ORIGIN AND EVOLUTION OF THE PLEISTOCENE OLORGESAILIE LAKE SERIES: KENYA RIFT VALLEY

Volume I: Text

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ABSTRACT

The Olorgesailie Lake beds were investigated in order to explain the existence of the former lake, place the beds in a Pleistocene chronology, and evaluate the evidence for climatic change.

This was done by preparing a denudation chronology for the Kenya Rift Valley. Chronologies derived from volcanic and sedimentary stratigraphies, palaeomagnetic observations, and geomorphological analysis were combined to produce an account of drainage since 2.3 Ma BP.

There was a sequence of Quaternary Lakes, Olorgesailie representing only one episode in a transition from continental to internal drainage caused by the evolving Rift. The stratigraphic facies originated in volcanic and tectonic events, with no evidence of climatic change, other than dessication associated with a lowering Rift floor. The disruptions also explain lake extinctions outside the Rift.

The results suggest climatic shifts in East Africa were insufficient to cause significant environmental changes. The methodology could provide approximations of climatic conditions at other pre-historic sites.

RESUME

Nous avons étudié les sediments lité's du lac Olorgesailie afin d'expliquer l'existence d'un ancien lac, d'établir l'age de ces lits à l'interieur du Pleistocène, et d'évaluer l'évidence de changements climatiques.

Dans ce but, nous avons établi une séquence chronologique de denudation pour la Rift Valley du Kenya. Nous avons fait des determinations d'âge de roches sedimentaires et volcaniques, des observations paléomagnetiques de même qu'une étude geomorphologique afin d'obtenir une étude du drainage depuis 2.3 Ma BP.

Il y a en une série de lacs Quaternaires, Olorgesailie ne représentant qu'une seule période de transition d'un drainage continental vers une drainage interne, du au development de la Rift. Les facies stratigraphiques ce sont formés lors de périods volcanique et tectoniques, sans évidence de changement climatiques autre qu'un assèchement rattaché à l'affaisement de la Rift Valley. Les dislocations expliquent aussi la disparition des lacs a l'exterieur de la Rift Valley.

Les résultats suggèrent que des changements climatiques en l'Afrique Orientale n'çtaient pas suffisants pour créer d'importants changements dans l'environment. La methodologie pourrait indiquer des approximations de conditions climatique à d'autres sites préhistoriques.

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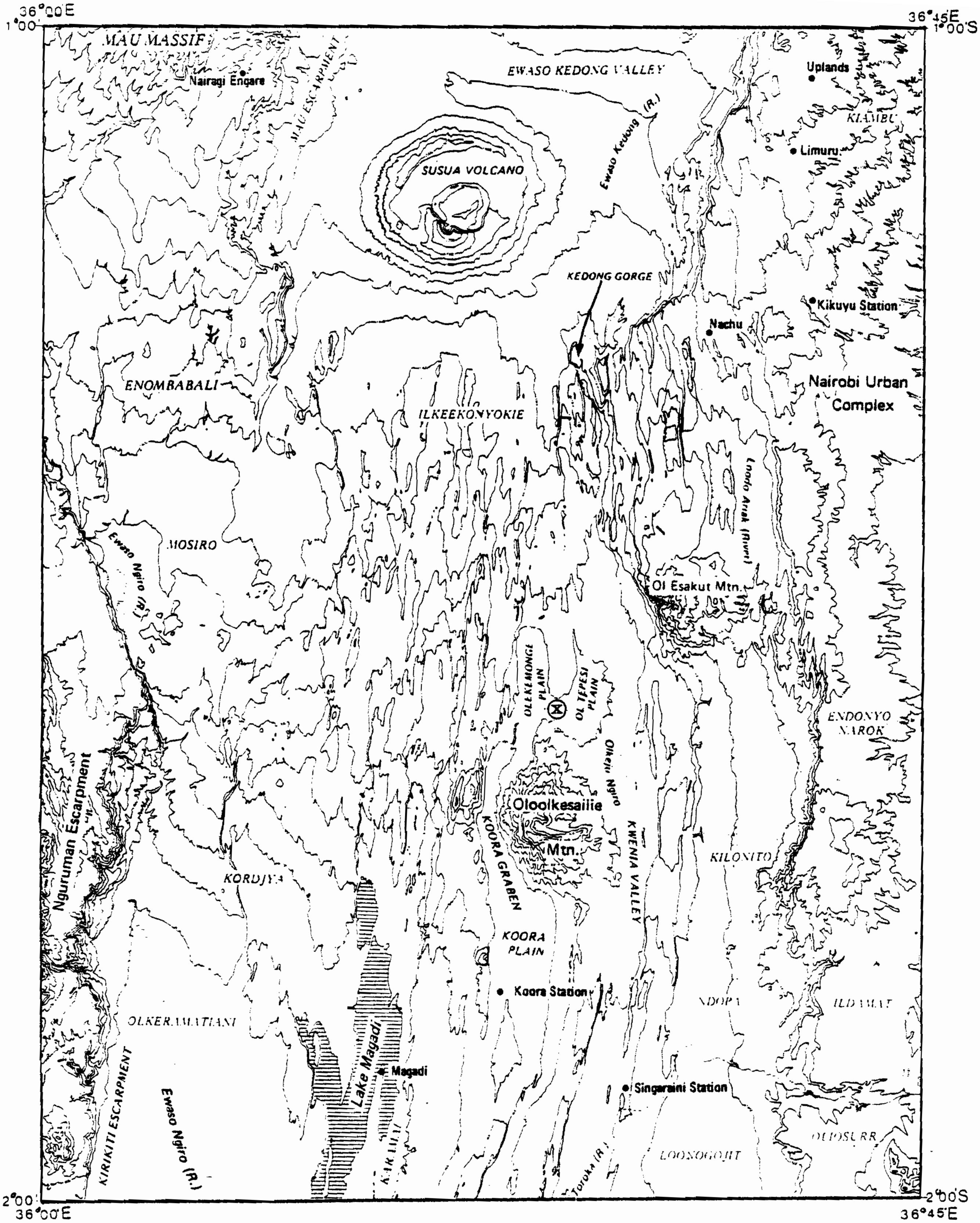

Fig. 1-1 General location map of the study area. Scale 1:550,000. Contour interval 100 m. 'X' indicates the Olorgesailie historical site.

Chapter One

INTRODUCTION

I. THE PROBLEM DEFINED

At Oloolkesailie in the Kenya Rift Valley, 50 kms southwest of Nairobi, (Fig. 1-1) there is a well-known rich prehistoric site which provides a succession of Acheulian occupation places within a clearly distinguishable sequence of lake-beds which are more than 50 metres thick. Stone tools of the Acheulian industry occur in great numbers at sharply defined nonsequences in the stratigraphy, and it has been shown that they represent former camp sites on land surfaces associated with the shores of the former lakes. Because no datable organic remains have been found, there are no firm ages for the sites. Potassium/argon dating of volcanic rocks from the enclosing beds, consisting of reworked materials, gives wild contradictions, the dates ranging over 2½ million years. The only certain date is provided by an alkali trachyte which underlies the entire lake sequence, and it has been assigned an age of 0.72Ma±.09 (Fitch and Miller, unpublished: cited in Isaac 1968, and in Baker et al., 1971).

Howell and Clark pointed out that at Oloolkesailie:

'The present rainfall (18 to 20 ins) and small watershed are inadequate to explain the existence of the lake. A rainfall substantially greater than today, with repeated fluctuation in precipitation-evaporation ratios is requisite to account for the lake and the multiple nonsequences within the succession of sediments.' (Howell and Clark, 1963, p. 482).

The present topography of the area could not retain a lake at Oloolkesailie even under humid conditions since it opens southward through the Koora graben on to much lower terrain. Given the present topography, a lake at the level of the lowest lake beds would have overflowed the containing horsts and would have extended over an area of 16,000 kms^2 (incorporating the areas of the Lakes Magadi, Natron, and Manyara) for which there is no evidence whatsoever. Since the lake beds lie in a complex of grabens, the lake site was clearly created by tectonic activity, and the lake can be assumed to have drained from the same cause. Baker, for example, (1958 p. 37) suggested 'deepening of the troughs southward'.

In the late 1950's and early sixties, critical reviews of the stratigraphies associated with human remains and artifacts in East Africa challenged the existing interpretations, especially in regard to the climatic implications. In a 1959 review of African stratigraphies which were generally supposed to indicate climatic change, Flint rejected that explanation for all but the Oloolkesailie site where the numerous nonsequences (17 land surfaces) and the small drainage area of 650 kms^2 led him to suggest that if frequent climatic change could be proved anywhere in Africa, Oloolkesailie was the only site likely to provide firm evidence (Flint 1959b, pp. 354-355).

It is the intention of this thesis to attempt an explanation of the origins of the Olorgesailie Lakes*, to examine various stages in their existence, and to provide an explanation of their disappearance This requires an analysis of the landscape in a larger setting, involving a study of the evolution of this section of the South Kenya Rift Valley since the beginning of rift activity.

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*All place names in this text use the most recent standardized transliterations as they appear on Kenya topographic maps after 1973. However archaeological sites, rock formations and rock types, geomorphological features _et cetera_ may have older transliterations which differ significantly in their spelling. All technical names have had their original spellings retained in order to conform to the published literature.

II. THE STUDY AREA DEFINED

Because streams descend both flanks of the Rift today and because such streams could have supplied lakes on the Rift floor in the past, this study incorporates both walls of the Rift, east and west. The northern limit is the Orgaria-Longonot ridge which blocks the Rift wall-to-wall at South latitude 0°50', cutting off surface drainage from the north. This limitation is arbitrary because the ridge appears to have been traversed at one time by a stream from the well-watered area to the north, specifically by a supposed overflow of the fresh water Lake Naivasha through Njorowa Gorge. However, it will be shown in the following pages that there is no demonstrable connection between the Njorowa Gorge and any recognizable past or present drainage channel in the Olorgesailie Lake system. The history of Njorowa and its thick accumulations of water-laid deposits may be finally linked in some way with the history of the Oloolkesailie sector, but for the present it remains a separate and major problem.

To the south, the limit of the study area has been set by the altitude of the floor of the Lake Natron depression. At 598 metres it is now the lowest area in the Rift Valley system, and the salt deposits of Natron and Magadi, whatever their previous altitude, represent the base level to which water in the fresh water Olorgesailie Lakes must have responded.

The study area therefore extends between 36° and 36°40' east, and from 1° to 2°20' south.

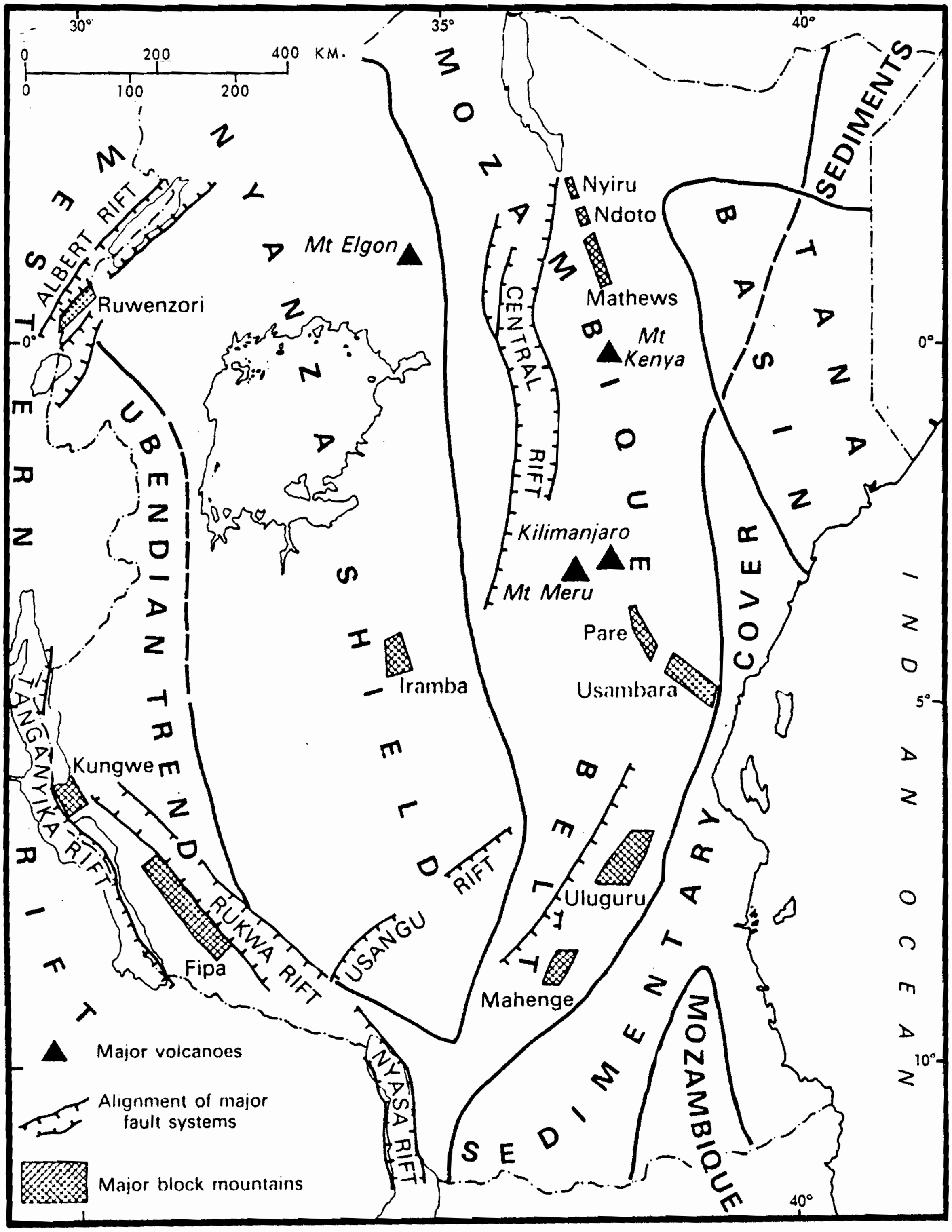


Fig. 1-2 The structural geology of East Africa. (From Morgan, 1973, 'A structural sketch', p.4)

III. A GENERAL SETTING OF THE PROBLEM

The general features of the structural geology of East Africa are shown in Figure 1-2 (Morgan, 1973). The Kenya Rift Valley lies wholly within the Mozambique Belt of intensely folded metamorphic rocks. They are predominantly gneisses, schists, quartzites, and crystalline limestones, and although they are completely obscured by volcanic lavas over most of the study area, they occur close upon the flanks of the Rift, east and west. In literature up to 1965, and even later (e.g. Ojany and Ogendo 1973, cited below) they are described as basement rocks, but since 1965 they have been recognized as a metamorphic fold belt against the true basement of the Nyanza shield to the west. There are some indications that the Rift Valley faulting coincides with, and perhaps follows, the general north-south linear trend induced in the rocks of the belt by metamorphism.

A simplified version of the geology of Kenya appears in Figure 1-3. It is taken from Ojany and Ogendo (1973) and the study area is identified on it. The East African plateau lies west of the Kenya Rift, reaching its greatest height in the Kenya Dome around the Rift itself, and it will be noted that all post-Cambrian sedimentary rocks lie east of the Rift in the area of marine transgression, and in the downwarp shown as the Tana Basin on Morgan's map (Fig. 1-2) but more generally known as the Habaswein depression.

The physiography of East Africa has evolved as a series of peneplanations which have been described separately or collectively by Dixey (1938, 1945, and 1955), Pulfrey (1960), Saggerson and Baker (1965),

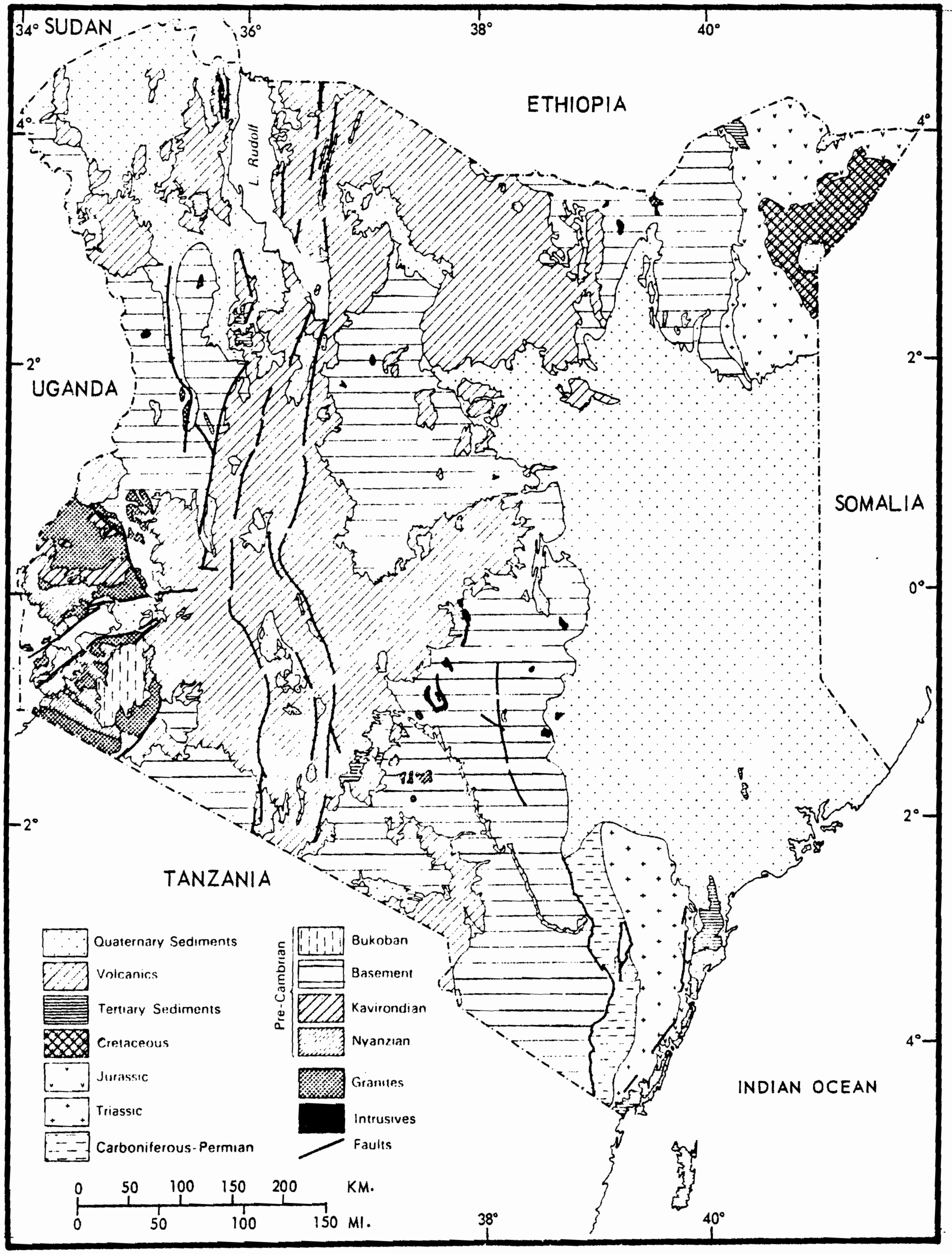


Fig. 1-3 Geology of Kenya. (From Ojany and Ogendo, 1973, p.21)

and L. C. King (1967). Various peneplains are held to be recognizable over much of Sub-Saharan Africa (King L.C. 1967, p. 229), but they have acquired a local terminology in East Africa. The African surface is here known as the 'end-Cretaceous'. The mid-Tertiary (or 'post-African'), which occupies the greatest area, is known as the sub-Miocene Bevel. The end-Tertiary, which created the great plains of Eastern Kenya and coastal Tanzania, retains its name, but, having followed a period of up-warping in Kenya, it intersects the sub-Miocene surface along an extensive morvan 300 kms east of the Rift Valley (Pulfrey 1960, p. 10).

The end-Tertiary period ended with an up-warp which created the Kenya Dome. While uplift did not exceed 200 metres in the first movement, rift faulting was apparently initiated at about the same time, although the exact sequence and scale of events is still not clear at the present time. The continental watershed is believed to have been near, or at, the site of the Rift at that time (Cooke 1957, Pulfrey 1960 p. 14) but that theory too remains controversial. The structure and geophysics of the Great Rift Valley system have not been fully understood, and there may not be one common mechanism or age (Baker and Wohlenberg 1971, p. 541; and Fairhead, Mitchell and Williams 1972, p. 69). However, this thesis is concerned only with the landscape that formed in the area of the Olorgesailie Lakes and does not attempt to deal with the geophysics of the Rift System.

The study area lies wholly within the sector created by the sub-Miocene planation as shown by Pulfrey, but the structure and the former surface have been almost completely obscured by late Tertiary and Quaternary volcanics (Fig. 1-3), and so an understanding of the morphology

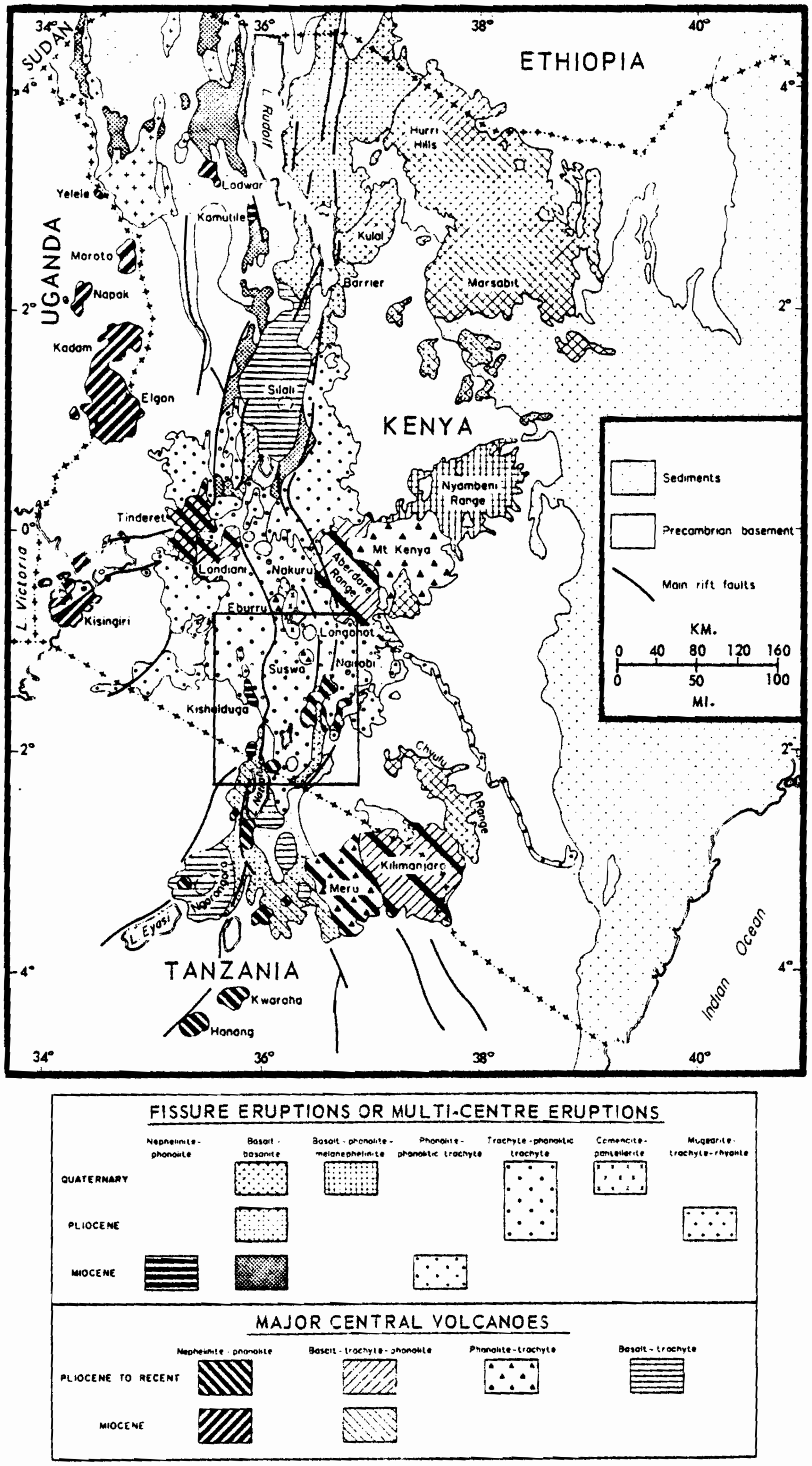


Fig. 1-4 The main volcanic associations of Kenya (from Williams, 1970, p.6). The general area of the study has been outlined at centre left.

and stratigraphy of central-vent volcanoes, fissure flows, and flood lavas is highly relevant to any analysis of events. Figure 1-4 shows the detail of the area described as Quaternary volcanics in Fig. 1-3. Figure 1-5 from Baker and Mitchell (1976) shows the stratigraphy of the volcanics in the study area itself. Although this thesis later modifies some parts of that map and the stratigraphy, nevertheless the map serves to show that, apart from six central vent volcanoes within the Rift and one on the eastern flank, the area is almost completely covered by flood lavas, principally trachytes and basalts, ranging in age from Pliocene to Recent. They are associated with the process of faulting.

The Kenya Rift Valley is a complex graben of unknown age which has evolved during Miocene, Pliocene, and Pleistocene time (Saggerson and Baker 1965), and it traverses the Kenya Domal uplift where erosion surfaces suggest that the dome developed in Miocene and Pliocene time. The Kenya Rift Valley is a part of the eastern Rift System of Africa, which is, in turn, a continental extension of the world rift system (Fig. 1-6). The southern sector of the Kenya Rift near Nairobi is often called the Gregory Rift and its tectonic features have been summarized:

> The Gregory rift is in the central part of the Kenya rift zone, and is a complex graben 60-70 km wide bounded by major normal faults arranged _en échelon_. Broad step-fault platforms occur locally on each side of the graben, and between the hinge faults _en échelon_ there are sloping ramps descending from the flanking plateau to the rift floor. The fault escarpments are well preserved and range up to 2,000 m in height in the central sector. The thickness of the volcanics of the plateau (up to 2,000 m) and the still greater thickness of the volcanic and sedimentary fill in the rift floor which is inferred suggest that the throws of the major faults may reach 3000 - 4000 m. The floor of the Gregory graben, including the step-fault platforms and ramps are cut by dense swarms of

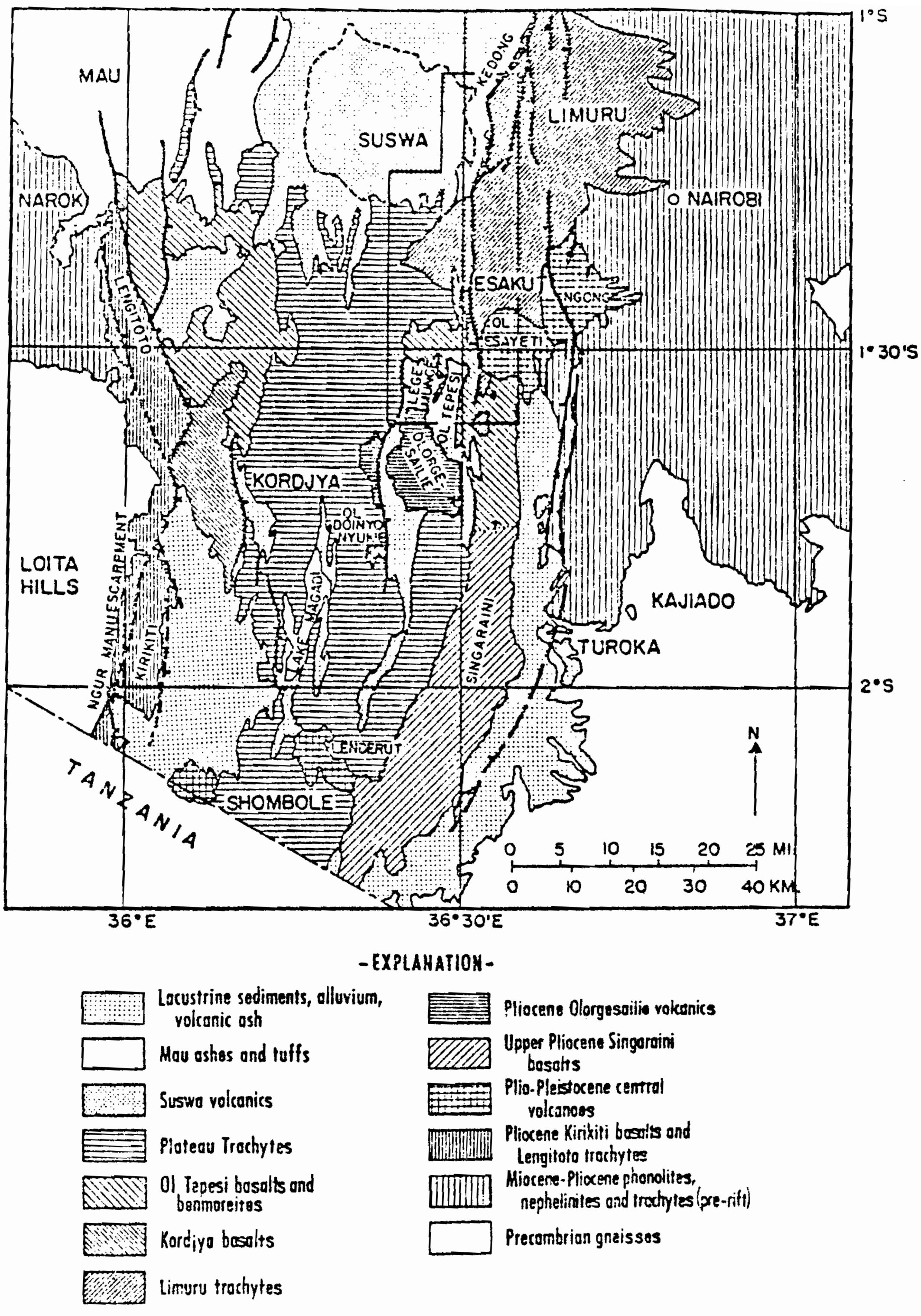


Fig. 1-5 Geological map of the southern part of the Kenya rift valley. (From Baker and Mitchell, 1976)

> young sub-parallel minor faults. (Baker and Wohlenberg 1971, p. 538).

The latter form of faulting has been called grid faulting, and, together with the central vent volcanoes, provides the dominant characteristics of the rift floor. The faults occur every few kilometres or so, and in some areas they occur at intervals of a few hundred metres. The relief of the fault escarpments is significant, ranging from tens of metres to as much as 300 metres, as at Kordjya or Shanamu. Some faults can be traced for more than 100 kms but, as many cross each other, or bifurcate, and include pivotal throws, the topographic forms are not so persistent. As a result, the terrain consists of near parallel horsts and grabens in a great variety of sizes, often en échelon, and sometimes tilted, and all aligned approximately north-south with a consequent strong control of routeways and potential drainage channels (Fig. 1-7). Baker notes that 'the extent and number of these fault swarms and their youth are unequalled in any other known continental structure outside the eastern rift of Africa.' (Baker 1970, p. 194)

The Rift faulting, followed by swarms of grid faults on the Rift floor, created numerous depressions which, in combinations with the growth of volcanoes and flows of flood lavas, led to the initiation of a series of Quaternary lakes: Lakes Turkana (Rudolph), Logipi, Baringo, Harrington, Nakuru, Elmentaita, Naivasha, Magadi and Lake Natron in Tanzania. Of these, only Magadi lies in the study area. There are also seasonal and ephemeral lakes like Kwenia and Cabongo, and unmistakeable former lake floors like those at Oloolkesailie, Gicheru, and Kariandusi. These former lakes, and the presence of raised shorelines around Lakes Naivasha and Nakuru (Nilsson, 1929, 1935, and Washbourn-Kamau, 1970) have been taken to indicate climatic change, and the existence of unconformities

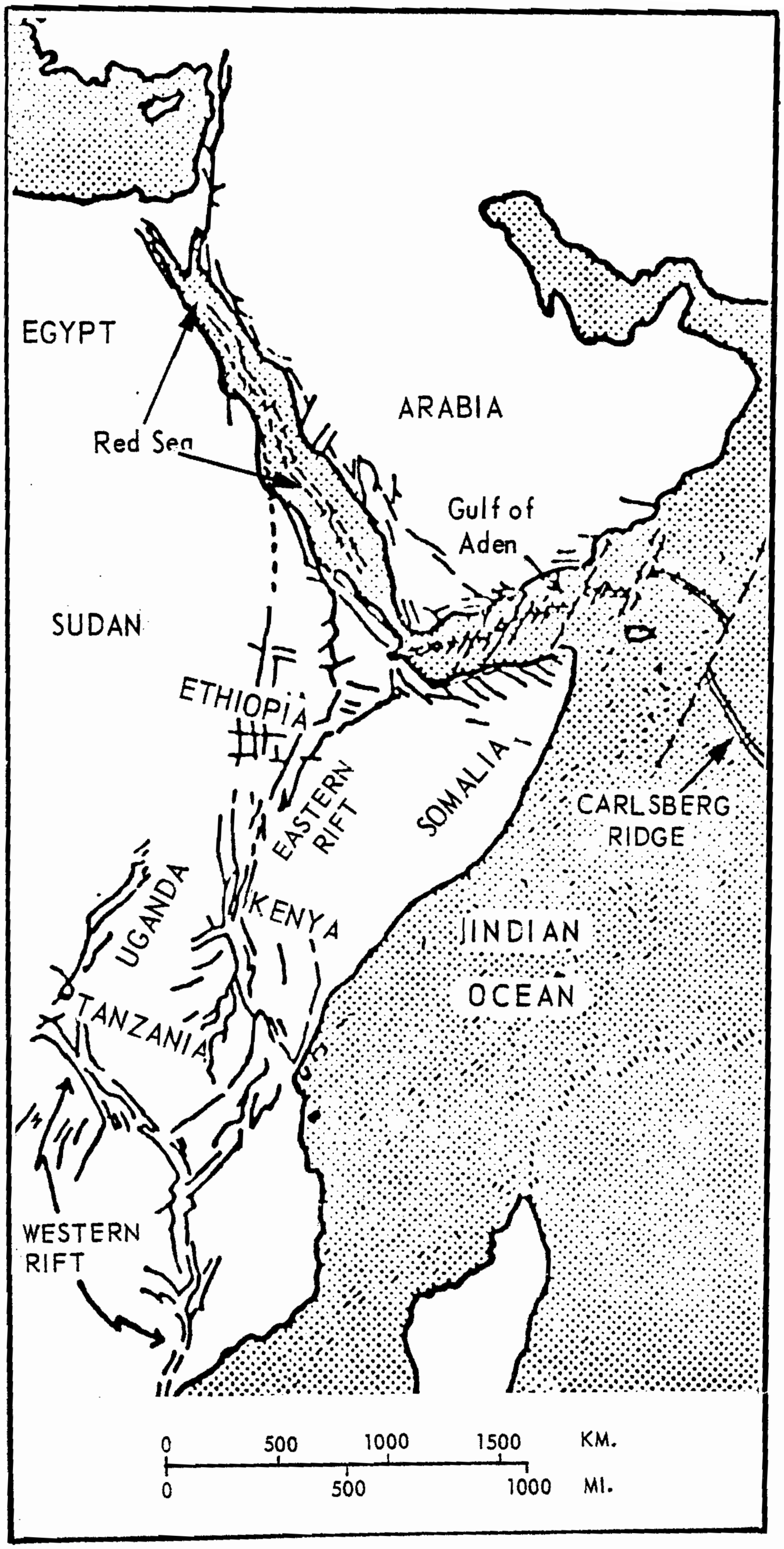


Fig. 1-6 Structural pattern of the Afro-Arabian rift system. (From Baker and Wohlenberg, 1971, p. 538)

in the various sediments has led some scholars to postulate frequent change (Nilsson 1935 and 1940; Cooke 1957; and Flint 1959a and 1959b).

There have been recurrent attempts to identify a single large Quaternary lake within this sector of the Rift. Gregory proposed such a lake south of Orgaria-Longonot (1896 p. 94), and so did Parkinson (1914), while Willis (1930 p. 279), Solomon (in: Leakey 1931, p. 246), and Cole (1954) have all suggested an equivalent lake extending northward from Kariandusi to Lake Baringo in the northern sector. These hypotheses of large lakes are based upon recognition of small areas of lake deposits scattered over a topography which could now hold water over larger areas. The failure to find a continuous distribution of sediments, or continuous shorelines has resulted in most researchers concluding that there were only relatively small individual lakes responding to the local physiography and conditions, although they recognize that tectonic displacements have taken place in some examples.

The grabens offer a variety of sedimentary fills, including former lake floors (such as those at Oloolkesailie and Gicheru), ephemeral lake sites (such as those at Kwenia and Cabongo), and plains of windblown sediments and ash. The Magadi soda lake lies in a complex of grabens and horsts, but it is also the lowest sector of the area, and is composed of soda deposits of various kinds and a number of salt lagoons of fluctuating volume. The only obvious exceptions to the fault forms in the landscape are provided by the volcanoes and the Kedong Valley.

The central vent volcanoes of Susua (Recent), and Oloolkesailie, Shanamu, Shombole, Ol Doinyo Nyegi, Lenderut, and Esakut (which are all held to be Pliocene in age), are of classic forms although they are all in stages of erosion appropriate to their age and composition. The Kedong

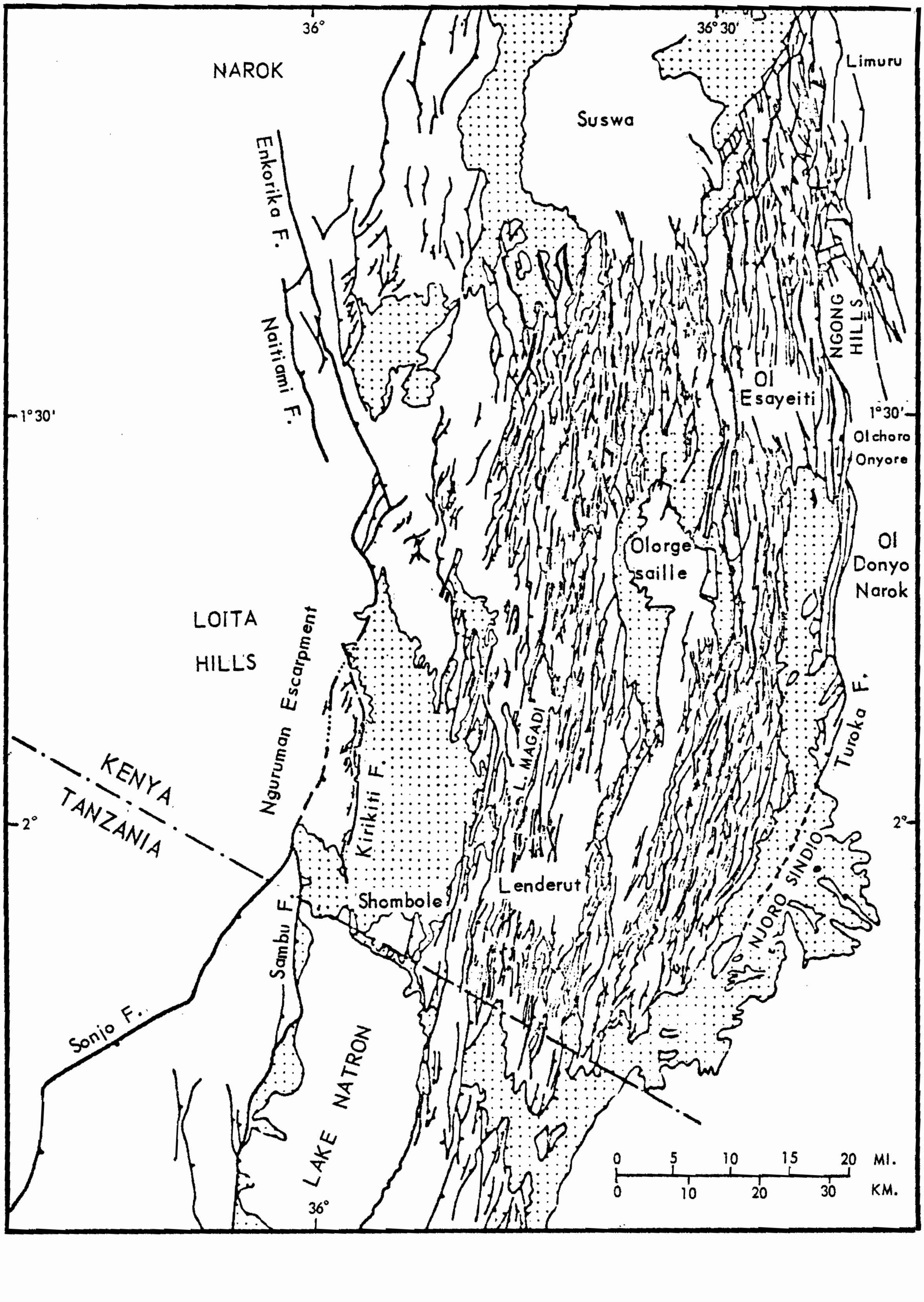


Fig. 1-7 Fault swarms on the floor of the South Kenya (Gregory) rift valley. Commonly known as Sike's grid, or grid-faulting. (From Baker, 1970)

Valley is a misleading name for the ash-covered area blocked off between Susua to the south and the Orgaria-Longonot ridge on the north. A gradient depression aligned NW/SE can be measured, but it is so gentle that the visual impression is of a relatively featureless plain traversed in the east by the modest stream of the Ewaso Kedong in a superficial stream channel a few metres deep.

The Olorgesailie archaeological site is found in ancient lake beds which underlie the plains of Olekemonge and Oltepesi on the floor of a multiple horst and graben complex near the foot of the Pliocene volcano Oloolkesailie. The drainage area supplying those former lakes is described by Flint (1959b, p. 355), Howell and Clark (1963), and Isaac (1968), as relatively small, since the existing seasonal network of streams drains an area of approximately 650 kms^2. The network flow results in a reliable seasonal stream which crosses the Oltepesi and Olekemonge plains and enters the upper part of the Koora graben where the water sinks and the stream is lost. In explaining former lakes, however, there are other possible origins of water supply that must be considered. The Turoka river, which now drains into the Kabongo depression in the south could have fed the Olorgesailie Lakes if there was no southward tilt of the Rift floor. On the western edge of the Rift there is a perennial stream, the Ewaso Ngiro, which is joined in the Rift by several perennial streams off the Loita Hills, and if the former Olorgesailie Lakes had been Rift-wide at the present altitude of the lake-beds, the Ewaso Ngiro would have been a major source of water supply. One or all of those rivers could have maintained a lake during climatic periods of increased precipitation and decreased evaporation such as have been suggested.

An indicator of earlier hydrographic networks is provided by the Kedong Gorge. It is a dry gorge which opens on to the Oltepesi plain at 1130 m± (Folio map 5). It is more than 21 kms long with a maximum depth of 200 m, and the floor is entirely cut in volcanic lavas. A large stream made the gorge at some time past, and such a stream could have maintained the Olorgesailie Lakes. This could be described as the conventional view, but it has never been demonstrated, or even seriously discussed except by Sikes (1926) who writes of a 'Kedong River' *per se*.

The Kedong gorge opens out of the Kedong Valley, a sector of the Rift isolated between two cross-Rift barriers caused by the Susua volcano and the Orgaria-Longonot volcanic ridge (Fig.1-1). The sector is sub-arid (<400 mm precipitation) but it receives spring water and seasonal streams from the eastern flank of the Rift Valley. These contribute to forming the Ewaso Kedong, a small seasonally variable stream which at its highest level of flow reaches no more than 5 kms into the Kedong gorge. It is an ineffective and superficial stream which merely re-sorts surface debris.

There is, however, another apparent former source of water supply to the Kedong Valley, one coming from the spectacular Njorowa gorge which breaches the Orgaria-Longonot ridge. Although it is now dry the gorge is generally supposed to have been an overflow for high levels of the constantly fresh lake Naivasha (Nilsson, 1929, 1931, 1935, and 1940).

The Njorowa gorge provides a possible drainage way to a large potential water supply for the Olorgesailie Lakes, because Naivasha receives large perennial stream flows from the Kinangop platform and the western foothills of the Aberdare Mountains. The study of that area is beyond the scope of this thesis but it is necessary to say that there are severe problems in demonstrating the overflow hypothesis, or a past connection between the Njorowa and Kedong gorges, while there has been no success in dating the Njorowa gorge or the rock in which it is cut.

The distribution and apparent relationships of these various features are clearly shown in Folio Figure 2, a Landsat colour composite photograph of the study area at a scale of 1:500,000.

Given this general setting, a solution to the Olorgesailie Lakes problem requires the preparation of a denudation chronology for the southern Kenya Rift Valley, with particular emphasis upon drainage patterns, and a search for climatic indicators of any type. Because rifting may have disrupted pre-existing drainage and initiated the Pleistocene lakes the chronology extends back to the pre-Rift situation, as far as it can be reconstructed.

IV. FIELD WORK

The field work was carried out during 1971 and 1972. Using the resources of the National Air Photo Library of Kenya, a photo-interpretation of the geology and physiography was completed at a scale of 1:50,000. It was then plotted on final drafts of the new metric contoured maps then being prepared in Canada and Britain.

The metric maps have since been published, and reduced to 1:100,000; they provide the bases for Folio maps one to twelve. Kenyan Government triangulation stations appear on the maps, but the density of supplementary vertical control points was increased by helicopter-borne barometric traverses in the original compilations, and the accuracy is claimed to meet U.S. and Canadian governmental standards, i.e. 90% of all points on a contour lie within a height of half the contour interval.

It should be noted that the maps are grossly optimistic about the drainage net, showing large numbers of stream channels within the rift as perennial streams, whereas there are only six streams which flow throughout the year. The overwhelming majority of the 'streams' shown can hardly even be considered as seasonal, and most are essentially ephemeral, channels carrying stream-floods only during actual periods of heavy precipitation. The geomorphological mapping in this thesis attempts to correct this potentially misleading feature of the published mapping. Less importantly, the symbols for 'Other tracks and footpaths' can be serously misleading. They may represent major routeways motored with ease between the settled areas, whereas those indicated on the floor of the Rift are rarely anything more than Maasai footpaths to be taken in single file, often in terrain impassable for vehicles of any kind.

The geomorphological overlays on the Folio maps identify water erosional forms such as former stream channels, including those diverted by faulting, as well as wind and water gaps. Among the constructional features shown are former lake floors, diatomites and diatomaceous deposits, ancient deltas, alluvial fans and delta cones. New and problematic or controversial geological boundaries have been recorded, and other information from geological memoirs was corrected and precisely plotted wherever necessary for the purposes of this study. Distinctive terrains such as those formed on archaean rocks or orthophyric trachytes, have been outlined and identified. All the fault escarpments have been plotted and the downthrow indicated, but the symbols are only generally located at the escarpments and do not pretend to locate the actual fault. The heights of the escarpments can be obtained from the contours on the base map.

The interpretation maps were the basis for the field work but were also modified by it. They allowed an overview of structure and landscape, which revealed a number of anomalies. The location and the extent of geological outcrops varies considerably from the published information, and there are a number of flows from Susua not previously recognized. The photo interpretation revealed many geomorphological features not previously reported, such as the former drainage channels south of Susua, some truncated or dislocated by faulting. It also showed a series of channels cut in rock on the slopes flanking the southernmost Koora graben; previously unreported terraces, delta forms, wind gaps, water gaps, and former channels were found scattered across the area as a whole.

The features plotted on the interpretation map were for the most part verified in the field, the exceptions being the many fault escarpments (it being neither practical nor necessary to view them all), and a small number of the conjectural lake floors. In a few cases the field observations corrected the original interpretation, as for example at the Kedong Gorge, where features originally plotted as alluvial terraces and a delta were found to be made of lava.

The greatest difficulty in the field work arose with the plains that occupy the grabens. The materials that underlie the plains are often mixed, and in almost every case they are masked by a thick cover of wind-compacted dust. Traditionally in Kenya the geologists have had great difficulty in classifying the materials in the floors, and there is no common terminology, in spite of a review paper on late Tertiary and Quaternary sediments of the Kenya Rift Valley published by McCall, Baker, and Walsh in 1967. Saggerson (1971), for example, has divisions of the Quaternary which places in one group 'alluvium, clays, and swamp soils'; in another, 'sediments, loess, lacustrine deposits, and diatomite', while 'ashes, pyroclasts and sediments of the Kedong Valley' and 'terrestrial deposits with artifacts' make up his last two groups. Baker, and Matheson (1958 and 1964) both group 'loessic soils and hill wash' under one heading, while McCall (1966) has one class 'sediments in lake basins and swamps', and another 'superficial deposits, volcanic soils'.

Volcanic ash is found everywhere, and only in the Koora, Gicheru, and Oltepesi areas are there pure diatomites which unequivocally indicate fresh-water lake conditions. At Mosiro the materials are strongly diatomaceous, but, elsewhere, examination under a microscope invariably showed fragmented diatoms distributed in varying quantities throughout every grab sample taken from the surface, and there is no certainty that such materials are not reworked and wind emplaced. Diatoms in higher concentrations induce a blocky structure in soils but again the microscope examination frequently showed fragmented diatom material and many of the thicker deposits may have been reworked and redeposited by water.

In the absence of deep cores it was difficult to be certain as to whether the plains within a graben or basin are dust-covered lake floors, colluvium, or loess. Ash occurs loose everywhere but is also found as airfall tuff or tuffaceous material, water stratified tuffs (with or without current bedding), and as a matrix or component in reworked and stratified mixed materials including loosely compacted loess. Failure to find stratified or blocky structures of diatomite, or water stratified materials, in gullies, ravines, and drifts was taken to imply uncertainty about a lake origin, however appropriate the landform. Stratified and otherwise distinctive materials are identified on the maps and discussed in the text.

Some local height differences were taken using a Paulin altimeter, but where a traverse could not be closed upon itself within an hour or less, the altitudes quoted and all profiles presented rely upon the topographic maps.

Magnetic polarities were determined in the field using a portable flux-gate magnetometer on loan from the Department of Physics of the University of Nairobi. The polarities of cleaned samples were derived in the laboratory by Dr. Andrew Brock, then of the University of Nairobi, now at the University of Lesotho. (Appendix I)

Geological sections were recorded and appropriate samples were collected at every study site. The samples have been identified in hand samples by Dr. Brian Baker of the University of Oregon, or by Dr. L.A.J. Williams, then at the University of Nairobi and now at the University of Lancaster. Most were identified later from thin sections either by Dr. Rob Crossley of the University of Malawi, or Dr. John Walsh, then Director of the Geological Survey of Kenya (Appendix II). The sample sites are indicated on the Folio maps.

Originally some samples were to be dated by the potassium-argon method, but concurrent work by Crossley and Knight leading to doctoral theses at Lancaster and London in 1976 has made such dating unnecessary, and correspondence and manuscript from Crossley and Knight have supplemented the published literature.

An attempt to map the depth of lake deposits using a Huntec FS3 hammer seismograph was abandoned because the underlying horsts and grabens in the area surveyed (Oloolkesailie) had a relief and spacing that confused recordings for depths greater than 10 m±. The technique would be useful in some of the larger graben floors if equipment could be carried in.

Chapter Two

PREVIOUS WORK

Although there is now a considerable body of literature dealing with the geophysics, tectonics, stratigraphy, petrology, and geochemistry of the Kenya Rift Valley there is relatively little directly related to landscape and drainage evolution within the study area. There are some archaeological publications which include stratigraphies, and some offer speculations about landscape evolution. Some work in other sectors of the Rift Valley and some publications relating to East African landscapes in general have been useful, but the outline given here confines itself to directly relevant material.

Recognition of the features comprising the Great Rift Valley system of Africa began with the discovery of Lake Tanganyika by Burton and Speke in 1857, followed by Livingstone's mapping of Lake Malawi (then Lake Nyasa) in 1859, but the recognition of the nature of the whole did not emerge until immediately after the first scientific examination of the study area. G.A. Fischer descended into the Kenya (or Gregory) Rift west of Mt. Meru early in 1883 and worked northward via Lake Natron and the Nguruman Escarpment to Njorowa Gorge, reaching Lake Naivasha in June. His work was published in 1884, when it appeared at the same time as a paper on his geological samples by Mugge. Meanwhile Joseph Thomson, who had traversed the sector further north a few months after Fischer in 1883, had published a general account (Thomson 1884). In a discussion at the Royal Geographical Society, Francis Galton pointed out that Thomson's 'discoveries', Lakes Naivasha and Baringo, lay in a trough 'which begins with the

Dead Sea, extends down the Red Sea and ends at Tanganyika' (Thomson, 1884, Discussion, p. 711).

It is a curious fact that two key papers in the early work on the Rift Valley were prepared by men who never saw it. The travels of Thomson (1883), Teleki (1887), and Hohnel (1887), which delineated the physiographic characteristics of the Rift Valley in Kenya had all been guided by a map of Masailand prepared by Clemens Deinhardt of Lamu in 1881, from information he had gathered at the coast. The precise descriptions of the travellers in turn inspired a monograph by Suess, "Die Brucke das Ost-Afrika" (1892), in which the tectonic nature of the system and a theory of the mechanism involved were clearly enunciated. The speculations of Suess led J.W. Gregory to visit Africa in 1893, at which time he traversed the northeast corner of the study area at the Kedong Scarp. In his book of 1896 he described all the essential features of the structure, and outlined a stratigraphy of the volcanics which was correct in relative sequence and only marred by an error in absolute age because he regarded the Pleistocene sediments as being of Oligocene or Miocene age, and thus had displaced the entire sequence accordingly. His book presented this information along with the hypothesis of the existence of a great former lake (Lake Suess) in the Rift west of Nairobi, his recognition of the Kenya dome, and the keystone concept of rifting.

Lake Magadi was surveyed by Burnham in 1904, and in 1908 Coates made an economic survey of the Magadi soda deposits for the Colonial Office. The results were used in manuscript form and not published until 1923, long after the building of a 91 mile railroad to Konza on the main line between 1911 and 1914, and the beginning of active production of soda ash in 1916.

The Pleistocene stratigraphy and geomorphology acquired a special significance along with the start of intensive archaelogical and anthropological work which led to a realization of the importance of Rift Valley sites in understanding human evolution. The first mammalian fossil from East Africa (an equid jawbone) was found in the sediments of the Morendat River during 1908 (Ridgeway 1909).

Collie in 1912 published a first geomorphology of the northern sector. Parkinson prepared a geology and physiography of the Magadi area in 1913, which remained the principle reference for geologists in the southern sector until Baker's memoirs of 1958 and 1963. Parkinson described the fault structure and lake sediments, and noted the scattered distribution of lake deposits in troughs east and west of Lake Magadi, but followed Gregory in assuming their common origin in a single large lake disrupted by subsequent faulting. He also discussed a section (no longer available) which was provided by a 100 foot shaft in what he recognized as lake beds in the Koora Graben.

The first prehistoric human artifacts from East Africa were found at the Oloolkesailie site by Gregory and Hobley in 1919. They found Acheulian hand-axes, but did not realise they had been contained in the lake-beds and assumed they were modern tools brought to the site in order to mine the white diatomaceous earth as a pigment (Gregory 1921). On the same visit Gregory made a traverse from the Kedong Valley to Mbgathi and then to Kajiado.

A second geomorphology which closely parallels the purpose, but not the conclusions, of this thesis, was published by H.L. Sikes in 1926. In it he examines the structure of the east flank of the Rift at the Kedong Escarpment and above the Kedong Gorge, and develops Gregory's hypothesis of a former drainage system linking Hell Gate (the Njorowa Gorge) and the Kedong Gorge. He also claimed to recognize erosional characteristics within the grid-faulted landscape. Although the present work, with the advantage of recent contour mapping, modifies all but the most general concepts, Sike's paper of 1926 is one of the few publications fundamentally relevant to this study. His observations are discussed in detail in later chapters.

The period 1927 to 1940 saw the stimulating work of Erik Nilsson in the lake basins to the north. That work led to the concept of multiple climatic changes, as supposedly evidenced by the raised beaches around Lakes Naivasha and Nakuru. In this period also appeared the parallel efforts of L.S.B. Leakey. Leakey revealed the wealth of Pleistocene materials, including human remains and artifacts, that were available within the Rift sediments of the same area. Although Nilsson's conclusions are now severely modified or even rejected, and although Leakey's climatic sequences (frequently modified by himself and others) are controversial, the work of these two men led directly to the present concepts of the Rift deposits, and it revealed the importance of decoding these deposits for the purpose of tracing and dating human physical and cultural evolution.

J.A. Stevens published observations on saline springs in the study area (1932), and Bailey Willis extended work on the geophysical aspects of rifting (1936). J.J. Shand published two papers (1936 and 1937) on structure and morphology which touch upon the northern sector, and Henry Gould Busk published a block diagram of the 'Great Rift Valley from Nakuru to Lake Magadi' (1939) which remained extremely valuable until the appearance of the first contoured topographic mapping for the area south of Longonot, in draft by 1972, and published between 1973 and 1975.

The Oloolkesailie artifacts and their true significance were first investigated by Mary and Louis Leakey in 1941, and serious work continued throughout World War II and after (Leakey, L.S.B., 1952; and Isaac 1968). During that time the stratigraphy of the lake beds was thoroughly mapped, first by R.M. Shackleton in 1942-43 (Shackleton 1944, and in: Baker 1958), then later in minute stratigraphic detail and with detailed facies descriptions by Isaac (1968). Isaac's work established the problem of dating the artifacts from the enclosing materials, but he clearly identified the lake facies characteristics, the deepening of the lakes toward the southwest and the numerous disconformities as land surface.

There is a description by Spink and Stevens (1946) of a traverse of the Nguruman escarpment, which revealed the fundamental structure of the western flank of the Rift and also demonstrated the westernmost fault of the Rift, masked beneath a basalt flow. Sonia Cole concludes a general geology in her "Geology of Kenya" (1950) with some notes on the sediments. B.N. Temperley (1951 and 1955) was the first to draw attention to the physiographic distinctiveness of the orthophyre trachytes in the area, and he first described the 'hot cross bun' topography. He theorized upon its origins, and also offered some intriguing speculations upon the cause of grid faulting. In 1960 Pulfrey published a map of the sub-Miocene bevel (surface), a distinctive feature of the study area.

Almost all of the known geology and structure are subsumed in a series of reports from the Geological Survey of Kenya published between 1957 and 1971. Joubert (1957, from fieldwork in 1952), Baker (1958, from fieldwork in 1952), Thompson and Dodson (1963, from fieldwork in 1955-56), Matheson (1966, from fieldwork in 1957 and 1958), Randel (1970, from fieldwork in 1964), and Saggerson (1971, from work between 1961 and 1967). These reports and their maps have a common stratigraphy with minor disagreements or errors in the location of some outcrops, and together they provide a picture of the essential structure and the surface outcrops. Each one includes a physiography and analyses which contribute to an understanding of the evolution of the topography and drainage. There are important summary papers by Baker, Williams, Miller, and Fitch in 1971, and Fairhead, Mitchell, and Williams in 1972.

A paper by Battistini (1971) on the evolution of the Kenya Rift Valley relies wholly upon previous accounts for the structure and sequence, but there is an original contribution on lava-filled former river channels in Kenya by Bhatt, Akizuki, and Hove (1975), with an example postulated at Joroi.

In 1976 Crossley and Knight both completed doctoral theses which dealt with the geology of the western wall of the Rift, south of Naivasha, and their information has been used from manuscript and personal correspondence. A paper by Baker which parallels some details of this work in dealing with the detailed geology of the Kedong Gorge appeared in September 1976, and is discussed in Chapter Eight.

Dating of some Rift volcanics has been provided by Evernden and Curtis (1965), Baker, Williams, Miller, and Fitch (1971), Fairhead, Mitchell, and Williams (1972), Baker and Mitchell (1976), Crossley (1977, personal communication), and Knight (1977, personal communication). There are overlaps, contradictions, and ambiguities in the dating which are described in Chapter Three.

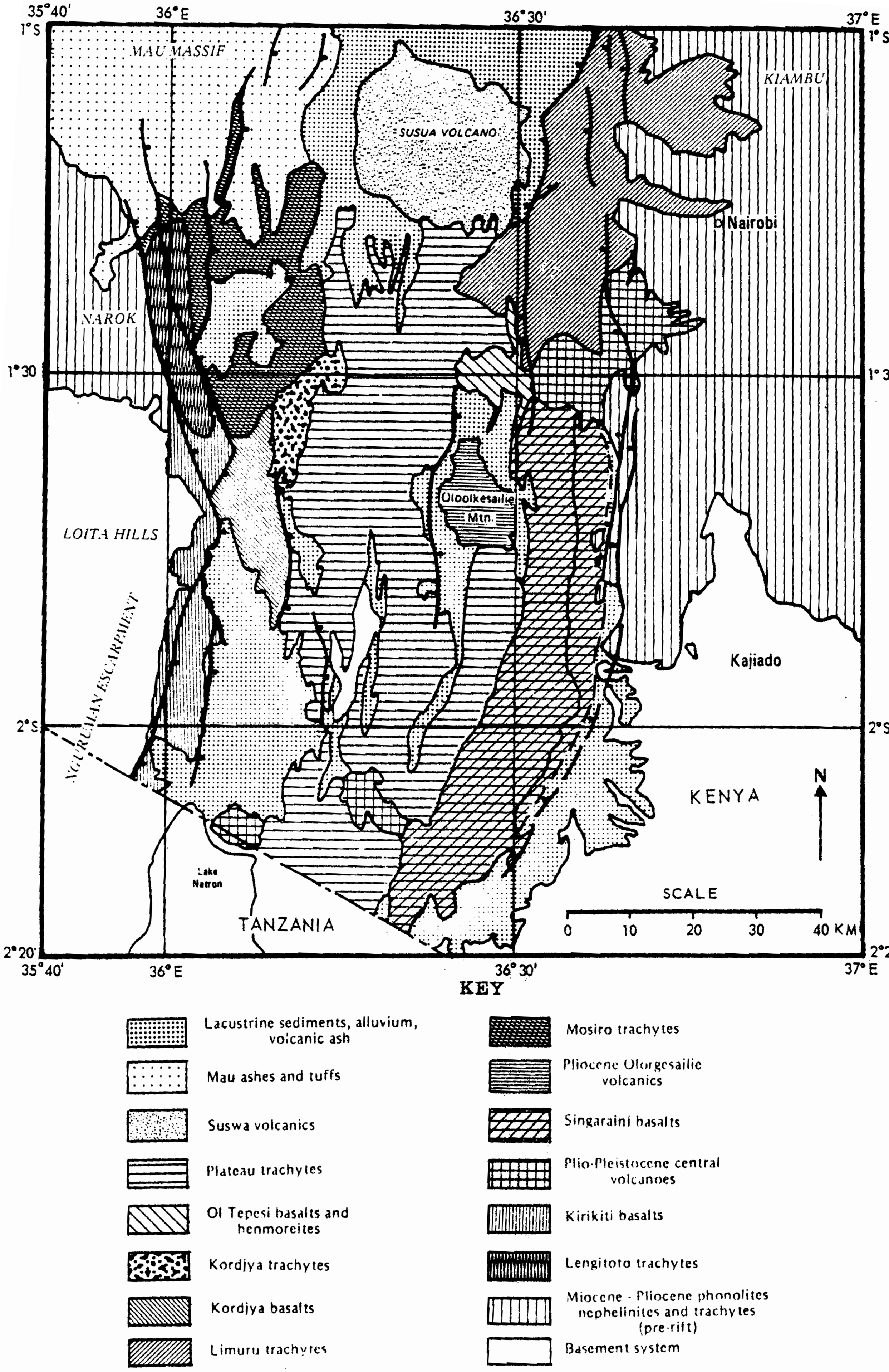


Fig. 3-1 Geological map of the area as revised by this study.

Chapter Three

GEOLOGY OF THE SOUTHERN KENYA RIFT VALLEY

I. GENERAL

The Precambrian rocks of the sub-Miocene surface in the area have been almost completely buried by flood lavas and central vent volcanoes of Miocene and Pliocene age (Baker, et al., 1971). Vulcanism and tectonic activity in Pleistocene time have modified the end-Tertiary landscape extensively, but the Pleistocene volcanic rocks did not extend beyond the Cainozoic flows in the southern Kenya Rift Valley (Williams: in press).

Some of the volcanic materials provide excellent opportunities for dating, using the Potassium-Argon isotopic age determination technique, and the dated stratigraphies are helpful in dating geomorphological events. The flood lavas also provide a useful analytical tool wherever they have flowed freely over extensive areas, since they may then be interpreted, with caution, in much the same way as sedimentary strata; and their altitude, attitude, distribution, and relationships may have great significance in explaining the evolution of the local landscapes. Tectonic activity has had a dominant rôle in forming the details of the present topography, and would have affected any drainage systems in the area.

In general, the geologists have restricted themselves to stratigraphy, geochemistry, and dating. Aside from direct inferences as to the structural relationships at major faults, or in recognizing ramps and platforms of the Rift Valley structure, they have not used altitude and attitude to explain the physiographic evolution of the area. Figure 3-1

Table 3-1 Published stratigraphy of the southern Kenya Rift Valley 1976

	West Flank	Floor	East Flank
	Lakes Natron & Magadi (3) High Magadi (3)	Suswa Volcanics (5) Baragoi trachyte 0.4-0.36 Ma (Baker, pers. comm.)	
F7			
	700m lake beds (3) Mosiro basalt .6 Ma (4)/Lengorale trachyte (3)	Legemunge beds .42 Ma (1)	
F6			
	Oloronga beds .8 Ma (3) Mau ash .7-1.7 Ma (4) Magadi trachytes .7-1.4 Ma (3)	Plateau trachytes .63-1.25 Ma (1) Gesumeti trachytes .9-1.25 Ma (5)	
F5			
	Minor Kordjya basalts Kordjya trachyte (3) Kordjya basalt 1.7-2.2 Ma (5)	Ol Tepesi basalts 1.4-1.6 Ma (5) (includes benmoreite) Ol Keju Nero basalt 1.65-1.91 (5)	
F4			
	Mosiro trachyte 2.1 Ma (4) (3)	Limuru trachyte 1.9 Ma (3) (5) Shombole volcanics 1.96-2.00 Ma (5) Olorgesailie volcanics 2.2-2.7 Ma (2) Singaraini basalts 2.3 Ma (5)	Limuru trachytes
F3			
	Kirikiti basalts 2.7-3.0 Ma (3)	Lenderut volcanics 2.5-2.7 Ma (5)	Middle trachytes(5)
F2			
	Oletugathi ashes & Hawainite (4) Enamkorian ashes & Hawainite (4) Entopot ashes and tuffs Ngurumanite/'Endosapia trachyte' 3.2-5.1 Ma (3) Lengitoto trachytes 5.0-6.9 Ma (1) (3) (4)	Ol Esayiti volcanics 3.6-6.7 Ma (5)	Lower trachytes 3.0-5.0 Ma (5) Ngong volcanics Kerichwa tuffs 4.8-5.7 Ma (1)
F1			
	Narok phonolites 7.0-9.0 Ma (4) Lisudwa Kishalduga melanephelinites 12-15.2 Ma (3) Eastward tilt > 16 Ma (4) Basement 450 Ma	Base not exposed	Nairobi, Kandezi Mbgathi phonolites & trachytes 5.2-10.2 Ma (5) Kapiti phonolite 13.4 Ma (5) Basement 450 Ma

References are to summary publications and may not indicate original provenance (see Table 3.2)

1. Baker, Williams, Miller, and Fitch 1971. 2. Fairhead, Mitchell, and Williams, 1972. 3. Crossley, 1976. 4. Knight 1976. 5. Baker and Mitchell 1976. F = period of major faulting.

presents the distribution and stratigraphy as revised and used in this work.

II. THE CHRONOLOGY AND SEQUENCE OF THE RIFT VOLCANICS

The stratigraphy of the southern Kenya Rift Valley as known to 1976 is shown in Table 3-1, which has been assembled from Fairhead, Mitchell, and Williams (1972); Baker and Mitchell (1976); Crossley (1976); and Knight (1976). It is a result of numerous major revisions in the years since 1970, and there are still uncertainties and conflicts as to the distribution, sequence, and correlation of some members of the table. The uncertainties are identified in Table 3-2 which summarizes the stratigraphies and dates that have appeared since 1965. It shows a variety of conflicts in dating which lead to significant uncertainties about the sequence of events, while at the same time indicating possible correlations between some flow series which are at present described as separate units.

The Lengitoto trachytes now seem to be firmly dated at 5.0 - 6.9 Ma (Crossley 1976), making it a contemporary of the Kerichwa Tuffs, and the Ngong and Ol Esayiti volcanics, and it is the oldest material shown to postdate early Rift faulting in the Kenya Rift Valley.

The Kirikiti Basalts have had their ages reduced to the period 2.5 - 3.1 Ma, but the frequently postulated corellation with the Singaraini Basalts is not supported, since the latter have been assigned a range of dates that spans the period 0.82 to 2.31 Ma. Baker and Mitchell (1976) have identified two new basaltic series, the Kordjya on the western floor of the Rift, with ages between 1.66 and 2.17 Ma; and the Ol Tepesi in the east, with ages ranging from 1.42 to 1.81 Ma (but see Table 3-2). Baker also suggests that the Ndopa platform is covered by Ol Tepesi basalt, not Singaraini basalt (Fig. 1-5). Both the newly designated basalts en-

Table 3-2 Ages of the Rift Valley stratigraphy, including apparent contradictions, and problematic samples. In order of Table 3-1

Formation	Age(Ma)	(P)olarity	P=age	Sample	Reference	Remarks
Suswa volcanics	Lowest flows show reversed polarity lying over Alkali trachyte with normal magnetism. Could be .02-.03Ma (Laschamp event) but underlies phonolites dated to .1±.01Ma (Baker, pers. comm.)					
	0.70-.89	R	✓	Marsden	This text	Pre-Brunhes epoch-Post Jaramillo event.
Baragoi trachytes	0.4-.36	Baker personal communication 1978				
Legemunge beds	0.42	Youngest material contained in unsatisfactory series (see p. 1) Isaac's bed 10. Publication 1,7.				
Mosiro basalt	0.6±0.1	N	✓	Knight	6	
Lengorale trachyte	0.63±.09	N/A		Baker	2	
	0.64±.09					
Oloronga beds	0.78±.04	N/A		Eugster	3	
Alkali trachytes	0.72±.09	N/A		Baker	2	
	0.91±.09					
as:'P1V$_2$'	0.802	N/A		Baker	1(K661)	
Plateau trachyte	0.84±.03	R	✓	Brock	3	
	0.86±.03	N	(✓)	Brock	3	Correct P at max. error
	0.89±.03	N/A		Williams	3	
	0.93±.06			Baker	7	Top flow near Olorgesaili
	1.17±.04	R	✓	Baker	7	Bottom flow of above
	1.36±.04	N/A		Baker	2	
	1.42±.05					
as: Magadi trachyte	1.4 ±.1	R	✓	Crossley	5	
as: Gesumeti trachyte	(0.9-1.25)	R	Stratigraphic dating only(7)			Corrected to ∿1.95 (Baker pers. comm.)
Singaraini basalts	0.82±.08	N	X	Williams	3	
	0.92±.07					
	1.31±.06	N	X	Williams	3	
	1.44±.05					
	2.31±.01	N	(✓)	Baker	7	Polarity agrees with age only at maximum error
	2.33±.09	N	(✓)	Baker	7	

(continued)

Table 3-2 (cont'd.)

Formation	Age(Ma)	(P)olarity	P≠age	Sample	Reference	Remarks
Kirikiti basalts						
	1.00±.01	(N)+R	R✓	Shackleton	3	Intrusion? (5)
	1.27±.08	(N)+R	R✓	Williams	3	Intrusion? (5)
	1.31±.09					
	2.5 ±.2	N	✓	Crossley	5	
	2.5 ±.7	N	✓	Crossley	5	
	2.68±.16	N	✓	Baker	5	Lies below rock dated at 2.93 Ma
	2.7			Beloussov	4	
	2.7 ±.2			Baker	7	
	2.93±.2			Baker	7	Lies above rock dated 2.68
	3.1 ±.2			Baker	7,5	
	5.03±.2			Baker	2	Mistaken identity
	5.07±.1			MB39		Not Kirikiti (5)
	5.13±.1			Baker	2	Mistaken identity
				MB38		Not Kirikiti (5)
Ol Tepesi basalts						
'Upper'						
	1.42±.06	R	✓	Baker	7	
'Lower'						
	1.4-1.64	on stratigraphic grounds (7, p. 472)				
'Benmoreite'						
	1.65±.06	R	(✓)	Baker	7	P correct at lowest error
'Benmoreite'						
	1.81±.05	R	✓	Baker	7	Rejected by Baker (7, p.472)
as: P1V3						
	2.4	N/A		Baker	1(K652)	Benmoreite under old name of Upper Orthophyre trachyte. Rejected by Baker
Limuru trachyte						
	1.55±.09	N/A		Williams	2	Limuru type site north-east of Nairobi
	1.59±.09					
	1.72	N/A		Williams	1(KA654)	
as:P1V2						
	1.74	N/A		Baker	1(KA650)	Baker's Plateau trachyte
	1.84±.06	R	✓	Baker	7	Rim of Rift
	1.91±.06	R	✓	Baker	7	Rift Valley floor
	1.94±.06	R	✓	Baker	7	(Nkidongi)
	1.96±.04	R	(✓)	Baker	7	Esakut platform P correct at lowest error

Baker (pers. comm. 1978) 'of 8 Limuru ages 6 fall in the range 1.84-1.96 m.y. consistent with the magnetic polarity' (Matuyama R), but his table shows 'Lower Limuru ~1.9-2.1' 'Upper Limuru 1.7-1.8 m.y.' Neither fit the polarities. See Appendix I.

Ol Keju Nero basalts

1.64-1.79 N Baker dates by stratigraphy only. Lies above Limuru trachytes and below Ol Tepesi basalts.

(continued)

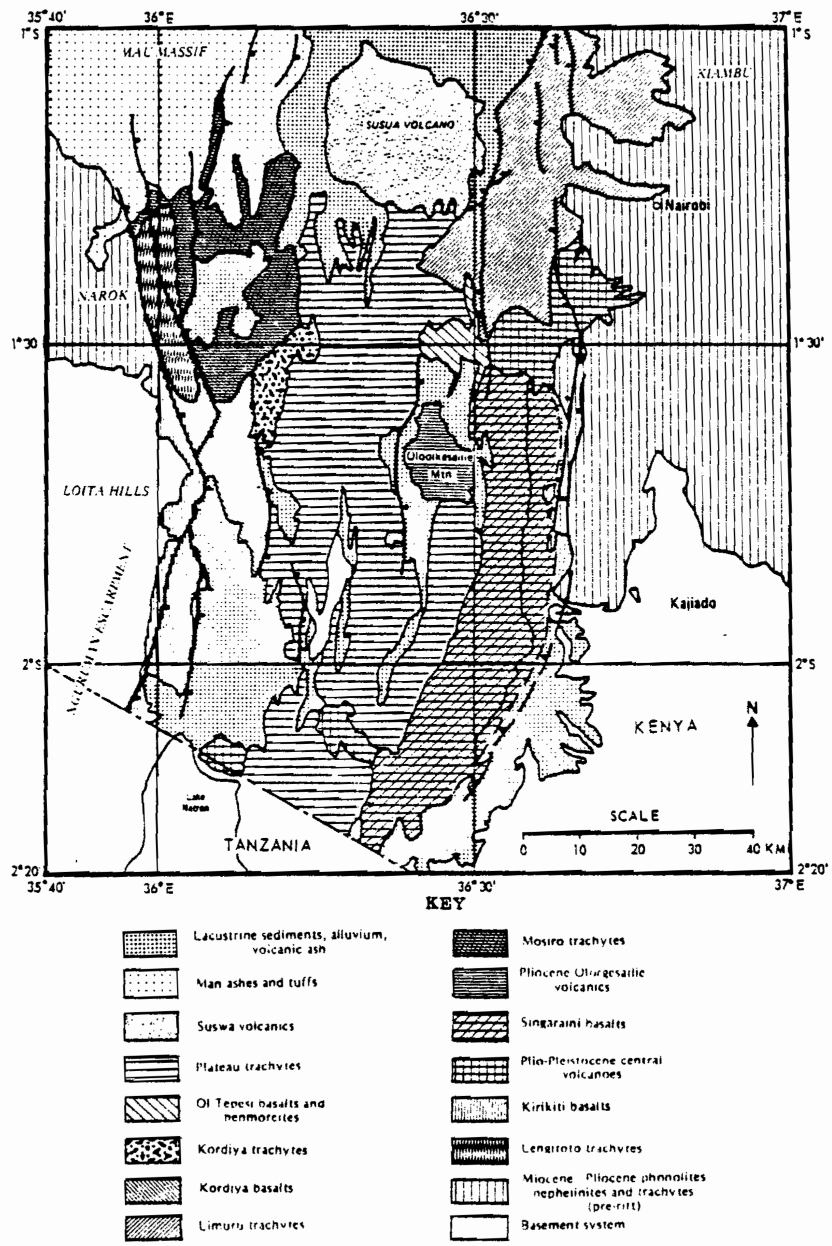
Table 3-2 (cont'd.)

Formation	Age	(P)olarity	P=age	Sample	Reference	Remarks
Kordjya basalts						
'Upper'						
	1.66±.05	N	✓	Baker	7	Top flow (7)
Kordjya trachyte						
	>1.66	R	✓	Crossley	5	Enclosed in Kordjya basalt so = Matuyama R 1.79-1.95.
'Lower'						
	1.76±.06	N	✓	Baker	7	
	2.17±.01	N	X	Baker	7	Not the lowest flow (7)
Mosiro trachytes						
	1.9 ±.1			Knight	6	
	2.1 ±.1			Crossley	5	
	2.3 ±.1			Knight	6	cf Limuru trachyte
(Gesumeti trachytes) relocated from Table 3-1						
	'4 dates 2.0 to 1.9 m.y.'			Baker (pers. comm. 1978)		
Shombole volcanics						
	1.96±.07	R	(✓)	Reilly	3	P correct only at limit of error
	2.00±.05	R	(✓)	Reilly	3	
Olorgesailie volcanics						
	2.21±.06	-		Reilly	3	
	2.40±.07	N	✓	Williams	3	
	2.60±.06	N	✓	Reilly	3	
	2.62±.08	N	✓	Williams	3	
	2.7	N/A		Shackleton	1(KA662)	
Nairobi trachyte						
	3.17±.06	N/A		Williams	2	
	3.45±.16					
Endosapia trachyte (A changed Lengitoto? (5))						
	3.2			Beloussov	4	
	5.1			Baker	(2),4	as: Kirikiti basalt
Kerichwa Valley tuffs						
	4.8-5.7 Ma				(2)	
Lengitoto trachyte						
	5.0			Williams		
	5.5			Williams	5	(personal communication Williams to Crossley)
	5.5			Williams		
	5.8			Knight	6	
	6.9±.02			Crossley	5	
Ngurumanite and melanephelinite						
	5.0			Baker	2	
	5.8			Beloussov	4	
Kishalduga melanephelinites						
	12.2-15.2	'oldest dates reported from S Kenya Rift (5)				

References

1. Evernden and Curtis, 1965
2. Baker, Williams, Miller and Fitch, 1971
3. Fitch, Miller and Williams, 1972
4. Beloussov, et al, 1974
5. Crossley, 1976
6. Knight, 1976
7. Baker and Mitchell, 1976

Table 3-2 (concluded)



Distribution of rock-types described in Table 3-2.

close beds of coarse orthophyric trachytes of similar appearance, and both trachytes occur high in their sequences, inviting comparison in spite of the apparent age difference.

The distribution of the Limuru Trachyte is now shown to extend to the floor of the Rift, but the age determinations range from 1.55 to >1.96 Ma (Table 3-2), and there is a question as to whether they postdate, predate, or enclose the Ol Tepesi sequence. The Mosiro trachytes of the western Rift floor invite corellation with the Limuru trachytes on the grounds of age, and also for their chemistry (Crossley, Knight, - personal communications). In this study evidence will be presented which suggests that there are two significant variants of the Mosiro trachyte, one of which corellates with the Limuru trachyte, while the other predates it (see Chapter Five).

The former three divisions of the Plateau trachytes have been eliminated leaving an alkali trachyte with a variety of names: Plateau trachytes (Baker, 1976), Alkali trachytes (Randel, 1970), Magadi trachyte (Crossley, 1976), and the Lengorale trachyte (Fairhead _et al_., 1972). If the Lengorale trachyte is truly a member of the series then the ages range from 1.42 to 0.63 Ma. The literature tends to treat these alkali trachytes as one series, but there may be several. There may also be a relationship with some early flows of the Susua volcano. Johnson (1969) and Randel (1970) had difficulty distinguishing some trachyphonolites of early Susua from the alkali trachytes below them, and my samples gave a similar difficulty (p.116)and Crossley, personal communication (1977)). The Susua rocks are undated as of 1978 and are widely believed to be very young, but since all my samples from the lower flows show remnant magnetism with reversed polarity, an age greater than 0.7 Ma seems likely (see Chapter Seven).

Knight (1976) has identified a Mosiro Basalt in the west. It postdates all other lavas in the sector with an age of about 0.6 Ma, and it has been used by both Knight and Crossley (1976) to date the most recent movements on the western flank of the Kenya Rift Valley. Finally Baker (personal communication 1978) has dated a new discovery, the Baragoi trachyte in the Kedong area at 0.4 to 0.36 Ma.

Uncertainties in relation to the ages and sequences of the various basalts and trachytes all have direct significance for a geomorphology of the area and this work required a resolution of some of the problems. The resultant preferred stratigraphy is shown in Table 3-4, with references numbered to pages in this text.

III. STRUCTURE AND SEQUENCE IN RELATION TO LANDSCAPE EVOLUTION AND THE DRAINAGE

1) The 'Basement System' of the Mozambique Belt.

The structure underlying the Kenya Rift was described as a shield basement until 1965, when Sanders showed that the Archaean schists, quartzites, crystalline limestones, and gneisses were all metamorphosed sediments which had accumulated in a geosyncline east of the Nyanza Shield and then been folded and compressed against it (Sanders 1965). He called it the Mozambique Belt. Some materials date back 3,000 million years but the metamorphism is supposed to have occurred mainly in late Precambrian time and there was some movement as late as the Cambrian (410 Ma) (Sanders 1965).

The term 'basement', although technically incorrect when applied to the Mozambique Belt, has survived in the form 'Basement System', (e.g., Ojany and Ogendo, 1973) and there is a certain logic to the term, since it is more informative than 'Precambrian gneiss' or any other neutral

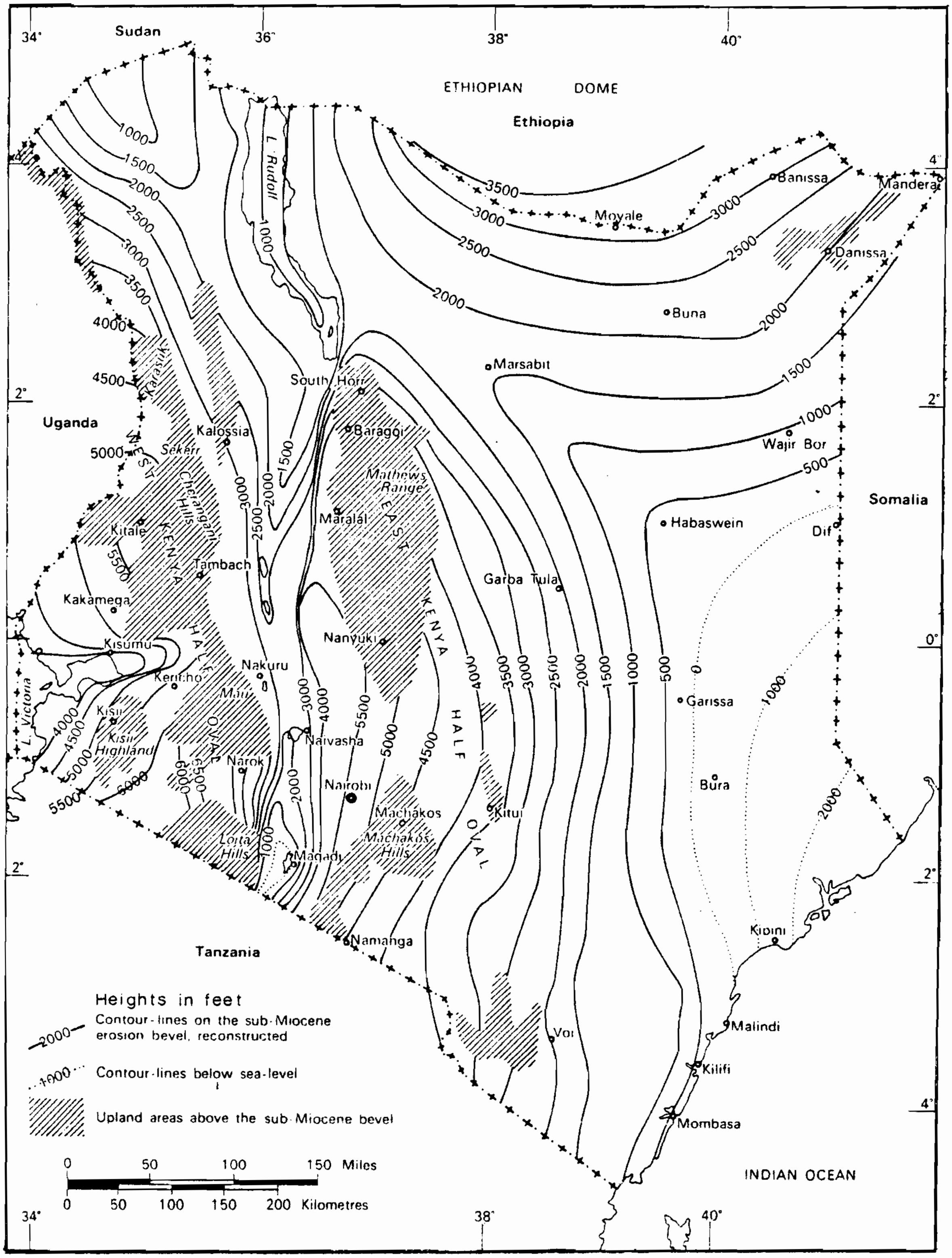


Fig. 3-2 The sub-Miocene bevel. (From Ojany and Ogendo, 1973, p. 29)

term, and the rocks provide the lowest and oldest datum for any study in the area.

In the study area, rocks of the Mozambique Belt have been submerged by volcanics except on the eastern rim southwest of the Turoka River (Figure 3-1), and in the Loita Hills beyond the Kirikiti basalt terrace in the west (Fig. 3-1). They have also been recognized in the walls of the deep gorges that traverse the terrace itself. (Spinks and Stevens, 1946, p. 248; Baker 1958, p. 9).

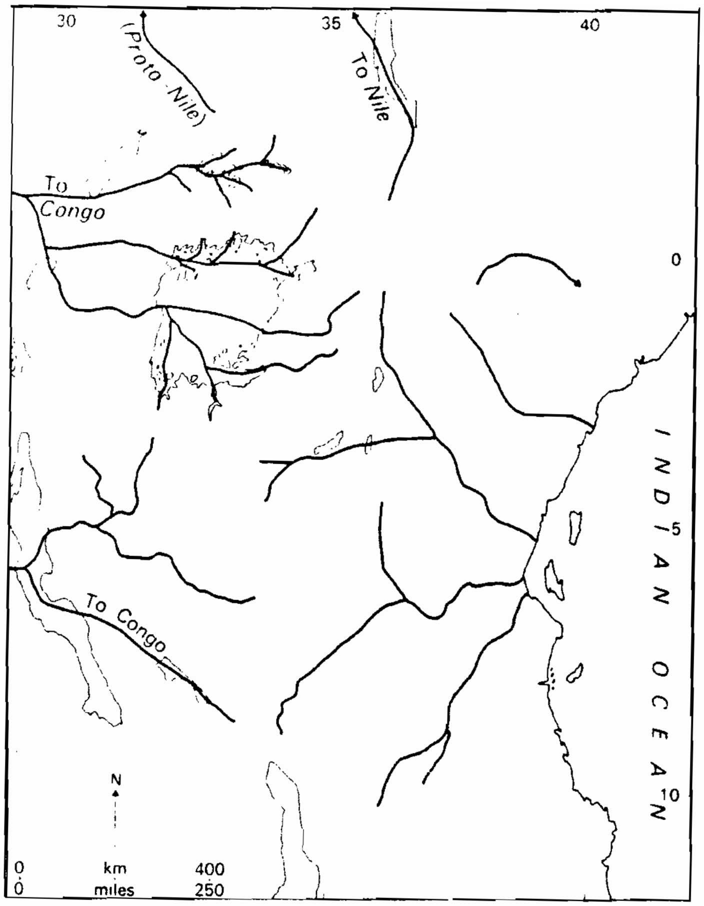
Pulfrey (1960, Fig. 3) describes the Loita Hills, and the Archaean massifs near Kajiado, Metu, and Namanga on the east, as remnant hills on the sub-Miocene bevel which is cut entirely into Basement System rocks in western Kenya (Fig. 3-2).

The sub-Miocene surface proper is shown extending to the edge of the Rift between Torosei and Oliosura at a height of about 5,000 feet (1520m) with a small sector downfaulted inside the Rift from the Turoka River to Torosei. It is covered conformably by Singaraini basalt at its western limit inside the Rift, and cannot be recognized anywhere else within the Rift.

Joubert claims that the mountain Ol Donyo Orok, 30 kms east of the Rift, near Namanga, shows remnants of four erosion surfaces (1957, pp. 3-5): an 'oldest' peneplain between 6800 and 7300' (2070 - 2225 m), the 'end-Cretaceous' at 6000 to 6500' (1825 - 1980 m), the 'sub-Miocene' at 5000 to 5500' (1520 - 1675 m), and the 'end-Tertiary' around the base of the mountain between 4000 and 4500' (1215 - 1370 m). Given those altitudes, his 'end-Tertiary' is the same as Pulfrey's sub-Miocene, and the other surfaces may be wrongly named. The two older surfaces are also recognized by Joubert at Kipapiyoi, 5 kms from the Rift edge, northwest of Metu, and at Lemelebbu, 11 kms from the Rift edge near Turoka. The end-Tertiary surface certainly lies entirely east of the Rift Valley site, and neither of the oldest surfaces has been recognized within the Rift.

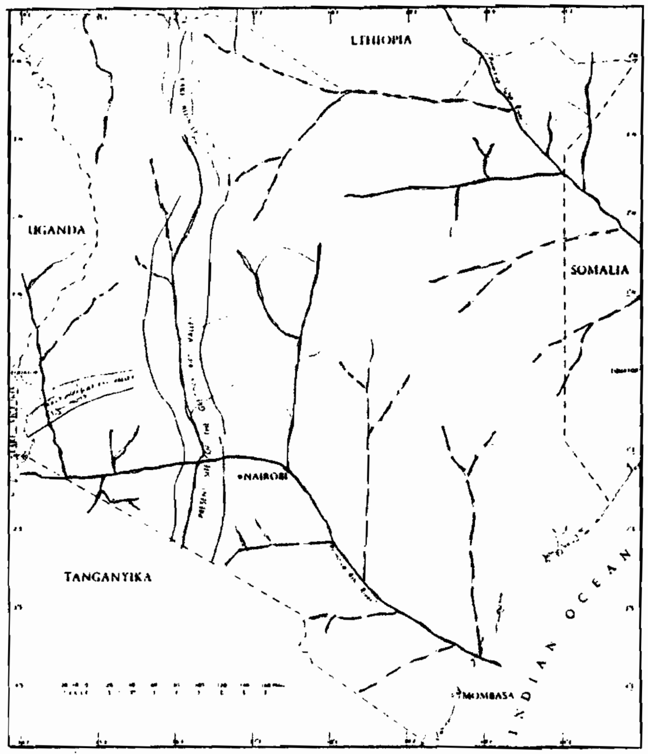
The sub-Miocene bevel on the Basement System clearly shows the 'rise to the Rift' identified by many authors. The evidence for a topographic low along the axis of the Rift in Tertiary time (Pulfrey, p. 13) is not as convincing because it depends upon projected and conjectural contours for the part of the surface now submerged within the Rift, and there are also fundamental disagreements about the original form of the sub-Miocene surface. Dixey (1945) saw the existing slopes and altitudes on the bevel as normal if there had been a watershed along the line of the Kenya Rift in early Tertiary time. B.C. King (1958, p. 106) recognized that the surface had been warped, but still favoured a watershed close to the Kenya Rift, whereas Pulfrey (1960, p. 15) considered the watershed to be lying much further west, near the present site of the Western Rift Valley, with a subsequent severe doming in the area of the Kenya Rift, and uplift of as much as 6000' (1800 m).

A knowledge of the surface in Miocene time is crucial to an understanding of the drainage pattern of Kenya in late Tertiary time, but in the present state of knowledge no firm conclusions are possible. The debate has been carried out at a somewhat abstract level, often based upon such arguments as widely varied assumptions of slope values on peneplained surfaces, or subjective perceptions of the form of the Kenya Dome. There are flatly contradictory hypotheses as to the controls for early Tertiary



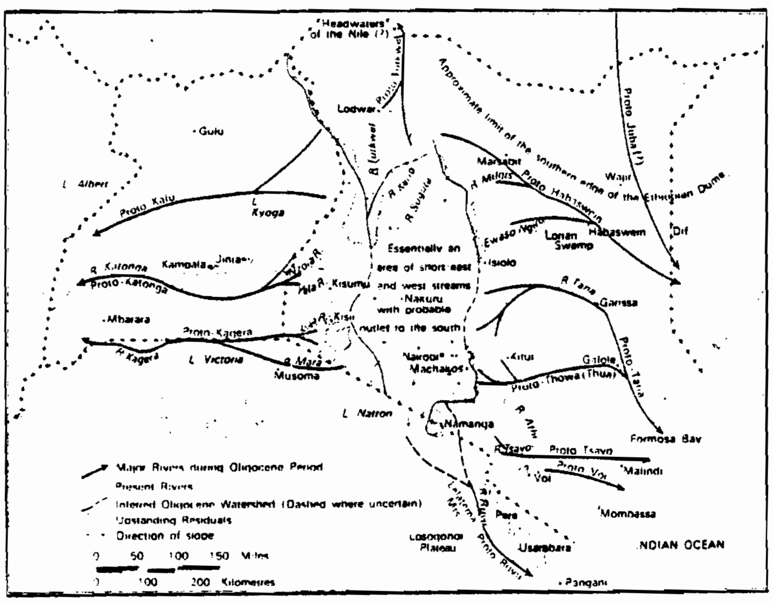
A tentative reconstruction of the drainage in the Miocene period (*after Cooke, Pulfrey and Teale*)

A From Morgan, 1973



Possible early Tertiary drainage pattern in Kenya.

B From Pulfrey, 1960



A suggested reconstruction of early tertiary drainage patterns in Kenya

C From Ojany and Ogendo, 1973

Fig. 3-3 Three versions of East African drainage in Tertiary time.

drainage; for example, Pulfrey envisaged a roughly north-south orientation guided by trend lines in the Mozambique Belt, and Ojany (1973) postulated an east-west orientation consequent upon the regional slope. The resultant reconstructed drainage nets differ drastically, but can be reduced to three fundamental versions: one in which the Atlantic-Indian ocean watershed lay near the present site of the Kenya Rift (King, Dixey, et al.), one in which the watershed lay near the present site of the Western Rift (Pulfrey), and one in which there is interior drainage to a downwarp lying over the site of the present Kenya Rift with an ultimate flow southward to a proto-Ruvu River, then east to the sea in Tanzania (Ojany) (Fig. 3-3).

In this study there are no assumptions about the precise age, form, or extent of the early Tertiary drainage net, but it does recognize the existence of topographic lows of the sub-Miocene surface lying between remnant hills on both edges of the Rift at about 1°20'S, for example the Narok gap provided by the Loita Plains between the Loita Hills and the Mau Massif, and the equivalent gap occupied by the Nairobi urban complex between the Kiambu Ridge of the Aberdares and the Ngong Hills. The floors of both the Nairobi and the Narok depressions have been covered by late Tertiary lavas and tuffs, while in the former case the gap is more apparent than real, the result of basaltic massifs formed on the sub-Miocene surface (The Aberdares and the Ngong Hills). The Kiambu ridge of the Aberdare's, for example, has been built up across the course of the proto-Athi as hypothesized in Pulfrey's reconstruction; and the Ngong Hills narrowed the pre-existing gap by building up northward of the Kajiado sub-Miocene erosion remnant. The present Nairobi gap is therefore much more restricted than the original, and the floors of both the Narok and Nairobi gaps are now at a higher level than originally because of subsequent lava flows

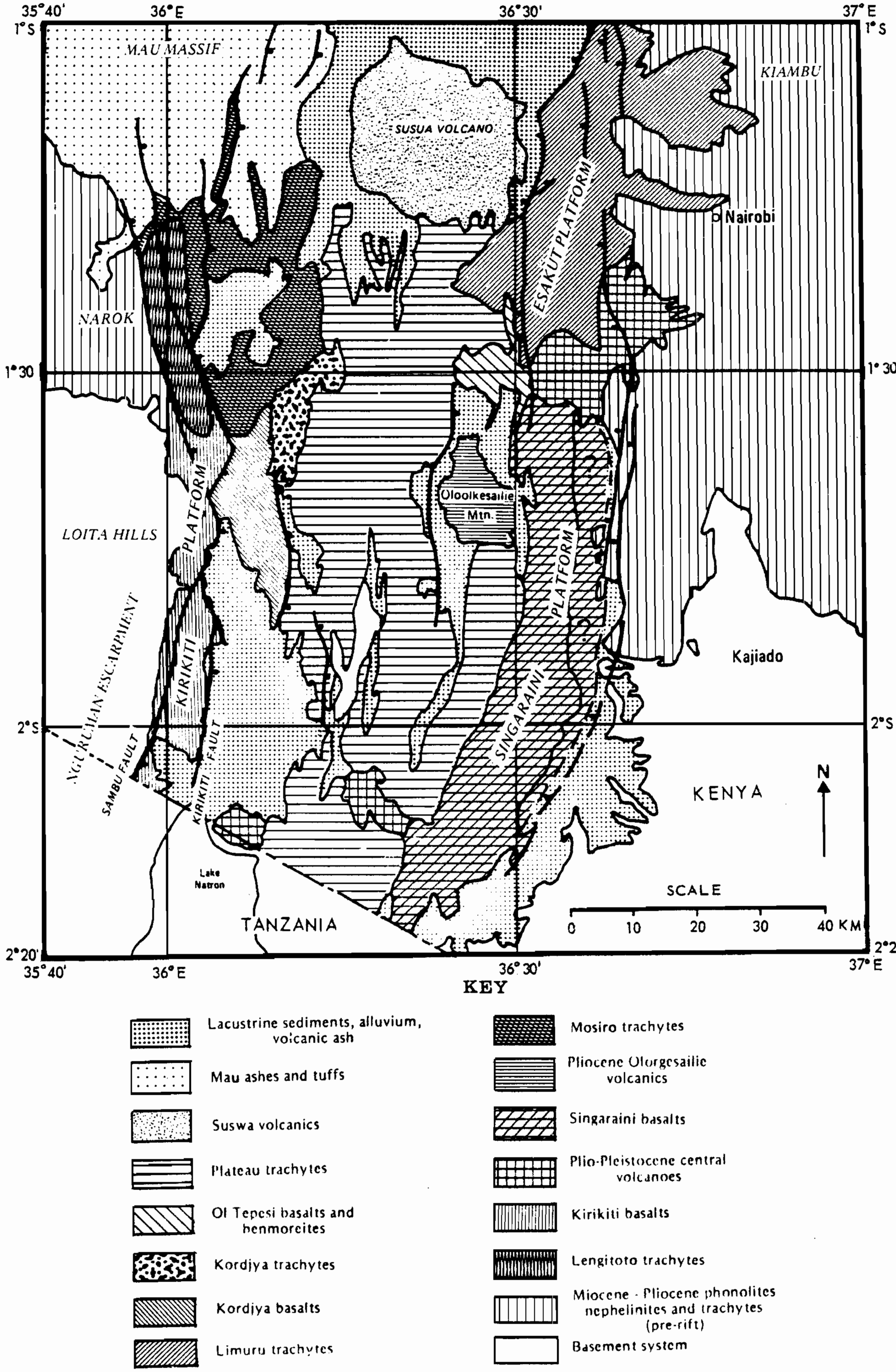


Fig. 3-4 The Kirikiti and Singaraini basalts.

within them. In subsequent pages it will be shown that the Nairobi gap had the form of a broad valley occupied by streams in late Pliocene time. Thus, although the present topography may owe its basic form to the sub-Miocene surface, this work does not depend upon the precise form of that surface, or upon any postulated early Tertiary drainage in demonstrating changes to the pre-Rift drainage and their consequences.

There are two other points of importance about the Basement System. Pulfrey has shown that there are no Tertiary volcanic rocks older than the Miocene in Kenya, and the late Tertiary volcanics all lie on the sub-Miocene surface. This limits the sequence known to be buried in the Rift Valley, and suggests that if the Rift Valley is younger than early Miocene, the volcanic stratigraphy may be used to date all the events in the evolution of the form.

Finally, the Basement System in the area provides a useful datum. In spite of the end-Tertiary doming the hills east and west of the Rift can be shown to have been essentially stable since late Pliocene time, and the basement surface provides a datum for measuring relative movement within the Rift; for example, in the discussion of the Kirikiti and Singaraini Basalts (see below).

2) <u>The Kirikiti and Singaraini basalts</u> (Fig. 3-4)

The Kirikiti and Singaraini basalts are olivine basalts forming large terraces which stand above the Rift floor on both flanks of the southern part of the southern Kenya Rift Valley. The terraces invite correlation as remnants of a single flow which once covered the floor of the Rift, but the fact has never been demonstrated. The geological map prepared by Baker in 1958 includes a section showing the Kirikiti Basalt of the western flank underlying the entire Rift floor west of Ololkesailie Mountain. However the Singaraini basalt of the eastern flank is shown separately from the Ol Keju Nero basalts of the rift floor in the stratigraphic table. His memoir only suggests that the Ol Keju Nero is 'probably' contemporary with the Singaraini and that while a correlation between the Singaraini and the Kirikiti is 'open to speculation' they are both overlain by the Plateau trachytes (Baker 1958, p. 16). He concluded that after the end of volcanic activity at Oloolkesailie 'basalts were erupted over a wide area in the Rift Valley and must have covered a large part of its floor. After the eruption of these basalts faulting took place along the Nguruman escarpment and along the Kwenia trough, and probably also to the east of the area, on a line west of the Turoka railway station'.

The hesitation in accepting the correlation of the Singaraini and Kirikiti basalts seemed justified when K/Ar dating of the Kirikiti basalt produced ages of 5.03 and 5.13 Ma (Baker, et al., 1971, p. 199), and although there was then no absolute date for the Singaraini basalt it was placed above the Kirikiti basalt in their stratigraphic table (p. 209). The Singaraini basalts were later dated at .87 and 1.37 Ma B.P. (Fairhead et al., 1972, p. 67), but even when new dates for the Kirikiti basalt gave 1.0 and 1.31 Ma, Fairhead, Mitchell, and Williams confined themselves to saying that 'these basalt ages for the Singaraini are in general agreement with the ages reported here for the Kirikiti basalts.' (1972, p. 68).

The Kirikiti structure was analysed carefully by Crossley in his doctoral work (1976) and he showed cause for doubting the validity of both younger and older dates and proposed ages between 2.5 and 3.1 Ma for the Kirikiti basalt proper (Crossley 1976).

In 1976 Baker regrouped the basalts of the eastern flank and floor in terms of K/Ar dates and magnetic polarities. He retained the Singaraini basalt for the southern part of the Singaraini platform and assigned ages of 2.31 and 2.33 Ma. He showed that rock from the northern part of the platform, at Loodo Ariak, consistently shows younger ages and a different polarity, and included them in a new series, the Ol Tepesi basalts which are also found on the rift floor north of Oloolke-sailie Mountain, with ages ranging from 1.42 to 1.65 Ma (Baker and Mitchell 1976, p. 471). The relatively small outcrop of Ol Keju Nero basalt, originally a separate series, was included in the Singaraini basalts by Fairhead, <u>et al</u>., but they are now again separated by Baker and given an age between 1.64 and 1.79 Ma on strictly stratigraphical grounds (Ibid, p. 471). There are still some difficulties with the interpretation (see Appendix II). All the available dates and polarities are indicated in Table 3-2 together with their sources.

The problems in relation to the Kirikiti and Singaraini basalt platforms must be resolved since they have great significance in any geomorphological study. Both platforms are large features, and both would be traversed by any streams entering the Rift after their emplacement. Both show geological contacts overlying Basement system rocks, and together they provide a maximum age for the terrain downfaulted between them. Although both have been described as step-fault platforms, this is not the case, since both show contact lines at limiting faults of the Rift Valley in this sector. The platforms will be discussed separately and then their essential features will be compared.

2a. The Singaraini platform (Fig. 3-4) has a maximum width of 15 kms and extends southward 80 kms from the flanks of Ol Esayit to Loonogojit, where it begins to lose the distinctive character of a platform. The surface rock is an olivine basalt which overlies the volcanics of Esayit at 1500 m in the north, and apparently flowed against the foot of the Ngong-Turoka fault escarpment to the east, after the fault had formed in Tertiary volcanics which range in age from 13.0 Ma (Kapiti phonolite, Fairhead, et al., 1972) to 3.61 Ma (Esayiti volcanics, ibid., p. 68). The age of the basalt thus provides a minimum age for the first Rift faulting on the east (Ibid, p. 68).

The Ngong-Turoka fault escarpment rises nearly 400 m above the platform in a series of tear faults at Ol Orian (Folio map 9), but there are only 300 m of Tertiary volcanics, so basement system rocks may be masked at the base. Basement system rocks can be recognized in situ at 1700 m in the Turoka gorge outside the Rift, just off the platform; also at an altitude of 1520 m inside a rift fault just south of the Turoka River where the basalt flows against it. The basalt also flowed against downfaulted outliers of the Kapiti phonolite and Kerichwa Tuffs. From Loonogojit the basalt surface declines gently southward to about 1280 m at the Kenya-Tanzania border where the character of the rift valley has been lost. In this sector the basalt may thinly overlie previously downfaulted and downwarped basement system rocks (Joubert 1957).

The platform is overlain in many places by unconsolidated Quaternary deposits and in some places they have masked the contact of the basalt and the bounding fault-scarp, but there is no doubt that the basalt lies conformably on the surface it covered, that it is very thin at its

Table 3-3 Altitude of basalts on Singaraini Platform

Locality	Highest exposed basalt		Break of slope
	(Massif of Ol Esayeti)		
a. Ol Orian (a horst)	1520 m	← same →	1520 m
b. Lodariak	1460 m		1500 m
c. Engonyo Ngiro	1440 m		1480 m
d. Kironito	1380 m		1460 m
e. Elangata Wuas N.	1440 m		1460 m
	(Turoka River)		
f. Elangata Wuas S.	1440 m		1460 m
g. Ndopa River	1460 m	← same →	1460 m
	change of slope between g and h?		
h. Loonogojit	1380 m		1440 m
i. Torosei	1375 m Maximum possible. Basement system rocks at same height.	← same →	1375 m
	(Platform loses character near Kenya-Tanzania border)		

Table 3-3 Table showing the altitude of the basalt contact at the rift edges of the Kirikiti and Singaraini basalt. The locations named extend over more than 65 kms.

eastern limit, and that it flowed against the fault scarp. There is no basalt on the fault face above the platform, so the platform has not been downfaulted since emplacement. Some minor scarps in basalt are downfaulted toward the Rift wall so more basalt must lie to the east. Basalt is found north, south, and west of erosion remnants on the floor, and a uniform plain of clastics known to overlie the basalt continues around the erosion remnants without any change in attitude or altitude. The remnants are of downfaulted Kapiti phonolite and Ol Doinyo Narok agglomerates, as at Kironito (Folio map 9), or basement system metamorphics as at Torosei (Folio map 12). There is a small granite steptoe in the basalt to the south at Lebor which lies at least 2 kms inside the basalt limit (Baker, map, 1963).

The altitude of the contact line is highly significant. Table 3-3 shows the altitudes along the eastern perimeter. The first column shows the altitude of the most easterly basalt recognized at the surface. The second shows the maximum altitude of the contact deduced by extrapolating the surface of the basalt eastward to the break of slope which can be recognized at varying distances from the foot of the Rift escarpment (see Folio maps and overlays 9, 12).

The flow edge at the back of the Singaraini platform is remarkably level, dropping a demonstrable 85 m in 65 kms (b-i, Column 1), but more probably 50 m± in 45 kms (b-g/h, Column 2) and then falling away more rapidly southward from a hinge-line near Loonogojit. These are gradients of 1:765 and 1:900, either of which would appear horizontal to the eye.

In earlier maps, Baker (1958), and Matheson (1966) show the platform scarp overlooking Plateau trachytes at Loodo Ariak. In later revisions Baker shows the same area as Ol Tepesi basalt above and below the scarp, with steptoes of Limuru trachyte west of the fault (1976, Fig. 3). There are serious problems with Baker's stratigraphy, explained in Appendix II, but although the volcanic structure and sequence in the Oloolkesailie area remain debatable, some facts are certain.

The basalt of the Singaraini platform lies against the base of the Esayiti volcano and post dates it. Basalt appears below the limiting scarp at 1100 m, so even if the basalts of platform and floor are the same, the base of Oloolkesailie volcano has dropped 200 m since the basalt was emplaced. The surface of the Ol Keju Nero basalt can be seen at 930 m± at the foot of Oloolkesailie volcano and there are no other basalts visible upon the flank of the mountain so the base has lowered a further 170 m for a total of 370 m. If the Ol Keju Nero basalt is a separate unit with a thickness of 85 m, older than the Ol Tepesi, and younger than the Singaraini basalt (Baker 1976, p. 470), one must add 85 m to the depression, since it would have been covered by the Ol Tepesi flows if it had existed at its present altitude when the Ol Tepesi was emplaced. The base of Oloolkesailie Mountain has therefore been lowered a minimum of 370 m, a maximum of 485 m, and a probable 455 m. At the time of emplacement of the platform basalt the base of Oloolkesailie stood much higher, level with the Esakut platform, and was linked at its base to the Esayiti volcano with a col at a minimum height of 1470 m or a maximum of 1585 m. Thus the volcano provided a barrier against north-south extension of flood lavas. Any basalts flowing at 1500 m or less would be excluded from the northern sector, or at most would have thin flows northwest into the Kedong sector. In subsequent pages it will be suggested that this barrier explains why Limuru trachytes (found at altitudes below the basalt cover, and Baker demonstrated that the Kirikiti basalt concealed a step-fault so that it overlaps basement system rocks outside to the west of the Rift Valley.

Crossley showed that there are 550 m of Kirikiti basalt underlain by 200 m of what is probably a changed Lengitoto trachyte (a probable source of the older ages for the 'Kirikiti basalt'), and that it lies against a fault scarp in the Lengitoto trachyte to the north (Crossley 1976). The surface of the platform is not formed entirely in Kirikiti basalt. Knight (1976) has shown that the basalt which surrounds the large steptoe of Lengitoto trachyte west of Mosiro (the Lenkutoto plateau), is 10 metres thickness of a much younger basalt which overlies the Kirikiti basalt. He has named it the Mosiro basalt and gives an age of 0.6 Ma.

The surface of the platform at Purrko is Lengitoto trachyte with a small area of Mosiro basalt overlapping it near the Ewaso Ngiro gorge at 1500 m. At the north end of the Lenkutoto plateau the surface is Mosiro basalt at 1500 m, with the Kirikiti surface at 1460 m below both it and a wedge of Mosiro trachyte. South of the plateau at the Endosapia River, the surface is Kirikiti basalt at 1460 m, and at Oloibortoto the Kirikiti basalt surface is at 1450 m. The point where the Kirikiti basalt surface begins to decline southward coincides with the intersection of the Sambu and Kirikiti faults. (Fig. 3-4) Crossley has shown that the Sambu fault has pivoted down since the emplacement of the Mosiro basalt, with zero motion at Oloibortoto and 600 m or more displacement at Namutuakit in the south. However, west of Oloibortoto the Kirikiti basalt had overstepped the Sambu fault and has been left above the scarp at 1460 m, whereas further south, the basalt flood did not reach the fault line, and was all carried down on the downthrow side.

In spite of some masking by alluvium the Kirikiti basalt at the western limit of its flow can be seen to overlie and interdigitate with the erosion surface of the Loita Hills basement rocks, and ancient (10 Ma) melanephelinite intrusives (Fig. 3-4 and Folio maps 7, 10). It only does so at its original altitude for ≈20 kms between the Lengitoto River and Nguruman Lodge, but that is enough to show that the lava which originally overflowed the Sambu fault and cooled on a basement surface outside the rift valley is horizontal and in its original position. The contact line is at about 1460 m. The Kirikiti basalt continues northward below the Mosiro trachyte and the Mosiro basalt at a similar altitude, which gives a horizontal or near-horizontal extent of more than 45 kms while the remainder of the basalt southward is shown to have been downfaulted. The outer edge of the platform lies at 1400 m between the Lenkutoto plateau and the Oloibortoto River, from which point it declines southward with the basalt surface. The height of the scarp is about 120 m at Sosian, exceeds 600 m at Oloibortoto, and then the height declines gradually southward. Crossley (in press) gives an age span of 2.5±0.2 to 3.1 Ma for the Kirikiti basalt.

2c. Comparison of the platforms. The terraces of the southern Kenya Rift Valley are remarkably similar in many respects. The chemistry of the basalts is essentially identical. Although neither has especially distinctive characteristics, there are many similarities in the chemistry (Joubert 1957, p. 33; Baker 1958, pp. 16-17; Crossley 1976, personal communication). Both basalts are limited in their northern extent by high ground, and both form platforms that are nearly horizontal over considerable distances. The altitude of the contact line at the back of each platform is also similar.

North

	Kirikiti platform		Singaraini platform		
	Sosian	1490 m	1500 m	Loodariak	
W	Endosapia	1460 m	1460 m	Turoka	E
	Oloibortoto	1450 m	1440 m	Loonogojit	

South

Both platforms have major faults facing inward to the Rift, and both have younger lavas flowed against them. Both flow against and across the outermost early Rift faults, and both lie against and upon basement system rock. Both have large sectors which have not moved relative to the basement systems since their basalts were emplaced.

For reasons explained in Appendix II, I do not believe that the Singaraini platform is overlain in the north by Ol Tepesi basalts, but even if it is, the ages for true Singaraini basalts at the Singaraini trigonometrical station on the southern part of the platform are 2.31±.10 and 2.33±.09 (Baker 1976), which fall within the limits of error for Crossley's uppermost Kirikiti flow at 2.5 Ma±.2 (Crossley 1976, and in press).

It is not known whether the Singaraini platform has a simple or complex structure and there is no known thickness for the Singaraini basalt. However it would seem permissible to equate the uppermost flows of the Kirikiti and Singaraini basalts and take their mean date of

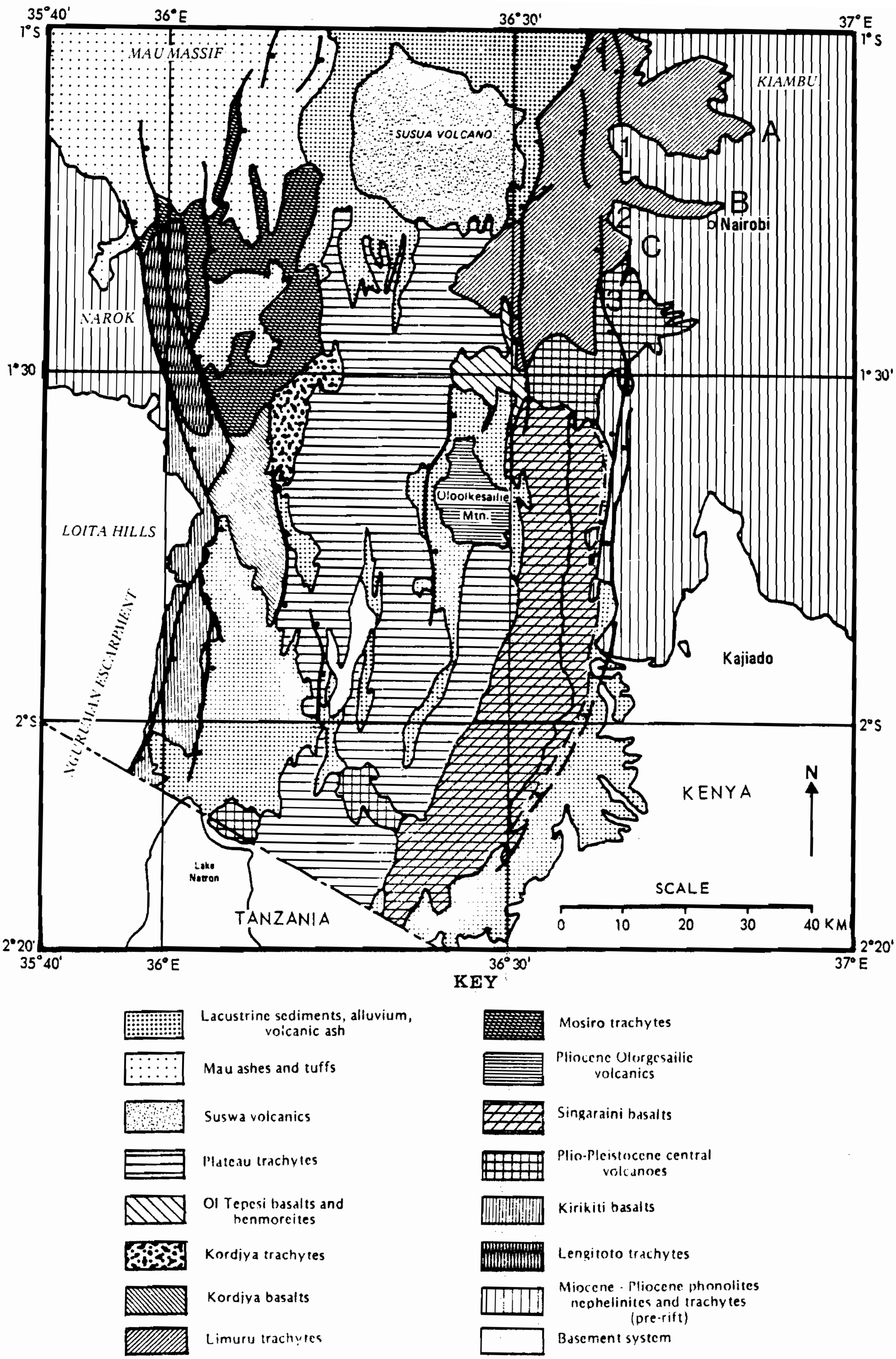


Fig. 3-5 The Limuru trachytes.

2.3 Ma±.2 as a maximum age for both platforms, and any drainage that may have crossed them. They also predate every feature that lies on the Rift floor between them, except the central vent volcanoes. They indicate that there has been no warping or tilt in the basement system since their emplacement.

3) The Limuru trachyte (Fig. 3-5)

The Limuru trachyte was formerly shown to occupy an area on the rim of the Rift Valley between Ngong and Limuru north-west of Nairobi (Saggerson, map; 1971). The eastern boundary of the Limuru trachyte conforms in many places to a series of minor west-facing scarps which extend northward from the Turoka-Kiserian fault, along the line Kikuyu-Uplands-Limuru; but between Githerioni and Tigoni on the north, the trachyte overflows the rift structures and extends 17 kms eastward as a tongue 14 kms wide, which obviously flowed within a major depression on the outer flank of the Rift, and reached well beyond all rift faulting ('A' on Fig. 3-6). The flow immediately overlies undated Tigoni trachytes and Nairobi trachytes (3.2 - 3.5 Ma, Baker et al., 1971), which in turn overlie the Upper Kerichwa Tuffs (4.84 - 5.67 Ma, Baker et al., 1971). The tuffs occupy a much larger area, overlying everything between Ngong and the Kiambu Ridge. It follows from this sequence that the valley in which the Limuru trachyte flowed must postdate the Kerichwa tuffs and pre-date the Limuru trachyte. The existence of other tongues of Limuru trachyte to the south demonstrates that the pre-Limuru surface sloped to the east, and occupied valley forms. There is a second tongue, 12 kilometres in length but only 3 kms wide which overflowed the scarp east

of Kikuyu Station (B on Fig. 3-6) and a minor lobe (4 X 3 kms) (C on Fig. 3-5) which overflowed the scarp at the height of land near Gikambura above the Riu swamp.

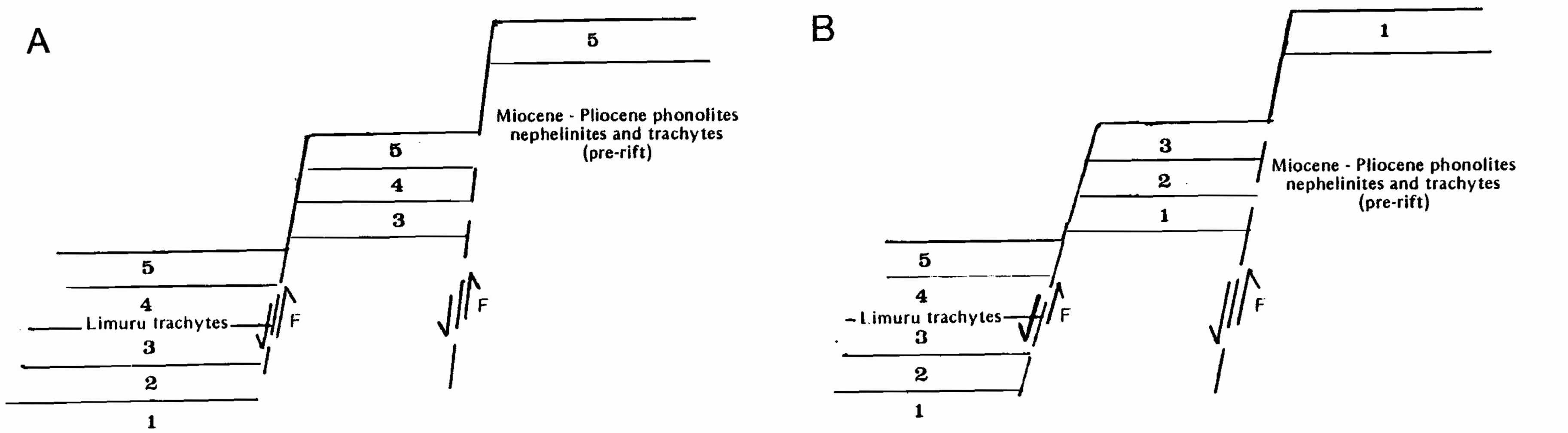
The Limuru trachyte surface slopes southward from 2460 near Kirenga in the north (Folio map 3) to 1980 m under the Ngong Hills (Folio map 6), but the range of altitude at which the lava overflowed the Rift limits is much less: 2380 m at Kirenga, 2200 m at Tigoni, 2000 m at Kikuyu, 2020 at Embakasi Forest. The overflow was relatively thin since windows of Tigoni trachyte appear at Rironi 5 kms inside the Limuru, and east of Muguga Station.

Limuru trachyte also covers the Esakut step-fault platform within the Rift, except where it lies against the lower slopes of the central vent volcanoes of Esayit and Esakut which were active until 3.61 m.y. BP (Fairhead et al., 1972, p. 68). It has suffered severe grid faulting, which is shown in detail by Saggerson (map, 1971). The faulting occurs above and below a subsidiary step on the step-fault platform which occurs at a line Githingucho-Makutano-Lusigeti. (Folio maps 3, 6). The step is several hundred metres in height at the Kedong scarp, but it is only 170 m high at Makutano, and much less obvious at Lusigeti before it resumes as a major fault scarp on the western slope of the Ngong Hills. Both platform surfaces have considerable relief due to the presence of multiple major horsts and grabens, but the upper step ranges between 2400 m and 1980 m and lies some 160 m below the Rift edge, while the Esakut platform proper ranges from 2000 to 1600 m and lies nearly 500 ms below the rim. Both steps are gently tilted southward (see Folio maps 3 and 6).

The distribution of Limuru trachyte shown on Saggerson's map does not match up with the map of the area to the west by Randel (1970) who showed the platform formed in Alkali and Orthophyre trachytes (Baker's former 'Plateau trachytes' which included an 'Upper' and 'Lower' orthophyre trachyte). Baker has corrected this (1976), and now shows the Limuru trachyte on the rim, platform, and the rift floor in the area of the Kedong Gorge. The field work reported here showed that Baker's 'Lower Orthophyre trachyte' (see p.134) was an areal extension of the Limuru trachyte (see Chapter Eight), and that the so-called 'Upper' orthophyre trachyte was not the youngest of the series, but the oldest, and lay below the Alkali trachyte. Baker (1976, p. 476) has accepted the equation of the Limuru trachyte and the Lower Orthophyre trachyte and now places it below the Alkali trachyte in his stratigraphy, but still holds that the Upper Orthophyre (now renamed the Ol Tepesi benmoreite) although below the Alkali trachyte, is above the Limuru (Table 3-1).

This is a very complex area structurally and petrologically and serious problems remain with the stratigraphy and dating shown in Baker's 1976 paper (see Appendix II). Baker assigns a mean age of 1.91 Ma to the Limuru trachyte, whereas Table 3-2 suggests a greater range of ages; from 1.55 Ma (Williams, in: Baker _et al_., 1971), to 1.96±.04 Ma (Baker 1976, p. 477), with an independant dating of 1.74 Ma from Evernden and Curtis for a Limuru trachyte under its former name of Lower Orthyphyre trachyte (1965, KA650).

In the existing circumstances, the complete concealment of the base of the Limuru creates an enigma. If the Limuru filled a pre-



A Flows fill rift and overflow

B Rifting and flows contemporary

Fig. 3-6 Two possible sequences of Limuru trachyte flows. The first assumes the lavas filled a pre-existing rift form and overflowed. In the second the lavas began to flow at the same time that rifting began. The second version creates a metachronism, and there could be more than one if rift-faulting continued through the time of flow.

existing Rift graben, as the Lengitoto trachyte did, then the overflow at the rim would be the youngest flow. If the Limuru began flowing at the commencement of rifting on the east, which seems indicated, the flows on the surface of the rim will be the oldest, while the uppermost lavas on the floor would be the youngest, creating a metachronism (Fig. 3-6). Given continuing flows over an extended period of time, and multiple episodes of faulting, many complex variants are possible; every flow in each sector will need to be dated to settle the sequence of events. Meanwhile, apparently contradictory datings may be expected.

The importance of the Limuru trachyte and its structure is that the flows may help give a maximum age for the last Rift movement on the rim in the east, while the subsequent physiographic evolution on the rim, the platform, and the floor will help explain events in the history of drainage across the Rift site (Chapter Six). Knowledge of the Limuru trachyte also helps evaluate events in the Kedong Gorge, a gorge cut by a stream that may at one stage have fed the Olorgesailie Lakes.

There is a possible relationship between the Limuru trachyte and the Mosiro trachyte on the western edge of the Rift (Fig. 3-6). Knight (1976, p. 106) speculated on the similarities of the two rocks and quoted Baker: 'The Mosiro trachyte as defined and described here corresponds to the Limuru trachyte on the eastern side of the Kenya Rift Valley (B. Baker, personal communication).' Knight concluded '. . . although no unit can be directly correlated . . . due to the lack of a contiguous outcrop . . . the major oxides and trace elements of the two trachytes have shown distinct genetic similarities,' There are reasons to equate the two trachytes also on physiographic evidence. The Mosiro trachyte overflowed the Rift boundary fault westward along the line of the Sosian-Rundurutu scarp at a height of 2040 metres. The overflow may be higher, at 2400 metres, under Mau ashes near Nairage Engare. Within the Rift it flowed against the Lengitoto trachyte after faulting began, but before the Lengitoto fault in the Kirikiti basalt. It was subsequently lowered as a ramp, sloping uniformly southward from >2040 to <1400 m on the Mosiro platform. West of the Rift where it overflowed the limiting fault the rock has not moved since emplacement. The altitude of the Mosiro trachyte at the rim equates very closely with the altitudes of the Limuru trachyte on the eastern rim (p. 50), and both trachytes have the form of overflows into pre-existing troughs on the outer flanks of the Rift, and both flowed after faulting had begun but before downthrow had proceeded very far.

Apart from the physiographic evidence presented in Chapters Five and Six, analysis of my samples and comparison with the materials of Crossley and Knight suggest that there may be two trachytes under the present name of Mosiro trachyte. For the reasons stated above the younger of these two is corellated with the Limuru, and it is probable that at the time of its emplacement the Limuru trachyte bridged the Rift Valley and overflowed within topographic lows on opposite flanks of the Rift.

In Table 3-2 all the available dates for the Limuru trachyte are listed as well as the magnetic polarities. The selected preferred age range around 1.91 Ma in Table 3-1 is not certain, and the ages may range from 1.55 Ma to >1.94 with the base not seen (Table 3-2), and may include two phases (Appendix II and Table 3-4).

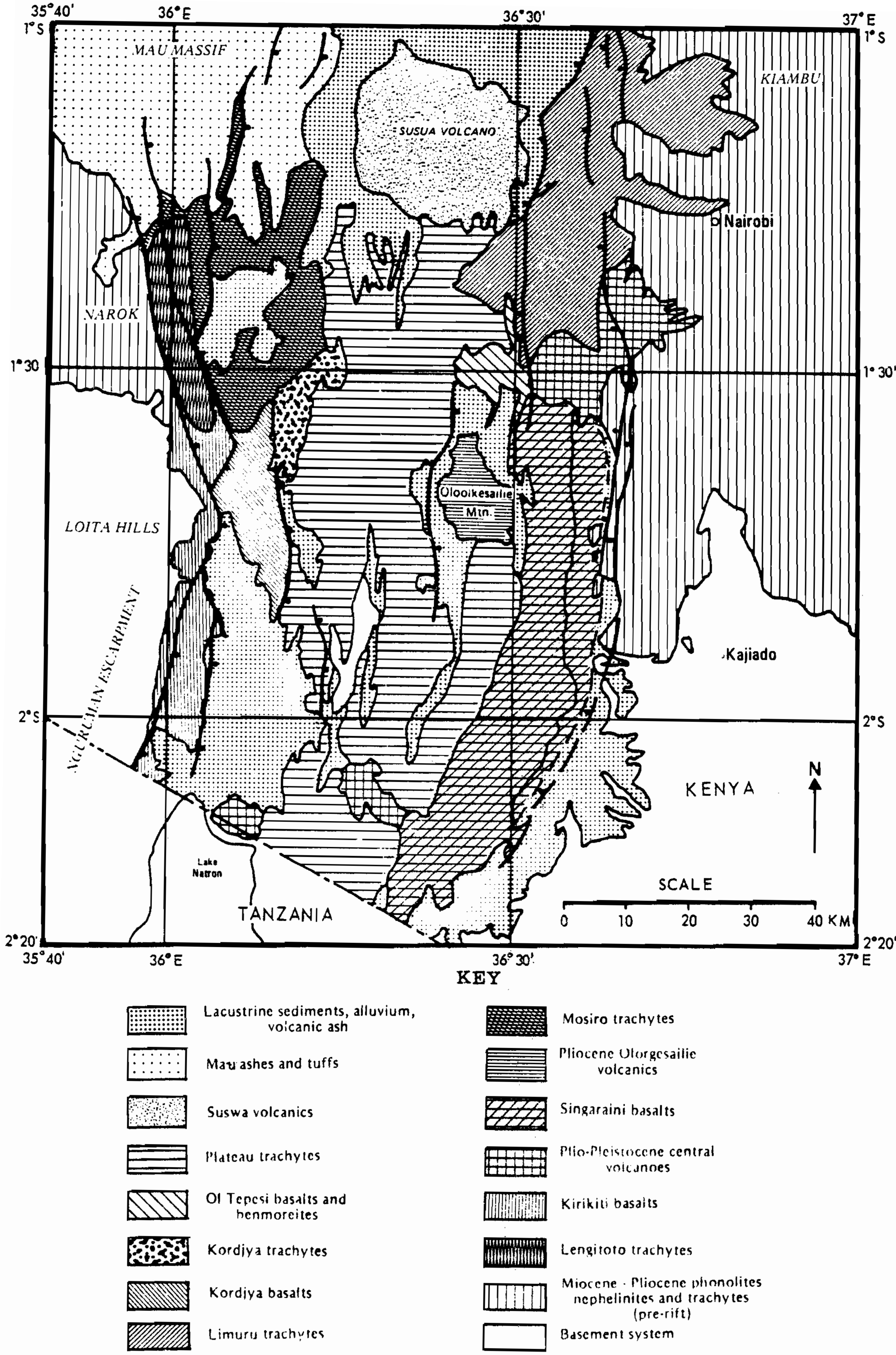


Fig. 3-7 The Plateau (Alkali) trachytes.

4. The Plateau trachytes (Fig. 3-7)

The term Plateau trachytes was formerly used to describe all the trachytes of the southern Kenya Rift Valley floor. Baker's 1958 map showed Lengitoto trachyte as the lowest unit, followed by the Alkali trachyte, with an Orthophyre trachyte on top. Subsequently the Orthophyre was divided into 'Upper' and 'Lower' orthophyre trachytes, and in 1963 the Lengorale trachyte, closely related to the Alkali trachytes, was added as the youngest member. Finally, in 1976 Baker added the Gesumeti trachyte (1976, p. 474) below the Alkali trachyte. Crossley (1976) calls the alkali trachytes Magadi trachyte in his area.

In 1976 Crossley removed the Lengitoto trachyte from the Plateau formation by showing its great age. Baker (1976) has recognized that the 'Lower' orthophyre trachyte is the Limuru trachyte and predated the Plateau series, while the 'Upper' Orthophyre has been assigned to the Ol Tepesi basalt sequence, and renamed as the Ol Tepesi benmoreite. In 1978 the newly designated Gesumeti trachyte was withdrawn from the Plateau series and is now described as the uppermost member of the Limuru trachytes (Baker 1978, personal communication). Thus, the Plateau trachytes series now contains only the Alkali trachyte (under the names Plateau trachyte, Alkali trachyte, Magadi trachyte), and possibly the Lengorale. The age range is from 0.7 Ma (Baker et al., 1971) to 1.4 Ma (Crossley 1976). Crossley sees the Lengorale as a separate local effusion. The Lengorale has been given an age of 0.6 Ma (Baker et al., 1971). This text uses the term Alkali trachyte to avoid confusion with other former members of the series and because of its distinguishing characteristic.

It will be shown that the distribution of alkali trachytes in the northern sector is more limited than indicated in the map accompanying

Randel's report (1970), but the distribution in the south is more accurately shown by Baker (1958), except for a small sector west of Kordjya which is now known to be a Kordjya basalt (Baker 1976, and Crossley 1976). Field work has shown significant altitude relationship with the rocks overlain by the alkali trachytes, and with the Susua volcanics which closely succeeded the last flows of Alkali trachyte in the north.

The rock outside the rift in the west at Kaitururu, and within the rift at Koromoto, is not alkali trachyte as shown by Randel (1971) and Baker (1976, p. 468), but Mosiro trachyte (samples M34, M38, M40, and M45). The alkali trachytes lie below the scarp at Koromoto, at 1500 - 1600 m, and against the Mosiro trachyte, whereas a little further south they have overflowed the edge of the Mosiro platform at 1460 m± (Folio map 4). At Kordjya the Alkali trachyte overflowed the Kordjya basalt and is now found at 1000 m, above the Kordjya fault scarp, while Alkali trachytes are recognized at 800 m, below the Nguruman Escarpment although the contact with the fault scarp is masked by sediments. Clearly the lava flowed after the Koromoto fault, before the Kordjya fault, and after at least some downward movement along the Kirikiti. There is no evidence anywhere of renewed movement at the limiting fault lines after emplacement.

In the north the Alkali trachyte surface passes below Susua volcano, and the sediments of the Kedong Valley. The highest observed outcrop below Susua is at 1440 m. To the east, the perimeter contact is with faulted Limuru trachyte and various basalts. The line contact is at 1280 m in the Kedong Valley but within the Kedong gorge the upper surface of the Alkali trachyte declines steadily from 1240 m at Baragoi to 1170 m near Emerit. Below the Singaraini basalt escarpment, the altitude is 1180 m±, but southward where the escarpment disappears, the trachyte con-

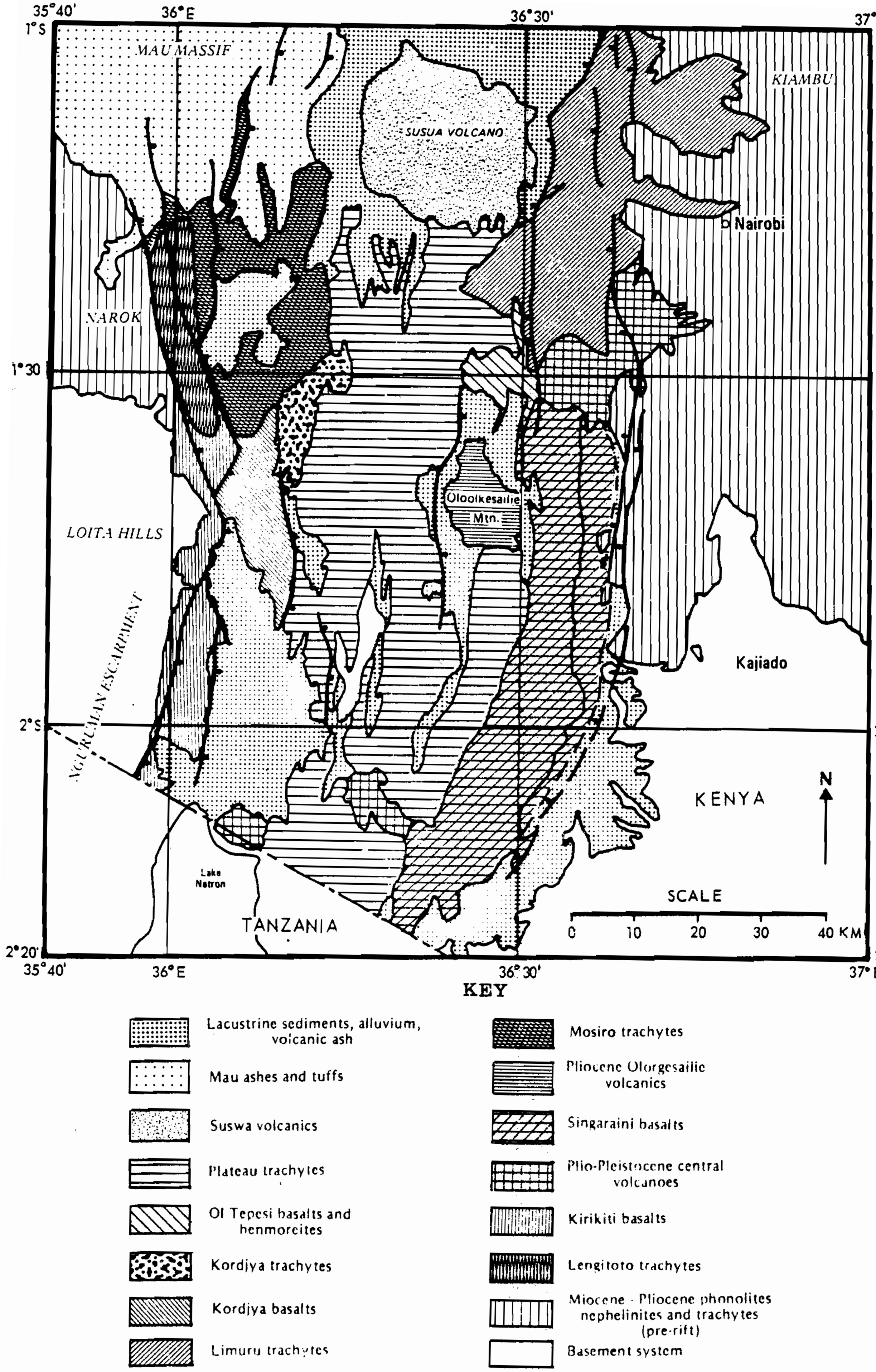


Fig. 3-8 The Suswa volcanics. For extension of older flows see text.

formably overlies basalt at $\simeq 900$ m, and alkali trachytes can be seen over a large area on the eastern shore of Lake Natron at altitudes down to 700 m.

The gradient on the contact line in the Kedong Gorge is 100 m in 17 kms or 1:170. This gradient projected northward would have the surface pass below the Kedong Valley and the Orgaria-Longonot ridge. The gradient from the highest observed contact to the lowest surface is 700 m in 117 kms or 1:167, which suggests a considerable uniformity in the gradient, and implies that all the trachytes represent a single episode of widespread lava flooding.

Crossley (1978, p. 26) believes that the tilt of the Rift floor occurred after the emplacement of the Magadi trachyte, citing the declining fault displacements northward, and the absence of differential accumulation among the volcanics. It is obvious that the grabens and horsts within the floor of plateau trachytes have tilted southward, but the evidence of the contact line suggests that the general gradient at the boundary of the outcrop is original and that the lava flowed in a rift valley which then had increased displacements northward along the limiting faults.

The Alkali trachyte surface has been severely modified by grid faulting, so the surface presents a complex terrain of horsts and grabens with relief ranging from a few metres to more than 400 m, as at Kordjya. This is the surface on which the Olorgesailie Lakes as well as the drainage system that fed them formed, and the alkali trachytes provide a maximum date for events at the Olorgesailie historical site. Many of the grabens are occupied by Pleistocene lake floors (shown on Folio maps).

Table 3-4. Revised stratigraphy of the South Kenya Rift Valley 1978 (see Table 3-1 and Appendix II)

Western Flank	Floor of the Rift	Eastern Flank
Lakes Natron and Magadi		
High Magadi		
	Orgaria-Longonot volcanics ≈ 0.1(~0.01?)	
High Natron (700 m lake)	Susua pyroclasts, caldera, and cone end 0.1	
----minor faulting		Secondary Olorgesailie (Koora) lake
(subsiding Rift floor?)	(Susua) quartz trachyte (Baker s Baragoi? 0.36 - 0.4)	Olorgesailie lakes (Legemunge beds)
	Susua pyroclasts and caldera begin > 0.4	Olorgesailie lake begins
----Grid-faulting ends ----	Grid-faulting ends----	----
Mosiro basalt 0.6		Grid faulting of Limuru trachyte
Orkaramatien (lake) beds		on Esakut platform
----Grid-faulting begins----	Susua shield phase begins >0.69,< 0.89----	----
Lake Natron begins		
Magadi trachytes 0.81 - 1.4	Plateau trachytes (≈ Magadi, Alkali trachytes)	
----faulting----	----	--- ? --- ? --- ? --- ?
minor Kordjya basalts	Ol Tepesi basalts 1.4-1.6 Late Limuru trachyte 1.55?	(Youngest overflow Rift edge?)
N. Kordjya trachytes >1.79, <1.95 ≈?≈	Ol Tepesi benmoreite ≈?≈ Gesumeti trachyte >1.79, <1.95	⇧
Kordjya basalts 1.7 - 2.2	(Ol Keju Nero basalt 1.9) ?	
----faulting----	----	--- ? --- ? --- ? --- ?
		Limuru trachytes 1.55 - 1.96
Mosiro trachytes 1.9 - 2.3		(bottom not seen)
(First phase of Mosiro trachytes) 2.3±0.1	First phase of Limuru trachyte > 1.96(bottom not seen)	⇩
	Olorgesailie volcanics 2.2 - 2.7	(oldest overflow Rift edge?)
----faulting----	----	----
Kirikiti basalts 2.5±0.2 - 3.1		(Uppermost) Singaraini basalt 2.31±0.1 -2.33± 0.09
----faulting----	----	----
		Tigoni, Kabete, Karura trachytes >2.3, <3.5
Oletugathi ashes, etc.(see Table 3-1) 3.0 - 4.5	Ol Esayeti volcanics 3.6 - 6.7	Nairobi trachytes 3.2 - 3.5
'Endosapia trachyte' 3.2 - 5.1		
Lengitoto trachytes 5.0 - 6.9		Kerichwa tuffs 4.8 - 5.7
----Rift faulting begins----	--- ? --- ? --- ? --- ? --- ? ---	? no evidence of early Rift faulting ? ----

5. The Suswa volcanics (Fig. 3-8)

The Suswa volcanics have not been finally mapped. This study will show that phonolitic and trachytic flows from Susua repeatedly invaded the Kedong Gorge after it had been fluvially shaped, producing a complex stratigraphy. This study will also show that the earliest trachytic flows of Susua extended far south of the Suswa materials shown by Johnson (1969), or Randel (1970). Baker has dated a trachyte which invaded the Kedong Gorge at .36 - .4 Ma (personal communication). He has called it the Barajai trachyte and places it below the entire Suswa sequence. However, this study shows that an alkali trachyte (geological samples M2, M12) which may be the same as Baker's 'Barajai', overlie a Suswa flow in the Kedong Gorge, while farther west all the outermost Suswa flows as shown by Johnson have reversed magnetic polarities indicating an age greater than .69 Ma (Chapter Seven).

Table 3-4 is a summary of the stratigraphy of the southern Kenya Rift Valley with dates. It incorporates the changes resulting from this research, and identifies some remaining problems. The table has been used to provide the dates, ages, and sequences presented in this research and its conclusions.

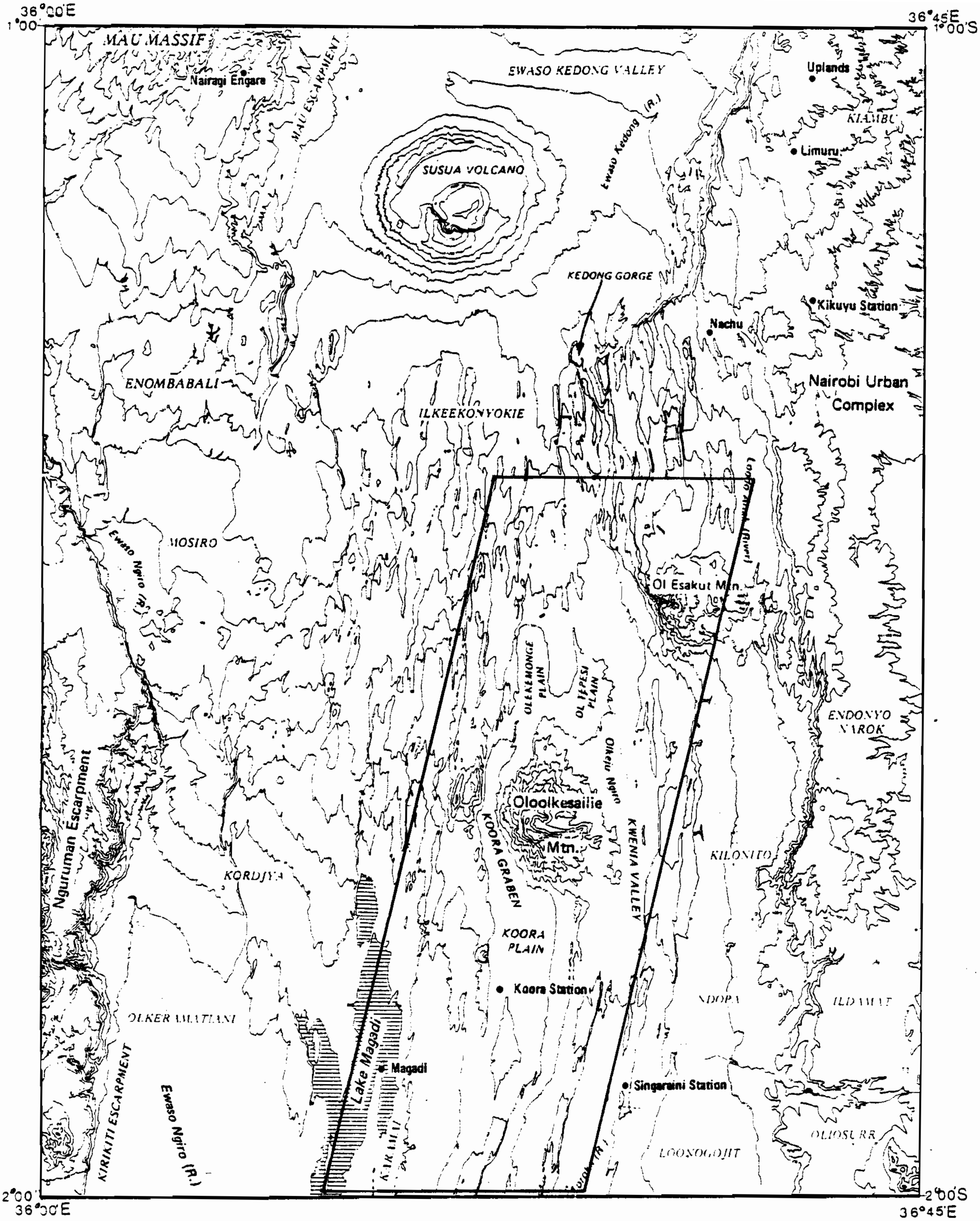


Fig. 4-1 General location map, Chapter four. The Olorgesailie Lakes site.

Chapter Four

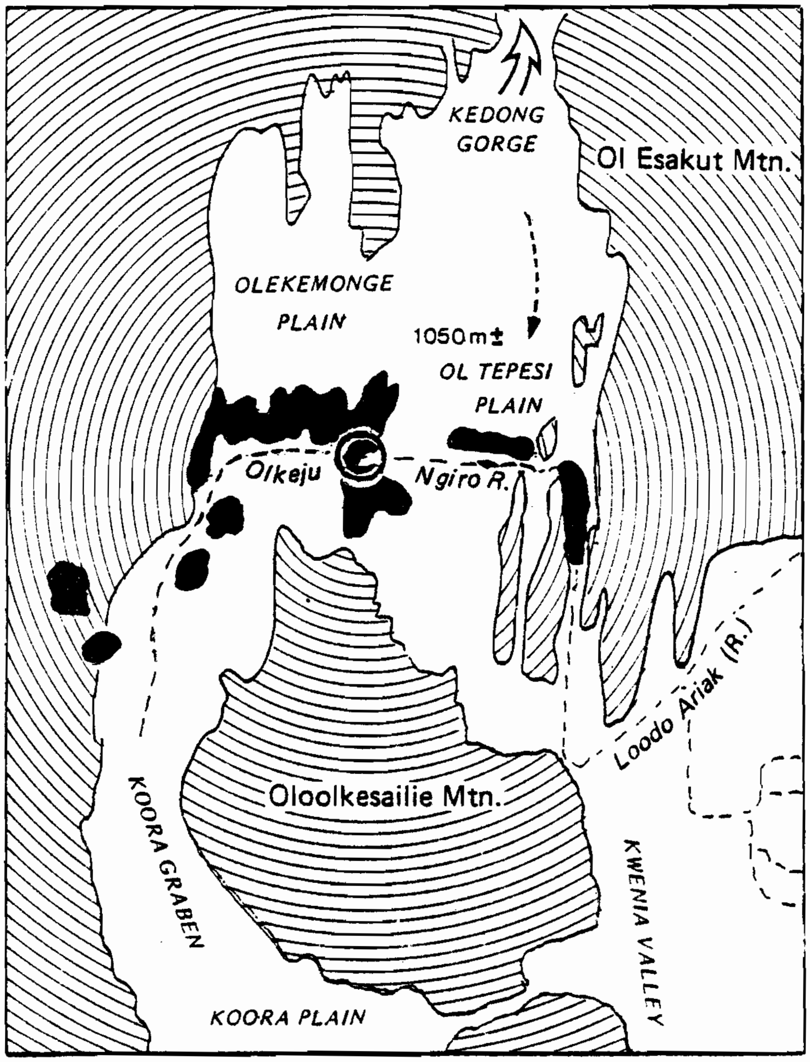
THE OLORGESAILIE LAKES SITE

I. THE OLORGESAILIE LAKE BEDS

The Olorgesailie historical site is located within Pleistocene lake beds which have formed the Olekemonge and Ol Tepesi plains (Fig. 4-1). The plains are separated by a minor fault scarp so that Ol Tepesi lies slightly below Olekemonge. The lake beds in the Ol Tepesi plain have been covered by more recent deposits, but they are exposed in the channel of the Ol Keju Ngiro river. There are also minor fault displacements within the lake beds at the site, but it is clear that the plains represent a single original floor created by a sedimentary fill in a pre-existing complex of minor horsts and grabens. The plains are flanked east and west by major inward-facing fault-scarps, and to the south by the 1700 m cone of Oloolkesailie, a central vent volcano of Pliocene age (Fig. 4-2).

There are approximately 40 m of lake beds exposed at various parts of the Olorgesailie site and it has been estimated that as much as 20 m of the uppermost beds have been removed by erosion.

The stratigraphy has been carefully analysed by Isaac who based his approach upon a manuscript map by Shackleton, surveyed at a scale of 1:1,000 in 1944, and published as an appendix to Baker's Magadi report in 1958. Shackleton and Isaac use slightly different criteria in dividing the stratigraphy. There are 13 members in the series as shown in Table 4-1, which is a summary of details from Isaac (1968 Plates II: 8, 9, 10).



Lava terrain surrounding the former lake site

The Olorgesailie Lake beds

The Olorgesailie National Monument

Former river channels

Fig. 4-2. Plan of the Olorgesailie sedimentary basin (based on Isaac, 1977, Fig. 4).

The existence of hippopotamus and fish remains associated with the lowest thick diatomaceous deposits indicates a definite lake environment, and the presence of fresh-water diatoms throughout the sequence points to the permanence of the condition, in spite of the volcanic activities which are indicated by a variety of ashes and reworked tuffs in the sequence.

The lake beds contain 17 non-sequences which show by their form, or the materials at the interface, the existence of land surfaces at intervals during the history of the lake (Photo 4-1). It is not known whether they represent fluctuations of a shoreline (Shackleton 1944, p. 12), or arid intervals in which the lakes disappeared entirely. The archaeological sites are all located on flats near sandy rill channels well back from their contemporary lake shoreline, and it can be demonstrated that the lake margins lay generally to the north and northeast, with deeper water to the southwest in the direction of the mouth of the Koora graben. (Isaac, 1977, P. 21).

The entire sequence lies upon the uppermost of a series of alkali trachyte flows, which has an age of 0.72 Ma± .09 (Baker, et al. 1971 p.201). The lake beds must postdate the Koora graben in which they lie and must postdate all grid faulting,since Isaac has shown that there was only minor faulting during and after lake deposition, with a maximum vertical displacement of only 12 m which occurred during early deposition in member 11 of his series (Isaac, 1968, Plate II:9).

It has been generally assumed that the final lake was drained by earth movements involving downward tilting to the south. Careful examination of the lake beds during field work in 1972 showed little variation

	Measured observed thickness
Member 14 Pale diatomaceous siltstones, redeposited siltstones, and porous limestones. Outcrops are known only in the western sector of the Legemunge plain.	3m
Member 13 (Poorly exposed) Brown claystones, diatomaceous silts, and diatomites. Numerous root channels.	12m
Member 12 Vitric tuff with pumice lapillae, volcanic sand, redeposited sediment particles, diatomites. Locally vivid RED.	2m
Member 11 Over most of its distribution, the following sequence of lithologies can be distinguished: Brown siltstones and silty clays comparable to silts accumulating in the area today. (2 - 4m) Diatomites, volcanic silts, cemented by calcium carbonate (1 - 4.5m) Brown silts, clays, and fine sands (0 - 4m) Varied pale yellow volcanic silts, clays, and diatomaceous silts with hard RED bands (2 - 5m)	18m
Member 10 Coarse volcanic sands and pumice gravels, and subordinate quantities of lava granule gravel. Shows a facies change in the west (locs. O-D) with silts and redeposited diatomite predominating over sand.	3m
Widespread disconformity	
Member 9 Upper diatomites (1 - 2m) Upper volcanic sand (0 - 0.6m) A *main diatomite* bed with an ash fall horizon (2 - 4m) "*Basal bed*" of volcanic glass, sand, and derived sediment rubble (0 - 2m) The diatomites show facies change from pure diatomite in the west to diatomaceous volcanic silts in the east.	7.5m
Widespread disconformity	
*Member 8** Pale grey brown tuffaceous shales ("marls") with beds of hard volcanic siltstones which may be bright RED.	3.4m
Member 7 Pale yellow volcanic silts, diatomaceous silts, plus a paleosol horizon with partial alteration of underlying sediments to green clay. "Cut and fill" bedding evident in excavations. Fine subdivisions have been defined at the Main Site.	4.5m
Member 6 Greenish silty volcanic sandstone	1m
Member 5 Massive root marked greyish yellow volcanic silts. Weathered and altered during deposition.	2m
Member 4 Coarse volcanic sandstones and pumice granule gravels with finer grained sand and sandy silt facies in the west.	3.4m
Widespread minor disconformity	
Member 3 Grey silt, volcanic sandstone. Angular glass sherds of fine to medium grain size predominate, becoming coarser upward.	3.7m
Member 2 Diatomites, grading into fine silty volcanic sand.	5m
Member 1 Volcanic siltstones, diatomites, and brown clays with root channeling and paleosol horizons.	9m

*Members 5 - 8 are distinguishable only in the vicinity of the Main Site.

Table 4-1. Summary of the characteristics of the members of the Olorgesailie formation (from Isaac 1977, p. 19).

in absolute altitude of the upper beds westward from the site, specifically the red indicator bed M8 and a distinctive ash layer occurring in the lower part of M9. Since diatomites indicating stable fresh-water conditions, occur high in the sections, the lake conditions must have been maintained to the end, and the event which finally brought lacustrine condition to an end occurred outside the area, to the south (see p. 74). The highest lake bed remnant is at ≈1050m. A shoreline recognized by me at the exit of the Kedong Gorge lies at ≈1130 m, but it can not be positively linked with the Olorgesailie lake beds.

Dating of the beds and their enclosures has been remarkably unsuccessful. No human remains are associated with the artifacts, and potassium/argon dating of the stone implements would be non-relevant, and dating materials from the enclosing beds gives serious contradictions. For example, M4 yields dates of .486, 1.64, and 2.9 million years B.P., while M10 gives .425 and 1.45 million (Evernden and Curtis, 1965 p.359). Obviously the sedimentary materials have been reworked and redeposited at the site, but the dates for the youngest rocks in each layer provide a maximum age for each bed, and the youngest dates within each bed give a possible chronological sequence. Isaac accepts the only firm date as the 720,000 B.P. for the underlying trachyte, but in the 'Guide to the site' he suggests that archaeologists tend to accept the lower limit of 400,000 years as a reasonable and probable age for the lake beds because the cultural evidence elsewhere dates between 60,000 and 400,000 B.P. and because local erosion of the lake beds and a stream gorge superimposed from them into rock suggests something considerably older than 60,000 years.

Photo 4-1. A section of the Olorgesailie Lake bed series near the Olorgesailie Historical Site. Non-sequences and facies changes are visible in the upper beds.

At the present day the lake beds are suffering considerable erosion during heavy rains because of overgrazing by Maasai cattle, and there is rapid contemporary rill and gully erosion with vertically walled ravines up to four metres deep, but the major part of the erosion is old. The Ol Keju Ngiro river, a seasonal river, traverses the lake beds and the channel continues through a gorge cut in basalt. It is apparent that this section of the channel has been superimposed from the lake beds. There are falls and plunge pools in the course across the lavas, but the channel is graded in sediments above and below the gorge. A few kilometres below the gorge, the channel is cut in 'red beds' which are apparently inset within the lake beds, and were obviously deposited after erosion of the lake beds (Photo 4-2). They are described as bedded earths and clays in Baker (1968, p. 35). Field work showed that the beds are stratified but lack current bedding, so that they resemble catastrophic flood deposits of reworked lateritic soils. Similar deposits, but with a higher content of tuffs, can be found at the Baragoi sector of the Kedong Gorge.

II. CLIMATIC INFERENCES

One remarkable characteristic of the entire lake bed sequence is the apparent absence of organic materials other than the fragmented animal bones found at some site floors. The land surfaces are marked by sharply defined lithological changes and microfeatures of an erosion surface. There are scatterings of sands, gravels, and pebbles on the site floors, but there are no developed soil profiles, the (grass?) rootlet zones are within aggregates rather than soils and there is no plant debris. The two palaeosol zones reported by Isaac are not strongly developed and may not serve as climatic indicators. Baker reported 2.25 m of brown soil with

Photo 4-2. Channel of the Olkeju Ngiro stream below the Olorgesailie site. The Olorgesailie Lake beds appear at right middle ground. The 'red beds' in the foreground are inset within a former channel through the lake beds.

rootlets at the base of the lake beds, but it was not recognized in the present work.

The calcification of some diatomite beds may indicate strong evaporation characteristics at their surfaces, and the reddening of beds M8 and M11 may indicate laterization of the clays and silts under conditions of intense leaching and some heat, but there is no solid evidence of climatic conditions during the deposition of the beds, or during development of the land surfaces at the non-sequences. The only clear evidence of a different former environment is contained in Parkinson's report of the 100 ft (30.5 m) pit section dug in the Koora graben. In it he describes a silt band at 53 feet (16 m) 'crowded with snails' (1914, p. 42). Unfortunately that pit has been lost and the section cannot be re-examined, nor does the section as described resemble the lake beds at Oloolkesailie.

The physical facies reveal little about the climatic conditions. The diatomite beds indicate prolonged stable fresh water lake conditions. Richardson has estimated that a metre of diatomite represents >450 years accumulation under normal conditions, and sees the total accumulation of diatomites at Olorgesailie as representing 7-10,000 years (Richardson, 1966 p. 290-1). However, the unstructured diatomaceous sediments may represent diatoms settling in a matrix supplied by turbid flood waters, and even the pure diatom layers may have been reworked by water, although there is no evidence within the lake beds of any considerable river or stream. There are lenses of gravels, sands, and pumice lapilli, but they are unbedded, thin (10-25 cms), and small in area, often only a few square metres. They resemble the sort of material that would accumulate with ephemeral flood wash and sorting on the present surface under present conditions.

There are supposed to be current-bedded sands in Shackleton's bed L4 (1944 p. 7), but again they could not be found in 1971 or 1972. Although Isaac's regressive and transgressive sequences are clear, there are no compound foreset delta beds, no wave or torrent cross-bedding, or any other signs of moving water on a large scale. Ash bands and streaks in various beds almost certainly represent air-fall into still water during eruptions, while the thick ash layer (M9) may be airfall on a land surface. Some diatomaceous sediments may represent diatoms settling among water-suspended air-fall ashes, tuffs, and lapilli in a lake. In some cases, even the diatoms could have been air borne to the site, since during this work diatoms were found regularly in loose surface dust samples from some locations. Apart from the ash layers and streaks described above, the absence of structures suggests that most beds contain materials reworked and deposited under more or less catastrophic situations with rapid accumulations formed by settling out of turbid waters in a settling pond.

It is unfortunate that there is an absence of specific evidence for climatic change since no positive case can be established either way. If the beds or the surfaces are to yield climatic information they will require sophisticated analysis, possibly in terms of soil chemistry or micro-palaeontology.

III. THE PRESENT DRAINAGE SYSTEM

The Ol Keju Ngiro is the only active stream at the present time. It is seasonal and never reaches beyond the Koora graben before dissipating,even at maximum flow. It is supplied entirely from the eastern flank of the rift via six collectors on the Ol Doinyo Narok scarp, and it is joined by the Loodo Ariak which brings water from the Esakut platform

(Folio maps 6,9). The Loodo Ariak is the principle contributor, with perennial spring water from below the Ngong Hills, and heavy seasonal run-off from the Ngong Hills and Ol Esakut.

The stream channels are relatively insignificant on the Singaraini platform but they cross minor fault scarps without deflection and may be antecedent to grid faulting (water-gaps on Folio map 9 overlay). The net coalesces into four streams before leaving the platform, and they have cut back from the limiting escarpment in gorges. (A, B, C, and D on Folio map 9). Three of them have gorges 60-100 m deep and about 1 km long, but the Loodo Ariak has a gorge more than 120 m deep and over 4 kms long (D on Folio map 9). It has clearly been the dominant contributor to stream flow since the step fault originated.

In themselves the gorges do not indicate an age relationship to the escarpment since streams would cut back from the scarp whenever they formed. However,both the Loodo Ariak and the Ol Keju Ngiro traverse down-faulted basalts and grid-faulted alkali trachytes, and although the Ol Keju Ngiro has been diverted by some grid faults, there is clear evidence of a former channel continuing its line southwest into the Kuenia Valley (E on Folio map 9). Therefore the stream postdates the alkali trachytes but predates, or is contemporary with, grid-faulting. The river seems to have diverted itself upon its own alluvial cone at the mouth of the gorge so that it turned north and linked with the Loodo Ariak.

The Loodo Ariak provides even stronger evidence. There is a striking water gap cut in a horst (F on the Folio map), which is more than 40 m deep, and the Loodo Ariak continues its alignment southwest as the Ol Keju Ngiro without interruption before turning north at a fault scarp along the foot of Oloolkesailie mountain, to flow around its base. It thus predates all grid faulting along its path, suggesting an age close to 0.8 Ma (Table 9-1).

When the Ol Keju Ngiro turns north, it is on the Kuenia plain and is only a metre or so above the floor of the Kwenia 'Lake' which opens southward, yet it descends northward on the Olorgesailie lake beds and the channel is cut into them. This may be a result of capture by headward erosion, but there is a possibility that the stream was diverted by an alluvial cone (see p. 61).

The ephemeral Lake Kwenia site lies at altitudes between 1040 and 1060 m, with a sill on the south at 1060 m, from which water would escape southwest to the Koora graben at Oolkululu. There is a small wind-gap at 1050 m (A on Folio map 11). The Olorgesailie Lake beds have not been seen under the Kuenia surface or northward in the Ol Tepesi plain but the coincidence in height of the Kwenia plain and the uppermost Olorgesailie beds is exact and strongly suggests that the Kwenia Lake site was once an arm of the Olorgesailie Lake. If the Olorgesailie Lake had reached 1070 m (a height required for the deposit of the 20 m of sediments supposedly lost by erosion), the Lake would have had an overflow southward, south of Olorgesailie and into the Koora graben. However, the Koora can be shown to have deepened after the formation of the last Olorgesailie beds (p. 74), and the rock below the Kuenia sill shows no lake deposits, so the Kuenia site remained an embayment throughout the history of the Olorgesailie Lakes. It may have overflowed southward only during periods of high water, and in the period when Ol Tepesi was downfaulted. At that time there was sedimentation across the Ol Tepesi plain, and all the streams draining on to the Ol Tepesi and Kwenia plains would create a shallow lake from which at least some water may have left by the Kwenia overflow. There is now a low gentle sill northward in the Kuenia Valley and the modern Kwenia 'Lake', in its rare intervals of existence, would overflow southward.

Another stream system fed the Kwenia arm from a southeasterly direction: the Bakari and Iloodo Ariak (Folio map 12 and southwest corner of 9). They have eroded a considerable valley in the Singaraini platform but leave it without cutting a groge by descending a ramp <u>en echelon</u> between two faults. The channels terminate at a very large thin alluvial cone (1½ kms radius) in the Kuenia Valley which cannot be explained by their present almost ephemeral activity. This cone, only 15 m high, has created a water divide in the Kuenia Valley which provides the north limit of the modern Kwenia Lake, and may also have determined the present course of the Ol Keju Ngiro by directing it north.

The Turoka River conforms in its southwesterly course with the general direction of the Loodo Ariak. It is a seasonal stream which has created a major valley by headward erosion into the Rift wall. It has almost reached the water divide on the eastern wall of the Rift, and has a small drainage area. The channel on the Singaraini platform is superficial, with braided channels in a gentle depression often less than 10 m deep. The Turoka predates the grid faulting because, although it is diverted by minor fault scarps, in some cases it has superimposed itself on a number of horsts so that there are numerous water gaps along its course (Folio map 12, overlay). It finally turns south in a large graben (Folio map 11), and its course ends in the seasonal 'Lake' Cabongo which, like Kuenia, forms only in abnormally wet seasons. There is no evidence whatsoever of former channels continuing westward. Although the westerly grabens have been tilted south, the Turoka is unlikely to have flowed northward at any previous time since the present channel postdates the Singaraini basalt and the Singaraini platform is gently tilted southward and has been shown to be stable since its creation (p. 40).

Summary of present drainage

The drainage system of the eastern rift slopes predates the Olorgesailie Lake beds because the streams traverse the alkali trachytes and its grid faults, both of which predate the Lake beds. The streams always fed the Kwenia arm of the Olorgesailie lake and the overflow normally left through the Koora graben, but there may have been intervals in which water overflowed southward from Kwenia. The lake sediments formed a uniform plain in the Olekemonge and Ol Tepesi plains until the period of minor downfaulting which separated the Ol Tepesi and Kuenia plains. At that time there may have been a shallow graben east of the Olorgesailie historical site which filled with water from the Ol Keju Ngiro and the Kedong River from the north (see p. 65 below), so that sediments covered the eastern part of the Olorgesailie Lake beds. Overflow at the western limit of this temporary lake provided a stream which cut down through the Olorgesailie Lake beds in Olekemonge and superimposed itself upon the underlying Ol Keju Ngiro basalt and a spur of Olorgesailie volcano. The new river course was directed south by the walls of the Koora graben.

IV. FORMER DRAINAGE SYSTEMS

In chapters seven and eight it will be shown that streams entered the northern parts of the Olekemonge and Ol Tepesi plains during temporary phases of a progressive diversion of a proto-Ewaso Kedong River (to be called the Kedong River). The evolution of the Kedong River is described in Chapter eight, but there are certain points about that river which relate directly to the Olorgesailie Lake site.

There is a shoreline of a former shallow pond or lake at the exit of the Kedong Gorge. It may represent a high level of the Olorgesailie Lakes but there is no proven relationship to the Olorgesailie Lake beds. Southward from the shore there are three distinctive delta fan forms (D1 and D2 on Folio map 5 overlay, and D1 on Folio map 7 overlay). Form D1 on map 5 is not a sedimentary accumulation, but a tongue of lava which apparently spread out from the mouth of the Kedong Gorge. It is an aa flow (blocky lava), which stands 5 m above the plain. It is apparently superficial since there is a broad erosion channel lying to the east (A on Folio map 5 overlay) which is cut entirely in sediments.

The channel is several hundred metres in width and represents a major former river. It is not the result of present erosion, although its floor is now being eroded by small contemporary seasonal streams. This channel divides in the area west of the Emerit duka, so that there are three major channels with terraced banks, and one smaller narrow channel, declining across the surface of an intervening flat (B on Folio map 5, overlay). The whole complex is cut into and around a sedimentary fill 10-15 m thick. The fill has level surfaces above and appears to be a large deltaic deposit which stood at the head of a lake. The channels postdate it, having cut down after the delta was exposed by lake retreat.

The last and most significant of the three forms resembles a large braided delta or outwash fan which occupies the northern sector of Ol Tepesi (D1 on Folio map 8 overlay). It has an area of 7 x 3 kms and the surface ranges in altitude from 980 to 1020 m. Its outer edges are terraced, probably by recent erosion, and the surface is deeply incised by contemporary gullying. The gullies expose some bedded diatomaceous materials near the Ol Tepesi borehole, but in general they show unstratified and unstructured accumulations of diatomaceous ashes and silts. Nevertheless it is a deposit from fast moving water, because pebbles, cobbles, and small boulders are being exposed at every level in the matrix during erosion. It seems to represent deposition within a settling pond from fast moving water,and is deltaic in its nature. It was built at the head of the shallow lake in Ol Tepesi (p.62) by a late stage of the Kedong River. The delta lies on top of Ol Tepesi sediments which in turn overlie the Olorgesailie Lake beds. It was confined to the area east of the Olekemonge plain and postdates the dividing fault.

Summary of former drainage

The Ewaso Kedong does not provide water to the Olorgesailie site today, but a former Kedong River was a major stream which entered the area from the Kedong Gorge. There is now a deltaic deposit with an upper limit at ≃1070 m which probably represents deposition during a high stage of the Olorgesailie Lakes. This was dissected after the lake retreated so it follows that a large river continued to flow through the Kedong Gorge after the maximum stage. A second delta to the south was deposited in a lake at an altitude of 1020 m. The lake was a shallow one which formed in the Ol Tepesi after all sedimentation had ended in the

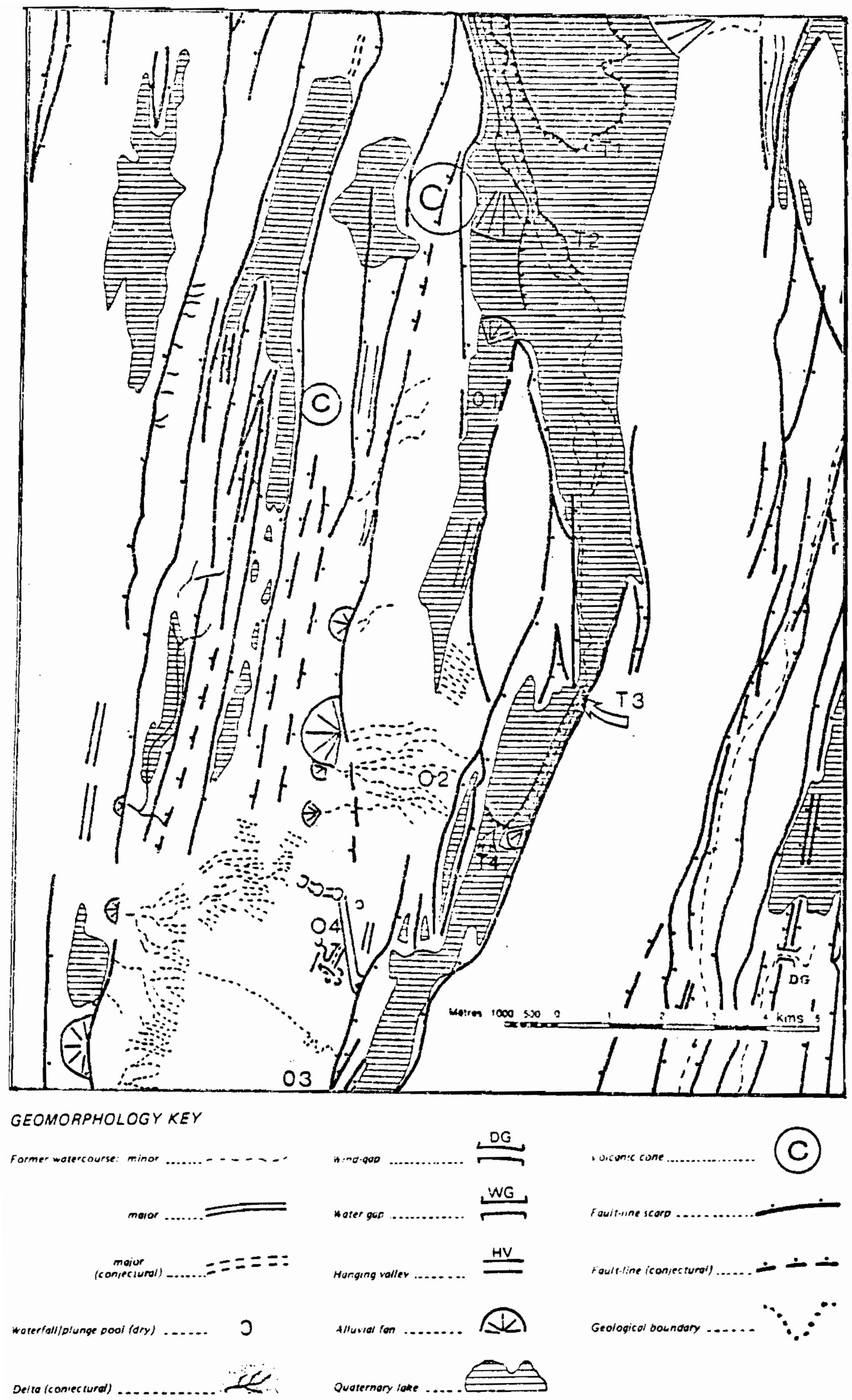


Fig. 4-3 The Koora Graben. Site of the second and final phase of the Olorgesailie lakes. The overflows (O) and terraces (T) are discussed in the text.

Olekemonge sector of the Olorgesailie Lake and subsequent downfaulting had lowered the Ol Tepesi plain. The post-Olorgesailie Lake (the Ol Tepesi Lake), was fed by the Kedong River and the Rift wall drainage via the Kuenia Valley. The Kedong River created a large delta-fan at the head of the shallow lake. As the lake overflowed westward across the Olorgesailie Lake beds the rapidly lowering overflow level soon drained the Ol Tepesi Lake and left the delta dry. The abandonment of the delta postdates the final retreat of the Olorgesailie Lake from the Oloolkesailie site and the first erosion of the Olorgesailie Lake beds, but the Kedong River did not supply water for much longer since there is no major former channel upon the Ol Tepesi plain or delta comparable in size to the old channels at Emerit.

V. THE EXTENT OF THE OLORGESAILIE LAKES

Isaac sketched a presumed northern limit for the Olorgesailie Lakes (Isaac 1968, Plate 11:5), and the Lake undoubtedly extended some way up the Olekemonge plain and up the Ol Tepesi plain toward the Kedong Gorge. No one has mapped the southern limit.

The Koora graben slopes gently and uniformly southward from ≃1000 m near Oloolkesailie to a low point at 774 m near the dry gorge above Siriata (04 on Folio map 11 overlay), before rising again to a saddle between faults _en echelon_ at 894 m (Ngadalat: off map). Diatomites and strongly diatomaceous sediments are found down to the lowest levels (Folio map 11 and Fig. 4-3). The various plains on the floor of the complex graben form sectors which have acquired local names: Ongata Oolkululu in the north, Oloyeiti near Koora station, Olkeri, and (the lowest area)

Siriata, but they are all parts of one floor separated by steps or terraces (T numbers on overlay of Folio map 11, and Fig. 4-3).

Baker (1958) shows a '30 foot terrace' (9.3 m) on his map (T1 on Fig. 4-3). When surveyed in the field this terrace has a height which varies between 7 m in the east to as much as 14 m in the central sector with an average of 12 m. The upper surface is a plane at an elevation between 852 and 854 m (as shown by numerous spot heights on the draft compilation of the base map). The terrace is built of strongly diatomaceous material which is readily identified on the face of the scarp but is masked above and below by dust and loessic deposits. There is no obvious stratification but the diatomaceous material is blocky and varies in diatom concentration at different levels. The feature is not an erosional shoreline bluff because the base is not level, and it is not a terrace cut by a river in alluvial deposits because it is not linear and has no matching bluffs opposed to it.

Baker also shows a '10-15 foot terrace', marked somewhat ambiguously on his map. The terrace (T2 on Fig. 4-3) has a quite different form from the '30 foot terrace' described above. It is a linear feature extending nearly nine kilometres northward in the mouth of the Koora graben. It consists of a pair of opposed bluffs facing each other across a flat floor and separated by distances that range from 200 to 2000 m. They can only be interpreted as paired terraces resulting from downcutting by a former stream, or by sheetwash and flash floods leaving the Koora. The varying width may be the result of meandering or channel shifting, but there are no obvious meander channels, and no alluvium on the floor. This floor stands at 840 m.

Photo 4-3. Delta terrace T4 in the southern Koora graben. View looking north from the Olkeri plain.

Photo 4-4. Perched diatomite deposits in the Siriata sector of the Koora graben (centre middle distance). View northeast from entry to overflow channel.

A step at 820 m in diatomites at a constriction in the graben (T3 on Fig. 4-3) is a contemporary erosion feature caused by a seasonal stream which cuts through the gap, because the 820 m floor continues southward without a break in the profile, but a terrace in the Olkeri plain (T4 on Fig. 4-3) closely resembles T1 as described above. It is smaller in area and only 6 m high (Photo 4-3). It has been dissected by contemporary slope-wash and gully erosion with one deep gully on the east which carries a seasonal stream. The materials are the same as in the terrace T1, and there is no stratification.

Diatomite deposits similar to the terrace materials are found on and around the lowest floor of the Koora graben (d's on Fig. 4-3). At the lowest point on the floor (785 m) there is a sprawling irregularly shaped hillock of diatomite, poorly vegetated, 10 m high and extending over an area 500 x 300 m. It is clearly an erosion remnant. Larger remnants occur on the flank of the graben to the west where two smaller deposits and a ridge of diatomite 5 kms long are perched with a base at 820 m and an upper limit at 840 m (Photo 4-4). The two smaller units are the most strongly diatomaceous. All three are heavily eroded so that no trace of a former surface appears. Other diatomite mounds can be recognized on the valley floor rising to the saddle at Ngadalat, but there is no shoreline at the saddle and no evidence of an overflow channel.

The Olorgesailie Lake system formerly extended 65 kms north and south, but the existence of overflows at different altitudes and the steps between the plains suggest that the lake may not have occupied the entire area at any one time (see below).

Photo 4-5. Overflow channels of former Olorgesailie Lakes system. The sill of the main gorge hangs in the west wall of the Siriata graben at an altitude of 830 m.

VI. THE OVERFLOWS FROM THE OLORGESAILIE LAKES

The lake site described above is a closed basin, and yet the stratigraphy indicates fresh-water environments throughout the period of sedimentation. There was therefore, an escape for the water during the history of the Olorgesailie Lake.

The eastern fault scarp of the Koora graben complex is consistently higher than the western escarpment. Air photo interpretation and field work indicated the existence of a number of water-eroded features on the western rim. Immediately west of the southernmost terrace, (T4), the lava surface slopes steeply westward away from the cliffed edge of the scarp at 880 m. The surface is scarred by a dozen dry, shallow channels cut by former streams. They are roughly parallel, close together, and oriented at a normal to the contours. They all terminate at a line along the east side of the Olkeri plain. Two of the channels are larger with clear evidence of recent ephemeral or seasonal stream activity, and they end at small alluvial fans, while the dry forms end at a large and very gently sloping alluvial fan almost 1 km in radius. All three fans stand at about 740 m. The channels appear to have been cut by water overflowing the rim of the Koora graben on a broad front. (02 on Fig. 4-3).

Farther south there is a dry gorge which, together with some 'depressions on lava surface' is noted on Baker's map of 1958. This gorge has greater continuity than Baker's map suggests (04 on Folio map 11 overlay). The gorge begins at the scarp cliff overlooking Siriata where two minor channels hang over the Koora graben with a threshold at 830 m (Photo 4-5). They amalgamate behind a former island of rock standing 8 m

Photo 4-6. Dry gorge of former Olorgesailie overflow channel. View to the northwest from the scarp edge near the sill shown in photo 4-5.

above the floor, and the larger gorge continues north across the regional slope as a gorge 30 m deep with a dry floor obscured by a talus including large angular boulders. (Photo 4-6). It is a former overflow channel for a lake which once filled the graben. After a northward trend for 1½ kms, the gorge turns west down the regional slope. The form becomes more open, with sub-angular and sub-rounded debris on the floor. There are three dry waterfalls with plunge pools in this sector, with the valley deepening at each one, and there is evidence that the course is being used occasionally by minor ephemeral run-off. The channel drops 80 m in little more than 1 km and then opens out upon a rock slope. A number of very small shallow stream-cut forms continue the line westward, but they cannot be distinguished on the ground in a terrain covered with similar forms (see map).

Immediately west of the entrance to the gorge lie the 'depressions' marked on Baker's map. One of them is linear and is clearly a short section of water-cut gorge ('a' on Fig. 4-3, and Folio map 11 overlay). It deepens southward before turning west, then north, and it finally debouches on the open slope, ending abruptly at a small dry fall and plunge pool. Another of Baker's 'depressions' opens into this gorge. It has the form of three bowls 100 m in diameter coalescing at their rims to give an irregular depression cut in alkali trachyte with a maximum depth of 20 m. The rim of the depression is unbroken, except in the west where the floor of the depression opens conformably into the gorge sector 'a' described above.

It has been suggested that the three bowls are small explosion craters which are typical of some lavas. However, there is no evidence of

Photo 4-7. Typical dry stream-course in sub-parallel pattern above the 700 m. shoreline (see text p. 70).

Photo 4-8. Prominent delta cones built out onto the Karamai plain by overflows from the Olorgesailie Lake system. The tops of the deltas lie at 690 m a.s.l.

such an origin, and, in view of the relationship to a water-cut gorge, they are probably plunge pools of a former overflow river. Such an explanation is not vital to the Olorgesailie analysis, but it is supported by the fact that they lie 600 m directly down-slope from the main gorge entrance. They could have formed at an early stage of overflow before the stream was directed to the main gorge along a fault-induced line of weakness.

Five kilometres to the west and southwest there is an area of terrain which exhibits a distinctive striping of tonal contrasts in aerial photography and LANDSAT imagery (Folio Fig. II:2, and Fig. 4-3). On the ground it can be recognized as a zone of sub-parallel shallow dry stream courses cut one or two metres into rock, with thorn scrub on the interfluves (Photo 4-7). The channels commence abruptly at a line along the 720 m contour and run down the general slope, dropping 20 m in 1-1.5 kms. They are difficult to recognize on the ground, but the general character is well displayed where the Magadi Railway follows a short channel segment near the Olkeri landhies. Northward in the sector, the channels tend to amalgamate in a crudely dendritic form, and converge at an eroded re-entrant of the scarp overlooking Karamai, where there is a prominent delta cone built out onto the plain (Photo 4-8). There is some evidence of contemporary erosion and deposition on a very limited scale, presumably during heavy rains. However, the channels are obviously relic features of a previous erosion episode, because identical features in the southern part of the sector terminate along a line just above an ancient shoreline bluff (Photos 4-9, 4-10). The bluff stands at an altitude of 703 m, 2 m above the plain which shows a sparse litter of debris, some of it water-worn. The bluff is formed in a sand, gravel,

Photo 4-9. Shoreline bluff of the High Natron-Magadi lake at 703 m. a.s.l., 105 m. above the present Lake Magadi.

Photo 4-10. View westward off the 700 m. shoreline bluff. The plain terminates at a fault scarp overlooking Karamatien and the delta structures shown in photo 4-8.

and cobble aggregate and must have been a shoreline for some significant interval of time.

This shoreline is almost 100 m above the highest recorded Magadi shore. The High Magadi beds of Temperley (1951, pp. 15,16) are described as 40 feet above Lake Magadi, giving an altitude of ≈606m, and Baker (1958, p. 37) recognizes a horizontal shoreline at that altitude as the upper limit for Magadi Lake levels. The High Magadi beds are horizontal, and there is no suggestion that they are downfaulted. Since the fieldwork was completed, Crossley has independently discovered a 700 m shoreline west of Magadi on the Ewaso Ngiro (Crossley, 1976, and personal communication).

One last area of indeterminate character remains. Across the tilted alkali trachyte flow surface south of the dry gorge 04 there is a zone of almost 16 kms^2 with a distinctive appearance on aerial photography (west of 03 on Fig. 4-3). On the ground there are no distinctive features; the surface is almost naked rock with an extremely sparse vegetation. The thorn bushes are 10-20 m apart and ground visibility extends more than a kilometre in any direction. There is a very sparse litter of cobble-sized debris, one or two pieces per 100 m^2, and occasional pockets and joints filled with gravel, sand, or dust. The cobbles are of alkali trachyte, but they are not _in situ_. This zone terminates at the line marking the head of the rock channels previously described (p. 70) which is also a break of slope at 720 m. On the higher, eastern, edge of the terrain the zone narrows and terminates at a horizontal sill one kilometre wide at an altitude of approximately 850 m between two higher ridges of the scarp edge overlooking the Koora graben (03 on Fig. 4-1). The sill is the site of a former overflow. The overflowing water in sheet-flood form failed to incise itself in the uniform and smooth lava surface, but, at the break of slope below, water became channelled and produced the sub-parallel net occupying the more gentle gradient westward to the former shoreline described on pages

VII. THE STAGES OF THE OLORGESAILIE LAKES

The evidence presented in the previous pages allows a reconstruction of the extent of the former Olorgesailie Lakes and of a number of events in their existence.

The Olorgesailie Lake formed at the Olekemonge-Ol Tepesi site after the end of the grid faulting in the region. The lake had a northward limit near the exit of the Kedong Gorge at approximately the present altitude. During high stages the lake extended into the Kuenia Valley and normally extended well down the Koora graben which pre-dates the Lakes' existence.

We cannot be certain of the southern limit of the lake during the earlier stages, but since the Lake post-dates the Koora Graben it certainly extended southward beyond Koora station. It probably overflowed south toward the Olkeri plain over a sill which is now at 870 m (O1 on Fig. 4-3). There is no certain proof that the Oloyeti and Oolkululu grabens, which lie _en echelon_ to the Koora graben existed at that time, but the diatomites near the overflow gorge O4 (Photo 4-4), can best be explained as perched remnants of sediments originally laid down in a shallow graben which later deepened by renewed faulting. The remnants post-date the start of faulting and by their thickness and extent they indicate prolonged fresh-water conditions. However, the present closed basin presented by the grabens is not filled with diatomites and if it had been filled with diatomites formerly, there is no mechanism for excavating the deposits. This suggests that the remnants are from a shallow southward extension of the Olorgesailie Lake which pre-dated a final deepening of the graben. Since no stratified deposits occur above them, they may be the equivalent of the upper diatomite members of the Olorgesailie Lake series, and the subsequent deepening of the graben which isolated them is the same event that led to the exposure of the Olorgesailie Lake beds (p.65).

The altitude of the perched remnants (820-840 m) is below that of the lowest Olorgesailie Lake beds (1010 m) but not so far below as the diatomites of the Siriata floor (785 m). This suggests that initially the graben tilted down faster than the enclosing horsts. That would be an early stage since later tilting was common to both (p. 75), and it is probable that in the first stage only the graben floor sank.

The Lake never extended south beyond Ngadalat where the controlling faults of the graben scissor at a present altitude of 894 m to close off the trough. The walls of the graben at that time must have stood at 1050 m or more, otherwise water could not have been retained at the Olekemonge site. Surplus water drained south over to the Olkerri plain.

The Lake then passed through the series of fluctuations implied by Isaac's stratigraphy. It is not possible to tell if the Lake dried up entirely between each episode or whether it receded temporarily at each phase*. It was supplied throughout the time of its existence by water from the Kedong Gorge and, to a lesser extent, by water via the Kuenia Valley from streams draining the eastern wall of the Rift.

At some time after the deposition of Isaac's lake bed M13, minor faulting lowered the Ol Tepesi basin which filled with water to form a very shallow lake. The overflow from this Ol Tepesi lake was westward over the Olekemonge sector of the lake beds and when it drained the Ol Keju Nero river system had its route diverted northward and incised into the plain north of Oloolkesailie. The Ol Keju Ngiro was supplemented by water from a Kedong River until shortly after the Ol Tepesi lake had drained, as shown by the Ol Tepesi delta fan, but the Kedong ceased flow some time immediately afterward.

At this time the terrain south of Oloolkesailie had already begun to tilt downward toward the south. The Lake shoreline moved southward exposing the northern lake deposits first, and leaving deeper water south and west, finally evacuating the Olekemonge-Ol Tepesi plain completely. This terminated the Olorgesailie Lake series as they have been described in the literature and allowed erosion to begin. Since deepening in the south extended the lake southward to a definite limit at Ngadalat, the lake may have moved south _en bloc_ as the low point of the containing basin shifted south. It was now fed by the Ol Keju Ngiro and the Loodo Ariak, but the Kedong had been lost as a contributor.

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* Throughout this text I refer to the Olorgesailie Lakes, although there is no certain proof that there was more than one, and the land surfaces in the stratigraphy may represent stages rather than lake intervals. I have used the precedent of the Great Lakes series in which individual stages have been given names as lakes.

The Oloyeti and Oolkululu sectors of the graben which had no outlets, filled with water and overflowed the western lip of the graben at 02 (Fig.4-3), at a height of 880 m. Tilting continued, and the lowest overflow point migrated to 03 and 04. These overflows are so close in altitude that they must have been contemporaneous. Both points are at gentle saddles in the western rim at 850 m. At this stage the overflow 03 was dominant and fed water to a highest Lake Magadi-Natron which had totally submerged Karamai and left a shoreline whose present altitude is ≃700 m.

Tilting ended at this time because the 700 m shoreline remains essentially horizontal. The overflow at 04 became dominant through downcutting at a fault line which is an extension of the Olkeri fault escarpment, and thenceforward took all the overflow of the Olorgesailie Lakes to the end of their existence. The gorge has a sill at 830 m, and the horizontal Magadi-Natron shore suggests that it and the 04 overflow are now at the absolute altitude at which the events occurred. The outlet 04 in its very last stages was the only overflow. The last stage fed a lower level of the Lake Magadi-Natron since channels from the gorge descend below 700 m at Karamai.

The absence of saline deposits within the Olorgesailie Lake beds and in the Koora generally is thus explained by the fact that the system was possessed of fresh-water inlets and outlets throughout its cycle: only on reaching local base-level in the Magadi-Natron lake or flats did the water stop moving and eventually evaporated, contributing any solutes that there may have been to the Natron and Magadi salt deposits.

The 'terraces' T1 and T4 can now be explained. In plan form they resemble deltas, and they cannot be interpreted as erosional terraces of any origin. Their altitudes provide supporting evidence in regard to the deltaic character. T1 with a surface at 852 and a lower break of slope at 840 m could possibly be an erosional bluff for a lake that overflowed at 845 m, but T4 with a surface at ≈840 m and a foot at 795 m could only have been eroded by a lake without an overflow. Such a lake would be saline, and of that there is no evidence. In addition to having an unsuitable plan form for terraces, both features face in the same direction (southward) down the valley gradient. There are no bluffs with other orientations as one might expect around a lake. T1 and T4 are therefore considered to be deltaic deposits or reworked diatomaceous material, largely derived from the Olorgesailie Lake beds. T1 was a delta at the had of the lake during the overflow at O3 and the first stages of O4, while T3 formed at the head of the final smallest Olorgesailie Lake which overflowed at 830 m. The river terraces T2 formed after the lowering lake level abandoned T1, but were probably cut by the streams that created T4.

The minimum downwarp implied by this sequence is in excess of 200 m: the elevation difference between the highest Olorgesailie lake bed and the overflow sill before downcutting, and may be as much as 300 m. This is the altitude difference between the shore at the exit of the Kedong Gorge and the overflow sill. All deposits in the Olekemonge-Ol Tepesi plains (except the red beds) predate the tilt, and all the surface materials in the Koora graben (except the diatomite remnants) postdate the tilt. The deposits on the floor of the Koora graben are probably at their original altitude since the gradient on the floor is 1:4,000 throughout the sector while the regional tilt of the lava surfaces in the containing horsts is 1:250.

The Olorgesailie Lakes apparently terminated abruptly since the lake below the last overflow was 50 m deep. Had that 50 m been maintained for any significant interval without an overflow, there would have been a recognizable saline stratum. Instead there are unmodified diatom deposits on the lowest floor and the general surface is of diatomaceous dust and ash. Although there is contemporary rill and gully erosion, and there are temporary pools on the surface after heavy rain, the Koora depression is never known to flood today.

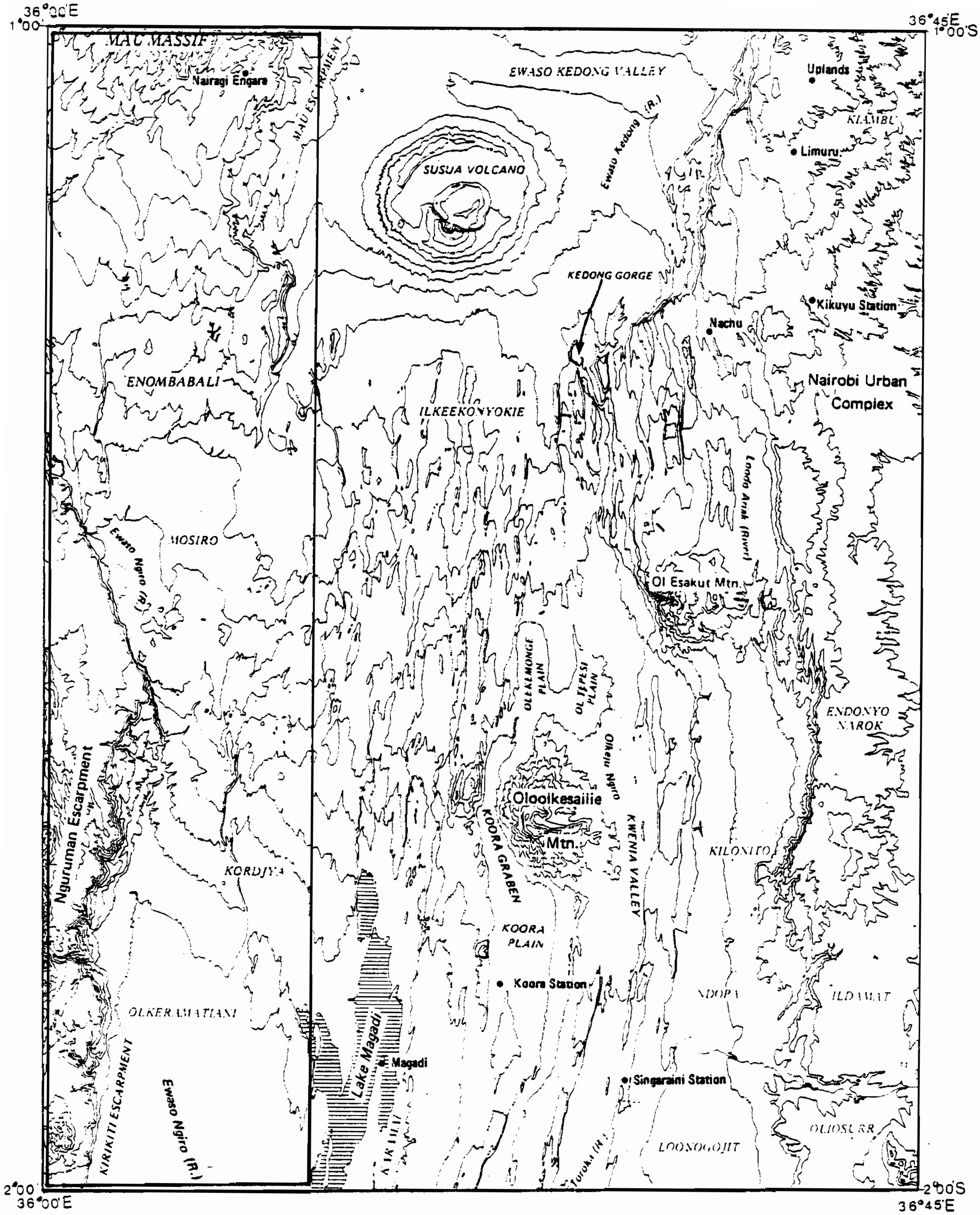

Fig. 5-1 General location map, Chapter five. The western flank of the South Kenya Rift Valley.

Chapter Five

THE WESTERN FLANK OF THE SOUTH KENYA RIFT VALLEY

I. DRAINAGE, PAST AND PRESENT

1) Contemporary drainage

The only perennial streams within the study area enter from the west. The Ewaso Ngiro is a perennial stream with a main course 150 kms long flowing northwest-southwest with a dozen tributaries which all drain southwestward off the southwest flank of the Mau massif. The course of the Ewaso Ngiro outside the Rift seems to be fault directed, and it may have intercepted streams which would otherwise have drained west to Lake Victoria via the Mara River. The Ewaso Ngiro valley is cut in volcanics which occupy the depression followed by Pulfrey's Primitive Athi River.

The Ewaso Ngiro enters the Rift Valley in a rock gorge 180 m deep, and it is joined within the Rift by three perennial streams off the Loita Hills; the Lenkutoto, the Entosapia, and the Oloibortoto (Folio location map, Fig. II:1). The latter are relatively short streams which do not cross the watershed of the Loita Hills and they are not relics of a large former drainage net. They are very deeply incised (500 m) in the Kirikiti basalt terrace which fringes the Nguruman escarpment, and although they are small enough to be described as misfit streams there is no positive evidence of a previous larger flow, nor do the walls of the gorges suggest a wetter environment in the past. The gorge floors are graded to the Olkeramatiani plain where large gently sloping alluvial fans have built up on the Rift floor. (Folio map 10). The Ewaso Ngiro bypasses Lake Magadi and sinks in the Ngare Ngiro marsh at the head of Lake Natron. The present Ewaso Ngiro could maintain a significant lake in a closed basin, but the present stream course could never have supplied the Olorgesailie Lake site.

2) Pre-rift drainage

Pre-rift drainage from a watershed to the west has been postulated by, among others, King (1958 pp. 103, 106), and Pulfrey (1960 pp. 13, 14). Any drainage from the west would be a likely source of water for lakes in the area if the first Rift faults faced westward, and when the Rift graben formed it would intercept any existing drainage and provide either lakes on the Rift Valley floor or a north-south diversion on the pattern.

The Ewaso Ngiro and its tributary the Seyabei occupy major valleys and there is no doubt about their antiquity. Wright showed that they predated the Plateau trachytes (as then defined) and had been dammed by them (1967 p. 29). This explains the curious condition in the Ewaso Ngiro gorge where 122 m of sediments are found west of the Rift Valley, above the river within the gorge, whereas there are no similar deposits at comparable altitude within the Rift itself.

Wright believed the rivers predated the Enkorika fault (Fig. 5-2, opposite p.80) and suggested that after the Lengitoto trachyte dammed the system a sequence of events involving faulting and lava flows created a series of three late-Tertiary/early-Pleistocene lakes (1967, p. 29). The events produced 200' (61 m) of waterlain ashes, and 200' of airfall tuffs, although the third, smaller, lake at the junction of the

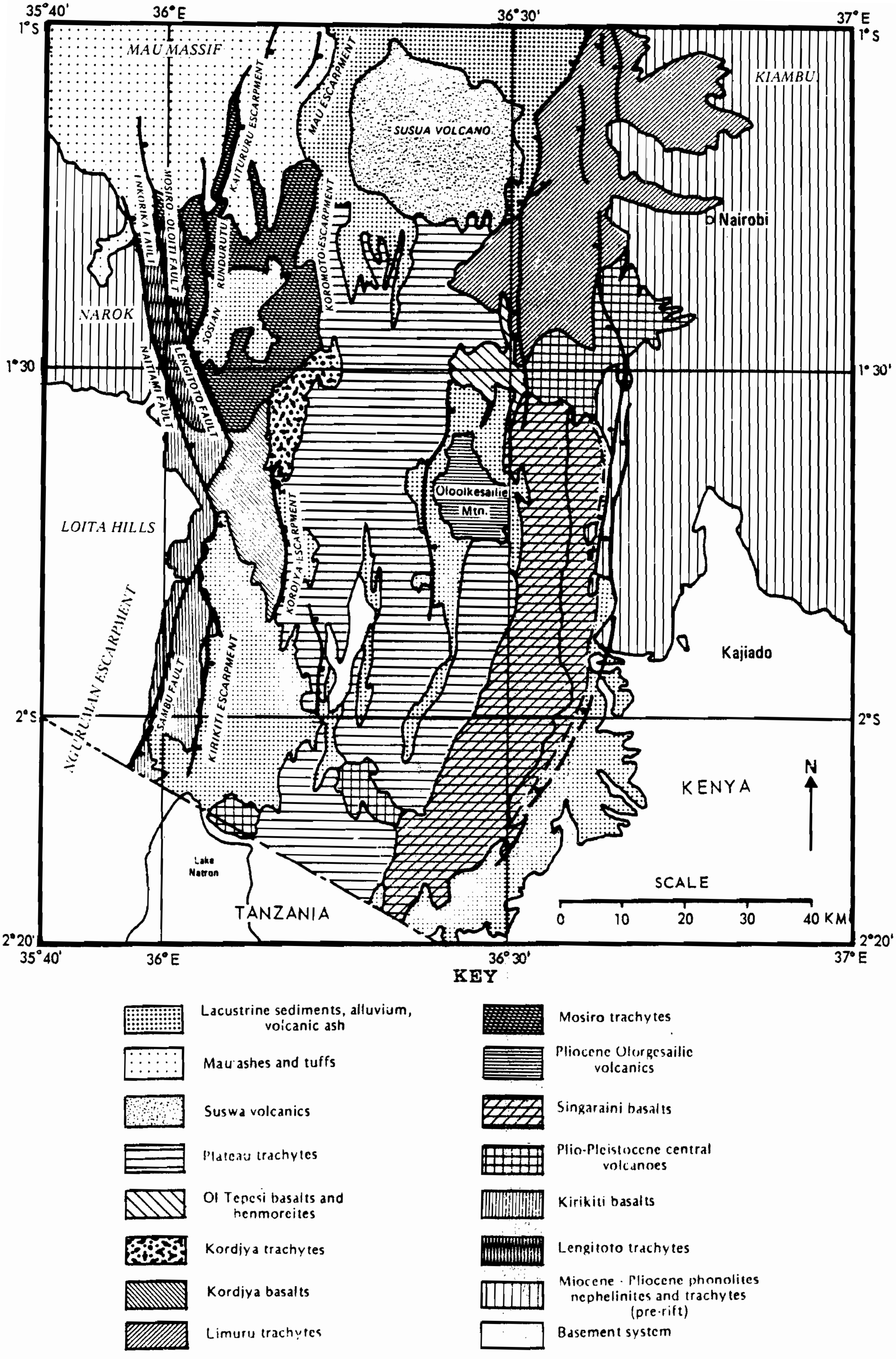

Fig. 5-2 Structure of the western flanks of the South Kenya Rift Valley.

Ewaso Ngiro and the Seyabei was not so deep. When the last lake drained, because of renewed Rift faulting along the Lengitoto fault, the Ewaso Ngiro cut the present gorge.

Wright describes the deposits in the gorge as stratified, occasionally current-bedded, and capped by an alkali basalt. Field work in the gorge confirmed this in general, but the basalt found was only 30 cm thick (Geological sample M36). Current bedding can be recognized at various levels within the deposits, but unstructured lamina 5-15 cms thick are dominant, and they resemble in their physical facies the stratified sediments of Njorowa Gorge and Baragoi. They were probably created by reworked sediments settling in still water, or could have been airborne debris that settled in still water. Wright considered the whole sequence to lie below the Alkali trachyte (1967, p. 27), but he does not state the evidence, and there is no section that shows it in the area.

II. AGE AND STRUCTURE OF THE WESTERN FLANK (FIG. 5-2)

1) Previous analysis

Wright had correctly interpreted the lake evidence, but his chronology was wrong because he had accepted Baker's stratigraphy of 1958 which held the Lengitoto trachyte to be the youngest of the Plateau trachytes (see p. 49). Randel (1970) also followed Baker, and he describes the pyroclasts in the gorge as above the Kirikiti basalt, interbedded with Alkali basalts, and capped with Orthophyre trachyte. It became clear during the present field work that Randel had defined the Orthophyre trachyte in terms of Baker's 'Upper Orthophyre', now known as the Ol Tepesi benmoreite, and he seems to have confused the 'Lower Orthorphyre trachyte' and the Alkali trachyte, since the distribution of

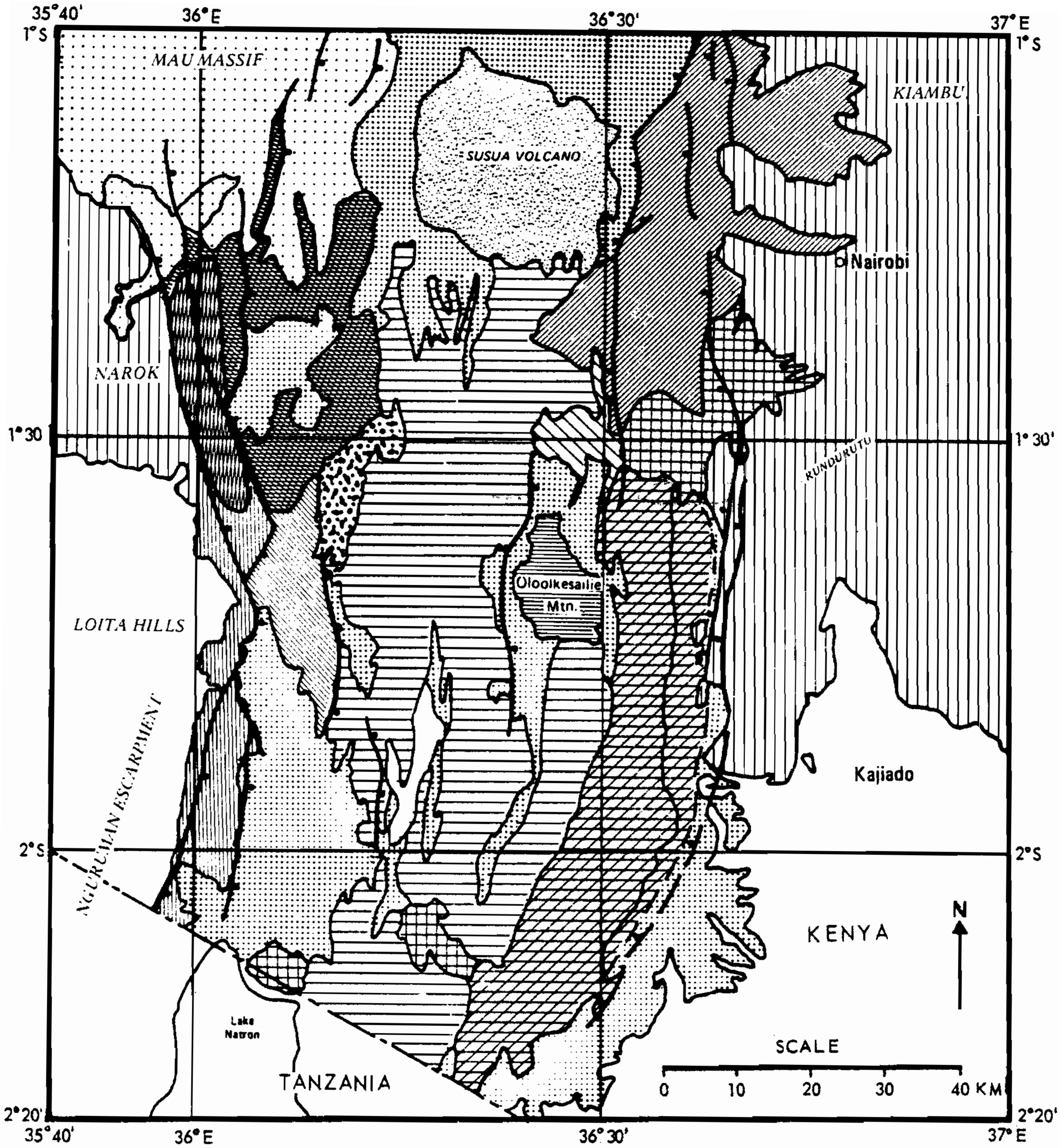

Fig. 5-3 The Oletugathi ashes, which may occupy the courses of a former west-east drainage net (Knight, 1976).

Alkali trachyte is not correctly shown on his map.

Recent work by Knight (1976, Ph,D. thesis, University of London, unpublished) has provided a sound stratigraphy for the area, and since his work subsumes the essential parts of Wright and Randel, while adding information about former drainage, and a chronology with K/Ar dates, it may be considered the definitive geology.

From the form and distribution of the Oletugathi group of ashes and tuffs which occupy old valley forms (Fig, 5-3), Knight has recognized an ancient drainage system with a main stream running from west to east. It lies over lavas in the depression supposed to have carried Pulfrey's Primitive Athi River (see p. 33 and Fig. 3-3). The drainage developed on Lengitoto trachyte which is much older than previously thought, since it has now been given ages ranging between 5.0 and 6.9 Ma by Crossley, Knight, and Williams (Crossley 1976). The stream valleys were then completely filled by the Entepot tuffs, Enamkorian ashes, and the Oletugathi ashes and lavas which date from 3.0 to 4.5 Ma BP (Knight 1977, pers. comm.). A new stream system began on this surface so the present Ewaso Ngiro - Seyabei system is a much younger stream system occupying radically different courses from the ancient streams. They originated parallel to the Oletugathi fault (south part of Enkorika fault, Fig. 5-2) some time after 3.0 Ma BP and incised themselves across the Lengitoto trachyte after the Lengitoto fault had renewed the Rift topography. This phase came to an end when the Mosiro trachyte (1.9 - 2.3 Ma BP) flowed against the Lengitoto trachyte at the Lengitoto fault-scarp and in places overflowed it. As a consequence the Seyabei was diverted southward (A on Folio map 4), and the gorge of the Ewaso Ngiro was invaded and blocked by lavas (B on Folio map 4), creating a deep lake over the gorge site.

Photo 5-1. Gorge of the Ewaso Ngiro where it cuts through the Mosiro trachyte 'dam' (see text), with the Seyabei sediments visible beyond. View north-northwest from the edge of the Rift Valley.

Between 1.7 and 0.6 Ma BP the Ewaso Ngiro overflowed at the 'dam' site while Mau ashes and tuffs accumulated in the gorge lake. What had been called Kirikiti basalt in the area by previous authors is really a much younger formation (Knight's Mosiro basalt, 1976) which erupted along the Mosiro-Oloiti fault about 0.6±.1 Ma, before renewed movement along the line of the Kirikiti, Lengitoto, Mosiro, and Sosian faults produced the present-day topography and caused the Ewaso Ngiro to incise its present gorge in its own sediments, and across the Mosiro trachyte dam (Knight, 1977 pers. comm.). (Photo 5-1).

0.6 Ma is a much younger age for the present topographic rift valley than any previously suggested, and it has been confirmed by Crossley for the area to the south where he records 660 m of downthrow on the Kirikiti escarpment after the Mosiro basalt was emplaced. He believes the course of the Ewaso Ngiro was relocated at that time along the base of the Lengitoto fault scarp. (Crossley, 1977 pers. comm.). The Orkaramatien sediments of the Olkeramatiani plain were displaced >200 m, and Crossley believes that other sediments high on the Kirikiti escarpment are reworked Orkaramatien materials, showing >600 m of movement. One consequence of this youthful age is that the former Ewaso Ngiro would have been able to pass across the Alkali trachytes of the Rift floor, since they had stopped flowing before 0.7 Ma BP.

The sequence described is correct in broad terms but there are several qualifications. The Oletugathi formation and its old drainage form could be equally easily interpreted as debris filling a valley system oriented to the southeast and broadly parallel to the present drainage rather than proving east-west flow (see Fig. 5-3).

Some movements along the Kirikiti-Lengitoto scarps undoubtdely took place after the eruption of the Mosiro basalt, but at that time there was already a large topographic Rift valley to the east, because Alkali trachytes (of the Plateau series 0.8-1.4 Ma) had flowed below the Koromoto escarpment at 1600 m leaving a relief of 200 m (pp. 49-50). There may be between 120 and 150 m of Alkali trachyte (Crossley 1976 Table 3, Baker 1976 p. 474) suggesting a previous relief of >320 m. On the east flank the Singaraini platform matches the Kirikiti basalt surface in altitude and age, and its form proves that the 400 m Turoka-Ngong fault-scarp above it has a minimum age of 2.3 Ma (p. 40).

The Koromoto fault-scarp (Fig. 5-2) is a major feature, it aligns with the Mau escarpment and the Kordjya escarpment, and is certainly the consequence of a Rift fault. The area between these escarpments and the Kirikiti-Lengitoto-Sosian-Rundurutu escarpment has the form of a ramp descending into the Rift from the Mau massif near Nairage Engare, and passing below the Orkaramatien beds on the Lake Natron floor (Fig. 5-2). The downthrow on the Kirikiti in its last movement may have been closer to the minimum of ≃200 m indicated by the positively identified Orkaramatien beds, because the Alkali trachytes lie below the Koromoto scarp but above the Kordjya scarp (i.e. pre-dating it), and has been preserved as a surface that shows it has tilted relatively little since its emplacement (pp. 43-44). Since the Alkali trachytes underlie the Orkaramatien beds this suggests that the ramp had not dropped as much as 660 m after the eruption of the last Alkali trachyte.

2) Structure, physiography, and drainage of the Rift flank

a. The Mosiro Ramp

The old Kijabe-Narok road climbs the western wall of the Rift west of Susua mountain in an embayment of the scarp, rising 300 m across normally water-eroded valleys in the back wall. To the south of the road there is a spectacular homologue of the Ethinyai escarpment on the east side of the Rift valley, which has not been described in the literature. A cross-fault truncates the north-south rift faulting leaving an abrupt north-facing escarpment more than 400 m high at the Tikako Hills (Folio map 1 Fig. II:3). Dry valleys traverse the scarp, hanging on the north face, but with gentle gradients southward on to the lower terrain of a step-fault platform or ramp (A and B on Folio map 1). The easternmost wind-gap leads directly into a major closed depression, and can then be linked to a valley which cuts back across the east-facing Koromoto escarpment and is used by a seasonal stream today.

This sector of the step-fault platform is traversed by only two relatively minor faults which show topographically as displacements of about 25 m. There is no equivalent of the grid-fault dominated topography of the Esakut platform.

The terrain westward lies at an altitude of 2000 m or more, and extends beyond the influence of rift faulting. The last visible faulted rock is at 2040 m on the Ol Kaitorror ridge, where there is a fault-scarp with at least 40 m downthrow to the east. That escarpment peters out northward, but another striking linear feature to the eastward is a fault with 80 m of throw which has been masked by ashes and tuffs. It extends northward beyond Nairagi Engare (Folio map 1). The terrain is otherwise a normal fluvial landscape with a simple consequent drainage pattern. The bed rock has been masked by the Mau ashes, but the fact that some buried escarpments can be recognized suggests that the underlying rock surface matches the general topography, and there is no deeply buried horst and graben terrain. The consequent drainage pattern is only modified around Nairagi Engare where headward erosion of streams flowing consequents and left isolated hills whose alignment suggests the direction taken by former stream valleys (1, 2, and 3 on Folio map 1).

The terrain has two distinct variants in terms of slope, slope orientation, and drainage density and maturity. The boundary between the two terrains is clearly marked by the Pinyini River (formerly the Ladere River) a tributary of the Seyabei (see Folio map 1). The river marks, and is guided by, the northwest boundary of a Mosiro trachyte flow, and the flow is thus shown to extend beyond the rift proper.

South of the Kijabe-Narok road, in the area north of the Mosiro village, the Mau ashes thin and disappear exposing a terrain of trachytic rocks which has a number of fault-scarps reaching 40 m in height, but which is in general a water-shaped terrain, as is demonstrated by the many fluvially eroded channels, and more significantly by the general contouring (southern portion of Folio Map 1 and northern portion of Folio Map 4). The gradient in this sector is reduced sharply from that of the general slope of the Mau (1:55 as compared to 1:25), but it is clear that the sector is a ramp descending into the Rift, since it drops below 1600 m and becomes bounded to the west by the Sosian-Rundurutu escarpment, a continuation of the line of the Kirikiti and Lengitoto fault scarps which mark the western edge of the Rift southwards.

This is the sector described by Baker (1970 pp. 165-6), where he suggests that trachytes, alkali basalts, and tuffs formed against the Lengitoto and Kirikiti faults, but overflowed the Enkorika and the Naitiami Faults. There are serious difficulties with Baker's interpretation. In his chronology (1958 p. 18, and 1970 pp. 165-6) the Plateau trachytes flowed after the formation of the Kirikiti and Lengitoto scarps,with only the Lengitoto trachyte predating the Kirikiti fault. He showed Alkali trachyte lying against the Kirikiti scarp, and Alkali and Orthophyre trachytes emplaced against the Lengitoto fault-scarp. Randel showed his Orthophyre trachyte placed against both escarpments, and Alkali trachyte at high altitudes around Ol Kaitorror. Because the Lengitoto is no longer considered to be the immediate forerunner of the Alkali trachyte, and because the Orthophyre trachyte is not the youngest of the Plateau trachytes, the former interpretations collapse. Crossley (1976) and Knight (1976) classify all the rock east of the Lengitoto-Sosian escarpments as a single Mosiro trachyte (see p. 49, and Fig. 5-2).

b. The Mosiro trachytes.

The chronology of the trachytes becomes crucial in interpreting and dating the drainage, and field work has shown that some changes in the stratigraphy are necessary in order to explain the topography. The prominent escarpment where the old Narok road crosses the Ol Kaitorror escarpment is shown as Alkali trachyte on Randel's map (1970). Samples show that is is an orthophyric trachyte resembling the Limuru trachyte in some ways, and it was so identified in hand sample by Baker; but unlike most Limuru trachytes it has a normal remnant magnetism (Brock 1972, for geological sample M45). Other samples taken from the area shown in Folio map 4 (M38, 39, 40, 41) do not show the surface rock as the Orthophyre trachyte of Baker's 1958 map (his 'Upper Orthophyre'), but can be equated with the former 'Lower Orthophyre" which is now recognized as Limuru trachyte. Knight (1977 pers. comm.) also correlates his samples from the same general area with the Limuru trachyte (see p.47). A more coarsely crystalline orthophyre resembling the Ol Tepesi benmoreite (samples M23-28, 34, 35 and M42-45) occurs in isolated hills north of Mosiro and becomes prominent at the foot and crest of the Sosian-Rundurutu escarpment (see the topography shown on Folio maps 1 and 4). The coarsely crystalline rock and its small rugged hill forms become dominant south of the Mosiro Lake floor, and extend as far south as the North Kordjya trachytes which it strongly resembles in petrology and landforms (Folio map 7, and Fig. 5-2)

Crossley, who has identified all my samples from this area recognized three broad types of the orthophyre trachytes:

Type a. Glomeroporphyritic with fine-grain fairly ragged-looking groundmass feldspars. Typical of Limuru trachyte.

Type b. Glomeroporphyritic with medium grained orthophyric textured groundmass.

Type c. Abundant unusually coase feldspar phenocrysts in a medium-grained groundmass.

Knight's Mosiro trachyte is of type b, while Crossley's Mosiro trachyte and the North Kordjya trachyte are of type c. My samples M38-41 fall within type b, but M23-28, 34, 35, 42-45 are of type c, showing that the petrology can be correlated with topography, and that both types

Photo 5-2. Typical distinctive terrain in the areas of North Kordjya trachytes and the Ol Tepesi benmoreites.

of trachyte are present north of Mosiro. There are therefore two sequences of orthophyric trachyte in the area. Type c, found in distinctive hills, is an older rock whose hills have been left as steptoes when flooded by lavas of type b. The type b terrain is coherent in area and form, and extends from Nairagi Engare west to the Pinyini River and south to the Mosiro plain where it has surrounded occasional eroded hills of the older trachyte. It failed to flood the hills of older trachyte south of Mosiro which at that time stood significantly higher.

Dates for the Mosiro trachytes (types b and c) range from 1.9 to 2.3 Ma BP (Table 3-2). The North Kordjya basalt (which contains the North Kordjya trachytes) dates between 2.2 and 1.7 Ma BP, but the trachyte is probably nearer 1.7 Ma since it occurs high in the Kordjya basalt formation. Both the Mosiro and the North Kordjya trachyte predate the Mosiro ramp and the Alkali trachyte. The Mosiro type b has very close affinities with the Limuru trachytes and is assumed by me to be a member of that formation (see p. 50).

The North Kordjya trachytes have a distinctive topography resembling that formed on Ol Tepesi benmoreite in the east, with heavily weathered rugged minor hill forms, and large distinctive boulder debris (Photo 5-2). A section at the north limit of the Kordjya plain shows that this erosion surface plunges abruptly below the Alkali trachyte at a sharp disconformity (Geological samples M86, M87). Crossley shows the same orthophyre trachyte plunging below Kordjya basalt on the west.

Photo 5-3. Lake sediments near the Mosiro store. The Lengitoto escarpment of the Kirikiti platform can be seen in the background, with the Loita hills in basement system rocks at the rear.

c. The Mosiro Lake.

The rock surface immediately east of the Ewaso Ngiro gorge is hidden by sediments which cover 150 km^2 of the terrain around the Mosiro trading post (Folio map 4)(LANDSAT image, Folio Fig. II:2). The materials are not obviously fluvially stratified, but diatom fragments can be recognized in every grab sample. Knight shows the Mosiro plain as Mau ash, but although ash is present in large quantities the soil samples do not resemble the Mau ashes. They contain diatoms, silts, and fine sand, and frequently show a blocky structure. They apparently represent materials settling in a still-water environment but they do not seem to be reworked tuffs from the Seyabei beds. The Ewaso Ngiro skirts the western edge of this plain cutting down to bedrock in most places and showing a mere 3-5 metres of sediment cover. Ten kilometres to the eastward the materials are equally thin with bedrock showing through. The thickness of the sediments in the centre of the plain is unknown, but around Mosiro gullies expose 7 m of sediments without showing bedrock (Photo 5-3). On the east the sedimentary plain ends at a thin flow of Alkali trachyte which overflowed the edge of the Koromoto escarpment (F1 on Folio map 4) and may have acted as a dam for an Ewaso Ngiro which traversed the ramp. The form of the sediments is not an exact plane, being gently dished toward the west because of contemporary stream erosion; and the floor must have been tilted after its formation because lake deposits occur at 1400 m in the north whereas the sill on the south is at only 1310 m in an open plain (OS1 on Folio map 7), from which isolated and distinctive hills of orthophyre trachyte rise steeply 20-50 m. The Mosiro Lake had at least one major overflow channel, now dry, which can still be recognized. It cut down as incised meanders 10-100 m deep in a gorge-like valley up to 400 m wide. The channel crosses the Kordjya basalt and joins the lower course of the Ewaso Ngiro (Ol on Folio map 7). The channel post-dates the basalts and the alkali trachytes, but pre-dates the time when the Ewaso Ngiro occupied its present course and cut down deeply enough to drain the Mosiro Lake. Crossley (1977 pers. comm.) ties the relocation of the Ewaso Ngiro to the last faulting event on the Kirikiti escarpment, and the age is less than 0.6 Ma.

d. The Kordjya Lake.

Crossley in his thesis includes a history of lake development in the Ewaso Ngiro depression (Ol Kariamatien plain) which lies south of the Mosiro Lake site (1976 p. 132). The Oloronga beds were followed by the Orkaramatien beds, both laid down in a gentle shallow depression. After further movement on the Kirikiti fault and the creation of the Kordjya and Magadi grabens, there was a lake which reached 700 m in the area, invading and drowning the Kordjya graben. Crossley identified two lower shorelines within the Kordjya graben at 679 m and 666 m, and he offers convincing evidence that the 679 m lake was independent and self-sufficient. He also shows that the last drainage at the 666 m overflow (RCOl on Folio map 10) was sudden and violent, leaving a scatter of boulder debris on the clean rock surface. It was caused by the sinking of the Magadi trough, with most movement on the Oleikonet fault which forms the present high scarp west of Lake Magadi. (Crossley 1978, pers. comm.).

Crossley also identified quartz sands and pebbles of metamorphic basement rocks found at the contact below the base of the Kordjya basalts where it lies upon the North Kordjya trachytes. He deduced that streams were running east-west at that time ($\approx$1.7 Ma BP) (Crossley 1976 p. 132). However, this was a relatively local phenomenon since the streams came from the Loita Hills which represent an erosion remnant, and the streams were not part of a continental drainage net.

The 700 m Kordjya Lake was probably an embayment of the 700 m High Natron-Magadi. Aerial photography shows a large gentle alluvial fan built on to the Kordjya plain, and water courses entering from the northeast (D1 on Folio map 10). Those courses are antecedent to the minor faults west of Lake Magadi and it seems that Lake Kordjya was fed at that time by streams running on the alkali trachyte and draining from the general area of the present Ndupa River, which would have been relocated to its present site by the collapse of the Lake Magadi graben.

III. GENERAL SUMMARY AND CONCLUSIONS

The western flank of the Rift is defined by two major fault systems one at the base of the Nguruman escarpment along the line of the Kirikiti-Lengitoto-Sosian escarpments, and another along the line of the Kordjya-Koromoto-Mau fault-scarps. They are separated by a ramp which drops from the altitude of the general surface outside the Rift in the north, to the floor of the Rift in the south.

Perennial streams off the Loita Hills are building alluvial cones on the foot of the ramp, but they have relatively small drainage basins and do not represent remnants of an ancient drainage net on a continental scale. About 2 million years ago they extended at least 10 kms further east, but there is no evidence that they were any larger at that time. The present streams are almost certainly misfits in the great gorges that cross the Kirikiti basalts but there is no proof of previously larger flows, and no indicators of climatic change in their channels or their deposits. The extended streams predate the Alkali trachyte on which the Olorgesailie Lake beds lie, and did not contribute to the Olorgesailie Lakes. The present streams never crossed the Alkali trachyte but became tributary to the Ewaso Ngiro.

In the north, the head of the ramp lies in the Narok gap of the sub-Miocene surface, which extends between the Loita Hills and the Mau massif. Like the Nairobi col on the eastern flank, the Narok col which was originally cut in basement system rocks has been floored with a variety of Miocene and Pliocene volcanics, including phonolites, nephelinites, and trachytes. It can be shown that an ancient stream system occupied the area, crossing the first Rift faults in the west and cutting down into Lengitoto trachytes during the period between 6.9 and 4.5 Ma BP. That system was obliterated by the Oletugathi ashes and tuffs, and it was replaced by a fault-directed ancestor of the present drainage net some time after 3.0 Ma BP. The ancestral Ewaso Ngiro-Seyabei system began to cut down when a shallow graben developed at the Rift site caused by renewed movement at the Lengitoto fault. The graben was later filled by an eruption of Mosiro trachytes which began about 2.3 Ma BP, damming the Ewaso Ngiro and diverting the Seyabei southwards. An eruption of a second phase of the Mosiro trachyte (here equated with the Limuru trachyte) overflowed the Rift Valley form in the north at Nairagi Engare, spreading westward well beyond the Rift, and it also drowned some of the earlier Mosiro trachyte terrain to the south. It was limited in southward extent by the higher residual hills of the first Mosiro trachyte. At that time drainage over the Mosiro Limuru trachyte conformed to the original lava flow surface, draining southwest in a pattern similar to that on the Mau but on a gentler slope, before being diverted into the pre-existing Ewaso Ngiro system at the flow perimeter.

The Ewaso Ngiro may have passed west-east across the Mosiro ramp at this time, but if it did the evidence is buried below sediments and alkali trachytes. Alkali trachytes flowed thinly over the eastern edge of the ramp sometime between 1.4 and 0.7 Ma BP and dammed the Ewaso Ngiro flow within a shallow depression on the Mosiro/Limuru trachyte north of the Mosiro trachyte hills. The Mosiro Lake formed and overflowed southward over a gentle sill among the Mosiro hills until further gentle movement of the ramp and strong renewal of movement along the Kirikiti-Lengitoto fault about 0.6 Ma BP initiated the present Ewaso Ngiro gorge and also caused an overflow channel of the Mosiro Lake to relocate along the Lengitoto escarpment. The incision of the channel drained the Mosiro Lake and created the present course of the Ewaso Ngiro within the Rift. The Mosiro Lake overflowed to various levels of a high Lake Natron-Magadi, including the last and highest level at 700 m.

An embayment of the 700 m lake in the Kordjya graben was also fed by streams passing over the Alkali trachytes in an approximately north-south direction and apparently independent of the Ewaso Ngiro supply.

Drainage over the Limuru trachytes and the ramp was in a significantly greater volume than today and appears to have come from the northeast, over the site of the present Rift. The topography north of Mosiro appears to have developed in a pluvial environment with more precipitation than exists today.

IV. SUMMARY OF DRAINAGE DEVELOPMENT

Streams from the west crossed the Rift site until after 4.5 Ma BP. Streams continued to enter the Rift Valley from the west until 2.3 Ma BP, at which time they were diverted southward within the Rift, near its western edge. In the period after 1.7 Ma BP these waters were being supplemented by streams draining an area to the northeast, apparently over the present site of the Rift, and after 0.8 Ma BP they were also being joined for a short time by streams running north-south over the Alkali trachyte that had flooded the floor of the Rift. These events pre-dated the final formation of the shallow graben now occupied by Lake Magadi. The range of ages given for streams within the Rift is limited by the youth of the rocks they flowed upon, and do not necessarily indicate that there were no earlier streams on the Rift floor.

The drainage systems that entered the Rift from the west could never have fed the Olorgesailie Lakes site. The older streams pre-dated the Alkali trachytes on which the lakes formed, while the later streams never crossed the Alkali trachytes, but were diverted down the western side of the Rift Valley. North-south streams over the Alkali trachyte, such as those that fed the Kordjya Lake had a different area of origin and they are discussed in Chapter seven.

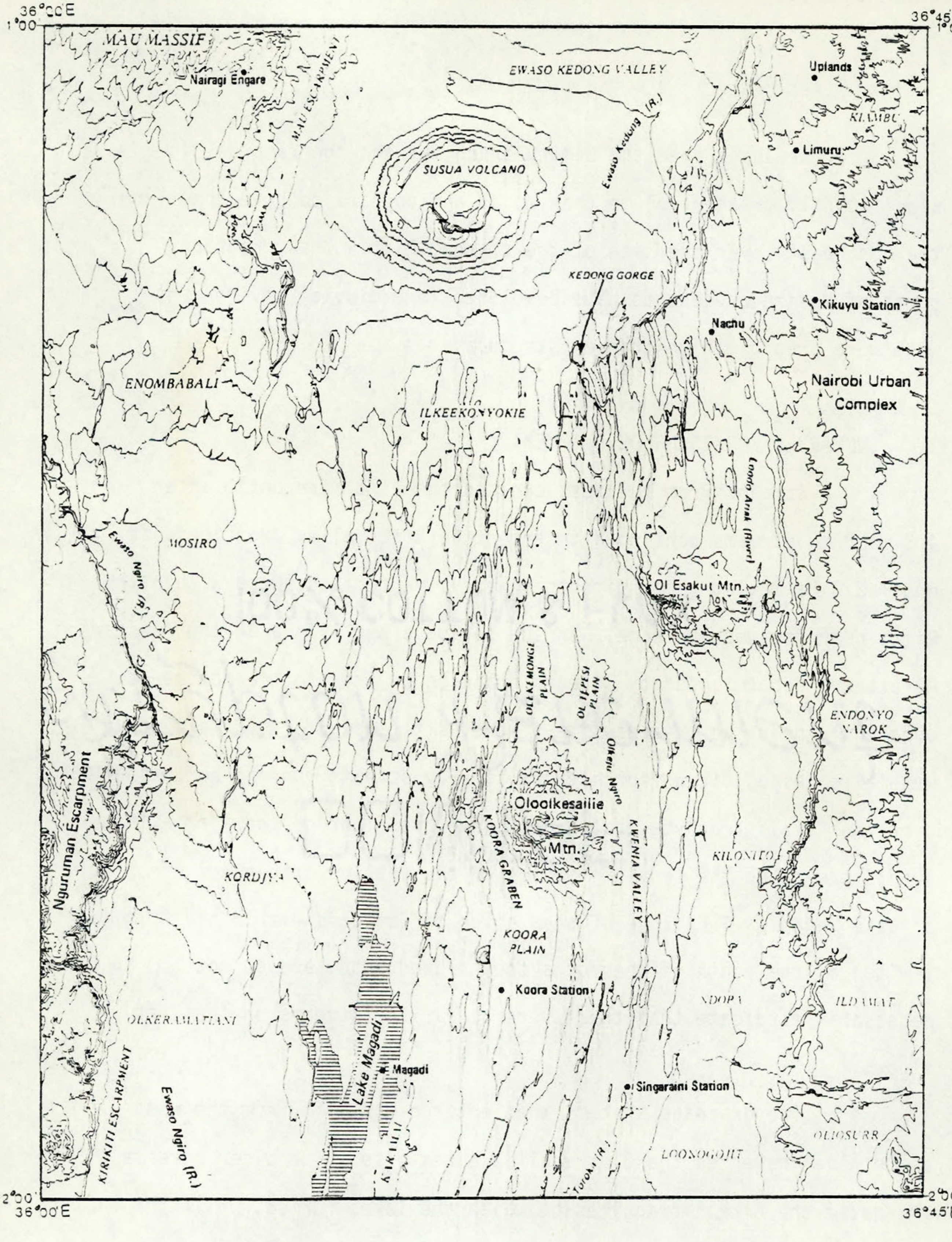

Fig. 6-1 General location map, Chapter six. The eastern flanks of the South Kenya Rift Valley.

Chapter Six

THE EASTERN FLANK OF THE SOUTHERN KENYA RIFT VALLEY

Pulfrey suggested that the Primitive Athi River crossed the site of the Rift Valley before the Rift formed on the sub-Miocene surface (Pulfrey, 1960 p. 13) and it has been shown that modest streams continued to enter the Rift Valley from the west between 5 Ma BP and the present (Chapter 5). Since any cross-rift drainage system would be beheaded by the eastern Rift faulting, analysis of the former drainage channels on the eastern flank might give dates for those stream systems that crossed the Rift Valley site, and those that were intercepted.

The eastern flank of the Southern Kenya Rift Valley has two sectors with quite different characters (Fig. 6-1). The Singaraini platform stands low in the Rift with a single well-defined scarp above it at an abrupt change in the surface geology, while the Esakut platform stands high above the Rift floor and then rises in a series of lesser escarpments to the rim of the Rift. The surface rock of the Esakut platform extends beyond the limits of the Rift Valley eastward (Fig. 6-2).

I. THE SINGARAINI PLATFORM (FIG. 6-2)

The Singaraini platform was formed when the Singaraini basalt flowed against the Turoka-Ngong fault-scarp which cuts basement rock of an erosion remnant on the sub-Miocene surface and nearly 300 m of Miocene

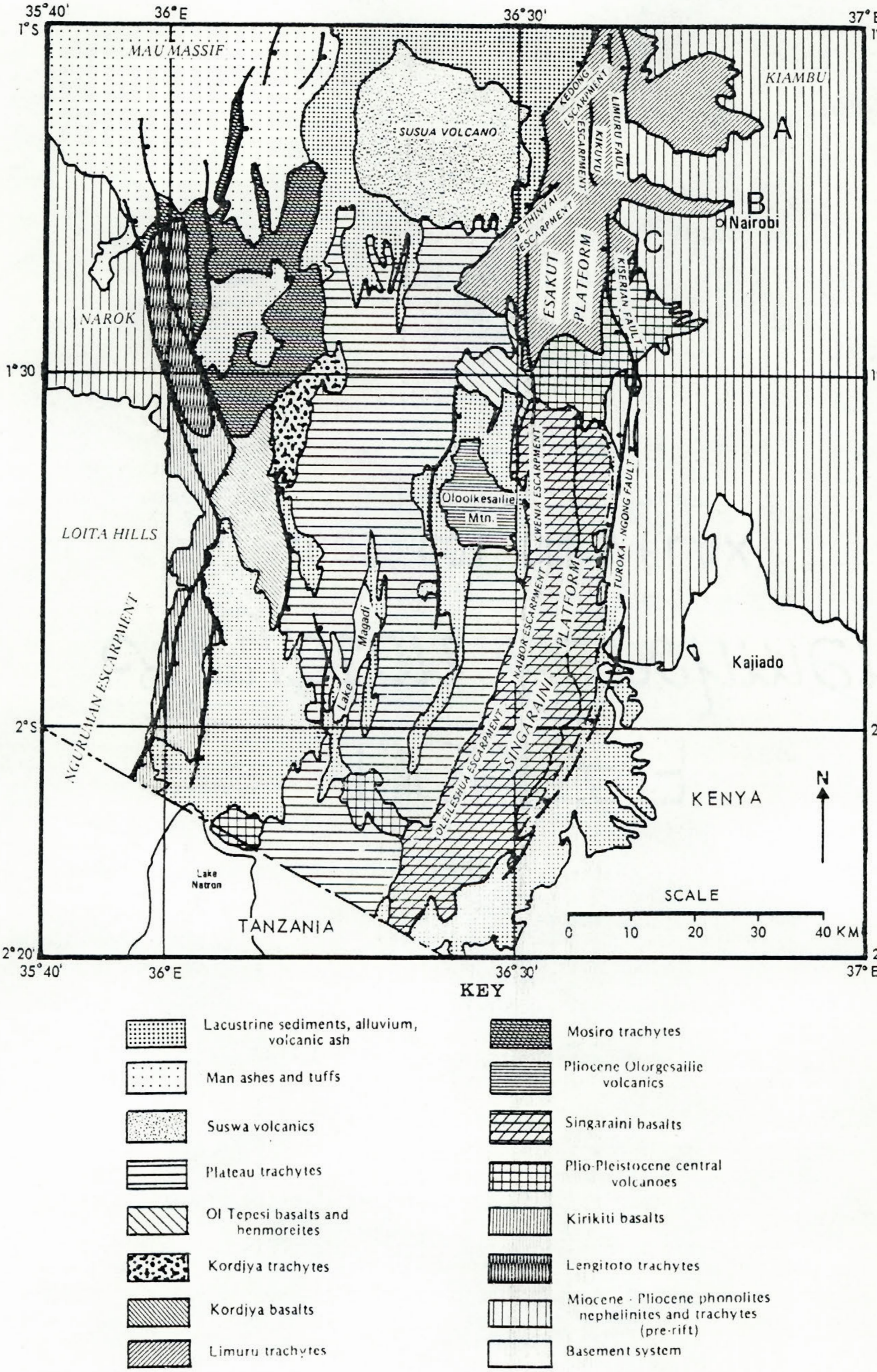

Fig. 6-2 Structure of the east flank of the South Kenya Rift Valley.

and Pliocene volcanic phonolites and tuffs which lie above it (pp. 37-8). The platform is almost horizontal and has a clearly defined escarpment where it overlooks the Rift floor (Photo 6-1). The Turoka-Ngong escarpment stands 400 m above the basalt, and although there are gentle saddles in the volcanic hills east of the Rift and relatively insignificant contemporary valleys there are no obvious former channels of major rivers draining to the east. All the streams in the area except the Loodo Ariak have formed on the fault-scarp and are now cutting headward during their periods of seasonal flow. Even the Toroka, which has an immense open gorge, must be the result of reverse drainage at the escarpment since it has not yet breached the watershed (Folio map 9). The Loodo Ariak drains from the Esakut platform where it has its origins in springs along the base of the Ngong Hills and it is supplemented seasonally by run-off from the Ngong Hills, which are high enough to intercept precipitation when the Rift floor is still dry. All the streams in the sector are seasonal.

The Singaraini basalt on the platform helps date the drainage net. There is very little incision on the basalt, even by the Toroka River, but there is clear evidence that the channels are antecedent to the grid faults, which they traverse in water-gaps (see pp. 59,60) and Folio maps 9 and 12). The Loodo Ariak also predates the limiting fault of the platform since it has superimposed its original line across trachyte horsts to the west (p.59). All the streams have cut gorges where they leave the basalt platform, but the Loodo Ariak is again outstanding since it has a significantly longer gorge than the

Photo 6-1. The Singaraini platform from below the Kwenia escarpment.

others, suggesting that it has consistently had a bigger flow of water. There are no large alluvial fans at the break of slope where the streams leave the Turoka-Ngong scarp and begin to cross the basalt. The lack of a channel on the basalt for the Toroka and the lack of a talus cone or alluvial fan in spite of the huge volume of materials removed from the Toroka Gorge suggest that ther period of maximum erosion by the Toroka may predate the Singaraini basalt and the eroded materials may lie buried in the Rift Valley.

The maximum age for all of these streams is provided by the age of the Turoka-Ngong fault which is less than 4.8 Ma (age of the Kerichwa tuff, the youngest rock cut by the fault). The channels where they run on the basalt must be less than 2.3 Ma old, and where they run on Alkali trachytes their age will be less than 0.7 Ma. With the exception of the Loodo Ariak it is clear that the streams incised themselves upon the basalt, but were deranged by the events that created the Singaraini platform and the subsequent grid-faulting in the Alkali trachytes on the floor of the Rift Valley (p.59).

In the study of the Olorgesailie Lake site (Chapter 4) it was shown that the Toroka flowed over the Alkali trachytes but never fed the Olorgesailie Lake site, being diverted southward into the ephemeral Lake Cabongo. It has been demonstrated that the streams over the northern platform did supply the Olorgesailie Lakes via the Kuenia Valley (Chapter 4), and the history is well understood).

The Toroka is the only water course that suggests wetter conditions in the past, because of the great quantity of erosion along the river and its tributaries. The debris from the Toroka erosion cannot be recognized above the Singaraini basalt and must be buried below it. There are no other traces of climatic shifts of any kind, and the wet period, if it existed, predated the Singaraini basalt (minimum 2.3 Ma) and post-dated the Turoka-Ngong fault-scarp (maximum 4.8 Ma). The other stream courses all suggest that they formerly carried more water, or were perhaps perennial, but there is no specific evidence of climatic shifts such as fluvial deposition, soil profiles, or organic remains.

1) Summary-drainage in the Singaraini sector

There is no positive evidence of streams having crossed this sector of the Rift Valley after 4.8 Ma BP except for gentle saddles in the hills east of the rim, and any evidence of earlier systems would have been buried by volcanic materials. The recognizable drainage in this sector is reverse drainage, which developed on the face of the Turoka-Ngong fault-scarp after it formed at a date less than 4.8 Ma BP. The large gorges of the Toroka indicate active fluvial erosion in the period before the Singaraini basalt erupted (2.3 Ma BP), but the other streams do not show a similar history. All streams reformed and crossed the Singaraini basalts after it cooled. When the Singaraini platform was formed (before 1.4 Ma BP since Alkali trachytes flow against the base) the streams began to cut back from the step. The streams beyond the platform maintained their courses across some of the Alkali trachytes but were soon disrupted by grid-faulting and there are no significant east-west channels on the Alkali trachytes. All the stream courses suggest that they formerly carried more water more often than at present. They may have been perennial, but there is no absolute proof, and, apart from

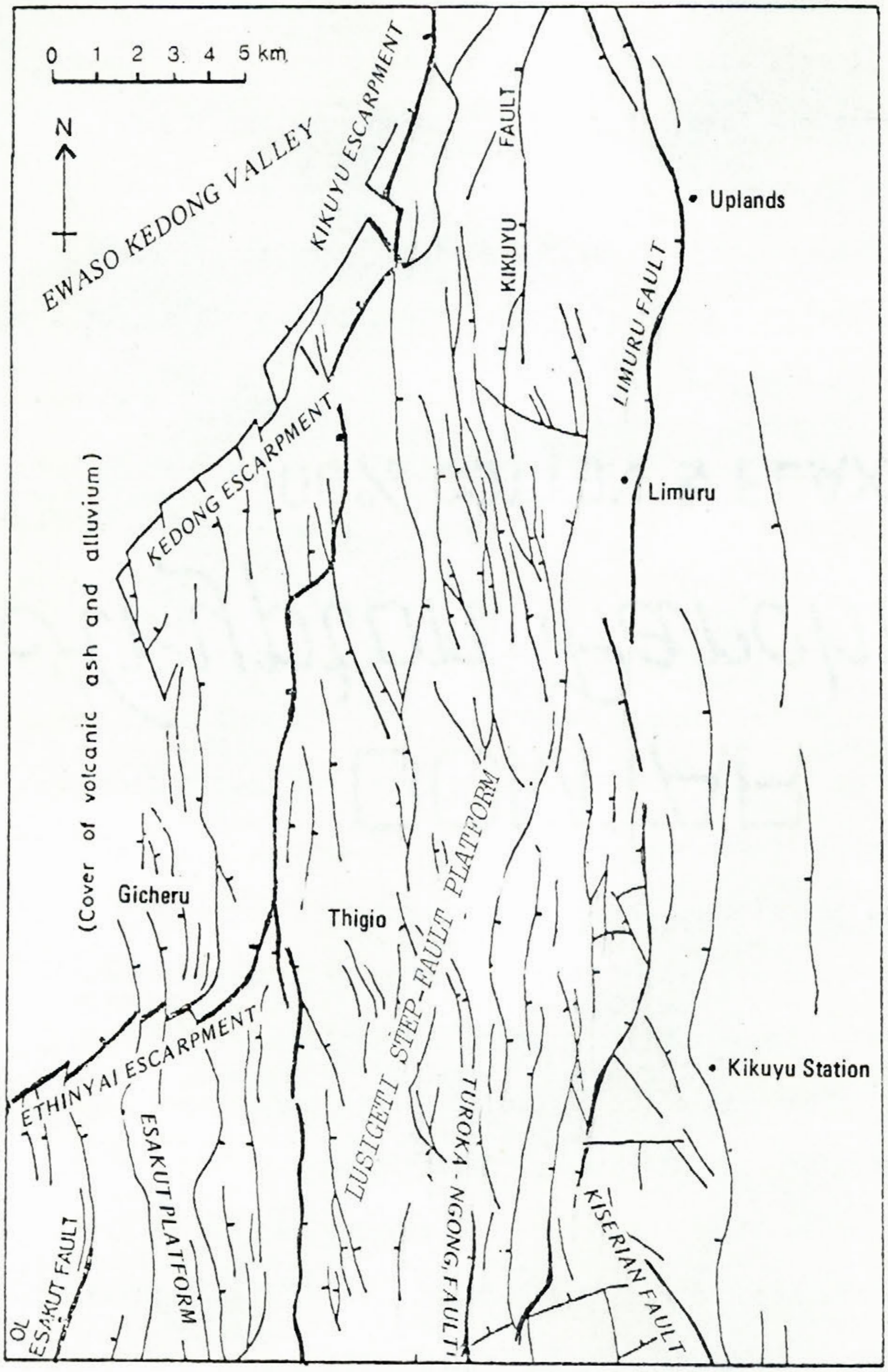

Fig. 6-3 The Lusigeti step-fault platform (part of the Esakut platform). For details see Folio maps 3 and 6.

the Toroka, no indication that there were significantly larger streams than the present maximum seasonal flows.

II. THE ESAKUT PLATFORM (FIG. 6-3)

The Esakut platform is a step-fault platform with an area of approximately 900 km^2. It stands 500 m above the floor of the Rift and about 500 m below the eastern rim. It has been severely grid-faulted and presents a complex terrain of horsts and grabens. It is usually described as extending between the Esakut fault and the Kikuyu-Ngong fault-scarps, but there are important rift faults east of that line, e.g. the Uplands and Limuru faults, although they show relatively little movement. The eastern boundary of the platform is not clear, and there is a subsidiary step-fault which lies east of the line of fault scarps that lie between Githingucho and Ngong, but west of the Limuru-Muguga-Kiserian fault-scarps (Fig. 6-3). It has been called the Lusigeti step-fault platform in this text. All the contemporary perennial streams lie eastward of the step-platform on the outer flanks of the Rift Valley (Folio map 3).

Except for the Plio-Pleistocene volcanoes of Ol Esakut and the Ngong Hills, the platform and the adjacent rim are covered by the Limuru trachytes. As described on page 45, the Limuru trachyte overflowed the Rift form eastward in topographic lows between low escarpments which held it back in places (1, 2, and 3 on Fig.3-5). The largest overlow (A on Fig. 6-2) extends 17 kms east, with a maximum width of 14 kms. The flow obviously occupied a broad topographic depression. The perimeter is irregular, but the salients and re-entrants are not evidence of pre-existing smaller drainage channels, because in most cases the re-entrants that show on the geological map are due to contemporary stream erosion cutting through the flows and exposing the rocks below, while leaving Limuru trachyte on the interfluves. In a few cases however, the flow salients occupy the valleys and, as at the Kiu and Riuru rivers, the lava flows were evidently guided by smaller channels within the broader depression. The flow immediately overlies undated Tigoni trachytes, which overlie Kabete trachytes and then Nairobi trachytes (3.2-3.5 Ma, Baker et al., 1971), which in turn overlie the Upper Kerichwa tuffs (4.84 - 5.67 Ma, Baker et al., 1971). The tuffs occupy a much larger area, since they overlie everything between the Kiambu ridge and Ngong, so the valley in which the various trachytes flowed postdates the Kerichwa tuffs. The form of the lobes of each successive trachyte show a gradual narrowing of the troughs in which they flowed. The Kabete trachyte lobe is 24 kms across, the Tigoni trachyte lobe nearly 16 kms, and the Limuru trachyte lobe is only 13 kms wide at the scarp rim. The earlier flows predate local Rift faulting, since only the Limuru trachyte has its distribution modified by the faults. The repeated recurrence of a trough which followed each lava flow and guided the next, suggests a constant major stream flow that maintained a broad fluvial valley until after 3.2 Ma BP.

That the sequence is not a topographic freak is shown by the occurrence of a second lobe 12 x 3 kms which overflowed at a trough in the scarp east of Kikuyu Station (B on Fig. 6-2) and a minor lobe

4 x 3 kms which similarly overflowed the scarp at the height of land near Gikambura above the Riu swamp (C on Fig. 6-2). There is thus clear evidence of a large and effective fluvial system crossing the eastern Rift fault sites between 4.84 and 2.2 Ma BP, the earliest suggested date for the Limuru trachyte eruption. There is also evidence that streams crossed the Limuru trachyte after its emplacement.

III. EVOLUTION OF THE PHYSIOGRAPHY ON THE LIMURU TRACHYTES

The newly established distribution of the Limuru trachytes shows that the area covered has a variety of precipitation regimes. The step-fault platforms and the area east of the Uplands escarpment coincide closely with the physiographic regions set up by W.T. Morgan. 1) 'The Kikuyu dissected slope' east of the Uplands-Limuru-Kikuyu line, 2) 'The Kikuyu undissected upland' west of the line, and 3) 'The Eastern Rift step-faults (north).' (Morgan, 1967, Fig. 2, p. 15). Morgan defined the first area solely in terms of its dissection by large numbers of sub-parallel consequent streams,but it is also an area of high rainfall and uniform slope. This sector shows very clearly on Folio map 3 (Folio Fig. II:5), and is called the Kiambu slope in this text. The second zone, misleadingly described as 'above' the first, is described as an area to which the streams of the first zone have not cut back, but it is also described as 'mostly grassland with low hills, some the result of faulting parallel to the Rift.' This has been called the Lusigeti step-platform in this text. The third zone is described as "a tectonic landscape, created by 'Sikes Grid', with some swamps and former lakes" and is referred to here as the Esakut platform.

The three divisions have different rainfall regimes. The Kiambu slope east of the Uplands-Limuru escarpments receives rainfall in excess of 900 mm per annum. There is an abrupt change west of the escarpments with annual rainfall of 500 mm or less, while west of the line Githingucho-Makutano-Lusigeti on the Esakut platform the rainfall drops away rapidly to near desert conditions (Thomson and Sansom, Fig. 6, p. 21, 1967).

The rainfall regimes are clearly reflected in the vegetation. E.C. Trump (1967, Fig. 12, p. 40) shows both upland areas without distinction as 'former forest', with the Esakut platform as evergreen bushland as distinct from the acacia savanna, and acacia bushland of the Rift floor. In fact the Kiambu slope is either forest or cleared land with African and plantation agriculture,while the Lusigeti step-platform has some managed forest areas (see Folio map 3), but in the main it is open grassland as described by Morgan (see background of Photo 6-3). The Esakut platform has scattered thorn scrub with areas of grass over the scattered swamps and lake floors (Photo 6-5, p.106).

East of the Uplands-Limuru line the Limuru trachyte has been deeply weathered and eroded. The structure and faulting cannot be easily recognized, and the deep river-cut valleys with thick soil covers on the slopes cannot be distinguished from those formed on the other trachytes and tuffs. West of the Uplands-Limuru escarpments on the Lusigeti step-platform the structure is obvious, with fresh fault-scarps, limited weathering, shallow soils if any, and only minor indices of fluvial erosion with some marked exceptions noted below. The Esakut platform shows an almost entirely tectonic landscape with former lake floors as superficial sediment accumulations below escarpments.

Photo 6-2. Ondiri, a typical swamp floor on the Lusigeti platform.

1) Former drainage on the Lusigeti step-platform

The two relatively arid platforms show clear evidence of a former drainage system in the form of wind and water-gaps cut across fault-line escarpments, and there are a large number of swamps and lake floors (Folio maps 3 and 6). There are also a number of broad gentle dry valleys which cross the height of land on the rim of the Rift Valley with swamp areas on their floors (Stereogram no. 1, Folio Fig. II:15).

When plotted on a map these features show a north-south linear distribution associated with the fault-line escarpments, but there is also an east-west relationship between groups of features which has been presented diagrammatically in Table 6-1. An 'x' indicates the presence of a feature of the type described in the column head. All the features lie west of the Uplands-Kiserian fault-line. The east-west pattern suggest a dendritic network rather than simple linear exotic streams crossing the platform.

The lake floors and some swamps represent deposits laid in water trapped against fault-scarps on a reverse slope, but some swamps occupy depressions on the floors of wind-gaps and they have been identified in Table 6-1. Between Kirenga and Kipruti on the line of the Upland-Kiserian faults there are six major swamp areas lying against fault-scarps (Photo 6-2). They are the Lari, Murengeti, Kiboko, Ondiri, Riu, and Kipruti swamps and they are listed in column 6 of Table 6-1. Lari and Murengeti have large and impressive water-gaps immediately to their eastward. Koboko has a significant wind-gap to the east which

Table 6-1

NETWORK OF WIND-GAPS, WATER-GAPS AND ASSOCIATED SWAMPS

Diagrammatic representation - all sites appear on Folio Maps 3 and 6. (s) indicates swamp within form. BV indicates broad open valley.

Wind-gap	Wind-gap	Wind-gap	North-South Channels	Swamp	Water-gap or Broad Valley
		(dry valley)	→		Kirenga
		(dry valley)	→		Githirioni
		X X		Lari	X
		X		Murengeti	X
		(dry valley)	→		Biberioni
		X X		Kiboko	(incipient) (incipient)
Mrithu			Tiekuno ↓		X
					Loreto
	Nderu		Rironi ↓		Holmewood
Nduma		Rironi			
Muikambu	Makutano				
Kiriri(s)	Thigio	Renguti	Muguga	?	
	Ndeiya				
Nachu(s)		Nyakumu(s) →	BV →	Ondiri →	BV →
		Gathegi (dry valley) →	BV →	Riu →	BV →
BV →		Ilkipikoni →		Kipruti →	BV →

aligns with an incipient water-gap, but also opens on to a valley which drains via the Loreto water-gap. At Ondiri there are a number of swamps lying in a poorly defined eastwest depression with a broad dry valley to the eastward cutting through the escarpment. The Riu and Kipruti swamps both lie in broad shallow valleys which traverse the height of land eastward from the Kikuyu-Ngong fault line (Folio map 6), and start as hanging valleys overlooking the Esakut platform at Gathegi and Inkipikoni.

There are water-gaps at Biberioni and the Loreto convent which are not associated with marshes, and east of Koboko in Limuru township there are two incipient gaps where headward erosion on branches of the Tigoni River has almost reached the escarpment (Column 6 of Table 6-1).

The Lari, Murengeti, and Koboko swamps, and the Loreto water-gap all have wind-gaps or dry valleys immediately to the westward, while Ondiri has the Nyakumu swamp lying to the west in the same broad valley.

Between Rironi and Muguga on the Lusigeti step-platform there is a major valley running north and south. There is no direct evidence of fluvial erosion or deposition, but it is possible to identify a rudimentary dendritic pattern of gentle valley forms which are not related to the fault patterns of the platform (W on Folio map 3). Immediately west of these valleys there are two large wind gaps at Makutano and Kiriri. The Makutano gap opens downhill onto a swamp area, and there is a square kilometre of swamp within the Kiroi gap. There are also two distinctive gorge-like wind-gaps west of Renguti.

Photo 6-3. View southward across typical west-east dry valley on the Lusigeti step-platform. Ngong Hills on left, Ol Esakut volcano on right horizon.

Photo 6-4. West-east wind-gap at Nachu. The other end of the gap hangs over the Esakut platform (Folio map 6).

The water-gaps in the Uplands-Limuru escarpments are occupied by streams which drain the Kiambu slope but they are not the result of headward erosion. In spite of the two incipient water-gaps the relationships between the swamps and the water gaps cannot be considered a mere coincidence. All streams turn west at the water-gaps. The four northern examples of water-gaps are aligned with wind-gaps to the west (Photo 6-3) and are approached from the west by dry valleys (see Folio map 3). There are more wind-gaps than water-gaps and some wind-gaps are not related to water-gaps, both facts implying the existence of a network to the west, and an origin other than that of headward erosion. The combined wind and water-gap system, when considered together with the depressions or cols which cross the watershed at the Rift edge, provides clear evidence of a drainage net which crossed the Lusigeti step-platform from the west and predated significant down-faulting along the Githingucho-Ngong fault line.

2) <u>Former drainage on the Esakut platform</u>

The terrain of the Esakut platform has no water-gaps since there are no streams, and does not have many examples of wind-gaps, but there are minor wind-gaps at Nduma, Muikamba, and Kiriri (Folio map 6), while at Nachu there is a sharply defined gorge-like wind-gap (Photo 6-4) which aligns eastward with a sequence of three swamps or lake floors (Photo 6-2) in a winding depression with is in turn aligned with the Riu swamp (Folio map 6).

Photo 6-5. Quaternary lake floor on the Esakut platform. View northeast across a graben from a steep fault-scarp.

A number of lake-floors are distributed across the Esakut platform (Photo 6-5). The sediments lie in downwarps of graben floors usually against an escarpment, like the 'swamps' of the Lusigeti step-platform. Some maintain patches of standing water on the surface during the rainy seasons, and they all have dug wells or boreholes which exploit ground water trapped above the underlying rock. None of the lake-floors lie along old water courses, nor is there any obvious relationship to wind-gaps. They were not shown to have stratified sediments, and there are no deltas or shoreline bluffs, but the sediments are strongly diatomaceous, and there is no doubt the lakes existed formerly as significant bodies of water. In the absence of a relationship to any drainage system they are assumed to have represented accumulated ground-water, but they may have resembled ephemeral lakes like Kwenia and Cabongo in that they were fed by heavy local rains. There is no indication of age except that they must post-date the grabens which were produced by grid-faulting (0.8 - 0.4Ma BP).

The Esakut platform formed when the Esakut fault dropped Limuru trachytes to the Rift floor. Because the downfaulted Limuru has been flooded by Ol Tepesi basalts the event occurred before the period 1.4 - 1.6 Ma BP (Table 3-4), but since Singaraini basalts were excluded from the Limuru sequence the fault must postdate the Singaraini basalts (2.3 Ma BP). The Kedong and Ethinyai faults, which truncate the platform northward, (Folio maps 1 and 5) later cut off all north-south streams over the platform. The faults must have occurred after the Esakut fault because otherwise there would have been a great lake dammed at the site of the Kedong Valley for which there is no evidence. The Ethinyai fault pre-dates the Alkali trachytes which flowed against the foot of the fault-scarp,which gives a maximum age of ≃1.4 Ma and a minimum age of 0.81 Ma BP. The history of the downfaulted sector is explained in Chapter 8.

3) Drainage across the Limuru trachyte - conclusions.

The evidence shows that there was once a drainage system crossing the Limuru trachytes, and trending between 90^{o} and 105^{o}. Faulting, with slow-moving small displacements along the Uplands-Kiserian fault-line, disrupted the stream flows and caused temporary ponding against the west-facing fault-scarps, but the streams (or their overflows) maintained channels across the newly forming escarpments. Drainage disruption must have occurred shortly after the emplacement of the Limuru trachytes because the trachyte flows were to some extent guided by the same faults along which later movement interrupted water drainage. The age of the trachyte ranges between 1.55 and 1.96 Ma but may have older rock below (see Table 3-2, and 3-4). Williams gives a date at Limuru of 1.72, and Baker gives one age of 1.84 at the rim (Table 3.2).

A later phase of faulting along the line Kirenga-Muguga must have caused larger and more rapid displacements because the streams could not maintain their channels through the resultant escarpment, and streams were diverted south along its foot. The clearest example is the system between Rironi and Muguga, but the streams may have been exotic, or did not flow for long, because there is no highly developed water-formed landscape.

Because there was less tectonic movement in the south the streams continued to leave the Rift via the low depressions north of

Ngong. There is a deeply eroded channel which swings south-east at the Riu swamp near Kikuyu (Folio map 6, and Stereogram 1; Folio, Fig. II:15) with low terrain down to the Mbgathi and Athi rivers. There is an equally large gap at the Ondiri swamp (Folio map 6, Folio plate 3), which opens southeastward into the broad valley of the Nairobi River. The Mbgathi-Athi River and the Nairobi River are misfit streams in very large valleys. Their forms contrast sharply with the valley forms of other streams on the Kiambu slope. Thus the Rironi-Muguga north-south streams may have continued to cross the rim of the Rift Valley and drain south-east on the regional slope.

The Githingucho-Lusigeti faults which created the Lusigeti step-platform cannot be dated directly, but may not have occurred much after the Uplands-Kiserian fault because the terrain of the step-platform, which has more rainfall than the Esakut platform, has been significantly modified by fluvial processes, whereas the Esakut platform has not, suggesting that it dropped to an altitude with more arid conditions before a fluvially modified landscape could develop. This second phase followed the first quite quickly, and completed disruption of east-west drainage, causing all streams to flow north-south inside the Rift (>1.6 Ma BP). However, the phase of north-south streams on the step sites had not lasted long before massive cross-faulting created the Kedong and Ethinyai escarpments and cut off north-south streams over the platforms (minimum date of <1.4 Ma BP, but more probably soon after 1.64 Ma). After that event any drainage would run north-south on the floor of the Rift, although some characteristics of the new pattern would be dictated by the form of the downfaulted Limuru trachyte, and would affect the water supply directly to the Olorgesailie Lake site (see Chapter 8).

IV. SUMMARY OF DRAINAGE ON THE EASTERN FLANK

South of the Ngong Hills there is no certain evidence of an ancient east-west drainage pattern other than some gentle saddles in the watershed east of the Rift Valley. Streams which later supplied the Olorgesailie Lakes developed as reverse drainage on the Turoka-Ngong escarpment some time after 4.8 Ma BP, and may have had their maximum flows in the period before 2.3 Ma BP. They imposed themselves upon some of the early grid-fault topography, but were disrupted by the major grid-faults in the Alkali trachytes on the Rift Valley floor which pre-date the Olorgesailie Lake beds.

North of Ngong, above the Esakut platform there is clear evidence of a major east-west drainage system which existed continuously between 4.84 Ma BP and the eruption of the Limuru trachytes, sometime before 1.96 Ma BP. The Limuru trachyte overflowed Rift fault-scarps at an early stage of their development (1.8 Ma±) through low openings provided by pre-existing water-eroded troughs. A drainage system then developed over the Limuru trachyte surface draining to the east and southeast. At some time shortly after 1.8 Ma BP, as Rift faulting proceeded, this net was interrupted in the north, creating a number of small lakes or marshes trapped against low west-facing escarpments. Tectonic activity was slow enough to allow downcutting to continue and the streams maintained their courses across the fault line. To the south, at Gathegi and Inkipikoni, tectonic activity was less and drainage was not interrupted. Further faulting then occurred more rapidly along the line Kirenga-Muguga, and the east-west streams were turned south as shown in the area of Rironi and Muguga. The waters continued to escape for a time across the rim of the Rift near Dagoretti and Kararapon, and then down to the Nairobi and Mbagathi systems.

A second major phase of faulting along the line Githingucho-Ngong created the Lusigeti step-platform shortly afterwards, and all east-west drainage stopped and was replaced by north-south streams. Any streams would be exotic, bringing water from higher ground to the north. The Esakut platform was created when the Esakut fault developed before 1.64 Ma BP, and although streams may still have flowed north to south across the platform and down the gorge of the Loodo Ariak for a short time, explaining the large size of its gorge, all the streams over the platform were stopped when the Kedong and Ethinyai fault-scarps truncated the platform to the northward before 1.4 Ma BP, redirecting any streams along the platform base and into the Kedong Gorge sector.

Grid faulting which created the Rift floor topography between 0.8 and 0.4 Ma BP also affected the platform and the step. On the platform a number of lakes or wet areas were trapped in lows against fault escarpments. The lakes may have been rain-fed but were not river-fed. It is a matter for speculation as to whether the dropping floor of the Rift would cause movement in the water table of the general area, with water migrating to springs on the walls of the Rift Valley until the water-table acquired a new equilibrium.

In all this time the Limuru trachyte terrain outside the Rift which remained at higher altitudes suffered constant fluvial erosion and modification, the landscape there acquiring a radically different character.

There was a significant drainage system leaving the Rift in the area until 1.4 Ma BP, and at that time the net was disrupted by tectonic activity rather than drying out during a climatic change. The disruptions redirected new streams from the west and the north, and restricted them to the floor of the Rift Valley where they became available to supply lakes and lake systems at suitable locations in an area of internal drainage. The major diversions occurred at the perimeter of the Esakut platform and in the general area north of the Olorgesailie Lake site.

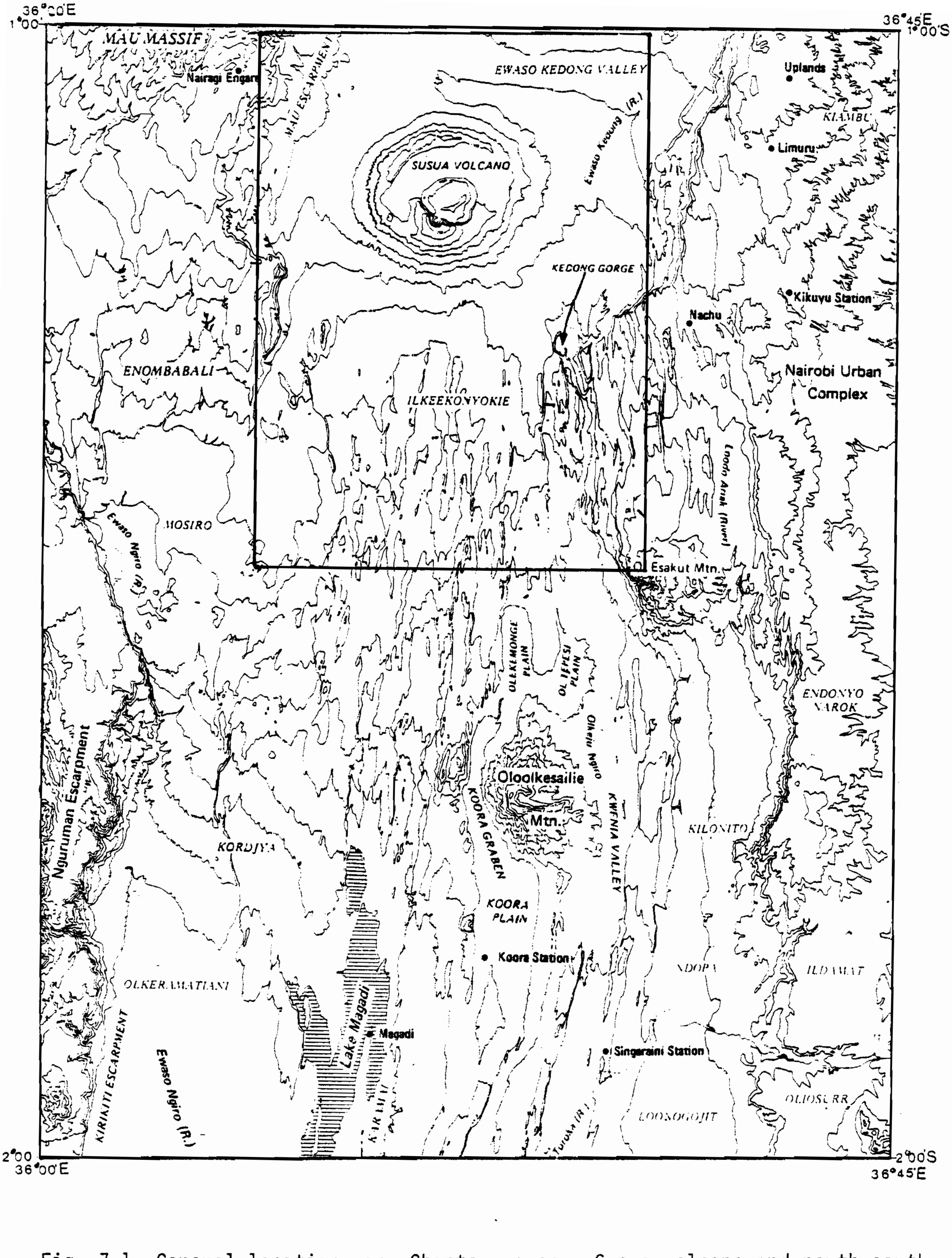

Fig. 7-1 General location map, Chapter seven. Susua volcano and north-south drainage.

Chapter Seven

SUSUA VOLCANO AND NORTH-SOUTH DRAINAGE (FIG.7-1)

I. EVIDENCE OF NORTH-SOUTH DRAINAGE ON THE RIFT FLOOR

It has been shown that east-west drainage crossed the northern sector of the Southern Kenya Rift Valley until some time in the period before 1.8 Ma BP (p. 109). After 1.8 Ma the evidence suggests that streams arriving at the Rift site from the west were diverted southward down the western edge of the Rift floor, while being supplemented by drainage off a Limuru trachyte surface that bridged the Rift but was higher northward, so that the stream pattern trends west of south in the west (p. 93) and east of south in the east (p. 107). The flow across the eastern limit was curtailed in the period before 1.64 Ma BP (p. 108) and after that date all north-south drainage was confined to the floor of the Rift. Alkali trachytes covered the floor in the period between 1.42 and 0.81 Ma (Table 3-4) and they were followed by grid-faulting which is strongly oriented north-south, and would exercise a strong controlling effect on drainage patterns. The grid-faulting is generally agreed to have taken place between 0.8 and 0.4 Ma BP (Fairhead, et al., 1972, p. 68), but both Fairhead (p. 66), and Baker and Mitchell (1976, p. 479) show most grid faulting taking place after the formation of the Ol Donyo Nyegi volcano, which is given an age between 0.57 and 0.66 Ma, although the date is questionable because the geological sample used has a reverse polarity and the date does not

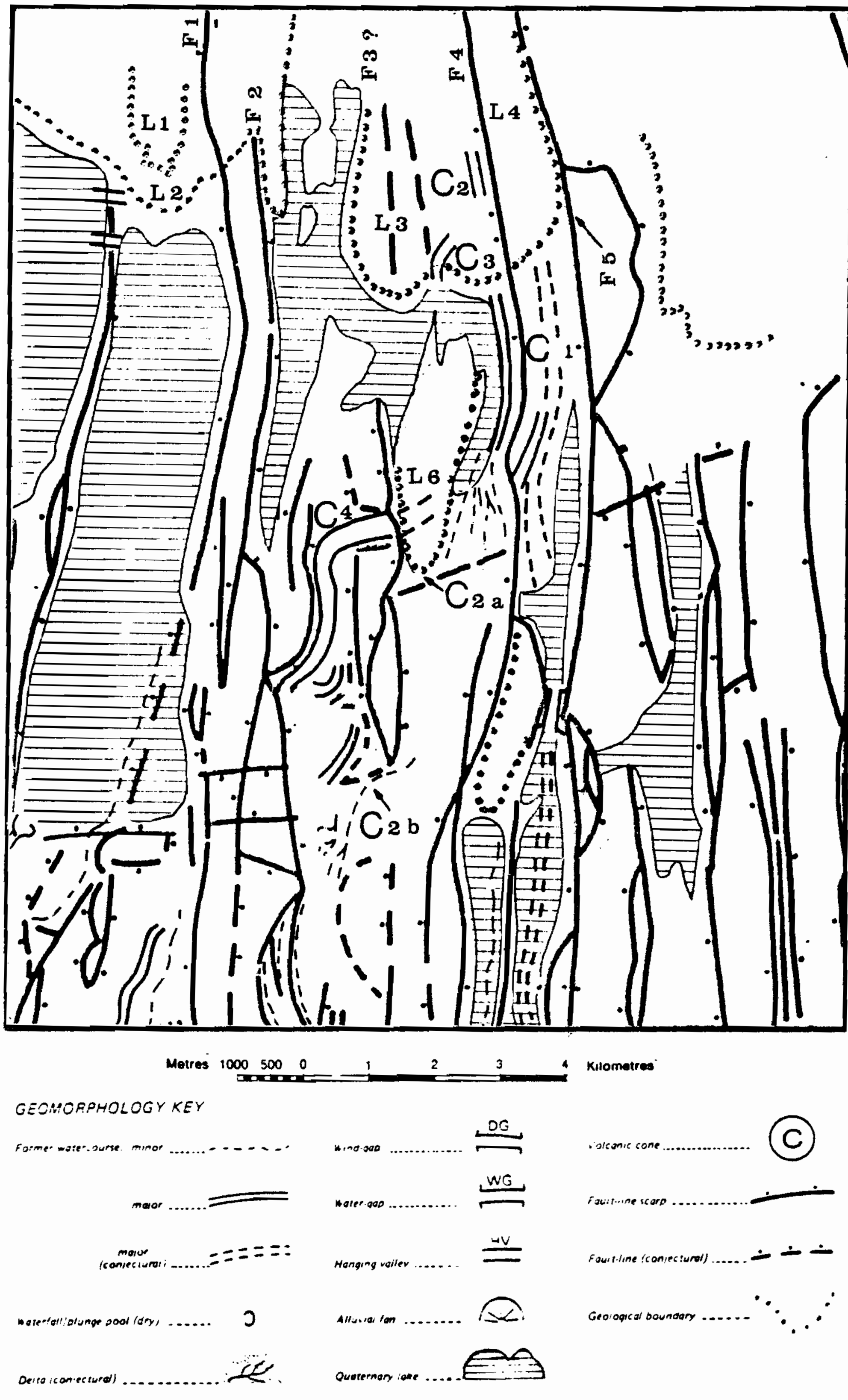

Fig. 7-2 The southern flanks of Susua Volcano.

agree with a period of magnetic reversal in the geomagnetic time-scale.

It has been shown in Chapter 4 that a river flowed through the Kedong Gorge after the emplacement of the Alkali trachytes, and streams are known to have flowed over the trachyte north-east of the Kordjya Lake (Chapter 5), and in the overflows from the Koora graben. Photo-interpretation of the area south of Susua Mountain has shown that there is a large number of features that can be interpreted as former watercourses over the Alkali trachyte, some of very great size, and they have been plotted on the overlays to the Folio maps 5, 7, 8, 9, 10, 11, and 12. In addition, many of the grabens in the sector are floored with sediments and resemble former lake floors. Depressions in the terrain surface (indicated with depression contour signs on each map) invariably occur in sediments, and they are aligned as sequences within the channel systems that follow some grabens. Many of the sediments are being eroded by contemporary ephemeral streams, but there are much larger dry channels which are interpreted as remnants of former river systems. Some former water-courses are broad flat-floored shallow channels up to 500 m across and 3-5 m deep, with gentle sweeping curves that do not conform to the faults.

In some examples the sinuosity of the channel reflects the form of an adjacent scarp, and it is no longer possible to say if the arcuate scarp foot was cut by a stream or whether the original fault was along an arc and guided the channel. However, channels guided by rock sometimes continue across alluvium (C1 on Fig. 7-2). Other channels are anomalous because they appear to begin or end abruptly at the foot of an escarpment (e.g. C4 on Fig. 7-2). The pattern formed by the channels is

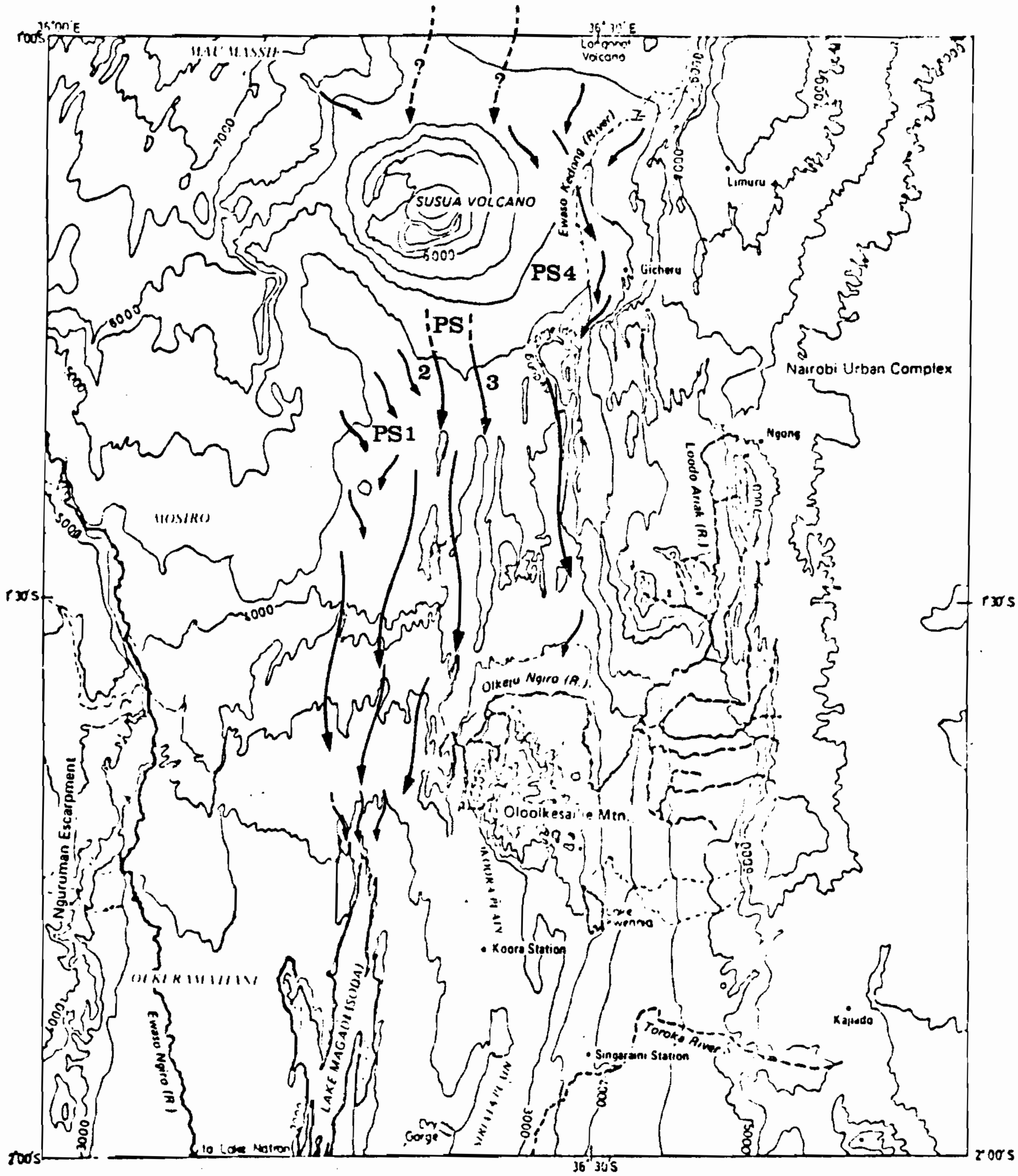

Fig. 7-3 Generalized version of former drainage channels on rift floor. Form-lines in feet.

apparently incoherent, and there is no one continuous single unit that can be shown as an unequivocal example of a former river.

The discontinuous elements form a general north-south network if viewed in connection with other features, and if one ignores that fault-scarps and assumes continuity under sediments on the graben floors. All the deflation hollows fall within such alignments, as do the ponds, which occupy natural depressions. A number of the 'ponds' shown on the modern Kenya metric 1:50,000 maps are dug wells, but they too fall within these alignments, although many small dug wells have been omitted such as those in the Kedong Gorge. Some of the discontinuous channel elements cut across small horsts, suggesting an antecedent history, while others,which hang in the walls of grabens,may predate the faults. Taken in total the evidence leaves no doubt that considerable rivers flowed north to south in the past. They predate some of the faults, but were disrupted by others, suggesting an age for the sytems broadly equivalent to the period of grid-faulting. The frequent disruptions prevented any stream establishing a single course over a long period of time, except in the Kedong Gorge (see Chapter 8), and the remaining evidence seems confused.

There are four major elements in the old drainage net (Fig. 7-3). A very clear grouping of antecedent channels brought water from the Susua/Mosiro plain (PS1 on Fig. 7-3), and those channels eventually reached the Ndupa River at the head of Lake Magadi. A second complex with two main elements occupied the grabens immediately south of Susua volcano (Ps2 and Ps3 on Fig. 7-3). They merge and formerly entered the Embalbal Olkineti Swamp. This swamp hangs over a valley with a number of deep channels cut in rock which descend to the alluvial flats on the northeast corner of Lake Magadi (Folio map 5, Fig. II:7). The general character of these three sectors is too complex to be plotted in detail, even at 1:50,000, and they are best shown in the stereogram (Stereogram 2, Fig. II:16). The fourth system lies to the eastward. There are a few indications of north-south channels draining into the Olekemonge plain, but north of Ol Tepesi there is a very strongly developed and unmistakable system of channels trhough the Kedong Gorge.

These former drainage systems formed after 0.8 Ma BP, on the youngest Alkali trachytes and only on the floor of the Rift. They are not fed from the west (p. 94), but the area to the north is completely blocked off by the Orgaria-Longonot volcanic ridge (p. 147). Susua volcano seems to stand astride the channel systems PS2 and PS3 and the channels seem to emerge from under the lowest flows of Susua as shown on Randel's map.

II. THE SOUTH SLOPES OF SUSUA

1) <u>The age of Susua volcano</u> .

Between 36°20' and 36°25' E on the lowermost slopes of Susua volcano (as shown by Randel (1970) or Johnson (1969)), there are a number of flows which show clear relationships to the grid-faulting (Flows L1, L2, L3, and L4; faults F1-4 in Fig. 7-2). In two examples grid faults displace the rock of the flow (F1, F4) and clearly postdate the rock, whereas in three cases grid fault-scarps have guided the erupting lavas and must pre-date them. The upper flows of Susua are

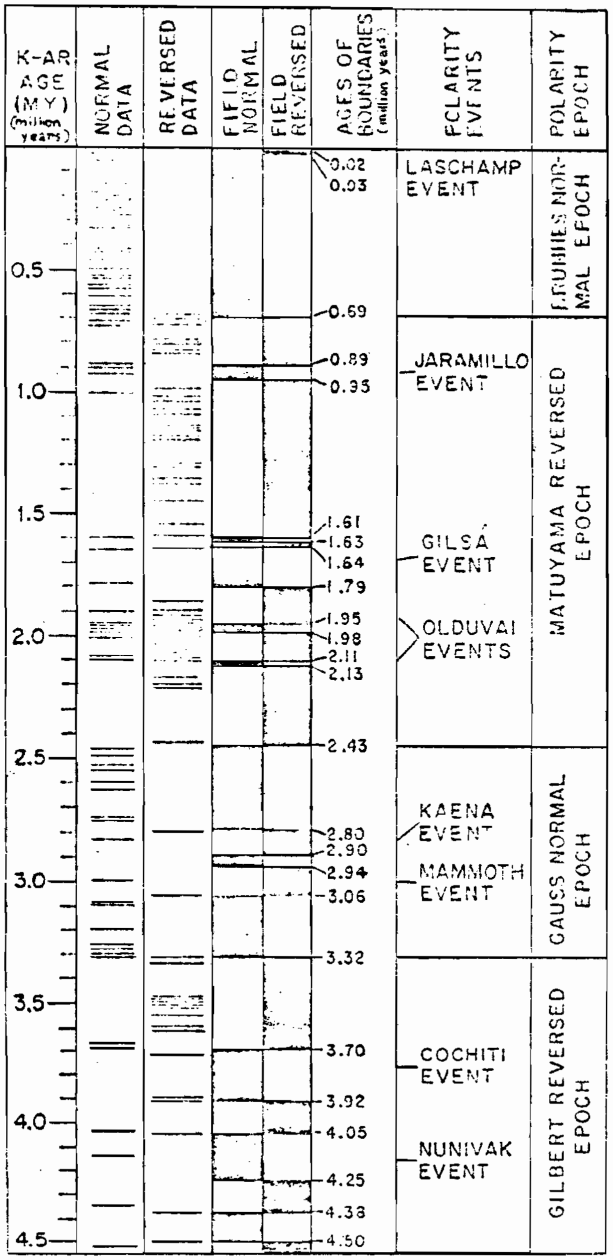

Table 7-1. Geomagnetic polarity time scale. (from Cox, 1969 p. 240)

not displaced by faults. This suggests close contemporaneity of the faults and the lowest flows,and dates for the flows would help limit the age of grid-faulting. Most geologists believe Susua is very young, and Baker has placed Susua above the Legemunge beds (i.e. less than 0.42 Ma BP), in his most recent stratigraphy (1976, p. 479), and above his newly described Barajai trachytes (0.4 - 0.36 Ma) (1978 pers. comm.).

Field work showed that there are a number of flows extending south of Susua which underlie Randel and Johnson's 'lowest' Suswa phonolites. Some of these flows extend as much as ten kilometres in thin lobes and tongues (Fig. 7-2) and one may extend south-east as far as the exit of the Kedong Gorge. Some of these flows cannot be plotted at 1:100,000, and they are best seen in the northern half of the central photograph in stereogram (Folio Fig. II:16). Dr. Crossley has identified my samples as trachytes, even when they were taken from Randel's Plpl flow (L1, 2, 3, 4 on Fig. 7-2) described on his 1970 map as a 'phonolite with globule surfaces'. Both Johnson and Randel remarked on the difficulty of distinguishing phonolites, which were often trachyphonolites, from the underlying Alkali trachyte, and for convenience they will be referred to as trachyphonolites here. The geological samples are all described in the sample summary. The samples from Randel's lowest flows (L1-4 on Fig. 7-2) all show reversed magnetic polarity (M105, 130, 132), and they overlie an Alkali trachyte with normal polarity (Geological sample M106). The Susua trachyphonolite cannot be as young as the Laschamp (reversal) event (Table 7-1) which has been dated to .02-.03 (Cox 1969 p. 243) because there are much older dates for Suswa volcanics higher in the formation. Given the age range for Alkali trachytes (Table 3-1, 3-2), it is reasonable to assume that the Alkali trachyte sample M106 dates from the

Photo 7-1. Former drainage channel in Alkali trachyte, viewed from the phonolitic lava flow that has overrun it. View southward of the channel C1 from lava flow L4 on Fig. 7-2.

Jaramillo (normal) event (0.95 - 0.89 Ma,Cox, 1969), and the Suswa trachyphonolites will fall into the period 0.69 - 0.89, which was all that remained of the Matuyama Epoch after the Jaramillo event. It follows that Susua is considerably older at its base than was expected, and if Susua overlies the drainage net it gives a significant age for a portion of the north-south drainage system.

2) North-south drainage and Susua.

Figures 7-2 and 7-3 carries a simplified form of the distribution of faults, flows, and channel forms but the features are best seen with strong magnification in the stereogram (Fig. II:16). Channel forms are identified with C numbers on the diagram. C1 is distinctive. It emerges from under the flow L4, and although it is initially guided by Alkali trachyte banks which could represent a very shallow graben (2 m) (Photo 7-1), nevertheless it predates the flow which shows no sign of the 'graben' faulting, although it was clearly guided by fault F5. The channel can be traced along a step-platform, through a water-eroded 'gate' where two faults scissor, and on south for a total of 20 kms, only fading away occasionally in alluviated basins resembling lake floors. Two gorges branch west from it, and over the platform edge; both lightly water-eroded through the scarp (Fig. 7-2). The channel is mildly sinuous and nowhere conforms exactly to the strike of the faults.

Channel C2 is more complex. It emerges from below a lobe of flow L4 and traverses a water-eroded valley east of a previously unmapped flow, L6, before opening into water-eroded terrain on Alkali trachytes. It was crossed by a secondary lobe of L4 flowing west off

Photo 7-2. View south across shallow channel (C4) incompletely filled with Suswa lava (L6 on Fig. 7-2). The channel C4 continues across the floor of the graben to the right. Channel C2a lies in the middle and left background.

the fault scarp (see Stereogram 2). That lobe dammed and diverted a major stream which then escaped at C3. Southward C2 followed a variety of courses, some due south, but at a late stage the stream flowed around the southern tip of L6 and into the next graben (C2a on Fig. 7-2). In its last phase the stream seems to have cut down across a broad hanging valley at C2b to join the major forms in the next graben.

Channel C4 is the most striking. Since it occupies a graben which shows clear evidence of cross-faulting (Fig. 7-2) there are some confusions of tectonic form and eroded rock, but there are four distinct sweeping channels in the area that can be recognized in the stereogram. The main channel C4 seems to begin abruptly at a fault-scarp in Alkali trachytes, but in fact the line of the channel is carried on in the surface of the flow L6 above the scarp, where a shallow broad channel (Photo 7-2) curves northeast across the rock. Although this depression has traces of water erosion, it is mainly the result of a thin trachyphonolite flow (samples M109-116) incompletely filling a channel in Alkali trachytes. The same flow terminated in front of higher ground to leave the channel at C2a.

The area north of C4 has a large depression but shows no obvious channel in the sedimentary fill. Given the age of the C4 channel (it must exceed 0.69 Ma), later sediments may have buried evidence northward, or the streams in the C4 area may have entered from the general area of C2.

III. SUMMARY OF SUSUA VOLCANO AND NORTH-SOUTH DRAINAGE

The last Alkali trachytes erupted in the area between 0.89 and 0.95 Ma BP. They were immediately occupied by a north-south drainage pattern which originated somewhere north of Susua. These channels had established themselves before 0.69 Ma because they were disrupted in some cases by volcanic flows that show reversed polarity remnant magnetism. The stream system and the earliest flows of Susua were contemporary with grid faulting, and both streams and flows were modified by faulting, the rivers being drastically re-organized by some events. It is not possible to tell if all the channel remnants are fragments of one shifting stream, but it seems probable there were several. The streams were exotic since although they appear to have been large, there is no locally developed dendritic network.

One major system reached the Lake Magadi site in the graben occupied by the Ndupa River. It cannot be traced northward of Susua Mountain and it is presumed that the evidence around Susua/Mosiro has been obscured by volcanic ashes. It probably predates the Lake Magadi graben and may have contributed to the High Lake Natron-Magadi (700 m lake). The other major system has two elements both draining toward Embalbal Olkimeti and thence over steeply-graded heavily-eroded valleys to Lake Magadi (Folio map 8). Any streams in the fourth grouping, PS_4 which may have entered the Kedong Gorges are discussed in Chapter 8. None of the streams described in this chapter could have fed the Olorgesailie Lakes, since there is no certain evidence of them crossing the major horsts marking the western limit of the Olekemonge Plain, and clear evidence that they contributed to the Lake Natron-Lake Magadi sector.

The north-south streams were beheaded by the growth of Susua. Once the volcano assumed its form any drainage from the north would be blocked and the streams diverted. Because the terrain is relatively high west of Susua, the diversions were to the eastward where there was lower ground. The growth of Susua displaced streams eastward, and thence into channels which could supply water to the Olorgesailie Lake site, first through Olekemonge and then by Ol Tepesi. Since upper flows of Susua have been dated to 0.36 Ma (Table 3-1), all streams down the centre of the Rift floor had ceased before that date. The same faulting events which had disrupted the drainage during its lifetime, also created the Ol Tepesi and Olekemonge grabens, and the drainage was diverted eastward shortly after major movement in the grid faulting had stopped.

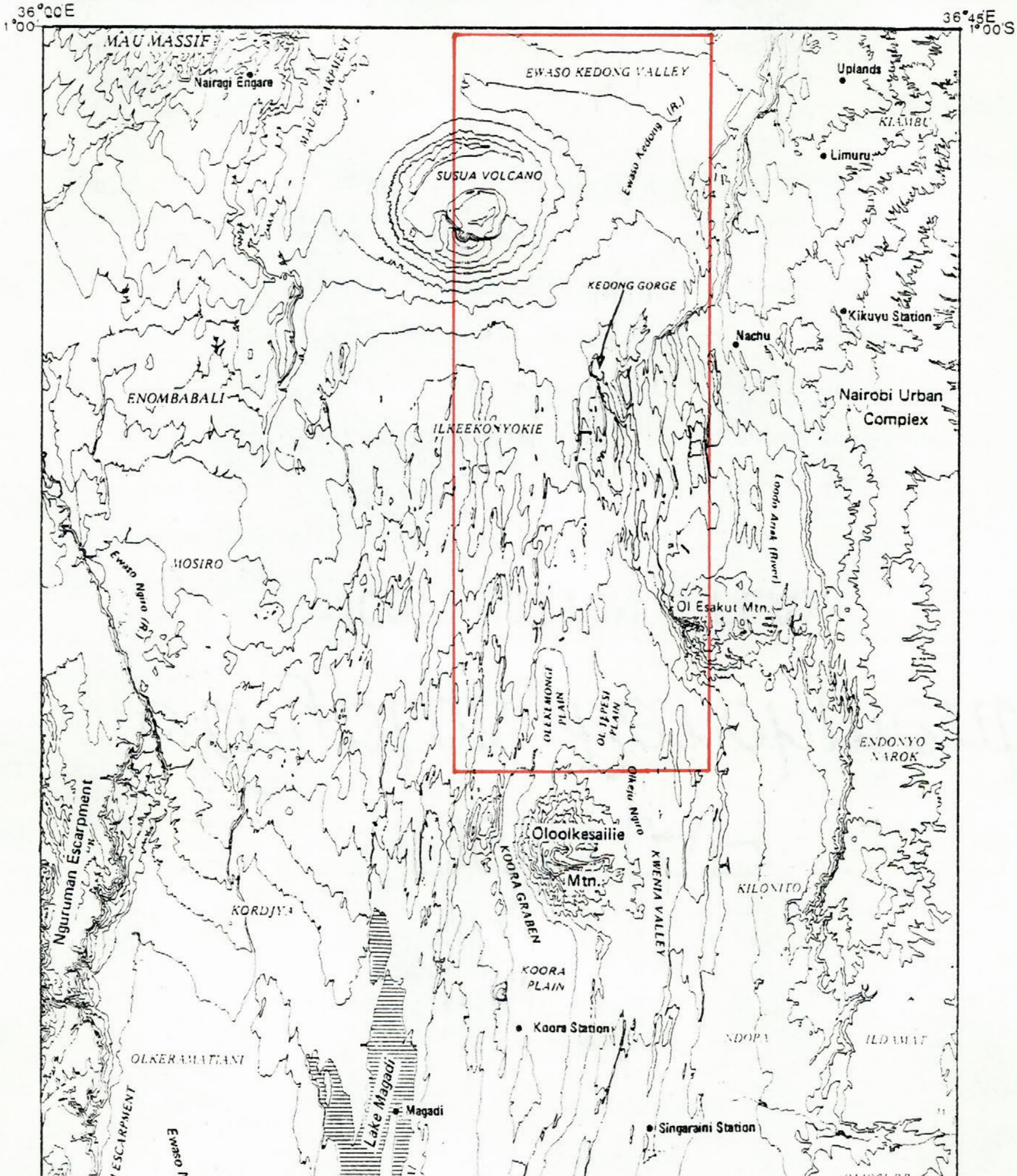

Fig. 8-1 General location map, Chapter eight. The Kedong Gorge.

Chapter Eight

THE KEDONG GORGES

I. THE KEDONG GORGE AND THE OLORGESAILIE LAKES (FIG. 8-1)

1) The significance of the Kedong Gorge

The Olorgesailie Lakes received water from a major stream coming through the Kedong Gorge (p.74). The Olkeju Ngiro in perennial full flow might be able to maintain small lakes such as those that existed at Olorgesailie, and its major tributary the Loodo Ariak, has existed since before the events which created the lake site (p.59). However, the channel of the Olkeju Ngiro on the Rift floor shows no evidence of having been a larger river in time past and the channel is well-adjusted to the present seasonal maximum flow. By contrast, the Kedong dry gorge, which ends 15kms north of the Olorgesailie Historical Site has a much greater capacity. Baker (1976, p. 475) postulated a former flood 30 m deep at Emerit, near the Southern exit of the Kedong Gorge, with a cross-sectional area of 25,000m^2, which is more than 150 times the capacity of the Olkeju Ngiro channel at the historical site. The evidence for such a large flood is ambiguous,and may have been misinterpreted,but there is ample evidence of continuing flows at least 4m deep within the main gorge, which still suggests a flow capacity 20 times that of the Olkeju Ngiro. The gorge also provides access to a much larger drainage area than that contained by the watershed of the Olkeju Ngiro drainage net.

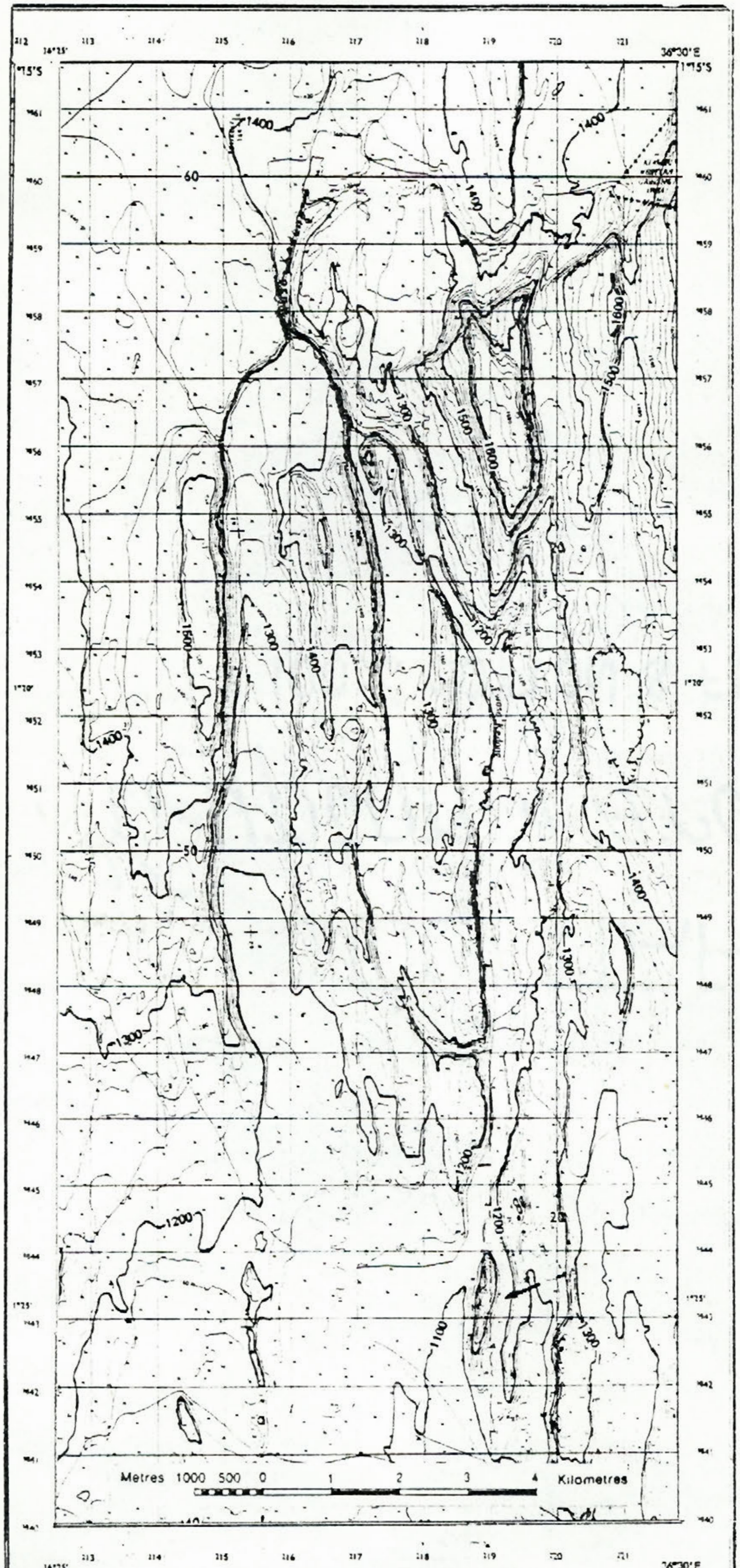

Fig. 8-2 The Kedong Gorge. Contour interval 20 m.

2) The character of the Kedong Gorge.

The Kedong Gorge is a dry gorge, nowhere less than 80 m deep (Fig. 8-2), which traverses terrain that has a general relief of 300 m, although some hills rise 600 m above the floor (Fig. 8-2, Photo 8-1, and Folio map 5). The gorge is 30 kms long and is apparently fault-directed in some sectors. Randel's geological map (1970) shows the gorge cut entirely in Alkali trachytes with two flanking hills of Orthophyre trachyte, but the geology is much more complex and an explanation of the geological and volcanic events is essential in order to explain the relationship of the gorge to the Olorgesailie Lake sequence. The former rivers that shaped the gorge are called the Kedong River in this text, to distinguish them from the present small stream which gives the gorge its name.

The contemporary Ewaso Kedong is a spring-fed perennial stream which traverses the eastern flank of the so-called Ewaso Kedong Valley. In the dry seasons it is a mere trickle, (Sikes, 1926, reported low season flows of one cusec) and even during the wet period of March-May, and thelesser rains of November, when the stream is supplemented by seasonal streams from the eastern flank of the Rift and sheet-wash within the Rift, it enters only the northern end of the Kedong Gorge and rarely reaches beyond the northern loop in the gorge known as Baragoi. The stream, when in flow, occupies a typical seasonal stream channel,with a cross-section of 3-4m^2 cut in sediments of the floor through Baragoi, but the water sinks into the sediments on entering the southerly straight sector known as Nkobirri. In the Nkobirri sector there are only superficial, shallow, braided channels on the sediments

Photo 8-1. General view southward within the Kedong Gorge.

and boulders, the result of sheetwash and flash floods when heavy conventional precipitation exceeds the infiltration capacity of the materials. It is clear that the Ewaso Kedong had no part in shaping the huge Kedong Gorge.

Major dry channels extend southwest beyond the exit of the gorge and link it to major deltaic deposits which represent the head of the former Olorgesailie Lakes at two late stages of their existence (p. 63).

II. THE ORIGIN OF WATER IN THE FORMER KEDONG RIVER

1) <u>The Naivasha overflow at Njorowa</u>.

Gregory was the first to recognize the existence of a continuous downhill gradient for hypothetical overflows from Lake Naivasha through Njorowa Gorge. From a sill at 1910 m near Fischer's Tower in Njorowa it is possible to identify a route which drops consistently across the Kedong Valley, through the Kedong Gorge and onto the Ol Tepesi plain at 1100 m. The present study extends that profile to a low of 774 m in the Koora graben (Folio Fig. II:18).

In 1926 Sikes developed Gegory's suggestion of a link between Njorowa and the Kedong Gorge. His paper described a former river with a large discharge that began 150 feet (45.7 m) above Lake Naivasha in the Njorowa Gorge, traversed the Kedong Valley, and passed through Baragoi and Nkobirri to the mount of the Koora graben (p. 392). He suggested that it was fed by a high level of Lake Naivasha, and claimed that the route is floored and flanked by lake and river sediments. He concluded that Baragoi and Nkobirri seemed to have been eroded in lower Pleistocene time (p.401), the latter in pre-existing sediments, and that previously drainage had followed different adjacent meridional valleys at different times. In more general terms he suggested that after grid-faulting developed, fluvial discharge must have been along parallel valleys of the grid. The 'vales' (grabens) are not grabens 'caused by trough-faulting' but represent 'gravity faulting and jointing', deepened and widened by erosion (p. 397). He recognized vestiges of river terraces and concluded that the pre-recognized vestiges of river terraces and concluded that the present form of the grid is largely due to erosion (p. 397).

In the present study, channels and terraces have been identified in grabens to the west and changes in the channels of the Kedong River west of the Esakut platform will be described. However, although Sikes established the idea that the course of the Ewaso Kedong had been changed, and that the river had formerly occupied parallel valleys, his evidence for specific channels on the Esakut platform cannot be recognized, nor would many geomorphologists accept his generalization that the graben-like forms of the grid-faulted sectors of the floor and the platform are the results of fluvial erosion exploiting fault and joint systems, with the steep walls explained by joint exfoliation. Sikes' geological and tectonic sequences are correct if one generalizes the lavas by grouping together the phonolites, trachytes, etc., but there is no precise support for his statement that the gorge seems to have been eroded 'in lower Pleistocene time'.

Careful examination of the long profile of the proposed former channel from Njorowa through the Kedong Gorge shows serious difficulties for the interpretation. Using pre-publication drafts of the newly prepared 1:50,000 metric maps of 1973 and 1974, (which show many spot heights plotted between contours, as well as a 20 m contour interval), two profiles were prepared. One shows the gradient plotted between points where a break of slope can be recognized (Folio, Fig.11:18)and a second in which the drop at dry falls (nick points) was excluded, and only the gradient of continuous channel floors recorded.

The first profile shows a gradient of 1:130 in Njorowa with the gradient steepening in the Kedong Valley to 1:105, and then steepening again through the Kedong Gorge to 1:80, before returning to 1:120 in the Ol Tepesi-Olekemonge plain, and then 1:408 through the entire length of the Koora graben. In the second version the gradient in Njorowa is approximately 1:200, and resembles the gradient of the most gently sloping floor of the Kedong Valley. Similarly, elimination of the dry falls in the Kedong gorge yields a gradient of 1:100, a little more that the 1:120 across the Ol Tepesi plain. The profiles of the Kedong Gorge, Ol Tepesi, and the Koora graben can be taken together to show a 'normal' graded profile, steeper headwards, more gentle downstream: 1:100, 1:120, 1:408. An attempt to continue the profile above the Kedong Gorge, or to identify a similar one, fails because there is a steep sector where the slopes of Orgaria link Njorowa and the Kedong Valley, and a convexity is introduced into the profiles of both versions:

Photo 8-2. The exit of Njorowa gorge seen from the south across the Kedong Valley.

either Njorowa 1:130, Kedong Valley 1:105, or Njorowa 1:200, slopes of Orgaria 1:45, Kedong Valley 1:200. In neither version can a graded profile be recognized above Njorowa, and no combination of gradients produces an acceptable graded profile from Njorowa to the bottom of the Koora.

2) The Kedong Valley.

Although the idea of Njorowa and the Kedong Gorge as homologues within a single contemporary drainage system seems obvious, it is not possible to demonstrate any former connection, and the LANDSAT false colour imagery (Folio Fig. II:2) is misleading because it shows prominent scars in the vegetation of the Kedong Valley which suggest a major channel of the type required, There is no delta at the month Njorowa, only a barely perceptible alluvial fan. There is no channel on the slope outside the gorge, although there are two minor single erosional terraces, one rock-defended. Neither of them is oriented to a drainage channel leading to the Kedong Gorge (Folio map 2). The stream-gorge characteristics and the thick sedimentary beds terminate abruptly at the exit, leaving a hanging valley that overlooks the basin containing Susua volcano. The slopes below the exit are no different from the other slopes of the Orgaria ridge (photo 8-2). There is no fault displacement at the exit and nothing to indicate burial of features by sediments in the valley.

There is no dry channel of a former river outside Njorowa although there is widespread superficial scarring, and contemporary stripping of vegetation by flash-floods during and after heavy rainstorms. It is these superficial scars which appear so prominently in the LANDSAT imagery whereas on the ground they represent micro-relief features only one or two metres in height.

There are deep dry gorges west of Njorowa which represent erosion by drainage from the hills of Orgaria itself, and at the foot of the slope there are sectors of braided channels at the lowest point of the valley cross-section (Folio map 2). They are oriented west-east and align with the lower courses of the Lelongo River and its northern companion, rather than the Njorowa discharge. The gorges and ravines of the Orgaria and Longonot slopes closely resemble the ravines described by Nilsson in the Naivasha basin (Nilsson 1935, and 1940) and, like them, they end abruptly on open ground, but there is no evidence that they end at a shoreline.

One hypothesis that could explain the apparent anomaly of the hanging gorge and its sediments would be the postulation of the presence of a former lake in the Kedong Valley with a perimeter at the level of the exit. The existence of exactly such a lake was suggested by Gregory, on the evidence of old terraces '500 feet above the floor of the Rift' on the Kedong escarpment (1896 p. 94). The terraces have not been recognized since, and the idea of a former great Lake Suess has been abandoned. However, in any interpretation , a depth of 500' (155m) would not reach from the low point of the Kedong Valley to the Njorowa exit, an altitude difference of 420 m.

Sikes (1926) posited the existence of a former lake in the Kedong, on the evidence of appearance, and the presence in the Kedong Gorge of comendite pebbles 'from Njorowa'. However, comendite has since been found in situ on the eastern flank of the Rift in the area of the present Ewaso Kedong drainage, and Sikes' arguments are in any case self-contradictory. His former streams were claimed to have deposited Aberdare lavas (p. 401) and were not from the Naivasha overflow, while the Kedong Lake floor, with a lake surface at 1700 m after grid-faulting, would have filled the Rift for hundreds of kilometres to the south.

There is another less spectacular channel crossing the Orgaria-Longonot ridge. It begins at Burri in the Naivasha basin and passes west of Longonot, with an exit that hangs over the Kedong Valley, like Njorowa. It has been cut 60 m into pumice lapilli strata, with a sill at 2100 m, 240 m below the general crest of the ridge. Before high levels of Lake Naivasha could overtop the land containing these channels in order to begin incision, water would overflow at two natural cols, one east of Longonot at 2120 m, and another at 2100 m among pumice hills at the soutern limit of Broad Acres farm. Thus if Njorowa began as an overflow of Lake Naivasha, it was the last of two, perhaps the last of four such exits, while both it and the Burri channel may have another origin.

As one example of alternative origins which have been suggested, Naylor (1972 pers. comm.) has pointed out that the sediments within Njorowa are stratified but lack current bedding. They were apparently deposited in still water to an altitude of ≃1880 m and this has led him to suggest that they were laid down in a caldera lake within Orgaria-Longonot, with the gorge as its overflow. The Naivasha Lake overflow would use the gorge only after its creation, and only during high stages.

The Orgaria ridge may be relatively young. Fission-track dating of material from Njorowa has given dates ranging from a few hundred to several thousand years (Williams 1977, pers. comm.), whereas the Kedong River can be shown to have existed before the Alkali trachytes, giving a minimum age greater than 0.63 Ma. If this date is correct it is not possible to connect the gorges of Njorowa and the Kedong as parts of the same drainage system.

The lake floor concept is the result of visual illusion. The contour maps show a valley rather than a plain (Folio maps 2 and 3) and the valley form is demonstrably formed by the intersection of the lower slopes of Susua and the Orgaria-Longonot slopes. Both Longonot and Susua have broadly elliptical bases and since the long axes of the elliptical structures are not parallel, the intersections of the slopes occur at greater distances and lower altitudes eastward, to provide the aspect of a broadening fluvial valley on a map (Folio map 2). In the field, the lower slopes are so gentle and the intersection so masked by wash and aeolian deposits that there is an illusion of a plain.

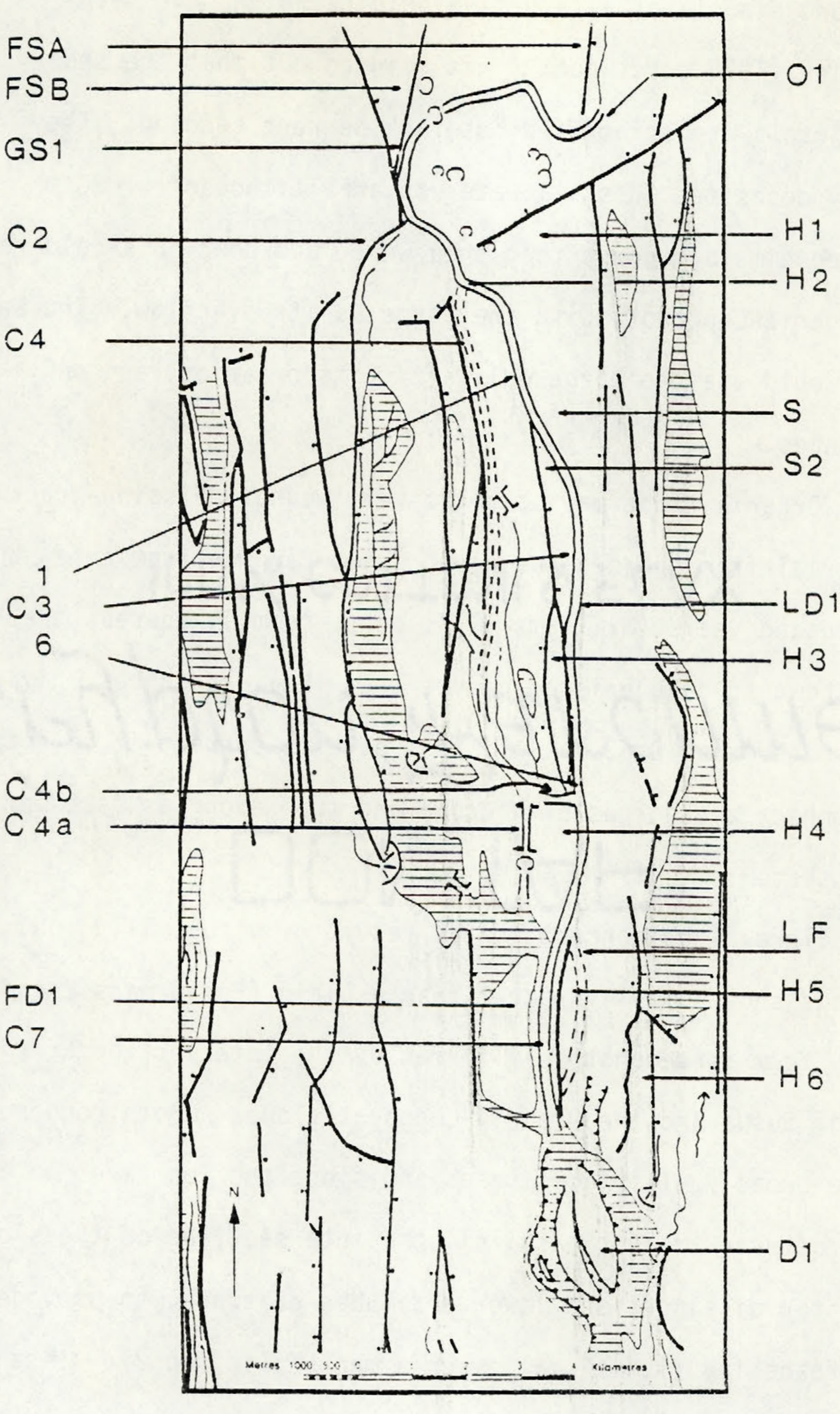

Fig. 8-3 The Kedong gorge. The letters are keyed to references in the text of chapter eight.

3) The Ewaso Kedong and the Kedong River (Fig. 8-3).

The true nature of the Kedong Valley is confirmed by the present course of the Ewaso Kedong which rises near the col between Longonot and the Rift flank, and follows a normal consequent course while on the slopes of Longonot, but is then diverted eastward by the lower flows of Susua, to a point at which it becomes directed by two east-facing fault escarpments more than 80 m high (Folio map 2).

The Ewaso Kedong is then deflected sharply back to the west by the massive east-west fault scarp of Ethinyai (320 m throw) and plunges into a rock gorge 20 m deep for 2½ kms before swinging south again at a north-south fault scarp to begin the Baragoi sector of the Kedong Gorge proper (Fig. 8-3). In this sector the Ewaso Kedong is following the course of the former Kedong River (p.123). The diversions and the incision show that the present form of the Kedong Gorge is eroded into Alkali trachyte, and thus post-dates the trachyte and the grid-faulting.

Sikes argues that the Ewaso Kedong predated the Ethinyai fault and formerly traversed the Esakut platform. In the col east of Sakureti, there is a flat alluviated area overlooking the first diversion of the river below (A on Folio map 3) which could be a former lake floor. Southward, a large, steep, water-eroded valley plunges to the floor of the main gorge. At its foot there are 25 m of water-lain (but not current-bedded) red sediments (Sl on Fig. 8-3). However, the Suswa flows and Susua-related land forms (including the course of the Ewaso Kedong) lie below and against the Ethinyai escarpment and must post-date it. Hence the river and the valley in the platform are independent features responding to the same fault.

The sediments (S_1 and S_2 on Folio map 5) have not been explained, but there is a lava fill which almost blocks Nkobirri at mid-point (LD1 on Fig. 8-3, and Stereogram 3, Fig. II:16). It has een severely eroded by streams, but it may have been a temporary dam at the time of emplacement, holding water to provide a settling pond within the gorge.

Temporary damming of the Kedong River at the escarpment in the Kedong Valley (D on Fig. 8-3) after the Suswa flows had diverted the Kedong River to the east side of the fault would provide a lake of modest size before the overflow (O1) cut down through the escarpment. Randel's 'Kedong Valley Sediments' are explained by this same mechanism. There is no evidence to support his placing all the Kedong Valley Sediments below the Susua lavas. After the overflow had been cut, the lake beds were eroded by a stream, or streams, incised into sediments over the area indicated on the overlay to Folio map 2. To the north and west the channels have been buried by ash and alluvium of the Kedong Valley. Since there are no channels over the ash cover, the channels are assumed to have been buried by ash after the water flow had ceased. The maximum extent of the Kedong Lake was about 10 km x 3 km, and the maximum depth was less than 80 m.

III. GEOLOGY OF THE KEDONG GORGE

The geology of the Kedong Gorge is much more complex than was suggested by Sikes (1926) or Randel (1970), and the stratigraphy and the sequence of events must be revised and detailed in order to understand the sequence of fluvial events in the gorge. The most recent publication of Baker and Mitchell (1976) provides a detailed survey of the Kedong sector, but my own field work did not lead to the same conclusions in a number of cases, and the account that follows is based on my own field observations.*

At the point where the Baragoi gorge turns south toward Nkobirri, two discordant valley junctions form striking features that hang in the western wall of the gorge (C2 and C4 on Fig. 8-3). The first occurs at the point of greatest relief in the gorge with a sill at 1360 m, 100 m above the floor in a cliff 200 m high. It is not an obvious fluvial form, being fault-directed and having a sill which is gently tilted plain about 1 km square, but within 2.5 kms to the south there is a distinctly water-formed dry valley close under the eastern edge of Najele which descends with a gradient of 1:40 to a plain of dust-covered sediments at an embayment of the Ol Tepesi plain. The channel lies on Alkali trachyte but the valley walls are Limuru trachyte.

The second channel (C4 on Fig. 8-3) hangs with a sill at 1280 m and slopes gently away from the sill (1:800) for 8 kms, before branching, with one distributary (4b on Fig. 8-1) turning east, and dropping rapidly (1:24) to the floor of the main Kedong Gorge in a steep water-eroded tributary gorge. The other distributary appears as a

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*Dr. Brian Baker was working in the field at the same time as myself, and kindly helped me on several occasions. His 1976 publication anticipated a number of my own conclusions, but some fundmental disagreements remain. Since the argument is complex and ranges beyond the immediate topic, the reasons for the differences have been outlined in an appendix (Appendix II).

Photo 8-3. Terrace of alkali trachyte inset within the Kedong Gorge.

Photo 8-4. Emerit hill near southern exit of the Kedong Gorge. Alkali trachyte of the Plateau series forms a terrace at the extreme left, and a lava fill in a former valley behind Emerit is visible centre left (see Fig. 8-3).

wind-gap continuing the line south (4a on Fig. 8-3). It terminates abruptly at a dry fall over 20 m high (Stereogram 3, Folio Fig. II:17). The first gorge (4b) descends around a hill, correctly described by Randel as an orthophyre trachyte, but the field-work shows an interesting situation.

The valleys containing the drainage channels are not basic erosion forms, but the channels have occupied or incised themselves in floors created by lava flows which flooded valleys and re-entrants of hills of a fundamentally different rock and structure. The hill H1 on Fig. 8-3 has Limuru trachyte in its main mass, but a coarse orthophyre trachyte is found at the base, and there is a low flanking terrace (5 m) of an Alkali trachyte in the gorge (Photo 8-3), probably Baker's Baragoi trachyte. The hills H2, H3, and H4, have coarse orthophyric trachyte in their uppermost exposures, with Limuru trachyte exposed at the bases, while H5 has a mass of the coarse orthophyre trachyte in its northern peak, and tilted Limuru trachyte in its main massif, with a terrace of Alkali trachyte to the north and Alkali trachyte completely filling a valley to its east. (Photo 8-4, and Stereogram 3, Folio Fig. II:17).

The Alkali trachytes have a distribution which shows they invaded well-formed valley features. Although the trachyte occurs in relatively thin sheets north of the Ethinyai escarpment (4m and 12m), it also occurs as a flanking terrace within the north end of Nkobirri, a major terrace south of Sakureti, and as distinctive matched terraces within the last 3 kms of the gorge, as well as in the fill behind the hill overlooking Njoroi stores (Photo 8-4, and H5 on Fig. 8-3).

The southern flows are more than 50 m thick. The floors of the valleys west of the gorge present a sinuous distribution of the Alkali trachytes, showing that they also invaded pre-formed valleys. The present gorges have in turn been cut in the Alkali trachytes, and are of fluvial origin. The Alkali trachytes are relatively horizontal (sloping gently southward), but the Limuru trachytes are severely faulted and tilted. Those observations make it necessary to revise the stratigraphy.

The memoirs and maps of Baker (1958 and Randel (1970) show an 'Orthophyre trachyte' as the youngest of the Plateau trachytes, but the distributions shown are not credible in terms of structure. Both maps showed the supposedly younger Orthophyre trachyte on the upper surfaces of sharply delineated horsts while the 'older' rock appeared on the adjacent graben floors, which is impossible as a structure, unlikely as an erosion feature, and completely improbable as a recurrent feature . When reviewed regionally, the Orthophyre trachytes were distributed to the sides of the Rift floor, while Alkali trachytes for a continuous and coherent area in the lower sectors of the Rift floor.

The original isotopic dating was controversial. Evernden and Curtis (1965) provided a K/Ar age of 2.4 Ma for a sample of the Orthophyre trachyte furnished by Baker (KA 652), significantly older than the Alkali trachytes. They insisted on publishing it, despite Baker's insistence upon a stratigraphic position above the Alkali trachyte.

Previous work by Temperley (1955), and Baker (1958), had identified two variants of the Orthophyre trachyte which were designated as 'Upper' and 'Lower', with the supposedly uppermost being a material that weathers easily and provides the so-called 'Hot-cross bun' features (Baker 1958, p. 21). The terrain is very distinctive with large sub-rounded boulders, coarse weathered detritus, and a rugged general aspect. There are no major scarp faces. Although the type features are found in the west, similar features have been identified in the Kedong sector (Stereogram 3, Folio Fig. II:17).

Many previously unrecorded outcrops of the 'Upper Orthophyre' trachyte were identified in the field, including the hill summits in the Kedong Gorge, and a number of them are identified on Stereogram 3. In every case, the form and an apparent anomaly is the same, with strongly eroded hills standing above relatively fresh lava surfaces of other trachytes.

All the evidence shows that, on geomorphological grounds, both orthophyre trachytes must lie below the Alkali trachyte and sections were found to prove this in the Ol Tepesi sector (RS on Folio map 8), at the head of the Kordjya plain (RS on Folio map 7), and within the Kedong gorge. The 'Lower Orthophyre' corresponds to the Limuru trachyte which occupies the entire area east of the Esakut fault, and the 'Upper Orthophyre' is the oldest trachyte of the three since it apparently lies below the 'Lower Orthophyre' (see below).

Baker and Mitchell (1976) revised Baker's 1958 stratigraphy. They showed the Lower Orthophyre trachyte as the Limuru trachyte with an age of 1.9 Ma (Table 3-1), renamed the 'Upper Orthophyre' as the Ol Tepesi benmoreite, and gave it an age of $\sim$1.6 Ma. They also identified some of the orthophyre trachytes (Hills Hs, H4, and H5 on Fig. 8-3) as a new formation, the Gesumeti trachytes. The Gesumeti trachytes are described as local eruptions during the early phases of eruption of the Alkali trachytes, probably between 0.9 - 1.25 Ma BP (Baker and Mitchell 1976, p. 475).

The detailed reasons for not accepted the Baker/Mitchell sequence are explained in Appendix II. The sections exposed in the Kedong Gorge suggest that the Limuru trachyte overlies the Ol Tepesi benmoreite, and that the Gesumeti trachytes long pre-date the Alkali trachytes, and may also pre-date the Limuru trachyte since every hill of coarse orthophyric trachyte stands above adjacent Limuru trachytes and in one case appears above a horst without recurring in the adjacent grabens (H6 on Fig. 8-3, and p.181). The Kedong Gorge at hill H2 on Fig. 8-3 appears to cut a section across a hill of a coarse orthophyric trachyte half buried in Limuru trachyte (Photo 8-5). All the cases are explained if the Gesumeti trachyte and the Ol Tepesi benmoreite are the same rocks, or phases of the same formation, and are the oldest of the trachytes. They would have suffered heavy erosion before being incompletely drowned by Limuru trachytes, and were left protruding as steptoes of various sizes and heights. Subsequent severe faulting gave the

Photo 8-5. Steptoe of orthophyre trachyte set in Limuru trachyte at southern bend of Baragoi gorge (H2 on Fig. 8-3). The former channel C4 passes right of the hill. Fragments of a Suswa lava flow can be seen resting on the sill.

general form of the present topography, but the steptoes would retain their original distinctive appearance, and would remain as hills above the adjacent lavas.

The latter sequence can be supported from available K/Ar dates which suggest that the coarse orthophyre trachytes all have ages between 1.9 and 2.4 Ma (p. 184), that they were eroded under normal fluvial conditions before being flooded by at least the youngest Limuru trachyte between 1.9 and 1.6 Ma (p. 185), and that Rift faulting created the present general land forms almost immediately after (p.106). Rivers then traversed the area before the eruption of the Alkali trachytes (1.4 - 0.8 Ma), because the Alkali trachytes invaded water-shaped valleys. Grid faulting followed, disrupting all three trachytes together. Streams then passed over the Alkali trachyte, leaving a series of water-cut channels before finally cutting the present gorge, which is re-excavated. This gorge was then invaded in turn by a thin flow of a quartz trachyte, and then flows from Susua volcano. Thus the gorge has a complex history as an erosional feature and great age.

IV. GEOMORPHIC EVOLUTION OF THE KEDONG GORGE

Streams flowing through the Kedong gorges sector before the Alkali trachyte flood could not have supplied the Olorgesailie Lakes which postdate the trachytes, but an account of the gorge which formed in the Alkali trachyte explains some fluctuations of the Olorgesailie Lakes.

Table 8-1. Geological section at Baragoi

3.5 m trachyte/trachyphonolite (surface of shelf. Randel's phonolite with globule surface)

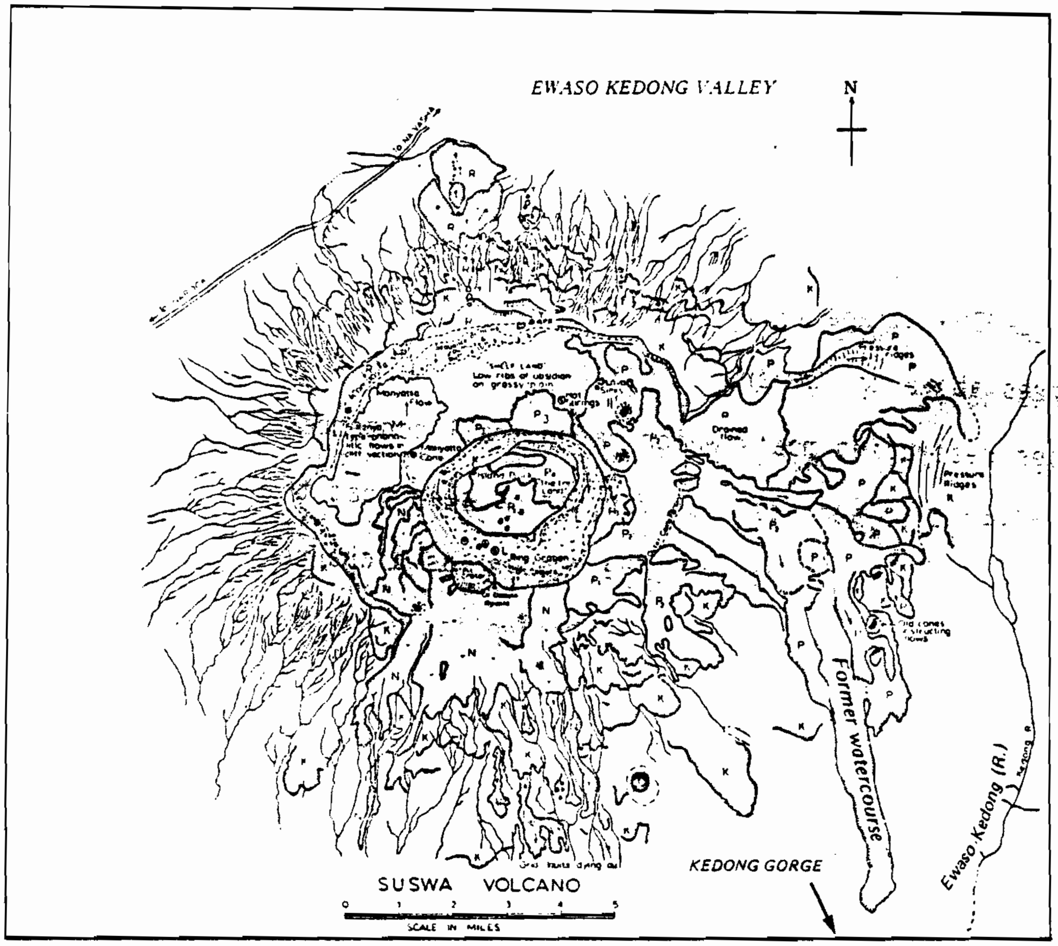
Contact masked

6.0 m	quartz trachyte (Baker's Baragoi t?)
0.6 m	cinder and ropy scoria
	erosion surface
1.2 m	stratified consolidated airfall tuffs
2.15 m	stratified airfall tuffs - loose
	erosion surface
4.0 m (max. 12m)	Alkali trachyte
	contact masked by talus
2.3 m	quartz trachyte ('rhyolite')
11 m	Limuru trachyte (bottom not seen)

The section repeats in the opposite wall of the gorge.

1) <u>A variety of channels through Baragoi and Nkobirri</u>.

A section exposed in the western wall of Baragoi (GS1 on Fig. 8-3) shows 3.5 m of a Susua flow (Plpl on Randel's map, 'phonolite with globule surfaces') overlying a volcanic sequence (Table 8-1). The uppermost flow has not been positively identified as a phonolite by Crossley, but may be a trachyphonolite (Geological sample M1, Crossley 1978, pers. comm.). The section below it shows six metres of an alkali trachyte overlain by ropy scoria, boulders, and pumice which may represent the trachyte's flow surface. The trachyte overlies two distinctive bands of tuffs at a marked disconformity, the highest being stratified, consolidated, airborne tuffs which lie conformably over loose airfall tuffs with a sandy texture that accumulated on a clearly defined erosion surface. The surface shows some smoothing, some boulders at the interface, and other debris. The tuffs represent Susua eruptions. The erosion surface is on a maximum of 12 m of a quartz trachyte which is almost certainly the Alkali trachyte, and the Alkali trachyte overlies 2.3 m of a highly quartzitic trachyte (M8), identified in hand sample by Baker as the upper surface of a 'Lower Orthophyre type' (Limuru trachyte), and by Crossley in thin section as a quartz-trachyte with almost enough quartz to be called a rhyolite. The rhyolite forms the floor of the stream above the bend, but a few metres southward the channel is in Limuru trachyte. In the section on the wall, the Limuru trachyte appears at the base (bottom not seen). The entire section is exactly matched on the east wall, showing that the gorge has been eroded in it since its emplacement and that there is no fault displacement.



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MAP. 1 - General map of the Suswa complex drawn from air-photographs.

Fig. 8-4 Susua Volcano with prominent flow occupying former channel of the Kedong River.

The uppermost disconformity in the section marks a marked erosion surface on the tuffs. The section exposed a V-shaped notch 14 m deep occupied by volcanic rubble typical of the base of a flow, hanging 26 m above the floor of the present gorge. (Photo 8-6). It is a cross-section of a small fluvial valley which has cut itself into tuffs and the upper part of the Alkali trachyte. It appears to have been filled by the furthermost extension of a prominent Susua flow of a non-porphyritic phonolite (Randel's Plp4)(Fig. 8-4) see also Folio map 2 and LANDSAT image (Folio Fig. II:2). The rock of the flow stands a few metres above the general surface, but it is flanked by gentle depressions resembling moats which carry small contemporary ephemeral streams. From this and its plan form it is seen that the flow was guided south in a pre-existing trough. The trough was a channel of a former Kedong River which predates the Susua phonolite and the Baragoi trachyte. The Baragoi flowed after the phonolite, but below it in altitude, drowning only the southernmost and lowest extension of the Susua eruption. The fluvial channel which guided the Susua flow is therefore >0.4 - 0.36 Ma in age, and younger than the Susua tuffs over the Alkali trachyte. The channel would have been completely buried until the section was exhumed by the Kedong River in a later form (see p.139).

The geological section in the south part of Baragoi is confusing. There is a loosely consolidated ridge of volcanic rubble including lava breccias, which represents a Susua flow on the floor of the gorge. Its base lies below both the Alkali trachytes, and it is inset in the gorge, but it appears to be overlapped by the stratified tuffs

Photo 8-6. Disconformity in volcanic stratigraphy, west wall of Baragoi gorge. Volcanic rubble at the right has filled a former stream channel cut in Suswa tuffs (left) and Alkali trachyte (foreground). The sequence is capped by an alkali trachyte which may be Baker's 'Barajoi trachyte' (see text).

and the Baragoi trachyte. It may have filled a major former channel of the Kedong River which postdates the Alkali trachyte. Fragments of the flow rest on the sill of channel 2 (Stereogram 3, Folio II:17, Photo 8-5). It was this flow that blocked the Kedong Gorge, and held the tuffs and Baragoi trachyte at 1350 m, although overflows of the latter are found in the south at lower altitude and without the volcanic sequence. The blockage is the prime cause of the stream overflow that later followed channel 4, but once the Kedong River cut back to the main gorge it easily removed the blockage and resumed a former path.

The volcanic section in Baragoi is not repeated in the Nkobirri Gorge. In the south the Alkali trachyte forms terraces nearly 50 m high flanking the present gorge, which has been cut in them. There is an Alkali trachyte which provides a lower terrace (5-6 m) within the gorge cut in the Alkali trachyte (Photo 8-3), and therefore postdates it. It may be the Baragoi trachyte. Outside the southern exit of the Gorge there is a feature which resembles a delta on aerial photographs (FDI on Fig. 8-3 and Folio map 5), but is a thin blocky flow of lava which is either the Baragoi trachyte, or a Susua flow which traversed the length of the Kedong Gorge and then fanned out and cooled on open ground at the exit. This event would stop river flow for some time, but river flow resumed because a large broad channel has been cut in the lava floor (C7 on Fig. 8-3, and Folio map 5). Within the gorge, the inset flow has been eroded, leaving only fragmentary terraces on the wall of the gorge and water-worn 'islands' of rock on the floor. This would be the last major stream through the gorge.

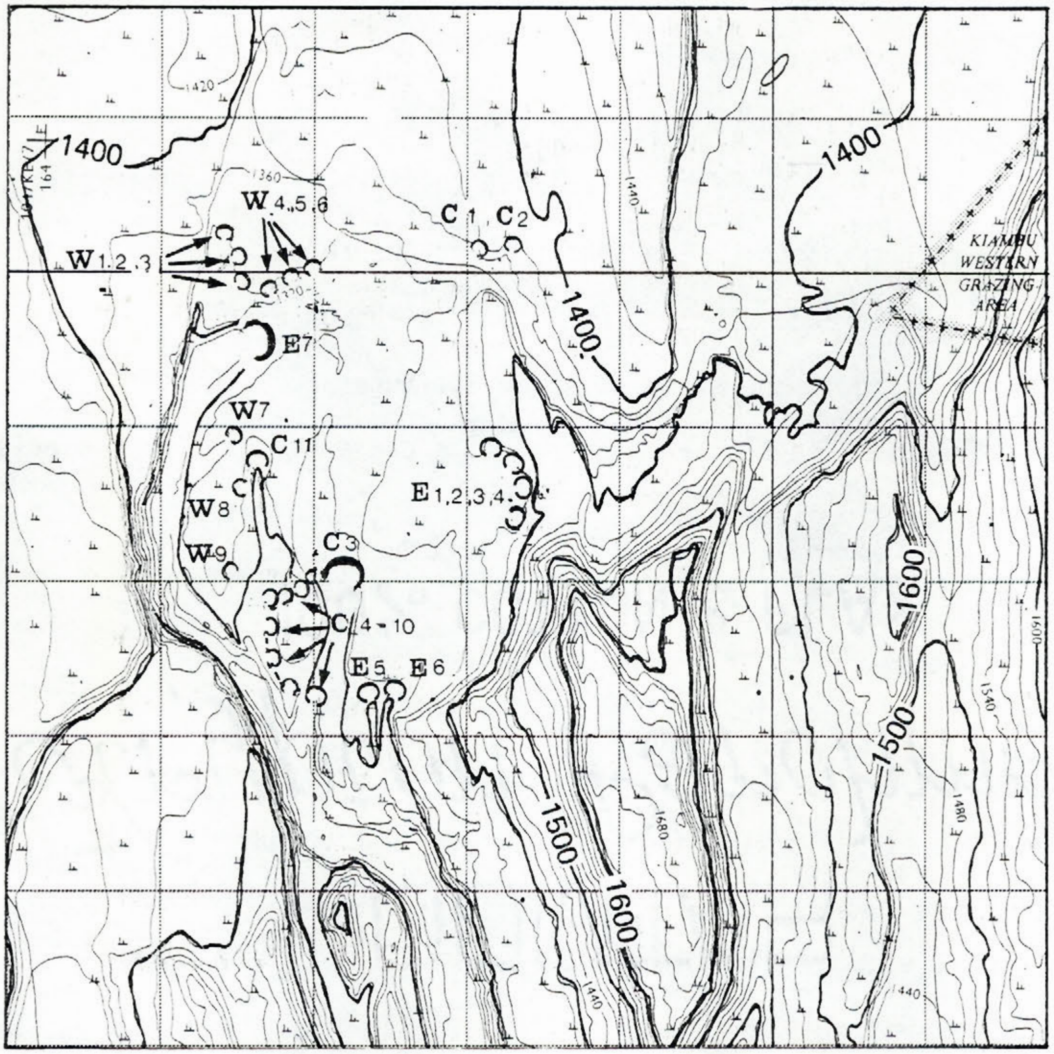


Fig. 8-5. Dry falls of former Kedong River in the Baragoi sector of the Kedong Gorge. Enlargement of area in the north of Fig. 8-2. 'C' symbols represent dry falls, open in the direction of flow. Numbers are explained in text. Contour interval 20 m.

2) <u>The Baragoi Loop and rivers from the Kedong Valley</u>.

The Baragoi loop encircles an area with a complex history. The uppermost trachyte has been stripped away by water-erosion, exposing the stratified tuffs over several square kilometres (Photo 8-7), and large streams have followed at least seven routes across the site. (Fig. 8-3).

There are twenty-five dry falls or plunge pools in the Baragoi sector, but they may represent phases of only three rivers. A western group (W numbers on Fig. 8-5) are all variants of a stream running south at the foot of a fault scarp. A central group (C numbers on Fig. 8-5) appears to represent a much larger stream flow which crossed the site directly north-south, stripping the Baragoi trachyte off the tuffs, and then for a time passing over into channel C4 (Fig. 8-3), before later plunging into the re-excavated Kedong Gorge. A third group (E numbers on Fig. 8-5) represent an overflow from the Kedong Lake which first flowed directly west, creating the multiple dry falls (E1 on Fig. 8-5) before being channelled northwest, probably along a fault-line, and creating the present form of the Baragoi gorge.

The western channel and its group of falls seems to be the oldest, since all the other channels hang over it. Most of the central group must have followed, since they are traversed by the present Baragoi gorge, and so must predate the eastern group of falls, although some minor features (C1 and C2) are oriented to the final gorge. The easternmost group (E numbers) were created by the overflow from the Kedong Lake (Fig. 3-5) and were the last in the sequence.

Photo 8-7. Dry falls within the course of the Ewaso Kedong at Barajoi. The youngest alkali trachytes are visible at left, above Suswa tuffs which have been exposed by erosion of the former Kedong River.

North-South streams on the Alkali trachyte crossed the site of the Kedong Valley and entered the present gorge sector in the period after 0.8 Ma BP. As Susua volcano grew, it blocked and diverted similar streams on the lowest floor of the Rift and re-directed run-off eastward to add to stream flow through the Kedong site where the Ethinyai escarpment, and the Baragoi scarp, reinforced by the shield mass of Suswa, created a funnel for all streams moving south in the Rift Valley. Subsequent Susua eruptions gave deep covers of tuff across the valley, but the streams maintained or reasserted themselves. A major stream channel entering the west side of the funnel was filled by a Susua lava flow which was captured and redirected, while the stream itself was deflected even further east. Shortly afterwards the floor was flooded by a younger Alkali trachyte (Baker's 'Baragoi trachyte'?), and presumably all drainage was again disrupted for a time. The Baragoi sector of the Kedong Gorge was filled to an altitude of 1350 m ± by the Susua flows and the overlying Baragoi trachyte, so that drainage overflowed the gorge and entered channels west of the Kedong Gorge.

Drainage resumed over the Baragoi trachyte and began to cut down at the old site, where it was fault-guided (Fault scarp B on Figs. 8-3 and 8-5). As more Susua flows built eastward, the south flowing streams were deflected even further east and large streams crossed the Baragoi site directly north to south (c numbers on Fig. 8-3). The stream at this period may have entered the hanging channels (C4 on Fig. 8-3) before erosion removed enough of the fill for the stream to resume its path down the former Kedong Gorge. Finally, all the streams were pushed far enough east to become trapped behind east-facing fault-scarps, and the Kedong Lake was formed. The Kedong Lake finally overflowed (01 on Fig. 8-3) and after creating several channels and falls to the south and southwest, finally assumed the course of the present gorge.

In the final stages at Baragoi, the Kedong River may not have been very large. The deepest gorge and the present channel course (far to the west) is narrow and has a much smaller capacity than the channels above like those on the trachyte and tuffs, which are for the most part broad and shallow.

V. SUMMARY OF DRAINAGE THROUGH THE KEDONG GORGES

There are a number of hills in the Kedong gorges sector which represent steptoes of highly porphyritic trachytes ≃ 2 Ma old. They appear to be water-shaped, but any record of a drainage pattern has been drowned by the youngest of the Limuru trachytes which innundated the area between >1.9 and 1.55 Ma BP.

There is no sure evidence of east-west drainage patterns over the Limuru trachyte on the floor of the Rift Valley such as has been shown on the Esakut platform (p. 109), but the terrain below the platform has such a violent history of rift and grid-faulting with repeated lava flooding since about 1.7 Ma that it would be surprising if any record survived. After the Esakut platform was created, the area was succesively invaded by the Olkeju Nero basalts in the south, the Ol Tepesi basalts in the south (two phases), the Alkali trachytes, a variety of flows from Susua volcano, and a younger quartz trachyte, probably Baker's Baragoi trachyte (Baker, pers. comm., 1978). Baker and Mitchell (1978) would add, as intrusions, the Gesumeti trachyte and the Ol Tepesi benmoreite (see Table 3-1).

A major north-south gorge was cut in Limuru trachyte because the Baragoi-Nkobirri gorges have Alkali trachyte inset and therefore the gorges predate it. A similar condition exists for the channels west of Gesumeti (C2 and C4 in Fig. 8-3), and in the lava-filled gorge east of Emerit Hill. All four features show a sinuous distribution of the lava fill, which suggests they are not merely fault-angle valleys between tilted horsts.

The north-south channels in the Limuru trachyte would have begun to form at the time when east-west drainage terminated because of movement on the Githingucho-Ngong faults between 1.8 and 1.64 Ma BP (p. 108), but they would be emphasized when the Esakut platform was first created, and then isolated from north-south drainage by the evolution of the Kedong and Ethinyai escarpments. Water from the eastern Rift flanks, which formerly drained south across the Lusigeti step-fault platform, was diverted westward and concentrated with other streams at a low point west of Sakureti and just outside the Esakut platform. The major faults, which delimit and generally guide the Kedong gorges, had formed before 1.65 Ma BP, because grabens on the floor were invaded by Ol Tepesi basalts which are found only below the platform. Apart from the basalts between the Emerit and Njoloi Hills (LF on Fig. 8-3), it is not possible to prove the basalts invaded riverine forms.

Alkali trachytes (1.4 - 0.8 Ma) occupied all the gorges, and their distribution shows that they floored or filled fluvially shaped gorges. They also created a temporarily uniform floor across the Rift and around the foot of the Ethinyai escarpment, upon which north-south drainage was entirely re-formed (see Chapter 7). Only in the Kedong sector, where large hills of Limuru and other orthophyre trachytes stood above the lava flood, would streams be directed along the former general lines.

Grid-faulting, or late rift-faulting, created the Baragoi fault scarp (FSB on Fig. 8-3) which, together with the Ethinyai escarpment, guided all drainage leaving the general area of the present Kedong Valley. A major channel ran north-south, continuing the line of drainage directly north of the Kedong Gorge and the Baragoi loop had not been formed. It was at this time (<0.8 Ma BP) that water could begin to supply the Olorgesailie Lake site. There is no direct evidence of the size of the flow.

Susua volcano began to form at ≃0.7 Ma (p.117). Its early eruptions had little effect on the Kedong sector, but as the shield phase of Susua developed, the sequence of eruptions caused major changes at the head of the gorge. The rising hill cut off north-south drainage on the central floor of the Rift Valley (p. 120), re-directing it eastward. At the same time eastward flows of Susua trachytes and phonolites began to modify the Kedong Valley drainage. One lava flow was intercepted by a Kedong channel and directed southward into the Kedong Gorge which became choked by volcanic debris. A phase of tuff deposition followed, during which streams may have maintained themselves, but the tuffs were followed by a sheet-flood of an Alkali trachyte. If this is the Baragoi trachyte, it dates to 0.4 - 0.36 Ma (Baker 1978, pers. comm.), which completed the fill at the had of the Kedong Gorge at Baragoi. Some of the latest trachyte spilled over and found its way at lower altitudes through the old gorge.

Drainage resumed over the blockage, and because Susua's growth concentrated all north-south drainage into the one gate below Sakureti, water flow reached a peak at this time. For a time the combined rivers escaped straight south over the volcanic fill, stripping off the Baragoi trachyte and cutting into underlying tuffs. For some time the enlarged Kedong River ran down a valley to the west of the Kedong-Nkobirri (Channels 4a/4b on Fig. 8-3). The episode caused severe erosion, but in the final version the channel 4b adjusted to the base level provided by the old Nkobirri. Late in this phase, water escaping across less competent rock of the lowest volcanic rubble fill, reasserted the old channel, and the Kedong Gorge was occupied by a Kedong river for a third time.

Continued expansion of Susua then diverted the north-south streams of the Kedong Valley eastward of east-facing escarpments in the Kedong Valley and created the Kedong Lake. The lake filled, then overflowed at the foot of Ethinyai escarpment, creating major falls and plunge pools (Photo 8-5), and re-orienting the direction of water flow. Subsequent faulting, or the exploitation of a pre-existing fault-line, re-directed the stream west, then northwest, until the present Baragoi was formed. The last phase began as a large stream, but the flow dwindled with time, and the deepest gorge form on the existing graded profile is only a few metres wide, with a capacity that is only one-tenth of the channels on the upper surfaces of the blockage at Baragoi.

All the rivers described could have supplied the Olorgesailie lakes. In the most simple sequence there are six episodes of violent change or disruption, and there may have been others associated with eruptions of Susua. The final streams were small, and although there are many stream courses incised on the Kedong Lake beds they are masked by ash and alluvium in the north and there is no evidence of major channels above the ash in the Kedong Valley. The ashes give way to the lower slopes of Mt. Margaret and Longonot Mountains thought to be much younger than Susua, and the evidence suggests that in the late stages of the growth of Susua and the early stages of the formation of Longonot, all north-south drainage stopped and continuous stream flow ended.

The Ewaso Kedong formed from springs on the Longonot slope. and is supplemented by streams from the Rift flank, in season. The superficial flood scars and the ravines on the flanks of Orgaria and Longonot (including the exit of Njorowa) indicate only ephemeral episodes and there is no trace of continuous flow. Although the ravines may be relics of a former wet period, the scars caused by sheet-floods can be seen being actively renewed today and are not ancient features. Any large channels that may have existed formerly have been buried by debris from Orgaria and Longonot.

It is assumed that the growth of the Orgaria-Longonot ridge, and the cutting off of north-south drainage, would mark the end of the Olorgesailie Lake system, but the ridge has not been dated, and there is no direct evidence that the ages coincide. One weak correlation is that the lowest stratum of Isaac's Member 13 in the Olorgesailie Lake beds contains a high concentration of pumice lapilli (Isaac 1968 Plates II:9, II:10), and the Orgaria ridge and the outer rim of the Longonot crater are built largely of pumice lapilli, the only major accumulation of pumice in the area. Whether the lapilli were airborne to the Olorgesailie site, or washed down later through the stream system, they would provide a maximum age for the upper beds at Olorgesailie.

VI. THE KEDONG GORGES AND THE OLORGESAILIE LAKES

There is no evidence that the rivers which traversed the Kedong gorges always entered a lake. A shoreline of a shallow water body can be recognized at the exit of the gorge at 1120 m, but there are no deltaic deposits. The stream channel crosses the lava 'delta' near the exit, and there are two major delta sectors to the south of Njoroi and at Ol Tepesi. The delta at Njoroi (D1 on Fig. 8-3) is a major deposit, masking water-eroded rock in places. It has been dissected and terraced by four channels of a major stream, presumably after the last time lake level dropped and exposed the delta. The delta and its erosion show a major river continued flowing after the time of maximum depth in the original Olorgesailie lakes. The Ol Tepesi delta is thinner, but much larger, and has been shown to be related to a late phase, because it postdates creation of the shallow Ol Tepesi graben which postdates all the Olorgesailie beds (Chapter 4). It represents a terminal phase since it has not been dissected or channelled by large rivers. If any other deltas were created at the head of the Olorgesailie Lakes they have been either buried or destroyed. The Njoroi delta surface stands at 1060 m, slightly higher than the highest surviving Olorgesailie beds at 1040 m.

The history of change, re-direction and stoppages in the Kedong River as shown by the Kedong Gorge provide ample reasons for the fluctuations in level shown by the Olorgesailie Lakes. The re-direction, volcanic episodes, and the creation of a Kedong Lake as a settling pond also help explain the varied materials shown in the Olorgesailie Lake beds' stratigraphy.

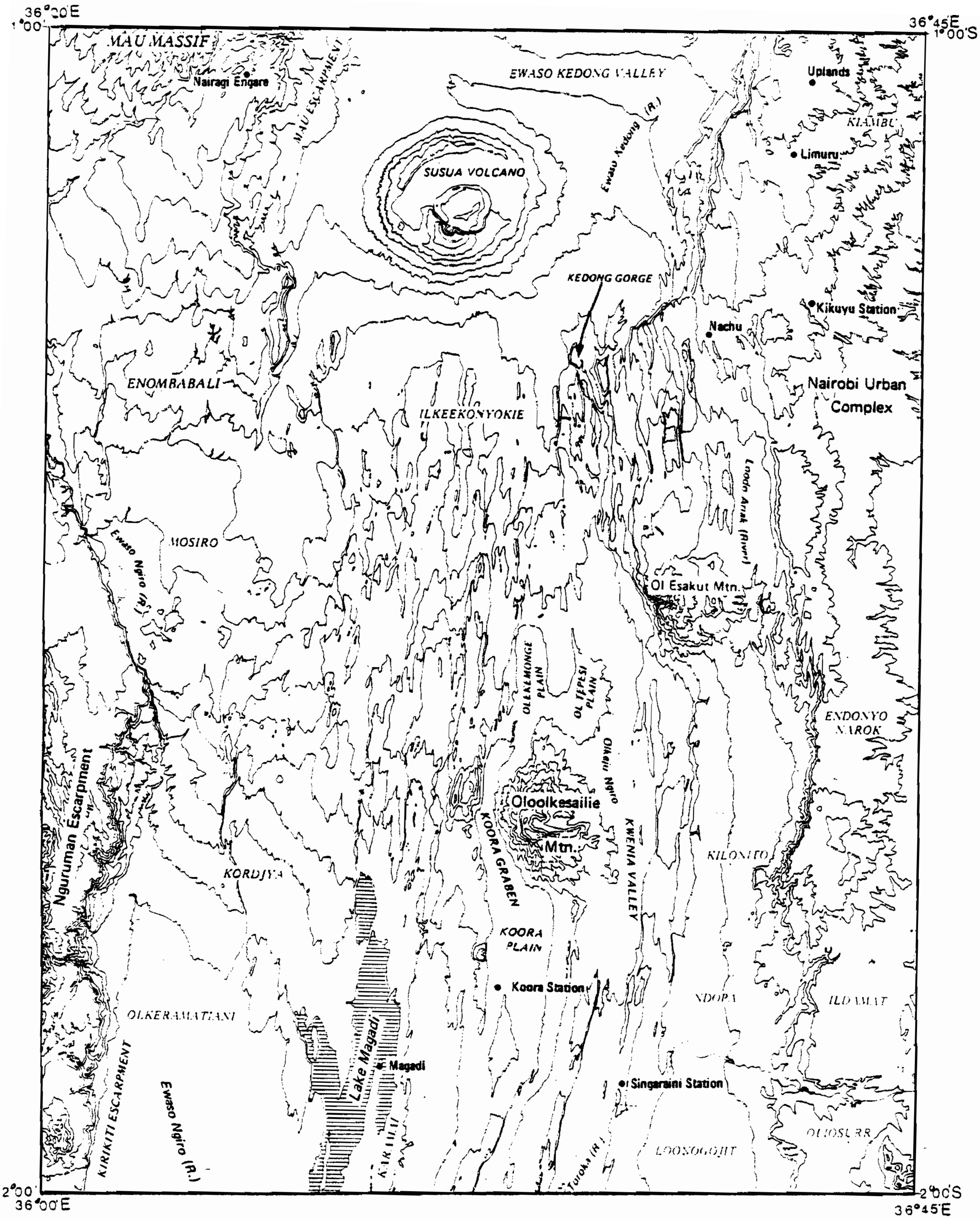


Fig. 9-1 General location map of the study area, Chapter nine. Summary and conclusions.

Chapter Nine

THE ORIGIN AND EVOLUTION OF THE OLORGESAILIE LAKE BEDS

The Olorgesailie Lake beds were considered to demonstrate frequent climatic change because of the many non-sequences in the stratigraphy. This work has shown, however, that once the full extent of the former lake was determined and the nature of its water supply explained, the lake beds need to be analysed within a larger context. The Olorgesailie Lake series represents only one incident in a complex readjustment of drainage over a large area. The studies of the larger context presented in the previous chapters allow a complete explanation of the origin and evolution of the Olorgesailie Lake beds.

The results of the analysis may be considered in relationship to three areas of interest. The relationship between the lake beds and climatic change, the relationship between the lake beds and drainage in the Rift, and the relationship between the non-sequences and the events which caused them.

I. THE OLORGESAILIE BEDS AND CLIMATIC CHANGE

The stratigraphy of the Olorgesailie Lake beds shows that the Ololkesailie site was occupied by a series of lakes, or a lake with fluctuating levels, which endured for some tens of thousands of years (p. 57). The beds occupy a basin in a complex of grabens which could not retain a lake today (p. 1), and the general area is in any case arid with only a small seasonal stream from the Rift flank crossing the site (p. 58). It has been assumed until now that the existence of the lake, the multiple disconformities in its deposits, its final death, and the subsequent dissection of its lake beds all indicate climatic changes, with recurring cycles of wet and dry environments (p. 1). Direct dating of the beds has proved unsatisfactory for a variety of reasons (p. 55).

There are other sedimentary sequences in the general area: pyroclasts and sediments of the Kedong Valley, the Kedong Lake beds, the Baragoi tuff sequences, the sediments of the Njorowa, Seyabei, and Kedong gorges, the materials in the Pleistocence Lake beds which occupy many graben floors, the Oloronga beds, the Orkaramatien beds, the High Lake Natron-Magadi deposits, High Magadi beds, and the sediments of Mosiro, Kordjya, and the Koora graben. There is no apparent correlation between any of them, and although some, like the Oloronga and Orkaramatien beds, follow one another in sequences, many show no evidence of similarity, and no evidence of sequential relationship.

The Seyabei sediments lack the inset diatomaceous beds of Njorowa, the Kedong Lake sequence does not resemble the tuffs at Baragoi, and neither resemble the reddish tuffs of the central Kedong Gorge, or the inset red beds at Ololkesailie, which are the only sediments in the area that resemble reworked (lateritic) soils. The diatomites at Gicheru contain more pure diatomaceous material than the Olorgesailie beds, and at Gicheru they follow each other without interruption by other materials. If any beds within any section are contemporaries, they are contained in sections with different and highly individual sequences. A close examination of the sediments has failed to find any contained climatic indicators other than the well-known viviparous beds at Oloronga and the Koora snail horizon (p. 57), and of course the diatoms which are contained in the diatomaceous beds. In some cases even the diatoms offer ambiguous evidence since they may have been re-worked,as at Njorowa Gorge, or in the Koora graben system (p. 76).

One characteristic of the physical facies which is common to the stratified sediments from the area is the almost total absence of current or cross-bedding of any sort. The overwhelming majority of the strata are structureless, a characteristic which is typical of deposits created either by air-fall into still-water, or by the settling out of turbid waters in still-ponds. Only air-fall tuffs are thin-bedded within the various strata. Most beds are relatively thick, and where coarser materials are involved, the accumulation was rapid during catastrophic episodes.

There are no soil profiles visible within the sedimentary sequences, and no vegetation horizons, not even tree stems or roots, as might be expected from a savanna surface before the advent of man. This reinforces the notion of frequent catastrophic accumulations rather than systematic and progressive environmental changes related to climatic shifts.

There are many former stream channels in the area, however, they are not arranged in dendritic patterns, and seem to represent the pathways of former exotic streams originating outside the area (p. 119), devoid of tributaries, and strongly guided by tectonic features in the landscape. There has been no significant fluvial development of the landscape of the Rift floor in ≈ 2 million years, and the dessication experienced during that time can be explained simply in terms of the altitude lost as the floor dropped out of the zone of orographic precipitation. Precipitation on the Rift floor (<500 mm) closely matches that of terrain at a similar altitude (700-1100 mm) throughout Kenya,and is considerably less than the rainfall it would now receive if the floor was at its original altitude.

The absence of evidence is always an unsatisfactory form of proof, but unless future palynological studies can retrieve indicators of climatic shift from the various deposits there is no evidence to support the hypothesis of climatic change as a reason for the frequent changes in sedimentation sequences, or to explain the growth and death of the various lake series. There is ample proof of climatic fluctuations around the world in the last million years, and climatic changes undoubtedly occurred in this sector of the Rift Valley, but they were apparently not of a nature or magnitude that could explain the major events that took place on the floor of the Rift. They were insignificant in comparison with the impact of a re-orientation of regional drainage, and the many sequence changes are fully explained by volcanic and tectonic episodes associated with the evolution of the Rift Valley in the sector between Longonot and Lake Natron.

II. THE OLORGESAILIE BEDS AND DRAINAGE IN THE RIFT VALLEY

It is widely accepted than an east-flowing drainage system reach or traversed the Rift Valley system in this sector during late Tertiary time, and that it was disrupted by doming in the mid-Pliocene period (p. 32). It is known that vulcanism began in the Rift area as early as the late Miocene (p. 23), and although the earliest history of the Rift is not understood it is certain that an early form of the Rift in this sector was flooded and filled by Lengitoto trachyte in the interval between 6.9 and 4.5 Ma BP (p. 92) and that a west-east river later resumed across the Rift site (p. 81). The river carved a significant valley which was filled and obliterated by Oletugathi ashes and lavas in the interval betwen 4.5 and 3.0 Ma BP, and the system was then replaced by fault-guided streams, direct ancestors of the Ewaso Ngiro and Seyapei, which intercepted drainage to the southwest off the Mau massif. The eruption of the Mosiro trachytes (2.3 - 1.9 Ma) diverted both streams southward at the western edge of the Rift floor, and their subsequent history was restricted to the west (p. 81), where with minor re-routing they contributed water to lakes on the lowest floor, in the area of the present Lake Natron.

There is no evidence that either river ever crossed the Rift. On the Mosiro trachyte surface streams were oriented to the southwest and appear to have originated from high ground which then existed over the present site of the Lake Naivasha basin (p. 94).

The eastern rim of the south Kenya Rift Valley shows a related history. In the south, east of the Turoka-Ngong fault escarpment there are only obscure suggestions of a former west-east stream system, but if such a system existed it was truncated by the Turoka-Ngong fault (≃4.8 Ma) and a reversed drainage was instituted on the fault-scarp (p. 96). In the north, on and above the Esakut platform, there is clear evidence of a major west-east drainage system which was effective from the time 4.84 Ma BP until the eruption of the Limuru trachytes between 2.2 and 1.8 Ma BP (p. 101). That system was replaced by streams draining southeast in conformity with the regional slope of the Kiambu ridge of the Aberdare mountains, and the streams appear to have originated to the west, and to the northwest, from higher ground over the present site of the Kedong Valley and the Naivasha Lake basin (p. 107).

The Mosiro and Limuru trachyte flows represent the same event,and both overflowed the rim of the topographic Rift Valley as it exists today (p. 48). Since the Rift Valley form predates the trachytes it is not certain whether they filled a topographic rift valley and overflowed, or whether they began to flow at a higher altitude at about the time that renewed movement began on the Rift boundary faults (p. 47). In either case they were restricted in their southward distribution by the high terrain of the central-vent volcanoes Esakut and Ololkesailie (p. 39), and by Shanamu and the Mosiro hills (p. 88).

At ≃1.64 Ma BP drainage across the eastern rim was disrupted by major movements along the Rift faults and all drainage directed north-south within the Rift Valley (p. 108). The streams were exotic and entered the area from the north. A significant stream traversed the site of the future Lusigeti step-fault platform and for a time escaped from the Rift across low ground, creating major channels along the Nairobi and Mbgathi valleys which are now occupied by misfit streams (p. 108). When the Lusigeti step-fault was isolated by a movement at its western edge the drainage was directed entirely internally within the Rift. A stream may have crossed the site of the future Esakut platform north to south for a time with an exit between Ngong and Esakut, incising the gorge followed by the Loodo Ariak. The Esakut platform was formed before 1.4 - 1.6 Ma BP (p. 108), and the Ethinyai scarp isolated the platform from north-south drainage causing all internal drainage to be directed to the lowest floor of the Rift (p. 108). At this time, a stream occupied the course of the present Kedong Gorge immediately below the Esakut platform, being guided to some extent by fault-blocks and residual hills. On the western flank, the Ewaso Ngiro and its tributaries crossed a similar platform, the Mosiro platform (p. 82), and the Lengitoto and Oloibortoto rivers also reached eastward across the floor as far as the present site of Lake Magadi (p. 91).

Alkali trachytes flooded the lowest floor of the Rift, as it then existed, between 1.4 and 0.8 Ma BP. They surrounded or covered down-faulted Limuru and Mosiro trachytes between the Esakut and Koromoto escarpments, and overlapped the Mosiro platform in the west causing a dam which created a shallow Mosiro Lake (p. 89). The Mosiro Lake overflowed southward and from that date all drainage entering the Rift Valley from the west was confined to the western edge of the floor and supplied fluctuating levels of a proto-Natron Lake (p. 93). The Ewaso Ngiro system never contributed to the Olorgesailie Lakes which formed above the Alkali trachyte after this date (p. 94).

In the central and east-central Rift, Alkali trachytes covered the floor, except for the central vent volcanoes, but including the floors of the Kedong gorges, and for a short time created a relatively uniform surface upon which the north-south streams completely re-organized themselves. The only exception was in the Kedong sector where the streams were still guided by the massive fault-blocks and steptoes of older trachyte which stood high above the new floor. The lava flood was followed by grid-faulting which began about 800,000 years ago (p. 119), and the numerous north-south horsts and grabens exercised a very strong control over the drainage pattern (p. 112), except in the Kedong sector where the pre-existing fault-blocks and steptoes were high enough to remain as dominant factors. Grid-faulting, specifically the Baragoi fault (p. 144), combined with the pre-existing Ethinyai and Kedong escarpments to create a natural funnel at Baragoi which tended to concentrate drainage from the eastern flank in the Rift floor immediately northward, directing it into the Kedong Gorge where it began to cut down into the Alkali trachyte fill. There were also major rivers in the central sector of the Rift at its lowest axis, along the line of the present-day Ndupa 'River'.

At ≃0.8 Ma BP Susua volcano began to form (p. 117). Its beginnings coincided with grid-faulting (p. 117), which was redirecting streams into a variety of channels in the Ndupa sector, but later flows of Susua were not faulted, and the growing volcano formed an effective blockage across the channels (p. 120). Although some drainage may have escaped west of the young volcano, by the time it had finished its first phase of development Susua lay as a thin shield assymetrically across the floor and highest in the west. Ultimately all north-south streams were diverted eastward, joining the streams already flowing into the Kedong so that all southward drainage in the Rift Valley became concentrated in the Kedong Gorge. The date was more than 0.38 Ma BP because a late trachyte flow of that age occurs in the gorge at Baragoi and lies above a Susua flow that had already occupied a deep channel cut in the Alkali trachyte (p. 138).

The Oloolkesailie graben complex was created after the first eruption of Susua and before the mid-period flows. The evidence for this lies in the alignment of the principal faults at Olekemonge and Ol Tepesi, which continue as the faults that interrupt the early flows of Susua (p. 120), but are not visible through flows of the middle period (p. 116). Furthermore the phonolitic Susua flow which enters the Kedong Gorge, described as a terminal flow of the first phase by McCall (1965), is guided by the fault-scarp that aligns with the western edge of Ol Tepesi and therefore postdates it (p. 120). There is no indication of the date when the Oloolkesailie grabens became a basin which could retain a lake but the lake did not form until grid faulting had ended ≃0.4 Ma BP.

The lowest point in the Rift lay to the south and west, over the present site of Lake Natron, and this area acted as a base level for the internal drainage of the Rift (p. 75). A proto-Natron Lake formed immediately after the emplacement of the Alkali trachytes, and went through a number of phases exemplified by the Oloronga beds, the Orkaramatien beds, the High Natron-Magadi Lake (the '700 m lake'), and the High Magadi phase. There were embayments at Orkaramatien, Kordjya, and Magadi. The lake High Natron-Magadi predates the end of minor faulting because at one stage during the last recession, faulting deepened the Lake Magadi site and there was a catastrophic drainage of the Kordjya Lake (p. 90). The last stages of the Olorgesailie Lakes coincided exactly with the beginning of the decline of the High Natron-Magadi Lake, and the last Olorgesailie overflow created large steep deltas in deep water, with tops at 680 m (p. 70). There is no evidence of fluctuation after that time, except in the High Magadi beds (p. 71), and the 700 m shoreline is horizontal, showing that it postdates major tectonic changes on the Rift floor (p. 75).

The Olorgesailie Lake formed during the period between the formation of the Olekemonge and Ol Tepesi grabens and the decline of the 700 m Lake Natron-Magadi. It formed above the lowest level of the Rift floor and remained independent of the 700 m Lake Natron throughout its existence. It always maintained an overflow and so remained fresh throughout its history. It also remained independent of any fluctuations or changes that may have occurred in the Natron Lake.

Today there are significant minor random fluctuations in the hydrological regime of the area. The Nairobi-Magadi road has twice been cut for prolonged periods of time by floods in the Loodo Ariak since 1946, and once in a dozen years, during prolonged rains, the dry 'Lakes' Kwenia and Cabongo may flood and become shallow lakes for a month or so, while small pools and ponds survive for several days after short convection storms over sediments with low infiltration rates, particularly in Orkaramatiani, Mosiro, and the Koora.

III. EVENTS IN THE LIFE OF THE OLORGESAILIE LAKE

The stratigraphy of the Olorgesailie Lake beds suggests an eventful history. The beds show multiple transgressions, with intervals of land surface erosion which suggests significant variations in lake level; but they also show extremely varied deposits: clay, silt, sand, gravel, ash, tuff, pumice, and diatoms. There is no consistency in the type of materials deposited during the lake intervals, and no obvious sequence or cycle (p. 58). Some beds, like the ash bands, indicate intervals of volcanic eruption, with air-fall of debris into still water, but others in which silts and diatoms are mixed may contain materials which have been re-worked and brought to the site by streams, or by winds across a still water silt-trap. The variety of materials, the catastrophic accumulation rates shown by some facies, and the recurrent land surfaces, show that the Olorgesailie beds represent a catastrophic sequence, and that the Olorgesailie Lakes have a highly individualistic history within the general sequence of drainage changes within the Rift Valley. Since drainage from the Rift flanks seems to have been consistent through time, the Olorgesailie Lake history indicates responses to volcanic eruptions, tectonic movement, and above all variations in the Kedong River and its routeways through the Kedong Gorges.

The Kedong River had made a Kedong Gorge long before 1.6 Ma BP (p.143), although it was disrupted and forced to reform over flood lavas of basalt in the Njoroi sector at about 1.65 Ma (p. 143). These events had an importance for the Olorgesailie Lakes because the proto-Kedong River channel having guided the Alkali trachyte flows in the sector,later determined the route of the streams which formed upon them and then entered the Olorgesailie basin.

The events of grid-faulting created the Olorgesailie site and also began to modify the north-south drainage by directing it within grabens (p. 119). In the east, streams from the north and from the eastern flanks of the Rift traversed the Kedong sector, and maintained a shallow lake in the area of the Olekemonge, Ol Tepesi, and Koora grabens. The largest north-south streams were at that time traversing the centre of the Rift and fed an early stage of Lake Natron at the lowest point of the trough.

By 0.8 Ma BP Susua began a first phase of growth. There may have been ash eruptions, but the evidence shows a series of 'clean' lava floods, and an early stage of shield development which spread across the floor of the Rift Valley (p. 120). The lava floods and faulting caused multiple re-orientations of drainage in the central sector. The early phase of Susua was followed by a second phase of cone construction, possibly after the formation of a caldera. The second phase was preceded by episodes of tuff deposition, and accompanied by intervals of ash, tuff, and pumice eruptions (p. 137). Some of the pyroclastics may have ended in the Olorgesailie Lake as airfall, but a great quantity was deposited in the general area of the Kedong Valley, and would later be reworked by a Kedong River.

The continuing buildup of the main cone of Susua diverted the streams in the central sector, and although some streams bypassed the western flank for a time (p. 114), all of the north-south drainage was finally directed east of the Baragoi fault and the entire drainage of the Rift was directed through the Kedong Gorge. This began a period of maximum flow and a considerable gorge was incised into the Alkali trachyte fill of the Gorge (p. 145). This period of maximum flow was also a time when the streams were crossing new terrain littered with fresh pyroclastics. They would be turbid, and large quantities of reworked sediments found their way into the Olorgesailie stilling-pond.

At a date before 0.4 Ma BP a large final flow of the first phase of Susua was diverted from its eastward path by the fault-controlled valley of the Kedong River, and turned southward into the mouth of the gorge, so that a tongue of volcanic rubble caused a blockage in the Baragoi sector (p. 141). This series of events would have the effect of blocking stream flow for sometime, and change the materials carried. It was followed by a second flood of an Alkali trachyte which sealed the surface at 1360 m in the Baragoi sector, while some spilled over to provide a shallow fill within the Kedong Gorge, even flowing beyond the mouth of the Gorge and cooling into a lava fan (p. 139). This event would also interrupt flow, and the stream that resumed over the last trachyte (0.36 Ma BP) first occupied a channel to the west of the present Kedong and entered Ol Tepesi at a new location over a waterfall in rock (p. 133). Later it cut back east into the former Kedong and resumed the lower part of its old route. There would again be fluctuations in stream flows, and variations in the nature of the materials brought down to the Olorgesailie Lake.

The waters in the Kedong Valley were then directed further eastward by subsequent flows of Susua and became trapped behind escarpments in the Kedong Valley, creating the Kedong Lake. The Kedong Lake acted as a sediment trap and its overflow would be relatively clear for some time. The overflow from the Kedong Lake was violent and cut a new series of paths across the blockage at Baragoi before finally resuming the oldest path through the gorge below the blockage (p. 145). The overflow cut a variety of channels in trachyte and tuffs before settling in the present course through the Baragoi loop. About this time the volume of water declined because this last gorge is narrow and has much less capacity than the upper broad channels (p. 147).

The Kedong Lake overflow eventually cut down far enough to drain the Kedong Lake, and a diminished stream of the Kedong River followed a variety of paths across the Kedong Lake beds (p. 146). These streams easily eroded the lake sediments, which were reworked a second time, and some of them would be transported to the Olorgesailie Lake site.

It is not yet possible to date the final phase of the Kedong River exactly. Late flows of Susua sealed off the upper part of a Kedong

River tributary, but the other channels over the Kedong Lake beds disappear below ash which postdates all of Susua, and seem to be associated with the growth of the Orgaria-Longonot complex. Although north-south streams may have continued to cross the Orgaria-Longonot site for a time there was soon a complete barrier across the Rift and all north-south streams stopped. All evidence of this phase lies deeply buried below Orgaria-Longonot ashes and lavas.

All of these events are reflected in the deposits of the Olorgesailie Lake and this explains their varied character. All the events described occurred before the lake at Oloolkesailie was drained, i.e. up to the time immediately after the deposition of the highest bed (p. 65). The Olkeju Ngiro might have been able to maintain a shallow lake after the Kedong supply stopped, but renewed movements in grid faults of the Rift floor extended and lowered the lake basin by deepening the previously shallow grabens at Oolkululu and Siriata (p. 74). The level of the Olorgesailie Lake dropped and the lake itself migrated southward, so that the head of the lake lay south of Oloolkesailie Mountain. The last of the Kedong streams cut down through its own deposits at Njoroi (p. 63). Minor faulting created a temporary shallow lake in Ol Tepesi (p. 65), but the overflow of the Ol Tepesi Lake quickly cut down through the abandoned Olorgesailie Lake beds and drained the Ol Tepesi Lake (p. 65). The very last phase of the Kedong River created a large outwash fan at the head of the Ol Tepesi plain before ceasing effective flow (p. 65).

The last stages of the Kedong River and the regular seasonal flow of the Olkeju Ngiro, combined with surface wash, caused severe erosion in the Olorgesailie beds, and the reworked materials were redeposited at the new head of the Lake, south of the Koora graben (p. 76). At this stage the entire floor of the Rift began to tilt gently southward and as the containing horsts were tilted the outflows from the Lake began to migrate southward utilising successively lower points on the western escarpment (p. 75). There were three distinct phases. The first overflow channels end above 800 m and represent a phase before the Rift floor had reached its lowest level, but the last two overflows run to the 700 m shore of High Natron/Magadi which had formed on the lowest floor of the Rift Valley (p. 75). The last overflow from a severely diminished Olorgesailie Lake coincided closely with the final fall of the 700 m lake, since the overflow channels cut below the 700 m level, but the deltas from them were built out into deep water from ≈680 m (p. 70). It seems likely that the two events are related, and they represent the termination of an internal north-south water supply. The subsequent water supply came only from the Rift flanks east and west, and Lake Magadi became an isolated completely saline lake with no feeders. Major tectonic movements had all ended.

The centre of the Olorgesailie Lake basin shifted south and then drained in a fairly rapid sequence. The overflows 2 and 3 are not deeply incised and only the final overflow seems to have had any significant duration (p. 75). There is again evidence of a catastrophic sequence. The final death of the lake is linked to a physical blockage of the former water supply, and the stoppage may have been abrupt, because there was no final saline phase.

Table 9-1 Expanded scale table, Rift Valley drainage after 2MaBP

*Dated event. All other events are in correct sequence between fixed dates. C=Kedong River channel. O-Lake=Olorgesailie Lakes. O(K)= Olorgesailie (Koora) lake, the Olorgesailie lake after moving south into the Koora graben.

MaBP	West	Central	East-central	Kedong Gorge
Present	L. Natron, Ewaso Ngiro		Ewaso Kedong, Loodo Ariak, Ol Keju Ngiro	Ewaso Kedong begins
		Growth of the Orgaria-Longonot cross-rift blockage		
0.1	High Magadi L. Magadi isolated Kordjya Lake	Susua lava over water-worn rock*		End of Kedong River
			Olorgesailie (Koora) Lake last overflow (04)	Reduced Kedong River
(0.2)	High Natron (700m)		O(K) Lake, overflow 3 O. Lake moves south into K.	Kwenia isolated (Temp) Ol Tepesi Lake
		Deepening Rift Valley floor? Koora deepens		Olorgesailie Lake ends Kedong River channel 5
(0.3)				Kedong Lake Kedong River channel 4b Kedong River channel 4a
0.4			Susua quartz trachyte (Baragoi?) seals Kedong gorge*	
		Major grid faulting ends*	Baragoi fault	Olorgesailie Lake begins? Max flow Kedong River
		Susua pyroclastics; caldera begins*	and cone phase	Olorgesailie Lake begins?
0.5	Ewaso Ngiro confined to west Mosiro Lake ends Movement on Kirikiti Fault*			
0.6	Mosiro basalt*	Ol Doinyo Nyokie* sinks? (Koora graben forms?) Ndupa River system ends		Olorgesailie Lake possible
	Orkaramatien (lake) beds			
0.7	Oloronga (lake) beds*	Ndupa drainage multiple diversions		
0.8		Major grid-faulting begins* Susua Volcano begins (shield phase)*		Gorge(C3)forms in Alkali t. Kedong River channel 2
0.9		Last flows of Plateau (Alkali) trachytes 0.89*		
		North-south drainage disrupted by active lava flows		inc. Kedong River
1.2	Mosiro Lake overflows south to Lake Natron			
1.3	Start of proto-Natron lake			
	Mosiro Lake begins*	All north-south drainage disrupted*		Alkali t. invades Kedong G.*
1.4	Magadi trachytes* ----------	Plateau trachytes*	----------	Alkali trachytes*
			Ol Tepesi basalts*.	Southern sector of Kedong River disrupted and channel buried*
1.5		All drainage north-south	Kedong gorge in Limuru trachyte west-east drainage ends Loodo Ariak develops on Esakut platform west-east drainage on Lusigeti platform	
1.7	Last Kordjya basalt*		Later phases of Limuru trachyte*? on floor? drainage to south-east over Limuru trachytes	
1.8	Drainage to south-west over Mosiro trachyte Ewaso Ngiro dammed, Seyabei diverted			
1.9	Later phases Mosiro t.*		early phases of Limuru trachyte (earliest not known)*	
2.2	Early phases Mosiro t.*			
2.3	Last Kirikiti basalt*	Singaraini basalt*	Ol Keju Ngiro and Turoka river systems in south. Functional before and after Singaraini basalt.	
		Cross-rift west-east drainage in northern sector of Rift only*		

Baker provides evidence which may give a date for a last flood in the Kedong Valley. A water-scoured lava flow from Susua is overlain by an unscoured Susua flow and dating of both rocks places the final fluvial episode at 0.1 Ma BP (pers. comm.). The scoured rock is from the post-caldera sequence of Suswa lavas which is in agreement with the sequence of events that has been identified here, but the incident has not been linked to the chronology. Until the Orgaria-Longonot complex is dated there will be no precise date for the end of the Kedong water supply to the Olorgesailie Lake series.

Thus the Olorgesailie Lakes may have existed for almost 300,000 years, between 400,000 and 100,000 BP. An ancestral lake could have begun to form as much as 690,000 years BP, but the main events in their history at the historical site began at a time shortly before 400,000 BP and may not have lasted more than 100,000 years. In a later part of its cycle the lake moved south in the Koora graben and its final draining closely followed the collapse of the Rift floor to its present altitude at Magadi. There is indirect evidence that a river system may have been active until 100,000 BP, but the end of the lake is associated with a cross-rift blockage caused by the growth of Orgaria-Longonot which blocked all north-south streams. The streams that were blocked were exotic to the area, and were probably similar in form and origin to the fresh-water streams that supply Lake Naivasha from the Rift flanks east and west.

CONCLUSIONS

The Olorgesailie Lake beds were chosen to study for two main reasons. They contain important and well-known archaeological sites which cannot be completely evaluated without a better understanding of the lake sediments and the former environmental conditions. More importantly, the lake beds have come to be regarded as presenting evidence of frequent climatic change during late Pleistocene time, and they do so with a clearly defined and areally restricted set of phenomena. The situation appears unusually favourable to furnished conclusions about climatic changes and their temporal distribution.

This work has described for the first time the full extent of the Olorgesailie Lakes, and demonstrated the sources of water supply and the overflows in some detail. The analysis provides reasons for the fluctuation of the former shorelines which provided the land surfaces on which the human sites were located. The variety of events in the history of the lakes which are indicated by the physical facies of the sediments have been firmly placed within a detailed sequence of drainage changes in the general area of the South Kenya Rift Valley. The Lakes were a direct consequence of events occurring within the evolution of the present topographic form of the Rift Valley. The evolution of the form is shown to be complex and has been described in more detail than previously.

It has long been recognized that one consequence of the topographic evolution of the Rift would be a re-orientation of drainage, but the Olorgesailie Lakes are now clearly shown to represent one phase in the transition from a continental external drainage net to an internal drainage system. Many of the sedimentation sequences in the Southern Kenya Rift have been shown to be sequential rather than contemporaneous. This explains why there has been so little success in the correlation of Rift Valley sediments, and the reasoning is likely to hold true for other localities in the Rift. The sequential nature of the different sediments provides little assistance for those concerned with the dating of areal distributions, but if the different localities can be made to furnish evidence of past environments there are stratigraphies available at frequent intervals throughout the Pleistocene.

The study shows that the physical facies of the Olorgesailie Lake beds can be fully explained in terms of normal fluvial processes drastically modified by volcanic and tectonic events. The thesis demonstrates that it is not safe to make any inferences about former climatic environment from the evidence available and that there is no case for frequent climatic change at the Olorgesailie site. The study also shows the importance of a geomorphological framework in making a first assessment of conditions at Pleistocene sites, including those in areas of internal drainage.

In isolating events in the Olorgesailie Lakes sequence the study has explored links with other Pleistocene Lakes and shown that they are not contemporaneous, nor are they isolated remnants of single larger lakes like the hypothetical Lake Suess. Although such large lakes could predate the drainage sequences described, the sequences themselves appear to be complete, and if complete they eliminate the possibility of the larger lakes ever having existed. The same logic may apply in other parts of the Rift Valley.

The study required an evaluation of the volcanic stratigraphy in some localities. The results show that the Pleistocene and late Pliocene volcanics of Kenya have a sequence and distribution that may be used to trace the development of drainage patterns, and may well have significance for geomorphic chronologies elsewhere in the Rift. In some cases they may also be used to demonstrate differential erosional development under varied precipitation regimes.

The dates identified for the disruption of east-west drainage provide a base for the further study of the ancient channels east of the Rift, and lake sequences outside the Rift such as those at Amboseli. The demonstration of beheaded drainage suggests a more likely mechanism than climatic change as a prime cause for drying out of the Amboseli lake beds and provides a more acceptable explanation of an altered hydrological regime.

All the evidence provided by the present study supports the idea that the Rift Valley floor dried out only once in the last million years, and that the drying was associated with the lowering altitude of the Rift floor. The semi-arid conditions on the Rift floor today are comparable with those in areas at the same altitude throughout East Africa.

APPENDIX I

GEOLOGICAL SAMPLES

Geological samples, Southern Kenya Rift Valley

All collection sites are identified by number on the Folio maps

Abbreviations:

AT	-	Alkali trachytes in Plateau series
Kkb	-	Kirikiti basalt
Kt	-	Kordjya trachyte
Lgt	-	Longitoto trachyte
LTa	-	Limuru trachyte
LTb	-	Limuru trachyte as 'Lower Orthophyre t'
Mb	-	Mosiro basalt
Mgt	-	Magadi trachyte ($\simeq$ Alkali trachyte)
Mtb	-	Mosiro trachyte, type 'b' (p. 93)
Mtc	-	Mosiro trachyte, type 'c' (p. 93)
OT	-	Orthophyre trachyte in Plateau series
Plp1	-	Suswa phonolite 'phonolite without globule surfaces'
Plp2	-	Susua phonolite with globule surfaces
Sb	-	Singaraini basalt
a	-	identification in hand sample
b	-	identification in thin section, J. Walsh
c	-	identification in thin section, R. Crossley

(m) palaeomagnetic sample

P1 polarity determined at site with portable flux-gate magnetometer

P2 polarity determined on cleaned samples in laboratory, A. Brock

N - normal, R - reversed, I - indeterminate

Geological samples, Southern Kenya Rift Valley, (Cont.)

Sample no.	Map shows	Identification a	b	c	Polarity P1	P2

Western flank of Rift Valley

a) Ewaso Ngiro gorge

Sample no.	Map shows	a	b	c	P1	P2
M21(m)	Lgt/OT	LTa	Lgt	Mtc	R	R
lowest of nine thin flows orthophyric trachyte under Mosiro-Oloiti scarp						
M22(m)	Lgt/OT	LTa	Lgt	Mtc	R	R
above M21 in face of scarped promontory						
M23	Lgt/OT	LTa(red)	-	-	R	-
above M22						
M24	Lgt/OT	LTa(purple)	Lgt	Mtc		
M25	" "	"				
above M23, distinctive coloration, weathered, fragile						
M26	Lgt/OT	OT	-	-	R	-
coarse grained ground mass, above M 25						
M27-28	Lgt/OT	$\simeq$M26		Mtc	R	-
sequence above M26						
M29	Lgt/OT	fine g. trachyte	-	-	-	-
last of the orthophyric trachytes, above M28, below surface flow of Oloiti promontory						
M32(m)	Lgt	AT	AT	Lgt	R	I
surface rock of Mosiro-Oloiti 'promontory' west of fault-scarp						
M33(m)	Lgt	basalt-porphyry	basalt	Mb	R	I
surface rock at top of promontory to south						
M34(m)	Lgt	OT	Lgt	Mtc	N	I
rock spur in course of Ewaso Ngiro gorge 40 m above floor						
M35(m)	Lgt	OT	OT	Mtc	R	R
rock spur in meander of Ewaso Ngiro, west of Oloiti. Massive bedded.						
M36(m)	Kkb	laminated basalt	basalt	welded-tuff	N	N
very finely laminated basalt overlying Seyabei sediments						
M37	Kkb	basalt	basalt		-	-
unlaminated and not firmly correlated to M36. Same as M33?						

Geological samples, Southern Kenya Rift Valley, (Cont.)

Sample no.	Map shows	Identification a	b	c	Polarity P1	P2
M38(m)	OT	LTa	LTa	Mtb	R	I
outcrop at scarp by road north of Mosiro stores						
M40(m)	OT	AT	LTa	Mtb	R	N
distinctive flow in horst west of Mosiro-Enombabali road						
M42-44	Mau ash	trach. glass	LTa	Mt?		
previously unmapped. surface of LTa flow? cf M18						
M45(m)	AT	LTa	Lgt	Mtb?	N	N
from fault scarp across Narok road. One of most westerly Rift faults						
M46	LTa	LTa 'type'	- but finer ground mass	Mtb		
check sample from Limuru trachytes on Esakut platform						

b) Kordjya plain

Sample no.	Map shows	a	b	c	P1	P2
M80	AT	Ves. AT	-	-	R	-
Alkali t. from terrace near Oloronga, a flow top?						
M82	AT	AT variant	-	-	R	-
from river-bed in NE corner of Kordjya plain						
M86(m)	AT	Dark AT		Mgt	N	N
flow immediately overlying coarse OT, strong regional discomformity						
M87(m)	OT	OT	-	Kt	N	N
distinctive coarse matrix orthyphyre t., resembles Ol Tepesi bemmoreite						
M88	OT	OT variant of above				
M89	Alluvium	AT coarse grained variant				

Eastern flank of Rift Valley

a) Esakut platform

M47-58, 90-104, represent attempts to locate OT on the platform and to distinguish flow fronts facing but not reaching the Ngong scarp and post dating it. Most samples were not used in this thesis. Samples shown here are selected to illustrate basic types and exceptions.

Geological samples, Southern Kenya Rift Valley, (Cont.)

Sample no.	Map shows	Identification a	b	c	Polarity P1	P2
M47(m)	LTa	'typical' LTa	LTa	Mtb or LTa	N	N
from horst west of road near Ethinyai. AT on Randel's map of 1970, Limuru t. polarity usually R.						
M50(m)	LTa	LTa				
from rim of Ngong escarpment, LTa on Saggerson map (1971)						
M91(m)	LTa	LTa	LTa		N	I
from flow front of a fresh form facing Ngong escarpment. P. unstable.						
M104(m)	LTa/AT	LTa		LTa	R	R
flow below top flow on horst overlooking Kedong. Boundary of map sheets; Randel (AT) and Saggerson (LTa)						

b) Magadi-Singaraini

M61-78 includes samples in area of Koora-Olorgesailie lake overflows and a traverse from Lake Magadi to the Singaraini platform in search of orthophyre trachytes in variant terrain shown by aerial photography.

Sample no.	Map shows	a	b	c	P1	P2
M61	AT	dark AT			R	
surface of Olkeri plain near railway bridge on 'Coopers Rd'						
M62(m)	AT	dark AT		'trachyte'	R	R
surface of flow at high-level deltas overlooking Karamai						
M63(m)	AT	'normal' AT			N	lost
chilled contact zone in flow below M62						
M66(m)	AT	'typical AT'			R	I
sample from surface at break of slope above banded overflow terrain						
M67-70	AT	all similar; typical AT's			R	-
a series from the surface traversed by O. Lake overflows						
M71*	AT	resembles OT (Baker ~top of AT flow)				
*Not in situ. Loose sample from many boulders included in the high-level delta beds, Vesicular, purple, resembles OT. cf M21, 22.						
M72	AT	vesicular AT				
sample from rock at exit of overflow gorge 04 (see p. 73)						
M74-75	AT	AT		'trachyte'	R	(74)R
samples from area suggesting OT in photography. These samples also prove that Alkali trachytes flowed below Singaraini basalt escarpment after faulting.						

Geological samples, Southern Kenya Rift Valley, (Cont.)

Sample no.	Map shows	Identification a	b	c	Polarity P1	P2
M76(m)	Sb	basalt		olivine basalt	N	N

surface flow basalt scarp overlooking Singaraini station

Sample no.	Map shows	a	b	c	P1	P2
M77(m)	Sb	basalt		olivine basalt	N	N

flow below M76

M78 At ? (unusual AT - Baker)
a third sample from the 'OT zone' (see M74-75)

c) Kedong gorge

M1 Plp ? AT 'trachyte'
uppermost flow on step platform west of Baragoi gorge. Randel's Suswa phonolite

M2 Plp AT 'trachyte'
same as M1, taken from rim of gorge

M3 M2 ropy scoria / cinder
a flow surface on a thin flow?

M4 under M3 stratified tuffs
with M5 represents distinctive widespread tuff deposits later buried by trachyte flood (M2) then re-excavated.

M5 under M4 unconsolidated (sandy) tuffs
see above. Lies on a marked local disconformity.

M6 under M5 AT AT Quartz t.
4 m exposed, 12 m maximum thickness; flow of Alkali trachyte

M8 AT AT/LTa? Strong quartz t.
(no felspar)
2-3 m of distinctive rock. Upper surface of Limuru t? Crossley suggests almost enough quartz to call it rhyolite (cf Saggerson in Kedong Valley, map 1971).

M9 (AT) AT AT Quartz t. ($\simeq$M6)
opposite wall of gorge above floor. Equivalent of M6

M11 cinder conglomerate over ropy lava
surface flow of M9? $\simeq$ M2 but no tuffs observed in this wall

Geological samples, Southern Kenya Rift Valley, (Cont.)

Sample no.	Map shows	Identification a	b	c	Polarity P1	P2
M12	AT	AT	AT	trachyte		

M12 and M2 are young quartz trachytes overlying Suswa tuffs and therefore <0.5 Ma. They may be ∼ Baker's Baragoi t.

M14	AT	AT(?M2)	AT	'trachyte'		

Lava 'terrace' 6 m high - lava flood in gorge after AT

M15	Plp2	OT? (chill contact)	-	'glassy trachyte'		

distinctive red band in wall of gorge. Resembles M22 of Mosiro.

M16	AT	LTa	glassy t.	'trachyte'		

from 'islands' left on floor of gorge by former river. 3-6 in high

M17	AT	LTa	OT			

the main mass of Sakuretti Mtn., east of the gorge

M18	AT	trachyte glass	glassy trachyte			

from wall of gorge on E, an inset flow. Compare M42-44 from Mosiro

M19	AT	LTa				

floor of gorge. Same as islands in former stream

M20*	AT	Chilled trachyte?	Suswa trachyphonolite?			

*Not in situ. Boulder from volcanic flow conglomerate occupying floor of gorge. Matrix cinder, tuffs, etc. Fills gorge but lies below M2, M3-4, and M12. Extension of a Suswa flow that entered gorge (see p. 146).

The south flank of Susua Volcano

M105(m)	Plpl	trachyphonolite		trachyte	R^{x4}	R

outermost edge of Susua flow - overruns AT of floor and predates grid-faulting

M106(m)	AT	AT		∼Mgt	N	N

from bank of former river channel invaded and overlain by M105

M109-116	AT	phonolite?		not Magadi trachyte*	N^{x3}	I 112

thin unmapped flows from Susua extending far south. Taken from shallow fill in fluvial channel cut in Alkali trachyte (p. 122)* Crossley describes varied petrology with no similarity to any Magadi (Alkali) trachytes. M109-116 lie over AT, below Plpl.

Geological samples, Southern Kenya Rift Valley, (Cont.)

Sample no.	Map shows	Identification a	b	c	Polarity P1	P2
M130(m)	Plpl	vesicular phonolite		trachyte ∿105	R^{x3}	R

taken from a flow that is guided by grid fault and postdates it. Same as 105 which is faulted. This dates grid faults (pp. 122, 123).

Sample no.	Map shows	Identification a	b	c	Polarity P1	P2
M132(m)	Plpl	∿M130		'trachyte'	N	R

flow is mounded and blocky with some mounds resembling steptoes but there was little variety in the samples.

Sample no.	Map shows	Identification a	b	c	Polarity P1	P2
M133(m)	Plpl	∿M130		-	N^{x5}	-

samples from mounds within Plpl flow. Note polarities

Appendix II

STRATIGRAPHY OF THE KEDONG SECTOR, SOUTHERN KENYA RIFT VALLEY

The southern Kenya Rift Valley has an extremely complex volcanic stratigraphy that has not been completely evaluated. The southern Kenya Rift Valley formed in stages, with 7 major phases of faulting (4 in the Kedong sector), and at least 26 volcanic sequences. The volcanic sequences included central-vent volcanoes, rift-wide lava floods, intrusions, and smaller localized events. The combination of vulcanism and tectonics has created a confusing situation with buried sequences, metachronisms, steptoes, and other apparent anomalies, in a terrain that is notoriously difficult of access. The complexity is nowhere more obvious than in the area of the Kedong Gorge; below the Esakut platform and between the volcanoes of Susua and Esakut.

Most previous work on the geology can be fairly described as reconnaissance, and there are no criticisms implied by even major changes in the stratigraphy, distribution and correlation of the volcanic materials. The major journals only began in 1978 to demand formal stratigraphic designations for work in the area, rather than the previously accepted practice in reconnaissance studies of using a generic rock-type name linked to a distinctive place-name (Limuru trachyte, Kirikiti basalt). There are three major works that can be said to have brought about this transition, and they are the doctoral

TABLE 1: *Stratigraphic succession of flows on the horst north of Olorgesailie National Park*

Age-Ma	Lava flows	Magnetic Polarity	Stratigraphic Group
	1 trachyte	R	Plateau trachytes
1.42	3 basalts	R	
1.65	1 benmoreite	R	Ol Tepesi basalts
	1 basalt	R	
	1 basalt (soil horizon)	N	
	5 olivine basalts (disconformity)	N	Ol Keju Nero basalts
1.91	1 trachyte	R	Limuru trachytes

TABLE 2: *Stratigraphic succession of the Gesumeti trachytes*

	Magnetic polarity	Thickness (m)
Feldsparphyric trachyte	R	45
Fissile aphyric trachyte	R	10
Microporphyric trachyte	R	25
Welded tuff with obsidian fiamme	-	7
Stratified tuffs	-	12
Fissile aphyric trachyte	R	15
Massive microporphyritic trachyte	R	48
Xenolithic aphyric trachyte (base of section not exposed)	R	30

TABLE 3: *K–Ar ages of lavas from the south Kenya rift valley*

Ref.	Location	K_2O	% Atmos. contam.	Age Ma
	(A) K-Ar ages from Kedong Olorgesailie area			
Plateau trachytes				
KLR-15	Top flow in scarp 4.5 km NW of Olorgesailie National Park	5.19	86	0.93 ± 0.06
KLR-5	Bottom flow in above section	5.32	80	1.17 ± 0.04
Ol Tepesi basalts				
KLR-62	Upper basalt flow, S. end of horst 1 km E. of Emerit	1.19	87	1.42 ± 0.06
KLR-18	Benmoreite lava, scarp 7 km NNW of Ol Tepesi	3.97	84	1.65 ± 0.06
KLR-3	Benmoreite lava, scarp 1.5 km NNW of Ol Tepesi	3.89	73	1.81 ± 0.05
Limuru trachytes				
KLR-37	1 km SE of Kampi ya Bibi	5.38	68	1.91 ± 0.06
KLR-60	Lower part of scarp, 1 km E. of Emerit	5.33	71	1.94 ± 0.06
KLT-2	Scarp E. of Ngong circular rd., 9 km N. of Ngong summit (E. of map area)	5.20	77	1.84 ± 0.06
KLT-3	Top flow in scarp 9 km NE of Emerit	5.17	44	1.96 ± 0.04
	(B) K-Ar ages from other formations of the southern rift valley			
Singaraini basalts				
KSN-7	Top flow in scarp at Singaraini trigonometrical station	0.57	88	2.31 ± 0.10
KSN-3	Lowest flow in scarp, as above	0.83	87	2.33 ± 0.09
Kordjya basalts				
KKR-22	Top flow in scarp, W. side of Kordjya depression	1.15	89	1.66 ± 0.05
KKR-21	Flow below KKR-22, same location	1.07	73	1.76 ± 0.06
KKR-17	11th flow below top of section, same location	0.88	88	2.17 ± 0.10
Kirikiti basalts				
KNG-1	Top flow, Kirikiti escarpment, 11.5 km S. of Oloibortoto River	0.72	92	2.93 ± 0.20
KNG-6	5th flow below top of scarp, as above	1.06	92	2.68 ± 0.16
KNG-21	9th flow below top of scarp, as above	0.54	94	3.1 ± 0.2

$\lambda_e = 0.584 \times 10^{-10}\ yr^{-10}$; $\lambda_\beta = 4.72 \times 10^{-10}\ yr^{-1}$;

$\frac{^{40}K}{K} = 1.19 \times 10^{-2}$ atom %

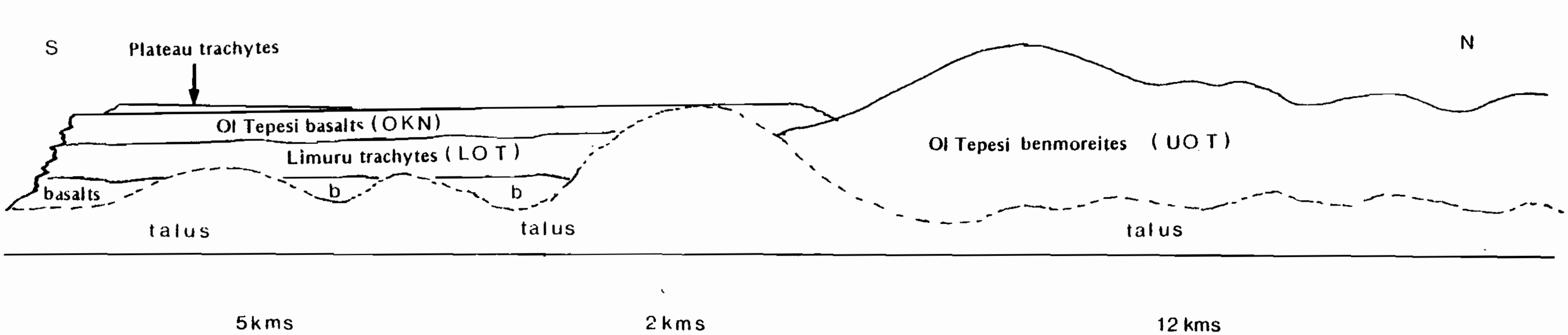
Table A2-1 Three tables from Baker and Mitchell (1976). They are discussed in Appendix II.

theses of Crossley (1976), and Knight (1976), and the summary paper by Baker and Mitchell "Volcanicity and evolution of the South Kenya Rift" (1976). They present very detailed observations, and attempt to provide a basic account of the geological events in the southern Kenya Rift Valley.

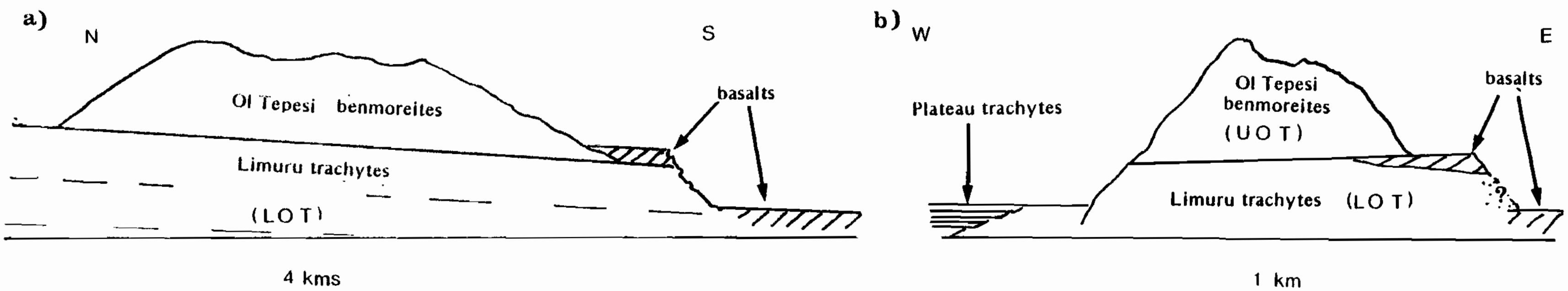
It became necessary to evaluate the stratigraphy of the volcanics in the Kedong sector in order to explain the events associated with fluctuations in the Olorgesailie Lakes (p. 11). The work was done in 1971 and 1972, and I was helped on two occasions by Dr. Brian Baker of the University of Oregon, the acknowledged authority in this area. He was kind enough to accept a stratigraphic change proposed by me and demonstrated in the field during a joint field excursion, and has since kept me informed of his work in an open and generous personal correspondence. His paper of 1976 confirms a number of my conclusions, and if I continue to differ in some others, I do so with the utmost respect, and in the knowledge that the situation is extraordinarily complex, and the available information incomplete.

The differences relate to the sequence and relative ages of the Limuru trachyte, the Gesumetic trachyte, the Ol Tepesi benmoreite, the Singoraini basalt, and the Susua volcanics. Baker (1976) presented the sequences showin the Table A2-1 (opposite). Baker has modified his stratigraphy in some minor details since (personal communication), and has explained that the various orthophyric trachytes may look alike in hand specimen, and can only be finally assigned to their correct stratigraphic groupings on the basis of geochemical characteristics. How-

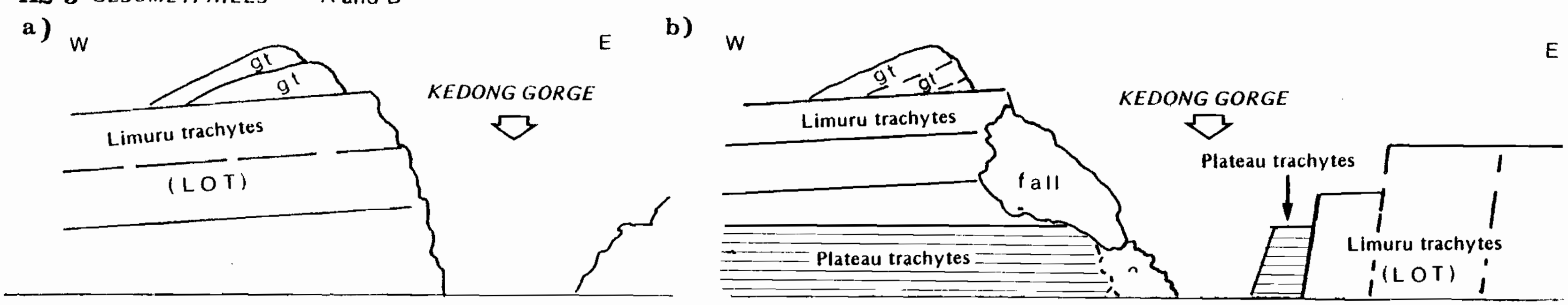
A2-1 *OL TEPESI ESCARPMENT*



A2-2 *NJOLOI HILL*



A2-3 *GESUMETI HILLS* – A and B



Figs. A2-1, 2, 3 Three geological sections from the Kedong Gorge sector. They are represented as they appear to the eye, but see discussion in text. UOT = Upper Orthophyre trachyte. LOT = Lower Orthophyre trachyte. OKN = Ol Kejn Nero basalt. gt = Gesumati trachytes.

ever it is also true that lavas of a single episode may have variations in their chemistry and texture from place to place (e.g. the various Alkali trachytes of the Plateau series (Baker, 1958, pp. 18-19), and may vary rapidly within a single sequence (e.g. the Gesumeti trachyte sequence of Baker's Table 2 (1976), shown in Table A2-1). My field-work brings the order and the published 'absolute' ages in doubt, on the basis of observed sections, geomorphology, and more complete mapping. The field observations are supported by a review of the K/Ar dates which appears below (p.184).

The following sections were observed in the Kedong Gorges sector. The designations are based upon appearance only. For the sake of clarity the names used are those that appear in Baker and Mitchell 1976, regardless of the final conclusion, but former names have been added in parenthesis to facilitate comparison with older literature, and to understand distribution over larger areas.

1) The Ol Tepesi benmoreite.

In the section west of the Ol Tepesi section (Fig. A2-1), the basalts and the Limuru are conformable, tilted very gently south-ward, and have contacts which are essentially plane surfaces. The Plateau (Alkali) trachyte is near-horizontal, and although it has over-flowed the upper basalt in the south, it lies below and against a fault scarp on the other side of the horst, where it overlies the benmoreite in exactly the same manner as the basalt in the east. The benmoreite appears only to the north, and there is a distinct hill within a prolonged ridge which slopes steeply to the contact (1:12), and passes steeply below the basalt (trachyte on the west). The benmoreite flow is very thick and outcrops above and below the altitudes of the near-horizontal Limuru in the sector to the south. Further north the ridge of benmoreite passes below Alkali trachyte without faulting, and without a talus over the Alkali trachyte, so that it presents a classic example of a steptoe. There is no evidence that it wedges out below the basalt and above the Limuru, and no proof that it drops below the Limuru trachyte.

To the west of Ol Tepesi the Alkali trachyte always lies directly on the benmoreite, and in the distinctive fault-scarp which provides the western limit of the Olekemonge plain (GS3 on Folio map 5) the benmoreite appears in the cliff face as a gigantic nonconformity, a section of a buried hill that rises out of and above the Alkali trachyte at its highest point. The Limuru trachyte is not exposed beside or below it in a clear vertical section of 120 m.

There is no direct evidence of benmoreite directly overlying Limuru trachyte except at the horst east of Njoloi which is mentioned by Baker (1976, p.472). At first glance the benmoreite clearly overlies the Limuru trachyte but there are difficult problems (Fig. A2-1). The benmoreite has a relief of 160 m. There are three strongly eroded summits, but the southern part of the benmoreite hill has a uniform southward slope and could be described as a surface tilted southeast. The Limuru trachyte below has a nearly horizontal surface. There is a litter of large benmoreite boulders ($3m^2$), but no great quantity of debris obscures the contacts. The basalts which overlap the southern foot of the hill lie directly on Limuru trachyte, as well as providing a faced scarp low down on the benmoreite (see Fig. A2-1b). The upper part of the faced scarp forms a clearly defined terrace with a nearly horizontal tread. East and west of the horst the grabens have floors of Limuru trachyte, or basalt directly over Limuru trachyte. Thus the benmoreite at Njoloi was a hill high above the Limuru trachyte when the basalt flowed, and the Limuru trachyte was not yet a horst. If the basalt is an Ol Tepesi basalt the sequence cannot be that shown in Baker's table (shown in Table A2-1), or in his section (1976, p. 470, Fig. 2, section C-D).

Basalt also lies directly on the Limuru trachyte in the east wall of the Kedong Gorge, opposite Gesumeti , and no benmoreite is visible above the Limuru, unless the benmoreite is related to the Gesumeti trachytes which occupy similar sites as distinctive hill summits perched on Limuru trachyte flows. The benmoreites as mapped by Baker form a classic steptoe and appear as a single continuous mass with one isolated outlier (Njoloi horst). There is no obvious explanation for the restricted area of deep flow that provided the outlier. The present surface of the benmoreite offers a gross potential nonconformity in contrast to the Limuru trachyte surfaces generally.

2) The Gesumeti trachytes.

The constant recurrence of coarse orthophyric trachytes as isolated hill summits is puzzling, especially since they seem particularly susceptible to erosion. The Gesumeti hills of the Kedong Gorge (see Fig. 8-3) show distinctive isolated peaks of Gesumeti trachyte. All three summits are perched on tilted Limuru trachytes (Fig. A2-1c). Gesumeti north and south are supposed by Baker to represent lavas and pyroclasts banked against a steep pre-existing fault-scarp of Limuru trachytes (Baker 1976, p. 474). They were cut by renewed movement on the fault (p. 475), and the piles of lava overtopped the bordering fault topography because of extreme viscosity of the flows (p. 475). He regards them as a fissure eruption in a narrow tectonic depression during the early period of Plateau trachyte eruptions between 0.9 and 1.25 Ma.

The Gesumeti trachytes cannot be interpolated in the Plateau (Alkali) trachyte series. They stand high above the basalts and far above the Alkali trachyte. They are very steeply tilted and appear to lie upon less steeply tilted Limuru trachyte, whereas the Alkali trachyte were emplaced after the most severe faulting and tilting of the Limuru. The Alkali trachytes occupy the floors of Kedong and Gesumeti below the summits, are nearly horizontal, and have not been faulted in the gorge since emplacement (p. 145). Thus, even if the Gesumeti trachytes postdate the Limuru trachyte they certainly predate the Alkali (Plateau) trachytes.

Although two of Baker's faced scarps lie west of the postulated fault (above), the feature at Emerit Hill (Folio map 5 and Fig. 8-3) lies east of the postulated fault on his map, and the same logics cannot apply. In fact, the controlling fault passes east of Emerit, which would allow the Gesumeti hills a common structure. A river once passed east of the Emerit Hill (p. 140) and its valley was later filled by Alkali trachyte and before that, the Ol Tepesi basalt (p. 144), so again the origins of the feature must long predate the Alkali trachyte and the Ol Tepesi basalt.

The area of orthophyric trachytes west of Gesumeti is much larger than has been supposed by Baker (see Stereogram 3 , Fig. II:17) and there may be other intrusions (or steptoes) on the flanks of the Esakut platform (p.135). The orthophyre trachytes have not been sampled, and it is not known if they represent one unit, or a variety of units.

3) Observations upon the geomorphology.

The evidence establishes a recurrent single anomaly; 'younger' lavas on horsts and hills, with 'older' lavas flooring adjacent grabens. There is no evidence of structure reversal by erosion. Without exception the hills of coarse orthophyre trachytes stand topographically above all adjacent lava flows, including the Limuru trachytes. They are the only lavas to show as erosional hill forms, but there is almost no visible talus or debris. The main mass of coarse orthophyres occupies a coherent area of $\simeq$ 100 km^2, plus the isolated units. They stand above severely faulted, and in some cases steeply tilted, Limuru trachytes. They stand in the same way above basalts and Alkali trachytes, and have been proved to have a steptoe relationship to them.

A single explanation that would fit every case is that they all represent the one single apparent anomaly, a steptoe, and that the rock of the steptoes predates the Alkali trachyte, the Ol Tepesi basalt, and at least the youngest of the Limuru trachytes.

4) The potassium-argon dates

Baker dates the Gesumeti trachytes, by interpolation, as erupted in the period between 0.9 and 1.25 Ma BP (Baker and Mitchell, 1976, p. 475). The logic for those dates no longer exists when the formation is relocated in the stratigraphy (see above). All the Baker samples show reversed magnetism (Baker 1976, p. 475).

The benmoreites have yielded K/Ar dates of 1.65± 0.05 Ma. Baker rejected the older date because 'in view of the polarities' (reversed) 'the 1.81 Ma date is considered high, possibly due to excess argon' (p. 472). Since the basalt above the benmoreite gives ages of 1.42 and 1.37 (p. 472) he gives the age span for the Ol Tepesi basalts, (which he says includes the benmoreites), as 1.4 - 1.65 Ma, during the latter part of the Matuyama reversed epoch, and after the Gilsa normal: citing Cox's 1969 geomagnetic polarity time scale. However Cox's scale (1969, p.) shows 1.65 Ma as normal, (the Gilsa event), and 1.81 Ma as reversed.

There is also another date for the benmoreite. Under its former name of Upper Orthophyre trachyte, a sample provided by Baker was dated at 2.2 Ma (Evernden and Curtis, 1965. Sample Ka 652). The evidence in both cases leans to the older dates. The Ol Tepesi benmoreites all show reverse magnetic polarity.

There is a similar case with the Limuru trachytes which also show reversed magnetic polarities. Baker and Mitchell disregard previous dating of the Limuru trachyte on the grounds that two dates, 1.57 Ma and 1.72 Ma (from Baker et al, 1971), 'would be more consistent with normal polarities' (Baker and Mitchell 1976, p. 470). He accepts a mean age of 1.9 Ma, based upon four new dates ranging from 1.84 to 1.96 Ma, (Baker's Table 3, cited in Fig. A2-1). However, one of the previous dates (1.57) does conform to the polarity time-scale, and of the two new dates cited, 1.84 and 1.96 Ma (Baker's Table 3, in: Fig. A2-1) 1.96 would have normal magnetism in the Cox scale (1969). It is only the average in each pair that supports his case, the separate pairs are equally inconclusive.

There is a further difficulty. All samples by other geologists show the Limuru as younger in age, including a sample provided by Baker under the former description of Lower Orthophyre trachyte. As Ka 650 it was dated at 1.74 Ma BP by Evernden and Curtis (1965).

There are nearly 300 m of Limuru trachytes in more than a dozen flows. Because of the way the Rift evolved it is possible for the uppermost flows at different sites to have different ages (p.47), and there could be a metachronism, or even multiple metachronisms, in the observations. It seems reasonable to assume a long interval of time for the accumulation of the Limuru trachytes, and there is no reason why they should not bracket the benmoreites,or other volcanic sequences.

Finally, there are two less compelling arguments. In this text the Limuru trachyte has been equated with one phase of the Mosiro trachytes, on the grounds of chemistry and morphology (p. 49). The Mosiro trachytes are firmly dated at 1.9 to 2.3 Ma by Crossley, and Knight (1976, see Fig. 3-2).

The Kordjya basalts of the west, identified and dated by Baker and Mitchell in the 1976 paper, and detailed in Crossley's work of 1976 (Fig. 3-2), show a coarse orthophyric trachyte (the North Kordjya trachyte) sandwiched between two basalts in an exact analogue of the Ol Tepesi basalts. In Kordjya the North Kordjya trachyte stands as a steptoe above Alkali trachytes and basalt which it predates, and provides an identical terrain to the benmoreite example (p. 88). The ages for the Kordjya basalts (Table 3-2) are 1.76 - 2.17 Ma for the lower basalt, >1.66 for the trachyte (by interpolation), and 1.66 for basalt above the Kordjya trachyte. If there is a parallel to the Ol Tepesi basalts, or if they represent the same event, there is again an argument for older dates for the coarse orthophyre trachytes, and increased evidence that they are included within the time span of the Limuru effusions.

Accordingly in this text I use the stratigraphy and ages shown in Table 3-4. In view of the tectonic history of the area, with the creation of stepfaults, fault-blocks, steptoes, horsts, and grabens it is possible for any younger member of this sequence to lie against a variety of older members, as e.g. Alkali trachyte on benmoreite in Olekemonge, Ol Tepesi basalt in Olkemonge, and Limuru trachyte in the Kedong Gorge, or: Alkali (Magadi) trachyte against Mosiro trachyte at Koromoto, North Kordjya trachyte at Kordjya, and Kordjya basalt at the Kordjya escarpment.

5) The Singaraini basalts.

Baker's map of 1976 shows the Ol Tepesi basalts and benmoreites extending over the area occupied by the Mosiro trachytes and the North Kordjya trachytes, as well as the northern half of the Singaraini platform (Baker and Mitchell 1976, p. 468, and as Fig. 1-5). They proposed name changes and changed distributions for the Ol Keju Nero and Singaraini basalts in order to occomodate the newly designated Ol Tepesi sequence. They retained an age of 2.3 Ma for the Singaraini basalts in the south (p. 471), consistent with their normal polarities, but show an Ol Tepesi basalt covering the northern part of the platform and give ages for the Ol Tepesi formation of 1.42 Ma - 1.65 Ma. The 1.65 is for a trachyte (benmoreite), not a basalt, and the polarity (reversed) is not compatible with the time scale. The 1.42 is comparable with dates provided by Fairhead et al (1972, p. 67) who gave 1.44 and 1.31 Ma, average 1.37 Ma, but questioned those dates in the belief that the samples were from an area of rock with normal polarity which would have been incompatible with all but one of the dates obtained (p.67). Baker and Mitchell describe normal polarities for the Ol Keju Nero and Singaraini basalts, and reversed polarity for the Ol Tepesi basalts (p. 471), but there is no citation for a reverse polarity collected on the platform.

It is theoretically possible for Ol Tepesi basalts to overlie the Singaraini basalt near Ol Orian but there are serious problems. It would have to have done so before the long (60 km) Singaraini escarpment formed. Alkali trachytes lie beside and above the Ol Tepesi basalt in Ol Tepesi (p.180), but it clearly flowed after the Singaraini fault-scarp formed in the south, and flowed against its base. The Ol Tepesi basalts would have had to flow at 1500 m on the platform, and there is no evidence of Ol Tepesi basalt over 1300 m west of Esakut. The Ol Tepesi basalt overlies downfaulted Limuru trachyte at ≃ 1100 m under the Esakut platform. If the basalt was originally at 1500 m it is hard to explain the absence of Limuru trachyte in, or on, the Singaraini platform.

I conclude that the basalts are not fully understood at the Olorgesailie site, that the Ol Tepesi basalts are younger than the Singaraini, and flowed below them, and that the Singaraini basalt may be the same as the Ol Keju Nero basalt (Table 3-2). The Ol Tepesi basalts do not extend over the area shown in Baker and Mitchell's map, but there may be a parallel sequence in the Kordjya basalts (p.186) which are distributed as shown in Fig. 3-1.

6) <u>The Susua volcanics</u>

Baker and Mitchell show all the Susua volcanics above the Legemunge beds (Olorgesailie Lake beds), and therefore <0.42 Ma. The Susua volcanics extend over a much greater area than he shows (p.116), and the lower beds of Susua show reversed polarities which requires an age > 690,000 (p.117). Susua flows underlie a later trachyte (the Baragoi trachyte) which is contemporary with the Olorgesailie Lake beds, and Susua eruptions continued for sometime after the Baragoi lava was emplaced (p.146). Baker and Mitchell (1976) follow Randel (1970) in showing a Susua flow above a high fault scarp at Baragoi, with 'older' Plateau trachytes below, an impossible structure. Either the Susua flow is much older than supposed, or the trachyte is young and not the Alkali (Plateau) trachyte.

The magnetic observations (p. 117) suggest that Susua is of greater age than supposed, with a shield phase that lasted 300,000 years or more, and the volcano dates well back in the Pleistocene as was originally suggested by McCall and Bristow in 1965 (1965 Fig. 3).

In my chronology I propose two distinct phases in the growth of Susua. A shield phase of lava flows following immediately upon the last Alkali trachyte eruptions in the sector, from ≃700,000 BP to ≃400,000. The shield was followed by the formation of a caldera, the Ol Donyo Onyokie cone, and a ring graben, with frequent emissions of pyroclastics and lavas to an unknown date, possibly as late as 100,000 BP. The uttermost extent of Susua is yet to be mapped,and the earliest flows were trachytic (p.116) so closely resembling the Alkali trachytes they succeeded, they may be difficult to distinguish.

The conclusions of this Appendix are included in the stratigraphy of Table 3-4 and that stratigraphy is the basis for dates and sequencing used in the text.

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