is the reason for most of the disagreements given here.

(i) Menengai shoreline:

Not mentioned by Leakey.

Height according to Nilsson (1931 shoreline list)

0.93 miles east of Nakuru Junction - 6415' R.D. (=6409±3' S.D.)

2.79 miles east of Nakuru Junction - 6418' R.D. (=6412±3' S.D.)

5.27 miles east of Nakuru Junction - 6425' R.D. (=6419±3' S.D.)

(all of these described as terraces).

Height according to my levelling:

Base of cliff, from 1¼ to 2¾ miles east of Nakuru Junction - 6370' S.D.

Top of this cliff is at circa - 6410' S.D.

Highest beach pebbles, circa 5 miles east of Nakuru Junction - 6381' S.D.

(ii) Misonge shoreline:

Height according to Leakey - 145' A.L. i.e. 5921' R.D. (=5915±3' S.D.)

Height according to Nilsson; described as a terrace 1.55 miles NNW of mouth of River Njoro - 5955' R.D. (=5949±3' S.D.)

Height according to my levelling; at a point about 2.5 miles NNW of mouth of River Njoro - 5944-5950' S.D. (base of cliff).

(iii) Magharibi shoreline:

Height according to Leakey - 379' A.L. i.e. 6155' R.D. (=6149±3' S.D.)

Not definitely identified in Nilsson's work.

Height according to my levelling; base of cliff - 6128' R.D. (=6122±3' S.D.)

(iv) Lion Hill Cave:

Height according to Nilsson - 6386' R.D. (=6380±3' S.D.)

Height according to Leakey - (1931a) 608' A.L. i.e. 6385' R.D. (=6379±3' S.D.); (1931b) 620' A.L. i.e. 6396' R.D. (=6390±3' S.D.).

Height of floor of cave according to my levelling - 6386-87' S.D.

Some of the differences in height here are too great to be fully explained by the difference between railway and Survey of Kenya data, even if it is assumed to be as much as 9' or 10'. In these cases it is worth while considering exactly what shoreline features were levelled to when these heights were obtained.

Nilsson gave quite a clear explanation of the features to which he levelled. The supposed former shorelines are said to be (i) wave cut-terraces and (ii) barriers. (See figure 5) The 'cut-terraces' were formed by erosion on a sufficiently steep shoreline, the barriers are depositional features formed on a more gently sloping shoreline. I feel rather doubtful about the likelihood of such barrier beaches being preserved close to the original water level and their value for showing the level of the former lake. The pebbles may, even at the time of deposition, have covered a larger vertical range than that indicated on Nilsson's diagram, and certainly since then they will in most cases have been washed down from their original position. In the Nakuru-Elmenteita basin I was not able to identify any of Nilsson's barriers, except possibly the accumulation of pebbles at 5/16 high up on Lion Hill. On the other hand his levelling of the 'cut-terraces' at the notch at the base of the cliff seems sensible. What is not clear is how he identified this point in the field, where the sharp break of slope shown in his diagram is usually obscured. In my work I drew profiles of all the shoreline cliffs (figures 1,2,3) and obtained the height of the break of slope from them. It does not seem that Nilsson levelled any such profiles; at any rate none are shown in any of the accounts of his fieldwork and I would think this implies that none were drawn. If this is so, he presumably estimated the position of the break of slope by eye. On these slopes, where the break of slope has been obscured by material washed down from above, this is not a very reliable method. From my own experience of the Menengai shoreline cliff, I would say that it woudl be very difficult to be certain about the position of the break of slope at its base to within less than 5'vertical range.

A more serious mistake in Nilsson's work on the shorelines is that a lot of the features he listed as 'cut terraces' seem to be small cliffs and breaks of slope of different origin. In the Nakuru-Elmenteita basin there are many small fault scarps; most of these run approximately north-south, as do the east and west shores of Lakes Nakuru and Elmenteita, and the faults might be taken for erosion cliffs of a former lake shore. Since Nilsson worked in this area, the importance of recent fine grid faulting here has been fully recognized (McCall 1967) and many of the steep rocky slopes that Nilsson could have identified as coastal erosion features are probably fault scarps. Although the lake surface may for a time have been up against some of these slopes, the base of slope cannot be taken as a wave-cut notch and its altitude should not be used as an indication of a shoreline level. In this context it is relevent to note that several of the supposed shoreline terraces described by Nilsson from the Ethiopian lake basins are believed by Mohr to be of structural origin. (Mohr 1963, pp. 200, 203)

It is possible that Nilsson identified some of the small erosion scars and cliffs on the slopes of Eburu as shoreline features. One of the Eburu farmers, who remembered Nilsson at work here, showed me a feature close to his farmhouse (at GR 480362 on map 133/1) which he said Nilsson had identified and levelled as a lake shoreline; it seemed to me to be a typical erosion scar. These scars are cut into coarse reddish-orange silts and can sometimes be traced almost horizontally for several hundred feet along a hillside; however many similar features run across the contours and their appearance is too fresh for shoreline cliffs of a lake that retreated several thousands of years ago.

Leakey's publications include few details about the recognition and measurement of the shoreline features. Solomon (appendix A in Leakey 1931b) referred to 'beaches' and 'terraces' as the evidence of the former lake, but did not describe them or how they were levelled. The same is true of Leakey (1931a) who mentioned the difficulty of levelling these features but did not describe them or exactly how it was done. His use of the terms 'beach' and 'terrace' is confusing and he also referred to 'beach terraces' (p. 500). Nilsson (1931 pp. 327-8) quoted a comment by Solomon from the monthly expedition reports which Leakey was sending him at the time: "The level of the beaches is taken to be the lowest point at which an outcrop of water-worn conglomerate occurs at the base of the cliff. This should correspond roughly to the lower limit of wave erosion in a shallow inland basin such as Naivasha, and thus to the height of the terrace overlain by the beach". This is the closest I can get to an original statement about this levelling. Some of Leakey's expedition reports are in the library of the Royal Geographical Society, but the early ones, which may have dealt with the work in the Nakuru-Elmenteita and Naivasha basins, are unfortunately missing. If this definition of the shoreline level, as quoted by Nilsson, was in fact the one used by Solomon and Leakey, I consider it to be rather unsatisfactory. Nilsson himself criticized it, saying ". . . his (Solomon's) way of levelling a beach does not give the real altitude of the level of the ancient lake or another level in a firm relation to the lake-level" (1940 p. 31). Solomon's definition seems to concern only beach material (i.e. water-worn pebbles); possibly there was a further description of the relief features, cliff or terrace, which was not quoted by Nilsson. It seems very unrealistic, in studying an outcrop of water-worn 'conglomerate', which has almost certainly been washed downslope and partly covered over since it lay on the lake shoreline, to attach much significance to the lowest point at which the outcrops can be seen. On Menengai, water-worn pebbles can be traced in abundance between altitudes of circa 6230-6380', on the north-east Elmenteita slopes, between 6140-6260' and higher. If anything, it is the highest occurrence of the pebbles that should be significant; even then possible down-washing must be allowed for. There seems no reason why any precise deductions as to the lower limits of wave erosion on the former lake shorelines could be made from most of the outcrops of beach pebbles as they occur today. According to Guilcher, "Deposits can only betray the position of a former shoreline without question when they take the form of a shingle beach, in which case they indicate the former high tide level except in the rare instance where the whole of the beach is composed of shingle" (1958 p. 41).

Temple, who worked on the former higher lake levels round the northern shores of Lake Victoria, defined the significant shoreline feature as "the inferred position of the concave break of slope at the base of the cliff before it became obscured by talus" (1964 p. 35). He levelled accurate profiles of these slopes wherever this could be done.

I would agree with Nilsson and Temple that the concave break of slope at the base of the cliff is in most cases the most suitable feature to identify and measure to give the altitude of the former lake shoreline. Although fluctuations in water level will certainly have taken place, this notch, if it exists, indicates the place where the most concentrated erosion went on, when the lake was at that approximate level. With the aid of profiles, a fairly precise definition can be made of a point which represents this break of slope. This is done by drawing an average slope for (i) the flat below the cliff and (ii) the free face of the cliff (see diagram 6) and defining the break of slope as the intersection of these lines. The cliff was probably never this ideal form but this does give a fairly rigorously defined point which can be used for comparison of heights and investigation of possible tilting. Uncertainty arises in the drawing of these two average slopes, but this is still less than the uncertainty inherent in identifying a single point on the surface as the break in slope.

I have tried to avoid the confusion of nomenclature that has arisen in the description of the different shoreline features. The terms 'terrace' and 'cliff' are used as shown in figure 6. The word 'terrace' I have used to mean the wave-cut bench or shore-platform which underlies the cliff; this is possibly a more limited use than is given by Nilsson, but it seems closer to its modern usage in geographical literature. (Eg.King 1959 pp. 288-93) I have used the word 'beach' to mean the water-rounded pebbles and sand which were laid down on the lake shore and which were usually overlying the terrace. It is thus only a depositional feature; according to Guilcher, "A beach can be defined as an accumulation on the sea shore of material, coarser than mud" (1958 p. 46). I have avoided the use of terms such as 'beach terrace'.

It would seem that the definitions of shoreline height used by Nilsson and myself are rather similar and it would be likely that we should record approximately the same height if we were levelling the same shoreline cliff and notch. This is in fact so for the Misonge shoreline, where I obtained a height of 5944-5950' S.D. and Nilsson's height was about 5949' S.D. I am not able to explain why Nilsson obtained heights more than 30' above mine for the Menengai shoreline, unless it is due to a further datum difference along the stretch of the railway west of Nakuru for which

I have not allowed. It would be reasonable to expect that the shorelines as defined by Solomon would be rather lower than mine or Nilsson's; this is in fact true of the Kisonge shoreline, but the Magharibi shoreline height given by Solomon and Leakey is nearly 30' higher than the value I obtained. Again it is likely that differences in datum can explain some of this discrepancy. However I would not claim to have explained fully all the disagreements that exist between my results and those of Leakey and Nilsson.

6. <u>The Gamble's Cave levelling</u>: A number of different heights for this site have been quoted by earlier workers. The comparison of these results is not easy, since it is not always certain whether they referred to the beach sand in the cave, or to a terrace or notch below the cliff behind the cave. The various heights given in the literature, and the possible features to which they refer, are summarized here:

Leakey 1931a	(the beach sand?)	6280'
Leakey 1931b	(the beach sand?)	(6276' (6286'
Nilsson 1931	(the base of the cliff)	6383'
Nilsson 1940	(the base of the cliff?)	6393'
	(the beach sand?)	6366'

(all heights presumably R.D.)

Result of my levelling 1966

(the beach sand) 6353' R.D.

The difference between the results obtained by Leakey and Nilsson is considerable; the lowest figure given by Nilsson, likely to be the height of the beach sand, is still 80' above the highest figure given by Leakey; even if Nilsson was referring to the level of the top of the section or original ground level in the cave this, according to Leakey (1931b p. 92) was only 28' above the rock and sand at the bottom of the cave, still leaving over 50' unaccounted for. The difference seems too great to be explained as the result of using a different datum, and anyhow it seems probable that both the levellers used the same railway datum.

I levelled from Elmenteita to Nderit Drift and then up to the cave via the Miti Mingi farmhouse (close to 10/13 on map 3). The work was done in June and September 1966. Climatic conditions were quite good although by 1 p.m. it tended to become rather windy. The lines of sight were kept short, almost always less than 50 yards, and in the thick bush near the cave they were much shorter than this. The actual levelling was not very complicated, although it was a long job, some of it along a very dusty road and some along a narrow track on thickly vegetated and quite steep hillsides. I levelled each section of the line twice, once in each direction, and in each case got a satisfactory agreement between the two results. (See Table of levelling results) The total distance levelled in both directions was almost 16 miles.

The difficulty lay not so much in the actual levelling as in the finding of height control. In the years since Leakey and Nilsson were working at Elmenteita the railway line, fuel siding and Decauville railway at Nderit Drift have all been removed, and much vegetation has grown up over parts of them. However I was supplied with all the old plans and sections of these lines, by the offices of East African Railways and Harbours in Nakuru and Nairobi. The height control I used was as follows:

(i) Plan 2567/2 of Elmenteita fuel siding (drawn for E.A.R. & H. by Fayle and Fane in 1926) shows the height of the bed of the Nderit river below the 'Trestle bridge' as being at 5996.6'. This bridge, now destroyed, was, judging from plan 2795/1 (Fayle & Fane 1927) not more than about 200' upstream of the Drift road and the present small bridge there. The gradient of the river here is not very great, and one can assume that the height of the river bed at the present Drift bridge should not be much below 5996.6' also. This is the point S_3, the river bed on the upstream side of the present bridge, that I used in my levelling.

(ii) At Elmenteita the former station building is now the Police post, and the goods shed and water tank remain on the other side of the road. There is unfortunately no benchmark on the station building, but from the line plan and profile of the old Uganda Railway (sheet no. 43, mile 429½) one learns that the formation level at the centre of the station building is 6011.32'. This, according to the railway engineer with whom I visited Elmenteita, would be near enough to the level of the top of the water tank which is on exactly the opposite side of the line. This is the point E_7 that I used in my levelling.

The heights of these two points, S_3 and E_7, are thus not more than approximations, although they seem to me to be based on sound documentation and not to allow the possibility of much error. This was borne out by the results I obtained for the height of the sand in the cave from levelling from each of these points. To summarize the results from the table:

From point S_3 at Nderit Drift to top of sand in cave = 356.37'

From point E_7 at Elmenteita to top of sand in cave = 341.42'.

S_3 is at 5996.6', therefore the sand is at 6352.97' R.D.

E_7 is at 6011.32', therefore the sand is at 6352.74' R.D.

Average is 6352.86' i.e. about 6353' R.D.

The agreement between the two values obtained from the levelling from S_3 and E_7 is strikingly close, suggesting that the approximations to the heights of these two points are good ones. I would think that this value for the height of the beach sand is close to the true answer. If the adjustment of -6' between railway and Survey data is accepted, the height of the sand bed in the cave is 6347' S.D.

7. The Menengai shoreline: the levelling of the shoreline profiles here was the most important part of this work. I levelled 13 profiles across this shoreline, within a distance of about 3¼ miles between points 681709 and 732709 on map 119/3. (See map 4) The average length of the profiles was about 400 yards or more. In several cases I was unable to continue them quite as far as I should have liked because of obstruction or cultivation at the ends of the profiles; however I think that in each case I obtained long enough lines to allow their projection to find the lower break of slope, as described above. I attempted to make the line of levelling close to the line of greatest slope of the profile, usually approximately at right angles to the cliff line. In each case I levelled in both directions between the end points at the upper and lower ends of the profile, not aiming to keep to exactly the same line between the two ends. I thus obtained two profiles for each cliff, from a few yards apart, which were usually almost identical.

The distance measurement was done by pacing; I then measured the length of my paces over fairly rough ground and found the average over 1000 yards to be 31.5" (2.62').

The height control for the Menengai shoreline was all on Survey of Kenya benchmarks and trigonometrical points, so that there is no inconsistency of datum between the different shoreline profiles. The distribution of the profiles is shown on map 4, the profiles themselves in figure 1. The best developed profiles are those from 0-7. West of profile 0, in the Nakuru Junction area, the cliff line is not well defined. Profiles 8 and 9 show the influence of a road cutting in the slope of the cliff; the old road from Nakuru to Eldama Ravine used to run across the shoreline at this point. To the east (profiles 13 and 14) the influence of the welded tuffs and ignimbrites which outcrop on this part of Menengai is felt and the break of slope between the cliff and terrace is not well defined.

8. The Bahati overflow: the opinions of earlier workers on the height of this area are discussed in Chapter 5. There was a marked discrepancy between their results and the height as indicated by the form lines on the most recent edition of the 1 : 50,000 map of the area. It seemed necessary to do some further survey work to check the accuracy of these form lines (which indicated contact between the Bahati Plain and Menengai caldera between 6350-6400') and to determine the exact height of the lowest point on the Bahati-Menengai caldera divide. I first levelled

along the main road (Nakuru-Solai) from the Survey of Kenya benchmark no. NKU/27 (altitude 6063.10' S.D.) which lies near the junction of this road with the Nakuru-Nairobi road. For several miles north from the junction the wall of Menengai volcano rises steeply to the west of the road and the Bahati Plain drops gently to the east. Then the crater wall drops sharply to the subsidence structure (a lateral graben) at which overflow may have taken place (the area OF on map 3). This area is shown in more detail in map 5, with form lines sketched from the 1: 50,000 map (119/1) and spot heights added from my levelling. The main road here is for some distance at a height slightly above 6390' S.D. There is a marked slope west from the road into the caldera (plate 3). East and south-east of the road, the land surface is almost horizontal for some distance and then slopes gently towards the centre of Bahati Plain. The spot heights on map 5 show that the form lines on the 1 : 50,000 map are substantially correct. Given the present land surface, a lake in the Bahati Plain would begin to overflow into the caldera at an altitude of just above 6390' S.D.

9. The Gilgil divide: the question of the exact altitude of this area, the pass between the Nakuru-Elmenteita and Naivasha basins, became less important when it became clear that the lowest outlet from the Nakuru-Elmenteita basin was

not here, but at the Bahati overflow about 200' below. However it still seemed interesting to check the earlier work done in this area, and to obtain an accurate height for the divide which might at a later stage be useful for comparison with the height of the divide south of Lake Naivasha at the Njorowa gorge.

Earlier opinions on the height of the Gilgil divide were in agreement that it is at about 6600', although they included no detailed maps or exact statements of where the watershed lies. According to Leakey (1931a and b) the pass is at "some 6600'". According to Nilsson (1931 p. 294) it is at about 2006 metres, i.e. 6586', while in his later paper (1940 p. 75) it is given as 2013.9 metres, i.e. 6612.3'. McCall (1967) mentioned the Leakey-Solomon figure of 6600' "which agrees with the measurements of the Survey of Kenya" (p. 66). From the contours on the 1 : 50,000 maps (nos. 119/4 and 133/2) it appeared that overflow between the two lake basins might take place between 6600' and 6650' in two places: (i) close to the line of the present Gilgil-Nakuru road and railway, at GR about 677473 on map 119/4 and (ii) slightly south of the old railway line and the Gilgil-Eburu road, at GR about 678450 on map 119/4. I levelled around both these areas, controlling my work from the benchmark at Gilgil station (B.M. VII/45, height 6572.30' S.D.). I was able to determine that the lowest point on the divide between the basins is at the second of these two places, across the ridge at GR about 678450 (map 119/4). (Point GD on map 3) The results of my final levelling here indicated that the lowest point on this ridge is above 6595' but certainly below 6600' S.D., probably between 6597-6598' S.D. The contours on the 1 : 50,000 map in this area are slightly inaccurate as they indicate that this ridge does not fall below 6600'. The divide in the area to the north, along the main road and railway line, is rather higher, slightly over 6608' S.D. If any overflow between the basins ever occurred, it would take place along the southern ridge at about the point marked GD (map 3).

<u>10. Notes on the place names and their spelling</u>: (i) in describing the possible lake shoreline features in the different parts of the basin, I have always tried to use simple geographical (locational) names which do not involve any assumptions as to geological or climatological correlations of the features. Even where it appears that features from widely separate parts of the basin can be attributed to the same stillstand of the lake, I have retained the distinct locational names for them.

(ii) Most of the place names in the Nakuru-Elmenteitá basin have been written in a number of different ways since they were first recorded by the early explorers at the end of the 19th century. In most cases this was because the writers were dealing with a language (Masai) which was unfamiliar to them and which had never been written before. Even today there is a lack of agreement as to how many of the place names in the Nakuru-Elmenteita basin should be written; this extends to recent editions of the Survey of Kenya 1 : 50,000 maps, where the spelling of some of the names has varied over a few years. I have tried in the text and on my maps to use the current form of the place names as found on the most recent edition of each map, although it is possible that within a few years some of these names may be given a different spelling. In some cases, where the most generally known spelling is different from that on the most recent map, I have kept to the well-known spelling, for example I have used Kariandusi rather than Kariandus.

(iii) In most cases the names are Masai words or derivations of them. In others, as for some of the archaeological sites, no indigenous name existed and a European name was given by the excavators. In the case of the tributaries of the River Nderit, Prettejohn Gully and Aspinal Gully, no obvious local name seemed available and the gullies were named after the farmer and farm manager who had been on this land during part of the 1950s and 1960s. The name Prettejohn Gully was originally coined by Isaac (pers. comm.).

11. Grid references of some of the most important localities in the Nakuru-Elmenteita basin.

The references are taken from Survey of Kenya maps, scale 1:50,000, the following numbers and editions;-

Map number	Sheet	Edition	Year
119/1	Menengai	4th	1955
119/3	Nakuru	6th	1964
119/4	Gilgil	4th	1960
133/1	Ol Doinyo Opuru	4th	1958
133/2	Naivasha	3rd	1956

Bahati

Bahati overflow	c.460760	(119/1)
3/1 and 3/2	454726	(119/1)
3/3,4 and 5	815695	(119/3)
3/6	464742	(119/1)
3/8	473762	(119/1)
3/10	517751	(119/1)
3/13	813706	(119/3)

3/15	811703	(119/3)
3/16	810702	(119/3)
3/19	815705	(119/3)

Eburu

8E/2	624373	(133/2)
8E/3	619366	(133/2)
8E/4	593367	(133/1)
9/1	577369	(133/1)
9/7	512395	(133/1)
EP_1	520359	(133/1)
EP_2	444383	(133/1)
c.533 (borehole)	517362	(133/1)
c.1877 (borehole)	538373	(133/1)

North East Elmenteita

8/1	622528	(119/4)

Elmenteita volcanoes (Karterit)

8V/4	645436	(133/2)
8V/8	636444	(133/2)

Gamble's Cave - Nderit area

Gamble's Cave	433394	(133/1)

Prettejohn Gully (upper part)	449386	(133/1)
10/5,6 and 7	c.433397	(133/1)
10/13,14 and 15	436400	(133/1)
Oldobeye diatomite pit (10/18)	458417	(133/1)
Nderit Drift	445427	(133/1)

<u>Gilgil divide</u>

8/9	689463	(119/4)
Gilgil Hotel	690458	(119/4)

<u>Gilgil escarpment</u>

8/4	666483	(119/4)
8/5	661488	(119/4)
12/3	667465	(119/4)

<u>Hyrax Hill area</u>

Top of Hyrax Hill	775692	(119/3)
Water tank Hill	783694	(119/3)
Lanet Lodge Hill (Plaat Hill)	800680	(119/3)

<u>Kariandusi and Kekopey</u>

8/3	657496	(119/4)
8/12	640503	(119/4)

Soysambu diatomite pit	854526	(119/3)

<u>Kiboko</u>

Shoreline cliff	c.780660	(119/3)

<u>Lion Hill</u>

5/1	794623	(119/3)
5/4	808618	(119/3)
5/10	799653	(119/3)
5/14	640811	(119/3)
5/15	803655	(119/3)
5/16	810605	(119/3)
Lion Hill Cave	809619	(119/3)

<u>Makalia</u>

11/3	726455	(119/3)
11/5	721451	(119/3)
Magharibi cliff	c.744456	(119/3)

<u>Mbaruk</u>

7/1	903605	(119/3)

Menengai

1/5	675701	(119/3)
1/7	676701	(119/3)
1/12	694693	(119/3)
1/21	703688	(119/3)
1/23	712703	(119/3)
1/29	698703	(119/3)
1/31	683697	(119/3)
2/2	718706	(119/3)
2/11	735703	(119/3)

Misonge

Cliff where profile was levelled	c.748682	(119/3)

Njoro Road

4/3	673682	(119/3)
4/8	677699	(119/3)

APPENDIX B

MOLLUSCA

Mollusca have been described from several Upper Pleistocene and Holocene lacustrine deposits in the Eastern Rift Valley, including some in the Nakuru-Elmenteita basin. In my fieldwork I found mollusca in a lacustrine silt at only one place, the locality marked 8V/8 on map 3; this exposure is not referred to in any other account of the basin.

The mollusca-bearing silts here are exposed in a small gully cut in the sediments which cover the lower parts of the northern slopes of the volcano Karterit. The gully is not more than 100 yards long and 15' deep; the silts are exposed in small patches in its sides. There are 3 or 4 small exposures within a distance of less than 30 yards, each being not more than 4' high and about 6' long. The silts occur beneath about 4-6' of brown-grey dusty soil. The altitude of the exposures which contain mollusca is from 6188-92' S.D. The mollusca occur in a matrix of diatomaceous silt. The silt varies in colour from almost white (probably in this case the result of weathering and drying out) to buff and light brown. It shows a rough horizontal banding, with darker and lighter stripes, but there are no marked discontinuities or changes in texture visible in the sections exposed. The mollusca tend to be concentrated in bands (see plate 16) where they are quite abundant, but smaller numbers of shells are scattered through the rest of the silt and there is no abrupt change in the character of the matrix at the boundary of the shelly bands. In one of the exposures there are two layers of fine pale grey ash, each about 1" thick, in a firm white silt underlying about 3" of buff-coloured silt containing mollusca. In the other exposures, some light grey pumice fragments are scattered through the silt, but these were few and are not concentrated into any kind of pebble band. The mollusca tend to be well preserved and it was easy to collect enough for examination and for carbon-14 dating.

Concerning the position of these silts in the geological sequence in the Nakuru-Elmenteita basin, the following comments may be made:

(i) In their position on the north-east slope of Karterit the silts seem to be part of a sequence of lake features which may be correlated in height with similar features in other parts of the basin. The altitudes of the features are as follows:

Shoreline notch on Karterit - circa 6365' S.D.
Highest pebbles on surface below notch - 6293' S.D.
Pebbles in section with silt - 6279' S.D.
Mollusca-bearing silt at 8V/8 - 6188-92' S.D.

The pebbles and silts are not as high as the highest comparable deposits preserved below the 600 foot shoreline elsewhere, but they are well within the range of heights of, for example, the sediments below the Menengai shoreline. It is reasonable to expect that on these rather steep bare slopes of the volcano, the highest deposits would be rather easily destroyed, and in fact there is no sign of lake sediments on the rocky slope west of the small patch preserved in the vicinity of 8V/8. At the same time, along the base of the eastern slope of the volcano, on flatter land, diatomaceous silts can be traced in several outcrops at 6320' S.D. and slightly above (e.g. 8V/4 on map 3).

(ii) It does not seem likely that the silts at 8V/8 are of the same age as the older diatomites exposed in this part of the basin, i.e. the small exposures at 8E/2, 8/4 and 8/5. The silts in these exposures are white, rather hard, and faulted; none of these descriptions can be applied to the matrix at 8V/8. From the small sections visible, it is difficult to determine whether or not the silts at 8V/8 are faulted; a slight dip seems visible in places, but this may well be due to slumping of material towards the centre of the gully. If they are faulted, possibly by the movements that have affected Karterit itself, the displacement would appear to have been very slight.

(iii) The silts at 8V/8, lying as they do on its lower slopes, are certainly younger than Karterit volcano, and, if McCall's correlation of the Karterit tuffs with the Kariandusi lake beds is accepted, the silts must be younger than the Kariandusi beds as well.

(iv) At the same time these silts are over 400' above the present lake level, and are substantially above the Magharibi and Misonge shoreline cliffs; they were therefore not laid down in a lake standing at the level of either of these cliffs. Some silts which are probably of a younger phase of sedimentation are exposed to the north-west of Karterit, north of the Gilgil-Elmenteita road; they are very white and have a finely fractured surface, quite different from the silts at 8V/8.

It seems reasonable to assume that the date measured for the mollusca in these silts (see below) is not too far from an approximate age for the 600 foot shoreline in the Nakuru-Elmenteita basin. The 600 foot shoreline is the only sign of a major stillstand of the lake above the level of the silts at 8V/8, and it is likely that, of the period while the lake was above this level, the greater part was spent near the 600 foot level, where the cliff line was cut. Although the mollusca cannot give as firm an indication of the age of the 600 foot shoreline as could material from a beach actually at that level, I would suggest that the discrepancy cannot be too great. At any rate it can be said that, at the date of these mollusca, the lake level stood above 6200' S.D., i.e. over 400' A.L. Nakuru. A report on the species of mollusca in two samples of the silt from SV/8 has kindly been prepared by Mr B. W. Sparks. He listed the following species:

<u>Corbicula africana</u> (Krauss) (most common)
<u>Melanoides tuberculata</u> (Müller) (second in abundance)

Very small numbers of:

<u>Pisidium</u> sp.
<u>Burnupia</u> sp.
<u>Bulinus</u> sp.
<u>Anisus natalensis</u> (Krauss)
<u>Biomphalaria</u> sp.

These are all freshwater species; no land snails were present in the samples. Sparks, following Mandahl-Barth, suggested that these snails, in particular <u>Corbicula</u> and <u>Melanoides</u>, are indicative of a lake of appreciable size rather than a small perennial or temporary body of water. It is not possible from these samples to obtain a precise indication of the depth of water or length of time implied by the deposit.

A sample of the mollusca was dated at Lamont Geological Observatory through the kindness of Dr David Thurber.[1] The age obtained for the shells using the 5585 half-life for radiocarbon and assuming the initial C-14/C-12 ratio to be

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1. Number of dated sample: L-1201.

atmospheric was 9650±250 years before 1950. In an attempt to determine the actual value of the initial C-14/C-12 ratio and thus obtain a more precise figure for the age of the shells, analysis was made of water sampled from Lakes Nakuru and Elmenteita in July 1965. Unfortunately the results of this analysis did not reach me before the thesis was bound.

The shells are, at any rate, not older than 9650±250 years.

The mollusca found in Nakuru-Elmenteita basin sediments by Leakey were described by M. Connolly (appendix D in Leakey 1931b). The localities at which they were found were Gamble's Cave, Lion Hill Cave and Nderit Drift. Particularly interesting are the mollusca listed from the beach gravel in Gamble's Cave:

(i) Lymnaea elmeteitensis? Smith, rare.
(ii) Bulinus sp., fragments.
(iii) Melanoides tuberculata (Müll.), very abundant.
(iv) Corbicula africana (Krs.)

(1931b p. 276)

Descriptions of lake sediments of Upper Pleistocene and Holocene age in the Baringo basin (Fuchs 1934) and the Rudolf basin (Fuchs 1934, Dodson 1963, Whitworth 1965) include references to diatomaceous silts and shelly limestones containing fresh-water mollusca. A number of species are recorded, not all of which are in the Nakuru-Elmenteita basin lists by Sparks or Connolly, but Melanoides tuberculata and Corbicula africana seem to occur in important numbers in almost all of the deposits described.

Unfortunately the presence of these species indicates little more than that, as in the case of the Nakuru-Elmenteita basin, the deposits formed in a lake of considerable size. It is not possible to make any precise estimate of the age of the deposits on the basis of their mollusca content; species similar to Melanoides tuberculata and Corbicula have been recorded in sediments in East Africa as old as Beds I and I at Olduvai, i.e. of the order of 1 million years old (Leakey 1965 p. 70). Nor can any correlation between the different lake basins be made on this basis.

APPENDIX C

THE ARCHAEOLOGY OF THE NAKURU-ELMENTEITA BASIN

The Eastern Rift Valley is rich in archaeological sites, most of which were first discovered and excavated several years ago. Much of the knowledge of the geology and palaeoclimatology of this area has been obtained during the course of primarily archaeological investigations. The resultant linking of these disciplines in the study of the East African Quaternary has in some ways been very valuable. On the other hand, the unification of the archaeological, geological and palaeoclimatic sequences into a single chronology seems to have taken place too soon, before enough was known about each of the sequences. It is now clear that much of the geological evidence appears to have been wrongly interpreted in terms of palaeoclimatology; the relationship of the archaeological and palaeoclimatological sequences must therefore also be reconsidered. At the same time it is clear that many gaps remain in our knowledge of East African, especially perhaps the post-Acheulian, industries. The archaeology-palaeoclimatology relationship is thus open to question from both sides.

In the Nakuru-Elmenteita and Naivasha basins there are a number of important archaeological sites of different ages. Table IX shows the industries which have been described from the area and some of the sites in the Nakuru-Elmenteita basin at which they occur. The industries are named according to the current but in many cases admittedly unsatisfactory terminology.

Table IX

East African prehistoric industries and the sites at which they occur in the Nakuru-Elmenteita basin

Industry	Sites
"Stone Bowl Culture" (Neolithic)	Hyrax Hill (Hyrax Hill variant) Njoro River Cave Nakuru Burial Site (Gumban B) Stable's Drift (Gumban A)
Elmenteitan	Gamble's Cave
"Wilton"	Long's Drift
Kenya Capsian	Gamble's Cave Prospect Farm Lion Hill Cave
"Magosian"	Prospect Farm Deighton's Cliff
Stillbay	Prospect Farm [Gamble's Cave][1]
Acheulian	Kariandusi

1. See p. 309.

Much of the early work on the former lake shorelines and sediments was done in connection with the investigations of Leakey's East African Archaeological Expedition in the late 1920s. Under these circumstances it was natural that the relationship of the different industries to the stages in the fluctuation of the lake levels and to the postulated climatic phases should have been worked out at an early stage and used as the basis of further deductions on the evolution of the lakes in the basins. For this early work, since absolute dates were not available, the industries were dated by reference to the palaeoclimatological evidence and not vice versa. It was said, ". . . the sequence of lake levels in the Nakuru basin . . . seems sufficiently well established to justify its use as a basis for the relative dating of the successive prehistoric settlements on Hyrax Hill, which were unquestionably influenced by changing climatic conditions" (M. D. Leakey 1945 p. 275), and the same reasoning was applied to other sites as well as Hyrax Hill.

The method of this reasoning was as follows: from the shorelines and sediments in the Nakuru-Elmenteita basin the pattern of Gamblian, Makalian and Nakuran wet periods was established. These were then correlated with the late- and post-glacial climatic fluctuations in Europe. (C. E. P. Brooks, appendix B in Leakey 1931b). It was assumed that the wetter and cooler climatic periods in Europe were closely contemporaneous with the periods of high lake levels in the Nakuru-Elmenteita basin. The approximate dates suggested for the East African wet phases were these (page references are to Leakey 1931b):

Nakuran post-pluvial wet phase:	850-0 B.C.	(p. 270)
	1,000-850 B.C.	(pp. 243-4)
Makalian post-pluvial wet phase:	9,000-3,000 B.C.	(p. 269)
	10,000-2,500 B.C.	(p. 270)

Gamblian pluvial: ended about 13,000 B.C. (p. 269)

The dates of the different industries were then based on the relationship of the sites at which they occurred, or the strata in which they were found, to the Gamblian, Makalian or Nakuran shorelines or sediments. Such a method of dating is clearly open to errors. Considerable doubt attaches to the whole question of the close parallelism of late and post-glacial climatic fluctuations in Africa and Europe, and to the exact pattern of the fluctuations in East Africa as shown by the changes in lake level in the Nakuru-Elmenteita basin. In this section I shall consider the possibility of error at the archaeological sites themselves, in the relationship between the strata which contain the cultural material and the supposed evidence of particular lake stillstands. I have tried to concentrate on the evidence of sites in the Nakuru-Elmenteita basin and the local relationship between prehistoric occupation and the former larger lakes, and to avoid much comment on the wider archaeological issues. However it has been necessary to include a certain amount of general discussion of African archaeology and the sequence and dates of industrial complexes in other areas.

Kariandusi

The site lies close to the Kariandusi diatomite mine at an altitude of about 6200'. It was originally excavated by the East African Archaeological Expedition between the years 1926-30 (Leakey 1931b). The site is now kept open by the Museum Trustees of Kenya.

Rolled and unrolled implements and a number of fossil bones are found in beach and torrent gravels above the thick pure diatomites of the mine. The implements are mainly hand axes and cleavers and belong to a stage in the Acheulian industrial complex. They are approximately contemporaneous with those in Olduvai Bed IV (stage 9 of the hand axe sequence) and at Olorgesailie and Kanjera.

The only absolute dates available for Kariandusi are some K/Ar determinations of the age of tuffs above and below the site, made by Evernden and Curtis (1965). These gave ages of 0·93-3·1 million years; Evernden and Curtis expressed most confidence in a date of 0·95 million years for pumice from within the diatomite 50' below the site. In view of the discrepancies between Evernden and Curtis' other results and current archaeological opinion (see below) it seems unlikely that even material from the diatomites some distance below the site can be almost 1 million years old.

In the small pamphlet on sale at the site (published by the Musèum Trustees of Kenya; the copy I have is dated September 1966) it is suggested that the age of this stage of the hand-axe industrial complex is about 130,000 years or a little more, although no explanation of this dating is given.

Absolute dates for comparable industries in other parts of Africa are unfortunately lacking. A K/Ar date for a rather older industry (Chellean stage 3 in Bed II at Olduvai) gave an age of 490,000 years (Hay in Leakey 1965 p. 99). A carbon-14 date for wood associated with the very late Acheulian at Kalambo Falls gave an age of 57,300±300 B.P. Between these limits, it is not possible to fix the date of the Kariandusi industry with much precision.

It has traditionally been held (Cole 1964 pp. 46,74) that the "Kanjeran pluvial", during which the Kariandusi site was inhabited and the diatomite was being deposited in a deep Rift Valley lake, should be correlated with the Riss glaciation in Europe. There is evidence from Acheulian sites in other parts of East Africa that conditions were rather moister than they are today. This is so for the late Acheulian at Kalambo Falls, and possibly also at Olorgesailie, where a fluctuating lake appears to have existed in what is now definitely an arid area. At Kariandusi the implement bearing gravels lie above thick layers (in all, over 100') of pure diatomite, indicating the existence of a large and stable lake in this area, relatively close in time to the period of occupation of the site.

It may be concluded that there was a phase of more humid conditions in the Rift Valley, during some part at least of the period of the Acheulian industries. There is evidence to suggest that this "pluvial" was later than was originally thought, and that if any correlation with a European glaciation is attempted, it should be with the early Würm rather than with the Riss. Such evidence includes the above-mentioned date for the late Acheulian at Kalambo Falls, and also the modern appearance of human skull fragments found with hand axes and fossil mammals at Kanjera and on faunal and archaeological grounds correlated with Olorgesailie, Olduvai Bed IV and Kariandusi. On this basis Cole (1964 p. 59) showed the Kanjeran pluvial correlated with the early Würm glaciation. Kariandusi is not actually marked on the table she gave but if the industry is assumed to be about the same age as those at Olorgesailie and Olduvai Bed IV, which are shown on the table, it should be younger than about 65,000 years.

Prospect Farm

This site lies at over 7000' on the northern slope of Eburu; it is thus well above any lacustrine sediments in the Nakuru-Elmenticta basin and even at the time of the highest lake it would have been several hundred feet above the shoreline. The site was excavated in 1964-7 by Barbara Anthony of Harvard University. Although her results have not yet been published, she very kindly discussed her work with me and showed me the site.

The excavation went through over 40' of rock, mostly weathered pumice and tuffs, bright red or orange in colour. A number of occupation levels could be distinguished in this section, as follows:

(a) Kenya Capsian within 2' of the surface.
(b) "Magosian" at about 3' depth.
(c) Stillbay layers at 9', 18', 33' depth.

Only one date is at present available for this site, for a piece of charcoal found with the Kenya Capsian tools at a depth of not more than 8-12" below the ground surface. Grass roots were present in this layer but according to the laboratory (Geochron) they did not contaminate the sample. The actual date obtained was 10,560$\pm$1650 years B.P.; the large uncertainty was because of the small amount of charcoal that was used. About 8000 implements were found in this layer, mostly rather big ones. It has been suggested tentatively that this industry can be attributed to the Lower Kenya Capsian or the lowest Upper Kenya Capsian (stage a) (Oakley and Campbell 1967 p. 24).

The only date for a "Magosian" industry in the Nakuru-Elmenteita basin is for a tuff burying such an industry at Deighton's Cliff Extension. A K/Ar measurement of its age was made by Evernden and Curtis (1965). The age obtained was 270,000 years. It seems unlikely that the tuff is as old as this. Isaac (p. 220 in Bishop and Clark 1967) commented that he had "extracted out of the level from which the K/Ar samples were taken large blocks of more ancient volcanic material that indicates contamination which might be responsible for the surprising K/Ar dates".

"Magosian" industries are generally considered to date from the very late Pleistocene; Clark listed the following carbon-14 dates (in Evernden and Curtis 1965):

Magosian at Kalambo Falls - 9550±210 B.P.
Magosian at Pomongwe (Rhodesia) - 15,800±200 B.P.
Lower Tshitolian (the equivalent industry in the Congo Basin)
Mufo (Angola) - 11,189±490 B.P.
Calunda (Angola) - 12,970±250 B.P.

Evernden and Curtis (1965) gave two K/Ar dates for material associated with the "Kenya Stillbay" in the Melawa gorge (Naivasha basin), each of over 200,000 years. These dates are regarded as quite unacceptable by most archaeologists; Clark listed carbon-14 dates of between about 20,000-40,000 B.P. for Stillbay and comparable cultures in Eastern and Southern Africa, e.g.:

Peers' Cave, Fish Hoek	36,000 B.P.
Upper Hazelspoort variant, Florisbad	19,000 B.P.

The Prospect Farm site lies high on the slopes of Eburu, well above even the circa 6400' shoreline level and at present has no permanent water supply. It is possible that the occupation of the site was only temporary or seasonal, but remains of different industries of a considerable range of ages have been found, implying that this may have been a particularly favourable location for settlement. This suggests the possibility that there was rather more water in the Eburu gullies (now dry for most of the year) during the period when the site was occupied. No stronger indication of palaeoclimatic conditions can, however, be obtained from this site.

Gamble's Cave

The site was originally excavated by the East African Archaeological Expedition (1926-30); the results are given in Leakey (1931b). The cave is the type site of the Upper Kenya Capsian (originally called the Upper Kenya Aurignacian). It is also of particular interest as being a site where a relationship between an archaeological sequence and palaeoclimatic evidence has been established.

Sediments to a total depth of 28' were excavated in Gamble's Cave II. The site is not really a cave but an overhanging rock shelter, cut in light grey tuffs. It may owe its origin to erosion by the waves of a high level Lake Nakuru. The original interpretation of the sequence of deposits and industries in the cave was given in Leakey 1931b (pp. 116 and 117). A summary of this is given in Table X. It now appears that certain aspects of this interpretation may need to be re-evaluated. A small section of the cave was excavated by Isaac and Clarke in 1964-5, but no account of their results has yet been published. I was not able myself to make a detailed study of the Gamble's Cave section and of course am not qualified to make any dogmatic pronouncements about the archaeological evidence. In this appendix I shall therefore limit my discussion to (1) the evidence of possible palaeoclimatic significance, the "beach sand" (layer 15) and the "aeolian sand" (layers 4 and 8), and (2) the possible age of the industries in the cave.

Table X

The sequence in Gamble's Cave II (from Leakey 1931b p. 116)

Layer 1	Modern occupation level.
Layer 2	Modern occupation level.
Layer 3	Sterile layer of dust and rock debris; probably represents the Nakuran wet phase.
Layer 4	Aeolian sand (red) representing dry period at the end of the Makalian wet phase.
Layer 5	Rock debris (sterile).
Layer 6	Prehistoric occupation level; Elmenteitan culture.
Layer 7	Rock debris (sterile). Layers 5, 6 and 7 together represent the Makalian wet phase.
Layer 8	Aeolian sand (red) representing period of desiccation at the close of the Gamblian pluvial.
Layer 9	Rock debris (sterile).
Layer 10	Mainly rock debris; a few flakes and broken tools of Kenya Stillbay type.
Layer 11	Level characterised by burials.
Layer 12	Prehistoric occupation level; upper Kenya Aurignacian type, phase (c).
Layer 13	Rock debris.
Layer 14	Prehistoric occupation level, tools of upper Kenya Aurignacian type. Arbitrary division into phases (b) at the top, phase (a) below. Layers 14-9 represent the gradual decline of the Gamblian pluvial after the second maximum.
Layer 15	Beach sand and gravel containing very many freshwater shells, chiefly Corbicula africana, Melanoides tuberculata; also a few rolled tools of lower Kenya Aurignacian type. This represents the level of Lake Nakuru at the second maximum of the Gamblian pluvial, and is approximately 500 feet above present lake level.

The beach sand: this material was accessible in a small exposure at the very base of the section in the cave. It was impossible when I visited the site to examine the sand in situ or to distinguish possible stratification. According to Leakey (1931b pp. 116, 276 and plate XIV) the sand contained large numbers of freshwater mollusca, mainly Corbicula africana and Melanoides tuberculata. Both of these species are characteristic of quite large bodies of water and have been found in a number of Upper Pleistocene and Holocene lake deposits in East Africa, including those at 8V/8 in the Nakuru-Elmenteita basin. I did not find any mollusca in my sample of the Gamble's Cave beach sand, but Isaac (pers. comm) found numbers of shells in this layer, and confirmed its identification as a beach deposit of the former Lake Nakuru. The sand contained well-rounded light grey pumice grains in the largest size range (over 1 millimetre); the smaller grains were almost all angular or sub-angular.

The 'aeolian sands': the 'aeolian sands' or 'red beds' (layers 4 and 8) were believed to represent the Makalian-Nakuran and Gamblian-Makalian dry intervals respectively. At present, however, they seem to be inadequate evidence of arid climatic conditions in the Nakuru-Elmenteita basin. (i) It is no longer believed that red sediments were necessarily formed or deposited in an arid environment.

Sediments are red because the iron they contain is preserved as ferric oxide (haematite) instead of being reduced to other iron minerals of different colours. Dunbar and Rodgers suggested that for the formation of red soil "the most favourable climate is that of the warm savanna with its strongly seasonal rains and widely fluctuating water table" (1957 p. 210). Recently, however Walker described a situation where red beds are forming in situ in an area with modern rainfall about 3" per annum, and commented, "Red beds should not be used as indicators of moist tropical source areas. On the other hand, it is emphasized that red beds per se are not necessarily reliable indicators of arid climates either" (1967 p. 366). There are plenty of red and orange-red sediments on the slopes of Eburu, not far from Gamble's Cave, from which the material in layers 4 and 8 may have been derived.

Reddening of the upper part of the "Gamblian" lacustrine silts at Gamble's Drift and Nderit Drift has been suggested as representing an arid "interpluvial". This reddening may indicate that a period of terrestrial weathering interrupted lacustrine sedimentation, but this is not in itself sure evidence of an arid climatic phase and the red strata at Nderit Drift and Gamble's Drift cannot be firmly correlated with sediments from Gamble's Cave, about 300' higher. It is possible that some of the discontinuities and changes in sedimentation along the River Nderit were caused by minor faulting and warping which may have occurred quite late in the history of this part of the basin.

(ii) The material in layers 4 and 8 does not show the most generally quoted characteristics of a sediment that has undergone a good deal of sorting by wind, viz. (1) the high sphericity and frosted surfaces of the typical "millet seed" desert sand grains and (2) good size sorting and removal of a large proportion of the finest material.

I made a brief examination of samples from layers 4 and 8 and can in general confirm Wayland's description (quoted in Nilsson 1931 p. 323). In both my samples, about 90% by weight was below 0.250 mm diameter.[1] Wayland quoted 54.4% as being below 0.254 mm diameter. The smaller grains in both samples were all angular (see plate 24); the only rounded grains were some of the largest pieces of pumice, above 1 mm (see plate 23). My observations agreed well with Wayland's; he mentioned rounded pumice grains but angular, fresh and unworn quartz and sanidine fragments.

There is no specific mention in the earlier accounts of the characteristics of layers 4 and 8 that were considered to be typical of an aeolian sand. Both the extreme fineness of the deposits and the angularity of most of the grains would seem to suggest a different origin. It is

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1. In layer 4 (the upper 'sand') 92% by weight was below 0.075 mm; in layer 8 (the lower 'sand') 87% by weight was below 0.075 mm.

possible that some of the material was blown into the rock shelter, but clearly it had not undergone much wind transportation or sorting beforehand. Even today in the Nakuru-Elmenteita basin, in particular towards the end of the dry season, much dust and fine silt may be transported by the wind. Small drifts of wind-borne material might well collect under overhanging rock faces on an exposed slope, such as at Gamble's Cave, without demanding climatic conditions noticeably more arid than those of today.

The age of the material in Gamble's Cave: since the beach sand was immediately overlain by a horizon containing Upper Kenya Capsian phase (a) tools, it is likely to be slightly earlier than this industry; there is no indication that a long period of time elapsed after the lake fell below this beach and before the Upper Kenya Capsian occupation. An age for this occupation will give an approximate age for the beach and thus for the 600 foot stillstand of Lake Nakuru.

Unfortunately there is at present no absolute date available for the Kenya Capsian in Gamble's Cave. Some carbon was found from the lowest 60 cms of material above the beach sand by Isaac and Clarke in 1964 (Isaac 1967 p. 30). The date for this carbon has not yet been published. In the absence of this information, it is necessary to establish the probable age of the Kenya Capsian in Gamble's

Cave by analogy with comparable industries in other areas for which absolute dates are available.

There has been considerable controversy about the age of the Kenya Capsian industrial complex. According to Leakey it was contemporaneous with the Gamblian pluvial and thus with the Würm glaciation. It would thus last from as early as about 40,000 B.P. until about 15,000 B.P. or a little later. This is considerably older than similar industries elsewhere in the world, for instance the original Capsian of North Africa, which is generally considered to date from about 8500 B.P. (Cole 1964 p. 256). However there is now quite a lot of evidence to suggest that some at least of the Kenya Capsian is considerably younger than this. I quote two of the most recent opinions:

"It now seems almost certain that, while the Lower Kenya Capsian appears during the Gamblian and may have begun as early as about 30,000 B.C., the Upper Kenya Capsian is either very late Pleistocene or more probably Post-Pleistocene and contemporary with typical Mesolithic industries elsewhere" (Cole 1964 p. 255).

"At least three stages of the "Kenya Capsian" industries have been identified, but as yet no absolute dates are available. Probably, however, only the earlier stage is of Pleistocene age, the others, which contain pottery, being probably of later date" (Clark 1965 p. 846).

The evidence for the relatively late date of the Upper Kenya Capsian includes:

(i) The general nature of the material in even the lowest Upper Kenya Capsian layer in Gamble's Cave 'layer 14 immediately overlying the beach sand and gravel), which has definitely "Mesolithic" implications and is strongly suggestive of a post-Pleistocene date. It includes (a) ostrich shell beads and pendants (b) bone awls (c) two pieces of pottery, about which Cole (1964 p. 265) quoted a comment by Arkell; "the Gamble's Cave pottery belongs to the Mesolithic Khartoum pottery group, tentatively dated to about 7000 B.C.", (d) a bone harpoon.

(ii) The bone harpoon is a small fragment, but enough of its butt end remains for its similarity to harpoons from Ishango, on the north-west shore of Lake Edward, to be visible. It was described by Oakley (1961) who compared it to bone harpoons of the late Ishangian industry, phase c. Unfortunately no really reliable absolute dates have yet been obtained for any material from the site at Ishango. I have not read de Heinzelin's original report of the excavations (de Heinzelin 1957); more easily accessible is a short general account of Ishango that he published a few years later (de Heinzelin 1962). In this he compared bone harpoons from Gamble's Cave, Shaheinab (Sudan), Nanoropus (at the north-west corner of Lake Rudolf) and other sites in the Sahara and West Africa with those from Ishango. He suggested that the technique of making these harpoons originated at Ishango and spread to other parts of Africa from there; the occurrences of bone harpoons at other sites are thus assumed to be younger than the Ishango occupation. Concerning the date of Ishango, de Heinzelin said; "The best archaeological and geological evidence date the site from some time between 9000 B.C. and 6500 B.C." (1962 p. 106), and that the occupation was for a few hundred years during this period.

Even accepting a date for Ishango towards the earlier part of de Heinzelin's 9000-6500 B.C. range and a presumably slightly younger date for the bone harpoon at Gamble's Cave, the lowest Kenya Capsian layer at Gamble's Cave is likely to be less than 10,000 years old, i.e. Holocene rather than Pleistocene.

(iii) Most people would not now accept that there is a Stillbay occupation level in Gamble's Cave (Cole 1964 p. 260). The evidence from Prospect Farm (see above) indicates that in this area the Stillbay definitely predated the Kenya Capsian, which entered after 11,000 B.P.

Hyrax Hill

The various prehistoric sites on Hyrax Hill were excavated by M. D. Leakey in 1937-8 (M. D. Leakey 1945). Some further work was done by R. J. Clarke in 1965-6 before the museum was opened; several of the excavated sites are now kept open.

The sites are of relatively recent age and must all post-date the fall of the lake below a fairly low level. The oldest site (M. D. Leakey's Site I) is a Neolithic occupation site and cemetry of the so-called "Hyrax Hill variant" of the stone Bowl culture. It was said to overlie a 335' A.L. beach, dating from a rest level during the recession of the lake from its 375' A.L. Makalian peak, whose beach is also found on the hill. The site was thus attributed to a date after the Makalian maximum, i.e. after circa 6000 B.C. This date is based on palaeoclimatic correlations (Leakey 1931b pp. 269-70) rather than on any archaeological evidence from the site itself.

Cole (1964 p. 283) mentioned that the earliest Hyrax Hill occupation had been thought to date from the period between about 5500-2500 B.C., but went on to say that the site may well be later than this. Posnansky (1967 p. 641) doubted the idea of a Neolithic beginning as early as the third or fourth millenium B.C. in East Africa, and suggested, "It would seem much more likely that Hyrax Hill should be dated to two millenia later if it is to fit into the scheme suggested by Sutton". (See below)

Site I would thus date from 2000 B.C. or later, and the beach pebbles on which it is said to lie need not be much older than this. I cannot myself confirm the importance of the 375' A.L. (=6151' R.D.) and 335' A.L. (=6111' R.D.) beach levels on Hyrax Hill. I found pebbles at 6180-6194' S.D., but could not distinguish any signs of important lower stillstands.

Njoro River Cave

The site is in a cave cut in the side of the valley of the River Njoro. It was excavated by M. D. Leakey in 1938 (M. D. and L. S. B. Leakey 1950). The original rock floor of the cave was said to be about 5' above the 1938 river level. The cave is well above any former high lake level in the basin.

The cave had been used as a crematorium; the material found included a number of human skeletons, bead necklaces and stone bowls. The industry was said to be Neolithic, slightly later than the "Hyrax Hill variant" of the Stone Bowl culture.

The occupation of the Cave was originally believed to post-date the Nakuran wet phase; it was said, "Even if the cave was . . . already in existence during the Nakuran, the rise of water level at that time must undoubtedly have been sufficient to flood it, and we must therefore conclude that its use as a crematorium was subsequent to the Nakuran wet phase" (M. D. Leakey 1950 p. 1). It was thus thought to be later than about 850 B.C.; this date of 850 B.C. for the

Nakuran wet phase was based on a correlation with the sub-Atlantic period in Europe. (Leakey 1931b p. 270) Later a carbon-14 date of 2980±8 B.P. (circa 960 B.C.) was obtained for material from the crematorium (Cole 1964 p. 286). This was believed to imply that the occupation of the cave was immediately before the Nakuran wet phase.

The cave was well above any former lake level in the basin, and the sequence of sedimentation and erosion in it could only indicate changes in river level which might not be related to changes in lake level. Richardson (1965 p. 329) commented that if, as seems likely, the climate in the Nakuru-Elmenteita basin during the Holocene was comparable to that in the Naivasha basin, it was not likely that conditions during the last 3000 years would have been moist enough for the Njoro River Cave to have been flooded. The cave does not give a real indication of past climatic conditions, but only that since about 3000 B.P. there appears to have been no erosion or deposition by the River Njoro at a level about 5' above its present (1938) level.

Stable's Drift and Nakuru Burial Site

These sites were both excavated by the East African Archaeological Expedition in the years 1926-30, and are described in Leakey (1931b). The sites are both of Neolithic age and on the basis of the type of pottery found, Leakey attributed Stable's Drift to the Gumban A industry, Nakuru

Burial Site to the Gumban B. Both these were said to be variants of the Stone Bowl culture, rather younger than its oldest example on Hyrax Hill..

Concerning Stable's Drift, it was said, "At the latter site the pottery was found in a bank of stratified mud which, by its level, seems to represent the upper limit of the lake during the Nakuran wet phase, and we may provisionally regard the Gumban A as belonging to about the period of the maximum of the Nakuran wet phase" (1931b p. 199). I did not succeed in finding this site or, along the relevant part of the River Nderit, any lacustrine sediments that might be correlated with the Misonge ("Nakuran") shoreline.

The Nakuru burial site was said to be on a circa 375' A.L. beach (i.e. a "Makalian" beach) but was attributed to the Nakuran wet phase on the following evidence: "The site is far from any stream or spring today, but only about half a mile away from the old beach of Lake Nakuru of the time of the Nakuran wet phase, when the lake stood one hundred and forty-five feet higher than it does today; and it is more than probable that this was the water supply of the Gumban B folk. The site moreover contains fish bones, whereas today Lake Nakuru has no fish, nor are there known to be fish in any of the streams running into the lake. It seems certain, therefore, that the occupation of the Nakuru site coincided with the period of the one hundred and forty-five foot lake, or at any rate with a time before it had dwindled so far as to have a soda percentage too great to be drinkable or to contain fish" (Leakey 1931b p. 32).

I was also unable to locate this site, which is apparently at the foot of the western slope of 'Water Tank Hill', the small rocky ridge east of Hyrax Hill. I could not find any surface beach pebbles around the foot of this hill. The mention of fish bones at the site is interesting in view of the present conditions in the highly saline lake.

According to Leakey's correlations, both these sites would be attributed to about the period of the "Nakuran wet phase" at around 850 B.C. I have been unable to confirm the evidence linking them with considerably higher levels of Lake Nakuru, and find both these correlations, in particular that of the Nakuru Burial Site with the maximum of the Nakuran wet phase, definitely unconvincing. Recent archaeological opinions would hold that both sites may be rather younger than has been thought. According to the recent classification of Sutton (1964) the pottery of the Kenya highlands can be divided into classes A, B and C. Class B comprises the Hyrax Hill and Gumban A variants of the Stone Bowl culture. There is no firm dating for this class, but it has been said, "It is probable that these groups stretch in time from the last millenium B.C. well into the first millenium A.D." (Posnansky 1967 pp. 636-7). The Gumban B pottery, as found at Nakuru Burial Site and various other sites, has been attributed to Sutton's class C. This class includes the pottery described from Lanet by Posnansky; a carbon-14 date of 375±100 B.P. (1585 A.D.) was obtained for this site. Posnansky suggested that comparable industries for other sites besides Lanet can be dated "within the first half of the second millenium A.D." (1967 p. 637).

APPENDIX D

DIATOMITE

Diatoms (Bacillariophyceae) are unicellular algae whose cell walls are made of silica. They are found widely in all aquatic environments, from large bodies of salt and fresh water to small pools and even on damp vegetation; in life they are free-floating (planktonic) or anchored to vegetation (epiphytic) or living in the loose, flocculated upper layer of the lacustrine sediments (epipelic). When they die, they sink to the bottom and over the years can accumulate in large numbers, since they are practically indestructible. Subsequent desiccation and compression will result in the formation of a rock called diatomite, which in its pure state is composed almost entirely of silica. When pure and dry it is very fine in texture and white or light grey or cream coloured. Usually the rock is not very hard, although baking by contact with lava and compression by faulting might make it harder. The softer, less pure (hence usually darker-coloured) sediments are known as diatomaceous silts, although there does not seem to be a generally agreed line of division between this term and the term diatomite.

Diatomites and diatomaceous silts are widespread in the Eastern Rift Valley, evidence of sedimentation in lakes and swamps during Holocene, Pleistocene and even pre-Pleistocene times. The Rift Valley appears to have been a particularly favourable environment for diatom growth; this was commented on by Hobley as early as 1910; he suggested that the Rift Valley volcanoes produced much siliceous dust which fell into the lakes and provided an abundant source of silica for the diatom frustules. A more general statement was made by Taliaferro; "practically all thick deposits of diatomaceous earths are closely associated with the products of volcanism, particularly volcanic ash" (1933 p. 54). These deposits are clearly evidence of some kind of aquatic sedimentation; even an impure diatomaceous silt, found in a place which is now dry, suggests that conditions there in the past must have been wetter. Thick evenly stratified deposits of pure white diatomite such as those at Kariandusi must have been formed in a rather deep, tranquil lacustrine environment and imply a considerable period of sedimentation. However it would be useful to obtain more precise information from the diatomaceous deposits, in particular: (i) in what depth of water a particular deposit was laid down, (ii) how long a period of sedimentation is implied by the deposit, (iii) how old the deposit is, (iv) can changes of environment be traced within a deposit by a study of changes in the diatom flora.

(i) The depth of deposition: it is possible to obtain an approximate answer to this question by a study of the individual diatoms which make up the sediment. Different species of diatoms have, within fairly rigorously defined limits, their own favoured ecological conditions; there is very little overlap or flexibility between the planktonic, epipelic and epiphytic communities mentioned above. The most straightforward ecological deduction lies in comparing the number of planktonic as against epiphytic and/or epipelic diatoms in a particular sample. Where planktonic forms predominate, it is reasonable to assume that the depth of water was such as to eliminate the growth of epiphytic and epipelic forms due to lack of light and suitable plant hosts. Where epiphytic and epipelic forms exist in fair numbers (even if actually outnumbered by planktonic forms) one can assume that the water was shallow enough to allow the growth of water plants and the penetration of light to the bottom. According to Round (1964 p. 1016) this would be, in temperate lakes, to about 5 m depth in the lake. Ross (unpublished note on some Rift Valley diatom samples, 1947) suggested that the depth at which diatom growth on the bottom of a lake is inhibited for lack of light (i.e. the compensation point) is about 15 m in the case of Windermere, but in the East African lakes, with greater plankton productivity, the light intensity falls off more rapidly with depth.

This report by Ross is on samples of diatomites from Kariandusi, Olorgesailie and the Baringo basin. The sample from Baringo, which consisted entirely of Melosira (a planktonic form), and contained very fine silt particles, was thought to be a central deposit, laid down in a large lake at some depth "appreciably below the compensation point". The Kariandusi sample, in which there was a considerable amount of fine silt and in which Melosira predominated, with a number of epiphytic and epipelic species, was said to be laid down "at a depth only slightly above the compensation point". This was thought to be at a depth of 2-4 metres, or about 100 metres from shore, since the silt fragments were not very coarse. The Olorgesailie deposit, which contained a large quantity of rather coarse silt, had a diatom assemblage in which the epiphytic and bottom living species were more frequent than Melosira; it was thought to have been a deposit laid down "near the shore or the mouth of a stream in shallow water, probably not more than 1 metre deep"

This brief report (quoted in Sonia Cole 1964 pp. 75-6) shows the kind of deductions which may be made from the diatom assemblages as to the environment in which diatomaceous deposits were laid down. I thought at one point of making a similar study of some of the Nakuru-Elmenteita basin diatomaceous material. Later it seemed that such investigations could add relatively little to the knowledge of the high-level diatomaceous silts which are seen to lie in shallow water sections with beach pebbles and sand, while a study of the diatom assemblages of the more central deposits would probably not immediately aid in correlating them with the shoreline deposits. I did, however, examine the diatomaceous silt samples under high magnification, mainly to check whether some of the very brownish fine silts were in fact diatomaceous. Many of these silty samples from relatively high altitudes (6250-6340') below the 600 foot shoreline contained large numbers of large whole diatoms; there were few Melosira, and a predominance of Epithemia and Rhopalodia, both epiphytic forms. This would suggest shoreline deposition comparable to that suggested for the Olorgesailie deposit by Ross, above. McCall suggested that, "Impure diatomites in the area probably formed in shallow water swamps and pondings in river courses, not necessarily in true lakes" (1967 p. 102). This may be true of some deposits, for example probably those "Gamblian" silts exposed along the Rivers Kariandusi and Kekopey, possibly also the highest silts along the Makalia. Even in cases of ponding along a river course, it would seem unlikely that the presence and level of water in such ponding was completely unrelated to the existence of a lake shoreline slightly lower down; i.e. the conditions were in a sense 'estuarine'. In some cases also, swamps might be extensions of a fluctuating shoreline, varying in size and wetness according to the season and the rainfall of the previous few years, although they could also exist at a higher altitude entirely independent of the lake shoreline level. In the latter case small silty diatomaceous deposits might exist which could not be correlated by altitude to any particular shoreline or to similar deposits.

In other cases, however, I would suggest that even small and rather silty diatomaceous deposits can be taken as evidence of sedimentation in a true lake, although in shallow water, for the following reasons: (a) Many of these small silty diatomite deposits occur in sections as part of a sequence of sediments, pebbles, sand and silt, which would seem to indicate sedimentation as a shoreline rather than in a swamp or river. (b) In some cases, such as on the south-facing slopes of Menengai, the topography does not seem such that a swamp or river ponding could have existed, unless the slope of the land at the time were very different.

(ii) The period of sedimentation: an answer to this question of the length of time spanned by a deposit depends on a knowledge of the rates of sedimentation when the deposit was forming. Unfortunately at present little is known about the rate of accumulation of diatoms on a lake bed, in high latitudes or in the tropics. Besides the question of diatom productivity, complicating factors such as the silt content and possible compression of the deposit arise. According to Conger (1942) the rate of accumulation in North Wisconsin lakes is about 1.2" in 100 years. In South Africa, according to L. E. Kent (1947), the rate of formation of kieselguhr (diatomite) "under favourable conditions" is sufficiently rapid for a layer a few inches thick to form in a fairly short-lived lake, resulting from exceptionally heavy rains in a usually dry pan. It is hard to know what to conclude from these statements; at any rate it is clear that no very definite deductions can be made from thickness of layer to number of years in forming. Certain of the Nakuru-Elmenteita diatomite outcrops show rather fine banding (in particular Soysambu, Mbaruk (7/1), and 8E/3). The bands are not quite similar in each of these exposures although in each they tend to be regular and close to horizontal. At Soysambu the colour variation is from white to light grey, and the bands are several millimetres thick. At 7/1 they are up to 2 cms thick and the lighter bands are harder and form positive micro-relief on the surface. The deposit at 8E/3 shows banding of up to 1-2 cms thick, with white bands alternating with rather darker, pale orange bands (plate 18). In Prettejohn Gully diatomite cliffs show very striking banding with layers of fine light brown sand alternating with white silt. The sand layers, usually narrower than the silt (of the order of ½-1 cm) are less resistant and form negative micro-relief. (See plate 19) Regular parallel banding of whiter, grey and orange layers (again the order of ½-1 cm thick, with the white layers thickest) is seen in many of the weathered diatomite outcrops above the Nderit valley, such as 10/13, 10/6, 10/7 (plate 20).

Other laminated diatomaceous deposits have been explained as the results of seasonal rhythms of sedimentation, i.e. the bands are a form of varves. Examples are the Middle Pleistocene diatomites of Valle dell'Inferno Riano, Rome, described by F. P. Bonadonna (1965). In these, a pair of light and dark bands averaged 1.05 mm thick; a study of the diatoms of the bands did indicate a variation which could be explained by considering the dark bands as resulting from summer sedimentation, the light bands from the winter. Tippett (1964) studied deposits from two small lakes in Ontario, Canada; here the thickness of a light-dark pair was only 0.2-1 mm. The evidence of the pollen and diatoms in these bands suggested that the light bands represented summer deposition, the darker bands the winter deposition.

Richardson (1965 pp. 143-50) described layering from some sections of his Naivasha core. In these pairs of layers the lighter ones, probably richer in diatoms, were the narrower. The width of the layers varied but was usually not much more than 3 mm. Richardson worked out that "the total average 'varve' widths for both the top and bottom portions of the core are less than the average yearly deposits of sediment calculated for these regions from radiocarbon dates" (p. 149). He concluded however that these layers probably were varves and that the discrepancies in thickness were caused by various sedimentation irregularities.

It is impossible at this stage to come to a definite conclusion about the nature and origin of the banded diatomaceous silts in the Nakuru-Elmenteita basin. It can be assumed that the main components of these deposits are: (i) diatoms which lived in the former lake and (ii) silt and other impurities, brought into the lake by the streams draining the catchment. Variations in the composition and rate of deposition of the sediment could therefore result from (i) variations in the abundance of diatoms, probably depending on fluctuating nutrient conditions in the lake, or (ii) variations in the amount of silt being brought into the lake; the underlying cause in this case would presumably be changes in runoff and erosional conditions on the catchment.

All the banded diatomites in the Nakuru-Elmenteita basin may not be of the same origin. Some, in particular those laid down quite near the lake shoreline, may owe their banding to variations in the amount of silt entering the lake, while others, laid down in deep water beyond the range of most of the coarser silt particles, may be banded because of changes in abundance of diatoms. It seems unlikely that a simple seasonal hypothesis of two bands of deposition to a year can explain all of these sediments. Most of the bands in the Nakuru-Elmenteita basin are wider than those described by Richardson, Tippett and Bonadonna (above). A rate of accumulation of diatomite of over 1 cm per annum would seem rather high, even in this silica-rich tropical environment.

Under the climatic regime of this area today, it is unlikely that simple "2 phase" annual varves would be produced. Nilsson, in his discussion of some other varved sediments in the Nakuru-Elmenteita basin (1931 p. 306) suggested that each annual varve should have four components (two rainy and two dry seasons) but stressed "there is required a very thorough study of these sediments before we can determine with full certainty what is to be referred to one varve". During this century the total annual precipitation in the Nakuru-Elmenteita basin has varied over a considerable range, and so have the lengths of the rainy seasons and the months during which most rain fell. It is possible that a similar high variability prevailed under the generally moister conditions when the diatomites were being deposited.

It is clear that the problem of the banded diatomites of the Nakuru-Elmenteita basin needs further study. This should include a comparison of the diatom assemblages in the light and dark bands in each deposit, and a study of the impurities in the darker bands. At present, although it seems clear that some rhythmic mechanism has produced these bands, they should not be interpreted in terms of years of sedimentation.

Since it seems impossible at this stage to use the method of 'varve-counting' to work out the numbers of years covered by these sediments, estimates of the length of time involved in their deposition must be approximate only. It is possible that the small, rather silty deposits, of the order of 2-3' thick, occurring at quite high altitudes within the area of the former 600 foot lake (e.g. 2/11, 3/6), result from deposition over several hundred years; larger, purer deposits, such as those at Eburu (8E/3) and of course Kariandusi and Soysambu, could imply several thousands of years of uninterrupted lacustrine sedimentation.

(iii) Dating of diatomites: at present there seems to be no means of dating to be obtained from the diatomites themselves. Being made up almost entirely of silica, radio-isotope techniques of absolute dating cannot be used; at the same time the individual diatoms do not show any appreciable evolution within the time-range of these Rift Valley deposits. Absolute dating may be possible where the diatomites contain shells; the carbonate from these may be dated by carbon-14 analysis. This has been done for diatomites in the Sahara and I was lucky to find a section (8V/8) where fresh-water mollusca occurred in quite a pure diatomaceous silt. (See Appendix B) Where such material is not available, estimates of the age of diatomites may be made from archaeological and fossil material found in association with them, and from their position in stratigraphical sequences.

(iv) Studies of changes in diatom flora: an example of such a study is Richardson's work on a core taken from the sediment below Crater Lake, Lake Naivasha. The diatoms in the different sections of the core were studied and the species counted. Mineralogical and chemical aspects of the core were also studied and carbon-14 dates were obtained at three depths of the core. It was possible to trace the history of Crater Lake from a time about 9000 years ago when it was deeper than it is now, to a period about 3000 years ago when it appears to have dried up completely, to the present rather small lake.

Although other aspects of the core were studied, the basis of the investigation was the change in diatom assemblages. These showed sharp variations within the core, and Richardson suggested "that these organisms [diatoms] are a sensitive index of varying lake conditions" (1965 p. 235). He distinguished two frequently occurring assemblages; the variations in species were said to be influenced by changes in lake level and in the fringing and aquatic vegetation of the lake. The lower part of the core, laid down in the large lake, was characterised by an assemblage of *Nitzschia fonticola*, *Melosira* and *Stephanodiscus*. Increasing numbers of species of *Fragilaria* from metre 14 of the core indicated a shrinking lake and more littoral conditions. The characteristic assemblage of the upper part of the core was dominated by species of *Melosira* and *Synedra* and was said to be very similar to the assemblages at present found in some of the small lakes in the Western rift.

A study of this kind can produce useful information about changes in a lake; it is, of course, not always certain that the changes in size and salinity of the lake which may be traced in this way are the result of climatic change. There are also problems associated with the interpretation of the diatom assemblages in terms of environment.

This is particularly true in the tropics, since rather little is known of tropical diatom ecology, and, according to Richardson: "The habitat designations accorded to diatom genera (or even species) in temperate regions often do not fit well in the tropics" (1965 p. 111).

It is possible that a similar kind of study might be made of a section of diatomaceous silt from one of the exposures of the Nakuru-Elmenteita basin, which would indicate a progressive shallowing or deepening of the lake during the period of accumulation of the silt. However it is doubtful whether such a study on an isolated diatomaceous silt exposure would give any useful information about the sequence of lake level fluctuations in the basin. A study of a core from beneath Lakes Nakuru or Elmenteita would be of much more value, in particular in indicating whether any prolonged periods of desiccation of the lakes have occurred during the last few thousand years.

Diatomites of the Nakuru-Elmenteita basin

Diatomites or diatomaceous silts are found in each of the groups of rocks listed in Chapter 3, from the Lower/lower Middle Pleistocene Enigma Cove sediments to the most recent deposits close to Lake Nakuru and at the top of the Makalia and Nderit sections. They indicate a long history of lacustrine sedimentation in the basin, interrupted at times by major and minor episodes of tectonics and vulcanicity.

The Kariandusi diatomites seem to have been described by the first European to see them Thomson, thus: "The trachytic rocks over which the Kekupè runs have, by some chemical process, been altered into a white and soft rock, exactly resembling chalk in colour, weight, and hardness" (1885 p. 349). Thomson's "Kekupè" river is probably the present-day River Kariandusi. Reference was made to the Kariandusi diatomites in a paper by M. Fergusson (1901) and a list of species, prepared by T. Comber, included with it. Short papers, by Hobley (1910) and Creighton (1911) mentioned among others, the Kariandusi and Nderit valley diatomite deposits, and included some slides of the diatoms. Gregory (1921) divided the Elmenteita basin lake sediments into two groups: "some are quite modern, but some of the others, as around Soit-Sambu and E. of Lk. Elmenteita, may belong to the Nyasan series" (p. 200).

Solomon (in Leakey 1931b pp. 255-7) gave a diagrammatic section of the Kariandusi deposits and divided them into Upper and Lower Kamasian (said to be faulted by more than 100'), overlain unconformably by Gamblian silts. Pulfrey (unpublished report in Dept. of Geology and Mines, Nairobi, dated 1944) considered that Solomon's section and explanation were oversimplifications, but he also suggested a rather similar threefold division. He was perhaps the first to suggest that the overlying "Gamblian" silts were riverine rather than lacustrine in origin. McCall (1967) included some sections and diagrams from unpublished reports by Pulfrey and Saggerson and gave a brief account of the mining and uses of diatomite, such as insulation, filtration and fillers.

A living site of Acheulian man, with many fine lava and obsidian hand-axes, was found in beach deposits above the main diatomite layers at Kariandusi. The correlations of this industry with others in East Africa, and the implications for the dating of the "Kanjeran" deposits which enclose it, are discussed in the section on archaeology, Appendix C.

West of Lake Elmenteita, on the gently sloping ridge between the lakes, is the diatomite deposit of Soysambu, also known as Kockum and Brown's (map 3). This deposit is attributed by McCall (1967) to the Middle Pleistocene, i.e. contemporaneous with the Kariandusi diatomites. This correlation appears to be based mainly on the fact that these were the two largest exposures of pure, white diatomite, suitable for mining, and are quite close to each other on either side of Lake Elmenteita. I am slightly doubtful about this correlation, and feel that the Soysambu diatomite might be younger (Upper Pleistocene) and could be correlated with diatomites at Oldobeye (10/18) and Eburu (8E/3). My reasons for believing this are the following: (i) the Soysambu section seems to be quite horizontal, and consists of a concordant, unbroken sequence from the pure diatomite, through fine pale brown silts to coarser darker silts to the present surface. In the section I studied, the white diatomite was reached at a depth of about 8'; Saggerson (in McCall 1967 p. 108) recorded thinner overburden, of 1 to 6'. There is no evidence of any faulting or tilting of the deposits, and the overburden might well be the kind of material that could develop above the diatomite during a few thousand years of weathering. It seems to me rather unlikely that such tranquillity is recorded in the Soysambu section if it does in fact date from the Middle Pleistocene, and hence predates episodes of faulting and vulcanicity and probable fluctuations in lake level. (The Soysambu exposure is at about 6200', well below the 600 foot shoreline level.) (ii) The Soysambu diatomite might be correlated with the others mentioned above. The Oldobeye pit is close to the same altitude and shows a very similar kind of section; the Eburu pit is higher (altitude 6320') but appears to be a shoreline deposit overlain by conformable bands of sand and pebbles.

It is possible that a comparison of the diatom assemblages of the Soysambu and Kariandusi deposits might provide an answer to this question. On the other hand the diatom assemblages in each case might be typical of deep water sedimentation and not show any significant differences that might help to determine whether or not they were laid down in the same lake.

A number of small isolated exposures of diatomite (8E/2,3,4) are found in the southern part of the basin, at altitudes above 6400', and have been discussed in Chapter 5.

<u>Conclusion</u>

In the volume published as a result of the 1965 Symposium on African later Tertiary and Quaternary Stratigraphy (Bishop and Clark 1967) it was said that, for indicating ecological conditions, "Studies of diatoms collected from East Africa have also proved disappointing. To a certain extent, the different species indicate the depth at which they were living, but they give little indication of the salinity of the lake" (p. 402).

I would suggest that diatom studies can be of more value to a study of East African Quaternary geology and palaeoclimatology than is implied by this comment. It does appear that their value for purposes of correlation and comparison between separate isolated deposits is likely to be rather small, since the assemblages indicate only local conditions and do not show any wider zonal variations or evolution. Studies such as the one by Ross of the Rift Valley diatomites are not likely to contribute a great deal more to our knowledge of former lakes and climatic fluctuations than can be obtained from wider geological investigations. On the other hand a study like Richardson's, in which a sequence of change with time is traced through a single core, is likely to provide much useful information of relative ecological conditions. Correlations between different areas may be made when enough such cores have been studied. Cores taken from lake beds are particularly valuable in indicating periods of desiccation of the aquatic environments in a lake basin; such evidence may not be so easily interpreted from outcrops on the surface and higher up in the basin.

APPENDIX E

CALCULATIONS FOR CHAPTER 6

The equation;-

$$A_L.E = P_L.A_L + A_B.P_B.K$$

A_L area of lake surface (Lakes Nakuru and Elmenteita)

A_B area of rest of catchment

E evaporation from lake surface

P_L precipitation on lake surface

P_B precipitation on rest of catchment

K runoff constant

Calculation 1

To arrive at a value for K under present conditions in the Nakuru-Elmenteita basin.

A_L = 20 sq. miles

A_B = 790 sq. miles

E = 74" p.a.

P_L = 25" p.a.

P_B = 38" p.a.

$$20 \times 74 = 20 \times 25 + 790 \times P_B \times K$$

$P_B.K$ = 1.24" p.a.

$K = 3.26\%$

Of the precipitation on the catchment, 3.26% contributes to the recharge of the lakes.

Calculation 2A

Assuming (i) the lake at the 600 foot level (ii) evaporation essentially the same as at the present, lessened only by the influence of increased cloudiness and humidity to a value of 70" p.a. (iii) in this case $P_L = P_B$, i.e. the rainfall is assumed to be the same on the lake surface as over the rest of the catchment. Under present day conditions this is far from true; it can be said that P_L is approximately half of P_B. When the lake surface was 600 feet higher the pattern of atmospheric circulation in the basin would have been rather different and the rain-shadow effect in the centre of the basin would certainly have been less. Although this is still an approximation, and the rainfall was probably higher on the highest western part of the catchment than on the surface of the 600 foot lake, it seemed better to assume that in this case $P_L = P_B$, rather than $P_L = \frac{1}{2}P_B$. (iv) K is taken to be 3.26%.

A_L = 288 sq. miles

A_B = 522 sq. miles

$$288 \times 70 = 288 \times P_B + 522 \times P_B \times \frac{3.26}{100}$$

P_B = 66.1" p.a.

Calculation 2B

Conditions as for calculation 2A, but value of K taken as 10%.

$$288 \times 70 = 288 \times P_B + 522 \times P_B \times \frac{10}{100}$$

$$P_B = 59.3'' \text{ p.a.}$$

Calculation 2C

Conditions as for calculation 2A, but value of K taken as 20%.

$$288 \times 70 = 288 \times P_B + 522 \times P_B \times \frac{20}{100}$$

$$P_B = 51.4'' \text{ p.a.}$$

Calculation 2D

Conditions as for calculation 2A, but value of K taken as 30%.

$$288 \times 70 = 288 \times P_B + 522 \times P_B \times \frac{30}{100}$$

$$P_B = 45.3'' \text{ p.a.}$$

Calculation 3A

Assuming (i) the lake at the 600 foot level (ii) evaporation of 60" p.a. (iii) $P_L = P_B$ (iv) K is 3.26%.

A_L = 288 sq. miles

A_B = 522 sq. miles

$$288 \times 60 = 288 \times P_B + 522 \times P_B \times \frac{3.26}{100}$$

P_B = 56.6" p.a.

Calculation 3B

Conditions as for calculation 3A, but value of K taken as 10%.

$$288 \times 60 = 288 \times P_B + 522 \times P_B \times \frac{10}{100}$$

P_B = 50.8" p.a.

Calculation 3C

Conditions as for calculation 3A, but value of K taken as 20%.

$$288 \times 60 = 288 \times P_B + 522 \times P_B \times \frac{20}{100}$$

P_B = 44.1" p.a.

Calculation 3D

Conditions as for calculation 3A, but value of K taken as 30%.

$$288 \times 60 = 288 \times P_B + 522 \times P_B \times \frac{30}{100}$$

$P_B = 38.8$" p.a.

Calculation 4A

Assuming (i) the lake at the 600 foot level (ii) evaporation of 50" p.a. (iii) $P_L = P_B$ (iv) K is 3.26%.

$A_L = 288$ sq. miles

$A_B = 522$ sq. miles

$$288 \times 50 = 288 \times P_B + 522 \times P_B \times \frac{3.26}{100}$$

$P_B = 47.2$" p.a.

Calculation 4B

Conditions as for calculation 4A, but value of K taken as 10%.

$$288 \times 50 = 288 \times P_B + 522 \times P_B \times \frac{10}{100}$$

$P_B = 42.4$" p.a.

Calculation 4C

Conditions as for calculation 4A, but value of K taken as 20%.

$$288 \times 50 = 288 \times P_B + 522 \times P_B \times \frac{20}{100}$$

P_B = 36.7" p.a.

Calculation 4D

Conditions as for calculation 4A, but value of K taken as 30%.

$$288 \times 50 = 288 \times P_B + 522 \times P_B \times \frac{30}{100}$$

P_B = 32.4" p.a.

Calculation 5A

Assuming (i) the lake at the 600 foot level (ii) no change in precipitation; rainfall on lake and in rest of catchment taken as 38" p.a. (iii) K is 3.26% (iv) the whole of the increase in volume of the lake is thus to be explained by a decrease in evaporation from the lake surface.

A_L = 288 sq. miles

A_B = 522 sq. miles

$$288 \times E = 288 \times 38 + 522 \times 38 \times \frac{3.26}{100}$$

E = 40.2" p.a.

Calculation 5B

Conditions as for calculation 5A, but value of K taken as 10%.

$$288 \times E = 288 \times 38 + 522 \times 38 \times \frac{10}{100}$$

$$\underline{E = 44.9'' \text{ p.a.}}$$

Calculation 5C

Conditions as for calculation 5A, but value of K taken as 20%.

$$288 \times E = 288 \times 38 + 522 \times 38 \times \frac{20}{100}$$

$$\underline{E = 51.8'' \text{ p.a.}}$$

Calculation 5D

Conditions as for calculation 5A, but value of K taken as 30%.

$$288 \times E = 288 \times 38 + 522 \times 38 \times \frac{30}{100}$$

$$\underline{E = 58.7'' \text{ p.a.}}$$

Calculation 6

Only a slight fall in precipitation would be necessary to end the existence of Lakes Nakuru and Elmenteita as bodies of water. During parts of the 1940s and 1950s the lakes were in fact reduced to small puddles on a saline crust. It appears that the lakes (and Lake Naivasha) were at their lowest between about 1945-1955.

Mean annual rainfall over Nakuru-Elmenteita catchment:

1938-1964	38.3" p.a.
1944-1954	36.0" p.a.

The annual rainfall over the years 1944-54 was thus about 94% of its value between 1938-64. If the rainfall had continued at its 1944-54 value it is unlikely that the lakes would have filled up again. Thus if the annual rainfall was maintained for any length of time at about 3" p.a. below its present value, the lakes would cease to exist. A similar increase in annual evaporation, of less than 3", might be expected to have a comparable effect on the lakes. Such an increase in evaporation, according to Langbein's figures (1961) could be caused by an increase in mean annual temperature of only about 1°C.

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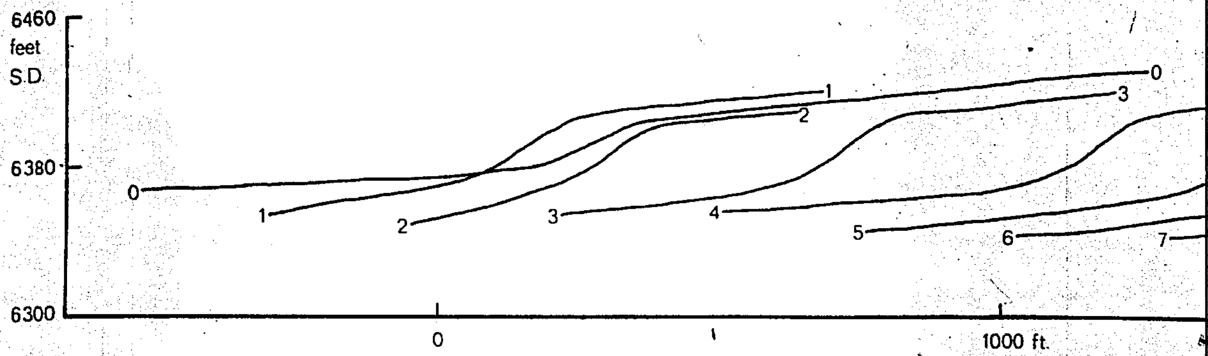
THE MENENGAI SHORELINE PROFILES 0–12



THE MENENGAI SHORELINE. PROFILES 9–14

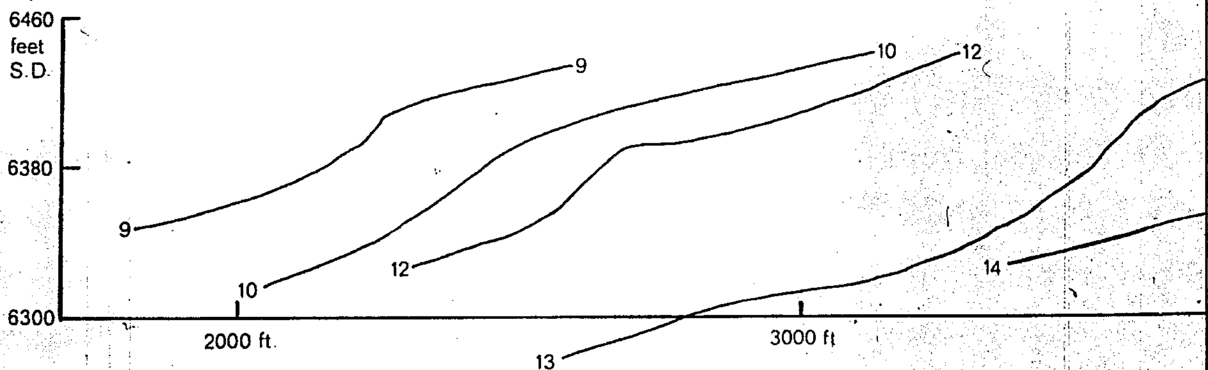


FIGURE 1

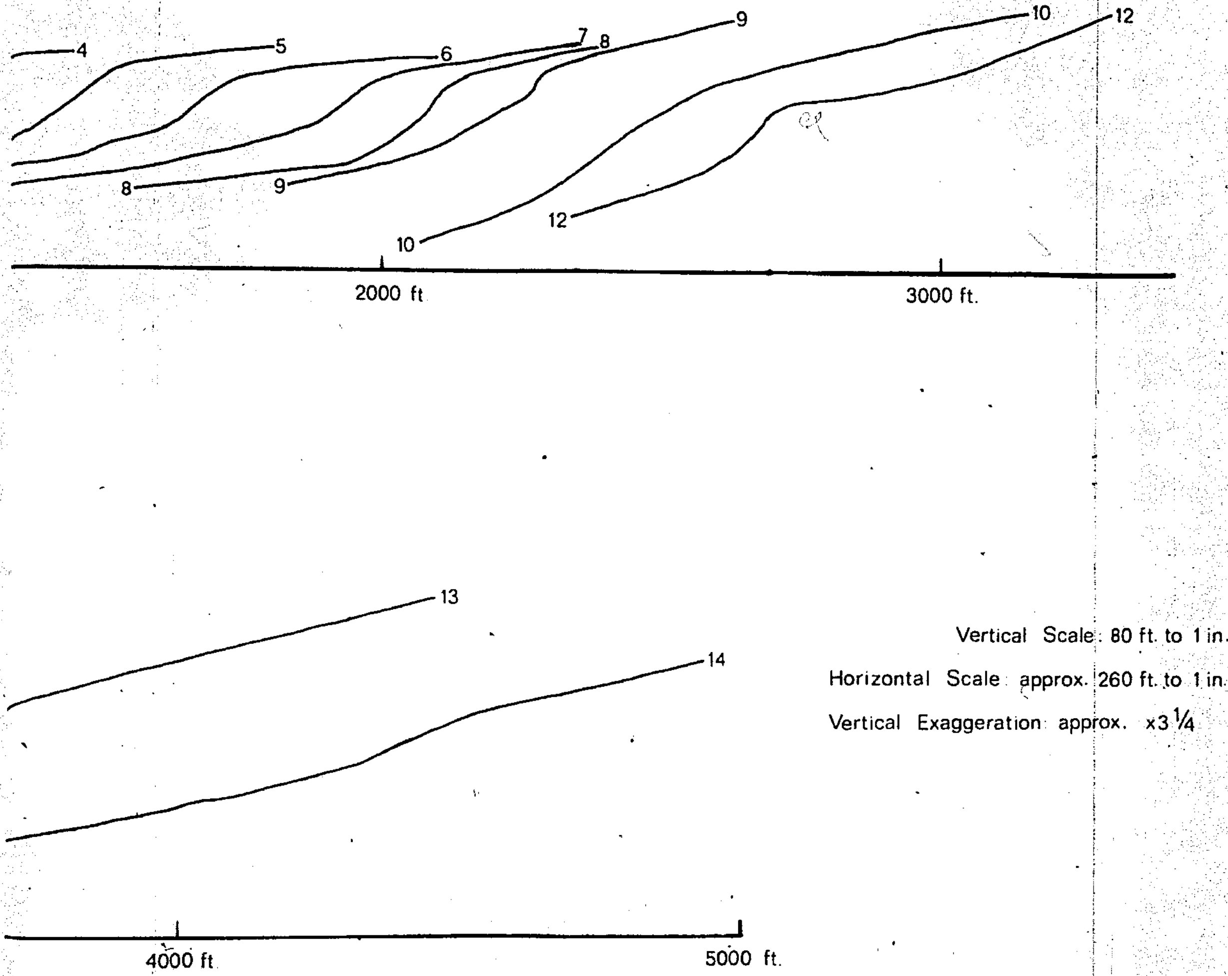

4
5
6
7
8
9
10
12
8
9
12
10
2000 ft
3000 ft.
13
14
4000 ft
5000 ft.
Vertical Scale: 80 ft. to 1 in.
Horizontal Scale approx. 260 ft. to 1 in.
Vertical Exaggeration approx. x3 1/4

FIGURE 2: PROFILE OF THE MISONGE SHORELINE

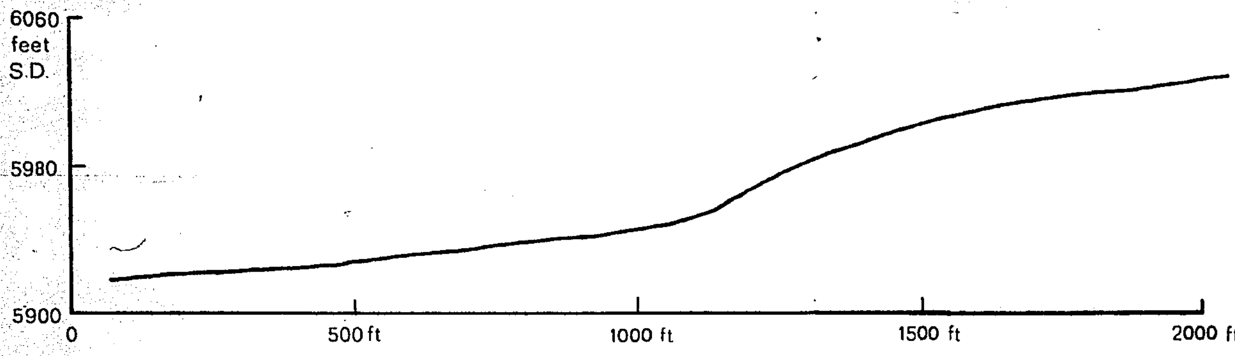
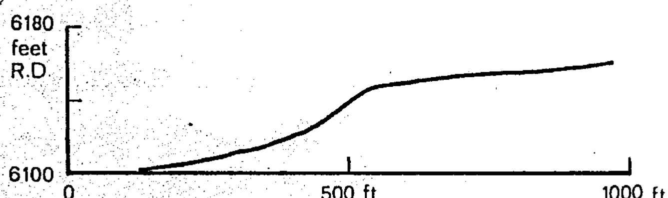


FIGURE 3: PROFILE OF THE MAGHARIBI SHORELINE



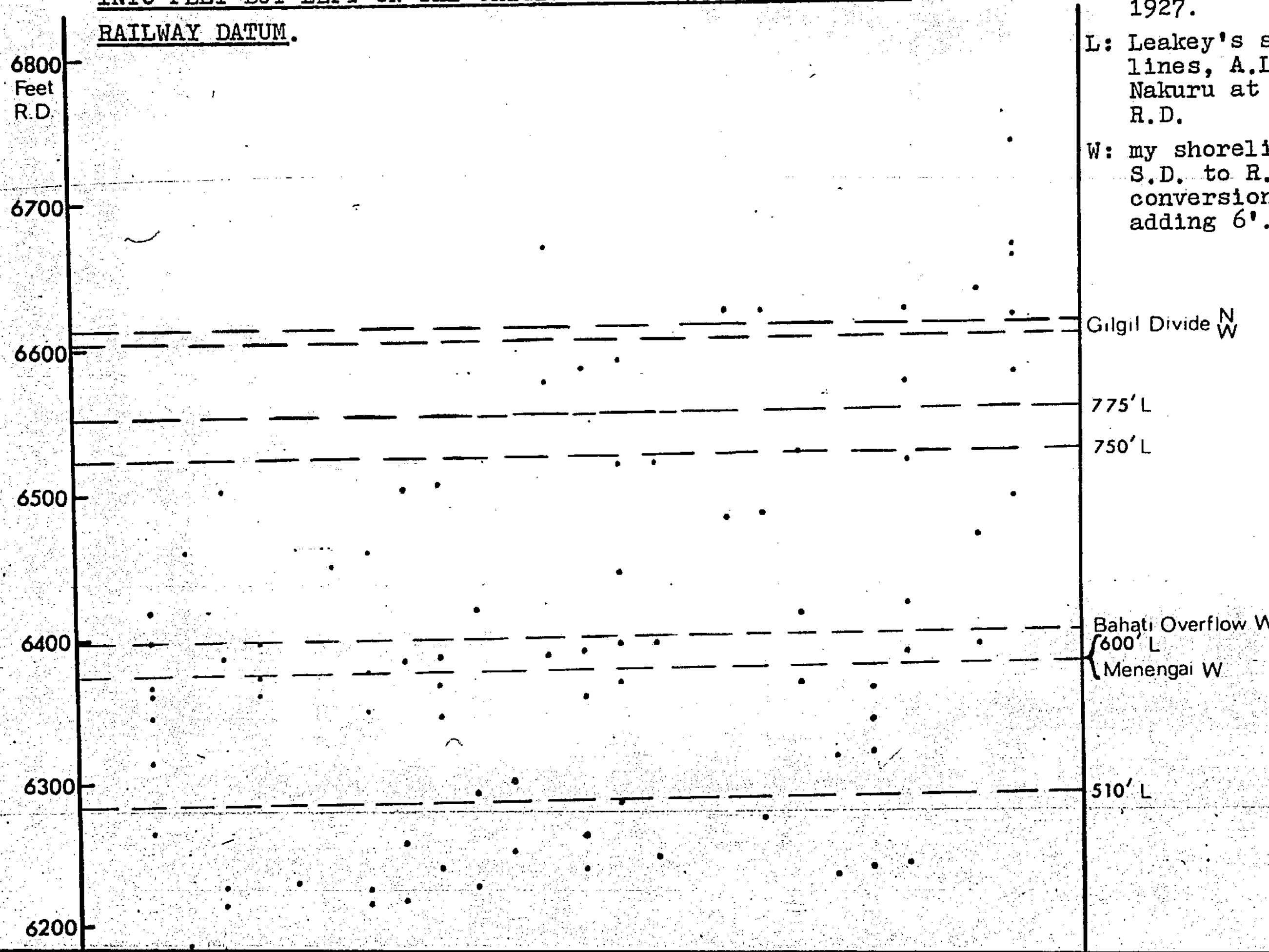
Vertical Scale: 80 ft. to 1 in.

Horizontal Scale: approx. 260 ft. to 1 in.

Vertical Exaggeration: approx. x 3 1/4

FIGURE 4

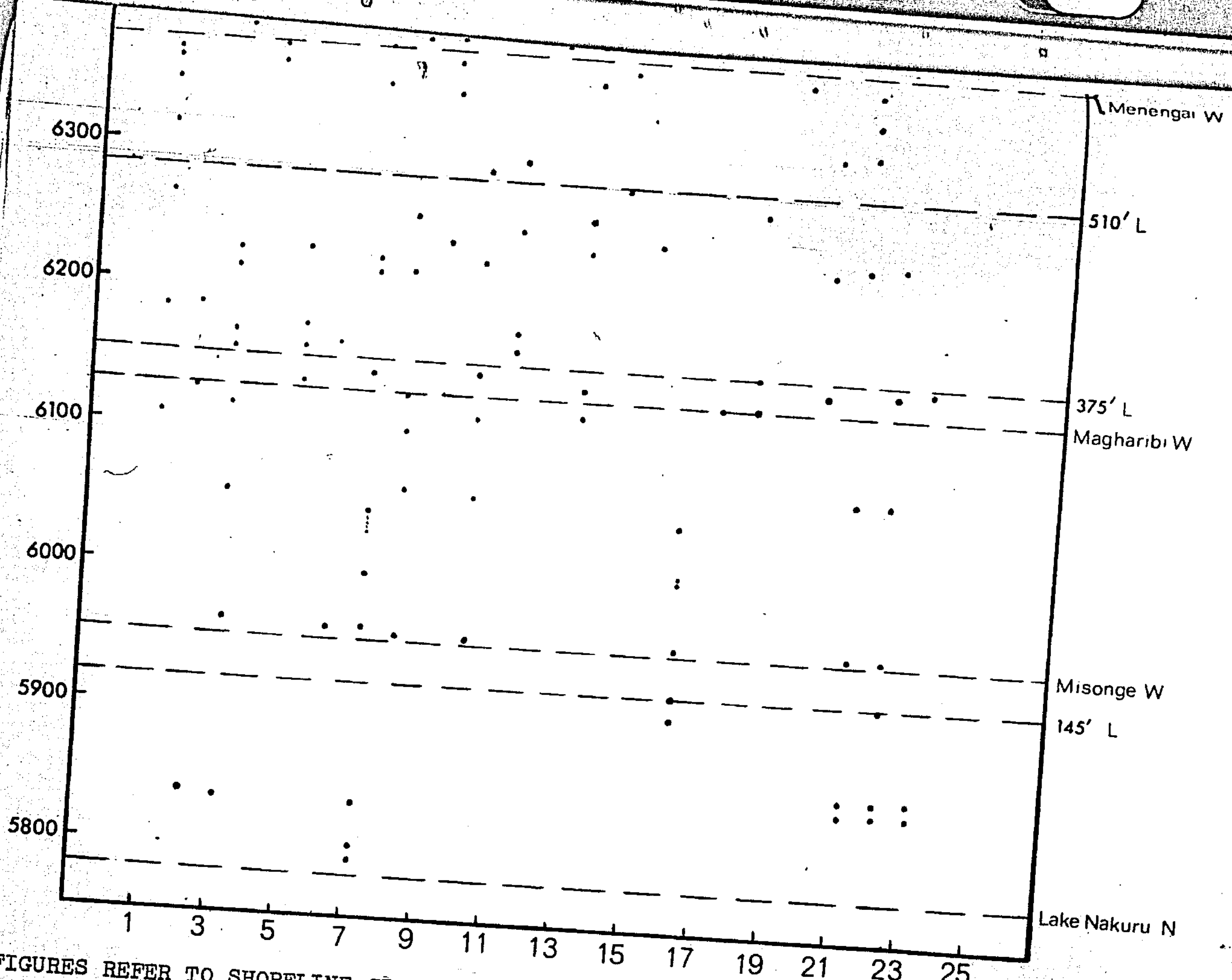
"LIST OF ANCIENT BEACHES" IN NAKURU-ELMENTEITA BASIN, FROM NILSSON 1940 pp. 75-7. NILSSON'S HEIGHTS HAVE BEEN CONVERTED INTO FEET BUT LEFT ON THE ORIGINAL DATUM, PRESUMABLY THE RAILWAY DATUM.



N: Nilsson's heights for Gilgil divide and lake level, presumably in 1927.

L: Leakey's shorelines, A.L. Nakuru at 5776' R.D.

W: my shorelines; S.D. to R.D. conversion by adding 6'.

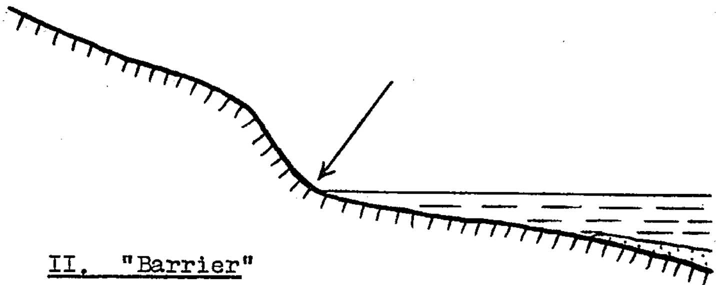


FIGURES REFER TO SHORELINE GROUPS GIVEN IN NILSSON'S LIST AND ON THE MAP (1940 p. 25).

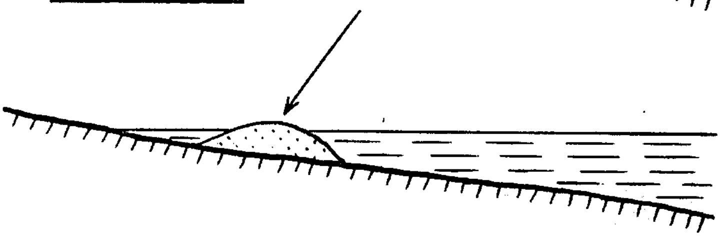
FIGURE 5

Nilsson's levelling of shoreline features

I. "Wave cut-terrace"



II. "Barrier"

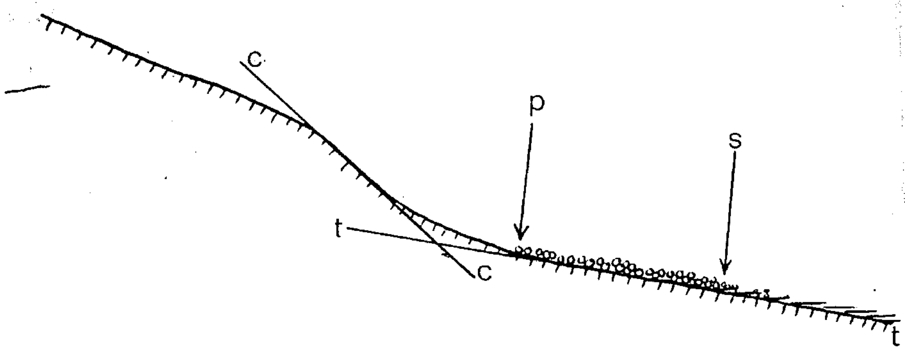


"The arrows show the parts of the shore-lines which are best marked and which I levelled".

(Nilsson 1931 fig. 36)

FIGURE 6

My levelling of shoreline features



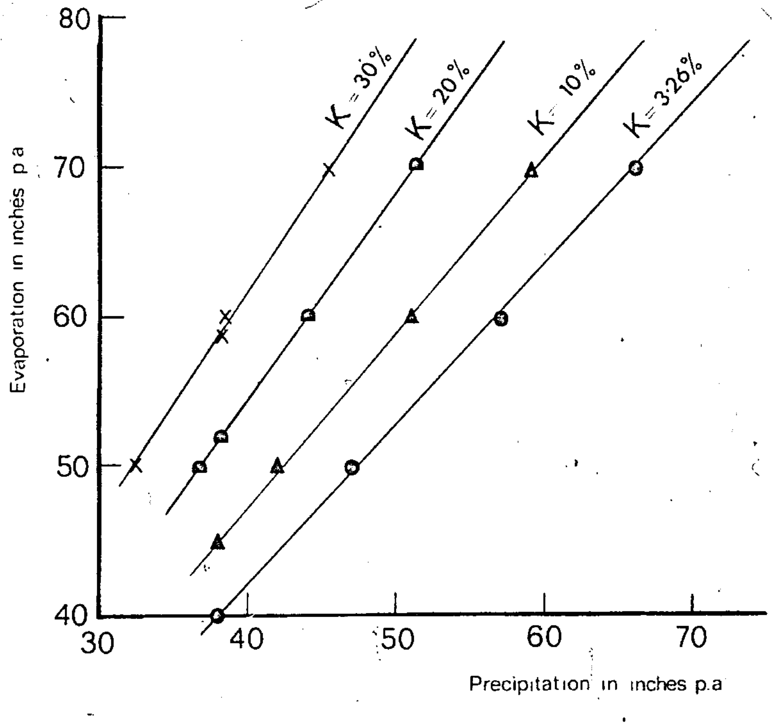
cc : approximate slope of cliff
tt : approximate slope of terrace

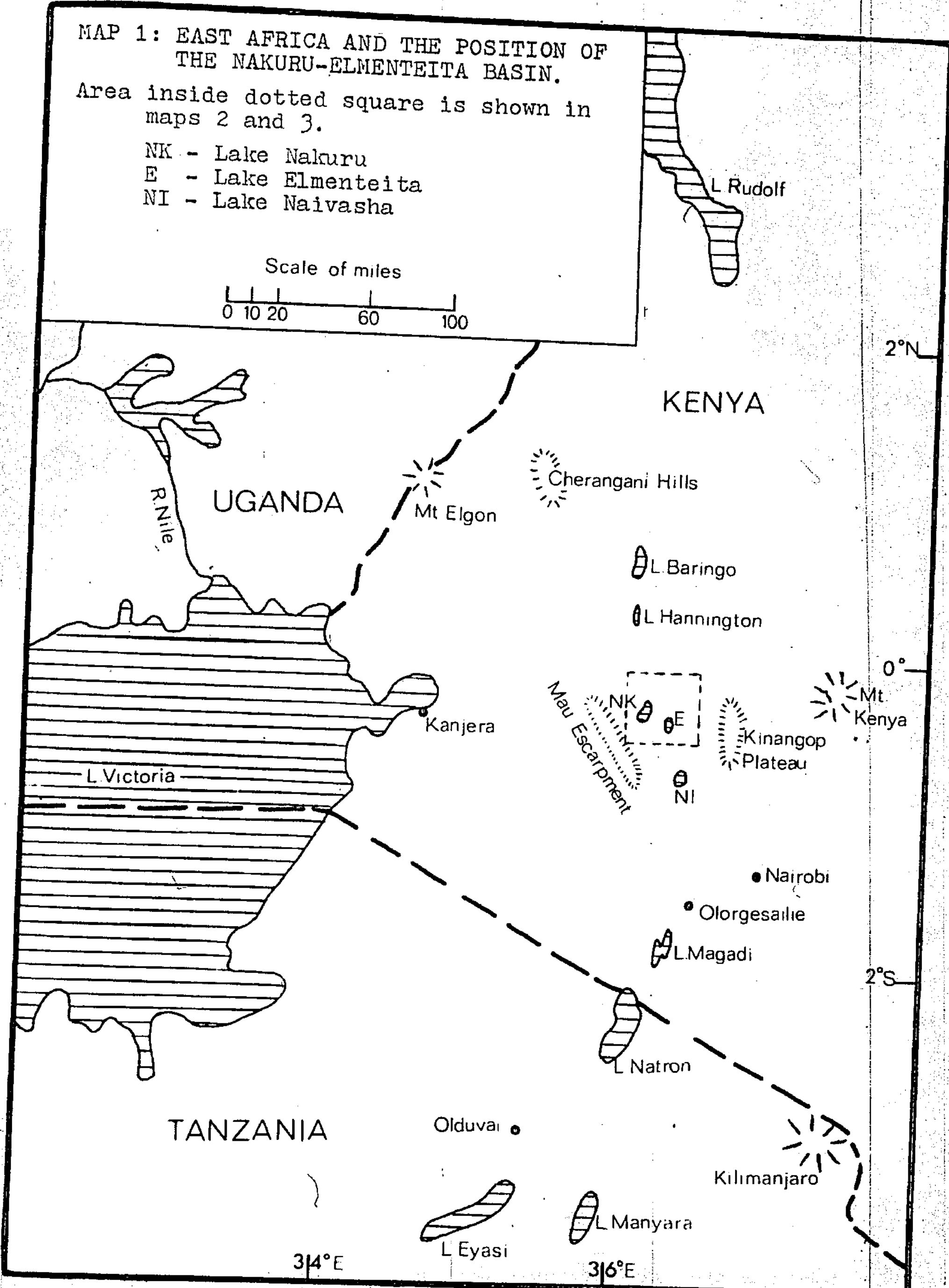
The point at the intersection of the lines cc and tt is taken as representing the height of the notch at the base of the cliff and thus the approximate height of the former lake level.

p : beach pebbles on the terrace; in most cases the upper limit was some distance below the base of the cliff.
s : sand and silt found in sections with pebble beds at a rather lower altitude.

FIGURE 7

GRAPH OF PRECIPITATION-EVAPORATION RELATIONSHIPS FOR THE 600 FOOT LAKE IN THE NAKURU-ELMENTEITA BASIN

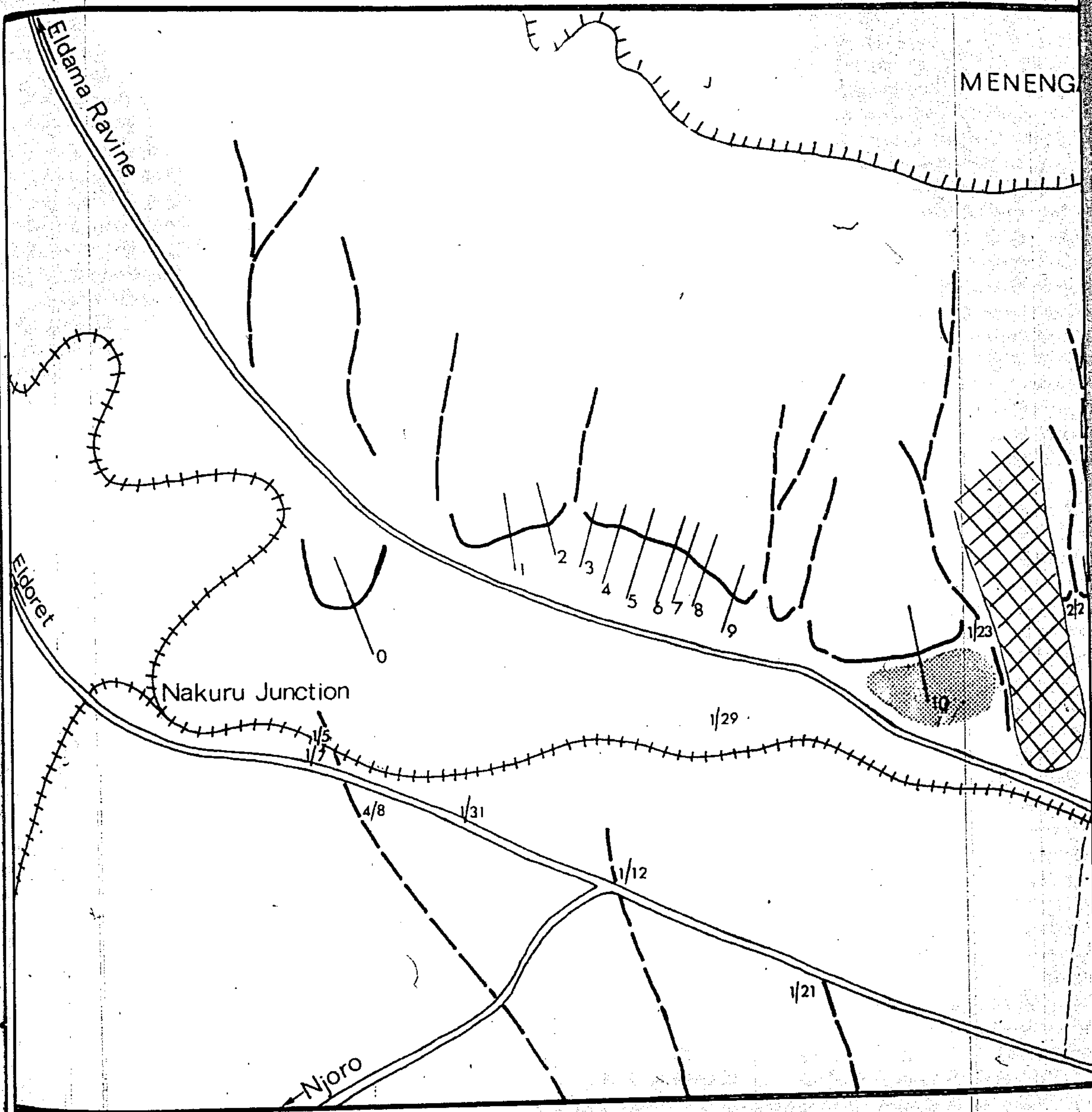




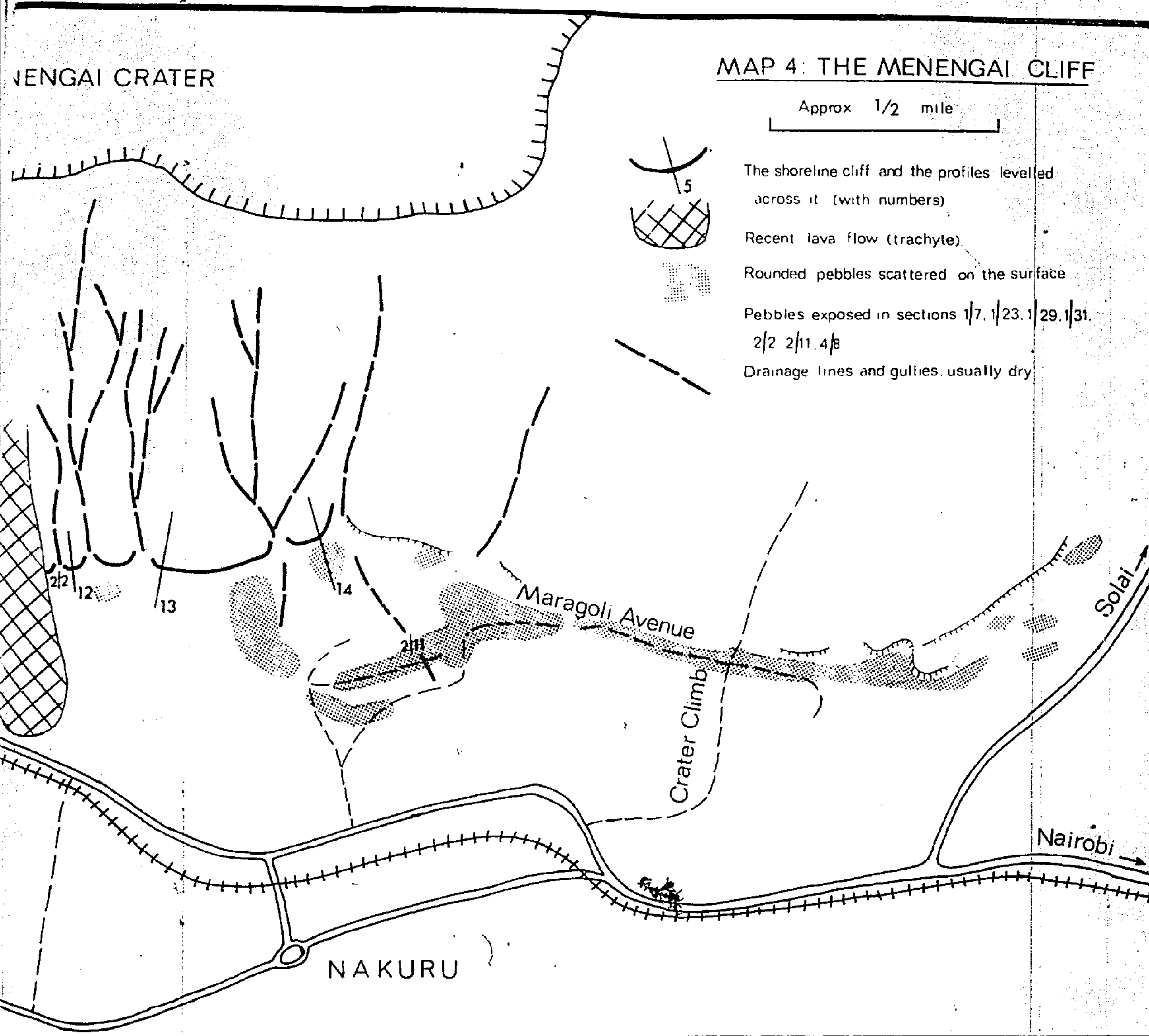
MAP 1: EAST AFRICA AND THE POSITION OF THE NAKURU-ELMENTEITA BASIN.

Area inside dotted square is shown in maps 2 and 3.

NK - Lake Nakuru
E - Lake Elmenteita
NI - Lake Naivasha

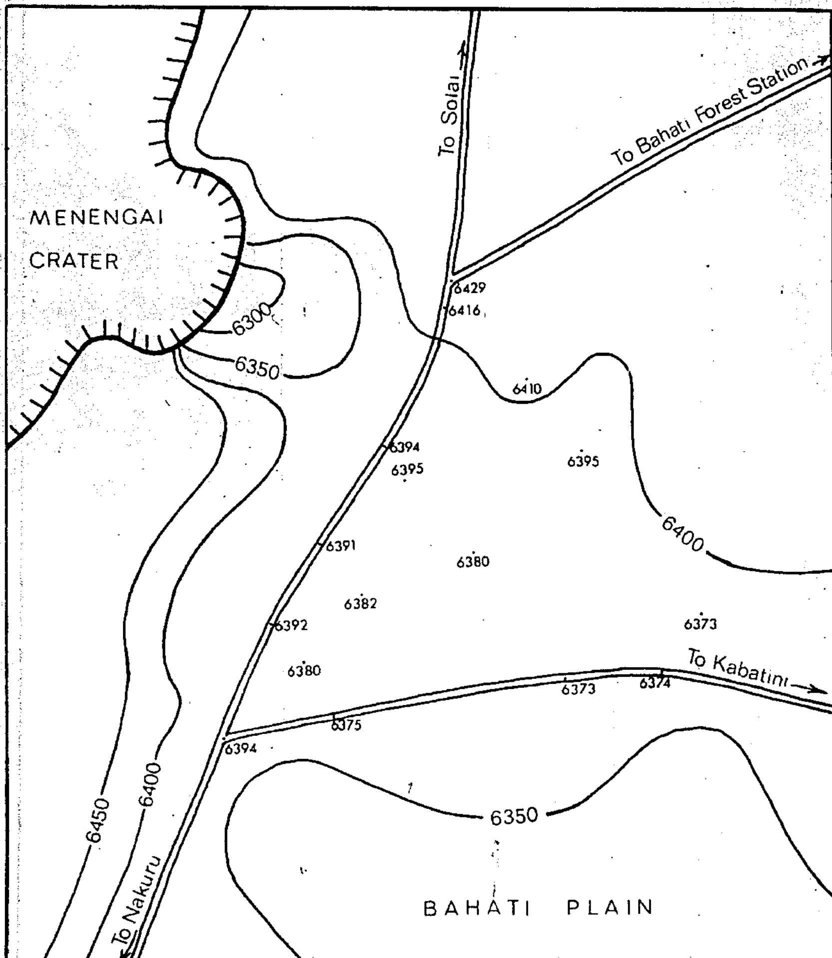


Eldama Ravine
MENENG
Eldoret
Nakuru Junction
0
1
2
3
4
5
6
7
8
9
10
1/23
2/2
1/29
1/5
1/7
4/8
1/31
1/12
1/21
Njoro



MAP 4: THE MENENGAI CLIFF
Approx 1/2 mile
The shoreline cliff and the profiles levelled across it (with numbers)
Recent lava flow (trachyte)
Rounded pebbles scattered on the surface
Pebbles exposed in sections 1/7, 1/23, 1/29, 1/31, 2/2 2/11, 4/8
Drainage lines and gullies, usually dry
NENGAI CRATER
5
2/2
12
13
14
2/11
1
Maragoli Avenue
Crater Climb
Solai
Nairobi
NAKURU

MAP 5: THE BAHATI-MENENGAI DIVIDE (Area marked OF on map 3)



Approximate scale of map is 2·8 inches to 1 mile.
The contours are sketched from those on the 1 : 50,000 map, no. 119/1 (4th edition).
The spotheights were fixed by my levelling; heights are in feet (S.D.).

Plate A1 (in pocket at back of volume): air photograph, scale c. 1:60,000. Shows;- (i) the southern rim of Menengai caldera (ii) the town of Nakuru (iii) River Njoro flowing towards Lake Nakuru (iv) the gullies on Menengai and their endings at the level of the Menengai shoreline (v) the Menengai shoreline, best defined between the points marked ● (vi) the Misonge shoreline, between the points marked x (vii) Hyrax Hill and Water Tank Hill (viii) the belt of trees round the north-east side of the lake in which lies the Kiboko shoreline.

Number of photograph: V13A 1079 020 Kenya.

Plate A2 (in pocket at back of volume): air photograph, Scale c. 1:60,000. Shows;- (i) the southern shore of Lake Elmenteita (ii) the volcanic cones Split Hill and Karterit (iii) young lava flows to the south and west of these cones (iv) locality 8V/8, from which the mollusca were taken, marked x (v) the Kariandusi diatomite mine in the north-east corner of the photograph (vi) the Gilgil escarpment along the eastern side of the photograph; the lines of both the new and old roads up the escarpment are visible.

Number of photograph: V13A 1072 013 Kenya.

PLATE 1(a)

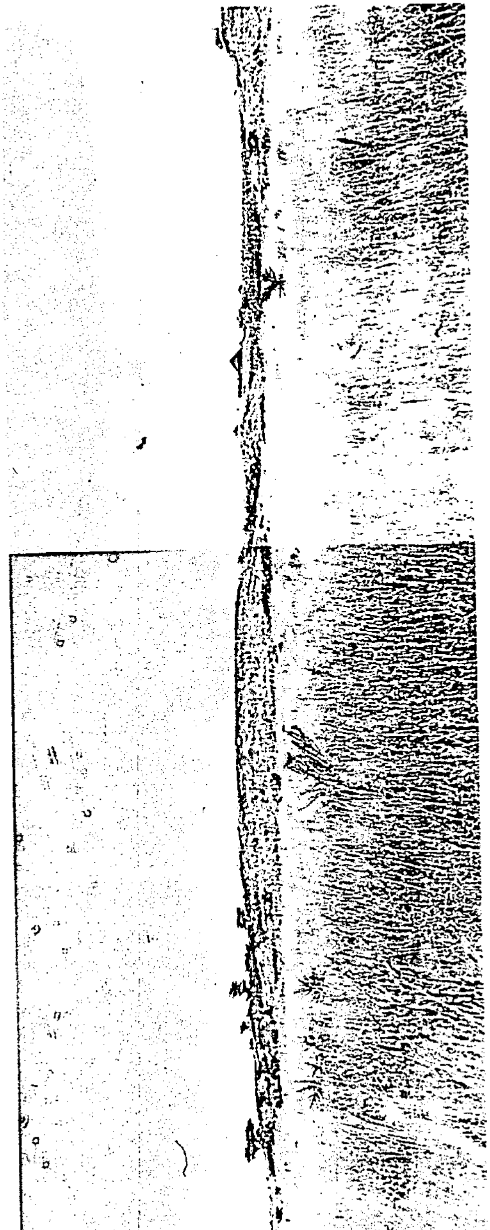


Plate 1(a): the western end of the Menengai shoreline; this is the spur across which profile 1 was levelled (see map 4). The photograph was taken from below the cliff. The mouth of one of the dry gullies is shown to the right of the photograph.

Plate 1(b): this shows the eastward continuation of this shoreline, and overlaps with Plate 1(a). The same gully is visible to the left of the photograph, and two spurs to the right of it. Profiles 2 and 3 were levelled across these spurs.

PLATE 1(b)

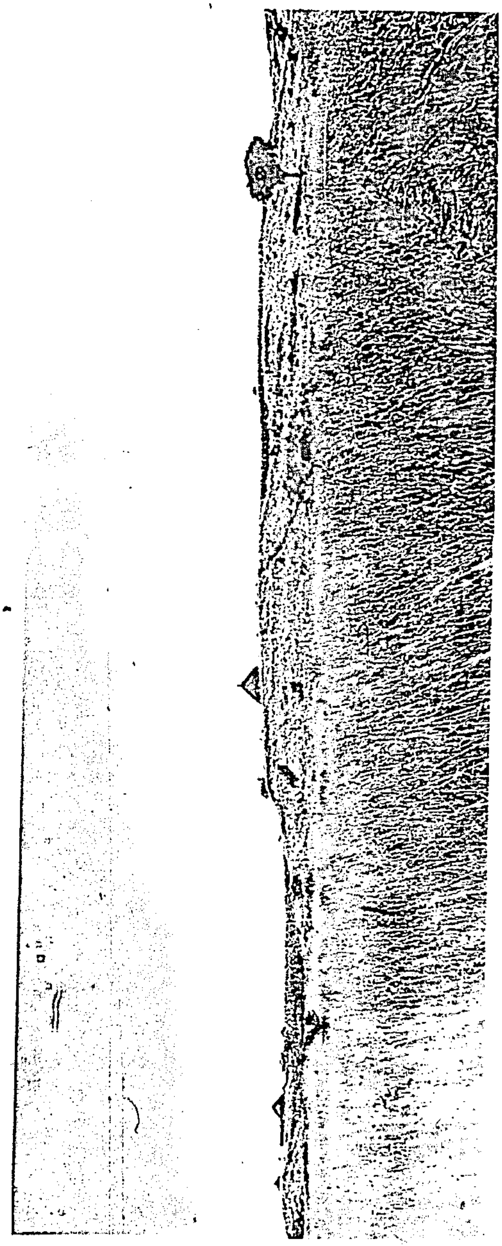


PLATE 2

Plate 2: the Menengai shoreline, western end. The photograph was taken from on top of the cliff, on the approximate line of profile 1, looking east along the cliff across which profiles 2 to 9 were levelled. The base of the cliff shows up especially clearly because of the vegetation discontinuity at its foot.

Plate 3: the Bahati-Menengai divide. The photograph was taken looking into Menengai crater from the main road Nakuru-Solai, slightly north of the point with altitude 6394' on map 5. The highest point on the rim of the caldera shows to the left. One of the youngest lava flows within the caldera can be seen just above the power line, rather dark in colour.

<u>PLATE 3</u>

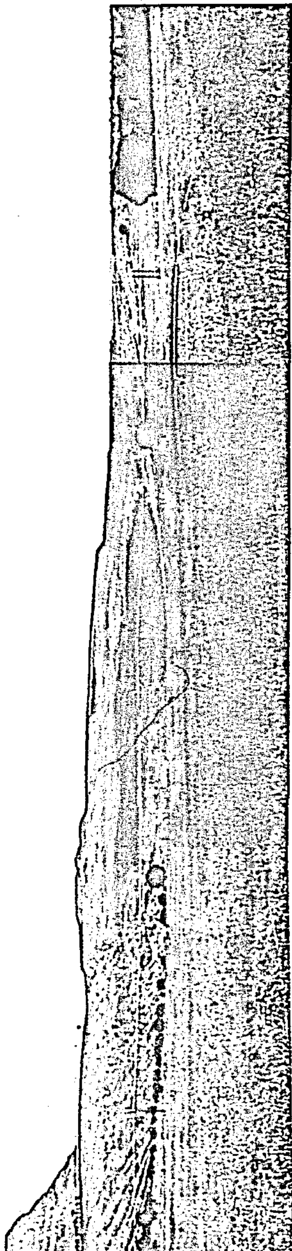


PLATE 4

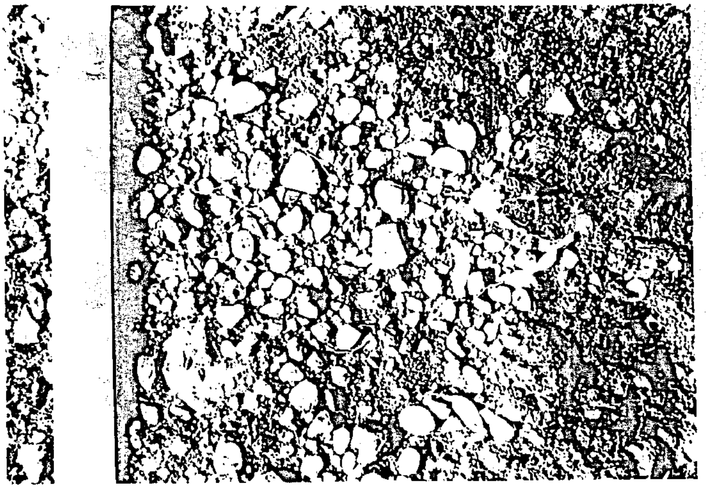


PLATE 5

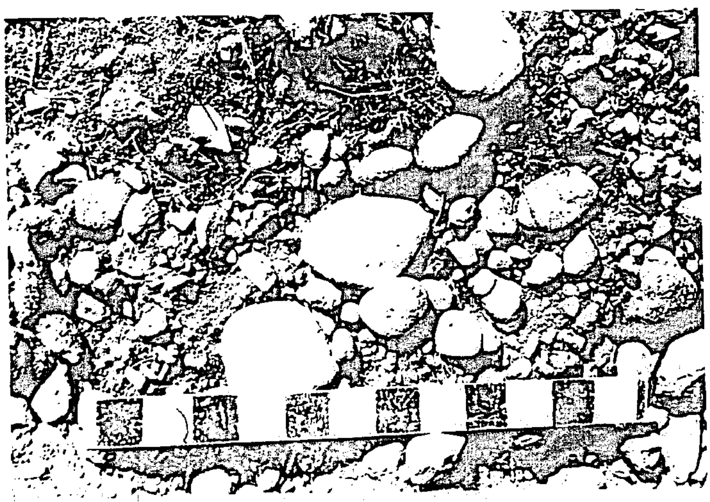


Plate 4: beach pebbles on Menengai, lying over an outcrop of vitreous tuffs and ignimbrites (showing in particular on the right of the photograph). These pebbles occurred along Maragoli Avenue (see map 4) at altitudes of 6350-6380' S.D. The scale is graduated in inches.

Plate 5: beach pebbles on Lion Hill near locality 5/16 (see map 3). The altitude of these pebbles is about 6380' S.D.

Plate 6: beach pebbles from the North-east Elmenteita area, at approximately 8/1 on map 3. Pebbles like this occur widely betwwen heights of about 6140-6260' S.D.; these ones were photographed towards the lower end of this range.

Plate 7: beach pebbles in a section over lava, close to the former Eburu station (8E/3 on map 3). The altitude of this section is 6256' R.D. (=6350±3' S.D.) Pebbles are found on the surface here up to about 10' above this; they are also found overlying diatomaceous silts in section 8E/3 (plate 11).

PLATE 6

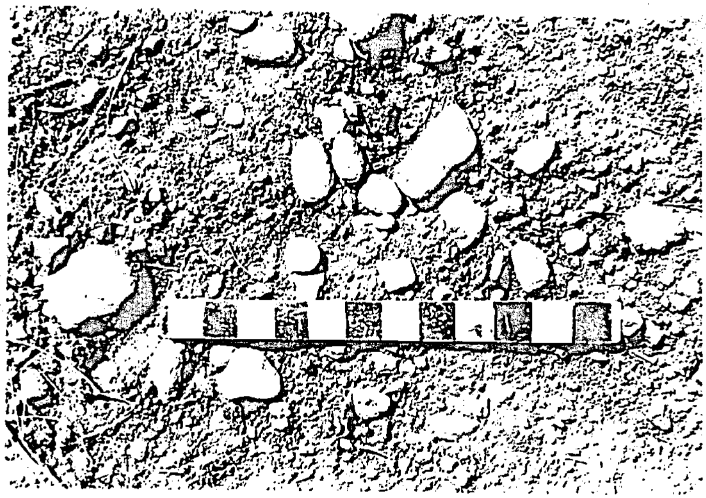


PLATE 7

PLATE 8

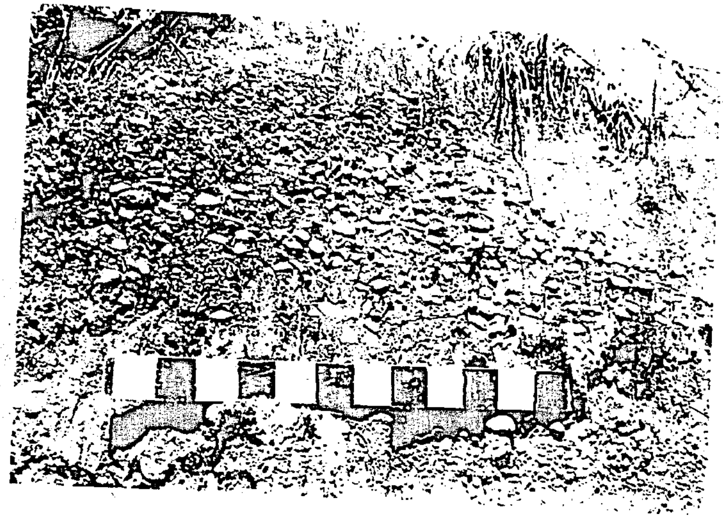


PLATE 9

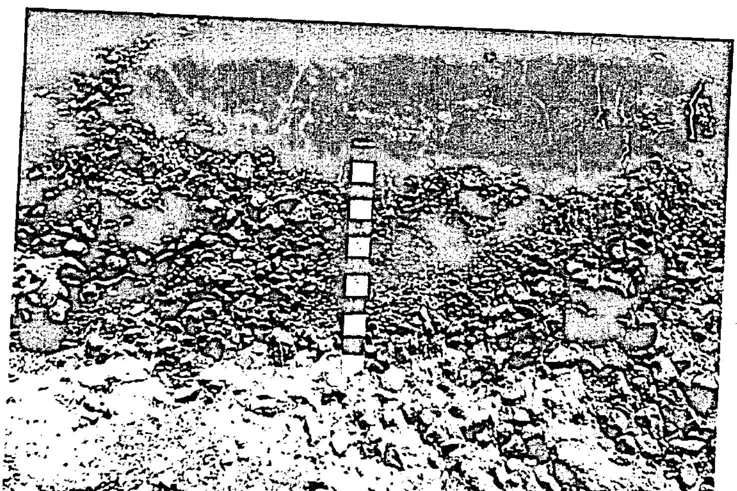


Plate 8: grey pumice pebbles exposed in the wall of Prettejohn Gully at an altitude of about 6300'. Similar pebbles are exposed here up to an altitude of about 6335' R.D. (=6329±3' S.D.)

Plate 9: pebbles in section at 9/1 (see map 3). The altitude of this pebble band is 6361' R.D. (=6356±3' S.D.). It underlies a layer of red sand and overlies a narrow band of impure diatomaceous silt.

Plate 10: stratified layers of grey pumice pebbles from 1/7 below the Menengai shoreline (see map 4). The altitude of these pebbles is about 6343' S.D.

Plate 11: pebbles over diatomaceous silt at 8E/3. The altitude of this section is about 6300' R.D. (=6294±3' S.D.). The knife is about 22" long.

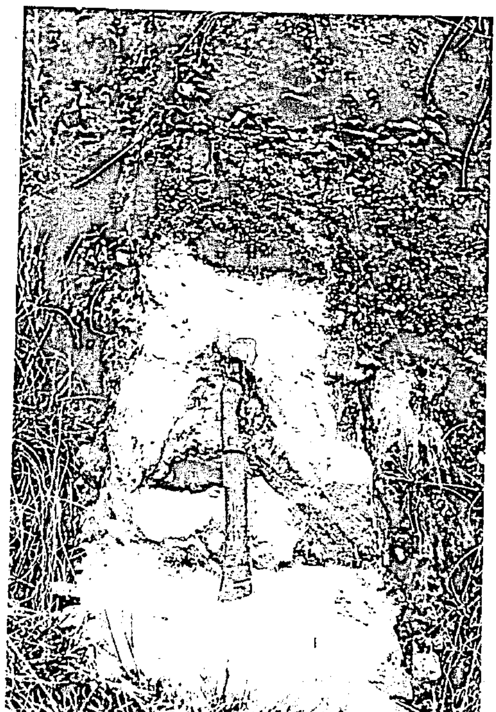


Plate 12: section 3/6 on the Bahati plain (see map 3). The altitude of this section is about 6343' S.D. The section shows;- (i) dark coloured soil at the top (ii) a layer of light brown diatomaceous silt (iii) a band of rounded pumice pebbles (iv) a layer of less well-rounded pumice fragments (v) surface of lava sloping gently down to the south-east (towards right-hand side of photograph).

Plate 13: section 3/6. Detail of pebble beds overlying the lava.

Plate 14: the north-eastern slope of Karterit volcano, photographed from along the track to Kariandusi station (above 8/12 on map 3). Two lines can be seen on the slope. The photograph was taken in early March, before a fresh growth of grass during the rainy season had made the lower line very hard to see. The western side of Karterit is not visible, but is hidden behind the hillside on the right of the photograph.

Plate 15: a closeup of the upper line on Karterit. The cliff is overhanging and is cut in the yellow slabby tuffs of the volcano. The altitude of the base of the cliff at this point is about 6360' S.D.

PLATE 14

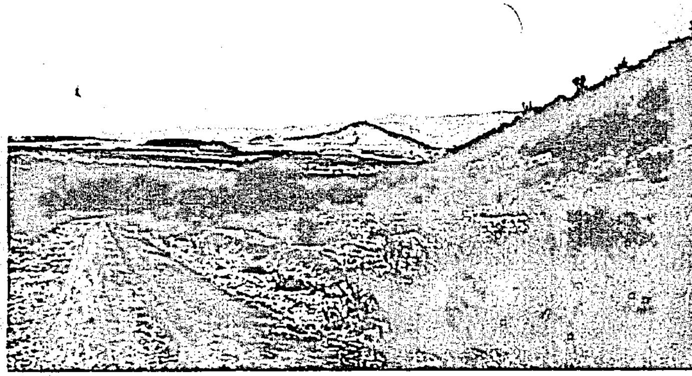


PLATE 15

Plate 16: mollusca in diatomaceous silt at 8V/8 (see map 3). The altitude of this exposure is about 6192' S.D. The pencil is 6" long.

Plate 17: section 8/5; lava and diatomaceous silt in a road cutting on the main road between Gilgil and Kariandusi (see map 3). The altitude of this exposure is probably rather below 6400'. These appear to be some of the oldest diatomaceous silts exposed in the Nakuru-Elmenteita basin.

Plate 18: banded diatomaceous silt at 8E/3. The altitude of this exposure is about 6290' S.D., slightly below the pebbles and diatomaceous silt in plate 11. The knife is 22" long.

Plate 19: banded diatomaceous silt from Prettejohn Gully. The altitude of these silts is about 6260' R.D. The dark bands are made of fine brown sand which is not firmly consolidated and is less resistant than the white diatomaceous silt. The bands can be traced along the exposures in the gully walls for several yards. The pencil is 6" long.

PLATE 18

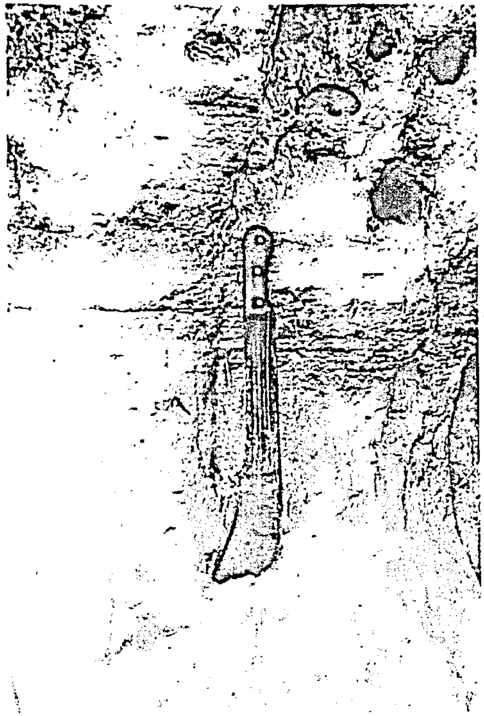
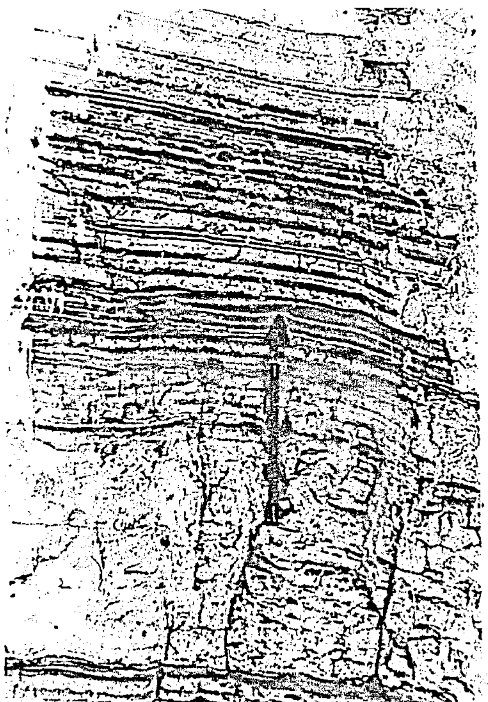


PLATE 19



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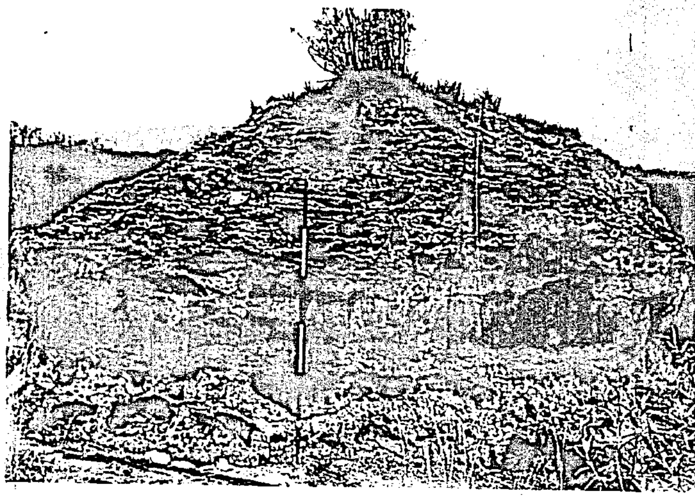

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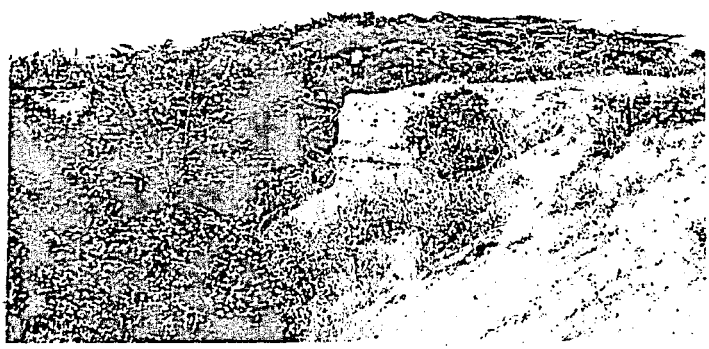

Plate 20: diatomite residual (10/13) on the Miti Mingi terrace near the River Nderit. Banded diatomaceous silts overlie coarse orange silt. The base of the diatomaceous silt is at 6256' R.D. (=6250±3' S.D.).

Plate 21: diatomaceous silt overlying coarse reddish-orange silt in a section (8/3) on the River Kekopey. The diatomaceous silt tapers out and is lost from the top of the section a short distance upstream from this exposure, at an altitude of about 6311' S.D.

Plate 22: the Magharibi cliff south of the River Makalia. Fine dark grey ash outcrops on the upper part of the cliff and overlies coarse bright red silt. The contact between the two layers is just below the horizontal ranging rod and is at an altitude of 6131' R.D. (=6125±3' S.D.). Rounded white concretions are washing out from the red silt and cover the ground below the cliff. The altitude of the base of the cliff is about 6128' R.D. (=6122±3' S.D.)(see figure 2).

PLATE 22

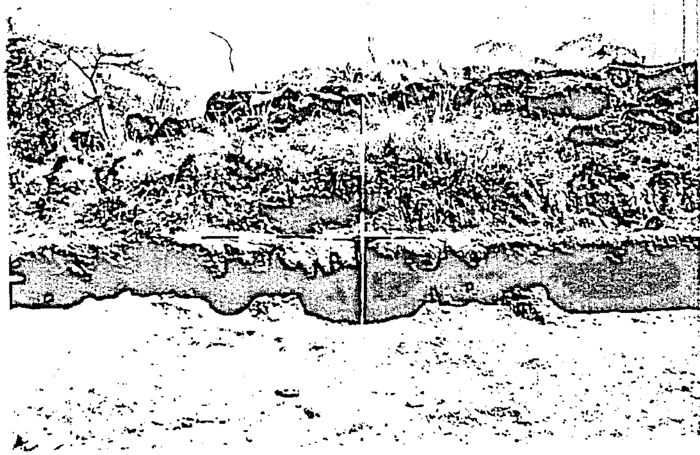

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PLATE 23

PLATE 24

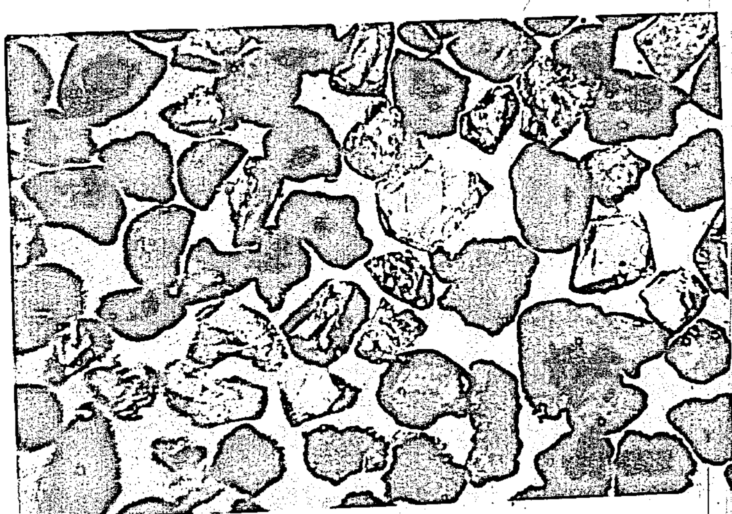

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Plate 23: material from the lower bed of 'aeolian sand' (layer 8) in Gamble's Cave. The smallest particles in this photograph are slightly over 1 mm in diameter. Most of this size range of the sample consisted of rounded particles of light grey pumice.

Plate 24: material from the lower bed of 'aeolian sand' (layer 8) in Gamble's Cave. These particles are in the size range 0.15-0.25 mm. Most of the particles are angular and have unworn surfaces.