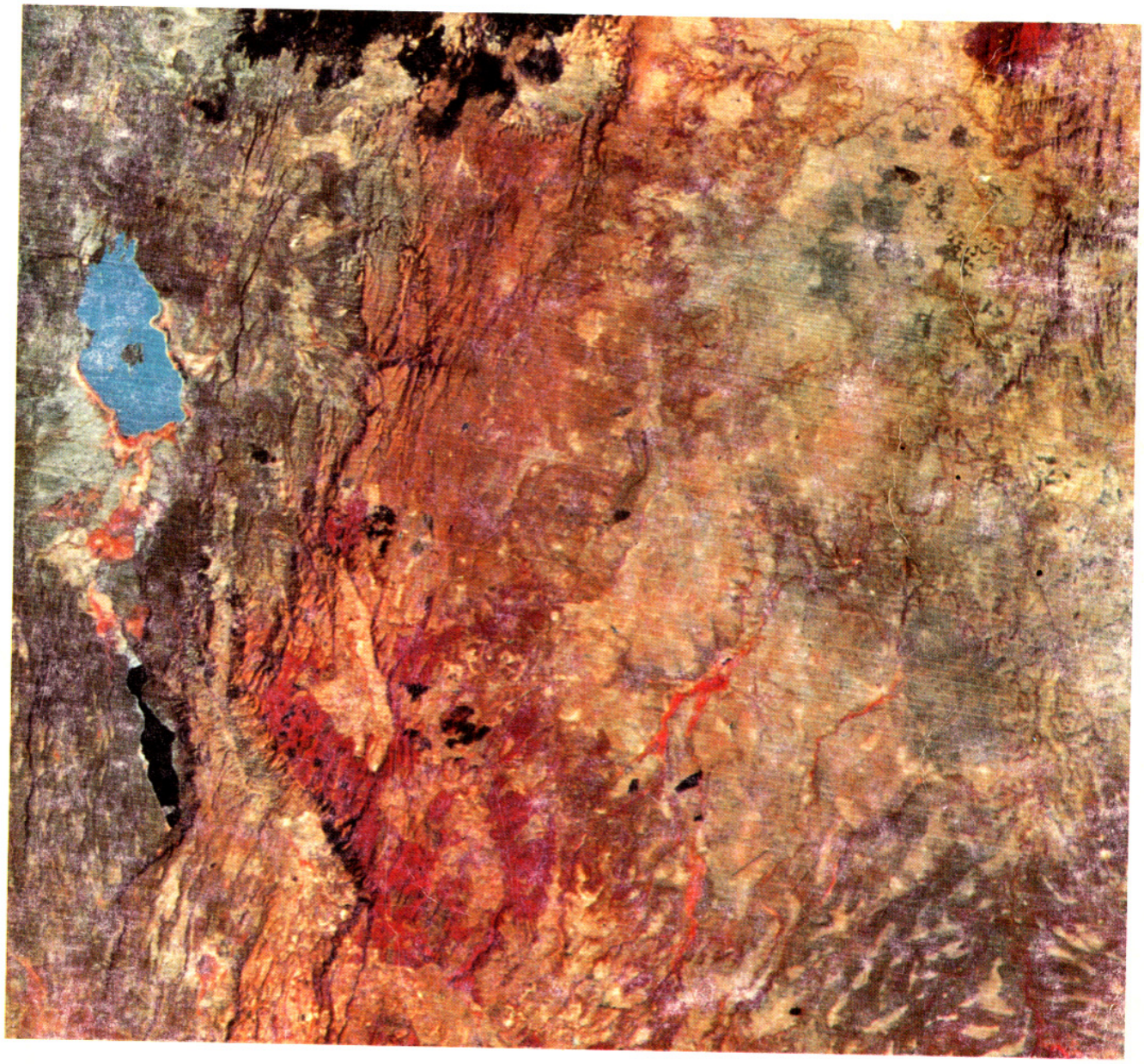
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MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES

MINES AND GEOLOGICAL DEPARTMENT



Geology of the Baringo–Laikipia area

Report 104

1988

MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES
Mines and Geology Department

Report 104

Geology of the Baringo–Laikipia area

Degree Sheet 35
with coloured 1:250 000 geological map and
results of geochemical exploration

B. D. Hackman

with contributions by
J. Ridgway and C. C. Rundle



NAIROBI 1988

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1:250 000 geological map of Degree Sheet 35 (in back pocket)

PREFACE

The area described spans part of the Gregory Rift in northern Kenya, the Laikipia Plateau, and a belt of Proterozoic basement in the upper Ewaso Ng'iro Basin. The presentation, which is somewhat biased in favour of a systematic record of the stratigraphy, is of considerable geological interest on two counts: firstly, the analysis of the Mozambique Belt rocks in terms of lithostratigraphic associations and tectonothermal episodes is essentially new—secondly the stratigraphic and structural detail of the Cenozoic volcanic sequences in the rift, largely gleaned from unpublished work, has been presented as a systematic 'guidebook', with apologies to the original authors where unwittingly misrepresentations or anomalies may have been perpetrated: for such errors the writer alone is responsible. The result, particularly for the Rift volcanics, cannot claim to be comprehensive.

Current exploration of the geothermal potential of this part of the rift reflects the hopes for further economic developments in that field. Elsewhere the industrial mineral resources deserve mention, notably the graphite of the Ol Doinyo Ng'iro area. The results of the geochemical exploration programme suggest that the Miocene alkaline intrusives of the Amaya Embayment merit consideration for further ground follow-up, as does the uranium potential of the eastern basement fringes.

The writer is particularly indebted to Dr L. A. J. Williams for his advice and for making available his review of the wealth of unpublished information which emanated from the EAGRU project, also to Drs J. Carney, P. S. Griffiths, J. S. C. Sceal and others for allowing material in their PhD theses to be used in this publication. The acknowledgement of all those people who assisted with the field work, logistic support and office documentation would involve the compilation of a very long list. The cooperation of Geosurvey International Ltd, and the University of Nottingham, is much appreciated for their provision of analytical results for the geochemical exploration programme. We are particularly grateful to the District Administration staff for Samburu, Laikipia and Baringo Districts for providing advice, support and security guards when necessary. I would personally like to thank driver/mechanic S. Lasoi Bwogo, geological assistants C. Okemba and Y. Otieno, and, in Nairobi, the Samburu–Marsabit project secretary Mrs Grace Macharia and Mrs Z. Kassam for typing and word-processing services.

An apology is due for some inconsistency with regard to the spelling of place names on maps and in the text. In general we have used the spellings on the most recent editions of the 1:50 000 topographic maps. Other spelling variations are shown afterwards in parenthesis if they have been used in the relevant literature. If the orthography conflicts with the standards of the local vernaculars we can only plead ignorance pending the compilation of an up-to-date gazetteer.

Finally some detailed descriptions have been taken almost verbatim from unpublished reports by the author's British and Kenyan colleagues—T. J. Charsley, M. Jali, J. Kagasi, R. M. Key, H. Muturi and A. F. Wilkinson—on this account, and for discussions and ideas, the author is much indebted.

B. D. Hackman
Samburu-Marsabit Project Leader
8 April 1988

Geology of the Baringo–Laikipia area

Abstract The Baringo–Laikipia area extends over about 12 210 km² of north central Kenya, bounded by the equator, latitude 1°N and meridians 36° and 37°E; the region spans part of the Gregory Rift, the Laikipia Plateau and the upper basin of the Ewaso Ng'iro River, which comprise the three major physiographic zones. The Ewaso Ng'iro–Narok and Ol Keju Losera River systems drain the central plateau and eastern uplands, while rivers from the western part of the plateau drain internally to the Rift, which features Lakes Baringo and Bogoria with contrasting water chemistry and circulating regimes. The area is founded on a Late Proterozoic to early Phanerozoic metamorphic 'basement', the Mozambique Orogenic Belt, which outcrops only in the east: in this area it comprises a tectonically stacked sequence of three lithostratigraphic associations, underlain to the west by a migmatite complex. These paragneissic and, in part, metavolcanic sequences have undergone a polyphase tectonothermal history, dominated essentially by regional metamorphism of upper amphibolite facies: certain episodes featured emplacement of ultramafic, mafic, migmatitic and felsic intrusives.

South of Lake Bogoria the Rift assumes a 'half-graben' aspect floored by grid-faulted salic flood lavas: to the north it is a normal deep graben with trachytic central type volcanoes (Korosi and Paka). Predominantly alkaline volcanicity continued from Miocene to Recent: the stratigraphy of the volcanics, and subordinate sediments, is in detail complex, described in terms of five essential volcanic 'groups'. The extrusives range from alkali-basalts to trachytes with voluminous Miocene phonolites forming the Laikipia Plateau on the extensive rift shoulder. On the inner zone of the shoulder erosion has revealed sub-volcanic Miocene intrusive complexes, predominantly alkali-syenites.

Significant graphite resources occur in the eastern basement, and the results of the geochemical exploration survey include recommendations to follow up base and heavy metal anomalies in the Amaya Embayment, also uranium and other heavy metals in the Mozambique Belt.

Generally the area has good ground and surface water resources; effective planning is required for future exploitation. The Rift is prospective for geothermal energy.

1 Introduction

Sheet 35 (Baringo–Laikipia) forms the south-west quadrant of the Phase I area of the Samburu–Marsabit Geological Mapping and Mineral Exploration Project—a Technical Co-operation venture between the British (British Geological Survey) and Kenyan (Mines and Geological Department) Governments. The major objectives of this first phase of the project were to produce geological maps of degree squares on the scale of 1:250 000, and to collect stream sediment samples and heavy mineral concentrates, particularly over the areas of Precambrian rocks, as part of a regionally standardised geochemical exploration survey (reported by J. Ridgway in Section 12).

British and Kenyan geologists mapped the eastern half of the area, using 1:50 000 topographic bases (eight map sheets) in 1981–82. Figure 1 shows the allocation of responsibility: 1:50 000 maps and the relevant draft reports are held in the Kenya Mines and Geology Department archives. The geology of the western half of the area, for which two published maps on the scale of 1:125 000 were already available (McCall, 1967; Truckle, 1977), was integrated into the accompanying published map by reduction to 1:250 000 and simplification of certain stratigraphic data: some loss of detail was inevitable. Published and unpublished data of Griffiths (1977, 1980) were used to revise the western half of McCall's map, especially for the Lake Bogoria area.

J. Kagasi carried out check traverses in the Mukutan

91/1	91/2 (B.D.H.)	92/1 B.D.H.	92/2 H.M.
91/3	91/4 (J.K.)	92/3 B.D.H.	92/4 R.M.K.
105/1 (J.K.)	105/2 (J.K.)	106/1 T.J.C.	106/2 M.J.
105/3	105/4	106/3 A.F.W.	106/4 J.K.

Brackets indicate check traverses

GEOLOGISTS

T.J.C. — T.J. Charsley
B.D.H. — Dr B.D. Hackman
M.J. — M. Jali
J.K. — J. Kagasi
R.M.K. — Dr R.M. Key
H.M. — H. Muturi
A.F.W. — Dr A.F. Wilkinson

Figure 1 Responsibility for geological mapping

(91/4), Ngelesha (105/1) and Lariak (105/2) areas in order to produce draft 1:50 000 geological maps for those topographic sheets. The writer also checked part of Churo (91/2), and Mr Okech collected geochemical samples around the alkaline rocks of the Amaya Embayment in that area.

Interpretation of aerial photographs and Landsat colour composite imagery (Path 181, Rows 059 and 060) greatly assisted the planning of field work and the completion of 1:50 000 and 1:250 000 geological maps.

The stratigraphy of the Cenozoic volcanics of the Rift Valley is reported here with extensive reference to unpublished PhD theses emanating from the East African Geological Research Unit.

Dr C. C. Rundle provided reports on radiometric age determinations for samples of Precambrian rocks, which he collected himself in 1982–83: the determinations were carried out in the British Geological Survey Isotope Unit in London.

1.1 LOCATION

The Baringo–Laikipia sheet is bounded by the equator and latitude 2°N, and longitudes 37° and 38°E, an area of 12 210 km² (Figure 2). Most of the region is in the Rift Valley Province of Kenya, Laikipia and Baringo Districts, although small areas are in the Samburu District (Loroki Plateau and Karisia Hills), the Turkana District (north of the Amaya Valley), and the Nakuru District (Solai and Subukia valleys) as shown on Figure 3. A small tract around Ol Doinyo Ng'iro, west of the Ewaso Ng'iro River, is a salient of the Isiolo District of the Eastern Province: also, on the southern boundary, south of Nyahururu, the northern extremity of the Nyandarua District of Central Province extends into the map area. The Degree Square 35 is numbered according to a grid covering the whole of Kenya, which has its origin (Sheet 1), at the NW corner at 5°N 34°E, in southern Sudan.

The following topographic maps cover the area:

1:50 000 contoured at 20 m intervals, Series Y731 (DOS 423):

Edition 3—DOS 1982: Sheets 91/1, (Nginyang), 91/2 (Churo), 91/3 (Lake Baringo), 91/4 (Mukutan)
Edition 2—DOS 1981: Sheets 92/1 (Sukuta Marmar), 92/2 (Lake Kisima), 92/3 (Sukuta Mugie), 92/4 (Kirimun)
Edition 7—DOS 1973: Sheet 105/1 (Ngelesha)
Edition 6—DOS 1973: Sheets 105/2 (Lariak), 105/3 (Solai)
Edition 7—DOS 1973: Sheet 105/4 (Thomson's Falls)
Edition 5—DOS 1973: Sheets 106/1 (Rumuruti), 106/2 (Mukenya)
Edition 4—DOS 1973: Sheet 106/2 (Pesi Swamp)
Edition 6—DOS 1973: Sheet 106/4 (Ol Pejeta)

1:250 000 contoured at 200 ft intervals, and in part at 500 ft intervals, Series Y503 Sheet NA-37-13 Edition 3-SK (1976), (Rumuruti): this sheet extends as far east as 37° 30′.

1.2 ACCESS

Access from the main centres to the south, in the Central District of Kenya, is good (Figure 3). Nyahururu is 198 km by road from Nairobi: north of that town the road to Maralal across the Laikipia Plateau is tar-sealed only as far as Rumuruti: however, in the Rift Valley an excellent

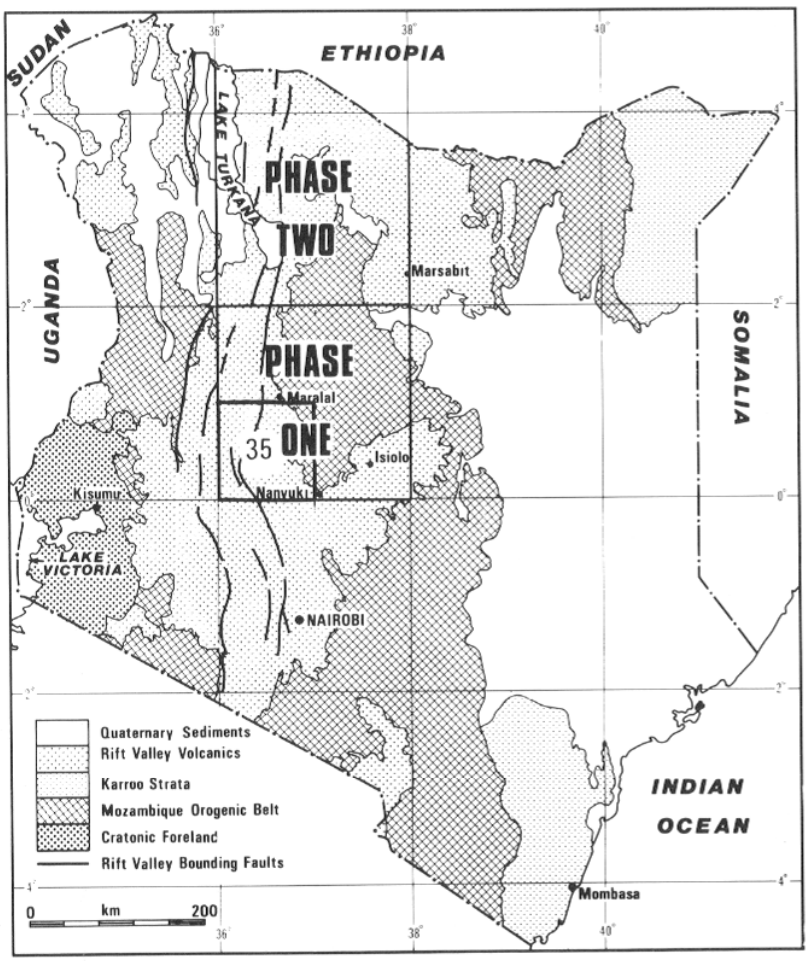


Figure 2 Location of the Baringo–Laikipia area

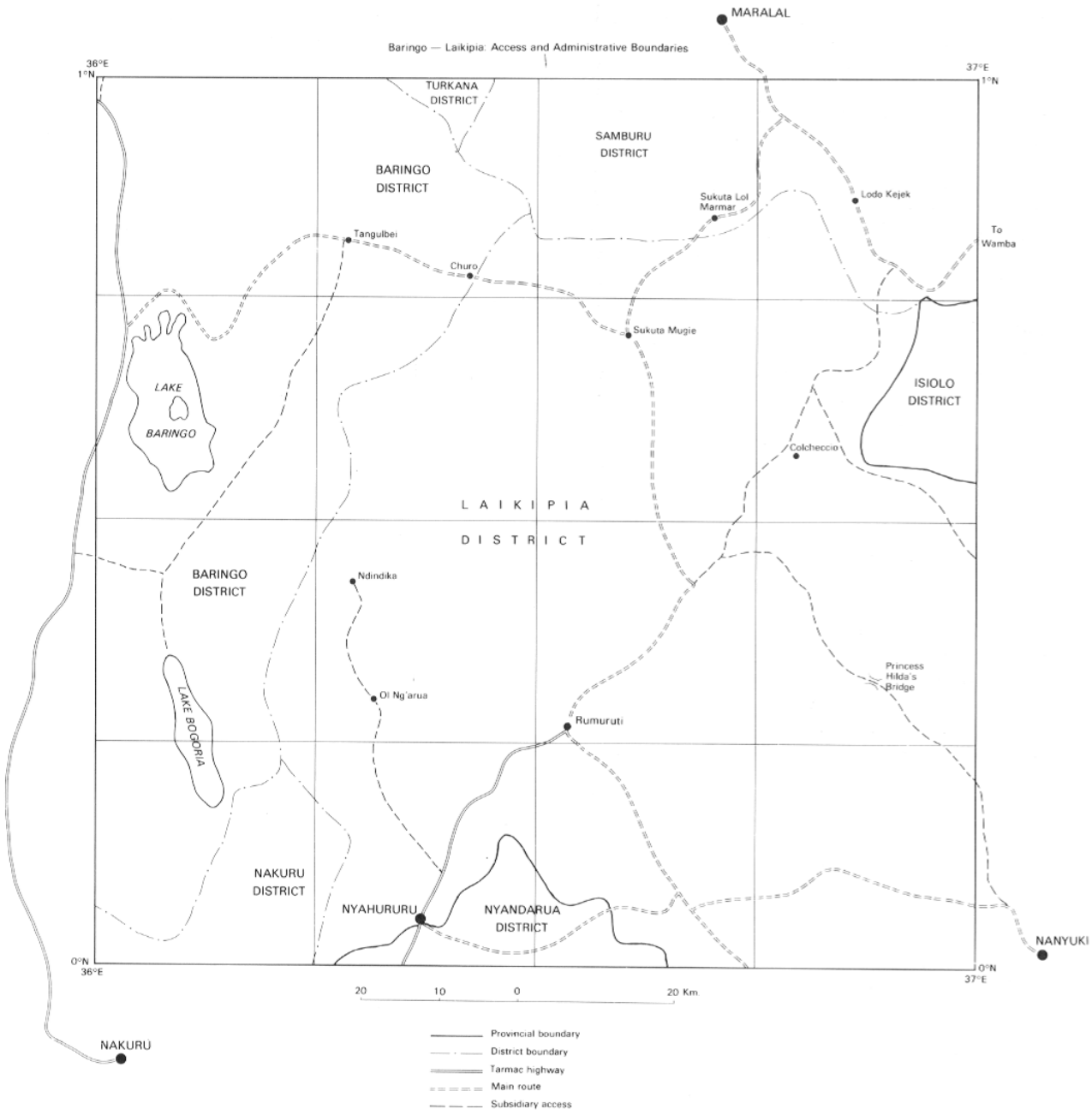


Figure 3 Place names, access and administrative boundaries

tarmac highway from Nakuru skirts the west shore of Lake Baringo and continues north to Nginyang, as one of the trunk routes to north-west Kenya. A good branch road from the north end of Lake Baringo via Tangulbei and Churo links with the Rumuruti–Maralal road at Sukuta Mugie. The agricultural area of the southern Laikipia Plateau is well served by a network of murram-surface roads linking Nyeri, Nanyuki, Rumuruti and Nyahururu. Of recent years the cross-country route from Wamba to Maralal, in the north-west, has been much improved where it crosses the southern end of the Karisia Hills ridge, above the Ewaso Ng'iro 'hairpin' bend.

A track linking the Wamba road to Rumuruti serves the Kirimun–Colcheccio area: north of Nanyuki the same area may be approached either by the Princess Hilda Bridge across the Ewaso Ng'iro, or via Mukogodo, Ol Doinyo Ng'iro and the river crossing at Lorkinyang. All these routes provide a good network of Land Rover tracks.

Remoter areas such as the Karisia Hills, Paka, the northern Amaya Embayment and the Ol Arabel Forest have to be negotiated on foot.

1.3 PREVIOUS WORK

Early records indicate that various European explorers visited parts of the Baringo–Laikipia area, and made observations on the geology and geomorphology.

The first, in 1883, was Joseph Thomson, whose name is perpetuated in Thomson's Falls (Plate 7), at Nyahururu on the Ewaso Narok River (Thomson, 1885).

Gregory (1896 and 1921) visited the Baringo area of the

Rift Valley in 1893, and crossed south-west Laikipia: he was the first to set up a periodic subdivision of the volcanic eruptions. Prior (1903) examined many of the rocks collected by Gregory, and Smith (1931) further studied the petrography, particularly of the phonolites. Maufe (1908) recorded some observations on trips through southern Laikipia (Ol Pejeta and Pesi Swamp areas). Shackleton (1946) mapped that half of the area east of 36°30′E, as part of a geological reconnaissance of the country between Nanyuki and Maralal. The field work took eight months in the period 1942–44, as part of a search for strategic minerals in wartime: the results were documented as a map on the scale of 1:250 000, with a covering Geological Survey report.

Bristow and Temperley (1964) produced a revised geological map (surveyed by Bristow in 1961) of the volcanics of central Laikipia, to illustrate a Water Development Department report on geology and groundwater conditions. McCall (1967) included the southern half of the Rift and the western edge of the Laikipia Plateau in his description of the geology of the Nakuru–Thomson's Falls–Lake Hannington area: the accompanying published map of the south-west quarter of Degree Square 35 (the Thomson's Falls–Lake Hannington area) was based on fieldwork completed in 1958–59.

In the 1970's the East African Geological Research Unit (EAGRU), directed by B. C. King, carried out an extensive geological mapping programme in the Kenyan north-central Rift Valley. For the purpose of this report the most important outcome was the publication of a geological map of the Lake Baringo–Laikipia area (Truckle, 1977), which covered the north-western quarter of Degree Sheet 35: over half of this area, to the east of Lake Baringo, was mapped by Carney (1972): Sceal (1974) mapped Paka Volcano and the area to the north, and Golden (1978) completed the Amaya Embayment–Chembalao Shield area in the north-west.

Smaller areas to the west were mapped by Martyn (1969), Chapman (1971b) and McClenaghan (1971), as part of their main project area in the Tugen Hills/Kamasia Range.

Also Griffiths (1977) revised the area around Lake Bogoria (Hannington) previously mapped by McCall. Much of Griffiths' interpretation of the geology has been incorporated into the present work, and the accompanying published 1:250 000 map.

The original EAGRU information is in the form of unpublished PhD theses; aspects of the research have been published in Bishop (1978), and as various separate papers during the seventies. A particularly valuable contribution to the volcanic stratigraphy was the comprehensive potassium-argon radiometric dating programme on the Cenozoic extrusives, more than 60 age determinations having been made by the BGS Isotope Geology Unit on rocks from the Baringo area.

Carney and others (1971) reported the discovery of fossil vertebrates in the Chesowanja Beds: following the identification of a partial cranium of *Australopithecus*; Bishop and others (1975) undertook more detailed investigations in that area in 1973.

Wohlenberg and Bhatt (1972) reported on an air magnetic survey of Lake Bogoria area, and Glover (1972) also described the chemistry of hot springs and gas at Bogoria as part of a United Nations Geothermal Resources Exploration Project in Kenya. An airborne infra-red survey (Noble and Ojiambo, 1976) confirmed hot spring locations in that area, and also reported on micro-seismic, hydrogeological and geochemical surveys.

1.4 WORK METHODS

The Samburu–Marsabit project team carried out fieldwork over the area of the eight eastern 1:50 000 topographic sheets during 1981 and 1982.

Field parties were each led by one geologist with a team of drivers, geological assistants, and locally employed casual labourers. Base camps were established at suitable locations: Land Rovers supported daily foot traverses. Stream sediment sampling and collection of bulk stream samples for heavy mineral concentration progressed in line with the geological mapping. Each of these eastern 1:50 000 map sheet areas required about four to six weeks of fieldwork for adequate coverage; geologists completed draft 1:50 000 geological maps and Mines and Geological Department internal reports. The data were incorporated in this account, and the results of the geochemical exploration programme are discussed in Section 12 by the project geochemist.

2 Physiography

The area is readily divided into three major physiographic zones (Figure 4).

1 The Gregory Rift Valley in the west, incorporating the lake basins of Baringo and Bogoria.
2 The Laikipia Plateau, corresponding essentially with a broad outcrop of Miocene phonolitic extrusives, bounded to the west by a magnificent series of faulted escarpments overlooking the rift.
3 The 'Basement' Uplands to the east, more rugged but generally somewhat lower than the Laikipia Plateau, drained by the middle Ewaso Ng'iro River system, and including the Loroki Forest/Karisia Hills ridge to the north, drained by the upper Seiya.

2.1 THE GREGORY RIFT

Here the Gregory Rift includes a spectacular section of the Baringo Basin, or the Baringo–Bogoria 'half-graben'. Occupying the western quarter of the map the rift is up to 30 km wide, extending from Nginyang in the north-west, at about 880 m above sea level, up to the Dispei Plateau south of Lake Bogoria, where the rift floor elevation rises to 1800 m. Faults trending NW–SE control an array of *en echelon* re-entrants in the alignment of the eastern wall of the rift, which is consequently not everywhere susceptible to clear definition, particularly south of Lake Bogoria; there the bounding fault escarpments trace out sigmoid curvi-lineaments enclosing partly alluviated embayments in the adjacent rift floor.

The rift floor displays considerable physiographic diversity, which may be described in terms of the following subdivisions (see Figure 4):

1a THE CENTRAL VOLCANOES: the low-angled 'central' composite cones of Korosi (1448 m) and Paka (1696 m) dominate the median rift north of Lake Baringo. These volcanic complexes are both about 15 km in diameter—Paka, with a central crater filled by a late basalt flow, is scored on its eastern flanks by a swarm of faults trending NNE: the same trend is seen on Korosi, manifesting as an alignment of scoria cones—the main fissure system may well extend under Lake Baringo to Ol Kokwe Island, which is a submerged southern salient of the Korosi massif.

1b FAULTED VOLCANIC ESCARPMENTS separate the alluvial and Quaternary volcanic median zone of the rift from the plateaux which form the outer rift shoulders (Plate 1). Between Lake Bogoria and the main Laikipia escarpment there is a complex of escarpments up to 12 km broad, deeply dissected by the Waseges and lower Ol Arabel river systems, including the *Siracho Escarpment*, flanking the west side of Lake Bogoria, and rising in the south to Kaptiony Hill (1788 m), and the *Kahone Range*, east of the Lower Waseges. These escarpments, mostly supporting a *Combretum* type vegetation, form a complex series of interlocking ramps, trending N and NNW, which, north of Lake Bogoria, slope regionally towards the north.

Karau (1486 m) may be considered a northern extension of this belt of escarpments, separating Lake Baringo from the Mukutan–Komol Basin: the same ridge continues into the massif of *Chepchuk* (1395 m), faulted against the eastern flanks of Korosi; this Pliocene ridge of phonolitic-trachytic volcanics, whose western flanks have been mutilated by median rift Pleistocene faulting, has its counterpart in the Loyamarok Plateau on the other side of the rift, north of Lake Baringo. To the north-east the N-trending escarpments of the Orus area form a bridge between Paka and the north-west salient of the Laikipia Plateau.

1c VOLCANIC PLATEAUX south and west of Lake Bogoria include the Dispei Plateau (McCall, 1967) and the Lake Haninngton Plateau. The Dispei Plateau, devoid of surface drainage, is a broken hilly complex of horsts and grabens, essentially a southern continuation of the Siracho Escarpment, which swings to the south-west at Emsos south of the Lake, and further south maintains a SSW trend as the Mugurin Escarpment (1780 m), with other minor escarpments to the east (Machandoi, Solai). The Lake Hannington Plateau attains an elevation of 1545 m (Kwaibus). Its relief reflects, in detail, an elaborate anastomosing pattern of grid faults which transect the dominantly trachyphonolitic lavas, drained by the north-flowing parallel configuration of the Mugurin– Ndolaita–Loboi systems. The area is covered by the mixed *Acacia* bush typical of the Baringo Basin.

1d THE ALLUVIATED AND LACUSTRINE AREAS: The multispectral Landsat imagery (see front cover) shows a dramatic distinction between the colours of *Lakes Baringo* and *Bogoria*, reflecting two different water circulation regimes, the former holomictic (fresh water favouring detrital sedimentation) and the latter meromictic (saline–alkaline, favouring evaporite deposition and the preservation of organic matter), the surface distribution of which reflects depositional environments.

The waters of Lake Baringo (970 m, 22 km long and up to 13 km broad) are believed to egress at its northern end by subsurface seepage, to emerge at Kapedo springs 110 km to the north (McCall, 1967).

The soda lake Bogoria, formerly Hannington (989 m) occupies a spectacular trough 18 km long and up to 5 km wide, bounded on the east side by the cliffs of the Siracho Escarpment rising over 700 m above the lake surface; the southern end of the lake features numerous hot springs and geysers. The lake has no exit, although some seepage may occur to the north through the Loboi Silts; the main recharge is from the Waseges River at the north end—accordingly the salinity of the lake increases towards the south.

The two lakes are separated by the 20 km wide *Loboi Plain* (Plate 2) at a height of about 975 m, parts of which are swampy: the ground water is saline, although the Perkerra River has been used for an irrigation scheme.

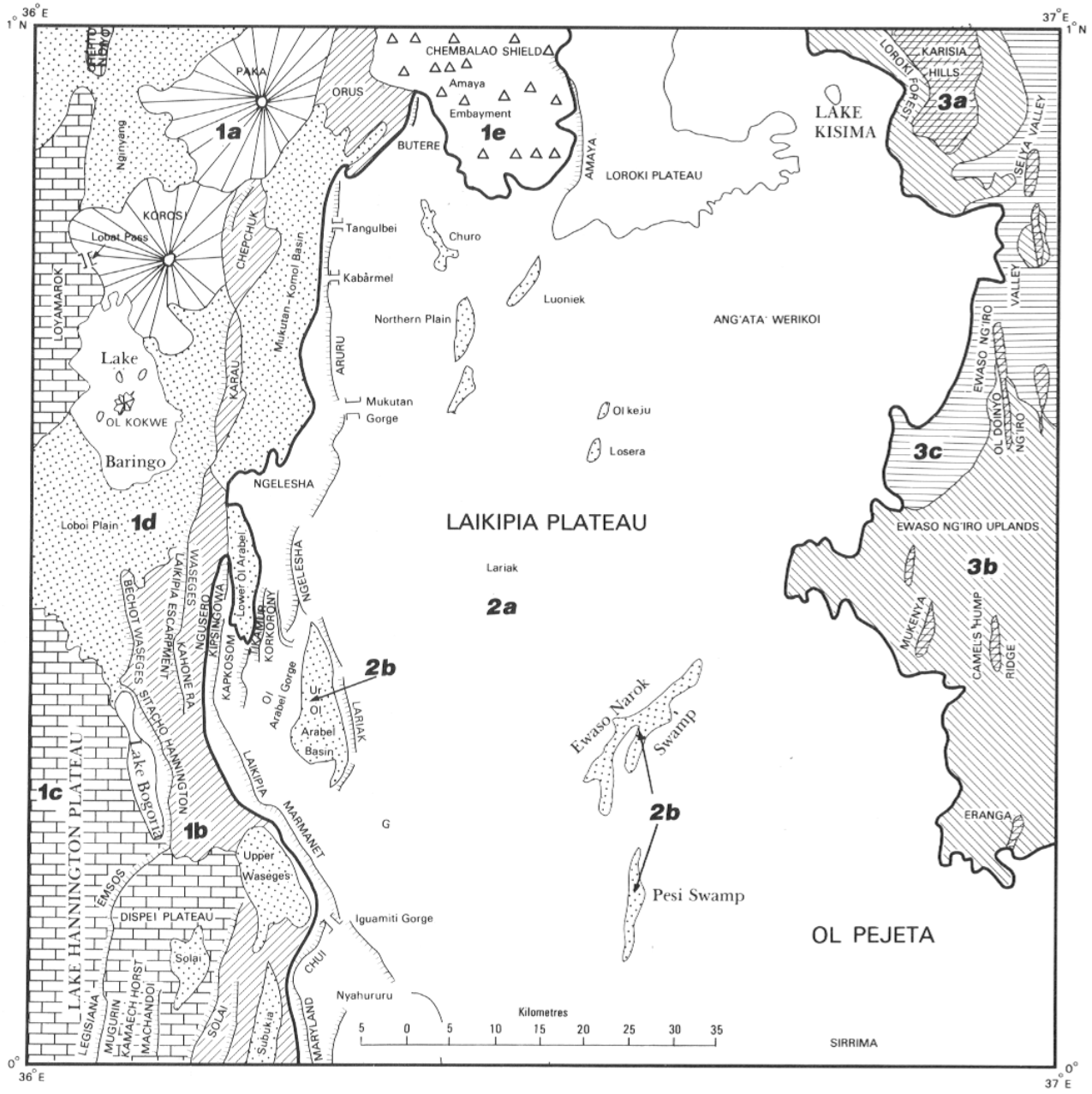


Figure 4 Physiographic zones

The interlacustrine watershed reaches a maximum elevation of 999 m about 4 km north of Lake Bogoria. Evidence suggests that the two lakes were combined during the Late Pleistocene ('Loboi Lake' of Farrand and others, 1976), but towards the end of the Pleistocene and in the earlier Holocene the 'Kokwob Lake' (see Bishop and others, 1971) stood at about 985 m, a larger precursor of Lake Baringo, but then separated from Bogoria.

There is no convincing evidence that Lake Baringo ever sustained a northward overflow by way of the 'Lobat Pass' between Korosi and the Loyamarok Plateau.

To the north the *Mukutan–Komol (*and *Tangulbei) Basin* extends also along the eastern side of the rift for about 40 km; it comprises a plain of aggradation, in part probably a palaeolacustrine belt, at about 1200 m, extending up to 10 km wide, flanked by the Aruru–Tangulbei Escarpment to the east and the Karau–Chepchuk ridges to the west. Carney (1972, p.22) ascribes ponding of the Mukutan and Kabarmel rivers in this basin, around 0.5 Ma BP, to damming by the Pleistocene volcanics to the east, which formed 'Lake Chemoigut' (Figure 6).

The Lower Ol Arabel Basin, below the Ol Arabel gorge, continues this Mukutan feature southward, separated from it by the Morilo–Ngarama and Ramaja horsts west of Ngelesha.

In the *Nginyang* area west of Paka there are extensive alluvial tracts, the Loyamarok (Loiyamarak) plain, drained by the Kogore River, and the Burususwa valley in the extreme north-west, both tributaries of the Nginyang River. These lowlands are diversified by extensive salients of lava and pyroclastics, satellites of Paka and Korosi volcanoes.

South of Lake Bogoria, small alluviated basins nestle between the curved escarpments, the largest of which is the *Upper Waseges* valley below the Iguamiti gorge; *Lake Solai* has been reduced to a swampy depression.

1e THE AMAYA EMBAYMENT, north of Churo, a feature about 20 km in diameter, extends north into the Cheptuimet area of the adjacent Degree Square sheet (No. 27): drained by the Amaya–Lochokio River systems, it includes the upper plain of the Amaya itself, and, to the north, the rugged, dissected Chembalao Shield (see Section 5.1), which contrasts dramatically with the somewhat more elevated, but level, Loroki Plateau to the east. Golden (1978, p.2) considered that the Amaya River formed a broad valley in this area in the Late Pliocene, possibly coinciding with an exhumed erosion surface which formed before the extrusion of the Miocene plateau phonolites.

2.2 THE LAIKIPIA PLATEAU

The monotony of the plateau surface, founded on Miocene 'flood' phonolites and sloping consistently at about 2–4° for over 50 km to the east, contrasts with the complexity of the Rift Valley to the west. The plateau occupies about 55 per cent of the total map area.

The term 'Laikipia Escarpment' has been used in a general sense for the main western boundary feature, corresponding in the south with the Marmanet Escarpment, but has also been applied to the Kahone Range and its northern extension west of the Ngusero valley. The *en echelon* aspect of the escarpment complex reflects the interference of two sets of normal high-angle faults trending NNE and NW: the right-handed sigmoidal pattern of the lower faulted escarpment south-east of Bogoria embodies the same two trends.

The stepped eastern shoulder of the rift culminates in an escarpment varying from c.2600 m in the Marmanet Forest (the highest point in the map area) to c.1900 m by the Churo 'saddle' south of the Loroki Plateau. To the east the Laikipia Plateau drops gradually down to an elevation of about 1645 m in the south, and, in the north, near Lake Kisima, to about 1737 m.

On the high western flanks of the Rift 'shoulder', rift-related faulting controls the outline of certain minor alluviated troughs on the plateau, the largest of which is the Upper Ol Arabel Basin: smaller basins to the north include the 'Northern Plain', Luoniek and Churo (Figure 4; 2b).

Further east the Ewaso Narok and Ol Keju Losera river systems do little to relieve the monotony of the high lava plains (Plate 3), typified by the desolate aspect of the Ang'ata Werikoi in the north-east: sporadic hummocky phonolite outcrops are separated by boulder-strewn plains speckled by shallow pans with ill-drained clump grassland (vleis or dambos), floored with black cotton soil. In the south, gentle warping of the lava pile has contributed to ponding in the valleys, e.g. the Ewaso Narok and Pesi Swamps, where papyrus, swamp grass and reeds flourish. The highest areas, the Marmanet and Ol Arabel Forests, support a montane sclerophyll vegetation, notably cedars and *Podocarpus*: to the north-east the forest gives way to more open and clumpy evergreen and semi-deciduous types: south-east of the Ewaso Narok an *Acacia depranolobium* association predominates in the mixed savannah and grassland.

On the *Loroki Plateau* in the north, the upper part of the lava sequence gives rise to a series of up to five escarpments, corresponding broadly to flow sequences within the Losiolo phonolites. The upper escarpment is the best developed, and appears progressively to overlap each of the underlying, less continuous, lava escarpments to the east. In the Lake Kisima area the lowermost 'step' of the lava plain is not bounded by an east-facing escarpment, but merges into the lower slopes of the Karisia Hills. Further south the margin of the plateau is clearly demarcated by a line of lava cliffs. To the south-east, in the Ol Pejeta area east of the Ewaso Ng'iro River, a series of low ridges trending WNW has been developed on a cover of Pliocene sediments. These undifferentiated secondary grassland ridges form a striking pattern on the Landsat imagery, contrasting with the deeper greens of the intervening lower ground, reflecting denser *Acacia* type (Upland evergreen) vegetation (Plate 9). Pliocene basalts in the same area, but west of the Ewaso Ng'iro, give a rather different aspect of the scenery, especially around Sirrima, where there are two small cinder cones.

2.3 THE 'BASEMENT' UPLANDS

In the east the 'Basement' Uplands show, in detail, a much more diverse topography, varying from c.1190 m in the lowest part of the Ewaso Ng'iro valley, to 2240 m at the summit of Rapa, the highest part of the Loroki (Leroghi) Forest. By virtue of correlation with the 'peneplain' of the Mid-Ewaso Ng'iro Basin in the area to the east, the lower valleys of the Ewaso-Ng'iro and Seiya rivers might be considered representative of the 'Sub-Miocene erosion bevel' of Saggerson and Baker, 1965 (i.e. the 'African' erosion surface or 'Moorland' widespread planation of King, Lester, 1983).

The *Ewaso Ng'iro Uplands* (Figure 4; 3b), rising to c.1675 m, support an 'upland Acacia type' vegetation. The landscape is much dissected, and it is a matter of conjecture whether it represents an end-Cretaceous or 'Kretacic' erosion bevel (Post-Gondwana) and whether the inselbergs rising above that level were carved from a still earlier (Gondwana) peneplained surface. Linear inselbergs such as Mukenya and Ol Doinyo Ng'iro (1859 m) clearly correspond with north–south granitic intrusives of Barsaloian trend (see Section 3.2): the reservations of Kroonenberg and Melitz (1983) that 'steps' separating summit levels of different altitude are commonly also lithological discontinuities, may be relevant in this context. (Their 'etchplain' concept interprets such discontinuities in terms of enhancement by differential chemical weathering during humid periods.)

The *Karisia Hills–Loroki Forest* massif (Figure 4; 3a) presents a steeper, more irregularly eroded face to the east than on the western side, which slopes down to Lake Kisima. Founded essentially on resistant migmatites and massive quartzofeldspathic gneisses, its north-westerly trend reflects Baragoian structures (Section 8.5). It is a higher relic of pre-'Moorland' planation phases: Shackleton (1946) considered that the even skyline of the Karisia Hills reflected the erosion surface of the Cretaceous peneplain. The soils tend to be reddish brown, sandy and stony loams on the lower slopes and dark brown loams in the highest parts of the forest.

2.4 DRAINAGE

West of the Laikipia Plateau the rivers drain inland, to the Rift Valley—to the east the Ewaso Narok–Ewaso Ng'iro system drains towards the Indian Ocean, as does the Ol Keju Losera–Seiya River, via the Milgis (Figure 5).

West of Nyahururu the watershed between the internal

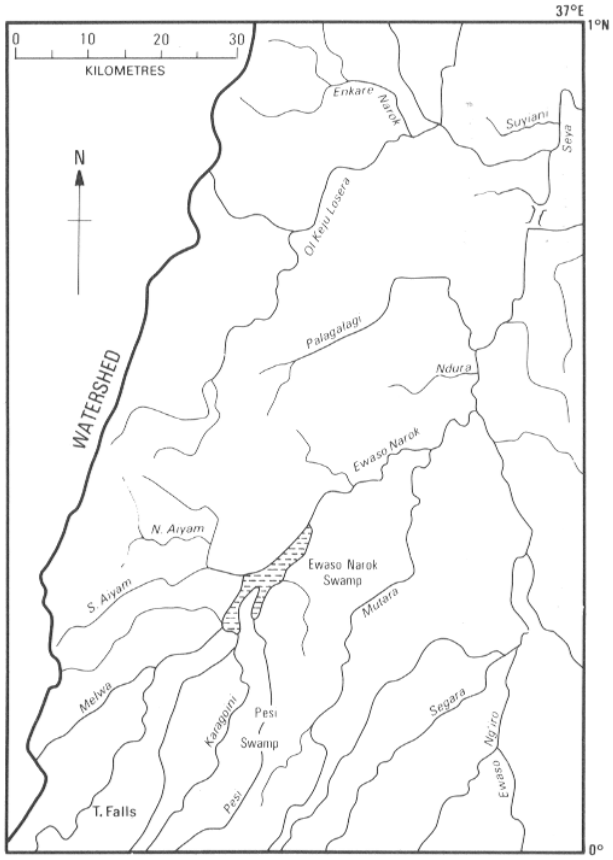


Figure 5 Ewaso Ng'iro/Narok and Ol Keju Losera drainage systems

and east-flowing drainage is aligned only 2 to 3 km east of the main Laikipia Escarpment, but northwards it is displaced to the east, until it coincides with the Loroki Plateau at the head of the Amaya Embayment.

The Ewaso Ng'iro, the largest river of the map area (Figure 5), flows almost due north for about 80 km, parallel to the meridional basement lineaments, but makes an abrupt bend to the east-north-east near Kirimun, whence it flows through a very straight gorge above Barsalinga, utilising a major joint parallel to a prominent set of lineaments in the Loroki Forest: 10 km to the north the Seiya, and its tributary the Suiyani, have cut deep valleys on the same trend, transecting the southern end of the Karisia Hills massif.

The configuration suggests that at an earlier stage the head of the Ewaso Ng'iro flowed into the Seiya, but was captured by the present day middle reaches of the east-flowing Ewaso Ng'iro: the lower altitude of the bed of the Ewaso Ng'iro, in relation to the Seiya, reflects the former's superior power of incision—over 300 m vertically in the main gorge east of Kirimun, with no evidence of bevels on the sides of the gorge.

The Ewaso Ng'iro/Ewaso Narok confluence above Lorkinyang coincides with a nick point at about 1615 m (Figure 7), 20 km downstream from the basement/phonolite boundary on the Ewaso Narok: the discontinuity on the Ol Keju Losera–Seiya profile at 1676 m (Figure 7) suggests a comparison; this coincides exactly with the phonolite boundary and is in accord with Pulfrey's (1960) assessment of the elevation of the sub-Miocene erosion bevel in this part of Kenya.

Hackman's (1986a) observations of underfit tributaries in the Ol Keju Losera Basin suggest that during pluvial periods the average surface discharge was much greater that it is at present: before stripping of the phonolite further east, in its present day lower (Seiya) reaches, a larger Ol Keju Losera–Enkare Narok system may have discharged directly into the proto-Ewaso Ng'iro in the Barsalinga area. The interplay of downcutting by these two rivers with the subsequent superimposition on a changing substratum (from Miocene phonolites to basement) could have led to alternation in the direction of river capture.

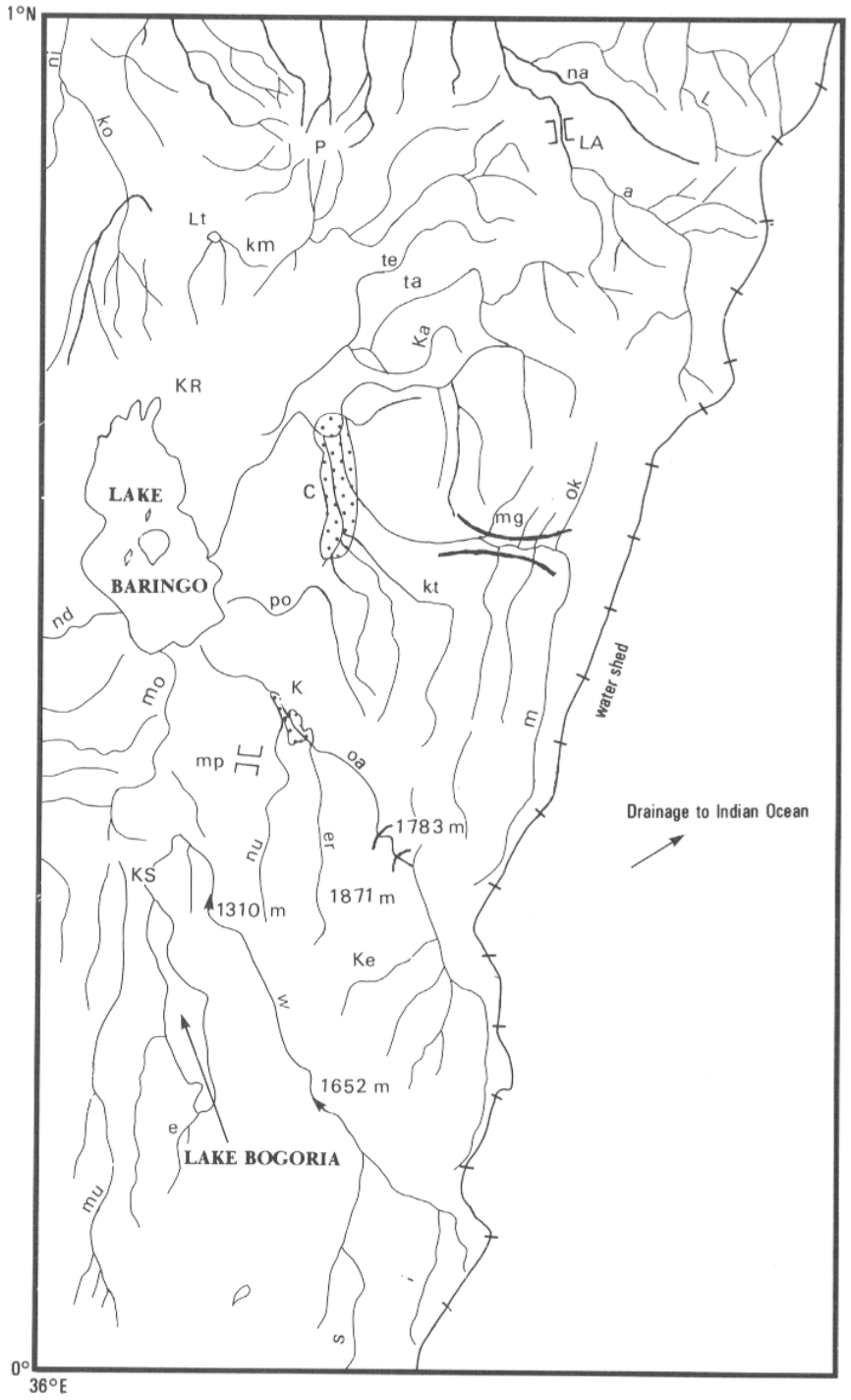
Discontinuities in the Ewaso Narok profile at 1768, 1829 and 2316 m, the last being the location of the impressive Thomson's Falls (73 m), cannot be correlated with pre-Miocene bevels, as the course of the river traverses Miocene volcanics—also they have no counterparts in the profile of the Ol Keju Losera to the north: such 'nick points' must be attributed to differences in bedrock or to warping and faulting confined to that southern part of the plateau.

A prominent but discontinuous ENE-trending lineament certainly controls the upper course of the Palagalagi (Palaglan) tributary of the Ewaso Ng'iro, and there is some evidence for fractures trending NW (e.g. the Enkare Nairoua tributary of the Ol Keju Losera), but the larger rivers, especially in the south, tend to meander over the plateau surface, generally as primary consequent streams, flowing NE or NNE. Late Quaternary warping of the rift shoulder, in part hinging on ENE-trending fractures, could explain the ponding of the Ewaso Narok and Pesi Swamps.

To the west, and across the Laikipia Escarpment complex, the internal drainage shows many interesting features (Figure 6). There are four river systems flowing north-west into the rift—the Waseges–Sandai, the Ol Arabel, the Mukutan–Tangulbei system and the Amaya: their courses exemplify the inability of geomorphic processes to keep pace with the volcano-tectonic evolution of the rift: erosion cycles have not been completed. Marked discontinuities in the profiles may be associated with gorges through sections of the multiple escarpment system; nick points as such cannot, however, be correlated in different streams, as the rejuvenation can be attributed to faulting along particular escarpments. For example, the gorge of the Iguamiti breaks through to join the Waseges across the escarpment formed by the Marmanet– Chui–Maryland fault zone. The lower Waseges (Sandai) has incised a tortuous ravine between the Bechot and Waseges Ranges (forming a ridge of Pleistocene trachyphonolites) immediately above its entry into the Kisibor Swamp on the Loboi Plain.

In the case of the Mukutan Gorge a powerful antecedent east–west drainage channel has been maintained, interpreted by Carney (1972) as representing an early Pliocene primary consequent stream draining into the rift, initiated by the rise of the 'Laikipia Monocline' to the east. Fed by a trellis headwater system following the NNE-trends of the rift boundary fault zone, the middle Mukutan maintained its course across a rising crestal horst (the Laikipia 'Anticline') throughout the Pliocene. There is a prominent nick point at 1830 m, at the Nandi Dam.

In contrast the Tangulbei and Kalabata–Lokwakipi systems to the north lost their downcutting power and directionality, assuming a somewhat deranged aspect. Further south, Griffiths (1977) speculated that in the middle Pliocene the lower Ol Arabel River flowed west to the Baringo Basin by way of the Moera Pass, now a wind gap across the Tasiokwank branch of the Laikipia Escarp-



a — *Amaya*
C — *Lake Chemoigut*
e — *Emsos*
er — *Ewaso Ronkai*
i — *Iguamiti*
ka — *Kabarmel*
K — *Lake Kapindasum*
ke — *Keniroi*
ko — *Kogore*
km — *Komol*
KR — *Korosi*
KS — *Kisibor Swamp*
kt — *Kutwa*
LA — *Lochoria Kosowa*
Lt — *Lake Tilam*
L — *Lochokyo*
mp — *Moera Pass*
mo — *Molo*
mu — *Mugurin*
m — *Mukutan*
mg — *Mukutan Gorge*
na — *Nasuru*
nd — *Ndau*
ni — *Nginyang*
nu — *Ngusero*
ok — *Okisim*
oa — *Ol Arabel*
P — *Paka*
po — *Porumbonyanza*
S — *Subukia*
ta — *Tangul bei*
te — *Terter*
w — *Waseges*

Nick points

Old lake sites

Wind gap

0 10 20 km

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Figure 6 Internal drainage into the Rift Valley

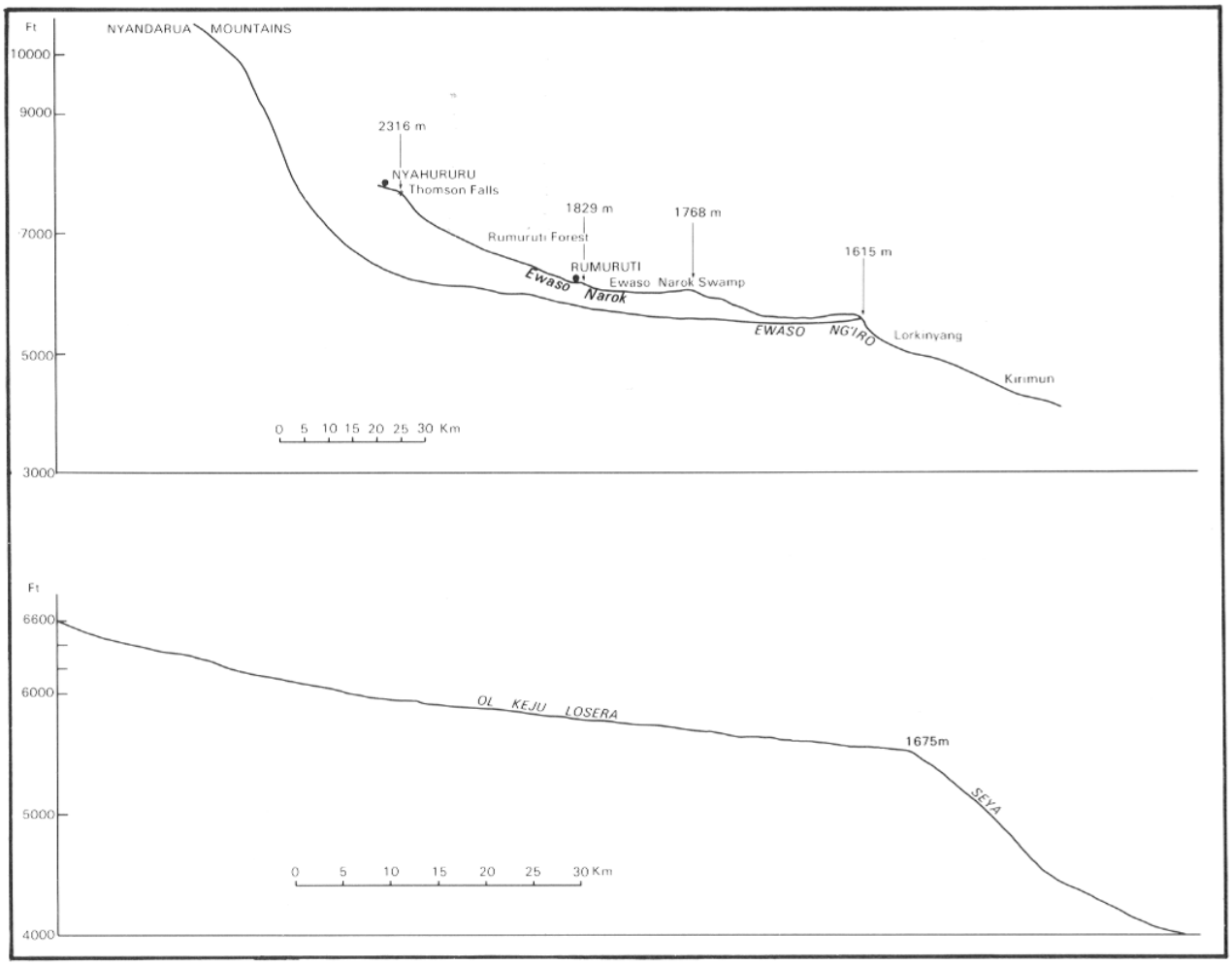


Figure 7 Longitudinal profiles of the Ewaso Ng'iro and Ol Keju Losera rivers

ment: however, regional northward tilt favoured the abandonment of the Moera Pass. In the late Pleistocene a lake formed over the present outcrop of the Kapindasum Beds, an aggraded area above the Ol Arabel–Ngusero confluence, dammed by the extrusion of the Paratallo volcanics to the north: the existing lower Ol Arabel Gorge probably owes its origin to the incision of an overflow channel. Similarly, to the north, the Porumbonyanza (Ngasotok), the Mukutan and the Tangulbei have each incised a small gorge through the Pleistocene volcanic ridges (Karau–Chepchuk) initially as overspill connections from the 'Chemoigut Lake' (Figure 6) into the Baringo Basin to the west.

A nick point at 1530 m, along the course of the Amaya River, corresponds with its departure from the upper valley of the Amaya Embayment (which is floored partly by the Pliocene Orus trachyte flow), and its entry into the Lochoria Kosowa gorge through Miocene basalts and overlying phonolites.

3 Stratigraphy

The stratigraphy of the area can be considered in terms of two major divisions: the Late Precambrian–Early Palaeozoic Mozambique Orogenic Belt (Section 3), and the Cenozoic volcanics (Section 5) of the Rift Valley and adjacent shoulder plateaux. The intervening hiatus represents a period of uplift, erosion and localised sedimentation, from the Late Cambrian to the Miocene: the related sedimentary rocks are described in Section 4. Metamorphic and intrusive rocks of the Mozambique Belt outcrop only in the eastern part of the area—in a belt not exceeding 30 km in width, in which the predominant grain of the structures trends north–south.

The Rift Valley, to the west, features a variety of volcanic complexes ranging in age from Miocene to Recent, lava flows and pyroclastics of 'central' type and 'plateau' lavas, with minor related intrusives. The eastern shoulder of the rift, above the Laikipia Escarpment, extends into the broad expanse of the Miocene flood phonolites, the Laikipia Plateau. In the south-east there is also an area of Pliocene lavas, the Laikipia Formation, and a sedimentary sequence of glaciofluvial origin (the Nanyuki Formation), derived from the Mount Kenya massif to the south-east. Minor Quaternary sediments and superficial deposits are described in Section 6.

Descriptions of lithostratigraphic units include sections on nomenclature, geographic distribution, morphology, reference sections, palaeontology, age, structural relationships, thickness, lithology and petrography, petrogenesis or sedimentation, generally in that order.

3.1 METAMORPHIC ROCKS OF THE MOZAMBIQUE OROGENIC BELT

The essential subdivisions of the Mozambiquian are shown in Table 1.

Table 1 Subdivisions of the Mozambique Orogenic Belt

5	Loroki Gneisses (mg^{qfLR})
4	Ol Doinyo Ng'iro Gneisses (mg^{DN})
3	Don Dol Gneisses (mg^{DD})
2	Undifferentiated migmatites (mm)
1	The Ndura Complex (mm^{NC}, mm^{hNC}, mm^{gNC})

The Ndura Complex

These westernmost rocks of the 'basement', first mapped by Key (1986) in the Kirimun area, have been categorised, in the course of regional investigations, as the 'Ndura Complex', named for the Ndura (Nduru) tributary of the Ewaso Ng'iro River. (Figure 8).

3 Almandine permeation gneisses (paragneisses) mm^{gNC}

2 Mafic permeation gneisses (orthogneisses) mm^{hNC}

1 Massive and flaggy *lit par lit* veined grey gneisses mm^{NC}

The massive and flaggy veined grey gneisses (mm^{NC}) are well exposed in the rugged country west of the Ewaso Ng'iro River, up to the edge of the phonolite plateau: they extend from latitude 0°40′N, in the Mukenya area, to beyond the northern boundary of the map sheet. These permeation gneisses give rise, especially in the north, to rugged ground, deeply incised by the Ewaso Ng'iro and its west bank tributaries. Their massive, competent aspect shows in the buttresses of bare rock on the walls of river gorges. Towards the south the relief is gentler, as the foliation in the gneisses tends to subhorizontal and the drainage network is not so well developed. Lineaments on aerial photographs are prominent only locally where the foliation is inclined at high angles. Exposures are generally good, and most transverse stream sections provide excellent rock surfaces: the variety of lithology is illustrated in the following reference sections:

1 The Ewaso Ng'iro River, south from the new road bridge at Crocodile Jaws as far as the east bank tributary at GR 2626 0638, provides excellent sections of flaggy permeation gneisses.

2 The Ndura tributary from its confluence with the Ewaso Ng'iro west to GR 2592 0630 (where a motorable track crosses the stream), furnishes exposures of both flaggy and massive permeation gneisses.

3 A less accessible cluster of kopjes at GR 266 073 has very good outcrops of massive granitic permeation gneiss.

The Ndura Complex gneisses embody rocks of different age, i.e. a gneissic palaeosome complex and a felsic neosome. Their age relative to other Precambrian units is uncertain: they appear to form a western massive 'foreland' to the biotite-paragneisses and related rocks exposed to the east. In detail the structures are highly complex, so that comments on relationships remain speculative. The *flaggy gneisses*, well exposed south of Crocodile Jaws, in part massive, are pale grey to white leucocratic rocks, weathering to shades of brown. The vein phase (20 to 50 per cent of the rock volume), comprises white quartzofeldspathic material, individual veins varying from 0.2 to 2 cm in thickness. The veins are subparallel to the gneissosity in the host leucocratic quartz-feldspar-biotite gneiss. Mafic bands are typically boudinaged: pegmatites and discordant felsic veins are common. Minor folds of varying style are ubiquitous.

The *massive pink-grey gneisses* are medium- to coarse-grained leucocratic quartz-feldspar-biotite rocks with a diffuse curviplanar gneissosity defined by biotite wisps. They tend to form 'whaleback' ridges and kopjes which weather to shades of brown, although in the incised river sections the rocks retain their pale pink and white freshness. The gneissosity, although diffuse, is clearly developed, and distinguishes these rocks from the G2 granites (described below). Small pegmatites are common, both concordant and discordant to the gneissosity, also quartz veins: but neither felsic nor mafic dykes have been noted in the permeation gneisses.

The permeation gneisses consist simply of quartz, biotite, rarely hornblende, plagioclase, minor iron ore,

apatite and variable amounts of microcline and untwinned feldspar. Green hornblende is in the form of corroded grains, partly replaced by fresh biotite blades. The matrix consists of embayed euhedral quartz, feldspar, ore and apatite grains: biotite defines any manifest fabric. Embayed quartz and feldspar porphyroblasts locally overgrow the matrix. The average grain size of the matrix is 0.4 mm, with porphyroblasts up to 2.5 mm in diameter. Neither quartz nor total feldspar content is less than 30 per cent of the mode, although the quartz/feldspar proportion is variable. Red garnets occur locally in both the flaggy and massive permeation gneisses.

It seems likely that there was more than one period of permeation, i.e. the early *lit-par-lit* venation was followed by 'soaking' which gave rise to the massive pink grey gneisses: the latter process was essentially thermal, but also tectonic, mobilising the various components to produce felsic zones and new biotite foliation.

The mafic orthogneisses (mm^{hNC}) define an interference fold structure, closing both to the east and the west, mapped in the north-central part of the Kirimun area: they are spatially related to the permeation gneisses described in the previous section.

The same unit has been mapped in the Maralal area to the north: its features merit comparison with the metamafic suites in the Barsaloi–Baragoi area (Key, 1987).

The unit is confined to deeply incised terrain adjacent to the Ewaso Ng'iro valley: the mafic orthogneisses are magnificently exposed in tributary beds, and also occur on 'whaleback' outcrops on the ridges. They are scored by lineaments trending ENE, related to joints which are followed by tributaries of the Ewaso Ng'iro.

References section are as follows:

1 Ewaso Ng'iro River at GR 2648 0675.
2 Lechachi River from GR 2700 0696 to its confluence with the Ewaso Ng'iro (over 3 km of almost continuous outcrop).
3 Muridjo River from GR 2687 0761 to 2676 0758.
4 Paregare River between GR 2674 0786 and 2668 0784.

The mafic orthogneisses tectonically overlie the permeation gneisses and locally underlie biotite-gneisses of the Don Dol and Ol Doinyo Ng'iro gneisses. The thickness may be estimated at several hundred metres, but this cannot be deduced as original, on account of major isoclinal folding.

Several felsic intrusive phases invade massive and banded dark grey biotite and hornblende-bearing medium-grained gneisses. Light and dark grey bands, up to several centimetres thick, are defined by variable content of felsic minerals: these bands are folded, isoclinally, in various styles. The gneisses are equigranular, with equant hornblende, biotite, plagioclase and quartz grains visible in hand specimen, and a uniform grain size of about 1 mm. Coarser mineral aggregates are also common, pyroxene-rich clusters being enclosed in hornblendic pods.

Within the banded gneisses are massive, homogeneous, dark grey rocks with the same essential mineralogy, in units up to several hundred metres thick. Both massive and banded gneisses are cut by the following minor intrusive phases:

1 Thin felsic veins, often *lit par lit* in the banded units.
2 Quartz veins and pods.



Figure 8 Distribution of migmatites



Plate 1 Lake Baringo from the south-west, with Ol Kokwe island: the Ngelesha Escarpment in the background

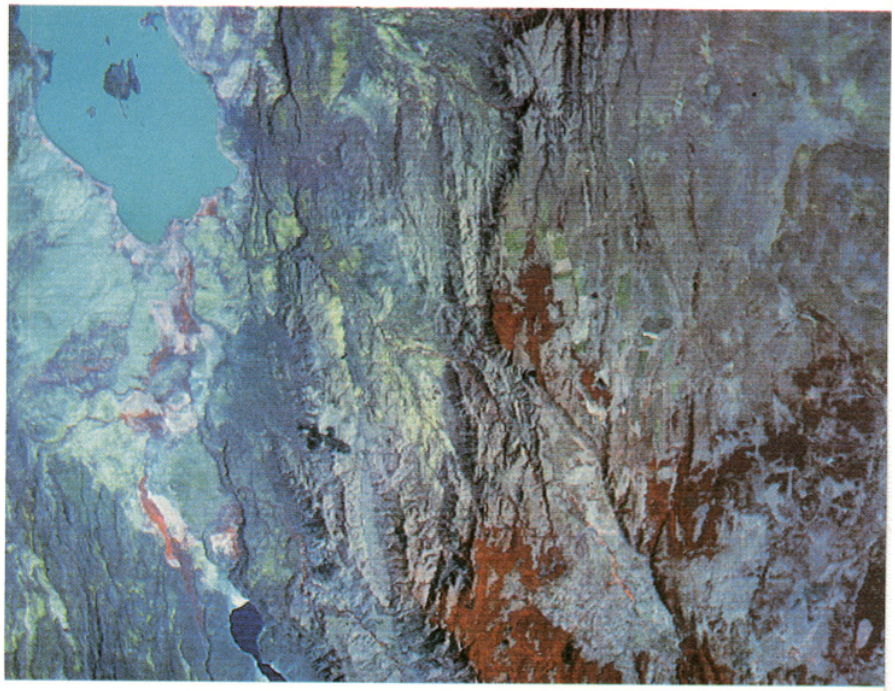


Plate 2 Landsat image showing parts of Lakes Baringo and Bogoria, separated by the Loboi Plain: the Ngelesha Escarpments rise to the east

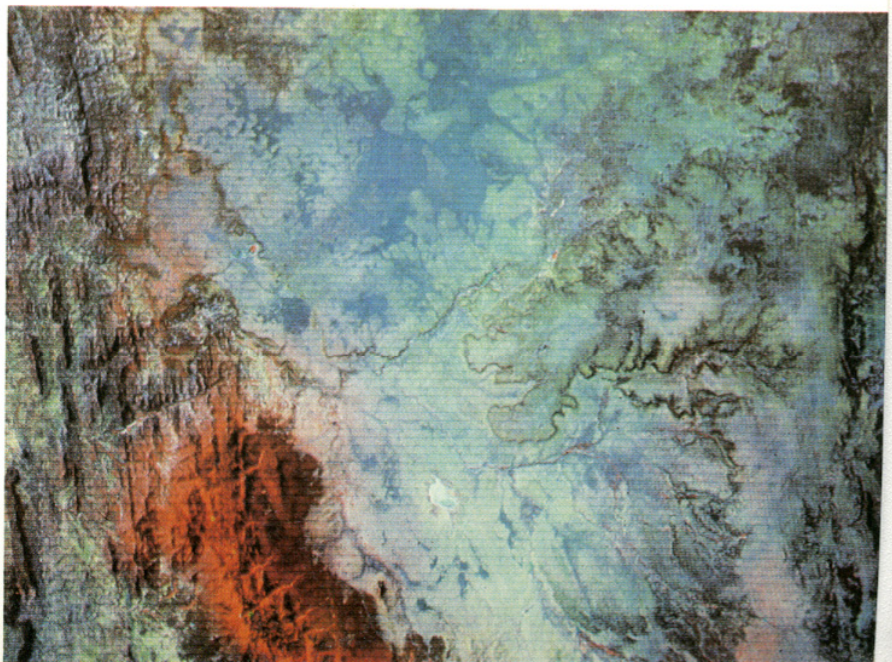


Plate 3 Landsat image of the northern Laikipia Plateau: the basement area in the north-east, scored by N–S lineaments, includes the forested Karisia Hills. South centre the dark blue area is the poorly drained Ang'ata Werikoi



Plate 4 Metadolerite dyke in amphibolitic gneisses, Lanfatu River, Kirimun area



Plate 5 The Laikipia Plateau in the Lariak area: view north-east from Kinamba, towards Sipili, a basaltic cone



Plate 6 The Loroki Plateau above the Amaya Escarpment

3 Disrupted quartzofeldspathic sheets.
4 Granite pegmatites.
5 Mafic dykes.
6 Amphibolite sills.

Several ages of felsic intrusives occur: the early veins define rootless folds, and are associated with zones of feldspar porphyroblastesis in which up to 50 per cent of the rock volume consists of equant feldspar grains up to several centimetres in diameter.

The pegmatites comprise a late phase, forming discordant planar bodies in fractures. The mafic dykes and amphibolite sills are early, folded with the gneissose banding of the host rocks. A single late phase metabasalt dyke was noted, 30 cm thick.

The equigranular texture was confirmed in thin section: the rocks contain hornblende, biotite, diopside, magnetite, quartz and apatite; modally andesine predominates. Quartz exceeds 10 per cent in all samples, and the mafic grains form 25 to 50 per cent of the mode. Biotite is dominant over the other mafic minerals, which it overprints.

These orthogneisses are regarded as altered volcanics or subvolcanic intrusives originally of mafic or intermediate composition: they form a petrologically coherent unit without metasedimentary seams. No primary structures such as pillows were found, therefore it is uncertain whether the rocks were originally extrusive, or emplaced at the interface of the massive and flaggy grey gneisses and the biotite gneisses of the Don Dol sequence.

Almandine permeation gneisses (mm^{gNC}) Garnetiferous migmatitic gneisses form mappable units within the biotite-gneisses of the Don Dol Gneisses, but are here on the basis of their more complex structure interpreted as an older unit 'infolded' within the Don Dol Gneisses. However, an alternative interpretation of the apparent simplicity of the Don Dol banded gneisses could be that a late fabric has obliterated the earlier structures, which are only preserved within the almandine permeation gneisses.

A major band of these garnetiferous gneisses can be mapped from the northern part of the Kirimun area, trending due north towards the Karisia Hills. Thinner units, less than 20 m thick, also occur as concordant bands within the biotite-gneisses of the Kirimun and in the Longopito and Mukogodo areas to the east (Key, 1986; Key and Jali, 1986).

The almandine migmatitic gneisses form the massive rock walls of the spectacular Ewaso Ng'iro gorge which trends along easting 269. Elsewhere these rocks form positive features such as ridges or kopjes in fact they underlie the highest point (1860 m) of the Ol Doinyo Ng'iro ridge, The elongate ridges define strong photolineaments: in the vicinity of GR 269 081–2 a major isoclinal fold is defined by the configuration of these lineaments.

The best exposures are in the above-mentioned gorge, which is difficult of access, and in adjacent stream sections. Rock pavements and vertical cliffs are accessible between GR 2700 0739 and 2693 0747. The main outcrop in the north of the Kirimun area defines a perfect isoclinal fold, with a total maximum thickness of 1500 m: the deduced unfolded thickness is about half of this.

The garnetiferous migmatitic gneiss has a very striking appearance: quartz predominates in the paleosome, with aggregates of coarse black biotite: the host gneiss and the white quartzofeldspathic neosome are spotted with red subhedral garnets up to 1 cm in diameter. The veins outline tight folds; they may have been transposed to define axial planar fabrics, which parallel the banding in the adjacent (Don Dol) biotite-gneisses. Tight folds are ubiquitous, even in the thin bands within the biotite-gneiss, although the adjacent gneisses appear unaffected. The vein phase makes up about 25 per cent of the rock volume: typically the almandine content is high, ranging up to about 15 per cent. Sillimanite occurs in an isolated outcrop, as the main modal mineral (with red garnet), at GR 2712 0597 at the southern extremity of the mapped outcrop.

Rare minor intrusive phases include:

1 Early thin biotite-rich mafic dyke
2 A 50 cm thick microgranite dyke
3 A 1 m thick metadiorite dyke
4 Quartz—white mica pegmatite
5 Quartz-feldspar-biotite pegmatite: with biotite books defining hexagonal prisms, perhaps after beryl (GR 2725 0652).

One thin section shows red garnets about 2 mm in diameter in a groundmass of biotite, quartz, oligoclase and orthoclase with traces of apatite. The garnets are subhedral, embayed, generally free from inclusions apart from quartz, and unaltered. The average grain size of the groundmass is 0.1 mm, unusually fine for this rock, which in the field is typically phaneritic. The groundmass is quartz-rich, and the biotite flakes define a weak foliation. The dominant feldspar is oligoclase, zoned (with twinned cores and untwinned rims). Feldspars may be partly sericitised.

Key (1986b) regards these garnet permeation gneisses as metasediments, and considers the modally important felsic vein phase to represent a product of anatexis. The original quartz content must have been high: possibly the rock was an impure sandstone.

Undifferentiated migmatites In addition to those migmatites designated as 'Ndura Complex', three areas to the south-east remain undifferentiated as 'massive permeation gneiss' (mm) notably around the Naia Sirua/Naso Ranch area, and the line of inselbergs which include the 'Camel's Hump' and Losarumuru on the Chololo Ranch. Jali (1983) refers to these rocks as massive, of granitic appearance, with randomly orientated quartzofeldspathic veins, lenses of amphibolite, in part agmatitic. In the poorly exposed easternmost outcrop the migmatites grade in part into coarse-grained pink granite-gneiss, contiguous with the Loldaika complex migmatites of Degree Sheet 36 (Hackman and others, in press), regarded as autochthonous zones of transformation of the Don Dol gneisses and the Mukogodo (older migmatitic) complex: in the area to the east the Loldaika complex comprises potassic nebulitic migmatite with sheets of leucocratic granite.

Don Dol Gneisses (mg^{DD})

Reference sections for this unit were defined by Key in the Mukogodo area (Sheet 107/1) of the Isiolo Degree Sheet (No. 36) to the east (Hackman and others, in press).

The Don Dol Gneisses occupy most of the south-eastern part of the Precambrian outcrop on Degree Sheet 35, and also outcrop in a discrete area to the west, where the Ewaso Narok River has disclosed a re-entrant in the escarpment of the overlying Miocene phonolites (Figure 9). These gneisses weather more readily than the granitic-migmatitic intrusives, thus tending to give rise to the low ground between inselberg ranges.

The predominant lithology is a uniformly banded leucocratic biotite-gneiss, but there is a great variety of

subordinate lithologies, particularly near the boundary with the overlying Ol Doinyo Ng'iro Gneisses (mg^{DN}): as certain of these lithologies are common to either unit, demarcation between them is rather arbitrary, especially in view of the tectonic complexity.

Typically the *biotite-gneisses* (mg^{DD}) are grey, and medium-grained, weathering to a pale brown: the gneissosity, usually reinforced by concordant white quartzofeldspathic veins, is defined by quartz-feldspar-biotite seams several centimetres thick, separated by biotite foliae up to 2 mm thick. In thin section the thicker seams appear as bands of equigranular quartz/oligoclase aggregates with smaller brown biotite blades and grains of ore. Microcline, microperthite, green hornblende and almandine have also been noted in these felsic bands.

Quartz (up to 80 per cent) dominates the modes of metaquartzitic facies. Intercalations of semi-pelitic biotite and hornblende-gneisses are locally common.

Sillimanite-gneisses (mg^{sDD}) outcrop as a narrow NE-trending ridge about 8 km long in the Mukenya area (Jali, 1983): in these rocks the sillimanite tends to form discrete bands, the fibres orientated parallel to the gneissosity, which in that area also trends NE. Microcline has developed locally at the expense of biotite, which is red-brown in thin section: garnet also occurs, and traces of magnetite.

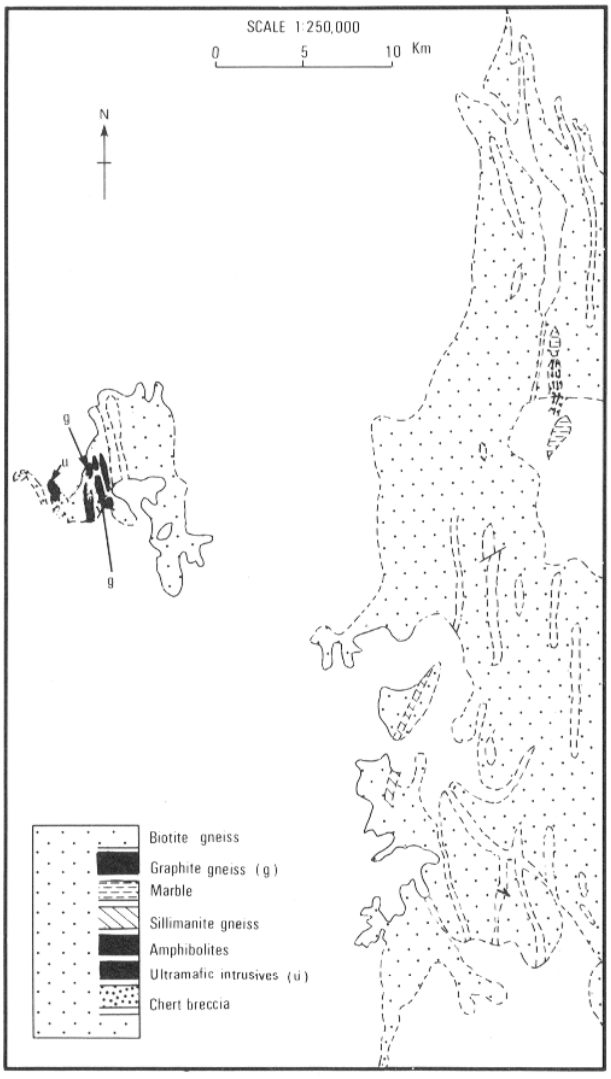


Figure 9 Distribution of the Don Dol Gneisses

Marbles (mm^{DD}) like those of the Ol Doinyo Ng'iro Gneisses are associated particularly with *Chert breccias* (mg^{DD}) on Lobor Soit (Figure 9): the latter consist of angular brownish ferruginous chert clasts in a matrix of the same: the breccia is clast-supported, the size of the angular fragments varying from 1 cm up to c.20 cm. Quartz-filled vughs are common. Two composite units of *amphibolite*, or mafic gneiss, (mh^{DD}) were mapped by Charsley (1984) in the Ewaso Narok valley (GR 2487 0506 and 2492 0507); they consist of biotite-gneiss, hornblende-biotite-gneiss and true amphibolites: the later are discordant bodies, indicating that they were either dykes or dislocated tectonically.

A sample of mafic gneiss from this area contained about 40 per cent quartz, 35 per cent plagioclase (oligoclase-andesine) and 15 per cent hornblende with accessory apatite and opaques: the texture is coarse-grained, inequigranular–xenoblastic.

A small *ultramafic–mafic intrusive* (mu^{DD}) occurs in the same area (GR 2464 0501): in the field the rock varies from a gabbroid, in part containing hornblende porphyroblasts and locally deformed, to a massive amphibolite. The body is lenticular and elongated N–S, subparallel to the regional foliation: its margins have been strongly sheared.

In thin section the amphibolitic rocks show inequigranular–xenoblastic texture, consisting predominantly of diopside and actinolitic hornblende derived therefrom. Plagioclase (andesine-labradorite) is unevenly distributed, and strongly altered to sericite and zoisite. Charsley (op. cit.) believed the original rock type to have been a pyroxenite, grading locally into a gabbroic facies.

Ol Doinyo Ng'iro Gneisses (mg^{DN})

These paragneisses are named from the Ol Doinyo Ng'iro area in the eastern part of the Kirimun sheet (92/4). Key (1986a) used sections in that area, and on the adjoining map sheet to the east (the Longopito area, Key, 1986a), for formal definition of the unit, which corresponds broadly with a north–south belt of pelitic schists and gneisses, associated with crystalline limestones, as mapped by Shackleton (1946). In the Baringo–Laikipia area these gneisses outcrop for 50 km along the eastern boundary of the map sheet, in a complex north–south belt up to 7 km wide (Figure 10). Grey banded biotite gneisses (mg^{DN}) predominate, with more massive quartzofeldspathic gneiss (mg^{qfDN}): especially diagnostic of this unit are thick sequences of graphitic gneiss (mg^{rDN}) and marble (mc^{DN}): amphibolites (mg^{DN}) are of lesser importance (Plate 4).

In the Kirimun area the Ol Doinyo Ng'iro Gneisses are infolded with the Don Dol Gneisses, so that detailed allocation of certain mappable units, to one or the other sequence of paragneisses, is difficult.

On the ground the lithological variety expresses itself as a series of N–S-trending ridges of quartzofeldspathic gneisses and marbles alternating with valleys underlain by less resistant biotite-and graphite-gneiss. The gneissosity defines strong lineaments on the aerial photographs.

The grey banded biotite gneisses (mg^{DN}) consist of quartzofeldspathic seams separated by biotite foliae: the rocks typically weather to brownish shades.

The stream through Ol Doinyo Ng'iro settlement provides a reference section (GR 2755 0693–2755 0670). Gneissosity may be regular over several square metres,

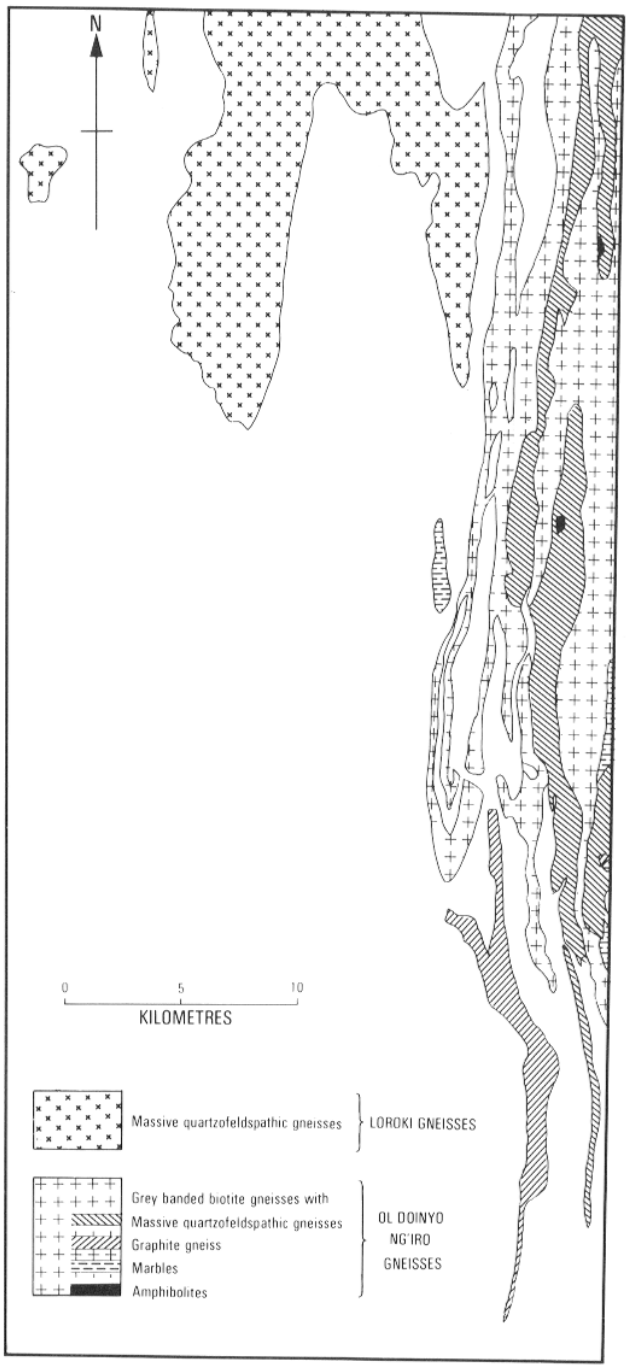


Figure 10 Distribution of the Ol Doinyo Ng'iro and Loroki gneisses

with individual seams ranging up to several centimetres. Boudinaged hornblendic, biotitic and felsic seams accentuate the banding. The strike of the foliation is usually N–S, with steep dips: minor folds of various styles are ubiquitous. Metaquartzite seams up to 10 m, and corundum-garnet-gneiss bands, also occur.

The *massive quartzofeldspathic gneisses* (mg^{qfDN}) are medium-grained rocks, locally weathering to a 'red bed sandstone' effect: red garnets and magnetite blebs are common. Good exposures are seen on the hills north of Ol Doinyo Ng'iro.

Graphitic gneisses (mg^{rDN}) have been described in considerable detail by Key (1982) in a special report on the graphite resources of the Ol Doinyo Ng'iro area. They cannot be distinguished from adjacent biotite-gneisses on aerial photographs. The rocks are medium-grained quartz-plagioclase-graphite-gneisses with about 10 per cent graphite flakes, puckered in the felsic seams: graphite flakes are up to 2 mm in length.

The interfaces between the graphite gneisses and adjacent rocks are defined by limonite seams, less than 15 cm thick, which are locally finely laminated, and veins of which invade the graphitic gneiss itself. The gneisses have, in places, a well-developed cleavage, but lack regular gneissosity.

Of special interest is the association, particularly at the structural top of the graphitic gneiss unit, with a weakly magnetic ironstone, which locally has structures of possible stromatolitic origin: individual laminae are c.1 mm thick and their convolutions define unbranched nodular growths up to 2 cm long and 0.6 cm high. The ironstone has a matrix of equigranular quartz with flattened vughs infilled with limonite.

Marble (mc^{DN}) outcrops in four places east and north of Ol Doinyo Ng'iro, three of them right on the eastern boundary of the degree sheet. They are medium-grained (0.1 to 1.0 cm) pure carbonates with less than 5 per cent graphite flakes: granular calc-silicate protrudes on weathered surfaces as yellow-brown pitted aggregates up to 1 cm in length.

Amphibolites (mh^{DD}) are limited to a few outcrops of small extent. They are massive medium-grained gneisses with seams of black hornblende and plagioclase separated by grey felsic seams.

Key (1986) interprets the marbles and related graphitic rocks of the Ol Doinyo Ng'iro Gneisses as indicating, respectively, an altered reef material, and a back-reef basinal regime of a near-shore subaqueous depositional environment. In contrast the biotite-gneisses, especially of the Don Dol facies, suggest more uniform arenaceous sequences.

Loroki Gneisses (mg^{qfLR})

The Loroki Gneisses take their name from the Loroki Forest, which covers the Karisia Hills massif.

Defined in the Maralal area to the north (Key, 1987), they were mapped by Muturi (1986) in the Lake Kisima area as a quartzofeldspathic gneiss unit tectonically overlying the massive and flaggy *lit par lit* veined grey gneisses of the Ndura migmatitic complex: the outcrop defines the two limbs of an antiform plunging to the north, which straddles both sides of the Karisia Hills ridge (Figure 10).

In the unforested areas these gneisses show pale highly reflectant tones on aerial photographs: joints and faults trending ENE give rise to conspicuous lineaments even under forest cover.

Key (op. cit.) quotes several reference localities in the Maralal area which may be used to formalise the sequence.

The Loroki Gneisses are underlain tectonically by the Ndura Complex migmatites, and overlain, in the Maralal area, by the Ol Doinyo Ng'iro Gneisses.

The dominant lithology is a massive, fine- to coarse-grained pale grey to pink or brown leucocratic gneiss, with variable accessory biotite which generally defines a weak foliation, locally enhanced by flattening of quartz grains and feldspar porphyroblasts. Usually the combined feldspar content exceeds that of quartz.

Subordinate hornblende-gneisses and flaggy muscovite-quartz-gneisses are described by Key from the Maralal area.

The Loroki Gneisses are interpreted as a sequence of altered clastic, essentially arkosic, sediments, and bear comparison with the Kotim Gneisses of the Isiolo area (Hackman and others, in press).

3.2 PRECAMBRIAN INTRUSIVES

The Ol Doinyo Ng'iro metagabbro (m^B)

This metagabbro intrusion extends northwards for 4 km from the village of Ol Doinyo Ng'iro: the width of the outcrop is about 400 m. The elliptical shape has been effected by the Barsaloian deformation, which has produced a number of small pods or megaboudins in the adjacent area (Figure 11).

The main metagabbro body has been incised meridionally along its strike by the Ol Keju Letale River. The valley sides are about 30 m high, and outcrops of the intrusive form small kopjes on the adjacent high ground.

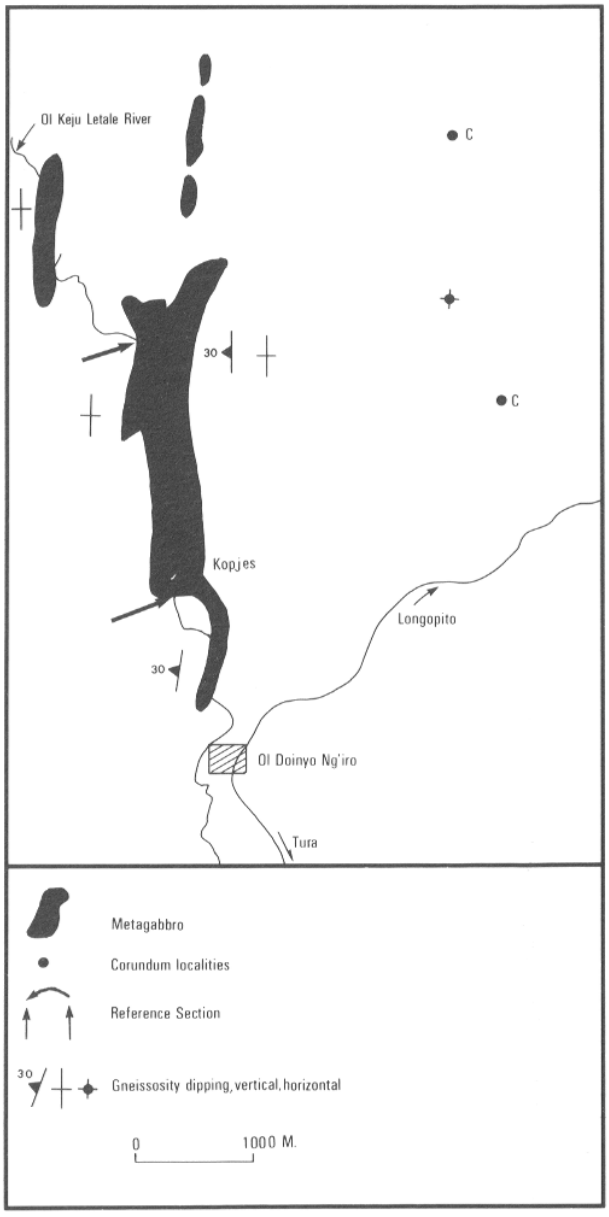


Figure 11 The Ol Doinyo Ng'iro metagabbro

On aerial photographs the metagabbro is not tonally distinct from the adjacent gneisses: the shape of the intrusives was determined by foot traverses.

The reference section may be defined as the course of the Ol Keju Letale River between GR 2750 0710 and 2749 0732, which shows almost continuous outcrop of the textural varieties, although locally obscured by laminated calcrete.

Two samples of the Ol Doinyo Ng'iro metagabbro were selected for K-Ar dating of biotites: they had very different K contents and gave significantly different ages (Rundle, 1985).

The apparent K-Ar age of 573 ± 13 Ma for one of the samples (which has a higher K content) is in accord with Rb-Sr ages from similar mafic and microtonalitic intrusives further east (cf. Sinyai Dolerite, Key and Jali, 1986). The other sample, with a lower K content gave an age of 597 ± 13 Ma: Rundle suggests the latter result is spuriously high due to preferential potassium loss. Rb-Sr analyses of seven samples show low values and a narrow range of Rb/Sr ratios: in spite of a high error assigned to the calculated age, the results accord with 'intrusion, or complete resetting, during the c.570 Ma event', i.e. comparable to the Sinyai Dolerite.

The intrusive post-dates the imposition of fabric in the Don Dol Gneisses, but predates the Barsaloian deformation, which ruptured the metagabbro, now disposed as several 'megaboudins' within the surrounding Don Dol biotite-gneisses: the smaller, more distant boudins are also recrystallised to hornblende-rich amphibolites.

Fine-grained marginal facies are still preserved in the main metagabbro body, and it is thought that emplacement post-dated the gneissic fabric in the Don Dol Gneisses.

The maximum thickness of the main metagabbro is 400 m.

Grain size increases gradually towards the centre of the main metagabbro. The marginal phase is fine-grained, with individual grains less than 1 mm in diameter. This passes into an intermediate 'metadolerite' phase with an average grain size of about 2 mm, compared to about 4 mm in the central metagabbro. The outermost rocks are dark grey, with black biotite defining a good foliation parallel to the intrusive margins.

The metadolerite and metagabbro are massive, and petrographically homogeneous. Dark crimson pyroxene grains are embedded in a matrix of equant light grey plagioclase, which forms 50 per cent of the rock: protrusion of the proxene gives a roughness to the weathered surfaces. Unorientated shiny black biotite flakes form small clots replacing pyroxene.

Gently dipping shearing zones, up to 1 m thick, trending NNE, and microtonalite veins and sheets, provide some textural variation.

The petrology of the fine-grained marginal facies is comparable to that of the cognate mafic dykes in this area.

In the coarse phase, brown biotite flakes overprint a matrix of fresh andesine and augite. Two sizes of andesine grains occur, the larger phenocrysts being internally strained and cracked. The augite has faint pink pleochroism, and the rims are slightly altered to green actinolitic hornblende. Ore trails occur throughout the groundmass.

In view of the possible interpretation of metagabbro slices in mobile belts as indicators of ophiolite suites, it may be significant that this intrusive was emplaced near the tectonic interface between the permeation gneisses to the west and the biotite-gneisses to the east.

G1 Granite

The granite sheet exposed on Lobor Soit may represent an earlier G1 intrusive phase; it appears to have suffered the same deformation as the adjacent metasediments, and predates the tectonothermal episode which formed the gneissosity. It is a pink-weathering, medium-grained leucocratic rock.

G2 Granite

A series of prominent narrow granite ridges trending from NNE to NW characterise the basement area from El Karama Ranch in the south to the northern sheet boundary. They predate the Baragoian deformation, and locally define Baragoian and Barsaloian fold closures. Characteristically they are leucocratic, varying from fine-grained homogeneous granites to medium-grained migmatites. These resistant granite ridges are often capped by tors of rock weathering to pink brown.

The G2 granites have been emplaced into the various paragneisses and permeation gneiss subdivisions, and in part represent granitisation of leucogneisses. Adjacent rocks have usually been soaked by felsic veins synchronous with the granites, especially in the eastern belt of permeation gneisses.

Usually a pegmatite phase is present, comprising only quartz feldspar and biotite. Mafic pods may have been inherited from precursor leucocratic gneiss (cf. the Sederholm effect).

The dominant minerals are quartz and other microcline or microperthite, with minor amounts of plagioclase, biotite, apatite, zircon, muscovite and/or garnet. Quartz constitutes up to 45 per cent of the mode, and the K-feldspar phases up to about 60 per cent. Quartz occurs as myrmekitic intergrowths with K-feldspar and plagioclase. Granulation of the coarse felsic grains is common, also internal strain and suturing of grain margins. The K-feldspar grains are usually replaced in part by sericite, more rarely by muscovite flakes.

The G2 granites are believed to have been derived, at least in part, from pre-existing leucogneisses by granitisation involving veining and remobilisation. Marginal migmatisation of the adjacent country rock is manifest by the density of the vein phases. These G2 granites tend to be concentrated in relatively narrow north–south belts of intense Barsaloian deformation.

In thin section, a granite from the Ewaso Narok 're-entrant' is seen to be composed of about 50 per cent quartz, 25 per cent microcline, 20 per cent microperthite and 5 per cent oligoclase, with only a small amount of accessory magnetite. Bands which are internally xenomorphic-granular have sharp margins, indicating cataclasis, with a proportion of fine-grained feldspar and quartz.

Foliation and intrusion is regarded as synkinematic with D2, and the folding and cataclasis probably was concomitant with D4 (the Barsaloian phase).

4 Miocene sedimentary rocks

Small pockets of sediment, with volcanic intercalations, are exposed sporadically on the north-eastern margins of the Pliocene plateau phonolites in the east of the area, north of the Ewaso Narok River. These rocks underlie the phonolites and fill depressions in the sub-Miocene land surface. Exposures are not good due to the incompetence of the strata, and the scree cover derived from the overlying phonolites.

Shackleton (1946) indicated that the thickest development of these sediments is in the Kirimun area: they are therefore described here as the *Kirimun formation* (Tms^K).

The Kirimun formation is well exposed to the west of Kirimun village and north of the Palagalagi River: smaller outcrops are found in the Lake Kisima area, on the scarp slopes of phonolite flows, notably north of Nkoteyia stream, in a road cutting on the Maralal–Wamba road, and in the Kelele River. To the east on the Isiolo sheet (Hackman and others, in press) similar sediments outcrop in the Barsalinga area and to the north on the Suari Plains.

These rocks are exposed below the phonolite escarpments, particularly in gullies formed by run-off from the volcanic plateaux. Volcanic scree usually obscures the upper parts of the sequence.

Outliers of the Kirimun formation are distinctive on aerial photographs as white patches with high reflectance: the boundaries on the geological map are based entirely on the photogeological interpretation.

Reference sections, in neither case comprising complete sequences, may be detailed as follows (Figure 12):

1 Due east of Kirimun township on the south-west scarp slope of phonolites at GR 2664 0802.
2 North of the Palagalagi River, on the eastern scarp slope of a phonolite tongue which parallels the course of that river. An east–west gulley at GR 2642 0699 provides good exposures.

Fossil Content: amongst other unidentified vertebrate remains Shackleton (1946) recorded the following from the Kirimun area:

Deinotherium hobleyi Andrews
Mastodon sp.
Chelonian scutes
Crocodile vertebrae

The age of the Kirimun formation, based on this fossil evidence, is deemed to be Miocene.

The Kirimun sediments are sandwiched between the basement and phonolites of the Rumuruti Group. The reference sections show intercalations of volcanic rocks, heralding the subsequent extrusion of large volumes of plateau phonolite, which are also dated as Miocene.

The maximum thickness of these sediments, from the section east of Kirimun, is about 30 m. The deposits are wedge-shaped and laterally they thin rapidly. To the north, in the Lake Kisima area, sections indicate thicknesses of only a few metres.

Figure 12 gives details of measured sections at the two reference localities. The lithologies are very varied, including sepiolite, white clays, diatomite, marls, shales,

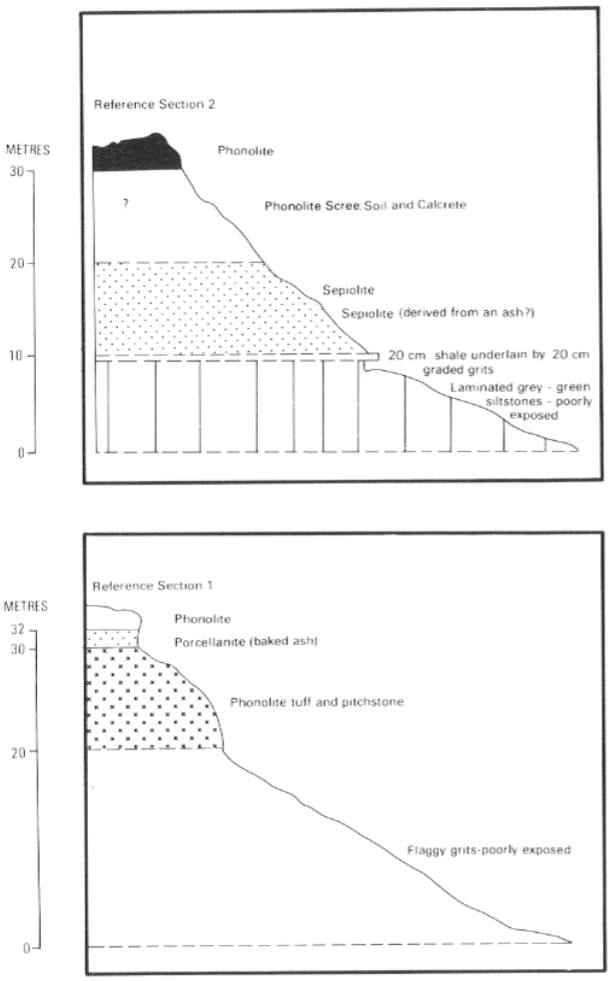


Figure 12 The Kirimun Formation—reference sections

vesicular tuffs, striped yellowish chert, laminated grey-green siltstones, graded grits, and grey calcareous gravels. Much of the sediment is poorly cemented and incoherent.

The following sequence is detailed from the first reference section:

	m
Top Phonolite	
3 Striped porcellanite (baked ash) layer	2
2 Black vesicular tuff and pitchstone	c.10
1 Poorly exposed sediments, including grits, marls and clays	c.20

The basal sediments are covered by a white calcareous soil with gravel beds containing calcrete, quartz and feldspar fragments up to 3 cm long. Locally quartz-rich flaggy grits, marls and silicified arkoses are exposed.

In the overlying volcanic layer there is a very weathered

fine-grained black pitchstone with oval grey-brown amygdales up to 0.7 cm long and forming c.10 per cent of the rock volume. Associated with this pitchstone is a scoriaceous variant, about 50 per cent of which is composed of tube-like amygdales of the same grey-brown material. Shackleton (1946) also recorded a pumiceous lapilli tuff from this area. The upper porcellanite, forming a continuous horizon at that locality, is an attractive olive-green to brown yellow, cryptocrystalline rock with a regular lamination of thickness c.1 mm. One thicker (2.7 cm) seam contains flattened ellipsoids of colourless material aligned parallel to the laminations.

The section in the Palagalagi valley showed the following sequence:

-Upper beds masked by soil derived from overlying phonolites.

	Thickness m
4 Sepiolite	10
3 Shale with concretions	0.2
2 Graded grits	0.2
1 Laminated grey-green siltstones (poorly exposed)	c.10

The grits (2) are normally graded, with coarser units containing subordinate layers of laminated shales. The overlying shales are pale yellow grey, with fine colour laminations and intercalations about 1 cm thick of somewhat coarser grit: they contain round concretionary structures. The sepiolite above that is massive, but poorly exposed: it is a fine-grained, yellowish grey homogeneous rock with crystal laths.

A thin section of a coarse poorly sorted grit, stained by iron hydroxides, from the Lake Kisima area revealed angular fragments of quartz, microperthite, plagioclase and chalcedony.

The Kirimun sediments appear to fill gullies eroded into the 'basement' surface. The graded beds indicate a shallow water deposition, probably fluvial, during the relatively wet Miocene period. The upper porcellanite and sepiolite units are thought to be altered ash deposits. The ashes at the reference section east of Kirimun have been baked by the superjacent phonolites. To the south in the Palagalagi valley, the sepiolites are separated from the phonolites and are not baked.

5 Cenozoic volcanics

At the time of writing (early 1986) no accounts had been published to establish formal stratigraphic nomenclature, on modern lines, for the complete volcanic sequence of this section of the Gregory Rift. Many of these units were introduced in the course of mapping by EAGRU: the following descriptions are not intended to formalise the stratigraphy—that awaits publication of the EAGRU data. A very large number of informal local names have been introduced into the literature, both published and unpublished.

The various volcanic units can be grouped into major suites commencing with the Miocene Samburu basalts at the base, on the eastern side of the Rift. These basalts are everywhere overstepped to the east by an extensive sequence of plateau phonolites, the Rumuruti Group, and, in the inner western margin of the Rift, by more diverse sequences of localised volcanics ranging, petrographically from alkali-basaltic to trachytic or phonolitic. The youngest central type volcanoes, Korosi and Paka, dominate the northern half of the median rift in this area.

The suites, broadly conceived on the lines of the 'volcanic groups' of King and Chapman (1972) are depicted in Table 2: the essential formations shown on the 1:250 000 map have been integrated into this scheme with the object of providing a framework for the systematic stratigraphic descriptions which follow. Numbers of relevant paragraphs in this report are indicated on the table.

An essential addition has been introduced to the system of King and Chapman (1972), in that Group II includes a division 'b' for sequences of phonolite trachytes (and phonolites) with subordinate basalts, of probable late Miocene age, which share sufficient features in common to justify such a grouping.

The petrographic terminology, of phonolites, trachytes and of rock types intermediate between these two terms generally follows Chapman (1971a & b).

5.1 SAMBURU BASALTS (Tmvb^{SM})

Shackleton (1946) coined the name 'Samburu Series' for the 'red and purple tuffs' and 'porphyritic basalts' underlying the phonolites of the Laikipia–Losiolo areas to the west of the escarpment. McCall (1967), under this heading, used the term 'Samburu Basalts', which has continued in informal usage by others such as Chapman

Table 2 Cenozoic volcanic associations

	Volcanic Group	Main Components	Subordinate Components	Western Shoulder	Median Rift	Eastern Shoulder	Laikipia Plateau	Southern Laikipia
Pleistocene–Recent	V b	trachyte/basalt central volcanoes (5.8)			Paka Volcano Korosi Volcano and Ol Kokwe			
	V a	flood trachyphonolites and trachytes (5.7)	basalts	Baringo basalts Baringo Trachyte Loyamarok Trachyphonolite Chemakilani basalts Murgusian basalts	Molo tuffs Koitumet basalts Jorokokwa phonolite Hannington Trachyphonolite Formation Kwaibus basalts Emsos mugearites	Mukutan and Mistoni mugearites Karau volcanics Chepchuk volcanics Chesowanja basalt		
Pliocene	IV	trachyte shield (5.6) volcanoes	basalts, sediments	Jamakana Formation Lokwaleibit basalts		Kokwapang'a basalt Orus Trachyte		Laikipian Formation
	III	basalts (5.5)	trachytes	Kaparaina basalts		Narokwe basalts		(Sirrima basalts)
Miocene	II b	phonolitic trachytes (5.4)	basalts			Tasiokwank and Iguamiti phonolitic trachytes	Losiolo Phonolites and Sipili trachytes	Thomson's Falls phonolites Pesi River basalts
	II a	phonolites (5.2)	trachytes, basalts			Alengerr tuffs Komol volcanics Katomuk tuffs Lopet phonolites Murgomul volcanics	Rumuruti Group phonolites (5.3)	
	I	basalts (5.1)	trachytes, phonolites			Sabit trachyte Samburu basalts		

and Brook (1978), for the oldest sequences of alkali basaltic and basanite rocks in the rift.

In King and Chapman's (1972) numerical system, the Samburu Series was included under Group I basalts, comprising also the Elgeyo Volcanics of the upper Kerio valley (Walsh, 1969) and the Kapchererat Basalts of the Tiati Hills area (Mason and Gibson, 1957). Griffiths (1977) referred to these rocks as the Samburu Basalt Group; but he questioned their correlation with the Simbara Basalts of the Aberdare Range on the basis of Pliocene dates quoted by Baker and others (1971).

The Samburu basalts outcrop in six separate areas on this degree sheet, on the west side of the Miocene phonolite fault escarpments (Figure 13), featuring both eruptive centres and 'plateau' lavas.

1 The Chembalao Shield (Golden, 1978), in the north, the largest of the outcrops, forms the foundation of the Amaya Embayment.

2 The Aruru Shield (Tangulbei Formation, centred on Katakan, and including Sabit (Carney, 1972), outcrops as a N–S strip on the eastern edge of the Mukutan Trough, extending from Tangulbei for 25 km to the south. To the north of Tangulbei (36°20.5′E: 0°54′N) there are two small outcrops of more alkaline basalts designated as the Siaris basanites ($Tmvb^{SM'}$).

3 The Morilo Shield (Morilo Formation, Carney, 1972), 10 to 20 km SE of Lake Baringo, forms a complex of faulted N–S ridges on the watershed between the middle Ol Arabel valley and the Mukutan Trough. It includes the Chepkenyon and Ngarama centres, with dyke swarms and associated plateau lavas. The hill Ramaja (Ramacha) offers a good sequence of the basalt flows.

4 The Ngusero area (Ngusero Formation, Griffiths, 1977) includes the outcrops of the Ngusero and Kahone escarpments, also the Moera Escarpment, a northern extension of the Kahone.

5 The Waseges and Siracho (Hannington) Escarpment (Bogoria Formation, including also the Ki'mai Centre of Griffiths).

6 Miscellaneous scattered linear strips of doubtful status, in the Upper Waseges valley, and between Solai and the Subukia valley (McCall, 1967).

In contrast with the overlying phonolites, the Samburu basalts give rise to fairly rugged, variable terrain on the western flanks of the main Laikipia Escarpment. They register clearly as strips of darker tone on the Landsat imagery.

Detailed correlation between the separate outcrop areas has not yet been established on the basis of age determinations. Shield-like eruptive centres have been identified by Carney (1972), Griffiths (1977) and Golden (1978): they feature abundant intrusives and pyroclastics, and are presumed to be the source areas for the plateau basalts. Rapid variations in thickness and lithology are to be expected, in a complex terrain where the products of adjacent shields interdigitate, and the density of dykes varies considerably.

The Aruru area best demonstrates the original basaltic shield form: the 'plateau' flows, after adjustments have been made for later northward tilting, can there be shown to dip radially at about 4° away from Katakon Hill, a source area featuring abundant pyroclastics and minor intrusives. Since the base of the Samburu basalts has nowhere been seen on the ground, thicknesses estimated from local sequences must be regarded as minimal.

In the south McCall (1967) thought the Samburu basalts to be well over 300 m thick, whereas Griffiths con-

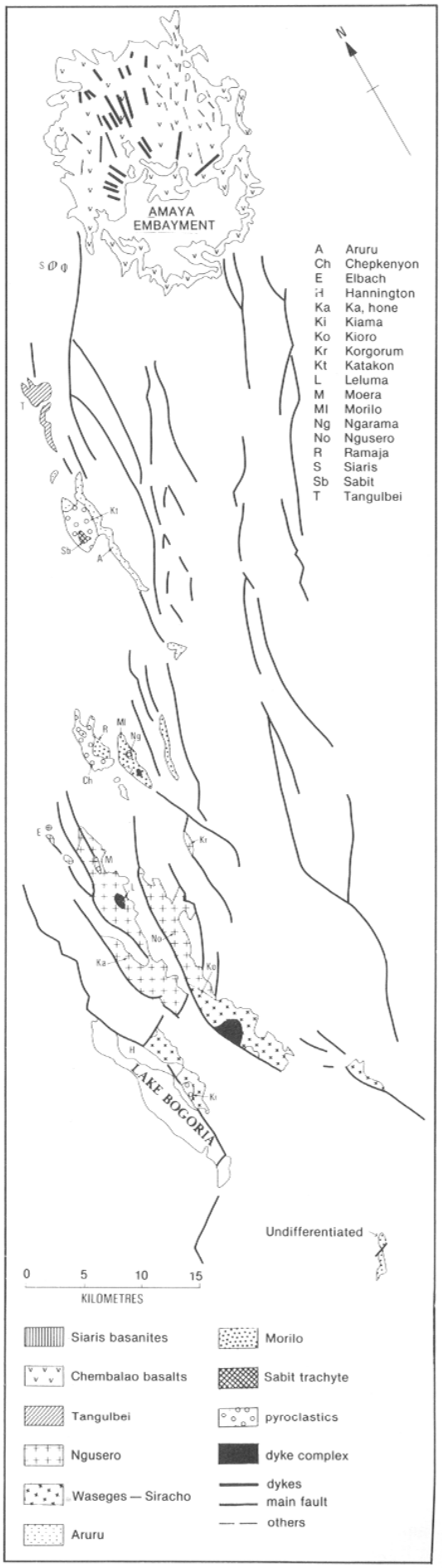


Figure 13 Distribution of the Samburu basalts

sidered the whole sequence to be at least 1070 m: he quotes the following thicknesses for specific areas:

Ki'mai	460 – 550 m
Hannington	850 m
Moera – Kahone	610 – 760 m

Further north Carney estimated the Morilo – Ngarama horst plateau lavas to range up to 425 m, the Aruru 'plateau' basalts up to 300 m, with a thinner sequence (down to 60 m) of ankaramitic basalts south of Tangulbei. In the Amaya Embayment Golden (1978) suggested a total original thickness of 1000 to 1200 m, but local sequences vary from 290 m north of Tangulbei to about 550 m.

Individual flows generally vary from 1 to 30 m in thickness.

Age determinations provided by the EAGRU project indicate an Early to Middle Miocene range:

Ki'mai (Naryongche River: feldsparphyric basalt)	11.8 ± 0.5 (doubtful)
Aruru Shield (Sabit trachyte)	14.2 ± 0.4
Tangulbei basalts (but a date of 11.6 ± 0.1 Ma for the *underlying* basalts was not acceptable).	pre 13.5
Chembalao Shield (Sesyon Hill, analcime-hawaites)	16.1
Kioro (mugearite)	20.7 ± 0.6

The Samburu basalts are exposed along a NNE-trending flexure, the Samburu Monocline, which defines the eastern margin of the rift. In the Baringo – Bogoria section this monoclinal structure passes south into a series of high-angle normal faults, which are displaced by faults trending NW, accounting for the *en echelon* aspect of the array of basalt outcrops (Figure 13).

McCall (1967) commented on the unusually high angle of eastward dip in the Samburu basalts, i.e. 10 – 35°, and exceptionally, near Subukia, 70°. The main sequences dip gently away from the principal faults, in a regular manner to the east. Radial dip patterns around zones of concentrated intrusion cannot be identified except in the case of Aruru, but there are marked variations in dip near those centres.

The base of the Samburu basalts is not seen in this area: in the Tirrtirr area west of Baragoi (Key, 1987), 90 km to the NE, they rest unconformably on metamafics and migmatites of the Mozambique Belt, Under the rift, the base of the unit is not shown on geological sections; the basement is not believed to be higher than about 300 m above sea level. To the east the Rumuruti Group phonolites overstep the Samburu basalts: the former rest on the basement on the west side of the Ewaso Ng'iro valley.

Very detailed petrographic descriptions of the Samburu basalts are available from Carney (1972), Golden (1978), Griffiths (1977) and Sceal (1974). For the purposes of this account the rocks may be considered under three headings; lavas; pyroclastics and intrusives:

Lava flows, or 'plateau sequences'

The lava types range broadly from picritic through mela-basanite and melabasalt, basalt, ankaramite and tephrite, to mugearite, hawaiite and minor trachyte/trachyphonolite.

Basanites, olivine-basalts and hawaiites (with or without analcime) dominate the sequence in many areas, especially Chembalao: ankaramites are common in the south, notably Waseges (where they feature glomerophyric titanaugite), Ngusero, and the lower part of the sequence at Ramaja Hill (Morilo area), also Aruru, where flows of vesiculated ankaramite are associated with olivine and pyroxene-phyric basalts, steeply dipping on the west slopes of Katakon.

Feldsparphyric basalts are common in the Waseges area, also towards the top of the Chembalao sequence, but are rare in the Ngusero area, where aphyric basalts, melabasanites and ankaramites predominate.

Mugearites and hawaiites are common towards the north, on the escarpment south of Tangulbei, also in parts of the Chembalao Shield: in both places they are notably porphyritic in kaersutitic amphibole. Sceal (1974) recorded three flows of nephelinite/basanite in the face of the escarpment near Siaris (GR 052 985), showing fine columnar jointing.

The *Sabit Trachyte* ($Tmvt^{SB}$) occurs as five small outliers mapped by Carney unconformably overlying the basalts of the Aruru Shield: they include saturated and phonolitic trachytes, the latter with sparse microphenocrysts of analcitised nepheline. The texture of these rocks is typically eutaxitic, with laths of sanidine and anorthoclase sub-poikilitically enclosed in aegirine-augite aggregates.

A date of 13.5 Ma is quoted for these trachytes, considered to represent a late extrusive phase from the Katakon Centre. At the top of the Chembalao sequence Golden also recorded two flows of anorthoclase-phyric trachyte at Sosyon (GR 235 058).

Xenoliths of pyroxenite and gabbro commonly occur in basanites and hawaiites in the most deeply eroded levels of the Chembalao Shield basalts. Peridotite xenoliths feature in the porphyritic or sparsely phyric basalts in upper parts of the lava sequence at Ramaja (Morilo area) and Katakon.

Pyroclastics

Pyroclastic sequences are believed to indicate proximity to the original 'central' extrusive complexes, and by analogy with multicentre shields east of the rift shoulder, may represent the latest phases of volcanic activity. Associated dyke swarms may also be significant; areas of high density intrusives perhaps correspond with essential Miocene subvolcanic 'plumbing'.

Four major areas of pyroclastics are noted here: Ki'mai (on the east side of Lake Bogoria), Moera (north of the Kahone Range), Chepkenyon (Morilo) and the Katakon centre of the Aruru Shield.

At Ki'mai the thickness of pyroclastics (predominantly basaltic agglomerates and tuffs), and the density of dykes, increase downwards in the succession to about 550 m in the Naryongche River section (GR 798 288).

In the Morilo area the pyroclastics feature incoherent yellowish red tuffs and crystal tuffs with amygdaloidal zeolite.

Sceal noted agglomerates and tuffs (associated with possible diatomites) overlying 12 m of red laterite north of Tangulbei at the top of his 'Tangulbei Basalt' sequence.

Minor intrusives

Dykes are particularly associated with the above mentioned pyroclastic zones and are concentrated with other intrusives in the Waseges area, at Lelumwa, Ngarama and Chepkenyon, in the Katakon centre and in parts of the Chembalao Shield.

In the Ki'mai centre numerous ankaramite and pyroxene-phyric basalt dykes up to 3 m thick trend NNW, inclined westwards at 65 – 90°. In contrast, on Waseges to the east, the dykes are mostly thinner, trending NNE and inclined to the east: there ankaramites predominate, also feldsparphyric basalts.

To the north dyke-swarms associated with the Lelumwa, Moera and Chepkenyon centres trend generally N–S, but not consistently: they include ankaramites, melabasanites, mugearites and lamprophyres. Two dykes in the Kahone Range (GR 802 400) are nearly 50 m thick. Plugs associated with the Lelumwa and Ngarama centres are ankaramitic; also at Ngarama there is a plug of aphyric melabasanite with ocelli of analcite, zeolite, biotite and alkali feldspar, and a high content of augite and ore.

In the Aruru area a 6 m wide ankaramite dyke trends NE, and is cut by a later swarm of aphyric basalt dykes trending NW.

The dyke swarm in the centre of the Chembalao Shield tends to be arranged radially with respect to the Murgomul Syenite (Section 7.1), but with a N–S bias. Golden noted that in this area salic rocks occurred more abundantly as intrusives than as flows—particularly mugearites (in a swarm just north of Murgomul), phonolites and trachytes. At Nasur (GR 172 017) he found an example of one of these dykes acting as a feeder to a flow.

Baker (1965) and McCall (1967) proposed that the Samburu basalts were extruded in a primitive down-warp or 'proto-graben', which was arched upwards during or after eruption giving rise locally to steep easterly dips.

Williams (1978) described the Quaternary multicentre basaltic ranges east of the Rift Valley: the Miocene shields such as the Chembalao may have developed in a similar fashion.

Petrochemically the Samburu basalts are a sequence of alkaline to highly alkaline rocks predominantly of mafic composition, but including also intermediate types.

Golden (1978) pointed out that the TiO_2 content of the Samburu basalts is higher than that in the younger basalts in the Rift succession—TiO_2 decreases progressively with time. Griffiths (1977) considered from evidence of trace element distribution that magma of basanitic type, characteristic of the Samburu basalts, could have given rise, by crystal fractionation, to the overlying Miocene phonolites. Carney (1972) provided petrographic data to show that phenocryst assemblage changes in lavas of mugearitic-hawaiitic composition could account for apparent discontinuities in the plots of constituents against 'solidification index'. Carney (1972) and Golden (1978) also discussed in detail the significance of kaersutite, in basic and intermediate rocks, in relation to pressure conditions in a hydrous system during the eruption process.

The ocelli in the Ngarama melabasanites were attributed by Carney to reaction between mafic host lavas and feldspathic xenoliths.

5.2 MIOCENE VOLCANICS OF THE INNER EASTERN RIFT SHOULDER

North of the Mukutan trough (the Tangulbei area) Miocene volcanics, in which thick pyroclastics are separated by two sequences of lava (basaltic, phonolitic and trachytic), crop out in the watershed area between the Komol and Amaya rivers, between the Paka volcanic massif and the Amaya Embayment.

In this area, conveniently designated as the Orus 'salient' of the 'inner eastern rift shoulder', the rather complex sequences were mapped, in the west by Sceal (1974) and to the east by Golden (1978): different groupings of the stratigraphic components by these two authors, sometimes using different names, has left a somewhat confusing picture in parts of the sequence. Pyroclastics form an important part of the sequence, which might be interpreted as the south-eastern sector of the 'proto-Silali' volcanic pile (Williams and Chapman, 1986).

For the purposes of compiling the 1:250 000 geological map it was necessary to simplify the stratigraphic column detailed on the 1:125 000 EAGRU map (Truckle, 1977): the essential elements of the scheme are summarised in Table 3.

Murgomul volcanics ($Tmvtp^{MR}$)

Trachyphonolites and ignimbrites (b^2, EAGRU) dip steeply off the northern flanks of Murgomul Hill (GR 2155 1000): the outcrop covers only about 4 km^2. No contacts with the syenites of the Murgomul plug (Section 7.1) are exposed, and the lower distal positions of the flows flatten out, resting almost conformably on the surrounding Samburu basalts. The sequence is about 100 m thick. No age determinations are available.

The lowest exposed flow in the sequence appears to be an olivine-analcime-hawaiite, resembling the rocks of the outermost zone of the Murgomul syenite intrusive. It is overlain by thin flows of pale weathering trachyphonolites, phonolitic trachytes and ignimbrites, capped by phonolitic welded tuff with conspicuous fiamme.

Various interpretations have been suggested for the relationships of the Murgomul volcanics with the surrounding rocks:

1 The volcanics are remnants of the superstructure of the Murgomul volcano, the intrusive plug for which is represented by the Murgomul syenite. (Golden, 1978).

2 The Murgomul volcanics were draped over a syenite complex which was exposed by deep erosion of the Chembalao Shield, i.e. juxtaposition of phonolites and syenites was fortuitous.

Such a situation might be linked with the possibility that:

3 Extrusion of the Murgomul volcanics was broadly synchronous with eruption of the Katomuk and Alengerr tuffs (15 to 9 Ma), which in part they resemble petrographically.

4 The Murgomul Volcanics are a localised intercalation within the Samburu basalts.

Williams (personal communication) has raised various objections to each of these proposals, based mainly on consideration of difficulties related to erosion and exhumation of the different rock units in the Murgomul area, particularly the Samburu basalts. In the absence of age determinations, and in view of the isolation of the Murgomul sequence from similar volcanics to the west, doubt still attaches to their status.

Lopet phonolites ($Tmvp^{LP}$)

The Lopet phonolites are named from the Lopet Plateau, 40 km north of Maralal on Degree Sheet 27: the term is used here in preference to the 'Losiolo Formation' of Truckle (1977), because Shackleton (1946) used the term Losiolo phonolites for a different sequence, described in Section 5.4. Williams and Chapman (1986) have renamed the sequence described here 'Losuwo' after a locality 38 km NNE of Churo: unfortunately that locality is not on the outcrop of the Lopet phonolites as described by Key (1987). Golden (1978) referred to this sequence as the Losiolo Trachyphonolites, which, on the basis of petrologic affinity, he bracketed with the overlying

Table 3 Miocene volcanics of the Inner Eastern Rift

Golden, 1978		EAGRU		SMP	
North	South	1:250 000 map (Truckle, 1977)		1:250 000 map: Sheet 35	
Kawetachom tuffs		Alengerr basalt	ca^3		
		Losogol tuffs	ca^3	Alengerr tuffs	$Tmvt^{AE}$
		Alengerr tuffs	ca^1		
	Geleamoi trachytes	Malemtik phonolite	b^7		
		Seronut Formation (Sceal, 1974)	b^6	Komol volcanics	$Tmvb^{KM}$
	Lotodo basalts	Komol Formation (Sceal, 1974)	b^5		
		Katomuk tuffs	b^{4a} b^4	Katomuk tuffs	$Tmvt^{KT}$
		Losiolo Formation	b^3	Lopet (Losuwo) Phonolites	$Tmvp^{LP}$
				Murgomul volcanics	$Tmvt^{pMR}$

pyroclastics (the Kawetachom Tuffs, including the Katomuk and Alengerr Tuffs), as the 'Losiolo Group'.

The outcrop of the Lopet phonolites frames the Samburu basalts of the Chembalao Shield on the western side, bounding the Amaya Embayment: they extend beyond Degree Sheet 35, to the north, for some 50 km along the eastern rift shoulder, and are contiguous with the phonolites of the Lopet Plateau north of Maralal. In this area they form a N-trending ridge about 12 km long, breached by the Amaya River and its tributary the Nasur.

Three age determinations on specimens from the Lopet phonolites to the north of the area gave consistent results (15.0 ± 0.4, 15.1 ± 0.4, 15.2 ± 0.4 Ma, i.e. Lower–Middle Miocene.

The Lopet phonolites rest unconformably on the Samburu basalts east of the Lacheriakosowa valley (36°21–23′E: 0°57–58′N), but no appreciable thinning is demonstrable against basalts.

Golden (1978), maintained that the Katomuk tuffs conformably overlie the Lopet phonolites: however Williams (personal communication) considers that on the eastern side there is evidence of a major unconformity where Katomuk tuffs rest directly on Samburu basalts.

The trachyphonolites are about 180 m thick in the Lacheriakosowa valley: they thin southward, towards Tangulbei, and disappear on the south side of the Amaya Embayment, pinched out by overlap of the Komol volcanics and the Rumuruti Group phonolites. In the area to the north-east of Maralal they thicken to over 750 m.

The Lopet lavas are mainly trachyphonolites and phonolites, although there is a range from analcime-mugearites to trachytes. At higher altitudes they develop a white weathered crust, but in the dry valley they are coated with a reddish brown desert varnish.

The general appearance, of aphanitic, rather fissile, green-grey lavas, is very uniform in the field: they may be sparsely porphyritic in anorthoclase, but without prominent nepheline.

The Lopet phonolites differ from the Rumuruti Group volcanics in the absence of flinty or mottled varieties, whereas such features are specific for the Losiolo phonolites of the Loroki Plateau (Section 5.4).

In hand specimen the phonolites, trachyphonolites and trachytes all appear similar, fissile dark green rocks, and cannot be distinguished macroscopically. Under the microscope they appear to consist of tightly packed laths of alkali-feldspar, with microphenocrysts (often in glomerophyric clusters) of anorthoclase, fayalite, ferroaugite, apatite and opaques. Aegirine-augite occurs interstitially, also aenigmatite, arfvedsonite and biotite.

Whereas trachytes have little or no nepheline, the phonolites carry up to 35 per cent, and also have interstitial kataphorite, analcite and/or zeolites. Less abundant mugearites may be flow-banded, in part with spherulitic texture, with microphenocrysts of oligoclase, ferroaugite and apatite.

Thin flows of phonolitic ignimbrite feature angular fragments of partly devitrified glass, and mottled light green fiamme in a dark greenish grey, flinty, flow-banded groundmass, partly composed of devitrified glass.

Katomuk tuffs ($Tmvt^{KT}$)

This formation comprises phonolitic ignimbrites overlain by unwelded pyroclastics and tuffaceous silts. It extends in a strip up to 6 km wide, north-north-east from the west side of the Amaya Embayment for a distance of about 60 km along the inner eastern rift shoulder.

The reference locality is Katomuk Hill on GR 36°23′E only 0.5 km north of the boundary of Degree Sheets 27 and 35. Golden (1978) and Sceal (1974) gave detailed descriptions of sequences in the Kukwachaiya (36°21′E: 0°55′N) and Nabwanget areas (36°22.5′E: 0°54′N) at the southern end of the chain of outcrops.

Gravels near the base of the formation at Nabwanget yielded teeth of *Dicerorhinus* and *Gomphothere* (Sceal, 1974). Under the uppermost white beds, soils contain many silicified tree trunks. The fossil teeth indicate an Upper Miocene age.

The thickness of the Katomuk tuffs is about 150 m in the north, but thins to about 50 m at Nabwanget.

In most of the area the ignimbrite sheets are nearly horizontal, although local tilting of fault blocks may have occurred: however, a regional dip of about 5° to the west is inferred to explain the non-appearance of the formation

to the east. Unconformity can be demonstrated at the base of the Katomuk tuffs in the Nabwanget area, where they rest directly on the Samburu basalts.

The ignimbrites are striking dark greenish brown flinty rocks, with flattened fiamme and angular lithic fragments, mostly of trachyphonolite, but also syenite and glass.

Friable tuffs and volcaniclastic sediments frequently form earth pillars: some white beds appear diatomaceous, but have not in fact been proved to contain diatoms. Golden described certain features in these tuffs as raindrop lapilli.

The ignimbrites feature numerous phenocrysts of alkali feldspar, nepheline, aegirine-augite and biotite, also, less commonly, fayalite and plagioclase; often the phenocrysts form glomerophyric clusters, usually in part resorbed. Towards the top of the Katomuk tuffs the proportion of unwelded tuffs, lapilli-tuffs and agglomerate increases: most of the lithic fragments are petrographically similar to the Lopet Phonolites. Occasional thin lava flows are of analcite trachyphonolite and zeolite mugearite, some with kaersutite microphenocrysts.

Komol volcanics ($Tmvb^{KM}$)

The term Komol Volcanics here subsumes three EAGRU units (Truckle, 1977)—the Komol Formation (b^5), Seronut Formation (b^6) and Malemtik Phonolite (b^6) (see Table 3). On the 1:250 000 geological map it was considered expedient to combine the first two formations, partly because they are both complex sequences of basaltic trachytic and phonolitic lavas, but they also appear to interdigitate south of Jarota, at 36°19.5′E: 0°51.5′N.

Sceal (1974) and Golden (1978) differed over details of the sequence, which are in any case of too local significance for the 1:250 000 scale. The Malemtik Phonolite itself is also too small to be shown on that scale.

The Komol Volcanics concept is in line with Golden's notion that the combined Komol and Seronut lavas form a shield within the pyroclastics, which he called the Kawetachom Tuffs.

Sceal (1974) introduced the name Komol Formation (EAGRU b^5) for the lava sequence in the Kukwachaiya–Nabwanget area, and assigned to the unconformably overlying Seronut Formation (EAGRU b^6) a pile of deeply weathered lavas of 'mugearitic' appearance, with trachyte/trachyphonolite intercalations near the base. The lower, more mafic part of the lava sequence was mapped by Golden (1978) as the 'Lotodo Basalts': his overlying 'Geleamoi Trachytes' are equivalent to the upper phonolitic–trachytic part of the Komol Formation as well as the whole of the Seronut Formation. The name Malemtik Phonolite (EAGRU b^7) was given to a phonolite flow which rests unconformably on Seronut Formation lavas at Naitai (36°18.5′E: 0°57.5′N).

The Komol Volcanics form a series of composite ridges, trending north 15 km from Seronut to the northern boundary of Degree Sheet 35, in part obscured by outcrops of overlying Alengerr Tuffs and the Orus Trachyte. Molgoltwa is a prominent hill, over 1560 m, rising 100 m above the Kokwapang'a Plain which is floored by the Orus Trachyte: outcrops also underlie the Rumuruti Group phonolites southward along the escarpment as far as Tangulbei.

The following succession has been detailed, largely by Sceal (1974) for the southern outcrops:

		Thickness m
7	Deeply weathered mugearites, with intercalated trachytes and phonolites near base.	?
6	Dark flinty trachytes and phonolites	120
5	Porphyritic phonolites	90
4	Mugearites	75
3	Olivine-basalt/hawaiite	12
2	Porphyritic mugearite	23
1	Deeply weathered mugearites	60

Sceal (1974) thought that a sequence of lavas he called the 'Molgoltwa Trachytes' underlay this succession: however Golden (1978) considered them to post-date the Komol Formation.

Unconformities in the sequence detailed above were noted between units 4 and 5, and between 5 and 6.

The following concordances should also be noted:

Units 1–4 = Lotodo Basalts (Golden, 1978)
Units 1–6 = Komol Formatio:., c.365 m (Sceal, 1974)
Units 6–7 = Geleamoi Trachytes (Golden, 1978)
Unit 7 = Seronut Formation (Sceal, 1974)

Ten specimens from the Komol Formation (4 basalts, 3 hawaiites, 1 mugearite, 1 trachyte and 1 phonolite) gave a range of ages from 11.9 ± 0.2 to 15.8 ± 0.3 Ma. For various reasons Golden considered that dates in the range 13.6 to 14.2 Ma (Middle Miocene) were acceptable.

Six specimens from the Seronut Formation were dated to range from 10.3 ± 0.3 to 13.4 ± 0.3 Ma (Middle to late Miocene). A specimen from the Malemtik phonolite gave a date of 13.9 Ma. Sceal suggested that this result, older than values for the underlying Seronut Formation, was due to assimilation of xenoliths from the earlier porphyritic phonolites.

In spite of the differences between Golden and Sceal over stratigraphic details and the placing of unconformities, in the south the Komol Formation overlaps the Katomuk Tuffs towards the east, which Golden attributed to progressive monoclinal downwarping during the Upper Miocene, also the Seronut Formation oversteps both these older formations to rest on the Samburu basalts.

Sceal found some evidence that the porphyritic phonolites (Unit 5, above) of the Komol Formation might have been extruded from a centre west of Molgoltwa, at about 36°19′E: 0°55.5′N. Some of the flows in the upper Komol valley were apparently extruded from fissures: two dykes recorded here expand into tholoid structures.

The mugearites of the Komol Volcanics are often poorly exposed, altered to brownish green or purple rocks, but with a trachytic or vesicular appearance still discernible, sometimes with calcite and zeolites in amygdales: they are sparsely porphyritic but may have abundant green pyroxene microphenocrysts.

The more resistant trachytes (in the upper part of the sequence) are usually black, aphanitic rocks with sparse feldspar, green pyroxene and amphibole phenocrysts: nepheline is rare, but analcite is common in the groundmass.

The hawaiite described by Sceal contains numerous phenocrysts of augite, also olivine (often enclosing biotite), set in a black groundmass which contains andesine.

The porphyritic phonolites display abundant phenocrysts of anorthoclase, nepheline, zoned green pyroxene and xenocrystal kaersutite. Analcite is abundant in the groundmass.

Alengerr tuffs ($Tmvf^{AE}$)

At Alengerr Hill (Ol Doinyo Lengere, c.1400 m, 36°19′E: 0°59.5′N) lavas of the Seronut Formation pass up into a sequence of phonolitic pyroclastics, designated the Alengerr tuffs (C^{a1}) on the EAGRU map. Basanite lavas capping Alengerr Hill, named the *Alengerr Basalt* (C^{a3}) are here included with the Alengerr tuffs, as the outcrop is too small to be outlined on the 1:250 000 map. A small outlier of the basalt also caps Chawit (1400 m) 3 km south of Alengerr Hill.

A mugearite from the southern side of Alengerr Hill was dated at 10.6 ± 0.8 Ma: Golden (1978) considered the date to be unacceptably young, however since the specimen possibly contained xenocrysts the determined age may be too old. King (1978) considered the Alengerr basalt at Chawit to be about 9 Ma old, probably on the basis of comparison with the Nasorut basalts at Lopogno, about 11 km north of Alengerr, dated at 9.41 ± 0.3 Ma.

Mugearites typical of the Seronut Formation interdigitate with basal ignimbrites of the Alengerr tuffs, whose upper members also locally overstep on to Seronut lavas. The Alengerr basalt dips gently westwards, with a slight unconformity at its base.

The Alengerr tuffs are about 270 m thick near the northern sheet boundary, and probably thicken northwards in the area of Degree Sheet 27. The Alengerr basalt is about 60 m thick on Chawit Hill, and 25 m thick on Alengerr itself.

Petrographically the lower parts of the sequence are pinkish brown to green flow-banded ignimbrites, interbedded with sparsely porphyritic trachyphonolites and phonolitic trachytes. Off-white rather incoherent phonolitic and trachytic tuffs and agglomerates dominate the upper part of the sequence. The Alengerr basalt is a basanite, porphyritic in pyroxene and olivine.

5.3 MIOCENE PLATEAU PHONOLITES: THE RUMURUTI GROUP

Shackleton (1946) named the 'Rumuruti Phonolites' of the Laikipia Plateau after the township of Rumuruti, the term 'Laikipian' having already been used by Gregory (1900) for the Plio-Pleistocene basalts of southern Laikipia. Shackleton also named the 'Losiolo Phonolites' of the Loroki area to the north from the escarpment 25 km north-west of Maralal, to the north of this map area: on his provisional geological map he did not separate these two sequences of phonolite, but in the course of remapping it has been found useful to retain and clarify the distinction between the Rumuruti (*s.s.*) and Losiolo phonolites: the latter are described in Section 5.4.

The name Rumuruti Group is employed here to cover all the Miocene plateau phonolites of the Laikipian region: younger extrusive formations, the Thomson's Falls phonolites and the Tasiokwank, Iguamiti and Sipili trachytes and phonolitic trachytes, clearly have some petrologic affinity with the Rumuruti phonolites, but are described in detail in Section 5.4.

The nomenclature of the Rumuruti phonolites was extended by various workers, in the course of which the significance of various subdivisions has changed somewhat. The sets of flows or subdivisions described by McCall (1967) in the south-west of the area have been used selectively by Carney (1972) and Golden (1978) further north in the faulted eastern shoulder of the rift. Sceal (1974) extended the concept of the Rumuruti Group to include other mixed volcanic sequences, such as the Komol volcanics, in the inner zone of the eastern shoulder: his usage is not followed here.

McCall (1967) emphasised that the earlier usage of such terms as 'Kenya' and 'Losuguta' type phonolites (Prior, 1903), which had a petrographic basis, could no longer be held to have any stratigraphic significance. Over 20 local names have been used to label phonolite types in Kenya (see also Campbell Smith, 1931; Williams, 1967; Lippard, 1973): however, several of these types may occur together within a single flow, simply as textural variations. Carney (1972) recognised three major sequences in the Rumuruti phonolites, each separated by an unconformity associated with a period of faulting; this became the basis for the subdivisions of the Miocene plateau phonolites according to Truckle (1977). Carney's scheme, based on detailed geological mapping on a 1:50 000 base also relied, to a certain extent, as did McCall's, on petrographic considerations, but in the context of more detailed groundwork in a limited area.

Bristow and Temperley (1964) in their groundwater assessment of southern Laikipia, added further to the nomenclature: the present survey has not, however, generally substantiated their proposals on the ground.

The essential unity of the Rumuruti phonolites as a group (including the Losiolo phonolites) is not challenged: remapping on a scale of 1:50 000 of the eastern and central parts of the Laikipia Plateau has demarcated a sequence of three, possibly four, major sets of phonolite flows, as well as the Losiolo sequence to the north. This broad scheme of revised nomenclature is here accepted as a basis for systematic description. Exact stratigraphic equivalence with Carney's three main subdivisions is not established, and is thought unlikely to be demonstrated if more detailed mapping is undertaken. In the central area (Rumuruti, *s.s.*) Charsley (1984) did not attempt to divide the group into formations as he felt that the subdivisions of Bristow and Temperley (1964) could not be confirmed on the ground, neither could the EAGRU (1977) scheme be confidently extended eastwards on to the central plateau. The structure is relatively simple in the eastern and central sectors of Laikipia, but few radiometric age determinations are available for that area: Carney's data were supported by age determinations but in a zone of extensive, complex faulting. Furthermore, the interdigitations of petrographic and textural varieties within a single flow sequence compound the uncertainties of relying on petrographic criteria.

It follows that the subdivisions elaborated on the accompanying 1:250 000 map represent a pragmatic compromise between different interpretations of the phonolite sequence.

Over most of the plateau areas the phonolites give rise to a rather monotonous landscape (Plate 5), relieved by a series of individual flow fronts which form minor scarp features, especially towards the eastern margins. On the intricately faulted eastern shoulder of the rift the plateau is bounded by a series of spectacular escarpments (see Section 2.1, Figure 4).

The Rumuruti phonolites everywhere rest with unconformity on the Samburu basalts, and appear to phase up into volcanics of 'Group 2b' type. Variations in thickness of the above subdivisions may be attributed not only to distance from eruptive sources, but also to the irregularity of the substratum on which the flows consolidated: for example, in the escarpment area, an episode of faulting separated R1 and R2.

The main subdivisions of the Rumuruti Group mapped

on the accompanying 1:250 000 geological map are detailed as follows:

Tmvp R5[1] Loiting Phonolites

R5 Losiolo Phonolites

R4 Upper Uaso Narok Phonolites	Upper	Rumuruti Phonolites
R3 Marmanet Phonolites		
R2 Lower Uaso Narok Phonolites	Middle	
R1 Ngelesha Phonolites	Lower	

Subdivisions R5 and R5′ are described in Section 5.4.

Lower Rumuruti phonolites (Tmvp[1])

NGELESHA PHONOLITES

McCall (1967) referred to the lowest lavas in the Rumuruti phonolite sequence as the 'Ngelesha phonolite flows' exposed in three different areas:

1 At the foot of the Ngelesha Escarpment east of Lake Baringo.
2 Overlying the Samburu basalts on the east side of the Wasages valley, 8 km east of Lake Bogoria.
3 North of the entrance to the Iguamiti River gorge, below the Marmanet Escarpment.

McCall described these phonolites as 'dark greenish black, compact and fine-textured lavas showing only sparse feldspar phenocrysts'. Vesicles are often filled with white zeolites, and are characterised by spheroidal weathering. Carney (1972) mapped these lowest lavas further north along the Ngelesha–Aruru Escarpment, and covering the plateau between the Mukutan gorge and the Amaya embayment. Referring to this sequence as the Ngelesha Formation (b^{7a} on the EAGRU map), composed of 'dominantly sparsely phyric types', Carney recognised four members:

4 Upper mottled aphyric phonolites (most widespread north of Mukutan gorge)
3 Bedded yellow lapilli-tuffs (primary air fall) c.3 m
2 Middle biotite phonolite (one flow, c.100 m in the Mukutan gorge)
1 Lower dark phonolites, with rare nepheline phenocrysts (two flows, c.240 m, at the base of the Aruru–Ngelesha escarpment).

Petrographically the lowest flows most resemble McCall's description: their dark, fissile appearance, and characteristic nepheline microphenocrysts are suggestive of trachyphonolites.

The 'mottling' of the upper flows is seen in thin section to result from the aggregation of groundmass mafic minerals into mossy poikilitic clumps, cf. the 'Kamasia' type of Prior, 1903.

Noteworthy is that the biotite of the second member, and the mottling of the fourth member are dominant characteristics of the overlying Uaso Narok and Marmanet formations respectively: clearly petrography of limited outcrops, in such circumstances, can be a fallible guide to stratigraphy, especially in faulted terrain such as the eastern shoulder of the rift.

On the eastern fringe of the Laikipia Plateau the lowest flows of the Rumuruti Group outcrop in two areas:

1 Between Mukenya and the Ewaso Narok valley.
2 Forming a platform west of Kirimun and Lake Kisima, and extending up the Ol Keju Losera valley abvoe Sukuta lol Marmar.

Discontinuous, and remote from the outcrops on the western side of the escarpment, the equivalence of these lower phonolites, or their continuity with the 'Ngelesha phonolites' as such, remains conjectural.

Key (1986b) describes the lowest flow exposed at Kirimun, in the north-east as a fine-grained, black, fissile phonolite, distinctive due to abundant vughs infilled by a white or yellow powder. The flow is covered by a bright red soil. Alignment of alkali feldspar phenocrysts suggest flow in an east–west direction: observations by Hackman (1986a) in the Ol Keju Losera valley above Sukuta lol Marmar suggest that the Lower Rumuruti phonolites flowed from the west-north-west.

The Ngelesha formation dips generally eastward at about 3–8°, although the plateau north of Mukutan gorge is stepped down by a series of antithetic faults (section BB′ on the 1:250 000 map).

Griffiths (1977) and Golden (1978) quote two radiometric dates from Ngelesha phonolites: one from Lokowabet (c.36°17′E: 0°44.5′N) gave 11.6 ± 0.29 Ma—the other (no locality recorded) was 10.8 ± 0.3 Ma. Supporting the correlation of the lower eastern marginal flows with the Ngelesha phonolites is a date of 12.0 ± 0.6 Ma from the lavas at Kirimun, at about 0°44′N, recorded in Baker and others, 1971.

Carney quotes a thickness of c.460 m for the Ngelesha phonolites in the Mukutan gorge: they thin rapidly to the west against the Samburu basalts. The lower Rumuruti phonolites are about 125 m thick at the eastern edge of the Laikipia Plateau.

According to Carney the tuffs outcrop only in the Mukutan gorge and in the adjoining escarpment areas: this, together with the greater thickness of the formation in that area, suggests proximity to an eruptive centre.

Middle Rumuruti Phonolites (Tmvp[R2])

LOWER UASO NAROK PHONOLITES

McCall (1967) described the Uaso Narok phonolites with reference to sections along the Rumuruti road about 13 km NE of Nyahururu, near the Ewaso Narok River.

As observed by McCall, the Uaso Narok flows show throughout considerable petrographic uniformity: characteristic is anorthoclase-phyric phonolite, with less obvious biotite flakes, set in a blue or dark green fine-grained matrix. Phenocrysts of aegirine and nepheline are occasionally observed.

Phonolites assigned to this sequence cover an extensive area of southern Laikipia and of the north-eastern part of the plateau around Ang'ata Werekoi: outliers also survive on the dissected Chembalao Shield . They form much of the faulted eastern rift shoulder between Ol Arabel and the Amaya embankment: in that area Carney (1972) designated a sequence of 'dominantly dark porphyritic biotite phonolites' as the Uaso Narok Formation.

Carney divided the Uaso Narok sequence into three units in the area of the Ngelesha–Aruru escarpments.

3 The upper mottled biotite phonolites—Upper Uaso Narok Phonolites.		
2 The middle dark biotite phonolites		Lower Uaso Narok Phonolites (b^{7b}) on EAGRU map)
1 The Lower tuffs		

The third, uppermost unit is described below as the Upper Uaso Narok phonolites.

The lower tuffs Carney described tuffs varying in thickness from 15 to 180 m in the Lokowabet–Tangulbei

area of the escarpment, between the Samburu basalts and the overlying biotite phonolites. They are mostly friable, fine-grained yellow tuffs, probably air-fall in origin, with calcareous concretions and mudcracks suggesting lacustrine conditions:

The dark biotite-phonolites are widely distributed throughout the outcrop: the flows are texturally uniform, of the 'Losuguta' type (Prior, 1903)—hand specimens are black and compact, with phenocrysts of alkali feldspar and nepheline, and flakes of yellow-brown biotite.

An age determination of lava from the Uaso Narok Formation (Putere horst, i.e. believed to be the lower biotite-phonolites) gave a date of 10.3 ± 0.3 Ma. The 'Upper Rumuruti Phonolites' of Baker and others, 1971, at Kirimun on the east side of the plateau gave a date of 12.0 ± 0.6 Ma, again supporting some correlation with a sequence of flows 60 km to the east of the eastern escarpment of the rift.

Carney's (1972) isopach map for his Uaso Narok Formation on the escarpment suggests a thickness of up to 150 m for the Lower Uaso Narok phonolites in that area: thicknesses to the south, in the Rumuruti area, must attain at least 300 m (Charsley, 1984, estimates 250 m near Rumuruti)—thicknesses amount to 100 to 150 m in the eastern extremities of the Laikipia Plateau.

North of Carney's area, in the Tangulbei–Siaris Escarpment, Sceal's (1974) 'Plateau Phonolite Formation' and overlying 'Tangulbei Phonolite' have been allocated here to the Lower Uaso Narok subdivision. At the base of his sequence is c.10 m of coarse conglomerate with clasts of porphyritic mugearite referred to the Komol Volcanics.

In the Rumuruti area Charsley (1984) describes rocks assigned to this sequence as medium to dark grey or greenish grey in colour, with local mottling. In the field they are 'either blocky with a sharp subconchoidal fracture, or fissile, an indication of an internal fluxional texture'. Phenocrysts consist of ubiquitous nepheline (up to 7 mm), alkali feldspar (sanidine, and some anorthoclase), less common biotite and rare pyroxene (augite or aegirine-augite). Analcite may form clear patches or be interstitial to groundmass feldspar. Opaques are conspicuously absent.

The two flows at Kirimun, described by Key (1986b), commence with a fissile, fine-grained black basal unit passing up into a slightly coarser-grained, more massive phonolite. Aligned vitreous to white anorthoclase phenocrysts in the upper part of the flow indicate E–W motion. Nepheline (equant) and, rarely biotite, also occur as phenocrysts, up to a maximum of 2 cm. In the fissile basal layer there is a strong vertical parting parallel to the E–W phenocryst alignment.

An agglomerate is exposed in the Palagalagi River south of the main Kirimun Road crossing: phonolite clasts up to 50 cm in size are contained in a matrix of comminuted phonolite.

Upper Rumuruti phonolites

MARMANET PHONOLITES ($Tmvp^{R3}$)

McCall (1967) described the Marmanet flows as 'a thick series of phonolites characterised by unusual white and dark patchy textures', particularly well developed on the summit of Marmanet Escarpment: he emphasised the considerable petrographic variety within the Marmanet flows, but referred to a fissile, dark brown, green and white mottled phonolite from Marmanet summit as 'typical'.

Carney (1972) described his uppermost Marmanet subdivision of the Rumuruti Group (B^{7d} of EAGRU) as characterised dominantly by highly porphyritic mottled phonolites; its upper member was biotitic, in addition to being highly porphyritic.

The Upper Rumuruti phonolites as they appear on the accompanying 1:250 000 geological map show McCall's original reference area, on the Marmanet Escarpment in the south-west, detached from the main outcrop, which encircles the Sipili–Lariak area in the centre of the Laikipia Plateau.

The Marmanet phonolites include here, for convenience, the 'Ndurumo phonolite flows' of McCall (1967), characterised by numerous prominent anorthoclase and nepheline phenocrysts, which outcrop on the surface of the Rumuruti Plain (on Ndurumo and Lariak estates): they are similar to the coarsely porphyritic 'Kapiti' type phonolites of Prior (1903). Here, in the centre of the plateau the upper surface of the Marmanet lavas rises to about 2000 m on the main watershed.

Two specimens of Marmanet phonolites collected by Carney, one probably from Ngyiepe (c.36°15′E: 0°30′N) and the other from Kurmakine (36°19′E: 0°33′N) gave ages of 10.6 ± 0.3 and $11.6 \gtrsim 0.3$ Ma respectively.

The maximum thickness of the Marmanet phonolites on the escarpment (Ngyiepe Hill) is about 245 m, where they infilled a graben-like depression east of the Ngelesha fault scarp. Further east on the plateau the formation thins down to 150 to 100 m.

Carney described the dominant 'Kamasia' (Prior, 1903) petrographic types of the Marmanet Formation as highly porphyritic, with a grey-white mottled texture: the dominant phenocrystal phase is sanidine, with numerous nepheline euhedra and occasional aegirine-augite microphenocrysts. The groundmass features rounded poikilitic aggregates of aegirine-augite (zoned to aegirine), also kataphorite and aenigmatite. He divided the Marmanet phonolites into three members, each assumed to represent closely synchronous eruptive phases:

4 Upper biotite-phyric phonolites (a single flow on the Tumut horst).
3 Garoua phonolite.
2 Ol Doinyo Oiroua phonolites.
1 Ngyiepe phonolites.

These sub-units are all essentially mottled porphyritic types, but (2) contains occasional biotite, and (3) has less abundant phenocrysts. Considering the present status of mapping, there is no justification for trying to recognise these subdivisions outside Carney's research area.

In the Marmanet Forest Griffiths (1977) described the Marmanet phonolites as 'sparsely sanidine-phyric ... distinguished by a green and white mottling caused by the sub-poikilitic, aphanitic groundmass.'

In the Rumuruti area, in the zone peripheral to and underlying the Sipili Trachyte, the Marmanet flows are distinguished from the underlying Lower Ewaso Narok solely on the basis of the greater abundance of large phenocrysts, noted by Charsley (1984) and confirmed by Hackman (1986b) on the plateau further north.

Williams and Chapman (1986) provisionally renamed the Marmanet formation 'Lariak', because 'the flows may not extend SW as far as the Marmanet Escarpment'. They suggest that thinning of the lava units to the west and east of the central (Sipili–Lariak) area of the Laikipia Plateau favours derivation from vents on the plateau, rather than eastward flow from vents concealed in the rift. In fact the Marmanet formation would still appear to be

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Plate 7 Thomson's Falls at Nyahururu

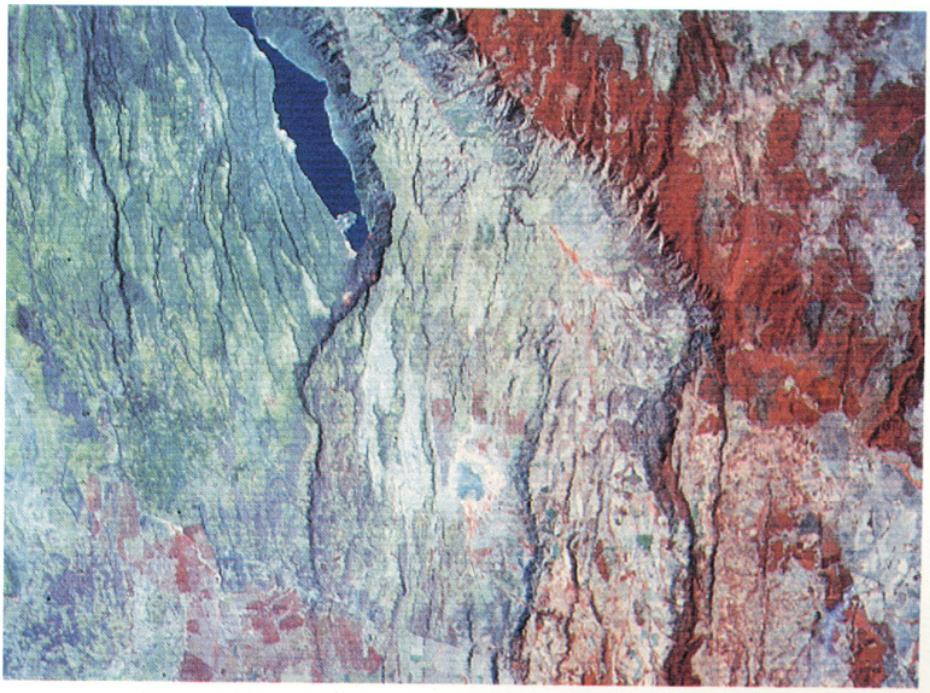


Plate 8 Landsat image of Lake Bogoria and the forested Marmanet Escarpment: parallel curvilinear faults flank the Solai graben in the south centre—grid faulting south-west of the lake

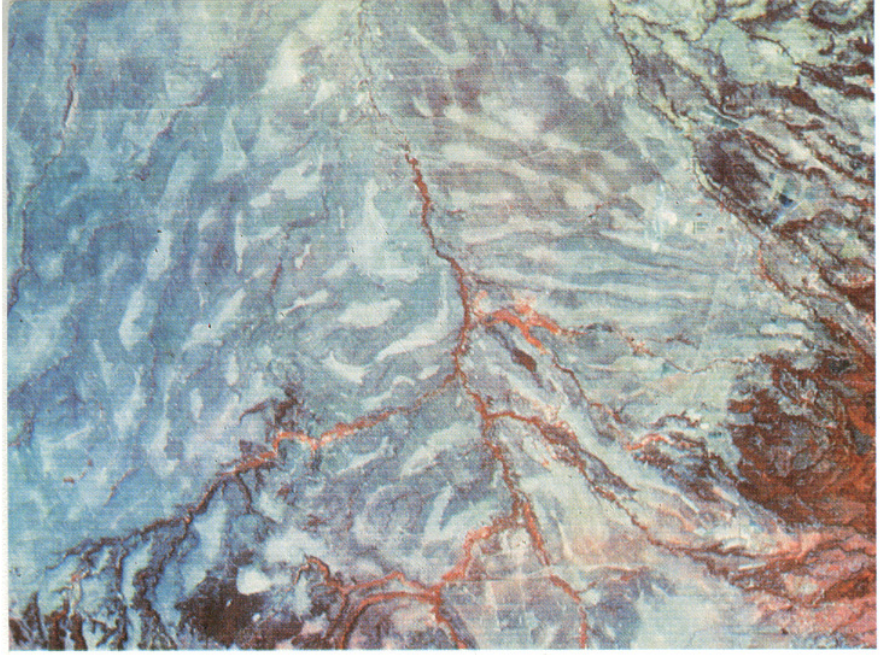


Plate 9 Landsat image of the Ol Pejeta area, drained by the upper Ewaso Ng'iro. Note the E–W-trending Sweet Waters Farm lineament in the eastern half of the frame

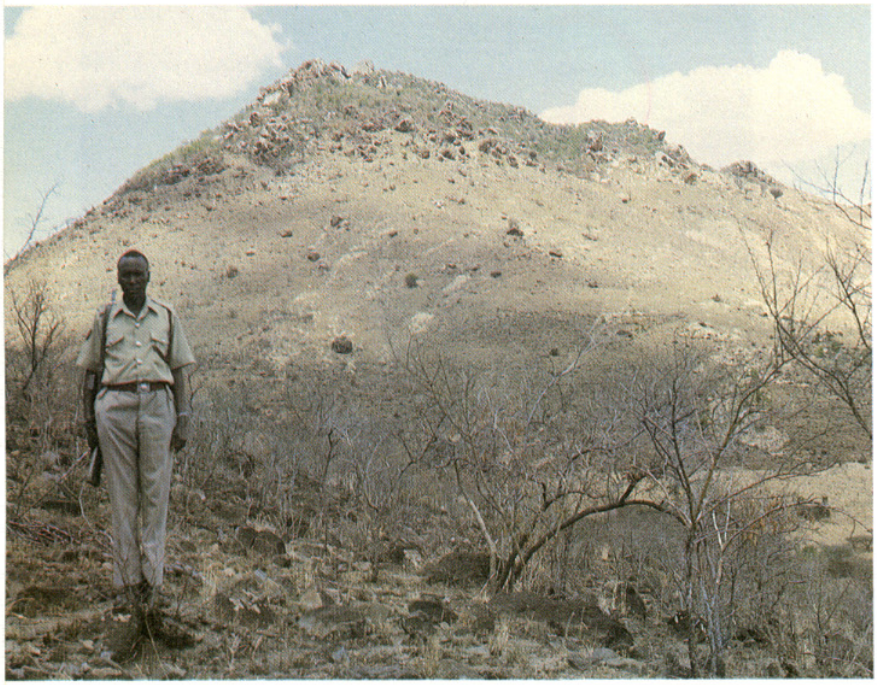


Plate 10 Murgomul from the east



Plate 11 Geyser on the west shore of Lake Bogoria, with the Hannington Escarpment behind the lake

thickest in the rift, but this may be due to preservation of lavas which filled faulted troughs, on the eastern shoulder: the concept of a 'Lariak Shield' centred on the outcrop of the Sipili Trachytes is considered in Section 9.3.

Upper Uaso Narok phonolites ($Tmvp^{R4}$)

The Upper Uaso Narok phonolites outcrop in an intensely faulted belt on either side of the 'Northern Plain' on the eastern rift shoulder, and overlap on to the Lower Uaso Narok and Marmanet phonolites further east in the Luoniek area.

Carney (1972) noted that the 'upper mottled biotite-phonolites', the third member of his Uaso Narok Formation (separated on the EAGRU map as b^{7c}) are intercalated with typical Marmanet flows on top of the Ngyiepe Escarpment about 8 km south-west of Kutwa. In the Luoniek area to the east, about 8 km west of Sukuta Mugie, Hackman (1986b) mapped Uaso Narok phonolites (brownish grey mottled sparsely feldsparphyric types) as overlying Marmanet phonolites: it was decided therefore to show $Tmvp^{R4}$ as intercalated between the Marmanet and Losiolo phonolites in the regional stratigraphic sequence, although Carney (1972, p.35), reported a 'localised flow *underlying* the Marmanet phonolites of Ol Doinyo Oiroua'.

For the area corresponding with the main outcrop of $Tmvp^{R4}$ Carney's isopach map for his Uaso Narok Formation (i.e. Lower and Upper Phonolites) and his sections of the upper mottled phonolites (1972, figs. 16 and 17) for the Kotomoc and Mendera–Churo areas, suggest thicknesses of 100 to 150 m. The thickest parts of the sequence in a faulted complex trending NNE correspond with what may have been extrusive dome or tholoid sources: such a concept is also supported by the occurrence of pyroclastics and glassy lavas in the same area, and by local anomalously high easterly dips of flow boundaries. In the Luoniek area Hackman (1986b) mapped a cluster of four small domes, aligned NW, below the low escarpment of Upper Uaso Narok phonolites (Gebere Nanyuki, GR 2245 0805): it is suggested that these domes are small tholoids developed in the vents from which the neighbouring phonolites were extruded.

In hand specimen these lavas are green, very fine-grained, with a conspicuous 'polka-dot' mottling, occasioned by glomerophyric aggregates of kataphorite and aegirine.

Phenocrysts of anorthoclase, nepheline and biotite may be abundant: the mottled lavas may alternate with flow banded and glassy phonolites with well-developed stratification.

5.4 LATE MIOCENE PHONOLITIC TRACHYTES AND BASALTS

Certain sequences of phonolitic trachytes and subordinate basalts are described here together as they share some common features, particularly petrographic similarity and comparable stratigraphic positions: they overlie and post-date the Rumuruti Group phonolites in the Laikipia area, and are all essentially late Miocene in age.

Provisionally they might be designated as the 'Lariak' group, a subdivision (b) of volcanic group 2 according to King and Chapman (1972).

The essential sequences are as follows:

1	Laikipia Escarpment (inner eastern rift shoulder)–	Tasiokwank phonolitic trachytes.
2	Central Laikipia (Lariak Shield)—	Sipili trachytes.
3	Loroki Plateau	Losiolo phonolites Loiting phonolites
4	South-west Laikipia	Thomson's Falls phonolites and Rumuruti Forest basalts.
5	Southern Laikipia	Pesi River basalts.

Tasiokwank phonolitic trachytes ($Tmvpt^{TK}$)

Griffiths (1971) recognised the *Tasokwan* (sic) Formation (Toscowan phonolitic trachyte, $C^{2\prime}$, of Truckle, 1977), as a sequence of diverse extrusives, undersaturated trachytes predominating, which rest unconformably on older Miocene basalts and phonolites in a belt extending for 40 km along the Laikipia Escarpment, south from the hill named Tasiokwank, 1535 m. Tasiokwank is located at GR 1827 0538 on Sheet 105/1 (Ngelesha), 1:50 000 topographic series Y731 (DOS, 1973).

To the north, Carney (1972) also described a small outcrop of the 'Tasokwan phonolitic trachytes' in the gorge of the Ol Arabel River at c.36°10′: 0°30.5′N.

McCall (1967) noted these trachytic extrusives (in part his 'Wasages', 'Ol Arabel' and Iguamiti phonolite flows) and included them within the Rumuruti Group phonolites, not demarcated separately on his 1:125 000 geological map.

On the 1:250 000 map accompanying this report Griffiths' boundaries for this unit have been accepted to the south of latitude 0°30′S: his mapping did not, however, extend south-east as far as the Marmanet Forest and the upper basin of the Waseges River—in that area the Iguamiti flows of McCall (1967, p.26, fig.3), have been included here, designated as $Tmvpt^{IG}$.

The formation as described by Griffiths includes subordinate mafic extrusives (the Mortalim basalts), thin phonolitic trachyte flows and tuffs (the Kinsoget trachytes) and partly tuffaceous lacustrine sediments (Kaptunai beds).

The trachytes vary in thickness up to about 150 m (in the Ol Arabel gorge). In the escarpment between Lake Bogoria and the Waseges valley they may be thicker, comprising up to five separate flows: usually flows terminate against positive features in the substratum, particularly related to pre-existing fault escarpments—changes of thickness are mostly related to the underlying topography. (Griffiths, 1977, constructed isopachs for the 'Tasokwan trachyte', in part related to pre-Tasokwan relief.) The Kaptunai sediments vary up to 30 m in thickness.

Two age determinations from the phonolitic trachytes are quoted by Chapman and Brook (1978) as 6.6 ± 0.2 and 7.6 ± 0.2 Ma (Late Miocene). On the basis of the first date Carney (1972) suggests a correlation with the Kabarnet trachytes (Walsh, 1969) on the west side of the Rift Valley, dated at 7.0 Ma.

The Tasiokwank lavas rest unconformably on different members of the Samburu basalts and the Rumuruti Group phonolites. The trachyte flows were banked up against prominent fault scarps in the older Miocene volcanics. When these faults were rejuvenated, 'facings' of trachyte were left on many of the escarpments. No flows are preserved east of the Ol Arabel River, presumably because of the barrier of horsts extending south from the Ngelesha Escarpment.

Characteristically the trachytes are phaneritic, and fissile, usually with a high proportion of porphyritic sanidine, but to the east there are outcrops of non-fissile green aphyric trachyte. Poikilitic aggregates of aegirine, aenigmatite and kataphorite occur in the groundmass,

sometimes with altered euhedral nepheline and interstitial analcite.

Other banded flows within the Tasiokwank sequence contain olivine, subhedral augite and abundant plagioclase laths (labradorite-bytownite).

At the northern end of the outcrop, Carney described the trachytes as coarse-textured, with groundmass sanidine laths showing strained extinction, rare subpoikilitic plates of arfvedsonite, zoned aegirine-augite aggregates, kataphorite/aenigmatite, and occasional euhedral sodalite microphenocrysts.

Griffiths (1977) considered that the Tasiokwank trachytes were possibly extruded from centres in the area of the Hannington Escarpment, i.e. between Lake Bogoria and the Waseges River. Carney (1972) speculated, on the basis of possible equivalence with the Kabarnet trachytes to the west of the rift that the sequence might have originated from the 'axial' region of the Miocene rift now obscured by younger volcanics. These two suggestions are not necessarily contradictory.

Sipili trachytes ($Tmvt^{SP}$)

As a result of investigations in the central Laikipia Plateau Bristow and Temperley (1964), described what they called the 'Upper Lava Group' of the 'Rumuruti (Phonolites) Series' in terms of the following sequence:

3 Basalts
2 Lariak phonolite trachytes
1 Phonolites and basalts

The 'Lariak' sequence was believed to be centred on the hill Ol Doinyo Loloip (Oliep) (GR 2133 0532).

McCall (1967) referred the Sipili flows, essentially the same phonolitic trachytes, to a subdivision of the Rumuruti Phonolites. On his 1:125 000 geological map they were categorised as Trachytes (Sipili), after a summit at GR 2086 0484. Carney (1972) was disposed, on the basis of certain petrographic textural, features to correlate these lavas with the Tasiokwank phonolitic trachytes. On the EAGRU map, Truckle (1977) retained the name Sipili Trachyte ($c^{1\prime}$): Charsley (1984) follows McCall's definition of the unit, but places them outside the Rumuruti Group.

The Sipili trachytes are placed prominently in the centre of the 1:250 000 geological map, underlain by, and surrounded by, the Upper Rumuruti Phonolites (predominantly of Marmanet type). They are bounded by an erosional escarpment 10 to 15 m high, prominent on aerial photographs and easily traceable on the ground.

They consist of peralkaline trachytes and trachytic tuffs which contain analcite locally (at their base in the Rumuruti area), and which overlie the phonolites of the Rumuruti Group. They are believed to have a local source within their main outcrop area in an eroded vent(s), which may be at Ol Doinyo Loloip, as suggested by Bristow and Temperley (1964), but there may be other vents. No other sequence overlies the Sipili Trachytes, but their maximum thickness in the centre of the 'shield' must approach 100 m.

The trachytes are medium light grey in colour, but brownish grey or olive grey in places. In the field they are commonly thinly banded and fissile with glistening surfaces due to aligned feldspar microphenocrysts. They are mostly blocky, but are brecciated in part.

They contain scattered feldspar phenocrysts (of sanidine or anorthoclase up to 6 mm) and microphenocrysts of sanidine, magnetite and fayalitic olivine set in a groundmass of fluxionally aligned sanidine laths. Other groundmass minerals include biotite, hornblende, kataphorite, cossyrite, aegirine-augite and opaques. Analcite was seen in the groundmass of two specimens from near to the base of the unit. Charsley considers them to be iron- and soda-rich peralkaline trachytes which may be locally slightly undersaturated and hence termed analcite-trachytes rather than phonolitic trachytes.

The Sipili trachytes overlie the Rumuruti Group, and at one locality (GR 2251 0499) trachyte overlies reddened pisolitic lateritised lava which is probably the weathered top of the Rumuruti Group phonolites.

Although there are important petrological differences between the Sipili trachytes and the underlying phonolites, such as the absence of nepheline and the abundance of opaque iron minerals in the former, some similarities exist. For instance, soda amphiboles are common to both. It is thought that they may be part of a single differentiation sequence, and their eruptions may not be widely separated in time. They may represent a late post-caldera stage in the evolution of the plateau phonolite shield (Williams and Chapman, 1986). The Tasiokwank phonolitic trachytes dated at 6.7 Ma invite comparison, but they are much younger than the Rumuruti Group of 10.6 to 11.7 Ma BP, and not Pliocene (the Pliocene–Miocene boundary is placed at 5.1 Ma BP by Harland and others, 1982).

Losiolo phonolites ($Tmvp^{R5}$)

Shackleton (1946) named these phonolites after a series of thin lava flows exposed in the cliffs at Losiolo on Degree Sheet 27, to the north of the Laikipia area (36°31′E: 1°13′N). He reported that they outcrop 'north of Lorogi' with 'no sharp separation' from the Rumuruti phonolites: the latter were not demarcated as separate from the Losiolo phonolites on his reconnaissance map.

The following quotation is pertinent: 'The dominant rocks are dark grey fissile phonolites, either non-porphyritic or with scattered anorthoclase phenocrysts less than 1 mm long .... The whole series recalls the Thomson's Falls phonolites of the south-west part of the area, and may be the same age.'

On Degree Sheet 27 Key (1987) mapped these phonolites as separate from the Lopet Phonolites (described as the Losiolo trachyphonolites by Golden, 1978), and from the Rumuruti Group phonolites *per se*. Hackman (1986a) found that Key's outcrop of the Losiolo phonolites extended to the south to include most of the Loroki (Leroghi) Plateau area east of the Amaya Escarpment, which was mentioned by Shackleton as 'the best section (of Rumuruti phonolites) within the area'.

The outcrop of Losiolo phonolites typically has thicker soil and vegetation covers than the drier areas in the rift to the west. On aerial photographs the smooth texture and uniform dark tone are characteristic, also, particularly on the Loroki Plateau (Plate 6), there is a fine sequence of lava flow escarpments, dissected by the headwaters of the Enkare Narok, which impart a perfect 'tabular' effect to the landscape due to the regular stratification of the flows, contrasting with the more hummocky aspect of the outcrops of the Middle and Upper Rumuruti phonolites to the south.

Key (1987) refers to the Ngerem precipice below Losiolo itself as the type section. He identified 18 flows in a vertical section of about 600 m.

On Degree Sheet 35 the Loroki Plateau is built up of a sequence of five flow escarpments, up to c.200 m in thickness. The uppermost flow oversteps the underlying

flows to the south, and in sequence up the Ol Keju Losera valley from Sukuta Lol Marmar, it rests successively on the Lower, and Middle (Lower Ewaso Narok) phonolites of the Rumuruti sequence.

The Losiolo phonolites clearly post-date the Middle Rumuruti phonolites, which they overstep: as they are not overlain by another dated volcanic sequence in this area, it can only be assumed that they are younger than 10 Ma, but probably still Late Miocene.

The lowest three flows of the Losiolo phonolite sequence are rather poorly exposed in the valley of the Enkare Narok, in the extreme north of the area: typical is a blue or black, rather fine-grained phonolite, weathering to a purplish grey colour. Flow tops may be amygdaloidal (with zeolites): hexagonal columnar jointing was noted at GR 2403 1058.

The fourth flow outcrops only in the valley of the Lariak Ng'iroin, a right bank tributary of the Enkare Narok. Petrographically it generally resembles the dominant rock type of the overlying fifth flow, which is volumetrically by far the largest and most extensive of the sequence.

Characteristic of this uppermost flow, or composite flow sequence, is a tough, brownish grey rather fine-grained mottled phonolite: parts of the flow show alignment of alkali-feldspar phenocrysts, and occasional biotite flakes. Flow tops may preserve subpolygonal mosaics due to crude columnar jointing; the bulk of the lavas are generally aphyric or sparsely porphyritic. Usually the rocks weather to an orange-brown rind several centimetres thick, occasionally pitted where small nepheline phenocrysts have weathered out. Clastic bases and scoriaceous tops to the flow may be up to 5 m thick. Occasional tuffaceous layers occur, especially on the northern Loroki Plateau—on escarpments they are usually poorly exposed. Many thin sections show flow orientation of feldspar laths: in the groundmass aegirine-augite, augite, cossyrite, kataphorite, nepheline, analcime and ore are all usual modal constituents.

The Loiting phonolites ($Tmvp^{R5'}$)

At the south-western extremity of the outcrop of the Losiolo phonolites there is a cluster of three phonolite domes at c.2000 m on the Lonkewan Escarpment (GR 2230 0900), clearly identifiable on aerial photographs. The acacia grassland yields poor exposures, but their structural significance is considerable in that they may be interpreted as plugged vents, a late phase of the Losiolo phonolites extrusive activity: also they are aligned WNW, parallel to and collinear with the upper Amaya valley.

Measured orientations of fissility and streams of vesicles thoughout the Losiolo lavas consistently indicate flow in a NW–SE direction, i.e. orthogonal to the flow trends of the underlying Lower Uaso Narok phonolites.

Feasibly the whole sequence, but especially the upper flow unit, could have been extruded from the area of the Loiting tholoids. The 'frothy' aspect of many of the Losiolo flows, with subordinate tuffaceous intercalations, suggests rapid extrusion—the regular stratification indicates that the land surface was a level plain.

The predominance of mottled phonolites, with some megascopic biotite, and the stratigraphic position, invites comparison with the Upper Uaso Narok phonolites. The Loiting tholoid cluster also suggests a north-easterly extension of the belt of domes and sources of eruption mapped by Carney (1972) in the Kotomoc–Churo area about 20 km to the south-west. Age determinations are needed from both areas to test the possibility that the Upper Uaso Narok phonolites are simply a south-westerly extension of the Losiolo phonolites, which has been involved in the intense fault swarm on the extreme eastern margin of the rift.

Rumuruti Forest basalt ($Tmvb^{RF}$)

McCall (1967, p.33) described basaltic lavas outcropping about 15 km NE of Nyahururu, in the Ewaso Narok valley and the Rumuruti Forest. The Samburu–Marsabit project did not investigate these rocks any further.

The Rumuruti Forest basalt was thought to represent one or more flows between the Rumuruti phonolites (Lower Ewaso Narok) and the overlying Thomson's Falls phonolites. Stratigraphically therefore their position is analogous to that of the Pesi River basalts as described by Wilkinson below.

McCall considered these rocks to be similar, petrographically, to the Samburu basalts, including rough-textured scoriaceous basalts and varieties porphyritic in augite and olivine.

Pesi River basalts ($Tmvb^{PR}$ after Wilkinson, 1983)

The 'Pesi River' basalts are a poorly exposed group of equivocal status. They outcrop along the upper valley of the Pesi River, but nowhere is a complete section seen. The basalts are overlain in the Pesi River by phonolitic trachytes, which may be part of the upper Rumuruti Formation or of the lower Thomson's Falls Formation.

Bristow and Temperley (1964) called these basalts 'Simbara Basalts' equating them with those of similar lithology from the Aberdares to the south of the present area and following Shackleton (1946). Both are 'Kijabe-type', i.e. they contain an abundance of large labradorite phenocrysts. These authors envisaged a buried spur extending north from the main outcrop of the Aberdares. However, Shackleton notes that they underlie the Thomson's Falls phonolites of Pliocene age, whereas Bristow equates them also with the lower Miocene Samburu Basalts which underlie the Rumuruti Formation phonolites to the north.

Thus the basalts have been interpreted in two ways, both related to the 'Simbara Basalts' in the Aberdares:

1 Unconformably underlying the Rumuruti phonolite sequence, and

2 Underlying, possibly unconformably, the Thomson's Falls phonolite and overlying the Rumuruti phonolites.

A third explanation ignores their petrological resemblance to the Aberdare lavas and regards them as a basal member of unusual lithology of the Laikipian Formation basalts. The latter are known to interdigitate with phonolite flows at the top of the sequence. Eruption from basaltic centres thus preceded, overlapped with and outlived the extrusion of Thomson's Falls phonolites.

The basalts outcrop east of the Pesi Bridge on the Nyeri–Nyahururu road at GR 2310 0089. They also occur sporadically on both sides of the Pesi River south and north of the road: the outcrop is too restricted for a characteristic morphology to be apparent on aerial photographs.

Only the section at GR 2310 0089 is worth recording as a reference section.

Whether an early flow of the Laikipian Formation or a northern extension of the Aberdare basaltic lavas, the Pesi

River Basalts are thought to underlie the Thomson's Falls phonolites and are thus older than the Pliocene. Bristow and Temperley (1964) place them below the Rumuruti Formation phonolites, implying an older date, but there is little evidence for this.

The thickness of the unit cannot be realistically estimated. Only 1 to 2 m are exposed at individual outcrops.

The basalts are massive, dark grey and crowded with long, narrow bladed labradorite feldspar phenocrysts. Tops of flows may be highly vesicular. They develop 'onion-skin' weathering and form nodular outcrops. In thin section bladed phenocrysts of labradorite are set in a groundmass of feldspar, augite and iron ore, with a typically basaltic intergranular texture.

Thomson's Falls Formation (phonolites and phonolitic trachytes with trachytic tuffs) ($Tmvp^{TF}$ after Wilkinson, 1983)

PHONOLITES AND PHONOLITIC TRACHYTES

Shackleton (1946) gave the name Thomson's Falls Phonolites to the series of phonolitic flows which overly the Rumuruti Group phonolites in the south-west of Pesi Swamp. They extend to the south, east of Nyahururu to Ol Kalou.

The type area is at Thomson's Falls (Plate 7) where the Ewaso Narok falls 65 m over a single phonolite flow (Bristow and Temperley, 1964). The phonolites form the deep gorge downstream of the falls. The name 'Thomson's Falls' has been retained for the waterfall although the nearby town was re-named Nyahururu after independence.

The sequence is given formational status in this account.

Between Pesi Swamp and Nyahururu the Thomson's Falls Formation occupies an area of about 450 km, underlying slightly higher and more dissected ground than that to the north.

Due to a characteristic fissility, surface outcrops of Thomson's Falls phonolite are usually flaggy. Internal shear stress during consolidation led to completely curved and convolute cooling planes along which the rock parts: this often results in the appearance of minor folding on rock surfaces.

Due to generally thicker soil development and vegetation cover the country underlain by Thomson's Falls phonolites is darker on aerial photographs than the surrounding areas.

In the area south of Rumuruti these phonolites are usually demarcated from underlying lavas by a marked erosional escarpment. Many streams, including the Pesi, Muruku and Moridjo, are actively dissecting this scarp by headward erosion.

The original reference section is at Thomson's Falls near Nyahururu. Good sections can be examined in the headwaters of the Muruku River at GR 2240 0096 and 2247 0089, along the Nyahururu – Nyeri road east and west of the Pesi Bridge, and in the Moridjo River at GR 2283 0052.

The Thomson's Falls Formation comprises the youngest phonolites in the southern Laikipia region: they overlie Rumuruti Group phonolites. In northern Laikipia a sequence of similar lithology, the Losiolo Formation, overlies the Rumuruti Formation. The Thomson's Falls and Losiolo Formations may be of similar age. Locally intercalated between the Losiolo and Rumuruti Formations, are phonolitic tuffs with vesicular lavas (Towana Formation, Key, 1987). Trachytic tuffs also overlie the Thomson's Falls phonolites in the Pesi Swamp area.

The Laikipian Formation basalts overlie the Thomson's Falls Formation to the east of Pesi Swamp. However, basalt flows certainly interdigitate with phonolite and there is good evidence to indicate that they occur throughout the Thomson's Falls phonolite sequence. It is suggested that the 'Pesi River Basalts' may be the lowermost part of the Laikipian Formation. It is clear, therefore, that eruption from basaltic and phonolitic centres overlapped: conceivably the former started before and outlived the latter.

The sequence consists of several flows, one of which, at Thomson's Falls, is at least 85 m thick (Bristow and Temperley, 1964).

South-west of Pesi Swamp the sequence achieves a minimal thickness of 120 m.

The lavas of this sequence are uniform in appearance. They are dark grey-green in colour with a conspicuous fissility, probably due to internal cooling along flow-planes which are twisted and irregular. Freshly broken surfaces characteristically show a series of stepped fractures. Weathered surfaces are bleached to pale grey or buff colour, and joint faces are often iron-stained. Small anorthoclase phenocrysts, often stained a yellowish colour, can always be seen, and rarely small olivines. Tops of flows are often highly vesicular, even scoriaceous, with pale green zeolite, carbonate or chalcedony filling vesicles. In vesicular varieties the lava is frequently black and glassy.

Phonolitic trachytes occur at, or near, the base of the sequence. They resemble those from the underlying Rumuruti Formation, being purplish grey in colour with small flattened vesicles showing a fluxional texture. They may also be vesicular and grade into normal phonolite.

The Thomson's Falls Formation *phonolites* display a fairly constant mineralogical character. Phenocrysts are predominantly elongated blades of sanidine or anorthoclase which may show zones of inclusions. Microphenocrysts of euhedral nepheline and rounded aegirine-augite and augite also occur. In one slide large phenocrysts of a highly altered ferromagnesian mineral (fayalite?) have been partially resorbed by nepheline and sanidine, whilst in others aegirine-augite phenocrysts have rims of magnetite grains and (?) apatite. Shackleton (1946) recorded fayalitic olivine phenocrysts.

The groundmass consists mainly of a felted mass of sanidine microlites with granular aegirine-augite. Small, euhedral nepheline crystals, are frequently outlined by growths of ferromagnesian minerals. They often enclose other minerals of the groundmass. Subordinate ferromagnesian minerals which may be present in the groundmass are pale green augite, dark brownish red cossyrite, kataphorite and mauvish amphibole. Magnetite grains are ubiquitous. Analcime is often present and may be altered to fibrous aggregates of zeolite (natrolite?). Shackleton (1946) also recorded small, flow-oriented orthoclase plates.

In the phonolitic trachytes tabular phenocrysts of andesine-oligoclase display a strong fluxional fabric parallel to groundmass feldspar microlites. Microphenocrysts of corroded aegirine or aegirine-augite may also be present, rimmed by dark brown amphibole, cf. kataphorite. Fayalite microphenocrysts were recognised in one slide.

The groundmass consists of sanidine microlites, aegirine-augite andesine laths and scarce euhedral nepheline. Magnetite is abundant, as specks and grains, and apatite needles may also occur scattered in the base.

Patches of brown glass and secondary calcite were also observed.

Shackleton (1946) described pale, trachytic pumice tuffs outcropping in the area of the Suguroi–Mutara rivers and around the headwaters of the Pesi River. He considered them to lie at, or near, the base of the Laikipia basalts. Bristow and Temperley (1964) recognised the Suguroi tuffs and also described a thick sequence of basaltic tuffs overlying the Laikipian basalts in boreholes sunk east of the Pesi River: they equated these 'Pesi tuffs' with the Kinangop tuffs, the main outcrop of which occurs to the south of Nyahururu. However, both the 'Pesi' and 'Suguroi' tuffs lie on the boundary between the Thomson's Falls and Laikipian Formations and are similar in lithology, and are therefore considered here under one heading.

A narrow band (2 to 3 m) of trachytic tuffs outcrops on both banks of the Suguroi River between GR 2401 0067 and 2357 0015. It is overlain and underlain by Laikipian basalts for part of its outcrop, but overlies Thomson's Falls Formation phonolites upstream. Tuffs also outcrop, but overlie Thomson's Falls Formation phonolites upsteam. Tuffs also outcrop east and south of Kiamariga Farm in the Mutara River, 2 to 3 km west of Suguroi. Further to the west thin patches of tuffs lie on the phonolite surface. These are best seen 1 km north-west of Uruku Farm in the Pesi River. It is probable that additional patches to those mapped occur on the phonolite plateau.

The tuffs are stratified and vary greatly in grain size from fine lapilli-tuffs to very coarse agglomerates. Massive homogeneous tuffs typically have a blocky fracture with rounded weathered surfaces.

The outcrop is generally too small to result in any characteristic feature on aerial photographs, although paler patches of outcrop on the phonolitic plateau are often associated with tuffs.

The best reference section of at least 20 m thickness, occurs in the Pesi River behind the dispensary at Uruku (GR 2304 0042). This section is underlain and overlain by phonolite lavas. A thin sheet of hard lava capping soft pyroclastics has resulted in a waterfall.

The tuffs occur at the top of the Thomson's Falls Formation phonolites. They often lie on the uppermost phonolite flow, but may be overlain by a thin phonolite sheet. As the overlying Laikipian basalts interdigitate with the phonolites, the tuffs are also found bracketed by basaltic flows.

The Thomson's Falls Formation is Upper Miocene to Pliocene (?) in age whilst the youngest Laikipian flows may be middle Pleistocene. The tuffs may therefore be Pliocene in age.

At least 20 m of pyroclastics are recorded in the Pesi River north-west of Uruku. However, the tuffs are usually thinner than this.

The trachytic tuffs vary widely in lithology: the most common type is a low density, friable, pale yellow, pinkish or grey pumice tuff in which clasts predominate over groundmass, Subordinate fragments of black glass and lava also occur and, more rarely, crystals and carbonised plant material. Tuffs of similar lithology and colour, but finer grain, have been quarried for building stone at Uruku and from the Suguroi.

The deposits are, in places, well-stratified and may display cross bedding. This suggests an air-fall origin, perhaps partially re-distributed by fluviatile agencies. At Uruku the fine-grained homogeneous tuff of the quarry sites is overlain by a coarse, friable, dirty grey volcaniclastic fluvio-lacustrine grit containing rounded to angular fragments of pumice and lava with shards of black glass.

Shackleton (1946) recorded thin (0.5 m) beds of diatomite intercalated with stratified tuffs in the Pesi River exposures, although not in the Suguroi. These are off-white, very low density and fairly pure. They also suggest a lacustrine environment of deposition. The massive homogeneous tuffs may be of ash-flow orgin, but show traces of welding.

The section in the Pesi River near Uruku shows a crude fining-upward sequence. At the base is a zone of very coarse agglomerates with 'bombs' of glassy vesicular phonolite up to 2 m in a coarse tuffaceous matrix. This passes up into medium- and fine-grained pumice tuffs as described above, but with no evidence of graded or current bedding. At the top of the sequence are very fine homogeneous tuffs with a clay-like texture.

Little can be observed in thin section. Fragments of 'flow-banded' glass (welded tuff?) and lava occur together with rare feldspar and ferromagnesian crystals and quartz grains, but brown amorphous glass constitutes most of the thin sections examined.

5.5 PLIOCENE BASALTS

The Pliocene basalts (Group III of King and Chapman, 1972) are represented by only very small areas on the inner rift shoulders—the Kaparaina basalts on the western side, and the Narokwe basalts at the southern end of the Karau Escarpment on the eastern shoulder. In the south-east of the map area the basaltic Laikipian Formation (Sirrima basalts) overlies the Rumuruti Group phonolites and extends south towards Nyeri. The sequence, which might also be included in this group, was described by Shackleton (1946): further information is available in Wilkinson (1983).

Kaparaina basalt ($Tpvb^{KP}$)

Originally named by Martyn (1969), Chapman (1971a) described as the 'Kaparaina Basalts Formation' (EAGRU, c^3) a sequence of up to about 550 m named after the Kaparaina Range in the Kamasia Hills to the west of this area. On this Degree Sheet it has been mapped only on the extreme margin of the area, on the west side of the Burususwa valley. The narrow outcrop, mostly obscured by alluvium, is of a fine-grained aphyric basalt, weathering to a purple-grey friable rock.

Pickford (1978) quotes five K/Ar age determinations for the Kaparaina basalts ranging from 3.9 ± 0.1 to 8.2 ± 0.4 Ma. The latter date may be anomalously old due to xenocrystal feldspar (Chapman and Brook, 1976).

Dagley and others (1976) deduced ages of 3.96 and 4.67 Ma for basalts near the base of the Kaparaina sequence in the Ndau River section (c.35°54′E: 0°30′N).

The petrography of these basalts is typical of the alkalic olivine basalt-hawaiite-mugearite association. Labradorite, usually zoned, and olivine, are the commonest phenocrysts.

Narokwe basalts ($Tpvb^{NR}$)

Carney (1972) described the 'Narokwe Volcano' (EAGRU-$c^{3'}$) centred on a hill about 5 km east of the south-eastern extremity of Lake Baringo. The total extent of the outcrop, including the hill Dikaluk c.2 km south-east of Narokwe Hill, is only about 3.5 km^2.

Carney quoted a date of 5.6 Ma, presumably from a sample of lava, which gives comparability with the Kaparaina basalts, on the other side of the rift, described in the previous section.

A basalt flow assigned to the Narokwe basalts rests directly on Samburu basalts on Dikaluk Hill. Narokwe Hill itself is a much faulted and dissected basaltic centre, with a plug about 60 m in diameter, and two dykes, surrounded by poorly exposed bedded tuffs, agglomerates and a few thin lavas.

The plug rock is a tough, well-jointed basalt conspicuously porphyritic in augite and olivine. In thin sections titanaugite microphenocrysts are observed. Gabbro xenoliths are similar to those found in the Samburu basalts of the Ngarama centre 8 km to the south-east.

The basalt flows at Dikaluk Hill are sparsely pyroxene-phyric.

Pyroclastics are well exposed in the gorge of the Porumbonyanza (Ngasotok) River immediately north of Narokwe Hill, where stratified purple tuffs and agglomerate dip at 20–30° NNW. They contain basalt blocks identical to the plug material, cemented by carbonate.

Carney suggested that the position of Narokwe Volcano was related to the northern extension of the Laikipia Escarpment fault complex.

5.6 PLIOCENE TRACHYTE SHIELD VOLCANOES

Group IV of King and Chapman (1972) is poorly represented in this area: volumetrically the most important unit is the Orus trachyte of the Amaya Embayment and the inner eastern rift shoulder, considered here together with the Kokwapang'a basalt. On the western shoulder the Jamakana (trachytic) formation and the Lokwaleibet basalt are also described in this group.

Eastern Inner Rift Shoulder

Orus trachyte ($Tpvt^{OR}$)

The Orus trachyte (EAGRU, c^{a4}) is named after an area around 36°17E:0°57′N. There a pattern of faulted, disconnected outcrops was mapped by Sceal (1974): two outliers form mesas to the south, in the upper Komol valley.

Larger areas form:

1 The plateau of Kamel (Kokwapang'a), where the lavas lap around the north side of the Komol Volcanics of Molgoltwa Hill (GR 2030 1022).
2 The level area of Pelesian in the Amaya Embayment about 12 km to the south-east.

The configuration of outcrops suggests that the trachyte filled a depression trending WNW–ESE, a broad, mature precursor of the Amaya valley: subsequently the formation was fragmented, particularly in the west, by faulting (e.g. the Orus Fault) and later erosion.

Photogeologically outcrops of the Orus trachyte are distinguished by the level, even texture of the surface, especially in the south-east, where there has been less dissection due to rejuvenation of the drainage consequent on lowering of the rift floor.

Three specimens of Orus trachyte yielded age determinations ranging from 1.6 ± 0.1 to 3.2 ± 0.2 Ma.

As two of the specimens were weathered, with zeolite content, Golden (1978) was disposed to accept a date of 3.2 Ma as the most reliable.

The age and relationships of the Orus trachyte merit comparison with the trachyte plateaux of Emuruagiring and Tirr Tirr, 50 and 100 km further north along the rift (Key, 1987).

The Orus trachyte clearly rests unconformably on the underlying Miocene volcanics, and was extruded after an episode of faulting, and subsequent erosion of the Rumuruti Group phonolites around the Chembalao Shield. Nowhere does the Orus trachyte overlie sediments, although Sceal (1974) recorded a thickness of 120 m, comprising two main flows, the younger of which is 75 m thick.

Fairly coarse-grained undersaturated trachytes dominate throughout, with variable proportions of phenocrystal anorthoclase: the phenocrysts may attain a length of 2 cm. Patches of turbid zeolite in the groundmass suggest pseudomorphed nepheline.

Fissility is due to parallel orientation of the anorthoclase (and locally, sanidine) microphenocrysts, which may show partial marginal resorption. Riebeckite, aenigmatite, aegirine-augite and arfvedsonite may form micropoikilitic segregations in the groundmass.

Kokwapang'a basalt ($Tpvb^{KK}$)

This sequence of basalts, described as the Kokwabanga (Kokwobanga) Basalt by EAGRU (e^{a2}), was mapped by Sceal (1974): they outcrop in faulted strips between the Orus–Alengerr salient and the western flanks of Paka Volcano, whose earliest flows they underlie.

Their age is presumed to be Plio-Pleistocene: Williams and Chapman (1986) treat them as Pleistocene. According to Sceal (op. cit., fig.12) their thickness is only about 6 m. The Kokwapang'a basalt (spelling from 1982 edition of the 1:50 000 topographic map) was erupted from three cones:

1 Kokwapang'a Hill in the south (36°17′E:0°54′N) where a cone developed on a surface of Orus trachyte.
2 In the Orus area about 5 km north of Kokwapang'a.
3 In the north-west (near Koluamosin) at 36°16.5′E:0°58′N, on a fault which displaced the Orus trachyte, and where basaltic cinders and a basalt flow overlie the Secumius trachyte (described here in Section 5.8, as part of Paka Volcano).

In the south these basalts are dominantly ankaramites, with more than 20 per cent pyroxene phenocrysts. In the north they are coarse-grained, aphyric and often vesicular.

The cinders in the north-west contain ejected blocks of basalt with olivine and pyroxene phenocrysts, i.e. resembling the Miocene lavas, also nodules of banded gabbroid and leucocratic material consisting mainly of anorthoclase.

Western Rift Shoulder

Lokwaleibit basalts ($Tpvb^{LL}$)

McClenaghan (1971) described and named this formation (EAGRU d^3), which outcrops in the Nginyang area straddling the junction between four degree square sheets (and four published geological maps) at 36°E:1°N.

Chapman (1971a) treated this unit as part of volcanic Group IV.

The reference section for this sequence is the gorge of the Lokwaleibit River 4 km to the north-west of 36°E:1°N, i.e. outside this map sheet area at GR 1330

1114. They outcrop over a small area in the north-west extremity of this degree square.

Photogeologically they are distinct from the underlying Kaparaina basalts on account of their lobate erosion pattern.

These basalts are probably of early Pliocene age: they are overlain by the trachytic Jamakana formation, for which a date of 3.4 Ma is available. To the north-west of the area flows have been dated at 5.1 to 4.4 Ma.

The Lokwaleibit basalts rest unconformably on the Kaparaina basalts to the south, and underlie the Jamakana formation which outcrops on the east side of the Nginyang River. Their outcrop is scored by numerous N–S-trending normal faults, defining a miniature horst-and-graben 'strip' effect, the overall structure approximating to a gentle composite arch. In this area the basalts dip generally at about 5° to the east.

McClenaghan quoted a thickness of about 120 m at the reference section, although the number of flows and the total thickness appear to increase eastwards.

The lowest flows are basalts with numerous coarse phenocrysts of labradorite, olivine and augite. Younger flows, predominantly fine-grained olivine-basalt with sparse calcite-filled amygdales, become progressively less porphyritic: there are persistent intercalations of tuffaceous lacustrine sediment with thin flows of trachytic welded tuff. Red weathering of the blocky upper surface of the lava flows indicates significant time intervals between extrusive episodes. The tops of flows are usually vesicular and scoriaceous, weathered to a purple-grey colour. In thin section the groundmass of the basalts is mostly labradorite, showing flow orientation. Minor flows of hawaiitic basalt are sparsely porphyritic, with small phenocrysts of andesine, augite and altered olivine.

McClenaghan (op. cit.) suggested that a single broad dyke trending north-east at GR 363 206 was a possible source for part of the basalt; thickening of the lowermost flows suggests derivation from the south.

Jamakana formation ($Tpvt^{JK}$)

McClenaghan (1971) described the lower units of this sequence on the west side of the Nginyang River, the main outcrop of which lies on the south-east flanks of Ribkwo Volcano to the north-west. In this degree sheet area it is exposed only in the extreme north-west, on the east side of the Nginyang valley, mapped by Sceal (1974).

The total area of outcrop is about 26 km².

Mammalian remains were discovered in the Jamakana formation, north of this area, at Karmosit, including hippopotamus teeth and the Bovidae *Tragelaphus sp.* and *Aepyceros* (Coryndon, 1978 and Gentry *in* Bishop, 1978).

At age determination from a mugearite specimen gave a result of 3.4 ± 0.2 Ma (McClenaghan, 1971).

A sequence of 150 to 200 m comprises pyroclastics and sediments overlain by mottled trachytic extrusives.

Sceal's (1974) succession is based on correlation with McClenaghan's sequence from the west side of the Nginyang River:

	Thickness m
6 Mottled feldsparphyric trachytes (3 to 10 flows) and thin pumice tuffs	c.90
5 Bedded white or pale yellow pumice lapilli-tuffs	up to 30
4 Welded tuff breccia	c.5
3 Pumice lapilli-tuffs	35
2 Mugearite	c.10
1 Pumice tuffs overlain by fossiliferous sediments	60

Locally the mugearite (2) and welded tuff (4) are permeated by opaline chalcedony. The uppermost unit (6) corresponds to the 'Cheptonowa trachytes' of McClenaghan (1971): Sceal (1974) identified the core of Cheptonoiyo (Cheptonoya) Hill, 988 m (36°1.5′E: 0°58′N) as an old cinder cone with red tuffs dipping radially outwards at 30°: these are intruded by minor 'microsyenites', not demarcated on the map, which merge into extrusive trachytes.

The pumice lapilli-tuffs (5) attain their maximum thickness around Cheptonoiyo.

5.7 FLOOD TRACHYPHONOLITES AND TRACHYTES

Group Va of King and Chapman (1972) includes, as essential components, the trachyphonolites of Loyamarok on the western shoulder, the trachytes of Karau and Chepchuk of the eastern shoulder, and the Hannington Trachyphonolite Formation which dominates the southern section of the median rift (Figure 14).

These units, together with subordinate basalts and mugearites, comprise an association which Griffiths (personal communication) considers should be recognised as the 'Hannington (Bogoria)-Baringo Group'.

Quaternary flood lavas of the Western Rift Shoulder

On the western shoulder five units have been grouped here with this division:

5 Baringo basalts
4 Baringo trachyte
3 Loyamarok trachyphonolite
2 Chemakilani basalts
1 Murgisian basalts

The Loyamarok trachyphonolite (3) is the most typical of these flood lava sequences. The Murgisian basalts (1) occur in the Nginyang valley in the north, while units 2, 4 and 5 outcrop immediately east of Lake Baringo.

Murgisian basalts ($Qpvb^{MG}$)

Sceal (1974) mapped this formation as the 'Jarota Basalts', which were recognised to be the stratigraphic equivalent of the 'Murgisian Basalts' 14 km to the north-west (McClenaghan, 1971).

Exposures occur in the north-west corner of the Loyamarok Plains (in the Jarota area).

The Murgisian basalts are presumed to be younger than about 3 Ma. They are probably of early Pleistocene age. In their reference area on Degree Sheet 27 they have a thickness of 86 m, but they are much thinner in this area. The sequence unconformably overlies the Jamakana formation: early mugearite flows from Paka Volcano (the Katatim flow) are banked against the Murgisian basalts on the south-east side.

The basalt is dark grey and vesicular, with phenocrysts of olivine and labradorite (and occasionally of pale brown augite) up to 3 mm, often in glomerophyric clusters.

The Murgisian basalts represent the last phase of extrusion associated with the Ribkwo Volcanic Complex (see Key, 1986), and were extruded on the south-east flanks of that volcano.

Chemakilani basalts ($Qpvb^{CM}$)

Chemakilani (1123 m) is a hill 5 km NW of Kampi ya Samaki, on Lake Baringo: it lies just to the west of the boundary of this degree sheet area.

Martyn (1969) described the 'Chemakilani Group', which was designated as the 'Chemakilani Formation' (trachytes, mugearites, etc.), e^1 on the EAGRU map.

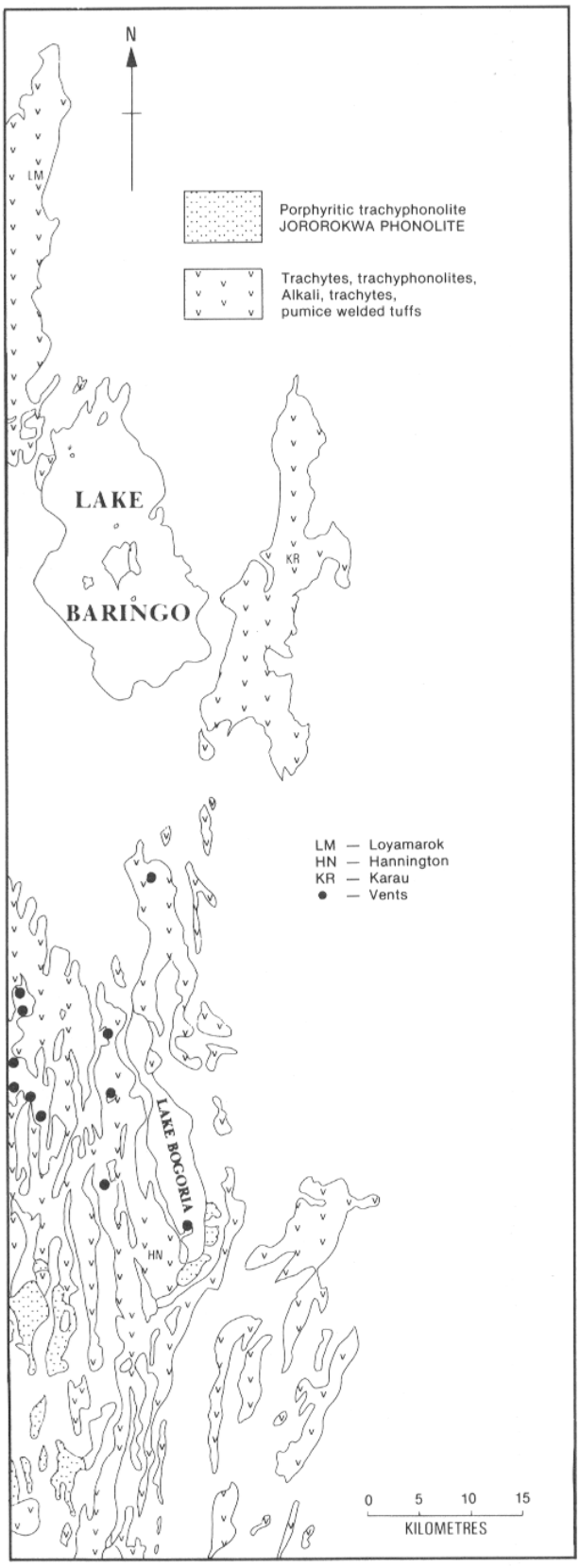


Figure 14 Distribution of Pleistocene trachyphonolites

Only about 1 km^2 of the Chemakilani basalts obtrudes on to this map sheet, surrounded by an outcrop of the overlying Baringo trachyte. In this area only part of a fairly complex sequence is represented, and the base is not seen: the rocks here were grouped by Martyn (op. cit.) as 'Nginyang Type' basalts, a name not used in the EAGRU compilation, presumably because the basalts at the reference locality of Nginyang were actually extruded from Paka Volcano.

An age of 1.8 Ma is given on the EAGRU map (Truckle, 1977), whereas Chapman and Brook (1978) quoted an age determination of 2.0 Ma.

The Chemakilani basalts in this area are petrographically similar to the rocks exposed on the slopes of Chemakilani Hill, which Martyn described as black-weathering, dark grey feldsparphyric basalts, with polygonal jointing.

Loyamarok trachyphonolite ($Qpvtp^L$· EAGRU: e^2)

Martyn (1969) mapped part of the southern end of the outcrop of the unit that he called the 'Loyamarok Phonolite'. Chapman (1971a) described a single flow of the 'Loyamarok Trachyphonolite Formation' impinging on the eastern boundary of his area. Carney also mapped part of the 'Loyamarok Trachyphonolites, and these rocks form part of the western boundary of the area mapped by Sceal (1974) as the 'Loyamorok Phonolite'.

The flow builds a well-defined low rocky plateau, covered with thick scrub, extending for 30 km along the western boundary of the degree sheet area. Like other areas of similar lithology, the plateau has a distinctive hummocky, lobate topography: it is likely that the existing limits of the outcrop correspond well with the original outlines of the flow. Pressure ridges parallel the outcrop margin: also a steeply inclined 'paraschistosity' (Martyn, 1969), an expression of the fissility parallel to the flow lines, manifests on aerial photographs as microlineaments.

An age determination has given a date of 0.57 Ma. The lava post-dates the development of the original east–west drainage system, which it has diverted into the north-flowing Burususwa River valley.

The Loyamarok trachyphonolite dips at a very low angle (about 1°) to the north-east, forming an escarpment parallel to the median rift.

The thickness of the unit is about 90 m in the middle of the outcrop, thinning gradually to the north, but more rapidly to the south.

The trachyphonolite is typically dark greenish grey to black when fresh, aphyric, with a fissile trachytoid texture: locally it is vesicular and flow-banded. Much of the flow is characterised by a partially devitrified ignimbritic carapace, appearing as a sheet, up to 1 m thick, of yellow glass enclosing flattened lava fragments.

In thin section abundant euhedral nepheline microphenocrysts (arranged in an ocellar texture) comprise 7 to 15 per cent of the mode. Sanidine is rarer, but aenigmatite, kataphorite, analcime and natrolite have been recorded, also aegirine-augite which often forms rims to the nepheline.

The base of the formation drops from an altitude of 1000 m in the south to about 850 m near Nginyang, presumably reflecting the original slope of the erosion surface over which the lava was extruded. Sceal (1974) suggested that the lava erupted from a fissure axial to the present line of the outcrop. There is little evidence for this, apart from a minor graben just east of the main watershed.

In most repects the Loyamarok trachyphonolite closely resembles the Hannington Trachyphonolite Formation (*q.v.*).

Baringo trachyte ($Qvpt^{BR}$)

Designated as e^3 on the EAGRU geological map (Truckle, 1977), the Baringo trachyte was described by Martyn (1969) as the 'Lake Baringo Trachyte', a unit within his 'Chemakilani Group'.

The Baringo trachyte outcrops over about 12 km^2 west of Kampi ya Samaki on Lake Baringo. It was the major source material for artifacts found in the Kapthurin Basin (Tallon, 1978).

The striking appearance of the outcrop on aerial photographs is due to lineaments which reflect pressure ridges resulting from the congealing of highly viscous lava. These flow forms indicate a source area in the southern part of the outcrop, about 3 km west of the map sheet boundary.

An age of 0.23 Ma is quoted for the Baringo trachyte (as a personal communication by J. A. Miller to Martyn, 1969).

The rock from a cliff north-west of Kampi ya Samaki was sampled for palaeomagnetic determinations (Dagley and others, 1978): 14 cores showed a northerly declination, but anomalously steep inclinations.

The trachyte seems to have flowed preferentially towards the north-east, presumably due to the original slope of the substratum. Its thickness is estimated to be up to 60 m.

The rock is fine-grained, black, streaked with green, and locally speckled, an expression of glomerophyric clusters of dark minerals. Sanidine forms about 60 per cent of the mode: otherwise aegirine-augite, aenigmatite and zeolites are commonly observed in thin section. Trachytic texture is very well developed, imparting a macroscopic fissility which resembles schistosity in the field: although subhorizontal near the source area, it is more often steeply inclined.

Baringo basalts ($Qpvb^{BR}$)

Thin basalt flows occur on the west side of Lake Baringo (e^6, Truckle, 1977), forming the greater part of outcrops which Martyn (1969) referred to 'Basalts of Nginyang Type'. They are well exposed on lakeshore promontories between Kampi ya Samaki and West Bay, and further north at Logoratibim.

These basalts are mostly younger than the Baringo trachyte (i.e. 0.23 Ma), but are in part essentially coeval.

Martyn described the configuration of ribbon-like outcrops extending westwards from the lake, comprising several flows of different ages. On the lake shore north of Kampi ya Samaki the flow at Logoratibim post-dates the Loyamarok phonolite but predates the Baringo trachyte, whereas other flows are younger than the Baringo trachyte. Martyn suggested that the basalts were mostly extruded from the east, filling areas of negative relief.

The Baringo basalts typically weather black, with a rough texture due to vesicularity. Columnar or rough blocky jointing is usual.

In thin section they appear fairly coarse-grained, with small labradorite and olivine phenocrysts in an intersertal to subophitic texture: augite tends to be titaniferous.

Quaternary Flood Lavas of the Eastern Rift Shoulder

Five mapped units are considered here:

5 Mistoni mugearites
4 Mukutan mugearites
3 Karau volcanics
2 Chepchuk volcanics
1 Chesowanja basalt

The Karau volcanics (3) are closely comparable to the other trachyphonolite sequences of the 'Hannington Group'.

Chesowanja basalt ($Qpvb^{CW}$)

Designated as $e^{4''}$ by Truckle (1977), this formation was first mapped by Carney (1972) in three segments in the Mukutan basin.

1 In a north–south strip trending some 5 km south-west of Tangulbei.

In the Chemoigut area:

2 Around Chesowanja hill, forming a low ridge trending north-east (36°12′E: 0°39.5′N).
3 Extending north-west from (2) to the gorge in the lower Mukutan River at 36°11′E:0°43′N.
(This was Carney's reference section).

This Chesowanja area was later mapped in more detail by Bishop and others (1978): they recognised the 'Chesowanja Formation', comprising two basalt flows about 12 m thick, and thickening to the north-west, both overlain by about 3 m of palaeosol.

An age for the upper flow was determined to be 0.71 ± 0.07 Ma (Bishop and others, op. cit.), but Hooker and Miller (1979) gave an apparent age of 1.42 ± 0.07 Ma for the same horizon.

Palaeomagnetics by Dagley and others (1978) showed the upper flow to have reversed polarity, but the lower flow was normal.

Acheulian artifacts occur in the upper parts of the weathering profile, with abundant calcrete nodules, which have developed on the upper basalt.

In the lower Mukutan gorge the Chesowanja basalt overlies yellow air-fall tuffs, which rest on trachyphonolites assigned here to the Karau volcanics. Two kilometres further north they abut against the southern end of the Chepchuk trachytes. However, in the Chesowanja reference area Bishop and others show the 'Chesowanja Formation' intercalated between the 'Chemoigut Formation' (part of the Chesowanja sediments, described in Section 6. 2), and volcanics of the 'Karau Formation', which are in turn overlain by more sediments (the 'Mukutan Formation'). To the west the main Chesowanja ridge is bounded by the Tarkokot Fault, which downthrows to the north-west (Bishop and others, op. cit., p.310). Folding on north–south axes preceded the extrusion of the Chesowanja basalt, and continued thereafter, giving rise to an asymmetrical anticline: to the west the dips are c.11°, to the east c.60°.

In the Chesowanja area the lower flow is a fissile olivine-basalt rich in plagioclase; distinctive flow textures are seen in thin section: the upper flow is an olivine basalt with diktytaxitic texture (Dickinson, 1965, p.101). In the Mukutan gorge the basalts have a distinct doleritic texture: large titanaugite crystals subophitically enclose plagioclase laths.

Carney (1972) believed these basalts to have been extruded from a fissure, and cites evidence of a dyke of identical rock type, 6 m thick and inclined at c.75°E, which intrudes air-fall tuffs on the south-east side of the Chesowanja ridge.

Chepchuk volcanics ($Qpvt^{CP}$)

Chepchuk (Chepchok), about 1380 m, is the highest point of a series of ridges trending NNE between the Tangulbei and Komol rivers. The area is at the most 8 km wide and about 13 km long, essentially founded on a complex of faulted pyroclastics, trachytes and anorthoclase-trachytes (respectively e^{c1}, e^{c2} and e^{c3} according to Truckle, 1977).

Carney and others (1971) quoted four age determinations on trachyte, and separate feldspar, from the Chepchuk volcanics, which ranged from 1.13 ± 0.06 to 1.22 ± 0.06 Ma. Dagley and others (1978) found that a sample of Chepchuk trachyte had reversed polarity, consistent with that age range.

According to Carney's (1972) reconstruction (Figure 15), the volcanic sequence at Chepchuk represents the eastern apron of a major volcano, of about the same dimensions as Paka, the western half of which was downfaulted towards the median graben, and covered by younger extrusives of Korosi and Paka (Figures 18, 19). The configuration of the volcanic units suggests two centres, one at Lotiamaleh (36°12′E:0°49.5′N) and the other (mostly obscured) about 4 km to the south-west (Figure 16). In the centre of the complex dips are high, but decrease eastwards until they are subhorizontal.

Carney detailed the following sequence:

5 Feldsparphyric basalts extruded in the Lotiamaleh caldera
4 North–south faulting, e.g. the Nagoreti Escarpment, with probable aggregate downthrow of over 900 m to the west.
3 Ring fracture at Lotiamaleh caldera in the north, and eruption of sparsely feldsparphyric caldera basalts
2 Minor extrusion of anorthoclase-trachytes and pyroclastics.
1 Simultaneous eruption of interdigitated quartz-trachytes and pyroclastics.

The uppermost basalts (5) have not been distinguished from the Korosi basalts on the EAGRU published map (Truckle, 1977).

The pyroclastic sequence, predominating in the west, comprises bedded tuffs, 'froth-flows' and air-fall tuffs, intercalated with streaky altered trachytes. Good sections occur along the face of the Nagoreti Escarpment.

Carney identified sequences indicating cyclic repetition of units, as follows:

	per cent
4 streaky holocrystalline trachyte/quartz trachyte	43
3 'froth-flows' (contorted vesicular trachyte)	26
2 streaky porcellaneous welded tuffs	13
1 basal incoherent pumiceous lapilli-tuffs	18

The quartz-trachytes are the most voluminous component of the Chepchuk volcanics, covering about 130 km^2.

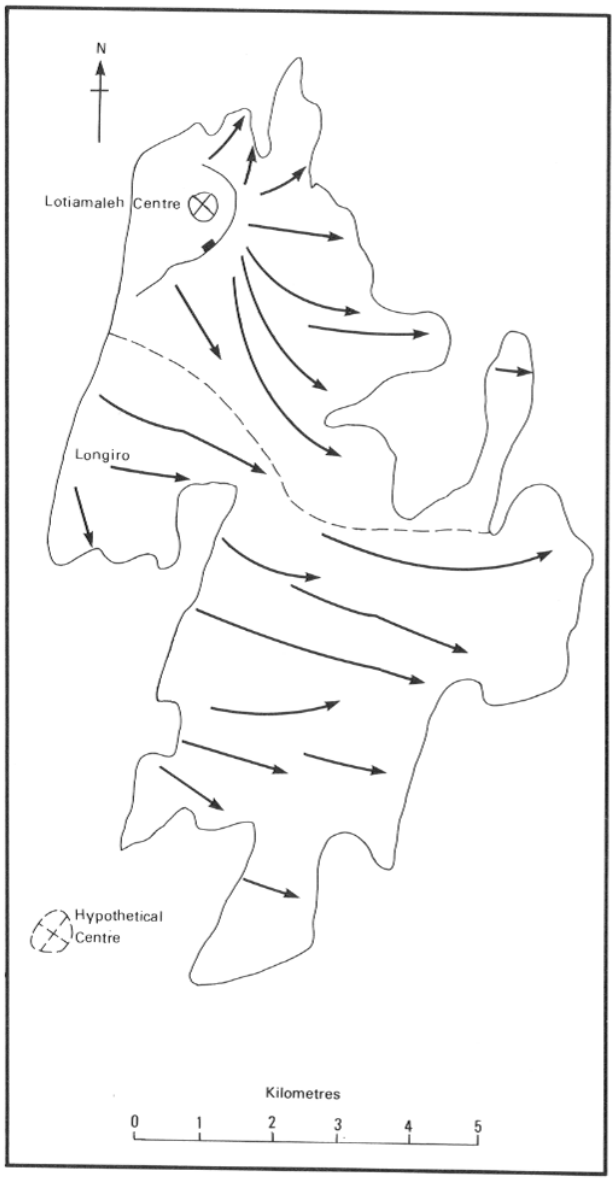


Figure 16 Chepchuk Volcano: centres of extrusion and direction of flow (after Carney, 1972)

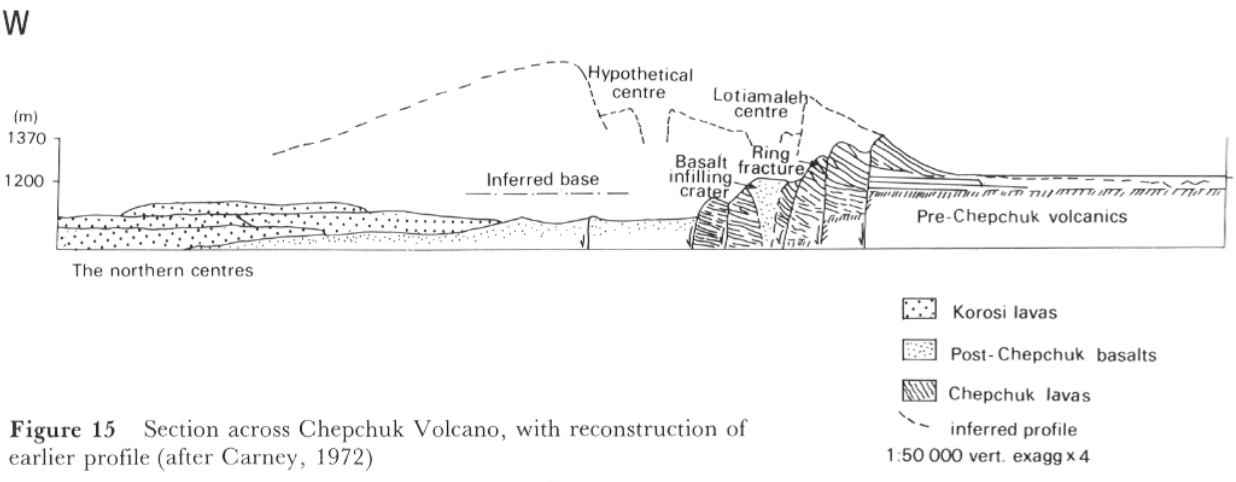


Figure 15 Section across Chepchuk Volcano, with reconstruction of earlier profile (after Carney, 1972)

Flow tops show well-preserved pressure ridges, scored by steeply inclined fissility, with flow fronts up to 15 m high. Flow soles are usually autobrecciated. Generally the indications are that the direction of the flow was towards the east or south-east.

Very fine-grained quartz-trachytes predominate, often with a pilotaxitic texture in thin section, defined by aggregates of sanidine microlites, aegirine-augite and aenigmatite.

Anorthoclase-trachytes (and trachymugearites) are intercalated with the uppermost pyroclastics on the western side of the outcrop. These trachytes are medium-grained with a distinctive orthophyric texture: the anorthoclase is zoned to sanidine, occurring with pale green augite and rarer arfvedsonite and fayalitic olivine.

A solitary trachymugearite flow contains corroded alkali feldspar in glomerophyric clusters, plagioclase, augite and olivine.

Karau volcanics ($Qpvtp^{KA}$)

The term 'Karau volcanics' is used here to group together the essentially trachyphonolitic Pleistocene extrusives of the Karau Escarpment east of Lake Baringo, i.e. it includes the volcanoes of Paratallo (e^{1a} of Truckle, 1977), Erinei (e^{3a}) and Karau (pumice lapilli-tuffs e^{4a} and welded tuffs e^{4b} related to those cones, also the 'plateau' trachyphonolites e^{4c} such as the Lokurutongwe flow between Karau and Narokwe Hill). Also included for description here are the 'Iguamiti Phonolites' of Carney, 1972 ($c^{22'}$).

These extrusives form a ridge about 5 km wide extending north–south for about 25 km, separating the Mukutan Basin to the east from the plains around Lake Baringo to the west (Figure 14).

From south to north there are three main volcanic centres:

1 Paratallo, 1370 m, with a well preserved summit crater at 36°10.5′E:0°31′N.
2 Karau, 1485 m, 10.5 km north of Paratallo: like Chepchuk the western side of its crater has been obliterated by faulting and erosion (Figure 17).
3 Erinei, adjacent to Karau, to the north-east: partly obscured by tuffs from Karau, the hill is built of frothy, poorly-stratified trachytic spatter.

A specimen collected west of Narokwe Hill, from a lava sheet predating volcanics extruded from the Karau centre, yielded a date of 0.56 Ma. Table 4 details Carney's sequence of events.

Table 4 Karau Volcano: scheme of events (after Carney, 1972)

Paratallo	Karau	Erinei
7	localised trachyphonolite flows	
6	tuffs, welded tuff and trachyphonolites	
5		trachyphonolites
4	Chesowanja basalt (*q.v.*)	
3	pumice lapilli-tuffs and welded tuffs	
2 Hannington	type plateau lavas	
1 trachyphonolite 'froth' flows		

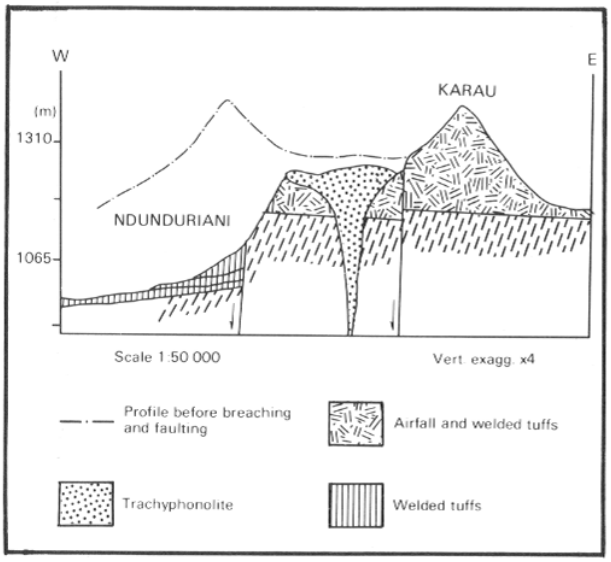


Figure 17 Karau Volcano, with reconstruction of original profile (after Carney, 1972)

Essentially the trachyphonolite lavas are fairly uniform in terms of their almost saturated composition, and their textural features. Nepheline phenocrysts, usually only visible in thin section, occur in a trachytic matrix, which may be coarse-textured, with abundant sanidine, groundmass aegirine-augite and aenigmatite/kataphorite, and pools of analcite, possibly of secondary origin. Griffiths (1977) designated the lavas of Paratallo as 'Kisonei' type.

The pyroclastics of Karau started with extrusion of incoherent pumice lapilli-tuffs and yellowish welded flows. Lapilli reach a length of 2.5 cm, the fragments including highly vesiculated black obsidian and pumice bombs up to 1.2 m in diameter. The welded tuffs are streaky and porcellaneous, in flows about 3 m thick, often phasing up into vesicular slaggy lava. Obsidian fragments are much compressed.

Certain interpretations of the stratigraphic detail of the Karau volcanics as described in Carney and others (1971) and Carney (1972) need to be reviewed in the light of the descriptions of the volcanic and sedimentary stratigraphy of the Chesowanja area by Bishop and others (1978).

The 'Karau Formation' of Bishop and others overlies unconformably the Chesowanja Formation (basalt), following a period of faulting and folding. Fifteen metres of pumice tuff interdigitate with 5 to 7 m of tuffaceous lacustrine beds, separated from the overlying Karau trachytes (dated at 0.54 Ma) by a pisolithic ferruginous calcrete soil.

The EAGRU map (Truckle, 1977) shows, derived from Carney (1972) a narrow outcrop of 'Iguamiti Phonolite' ($C2^{a'}$) along the western fringe of the Karau Escarpment. Carney compared this faulted sliver of speckled phonolites, on the basis of petrography, with McCall's (1967) 'Iguamiti flows' south-east of Lake Bogoria. There are no age determinations to justify such a correlation: for simplicity these rocks are shown as part of the Karau volcanics on the 1:250 000 geological map.

Mukutan mugearites ($Qpvg^{MU}$) ($e5^a$ of Truckle, 1977).

The 'Lower Mukutan Mugearite' of Carney (1972) overlies the Chesowanja basalt north of the lower

Mukutan gorge. This lava sequence thins eastwards, and is downfaulted to the west along the line of the Karau Escarpment.

Sixty per cent of the rock is composed of oligoclase/andesine laths showing flow orientation: alkali feldspar and diopsidic augite occur in the groundmass.

MISTONI MUGEARITES ($Qpvg^{MI}$) ($e6^a$ of Truckle, 1977).

The 'Mistoni Basalts' are grey, sparsely porphyritic lavas outcropping in disconnected strips west of the Karau Escarpment, against which they flowed, and were in part left as 'facings'.

The probable sources of these minor occurrences are obscured by downfaulting to the west, and by younger extrusives of Korosi Volcano.

Carney and others (1971) include the 'Mistoni lavas' in the 'Lower Mukutan Basalt', but according to Carney (1972) the 'Lower Mukutan Mugearite' predates, and the 'Mistoni Basalts' post-date the 'Chemoigut Beds' of the Chesowanja Sediments.

At Akapail (GR 1829 0765) at the northern end of the chain formed by outcrops of the Mistoni mugearites, on a small N–S ridge, a steep dyke of fissile mugearite intrudes incoherent yellow lapilli-tuffs, which dip gently eastwards.

Quaternary flood lavas of the Median Rift

The 'Hannington Trachyphonolite Formation' of Griffiths and Gibson (1980) floors the southern part of the median rift. The following associated sequences are considered here:

6 Molo Tuffs
5 Koitumet Basalts
4 Jorokokwa Phonolite
3 Hannington Trachyphonolite
2 Kwaibus basalts
1 Emsos mugearites

EMSOS MUGEARITES ($Qpvg^{E}$)

This sequence of mugearites and subordinate basalts was mapped by Griffiths (1977) on the main escarpment south of Lake Bogoria (36°6′E: 0°9.5′N). They are exposed in one stream section, although blocks are found for a distance of over 3 km along the scarp foot. A specimen of trachymugearite gave a K/Ar date of 2.5 ± 0.7 Ma.

The sequence is essentially as follows:

3 Up to 20 thin mugearite flows.
2 Two feldsparphyric basalt flows with an intercalated trachymugearite.
1 Agglomerates, with blocks and tongues of mugearite.

Griffiths (op. cit.) suggested that these mugearites were erupted from a fissure, a precursor to the main Bogoria Fault.

KWAIBUS BASALTS ($Qpvb^{KW}$)

McCall (1967) used the term 'Kwaibus Basalts' for a sequence of thin basalt flows outcropping about 10 km east of the north end of Lake Bogoria, around the hill named Kwaibus. He described them together with the 'Goitumet Basalts', which have since been shown to be much younger.

Griffiths (1977) found that these basalts extend considerably to the west of 36°E, as shown on the EAGRU map of the Eldama Ravine area (Truckle, 1978). However, the longitude of 36°E seems to bisect the original areal extent of the Kwaibus Volcano: Griffiths (op. cit., fig. 32) plotted ten of the known 19 eruptive centres in the outcrops to the east, on Degree Sheet 35.

No age determinations have been made on these basalts. A palaeomagnetic study of a sequence to the west of 36°E found normally magnetised flows underlying basalts with reversed polarity: the basal flows gave intermediate directions. Dagley and others (1978) deduced that the normal flows represent the Jaramillo event (0.89–0.95 Ma, mid-Pleistocene). Such a date accords with the relationships unravelled by EAGRU mapping.

Due to misconceptions about the relationships with the Koitumet (Goitumet) basalts and the Jorokokwa phonolite, the Kwaibus basalts were shown as Miocene on McCall's map: the maximum thickness of over 1000 m shown on his section is probably much exaggerated.

The Kwaibus basalts consistently underlie flows of the Hannington Trachyphonolite Formation. Outcrops are small and scattered rarely exposing more than eight flows, but their disposition conforms with a multicentre shield volcano concentrated on Kwaibus Hill.

Individual flows vary up to 10 m thick, sometimes with columnar jointing in their interior zones. The base of the basalts is not seen in this area, but to the west there is evidence of eruption on to a rugged land surface.

Spongy, cindery flow tops are characteristic of the Kwaibus basalts, with ropy surfaces. Petrographically they range from alkali olivine basalts to hawaiites, including also feldsparphyric basalts, usually with small phenocrysts. The vents are mostly cones of cinder and scoriaceous basalt, although thick units of reddish augite-rich tuffs are exposed in fault scarps, intercalated with the basalt flows. Near the vents the flows contain numerous leucogabbro nodules up to 5 cm in diameter.

HANNINGTON TRACHYPHONOLITE FORMATION ($QpvtP^{HN}$)

The late Pleistocene Hannington Trachyphonolite Formation has been defined by Griffiths and Gibson (1980), formerly described by McCall (1967) as the Dispei–Lake Hannington Phonolites. The official name of the lake is now Bogoria, although 'Hannington' has been retained in the formal stratigraphic nomenclature.

This tabular, or low-angle, shield occupies an extensive area of the southern part of the Rift Valley on Degree Sheet 35: it has been mapped up to 30 km to the west of 36°E, a total area of about 2750 km^2 (Figure 17).

The surface of the lava formation, formerly even, has been disrupted by a spectacular anastomosing system of grid faults (Plate 8). Two main phases of extrusion were separated by a period of faulting.

Chapman and Brook (1978) quoted four K/Ar age determinations for the Hannington trachyphonolites, ranging from 1.6 ± 0.2 to 0.3 ± 0.1 Ma. The Hannington flows are inferred to rest extensively on the Kwaibus Basalt, and are overlain by the Koitumet basalts and scattered trachytic pyroclastics (Molo Tuffs).

The composite formation, according to Griffiths (1977) probably resulted from the coalescence of rather fluid flows extruded over a short period from several small, widely dispersed vents. In the map area three early eruptive centres are known east of the Hannington Fault line, and one occurs in the Mugurin valley south-east of Lake Bogoria (Figure 17). The later eruptive phases were more active further west.

The known thickness of the sequence averages about 150 m, but approaches 300 m in the south (Kamaech Horst).

The formation consists essentially of salic undersaturated lavas ranging from trachyte to phonolite, with trachyphonolites predominating. Tuffs and agglomerates

are subordinate. About 60 per cent of the lavas are porphyritic, usually in alkali feldspar.

According to Griffiths the mineralogy of the rocks is remarkably uniform, especially as far as the groundmass is concerned. The predominant phenocrysts, in about 75 per cent of the suite are alkali feldspars, either anorthoclase (characteristic of those rocks with less than 600 ppm Zr) or sanidine (typical of rocks with more than 600 ppm Zr). Minor phenocryst phases include clinopyroxene (colourless or pale green augite and aegirine-augite), ore and olivine (restricted to some trachytes): the groundmass usually contains alkali feldspar, clinopyroxene and opaques, also (except in some trachytes) nepheline and aenigmatite; occasionally traces of apatite occur.

In spite of the relative homogeneity of mineral composition, Griffiths (1977) recognised certain distinct textural types which are apparently, in this area, characteristic of extrusions from particular centres. The three most important are:

1 Kaptim type trachytes: green or blue-grey fissile lavas granular, somewhat porphyritic in anorthoclase.
2 Kisonei type trachyphonolites: grey or blue-black, granular with sparse (up to 5 per cent) sanidine phenocrysts, often mottled or flow banded, and with dark inclusions of lava resulting from autobrecciation.
3 Belatiat type phonolites: dark blue-green, flinty or granular with about 10 per cent large sanidine phenocrysts.

On the basis of textural differences, Griffiths mapped two main subdivisions of the Hannington Formation in the area west of 36°E (Figure 17):

1 The '*Kepkeluon Phonolitic Trachytes*', outcropping in small faulted strips between Lake Bogoria and the Ndolaita valley, including an important element of 'Kaptim Type'.
2 The '*Changmasa Trachyphonolites*', a large continuous series of 'Kisonei type' accounting for most of the remainder of the outcrop, overlying and interdigitating with the Kepkeluon lavas. Vents are identified by massive agglomerate bodies, comprising angular vitreous blocks in a matrix of red and yellow tuffs.

The Changmasa trachyphonolites flowed up to escarpments in older volcanics of the eastern rift shoulder: a 'facing' of these lavas above the lake on the eastern escarpment was left on the hanging wall of the Bogoria (Hannington) Fault.

Griffiths and Gibson (1980) reported on the petrochemistry of a suite of 38 rocks from the Hannington Trachyphonolite Formation. Their study suggested petrogenesis in terms of differentiation by prolonged feldspar fractionation of trachytic magma, possibly in a single source chamber in the upper crust, with, initially, very low residual trace element abundance: the zirconium content was used as a suitable index of chemical, and hence, mineralogical variation within the Hannington Formation.

Jorokokwa phonolite ($Qpvp^{KJ}$)

McCall (1967) mapped porphyritic phonolites outcropping on the west side of the Mugurin valley and at the foot of the Legisianana (Changmasa) Escarpment, as the 'Jorokokwa Phonolite', bracketed together with the Rumuruti phonolites as Miocene on the basis of their petrological similarity to the Marmanet and Waseges flows of the Rumuruti Group. The EAGRU mapping and age determinations indicate, in fact, a late Pleistocene age.

Griffiths (1977) treated the Jorokokwa phonolites as a late phase of the Hannington trachyphonolite sequence, together with the 'Losaramat flows' on the south-east side of Lake Bogoria, on the Mwanasis peninsula, and southwards along the Changmasa Escarpment.

The thickness of the unit varies up to 100 m, structurally overlying the Changmasa trachyphonolites of the Hannington Formation.

Petrographically the Jorokokwa phonolites are mostly the flinty 'Belatiat' type of Griffiths (1977), conspicuously porphyritic in sanidine, although the Losaramat flows tend to be 'Kisonei' type phonolites, i.e. vitreous, flow banded and sparsely feldsparphyric.

Koitumet basalts ($Qpvb^{KO}$)

The Koitumet (Goitumet) basalts outcrop about 15 km SW of the southern end of Lake Bogoria, on the edge of the degree sheet area.

McCall (1967) described them as a series of lava tongues radiating from a hill west of Mugurin, which appears to be a central volcanic cone surmounting a broad dome about 7 km in diameter, straddling the 'Molo graben'. These basalts post-date the grid faulting of the underlying Hannington Trachyphonolite Formation: McCall mapped them, together with the Kwaibus basalts, as Miocene. Their thickness approaches 150 m.

The Molo tuffs generally overlie the edges of the Koitumet 'Dome', but locally they are intercalated with the Koitumet basalts (Griffiths, 1977).

Petrographically these basalts are very homogeneous; separate flows cannot be recognised, but the rock is well jointed. Characteristic is a rough-textured vesicular grey basalt finely porphyritic in labradorite.

Molo tuffs (Qpf^{M})

In the southernmost part of the median rift in this area, low ground is sometimes covered by thin tuff veneers, designated by McCall (1967) as 'Qtz'-tuffaceous sediments, red clay, silts and torrent wash (Mugurin beds). Griffiths (1977) mapped these outcrops as the 'Molo Tuffs', the largest of which (in this area) mantles the eastern flanks of the Koitumet basalt dome, in the Mugurin valley (upper Ndolaita River). Minor occurrences are also found on the Kamaech horst to the east and on the escarpment west of Lake Solai, but too small to be shown on the 1:250 000 geological map. The outcrops tend, on the low ground, to be buried beneath Recent silts, and extensive erosion has otherwise isolated them. Griffiths suggested that these tuffs originally covered a much larger area, as products of an ash flow derived from the south.

The Molo tuffs in part interdigitate with the Koitumet basalts, and are therefore of similar age.

Individual tuff units mapped attain a thickness of 6 m, usually separated from each other and from the underlying lavas (either Koitumet basalts or Lake Hannington trachyphonolites) by dark red clay soil.

On the Kamaech horst the tuff, in places up to 10 m thick, is similar, but more flinty, with flattened lithic fragments, partly of vitreous material. These occurrences were referred to by McCall (op. cit.) as 'ignimbrites' (Tvf_3), assignd to his Pliocene 'Kinangop Tuff Series'.

5.8 TRACHYTE/BASALT CENTRAL VOLCANOES

The two complex volcanic massifs of Paka and Korosi, the latter extending to Ol Kokwe Island in Lake Baringo, dominate the median section or inner rift depression of the rift valley north of that lake: the extrusives comprise

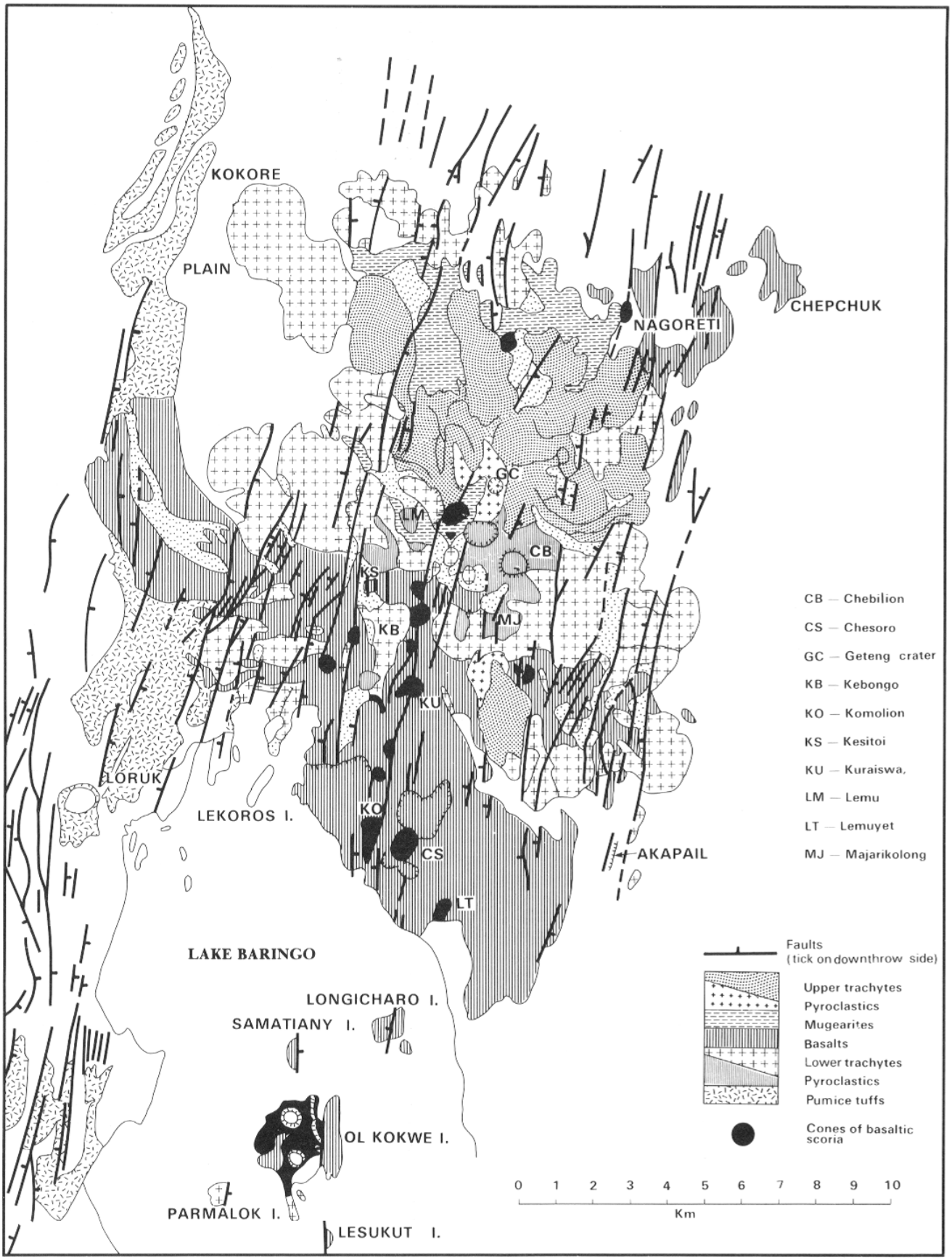


Figure 18 Korosi Volcano and Ol Kokwe (after Carney, 1972)

diverse sequences of trachyte, basalts, mugearites and pyroclastics recording a period of intense volcanicity, punctuated by phases of contemporaneous faulting.

Both Paka and Korosi retain an almost undissected surface relief: they are both low single multi-centre volcanic massifs, although Paka has a more conical aspect.

Pyroclastics and exposed basaltic extrusives, essentially erupted from fissures, are more abundant on Korosi than Paka. On both Paka and Korosi basalts make up 20 to 25 per cent by volume of the extrusive sequence (Weaver and others, 1972), i.e. basalts are more abundant than on other central volcanoes of the Gregory Rift.

Korosi Volcano

Korosi covers an area of about 250 km², reaching a height of 1446 m at GR 1800 0844 (Figure 18).

Trachytic extrusives, with pyroclastics around the multicentre vents, and later mugearites characterise the northern side of the volcano, and the summit area: in general the trachytes are not so rich in quartz as the Chepchuk volcanics to the east, but show a wide range of petrographic type. The southern part of Korosi, which may logically be extended to include Ol Kokwe island in Lake Baringo, is a complex of basaltic lavas and cones aligned along prominent fissures trending NNE. Carney (1972), who mapped the whole area in detail, proposed the following scheme of eruptive phases, not necessarily correlatable over all parts of the complex:

5 Upper Korosi Trachytes ($Qpvt^K$)
Faulting epidode
4 Basalts ($Qpvb^K$) and mugearites ($Qpvg^K$) of:
South Korosi – Ol Kokwe
Korosi flanks and summit
Nagoreti – Tapogh
Minor faulting
3 Middle Korosi Trachytes
2 Lower Korosi Trachytes
1 Korosi Tuffs ($Qpvf^K$)

$Qpvf^K$ (shown as one unit on Figure 18)

Carney (op. cit., fig.25) in his chronostratigraphic table for Pleistocene volcanics, allocates Korosi a time span of about 0.4 to 0.1 Ma.

The composite volcanic pile is probably between 700 and 800 m thick.

1 The 'Korosi Tuffs' outcrop on the Kokore Plain to the west of Korosi, but also locally on the summit and northern flanks. From 120 to 180 m thick, they are typically poorly sorted, incoherent, yellowish pumice lapilli-tuffs of variable grain size, and certainly of air-fall origin. They overlie and largely obscure thin mugearite flows, seen at the north end of Lake Baringo, which Carney named the 'Loruk Mugearites' (here considered with the Baringo basalts, or on a par with the Mistoni mugearites).

2 The 'Lower Korosi Trachytes', overlain by the later volcanic sequence, outcrop only around the fringes of the volcano. Sparsely porphyritic in anorthoclase (and sometimes fayalitic olivine), they contain kataphorite and aegirine-augite aggregates in a matrix of flow-orientated sanidine and anorthoclase laths.

3 The 'Middle Korosi Trachytes' were extruded, flowing to the west and east, from about a dozen pyroclastic cone or dome sources which are aligned along three north – south fracture belts, the middle one of which is axial to the present summit area.

The Chebilion cone, above the eastern flank, is the highest point of Korosi. About 1.5 km to the south is Majarikolong (GR 1798 0828), which features a north – south crestal fissure, into which 'a rib of strongly ridged trachyte protrudes through a mantle of pumiceous trachyte'.

Lemu, on the north-western side of Korosi, is an eroded cone, probably one of the oldest centres.

Petrographically, the trachytes associated with these and other centres vary from rare quartz-bearing types (also seen in the lower trachytes) to phonolitic trachytes with nepheline microphenocrysts: they may be highly or sparsely porphyritic in anorthoclase, with sanidine and anorthoclase in the groundmass, microphenocrysts of fayalitic olivine, also aegirine-augite, kataphorite and arfvedsonite.

The total maximum thickness of lower trachytes and middle trachytes together is c.210 m.

4 Basalts and mugearites, up to 120 m thick, occurring in three distinct areas, are believed to have been broadly synchronous: they were extruded along fissures trending NNE.

1 The *Nagoreti-Tapogh (Tabong) area* Basalts and mugearites outcrop over parts of the low ground between Korosi and Chepchuk, and have infilled valleys cut into the underlying trachytes on the northern lower slopes of Korosi. The mugearites of the Tapogh area, towards Paka, contain unusual aggregates of glomerophyric gabbroid. The distinction, on the ground, between these basalts and the lower basalts of the Paka sequence, seems to be arbitrary.

2 *Summit and northern upper slopes of Korosi* Mugearite flows have emanated from cones of cognate pyroclastics in these areas. There are also flows of anorthoclase-trachyte, associated with hybrid-type trachymugearites similar to some of the lavas found on Chepchuk.

3 *South Korosi – Ol Kokwe* A line of basaltic spatter cones trends south from the summit through the multicentre vent systems of Kuraiswa (Kechii, GR 1773 0800), Komolion (Gomulion) and Chesoro: Kebongo, a centre offset some 2 km to the west from the main fissure system, is a cone which has been banked up against an eastward-facing fault escarpment: the evidence indicates faulting contemporaneous with extrusion.

The trend may be extrapolated across Lake Baringo to include the cones of Ol Kokwe island. The intervening islets of Samatiany and Longicharo are entirely of the same basalt. Parmalok island, to the west, is a partly submerged trachytic centre.

The form of the extrusives varies from 'spatter cones' to flows of feldsparphyric or aphyric basalt: some cones, like Chesoro, have bedded agglomerate units. The essential contemporaneity of such different manifestations is very evident.

5 The Upper Korosi Trachytes, 90 to 150 m thick, outcrop on the northern and north-eastern flanks of the massif. They were extruded mainly from source vents on the northern summit, and have since been very little disturbed by faulting. Carney (op. cit.) identified six eruptive centres on the ground, including the largest crater on Korosi, Geteng (Kinyach on the 1982 1:50 000 topographic map), which is 600 m in diameter and 120 m deep.

These trachytes show a similar range of forms to the older flows, i.e. frothy, clastic, or as extrusive domes. They are porphyritic in sanidine and/or anorthoclase (and occasionally olivine): the groundmass contains those minerals also, also aegirine-augite, kataphorite, arfvedsonite and sometimes analcime.

Paka Volcano

This description of the volcano known to the east Pokot tribesmen as Paka (Pakka), is essentially due to Sceal (1974).

Paka is a complex multicentre low-angle basalt-trachyte volcano dominated by a young central caldera west of the

summit, 1.5 km in diameter, with very steep sides: Sceal believed this to have been formed by cauldron subsidence, because of its steep sides and the absence of evidence for explosive activity. The youngest trachytic activity of this centre has given the mountain its conical form. Within the caldera, on the west side, is a basaltic cinder cone surrounding a vent (Figure 19).

About 1 to 2 km to the south-east, along the summit ridge, is an older, smaller crater which was probably the source of the bulk of the extrusive pile on the east side of the mountain. The WSW alignment of the summit caldera area parallels that of the Silali Volcano to the north; however faults trending NNE, particularly the western 'Boundary Fault', and a swarm of faults associated with lines of cinder cones and vents on the eastern side of Paka, appear at times to have constrained the spread of extrusives (particularly the younger trachytes) across the rift, and so influenced the shape of the volcanic massif. The central bulk of the volcano occupies an area of about 40 km^2, but the derived extrusives, particularly the lower basaltic sequence, extend to over 25 km from the summit caldera.

Since the volcano has not been subject to much dissection, sequences have been determined from mutual relationships between flows and/or deposits associated with centres, rather than from vertical successions, which are rarely exposed. Aerial photographs of Paka reveal the pristine, unvegetated terrain: the volcanic structures, and the relationships between basaltic, trachytic and pyroclastic units show up in spectacular detail (c.f. Muruese), although the pyroclastics are not usually well exposed on the ground.

The following sequence is slightly revised from Sceal's (1974) scheme:

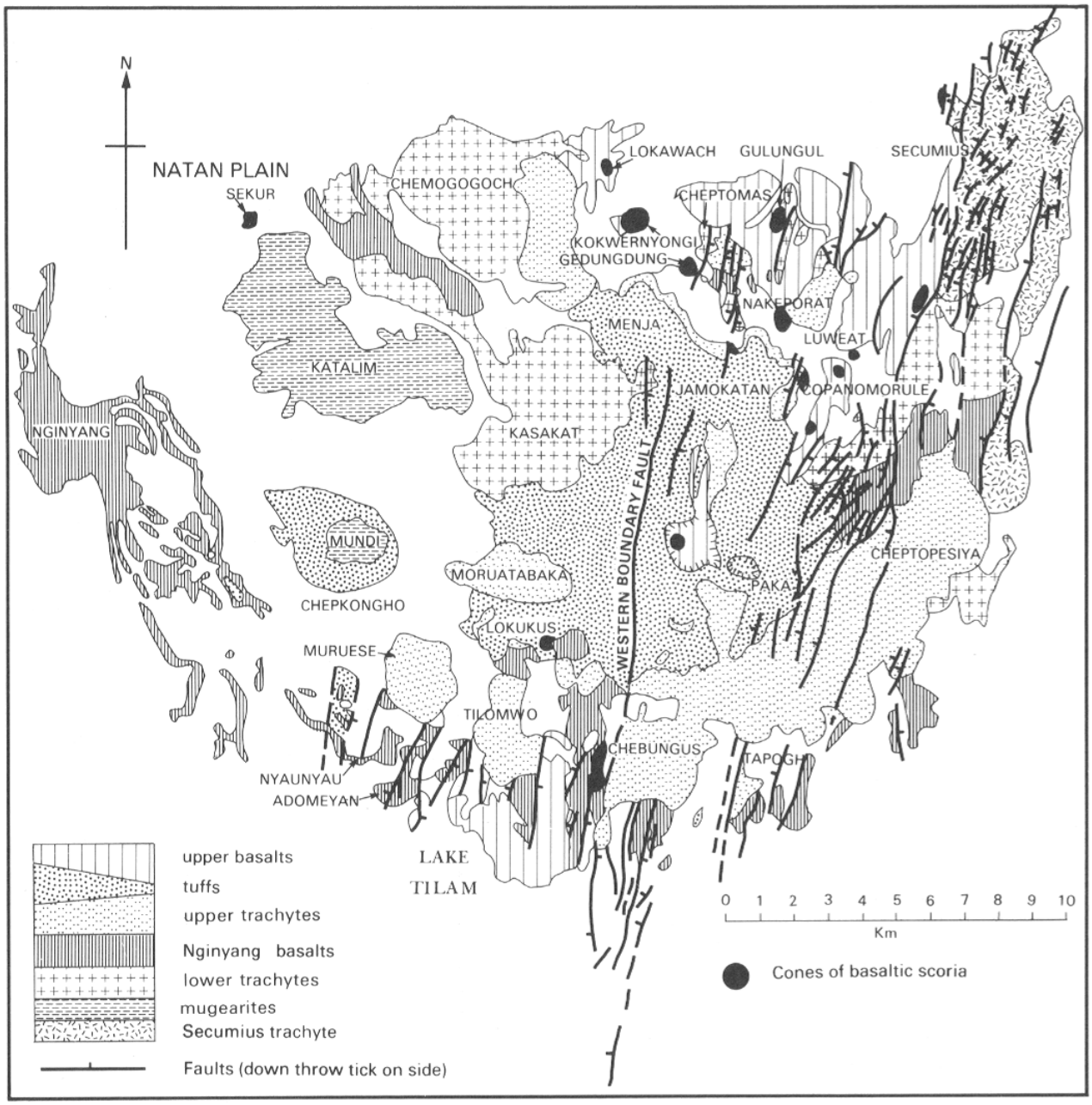


Figure 19 Paka Volcano (after Sceal, 1974)

6 Upper basalts (Qvb^P)
5 Upper trachytes and tuffs associated with the central cone ($Qpvt^P$ & Qvf^P)
4 Lower basalts (cf. 'Nginyang Basalt' Chapman) ($Qpvb^P$)
Faulting
3 Lower trachytes (Kasakat). ($Qpvt^P$)
2 Mugearites (Katalim) ($Qpvg^P$)
1 Secumius trachyte ($Qpvt^P$)

The age of this sequence probably ranges from the early Pleistocene: the youngest flows are believed to be only a few hundred years old, and fumaroles are still active in the vent in the Komol valley, and on the northern slopes. The aggregate thickness of the Paka volcanics probably exceeds 800 m.

1 THE SECUMIUS TRACHYTE The 'Secumius Trachytes' of Sceal (1974) (misspelt 'Secuminus', e^{a1} on Truckle, 1977), are described here for convenience as they occur at the base of the Paka sequence in a narrow faulted zone on the extreme east and north-eastern flanks of the volcano. These trachyte flows were banked up against fault scarps of the Orus trachyte (section AA′ on the 1: 250 000 map). Although mostly separated from Paka trachytes *s.s.* by the outcrop of the Kokwapang'a basalt, they cannot be distinguished from the former in the field. The reference area is at Secumius Hill 1.6 km north of the degree sheet boundary (Key, 1987). Although designated as Pliocene by Truckle (1977), they could be Quaternary: no age determinations are available.

Along most of the outcrop the Secumius trachyte dips north at a low angle.

Characteristically the rocks are analcime-trachytes with alkali-feldspar phenocrysts, up to 2 cm in length, but quartz-trachytes with sodalite microphenocrysts, and mugearites, also occur in the sequence.

2 MUGEARITES The Katalim mugearite, a tough deep grey vesicular rock, is a single flow, which clearly postdates the Jamakana formation and the Chemakilani basalts of the Jarota area, north-west of Paka. Its areal extent is about 26 km^2, extruded from a fissure source at GR 806 061. Most of the rock is made up of oligoclase laths, with a trachytic texture, and interstitial green pyroxene and opaques.

On the south side of Paka, near Tilam, a single flow of very fissile brown-green weathering mugearite, vesicular towards the top, is exposed below the 'Nginyang Basalt.' On the west side of Mundi Hill (GR 1022 1777) three mugearite flows dip west at about 2°, capped by a trachyte flow which Sceal considered was extruded from a vent at the top of the hill.

3 THE LOWER TRACHYTES The largest extent of these flows reaching down to the Natan plain (GR 1760 1100) on the north-west side of Paka, originated from the extrusive centre at Kasakat Hill (GR 1835 1040). Northwest of Kasakat there is an exposure of associated pumice lapilli-tuffs. Flows also cross the northern boundary of the degree sheet near Chemogogoch (GR 1810 1102), and inliers in younger flows occur at Cheptomas (a small cone surrounded by later basalts at 1885 1102) and at Jamakatan (1885 1077), also in the faulted sector on the north-east flanks of Paka. The Kasakat trachytes have blue-grey basaltic inclusions, porphyritic in feldspar, olivine and augite.

4 THE LOWER BASALTS A sequence of 6 to 8 visible flows, described as the 'Nginyang Basalt' by Chapman (1971), occupies over 10 km^2 to the south-west of Paka: they flooded the plains to beyond Nginyang township 24 km to the north-west. These basalts were extruded from two lines of NNE-trending fissures on the southern side of Paka, south of the vent named Lokukus at GR 1832 0992. To the south they are overlain by trachytes from Korosi, and to the east by the upper Paka trachytes. Other outcrops of these 'older' basalts are smaller, and widely disconnected. A solitary basalt flow outcrops at GR 1805 0995 on the north-west side of Paka, between the trachyte flows of Kasakat and Chemogogoch. To the east, on the north side of the volcano, a small basalt cinder and spatter cone (Jamakatan) occurs at GR 1886 1077 overlain by pumice tuffs, and almost engulfed by younger trachytes from the south. Further east Nakeporat (GR 1902 1085) is a small steep-sided cone breached on the north side by a basalt flow, which underlies a level area to the north-west; a neighbouring vent to the east is the source of a flow of highly porphyritic picrite-basalt.

Other basaltic outcrops in the north-east sector of Paka have been much disturbed by faulting. Minor flows are exposed on the south-east side, extending on to the Tangulbei plains: there, flow units dip east at 10°.

The Nginyang basalts are usually vesicular, fine-grained, black to blue-grey in colour, with phenocrysts of plagioclase, olivine and augite up to 5 mm in length. The plagioclase varies from An20 to An90, and the augite is commonly mauve and titaniferous. Textures are commonly intergranular.

5 THE UPPER TRACHYTES, extruded mainly from the central summit vent, gave the volcano its present conical form. The outcrops may be considered in terms of three sectors:

1 In the south-east, forming an arc from the southern end of the Secumius trachyte outcrop, including Cheptopesiya, to Chebungus in the south. Several large flows build up a series of fronts up to 30 m high, with well-preserved pressure ridges and tension fissures. Some of these flows are capped by 'button flows', which may be small extrusive domes representing the last phases of eruptive activity.

2 The western sector includes the flows of Moruatabaka extruded from GR 835 008; Muruese (Moruasse), a spectacular shell-like formation in plan with a peripheral flow front about 30 m high, parallel concentric pressure ridges and radiating tension fractures; also two trachyte flows to the east at Tilomwo. These were extruded from parasitic vents, but other flows overlying the older (Kasakat) trachytes were probably extruded from the western summit vent.

3 On the northern slopes only four late trachyte flows are seen, two of which certainly issued from the central vent. Cheptomas, referred to above, is also the site of a late trachyte dome, disrupted by faulting, with still active steam jets.

4 The circular summit caldera also formed at this stage, and a trachyte flow covered its floor and breached the crater wall on the northern side.

Towards the end of this second trachytic episode most of the Paka tuffs were extruded during a late phase of explosive activity, mostly as a thick capping to the summit area, and, because of the prevailing easterly wind, preferentially built up on the upper western flanks.

These pyroclastics are mostly yellowish pumice lapilli-tuffs with common obsidian fragments, but grey and red tuffs also occur, and a layer up to 1 m thick of vesicular obsidian.

Tuffs also drape Mundi Hill, an outlier in the Chepkongho plains to the west: they dip radially off the hill at 3 to 4°.

Most of the bombs from the agglomerates in the Paka volcanics are trachytic, porphyritic in sanidine, but Sceal also recorded syenitic bombs and rarer gabbroic nodules.

6 THE UPPER BASALTS are mostly restricted to the north and north-east of the volcano, extending beyond the northern boundary of the Degree Sheet. They are coeval

with the 'Katenmening Basalts' of Silali Volcano to the north (McCall and Hornung, 1972). On the north-east flanks of Paka three basaltic cones are aligned NNE, two of them breached to the north-east, including Copanomorule (GR 906 065) and Luweat (921 075). These cones are composed of basaltic spatter, with scoria, abundant fusiform bombs and fields of associated basalt flows.

Sceal considered that three very recent flows on Paka may be only a few hundred years old. One of these was extruded into the basin of the ephemeral Lake Tilam to the south: another is the youngest basalt of the western summit crater, which flowed through the breach created by the underlying trachyte (Plate 9).

Petrochemical evolution of the central volcanoes

Carney (1972, p.186) showed that Zr values from analyses of Korosi lavas when plotted against Ba, indicated relatively high concentrations of the latter element in mugearitic lavas, but strong depletion in the trachytes: he suggested that the barium content of the trachyte suite was inherited from more mafic parental material, possibly related to the removal of labradorite/oligoclase during crystal fractionation.

Sceal also plotted, from analyses of Paka volcanics, Zr values against Ce, La, Nb, Rb, Y, Zn and Pr. He found that concentrations of these elements were lowest in the basalts, moderate in mugearites and highest in the trachytes: Ba and Sr are at a maximum in the mugearites but, like Korosi, depleted in the trachytes.

In general the ratio of the trace elements to Zr is consistent throughout the Paka volcanics, whether basaltic or trachytic (e.g. Nb/Zr = 0.20 for Paka). For further details on trace element data, with particular reference to Paka, see Sceal and Weaver (1971).

Other volcanoes in the rift show similar consistency of ratios, but different values for each volcano, e.g. Nb/Zr = 0.29 for Nasaken Volcano (Weaver and others, 1972). This pattern suggests genetic and geochemical relationships over the whole range of volcanic rocks for each distinct complex such as Paka. The whole rock analyses also are 'compatible with the hypothesis that the trachytes were derived from the basalt by a process of fractional crystallisation'.

6 Quaternary sediments

The post-Pliocene sediment sequences include:

1 The Nanyuki Formation ($Qpst^{1-3}$) in the south-east, a glaciofluvial sequence derived from the Mount Kenya massif.

In the Rift Valley:

2 Fluvio-lacustrine sequences with some volcaniclastic admixture:
   a Chesowanja sediments (Qps^{CW})
   b Kapindasum beds ($Qpst^{KD}$)

3 The 'Baringo–Hannington Lake Beds', related to former higher lake levels include:
   a Ilosowuani beds (Qrs^{IL})
     Logumukum beds (Qrs^{LM})
   b Loiminangge beds (Qrs^{LG})
   c Kapthurin Formation (Qrs^{KP})

4 Fluviatile sequences:
   Ndolaita River sediments (Qrs^{DL})

5 Alluvium

6 Colluvium

6.1 THE NANYUKI FORMATION ($Qpst^{1-3}$)

The Nanyuki Formation outcrops in the extreme south-east corner of the area, east of the Ewaso Ng'iro River (Figure 20). Charsley and Kagasi (1982a) adopted the following scheme of subdivisions for the area around Nanyuki town, further east (GR 285 001):

3 Upper mixed member ($Qpst^3$)
2 Middle sand and silt member ($Qpst^2$)
1 Lower gravel member ($Qpst^1$)

The following description from the Ol Pejeta area is due to Kagasi (1983).

The lowest member outcrops in the Ewaso Ng'iro River south of Hulmes Bridge, in the Nanyuki River, the Mugwooni Ranch, and along one of the tributaries in the Sweet Waters Farm area.

The middle member outcrops over most of the area, overlain by outliers, which in the Sweet Waters Farm area have a distinctly linear (WNW) trend. The upper member outcrops in disconnected patches on the interfluves.

Each member shows a distinct tonal signature on aerial photographs and on satellite imagery (Plate 10). The lowest member gives rise to white to dark tones with quite strong relief, deeply dissected with dense vegetation cover. The middle member corresponds to medium tones, with scrub of moderate density: and the light tones of the upper member reflect the flat grassy ridges. In this area there is no continuous exposed section through the complete formation: Charsley and Kagasi (1982a) quote reference sections in the Nanyuki area for each of the members.

No fossils have been found, apart from a few unidentified plant remains (Shackleton, 1946). The lower and middle members may be correlated with the 'Uaso Nyiro Beds' of Shackleton (1946), regarded as Early Pleistocene in age.

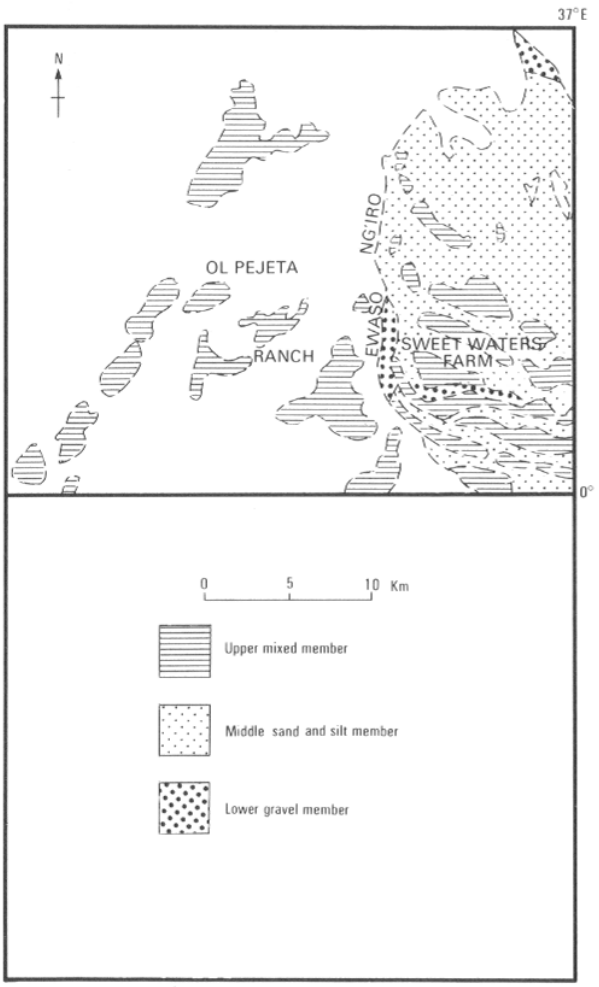


Figure 20 Distribution of the Nanyuki Formation

The thickness of the Nanyuki Formation is believed to vary up to about 40 m, partly according to the irregular topography of the substratum.

The lowest gravels are about 20 m thick, but the thickness of the upper member probably nowhere exceeds 10 m.

The lowest member ($Qpst^1$) comprises poorly-sorted, cross-bedded and graded gravels, with well-rounded clasts up to 11 cm in diameter, featuring prominently the nepheline-syenite derived from the summit plug of Mount Kenya, but also phonolites and 'basement' metamorphics: there are subordinate intercalations of sand, silt, soil and diamictons.

The 'middle' beds are of finer and better-sorted sand and silt: the upper member is composed of incoherent air-fall pyroclastics and porous colluvial soils, in part lateritised.

In Hackman and others (in press) the formation is regarded (according to Charsley) as an alluvial fan sequence derived from melting of snow and ice subsequent to a glacial maximum.

6.2 FLUVIOLACUSTRINE SEDIMENTS

Chesowanja sediments (Qps^{CW})

As demarcated on the 1:250 000 geological map the Chesowanja sediments incorporate both the 'Lower' ($e^{4'''}$) and 'Upper' ($e^{4'}$) 'Chesowanja Sediments' of Truckle (1977). Consequent on the interest generated by the palaeontologial and archaeological discoveries in the area, detailed work by Bishop and others (1978) has revised Carney's (1972) findings, also Carney and others (1971).

The Lower Chesowanja sediments correspond broadly with the 'Chemoigut Formation' of Bishop and others (op. cit.) and the Upper Chesowanja sediments can generally be equated with their 'Mukutan Beds', which in part may represent a lacustrine facies of the Karau volcanics. These two subdivisions are separated by the Chesowanja basalt (Section 5.7), and probably also by extrusives of the Karau volcanics (including Erinei). However some of the stratigraphic relationships are obscure, and irrelevant to the scale of a 1:250 000 geological map.

Carney (1972) first described all these 'basin' or lacustrine sediments under the term 'Chemoigut Beds'. Certain of these sediments which he designated 'Chesowanja Province' were described as the 'Chemoigut Formation' by Bishop and others (op. cit.): Carney's 'Chemoigut Province' corresponded to their 'Mukutan Beds'.

The *Chemoigut Formation* (Lower Chesowanja sediments) is exposed in three separate inliers along the crest of an anticline with an axis trending north. Acheulian artefacts have been found from at least five different horizons, and australopithecine remains were found in the upper levels. Lists of mollusca and vertebrates are detailed in Bishop and others (op. cit., p.325).

A volcanic bomb from the sediments yielded K-Ar dates ranging from 3.20 to 3.24 Ma, considered by Carney to be incompatible with the 'host' stratigraphy. Hooker and Miller (1979) thought the Chemoigut Formation to be older than 1.42 Ma. Dagley and others (1978) recorded most of the palaeomagnetic samples as showing reversed polarity, indicating an age between 0.7 and 2.4 Ma.

The sequence ranges generally from 25 to 50 m in thickness: it comprises a succession of grits, silts and red or brown clays with intercalated coarse tuffaceous sandstones. Some limestone beds and concretions are of algal origin, but there are also nodular calcretes, especially in the red clays at the base.

The '*Mukutan Beds*', or Upper Chesowanja beds are recorded to be only 6 m thick in the type section.

Kapindasum Beds ($Qpst^{KD}$)

The Kapindasum Beds (Griffiths, 1977) are lacustrine sediments which form a small outcrop (about 5 km^2) in the lower Ol Arabel valley, just south of the Paratallo volcanic centre (Section 5.7): these were mapped by McCall (1967) as stratified pumiceous sediments (Qt3). Aspects of the drainage pattern in that area are mentioned in Section 2. The sequence comprises up to 15 m of reworked waterlain tuffs, green and buff in colour, laminated and cross-bedded, with brown and orange clay intercalations. The sediments overlie the Karau volcanics of Paratallo: their volcaniclastic content decreases southwards, suggesting that Paratallo was the primary source of the material.

6.3 'THE BARINGO–HANNINGTON LAKE BEDS'

Ilosowuani (Qrs^{IL}) and Logumukum Beds (Qrs^{LM})

Griffiths (1977, p.107) details the sections of Logumukum, at the south-east corner of Lake Baringo, associated with strandlines on the east side of the Loboi Plain. McCall (1967) mapped these as 'tuffaceous sediments with post-Pleistocene mollusc fauna'. (Ql^{1}).

A sequence of about 6 m of earthy silts, grits, laminated diatomites, clay and reddened grits and clays (with phonolite and obsidian artefacts) is exposed in a faulted strip, tilted eastwards towards the 'Ilosowuoni Horst' (Ilosowuoni, Lonskwani GR 1752 0485). The upper eroded surface of this sequence is marked by 'strandline deposits' with dense mollusc concentrations, also local ironstone sheets and nodules.

At Logumukum, about 500 m to the north a similar sequence, but without the lower silts and grits, is overlain by the silts of the Loboi Plain.

Loiminangge Beds (Qrs^{LG})

These sediments outcrop about 10 km north-east of Logumukum, and are suitably grouped here with the previously described units. Carney (1972) provided a detailed map and gave the following sequence, totalling about 8.5 m in thickness.

3 Shingle deposits
2 Tuffaceous lacustrine laminated silts and clays with shelly beds (*Corbicula* and *Melanoides*), also fish-plates
1 Fluviatile conglomerates and silts

Similar tuffaceous silts and clays occur near Kampi ya Samaki on the west side of Lake Baringo, the 'Kokwob Formation' of Bishop and others (1969).

Kapthurin Formation (Qrs^{KP})

The Kapthurin Beds, or the Kapthurin Formation of McCall and others (1967), described by Martyn (1969), form a sequence of gravels, tuffs and red earths 100 to 200 m thick, notable for the discovery of a hominid mandible and Acheulian artefacts (Leakey and others, 1969).

Tallon (1976) showed that some of the lower tuffs were probably erupted from the same source as the Baringo trachyte. A sanidine feldspar, separated from the tuffs towards the base, gave K/Ar ages of 0.66 and 0.68 Ma, i.e. late Pleistocene rather than Recent (Chapman and Brook, 1978).

On this degree sheet a very small outlier of the Kapthurin Beds occurs on the west side of the Loboi Plains, on the sheet boundary near 0°5′N.

6.4 NDOLAITA RIVER SEDIMENTS (Qrs^{DL})

The Mugurin–Ndolaita River, east of Lake Bogoria, flows north to the Loboi Plain: over 13 km of its course the Ndolaita valley is infilled by a sequence of fluviatile

sediments and travertine deposits, which have effectively smoothed out the river profile to give a uniform northward gradient.

McCall (1967, p.73) referred to these as 'tuffaceous sediments, red clay-silts and torrent wash' (the 'Mugurin and Maji ya Moto beds, Qt_2), and believed them to be Late Pleistocene.

Griffiths (1977) described the sequence broadly as follows:

3 'Younger Fluviatile Sediments' (c.6 m thick) sands and silts, in part conglomeratic, as discontinuous sparsely exposed outcrops.

2 Travertine (deposited by fumarolic activity), with small gastropods.

1 'Older Fluviatile Sediments' (c.20 m thick): thick alluvial silts and clays with gritty and pebbly lenses overlying unbedded clays and silts with plant remains.

6.5 **ALLUVIUM** (Qrs)

Recent alluvial deposits tend to vary according to the nature of the underlying 'solid' geology.' Thus, on the metamorphic rocks of the Upper Ewaso Ng'iro Basin, only narrow strips of light brown medium-grained sand form the beds of the river valleys. On the phonolite plateau the broader valleys of the underfit streams are floored with silt or clay, and boulders are much less abundant than in the basement gorges to the east: on the flat interfluves an elaborate network of ill-drained 'pans' (*vleis* or *dambos*) is choked by volcaniclastic silts and clays, with pebbly gravels and impervious 'black cotton soil' (regur). Between the pans the higher parts of the plateau are covered with lava rubble and thin dusty soils. Wilkinson (1983) considered that thin patches of incoherent ashy soil covering much of the Laikipian basaltic formation in the south-east, and now largely incorporated in the soil profile, were of aeolian origin.

Further west the grabens on the rift shoulder, and the intervolcanic basins between the massifs in the rift floor, are obvious tectonic traps for sediment: the most extensive of such areas is that of the *Loboi Silts* (Qrs^{LO}), an expanse of over 200 km^2 of fluviatile and subaerial silts, grits and soils (not obviously of lacustrine origin) between Lakes Baringo and Bogoria. The Mukutan–Komol trough, and the Løyamarok (Loiyamarak) plains of the Kogore valley, are similar, but with a larger contribution of volcaniclastic sheetwash. The surfaces of the plains rise towards Paka and Korosi, and to the Laikipia Escarpment, as broad aprons of torrent wash, typically with braided intermittent drainage: the constituent material is mostly incoherent brownish and grey clay-silt soil strewn with basalt, trachyte and phonolite fragments derived from the coalescence of fans, and partly mobilised by subsequent sheetwash. To the south, in the Solai Basin (McCall, 1967, p.74), superficial deposits are not well exposed, although borehole records indicated several hundred metres of sediment: in the Ngendalel depression, 5 km to the west, thin-bedded silts bear witness to temporary ponding.

6.6 **COLLUVIUM** (Qrk)

In the east, reddish brown sandy colluvium accumulates over the basement rocks, notably around the base of inselberg features and at the bottom of the steeper valley slopes of the Ewaso Ng'iro system. Usually, however, the colluvium in this area is only a few metres thick, e.g. where it forms a well-drained platform for a citrus plantation by the Ewaso Narok River at GR 2482 0487. Much of the material was probably generated in the Pleistocene, during periods of heavier rainfall than experienced at present. In the volcanic zones of the west colluvium is more extensively developed at the base of the higher steep features of the Laikipia Escarpment complex, especially from the more resistant fine-grained basalts and trachytes: the less coherent coarser basalts and pyroclastics have been preferentially eroded. Wide aprons of talus and fanglomerate form the lower slopes of the escarpments surrounding the Amaya Embayment. Landslip is a marked feature of the left side of the Amaya valley below the Lacheriakosowa gorge, and of the Ngelesha and Aruru escarpments further south.

Archaeological note Walsh and Powys (1971) found worked obsidian flakes in the soil covering Mozambiquian paragneisses at the base of the phonolite escarpment, at about 0°29′N:36°45′E, near Kisima Farm. On the basis of comparative refractive index studies they suggested that the materials might have been derived from Eburru, 137 km to the south.

7 Cenozoic intrusives

The mapped intrusives recorded here in the Rift Valley have all been emplaced into Miocene volcanics, and are believed to be not substantially younger than the surrounding host rocks (Figure 21).

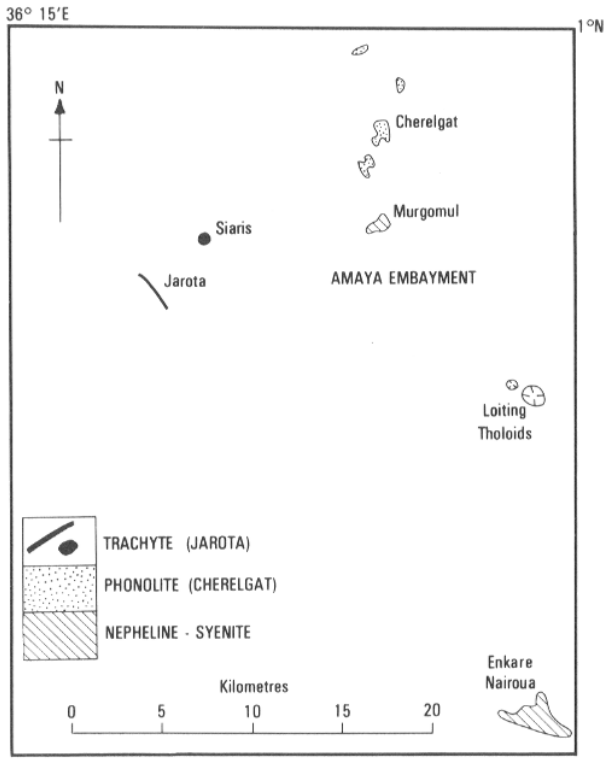


Figure 21 Distribution of Cenozoic intrusives

7.1 MURGOMUL SYENITE (Sy^n)

Murgomul Hill (36°25.6′E:0°54′N) protrudes about 300 m above the surrounding Samburu basalts, as a plug in the centre of the Amaya Embayment (Plate 10).

A composite alkaline intrusive, the central foyaite plug gave an age determination of 16.75 ± 0.4 Ma (Early Miocene), similar to a date from an analcime-hawaiite specimen near the top of the surrounding Samburu basalts (16.1 Ma).

Golden (1978) identified three concentric intrusive phases, the earliest of which forms an incomplete outer ring. No contacts with the Samburu basalts are exposed.

A crude layering, due to parallelism of large tabular feldspar phenocrysts, dips steeply away from the summit in a quaquaversal manner, presumably due to updoming when the crustal plug was emplaced.

The rocks range from coarsely porphyritic, dark analcime-hawaiites to syenodiorites: grey alkali-syenites dominate. Golden (1978) provided much petrographic detail of the various phases of this complex; he considered many of the rock types to resemble cumulates. Although contacts between various units were not seen *in situ* the sequence of intrusive phases outlined by Golden was as follows:

4 Late mugearite dykes
3 Central plug of coarse analcime-foyaite or rhomb porphyry, with anorthoclase phenocrysts up to 5 cm in length.
2 Outer ring of grey nepheline syenites and syenodiorites.
1 Outer dark analcime-hawaiite, varying to medium-grained microsyenodiorite, with abundant large phenocrysts of augite and plagioclase.

Golden attributed the coarseness of these intrusives to high volatile pressures, suggesting confinement by overlying volcanics during emplacement.

7.2 CHERELGAT PHONOLITES (Sy′)

The Cherelgat Phonolites form a series of intrusives trending generally NNE from a point 2 km west of the Murgomul plug, i.e. along a lineament parallel to the rift boundary fault. One of the occurrences, Kanakeru, is displaced from this alignment, about 2 km to the west.

The main phonolite bodies include:

1 Cherelgat Hill (36°26′E:0°55.5′N) a mushroom shaped intrusive fed by a dyke 4.6 m wide.
2 Tyemnateng (36°26.5′E:0°57′N), tholoid or sill-like offshoots from vertical dykes.
3 Roiting (36°27.5′E:0°58′N), a plug passing southwards into a prominent dyke.
4 Kanakeru (36°26′E:0°59.5′N), a plug with a sill extending on the west side.

The Cherelgat Hill phonolite gave a date of 13.9 ± 0.3 Ma (Middle Miocene). Golden (1978) also reported boulders of Cherelgat phonolite in the screes on the north-east slopes of Murgomul, interpreting them to be derived from unexposed dykes in the syenites which are dated at 16 to 17 Ma.

Petrographically these phonolites are mostly porphyritic (although nepheline is not always conspicuous), and sphene-bearing, like the 'Gwasi Type' of Williams (1967) but sodic amphiboles (kaersutite or kataphorite) often occur as phenocrysts. Locally they grade into trachyphonolites, and have affinities with some of the dykes in the Samburu basalts near the Nasur River.

Golden (1978) considered these intrusives to be surface or near-surface tholoids: the alignment of the outcrops suggests a series of plugs along a major Miocene fissure.

7.3 ENKARE NAIROUA MICROSYENITE (Sy^n)

Exposures of a porphyritic microsyenite, with phenocrysts of alkali feldspar up to 2 cm in length, were recorded by Hackman (1986b) in the Enkare Nairoua stream at GR 2251 0718 and 2243 0737. The rock shows 'onion' weathering, white to purplish grey in colour, an alkali

microsyenite with melanocratic schlieren showing evidence of chilling at the contacts: these schlieren impart a crude banding without consistent orientation.

In thin section the rock resembles the microfoyaitic facies of the Murgomul Syenite complex as described by Golden (1978). Phenocrysts of nepheline and anorthoclase exhibit a seriate arrangement, down to 2 mm.

The Enkare Nairoua intrusive appears to be associated with lineaments trending NW, and to underlie Middle Rumuruti (Lower Ewaso Narok) phonolites, although no contact relationships are exposed. It may be interpreted as a high level sill or tholoid. A whole rock analysis of a sample of the microsyenite is presented in Table 5.

7.4 BASALT AND TRACHYTE DYKES

Dyke swarms and other minor intrusives tend to be associated with pyroclastic zones in the Samburu basalts (see Section 5.1) notably in the Ki'mai area (Griffiths, 1977) and the Aruru Shield (Carney, 1972).

Sceal (1974) also mapped two trachyte bodies at Jarota (GR 030 960) and Siaris (055 990), up to 0.5 km wide and trending north-west, which intrude the Komol volcanics.

Table 5 Analysis of Enkare Nairoua microsyenite

	%
SiO_2	55.00
TiO_2	3.63
Al_2O_3	18.04
Fe_2O_3	3.79
FeO	1.58
MnO	0.39
MgO	1.11
CaO	1.26
Na_2O	5.93
K_2O	5.42
P_2O_5	0.23
LOI	3.98
Total	100.36
	CIPW NORM (water free)
or	33.22
ab	45.26
an	4.71
ne	3.26
ol (fo)	2.01
he	2.50
il	7.03
ap	0.57
cor	0.80
sp	0.16
Total	99.52

(East African Assays, Nairobi 1986), (GR 2249 0719)

8 Basement tectonic history and metamorphism

8.1 INTRODUCTION

The metamorphic rocks have been affected by a sequence of tectonic episodes (Table 6), individually identified in the field by small-scale planar and linear structures. The sequence is essentially similar to that detailed in Key (1987) for the Maralal area to the north, and by Hackman and others (in press) for the Isiolo area to the east.

The structural history of the 'basement' rocks in the east of the Baringo–Laikipia area is best described with particular reference to Key's (1986b) 'Notes on the geology of the Kirimun sheet', which serve as an appropriate model for the rest of the area.

The structural history of the 'basement' rocks of the Kirimun area can be interpreted in terms of several periods of regional tectonothermal deformation. The interaction of the various episodes has disrupted the metamorphic rocks on all scales to produce the following features:

1 Slicing of original lithological units, e.g. the marbles of Lobor Soit.
2 Several ages of boudinage structures.
3 Several fold styles related to different events, and in most outcrops two ages of small-scale (parasitic) folding may be seen.
4 Regional and small-scale interference fold structures.

Table 6 Geological history

Age		Sedimentation/Vulcanicity	Igneous intrusives		Tectonic episodes
Recent		Alluvium, colluvium Fluviolacustrine sediments			Marigat lineament—continued seismicity
		Korosi-Paka trachyte/basalt central volcanoes			
Pleistocene		Fluviolacustrine and glaciofluvial sediments			'Grid faulting'
	Gregory Rift	Hannington Group Trachyphonolites and flood lavas			
Pliocene		Trachyte shield volcanoes and basalts		5–6 Ma	Graben faulting
		Late Miocene phonolites and trachytes		9 Ma	'Box-fault' systems-ramps Monoclinal downwarping
Miocene	Laikipian Plateau and Eastern Rift Shoulder	Rumuruti Group plateau phonolites and Inner Rift Shoulder volcanics	Enkare Nairoua microsyenite Murgomul syenite, Cherelgat phonolites—dyke complexes	13–14 Ma	Faulting
		Samburu Basalts			
		Fluvial, terrigenous sediments (Kirimun Formation)			
		Sedimentation/Metamorphism		Thermotectonic episodes Ma	(approximate ages—from Rundle, 1983)
Early Palaeozoic				450	Late Mozambiquian phases
	Mozambique Orogenic Belt	Amphibolite Facies	Local melting—vein phases Ol Doinyo Ng'iro Gabbro	580	Barsaloian
		Amphibolite Facies	Local melting'—vein phases	630	Baragoian
		Amphibolite Facies	G2 granites	830	Sabachian
		Upper Amphibolite Facies	G1 granites: migmatites	?	Samburuan
		Sedimentation of Don Dol, Ol Doinyo Ng'iro and Loroki sequences			
?			older migmatites	?	Pre-Samburuan

5 Interlayering of migmatites and banded gneisses.
6 Transposed fabrics, and all planar fabrics, tend to be composite.
7 Minor intrusives of several ages are emplaced along brittle and plastic shear zones.

8.2 PRE-SAMBURU EPISODES

The pervasive effects of the early Samburu episode (D1) in rocks now exposed caused complete recrystallisation of rock textures, obliterating evidence of any (cold) tectonic episodes which may have affected the original supracrustal rocks.

8.3 SAMBURU EPISODE (D1)

An early (D1) high-grade tectonothermal event produced the pervasive coarse gneissic fabric in the various metamorphic rocks. The metamorphic fabric is defined by new mineral growth in seams and accentuated by felsic veining. The fabric was originally flat-lying and probably parallel to any primary lithological layering. Boudinage of competent quartz-rich and mafic-rich seams took place during D1. Minor folds are defined by discordant felsic veins. No regional folding is thought to have taken place: P max was vertical due to load pressure. Any earlier fabrics were obliterated by D1 structures.

8.4 SABACHI EPISODE (D2)

Regional recumbent folding defined by the gneissosity and major lithologic units followed D1. The best example of these (D2) folds is preserved in the major garnetiferous migmatitic gneiss unit cut by the (N–S) Ewaso Ng'iro River in the Kirimun area. A perfect isoclinal fold plunging steeply to the north is preserved in this unit with the fold trace refolded around a D4 (Barsaloian) synform. The D2 folds have been rotated and tightened into perfect isoclines by the D4 deformation. Rotation to compensate for the Post-D2 deformations indicates that the D2 folds had axes trending roughly WNW–ESE.

Shearing along subhorizontal surfaces took place during the generation of the D2 recumbent folds. Major movement took place along the thick graphitic gneiss unit extending across the whole N–S width of the Kirimun area. On a smaller scale the shearing reduced the originally continuous D1 gneissosity into slivers. Parasitic D2 folds (perfect isoclines of the gneissosity) are exposed in many outcrops.

Section AA′ on the 1:250 000 geological map also shows the interpreted axis of a 'pre-Baragoian recumbent fold' affecting the Loroki Gneisses closing to the east, itself folded by the effects of the D3 episode.

Rootless isoclines and discordances within the gneisses may be related to this, or the previous tectonic episode. Charsley (1984) observed an early mineral lineation plunging steeply SSW (at GR 2492 0517), which he interpreted as a product of the Sabachian deformation.

8.5 BARAGOI EPISODE (D3)

Although widely recognised in other areas (Key, 1987), there is scant evidence in the upper Ewaso Ng'iro basin for folds with axes trending NW or NNW, probably because they have been extensively overprinted by the N–S structures of the succeeding Barsaloi (D4) episode. However Charsley (1984) recorded a tight synformal structure oriented NNW beside the Ewaso Narok River (GR 2466 0485), also he noted elsewhere lineations plunging at $^{10}/_{160}$. It may be significant that the foliation and outcrop configuration in this Ewaso Narok 're-entrant' also have a tendency to trend NNW. Further north, in the Lake Kisima area, categorised on the inset to the main geological map as a 'Baragoian' tectonic domain, the broad antiform affecting the Loroki quartzofeldspathic gneisses closes in the Loroki Forest some 12 km east of Lake Kisima. The axis of this fold swings to the north-west in the adjacent (Maralal) area (Key, 1987) and is interpreted as a 'Baragoian' structure in that area, as shown on section AA′ for this degree sheet map.

8.6 BARSALOI EPISODE (D4)

A regional tectonothermal event produced upright folds, with N–S axial traces and low plunging (to the NNW) axes, succeeding D3. D4 stress was inhomogeneous to produce N–S zones of intense deformation separated by strain-free regions. The wavelengths of the regional D4 folds therefore vary from less than 3 km to about 10 km. Locally antiformal closures are sheared out. Interference of D2 and D4 folds has produced the 'arrowhead' fold closing to the east and west, defined by the mafic migmatite unit (mm^{hNC}) in the centre of the Kirimun area. The persistent graphitic gneiss unit which acted as a décollement zone during D2 defines the nose zone of a D4 synform (Key, 1982).

Parasitic D4 folds are the most common minor structure seen in the outcrops of metamorphic rocks. They are similar in style to class 2 folds of Ramsay (1967).

During D4 a pervasive planar fabric was produced in zones of high strain. In many cases this produced transposition of older fabrics into a new gneissosity. Good examples of transposition are seen in the major garnetiferous migmatitic gneisses where felsic veins are realigned along planes axial planar to D4 folds.

Similarly in the main graphitic gneiss unit (mg^{rDN}) there is a strong (D4) vertical foliation cutting an older (D1) horizontal fabric. In the adjacent gneisses a vein phase is injected along the vertical foliation to produce a new gneissosity, obliterating the older structures. In the G2 granites which post-date the D1 and D2 structures, there is a biotite foliation, axial-planar to D4 folds.

A strong linear fabric, invariably due to puckering of D1 and D2 fabrics, is co-axial to the D4 fold axes. Lineations in the Kirimun area plunge uniformly at a low angle towards about 350°.

Particularly in the fold noses a strong L-tectonite fabric may be developed parallel to the axial traces. Charsley (1984) mapped a zone of N–S shear and flattening followed by the Ewaso Narok River northwards from the road bridge at GR 2488 0500; there leucogranite-gneiss bands are vertically foliated, interpreted as early (G2?) granites recrystallised during D4 shearing.

The Kirimun area (Key, 1986b) is dominated by a flat-lying massive western migmatite block, overlain by a series of banded gneisses defining interference fold structures, but with a N–S regional strike. In the centre of the Kirimun Sheet (92/4) the migmatites and gneisses are infolded. G2 granite sheets define upright D4 folds trending N–S and plunging gently to the N.

8.7 POST-D4 DEFORMATIONS

Gently asymmetric undulations of the gneissosity are ubiquitous in areas where the metamorphic rocks are flat lying. The undulations may be due to D4 or to a later, less intense regional warping. The steeply dipping planar fabrics do not show the effects of this deformation.

The effects of the Loldaikan and Kipsingian events which are recognised further east (Hackman and others, in press), are not specifically identified in this area.

Faults are rare although brittle shears with dextral and sinistral senses of movement are common. The 'late' planar structures follow two major trends: N–S and ENE–WSW. The N–S set follows the regional 'grain' of the metamorphic rocks whereas the ENE–WSW set is parallel to the major joint direction in the basement rocks. The jointing is a late (possibly post-Miocene) event.

8.8 METAMORPHISM

The metamorphism accompanying the Samburu episode was sufficient to effect complete recrystallisation, and to produce new fabrics and mineral assemblages which destroyed pre-existing textures. The following minerals were formed or recrystallised at that time: quartz, plagioclase, biotite, hornblende, garnet, carbonate, ore, also microcline, diopside and sillimanite. The presence of the last three minerals indicates that the grade reached the upper amphibolite facies in rocks presently exposed. These assemblages were altered by later thermal events, notably effecting the conversion of mafic minerals to biotite.

Modal corundum was recorded at three localities in the Kirimun area, at GR 2708 0736 and also east of Ol Doinyo Ng'iro on the eastern boundary of the map. In these three places the corundum forms euhedral grains associated with garnet, K-feldspar and opaques, with or without biotite. The corundum developed early, i.e. pre-Barsaloian prisms may be aligned with the early gneissosity. Corundum is generally regarded as a low pressure mineral phase formed in silica deficient areas (Turner, 1968). Possibly in this area the corundum formed in response to the emplacement of the Ol Doinyo Ng'iro Metagabbro, or it may have formed at an early stage in rocks deficient in SiO_2 and enriched in Al_2O_3.

The massive autochthonous potassic migmatites and allochthonous (G2) granite sheets constitute a second major (metasomatic) phase. These migmatites are not everywhere differentiated in this area from earlier migmatites because there are places, especially within the massive and flaggy Ndura Complex migmatites, where biotite and K-feldspar have also developed during this second phase. Biotite and microperthite were the main products of this phase: occasionally muscovite formed, also other feldspar phases were sericitised.

During the Barsaloian episode (D4) biotite was formed at the expense of other mafic minerals to define the north–south tectonic fabric. As the Barsaloian phase waned, almandine porphyroblasts formed; possibly also kyanite developed locally. Upper amphibolite grade was probably reached during the Barsaloian phase in the shear zones where the gneissosity was subjected to transposition. However only lower to middle amphibolite grade prevailed during the main tectonothermal events following the Samburu episode.

For a more comprehensive account of the regional metamorphism in the Mozambique Orogenic Belt to the east of this area the reader is referred to Hackman and others (in press).

9 Cenozoic tectonics

9.1 INTRODUCTION

The structural history of the Baringo–Laikipia area from the Miocene to the present day is essentially the story of the evolution of the Gregory Rift in this area. Much has been published on the East African Rift System in general, and on the Kenyan rifts in particular, also in the context of speculation on its relationship to the world rift system. It is inappropriate here to review all the relevant literature, but the reader may be referred particularly to Baker and Wohlenberg (1971) and the chapters by Oxburgh, Shackleton and King at the beginning of the 1978 volume 'Geological background to fossil man'. A quotation from McCall (1967) is most apposite: 'The structural pattern of the area shows a complexity probably quite unparalleled in the Rift Valley system, owing to the number and variety of orientation of the faults'.

North of Lake Baringo the boundaries of the median rift trend NNE, enclosing the volcanic massifs of Korosi and Paka, which are displaced slightly *en echelon* in relation to each other, and are themselves scored by Recent fault swarms and fissure systems, which in part trend north as well as north-east, i.e. somewhat discordant with the rift boundaries in that area.

To the south of Lake Baringo the influence of faults trending north-west, such as the Marmanet and Ol Arabel fault systems, and their interaction with the NNE-trending boundary faults of the Laikipian Escarpment complex, becomes most evident (Plate 2). This southward change in structural pattern is clearly related to the south-easterly swing in the trend of the Gregory Rift to the south of the equator, between Nakuru and Naivasha.

The fracture pattern is described below, in Section 9.2. In the later sections an attempt is made to explain some aspects of this pattern in terms of historical evolution.

9.2 FRACTURE ANALYSIS

Figure 22 shows the main elements of the faulting and lineament pattern in the Baringo–Bogoria section of the rift, and on the Laikipia Plateau. The majority of faults are normal, synthetic with respect to the 'median' rift, with steeply dipping fault planes: rarely is the angle of dip as low as 50°. Five major trends of planar fractures have been recognised:

1 FAULTS TRENDING NW The most prominent of these is the line of the Sattima–Aberdares and Marmanet Faults. Its complement to the north, comprising the Lariak– North Arabel and other minor faults, is shorter, forming a belt of discontinuous fractures. Progressively towards the north-west both fault zones display a sense of *en echelon* displacement to the west. Lineaments of the same trend are also a feature of the eastern part of the Laikipia Plateau, but there is no evidence that they are the traces of fault planes—they are probably tension features. This north-westerly trend parallels the axes of major 'Baragoian' folds in the Mozambiquian basement (Section 8.5).

2 FAULTS TRENDING NNE These form a dense swarm, about 8 to 10 km wide, which corresponds generally with much of the eastern shoulder of the rift, although the extent of the Miocene shoulder itself is much broader in the north (c.25 km) than to the south of the Marmanet Fault (c.12 km). Although surface traces of these faults are conspicuous on aerial photographs and imagery, few of them are easily observed on the ground (Griffiths, 1977).

In the north the eastern margin of this NNE fault swarm is clearly demarcated by the Laikipia Monocline (Carney, 1972), clearly defined by dip variations, and the Loroki Escarpment. To the south interaction with faults trending N–S and NW–SE enhances the composite effect of sigmoidal elements which contribute to the flexure in the rift structure south of Lake Bogoria. The South Arabel and Iguamiti Faults form part of the eastern boundary of this zone, while the Changmasa–Legisianana Fault Zone, which at its northern end sweeps around the eastern shore of Lake Bogoria, comprises the boundary to the inner rift in that area.

Parallel structures, trending NE or NNE in the Mozambiquian basement, are a feature of parts of eastern Samburu District, attributed to the Loldaikan episode (Charsley, 1987).

Box fault systems Two intensely faulted areas north-east of Lake Bogoria, Kinsoget and Kopop (Griffiths, 1980), each covering only about 10 km^2, are of interest in that they comprise 'box-fault' systems of high density faults of different trends which appear to be major 'hinges' in the fault block system, reflecting in particular the interference of major fault sets trending NNE with the NW-trending Marmanet and Ol Arabel Fault systems.

3 FAULTS TRENDING N–S Fractures with a broadly meridional trend interact with the NNE-trending faults in the Miocene shoulder, but are the dominant structural elements of the rift floor, notably the grid-faulted platform west of Lake Bogoria and the fissure systems along which are aligned the vents and cinder cones of Korosi and Paka. It is noteworthy that these faults are parallel to the major 'Barsaloi' trends of the Mozambiquian basement (Section 8.6).

4 LINEAMENTS TRENDING WNW The interpretation of Landsat imagery has revealed a number of these trends, one of which is the 'Sweet Waters' lineament in the extreme south-east of the area: this traces out a ridge in the Nanyuki Formation, suggestive of a feature which reflects a buried basement structure. Charsley and Kagasi (1982b) described a similar example of the same 'buried' trend in the Marania area 50 km to the east (the Ndare Forest Lineament).

Minor features of the same trend also scar the southern Loroki Plateau, clustering around the Loiting tholoids (Section 5.4): it may be significant that these structures are collinear with the trend of the upper Amaya valley, and also parallel the crater alignment of Paka Volcano (Section 5.8) and Silali (Key, 1987). The results of an EEC-sponsored airborne geophysical survey have shown a regular pattern of linear magnetic anomalies trending

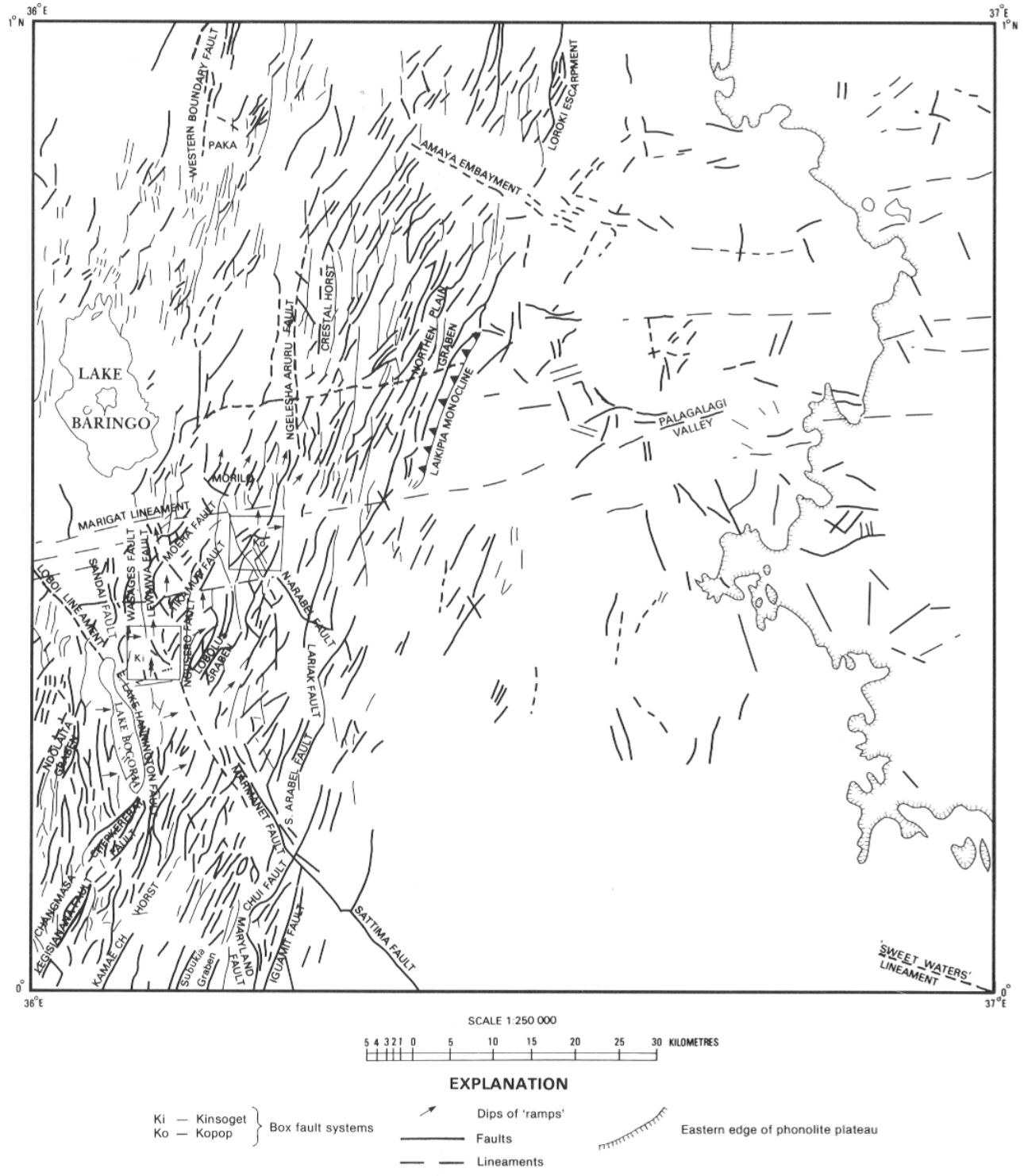


Figure 22 Fracture pattern in the Baringo–Laikipia area

NW and WNW on the eastern Miocene shoulder of the rift north of Maralal (R. Gedde, personal communication, Geosurvey International 1982). Similarly Wohlenberg and Bhatt (1972) noted that, particularly in the area south of Lake Bogoria, an aeromagnetic survey showed well-defined NW-trending magnetic anomalies across the floor of the rift. It is suggested that these buried trends may reflect fundamental contrasts in the basement which originate from Baragoian or earlier tectonic episodes.

5 Lineaments trending ENE These are a common feature of parts of the Mozambique Belt in northern Kenya, where they are believed to be mostly tension features of the late orogenic phase (Late Proterozoic–Early Palaeozoic). Essentially they manifest in the basement as well-defined, rectilinear joint swarms, locally with evidence of minor strike-slip shear, although the sense of movement in a given area may be equivocal. Lineaments of this trend also transect the northern Laikipia Plateau, e.g. the Palagalagi valley, which is

broadly collinear with a very subtle feature, the Marigat lineament: the latter, detected on special thematic mapping Landsat imagery (courtesy of the Remote Sensing Facility in Nairobi), is one element of a minor swarm which affects the alluvial area (Loboi Silts) between Lakes Baringo and Bogoria (see also Plate 2). These features have not been investigated on the ground, but they suggest very recent effects of a secondary tensional stress regime oblique to the primary rift axis. The direction accords with that of the Kavirondo Rift in western Kenya.

9.3 CENOZOIC TECTONIC EVOLUTION

Early–mid Miocene structures

Carney (1972) recorded the earliest Cenozoic faults as having affected the Samburu basalts (20 to 14 Ma), but that faulting predated the Sabit trachytes (pre 13.5 Ma) in the Aruru Shield area. McCall (1967) noted the distinct unconformity between the Samburu basalts and the overlying Rumuruti Group phonolites: eastward dips in the basalts increase towards the rift, and are too high to be primary features. Golden (1978) also believed that a phase of faulting and erosion of the Samburu basalts of the Chembalao Shield preceded the extrusion of the Lopet phonolites, which are dated at about 15 Ma. Carney observed minor faulting within the Rumuruti Group accounting for some unconformity between the 'Marmanet Phonolites' and the 'Lower Uaso Narok Phonolites', i.e. at about 10 to 11 Ma. Golden (1978) related Miocene phonolite dykes in the Chembalao Shield to tensional stress associated with an axis of mild downwarping, possibly the initial phase of the following episode. McCall was also disposed to attribute the high dips in the Samburu basalts to a post-eruptive phase of median upwarping.

Mid-late Miocene regional warping

Baker and Wohlenberg (1971) considered that the initial broad uplift of the Kenya Dome, of about 300 m, was effected in the late Miocene. The evidence from the Miocene eastern shoulder of the rift indicates that after the extrusion of the Rumuruti Group phonolites the area was subjected to a phase of regional monoclinal downwarping to the west (c.9 Ma). To the north, the 'Samburu Monocline' (Shackleton, 1946), is well defined. Golden (1978) traced its southerly extension into this area as the Putere–Kamuga lineament), but south of the Amaya Embayment its effect is less evident: the steep west-facing limb of the 'Laikipia Monocline', trending NNE (not collinear with the Samburu Monocline) was modified in the late Miocene by extensive faulting. By that time the centres of eruption had also shifted westwards.

Late Miocene faulting

In this area faulting antithetic to the regional rift system diversified the eastern shoulder, where faults of this age predominate: thus a subsidiary anticline, the 'Laikipian anticline' (Carney, 1972), trending roughly N–S developed with the first major faulting into the composite 'Crestal Horst' system, now deeply incised by the Mukutan gorge (Section 2.4), complemented to the east by the 'Northern Plain Graben', which is mainly demarcated by faults trending NNE (see section BB′ on the 1:250 000 geological map). Carney pointed out, as can be seen on Figure 22, that faults immediately to the east of the Crestal Horst trend NNE, but to the west they trend north or even NNW, a local example of the regional interplay of these two directions. The Lobolus Graben (Griffiths, 1977), is an analogous structure on the Miocene shoulder east of Lake Bogoria (section CC′). This phase of faulting (the first major faulting episode of McCall, 1967) produced a series of large eastward-tilted blocks bounded by an intricate network of major faults, to form a sequence of steps down to the floor of the Rift Valley: section CC′ on the 1:250 000 geological map shows the Samburu basalts dipping towards the rift, but Griffiths' (1977) data indicate back-tilting to the east (L. A. J. Williams, personal communication). This part of the horizontal section is therefore perhaps an unsatisfactory compromise to accommodate the mapped geological boundaries and the topographic detail. McCall estimated an apparent downward displacement of over 1200 m in the Lake Borogia area, while Carney (1972) estimated that the Ngelesha Escarpment faults to the north displaced the Miocene phonolites down to the west by at least 760 m: however the Quaternary volcanics cover on the rift floor does not allow the total displacement to be assessed. McCall (1967) assigned the NW-trending Sattima–Marmanet faults to this episode, also the North Arabel–Lariak system, and the NE-trending Iguamiti, Chui and South Arabel Faults: he considered faults of this phase to be less clearly spaced than faults of later phases, which produced complex 'grid' patterns in the rift floor.

Box-faults and ramps

Griffiths (1980) further analysed the complexity of the network of faults in the Miocene shoulder in terms of the association of the 'box-fault' systems and ramps of the escarpment complex north-east of Lake Bogoria. The progressive *en echelon* fault displacement of the eastern shoulder of the rift, so evident in plan, is enhanced by the recognition, in three dimensions, of a coherent pattern of elongated fault blocks or ramps (King, 1978) which are generally strongly tilted to the north or north-east (Figure 23), e.g. the very steep Morilo ramp inclined at about 15° to the north. The pattern is a development of the 'gangplank' type of structure in which fault block strips are maintained for only short distances along the trend of the fault, due to rotation about the fault-planes parallel to the rift margin. However, in this area, the consistent tilt direction of the ramps is unusual for the rift as a whole. Moore and Davidson (1978) described the essentially similar 'trap-door' effect from the Rift Valley system in southern Ethiopia. The box fault systems at Kinsoget and Kopop both consist of short curvilinear sets of faults that strike obliquely to the adjacent major faults, representing local depressions within the regional pattern. The Kinsoget system was formed prior to the extrusion of the Tasiokwank phonolitic trachytes, i.e. 7.6 to 10 Ma. The Kopop system is more difficult to date, but Griffiths (1980) thought it to have developed at much the same time. The ramps vary from 2 to 25 km in length, and appear to have evolved simultaneously with the box fault systems, which may have functioned as 'hinge' zones. Griffiths interpreted the positions of the box fault systems in terms of interaction with the line of the East Lake Hannington–Laikipia Escarpment–Ngelesha–Aruru Fault Zone: Kinsoget locates the intersection with the NW-trending Marmanet Fault, Kopop with the North Ol Arabel Fault. However, the mechanics of the box

fault/ramp association and its relation to the 'equatorial bend' are not fully understood. It is suggested that the interplay of differential lowering of the rift floor along the rift with strike slip shear could explain these features.

Griffiths (1977) interpreted the ramp structures as being conditioned by sinistral drag along the N – S boundary fault (Figure 24), which is interesting when contemplating the possibility that the Loboi Lineament might represent the displaced north-westerly extension of the Marmanet Fault Zone. Also the floor of the Gregory Rift itself invites comparison with a major north-tilted ramp.

The Laikipia Plateau

The disposition of lineaments on the Laikipia Plateau suggests that the Miocene phonolites have been faulted, but on the ground there is little evidence for displacement: also these structures may have been initiated later than the late Miocene – early Pliocene, but are mentioned here because of their likely association with that episode.

A swarm of faults trending NE affects the outcrop of the Sipili trachytes and the underlying phonolites to the south: there the configuration of escarpments, and the displacements, suggest the existence of a minor graben which was possibly associated with a now concealed Miocene eruptive centre responsible for the build up of the Lariak Shield. The swarm forms an eastern salient of the faulted Miocene shoulder, which, although discontinuous to the south, might be considered to extend south-

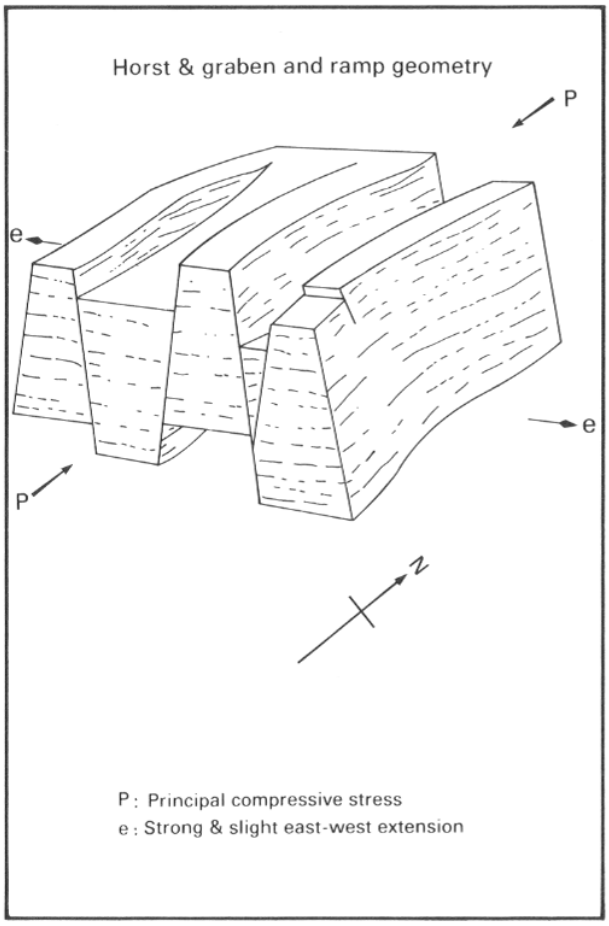


Figure 23 Horst-graben and 'ramp' geometry (after Griffiths, 1977)

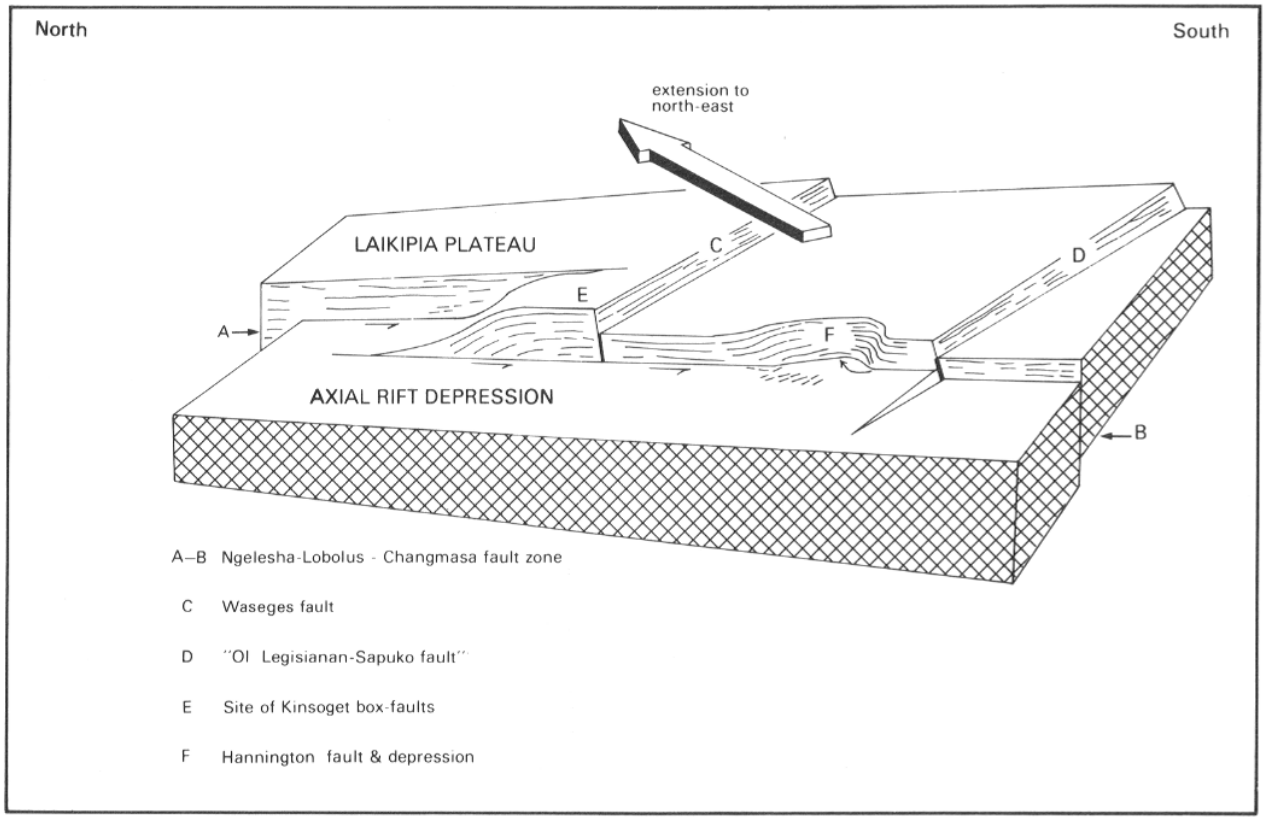


Figure 24 Vertical and strike-slip faulting in the eastern Rift Valley shoulder (after Griffiths, 1977)

west into the Ol Arabel and Iguamiti-Subukia horst and graben complexes.

The ENE-trending lineaments associated with the Loiting extrusive centres on the Loroki Plateau probably reflect structures associated with the late Miocene faulting episode.

In the west the pile of phonolite lavas itself dips regularly at about 4° to the east—to the east the dip is even more gentle, subhorizontal: minor variations may be attributed to irregularity of the substratum, and, at higher levels, to some overlap of the constituent flow units.

Early–Mid Pliocene Faulting

Griffiths' (1980) interpretation of the box-fault system ramp association was in terms of a Miocene age, although Griffiths (1977) assigned the developments of the Kahone, Tasiokwank and Ngusero ramps to his second period of faulting at 5 to 6 Ma.

McCall (1967) interpreted the Lake Hannington (Bogoria) escarpment fault as a single large fracture formed during his second major (Pliocene) faulting episode. He drew attention to a 'facing' of younger phonolites extending only a few kilometres to the east of the main escarpment, also to a facet at the foot of the Marmanet and Chui Escarpments.

Carney (1972) dated minor west-facing faults displacing the Narokwe basalts at 4 to 5 Ma, and also noted fault plane drag at the foot of the Ngyiepe Escarpment. All these features suggest some renewed Pliocene activity along the lines of these major structures which were initiated in the Miocene.

Pleistocene faulting

Another major phase of active faulting occurred in the early Pleistocene, evincing, together with the extrusive activity, westward migration, although no simple causal/periodic relationship is evident between faulting and extrusive phases. Baker and Wohlenberg (1971) estimated a further major uplift of the Kenya Dome (c.1400 m) during the first half of the Pleistocene. In this part of the rift the Nagoreti Fault swarm (Carney, 1972) effectively dropped the western half of the Chepchuk volcanics down about 1000 m to the west, to be buried by later extrusives: the Karau volcanics suffered a similar fate along the line of the Karau Escarpment (Figure 17): thus former multicentre shields have been sliced into linear outcrops parallel to the rift boundary trends. Further north the Orus fault downfaulted the Orus trachyte to the west (Sceal, 1974), although higher up the Amaya valley to the east Golden (1978) noted no further faulting: the Orus fault manifests, typically, as a zone of intense dislocation flanked by remarkably undisturbed ground. McCall's (1967) third major faulting episode was assigned to the early–mid Pleistocene: he considered it to be of lesser magnitude than the preceding 'major episodes', and suggested that the grid patterns characteristic of much of the rift floor developed as the 'active zone' narrowed. The broken aspect of the Lake Hannington Plateau, east of Lake Bogoria, reflects the complex closely-spaced grid faulting which affected the Pleistocene flood trachyphonolites (Plate 8). Griffiths (1977) emphasised that N–S faults are characteristic of the 'median' rift floor, not of the regional fault pattern of the Rift Valley system: however N–S-trends do occur on the eastern shoulder (Figure 22). The central volcanoes, Paka and Korosi, are transected by normal faults trending N and NNE: particularly on Paka these tend to cluster in marginal swarms which have confined the younger units of the extrusive pile. The West Boundary Fault (Sceal, 1974) has a downthrow of at least 60 m to the east. Tensional crevasses trending NNE are prominent on Korosi, where they locate lines of cinder cones. The NNE- and N-trending elements of the eastern marginal swarm of Paka (the Secumius Fault Zone), also the sinuosity of individual fault traces, suggest an element of dextral shear along the rift: further north Key (1987) suggests a similar dextral strike-slip component on the western shoulder of the rift, to account for migration of the seat of Pliocene trachytic volcanism.

South of Paka several separate intense phases contributed to the intricate grid faulting which preceded the extrusion of the upper trachytes and effected an aggregate downthrow of at least 180 m to the west. Sediments, such as the Chemoigut Formation (Section 6.2), have reacted locally to the Pleistocene stresses by folding, along N–S axes, presumably due either to a 'draping' effect above blocks in a horst-graben system, or as a response to oblique strike-slip movements in the infrastructure.

The western shoulder of the rift

The Loyamarok area here features only Plio-Pleistocene volcanic sequences: this area is but a minor fringe of the structurally complex Kamasia escarpments between the Gregory Rift and the Kerio rift valley 30 km to the west. Chapman (1971b) noted only a few faults on the Loyamarok Plateau, but none with throws of more than 6 m: erosion has not affected the fault scarps. Chapman suggested that the easterly slope of the Loyamarok Hills may be an original lava surface slope, later augmented by tilting.

Recent faulting

Carney (1972) recognised Recent faults affecting the Loiminangge beds south-east of Lake Baringo, where west-facing scarps up to 6 m high displace pre-existing piedmont fans.

The Marigat lineament is also a very recent structure affecting the alluvial plains, of especial interest since the trend suggests rejuvenation of buried Proterozoic structures in response to the neotectonic regime, as described in Section 9.2.

While acknowledging the general trend with time towards increasing confinement of faulting to the 'median' or 'axial' rift, continuation of activity on the rift shoulder was dramatically demonstrated by the magnitude 7.0 earthquake centred on the Lariak Forest in 1928 (Tillotson, 1938), when an elongate (28 km) curvilinear fissure appeared at the foot of the Laikipia Escarpment, i.e. along the line of the Marmanet Fault (McCall, 1967, p.87, fig.8). Major landslipping on the steep eastern shoulder escarpments continues as a contributory factor to the geomorphological evolution of the Rift Valley.

10 Geological history – a short commentary

A much generalised summary of the geological history is presented in Table 6 (p. 56).

The pre-Cambrian evolution of the Mozambique Orogenic Belt is conceived in terms of a sequence of thermotectonic episodes which have been defined particularly for the Isiolo area to the east (Hackman and others, in press) and the Maralal area to the north (Key, 1987). Previous concepts of the regional tectonic and metamorphic history (Shackleton, 1946; Hepworth, 1967) have accordingly been reviewed and considerably enhanced. However the age of the original Mozambique sedimentation, the early configuration of the orogenic belt in relation to the emplacement of the ophiolitic components, and the date of inception of the earliest (Samburu) tectonic episodes remain conjectural.

Much has been written on the Cenozoic development of the Rift, in terms of both the petrological evolution of the volcanics, and the structural history: the integration of these two themes on the regional level is a serious task, and most of the more recent attempts stem from the consideration of the extensive data emanating from the EAGRU project. Here it suffices to refer particularly to some important contributions:

1 Structural developments

Baker and Wohlenberg (1971)—structure and evolution; Shackleton (1978)—the East African Rift System.

Petrologic evolution of the volcanics:

2 Wright (1963)—differentiation trends in Cenozoic lavas; Wright (1965)—Cenozoic petrographic sub-provinces; Williams (1969)—volcanic associations in the Gregory Rift; Baker and others (1971)—sequence and geochronology of volcanics; King and Chapman (1972)—recognition of volcanic 'groups'; Williams (1978)—Quaternary volcanism.

3 Attempts to integrate both petrologic and tectonic aspects:

Baker and others (1972)—Eastern Rift System of Africa; King (1978)—structural and volcanic evolution of the Gregory Rift; Williams and others (1983)—The Central Rift (geothermal energy); Williams and Chapman (1986)—The Baringo–Bogoria sector of the Rift.

4 Regional and global tectonics:

Wright (1970)—comparison with mid-ocean ridges; Oxburgh (1978)—discussion of 'mid-plate' tectonics; Khan and Swain (1978)—geophysical investigations.

Aspects of the structural and petrochemical evolution of this part of the Kenya Rift tend to be easily subsumed in terms of generalisations which, particularly in the light of longitudinal variations, might appear to be rather simplistic, but nevertheless have some regional validity:

1 Monoclinal downwarping in the Miocene was followed by faulting leading to graben development, with some antithetic faulting on the eastern rift shoulder: the fault pattern suggests progressive confinement to a narrow 'Rift Valley' zone towards the Quaternary.
2 In general the chemistry of the volcanics was sodic-alkaline in the Miocene: the extrusives range from nepheline-normative basalts to the voluminous plateau phonolites. In the Pliocene and Quaternary the trend was somewhat less alkaline, ranging from alkali basalts with some tholeiitic affinities to trachyphonolites, phonolitic trachytes and soda-trachytes. Thus Williams and others (1983) noted that 'along the entire length of the Rift there are no strongly undersaturated phonolites younger than 7 Ma, apart from the phonolitic nephelinites associated with nephelinitic volcanoes'. Both mafic and felsic rocks show a general decrease in silica undersaturation with time.

The Bogoria–Baringo sector exemplifies the regional variation along the Rift in the sense that the Hannington Plateau area to the south is one of the 'gaps in the line of axial caldera volcanoes' (such as Korosi and Paka) which 'correspond closely to the regions of undersaturated salic volcanism' (Williams and others, op. cit.).

Such longitudinal variation in the nature of the extrusive activity may also be considered in conjunction with changes in structural symmetry in transverse section: thus Williams and Chapman (1986) describe the Rift at the equator, i.e. south of Lake Bogoria in this area, as a *half-graben*, faulted only on the eastern side. The volcanic pile on the eastern shoulder dips generally to the east, away from the Rift, at least as far north as the Amaya Embayment.

Also to the north of Lake Bogoria the Kamasia sequences to the west of this area dip away from the Rift, which in this sector accordingly forms an asymmetrical 'deep graben' changing around 1°N into a 'downwarped depression' where the volcanics on either side dip towards the centre of the Rift. The southern deep graben and eastern side of the equatorial half-graben (i.e. the Hannington Plateau) feature grid-faulted salic flood lavas, whereas trachytic central volcanoes such as Paka and Silali characterise the northern depression. This difference in extrusive style is also likely to reflect different levels of magmatic source, perhaps as a function of variations in dominant structural control of the main subvolcanic conduits.

11 Economic geology

11.1 ECONOMIC POTENTIAL

Five aspects of the economic potential of the area are worthy of emphasis:

1 The possibility of metallic deposits in the Amaya Embayment and the Karisia Hills.
2 Anomalies of uranium and associated elements in the Don Dol Gneisses of the eastern margin of the map area.
3 Industrial rocks and minerals, notably the graphite of the Ol Doinyo Ng'iro area.
4 Gemstones (minor deposits of beryl and varieties of corundum).
5 The geothermal resources of the Rift Valley.

The first two categories are dealt with here in a special report on the results of the Geochemical Exploration Programme by Dr J. Ridgway (Section 12). The other occurrences are described briefly below in alphabetical order.

11.2 BERYL

In the Kirimun area poor quality (i.e. white and opaque) beryl prisms occur as a major constituent in a quartzofeldspathic pegmatite east of Lobor Soit (GR 2759 0577). The prisms are less than 2 cm long and the occurrence has no economic potential. An abandoned pit has been dug into the pegmatite.

11.3 BUILDING STONE

The majority of the Proterozoic rocks are unsuitable for building stone because they are too friable, badly jointed or do not form outcrops suitable for quarrying. The permeation gneisses form large slabs in exposures along the Ewaso Ng'iro River which would be suitable for rough paving stone. However the massive granites and river sand could be used by the construction industry. The phonolites and trachytes of the plateau and rift are most suitable for ballast: the trachyphonolitic welded tuffs are especially suitable for building stone, also the more coherent porphyritic basaltic types—the 'softer' basalts and pyroclastics are generally not recommended, although a bed of fine- to medium-grained homogeneous tuff has been quarried for building stone near the Pesi River 1 km north-west of Uruku farm; the Suguroi valley has a similar deposit. Flaggy lavas are often used for dry stone walls on the plateau.

11.4 CLAY

The 10 m thick sepiolite unit forming the top of the Miocene sedimentary rocks around GR 263 070 in the Kirimun area could support a limited local demand for clay.

11.5 COPPER

In the Lentaarrai River (GR 2693 0880) in the southern Karisia Hills a pegmatite vein with a patina of ?chrysocolla was sampled by H. Muturi: assays by the Kenya Mines and Geological Department laboratory gave the following results:

Cu 7200 ppm
Ni 2000 ppm
Fe 2600 ppm

Despite the interest of the occurrence the size of the pegmatite precludes any economic significance.

11.6 CORUNDUM

Nicely formed corundum prisms are present in the vicinity of Ol Doinyo Ng'iro. No gem quality material was found although blue sapphire-corundum prisms were shown to Dr Key by a shopkeeper in Ol Doinyo Ng'iro.

11.7 DIATOMITE

McCall (1967) mentioned four deposits of diatomite, essentially thin bands which are unlikely to be of economic value. Two were in the Subukia area, in the south-west: a sample from the White Rocks Corner deposit on Nicholson's farm, 15 km further north was analysed (McCall, p.103), and found to be of poor quality.

Other diatomaceous sediments have been noted as constituents of Quaternary sequences elsewhere in the Rift (e.g. Section 6.2), which could be considered as prospective for diatomite, should the need arise. Shackleton (1946) recorded several beds of fairly pure diatomite about 0.5 m thick within trachytic tuffs in the Pesi River headwaters: these are also too thin to be of economic significance.

11.8 GARNET

Badly broken almandine garnets are common in the Kirimun area. No gem quality material was found. The largest specimens, as perfect trapezohedra, form float over the quartzofeldspathic gneisses north of Ol Doinyo Ng'iro.

11.9 GRAPHITE

A separate special confidential report has been written on the graphite deposits west of Ol Doinyo Ng'iro (Key, 1982).

Graphite gneisses were recorded in that area by

Shackleton (1946), and subsequently more detailed work was undertaken by the Kenya Mines and Geology Department (Stewart, 1963) but the low grade did not encourage further follow up until recent identification of local demand for graphite (a pencil factory at Nyahururu) and the advent of improved technology for separation and upgrading (Briggs, 1981). Key's mapping of the main graphitic unit has extended its length along the strike from 8 to 27 km: it forms the keel to a Barsaloian synform, with vertical thicknesses of over 30 m at the margins.

Graphite occurs as aligned flakes several millimetres in diameter, forming 10 to 20 per cent of the mode of medium-grained plagioclase-quartz gneisses. Key recommended further trenching in specific areas, and pitting near northings 061 and 066.

Another graphite gneiss unit at GR 2482 0500 consists of two separate bands with a graphite content of 10 to 15 per cent (Charsley, 1984). The extent and variation in graphite along the strike, and in the band to the south-east (GR 2491 0489) need to be investigated. Water is nearby and the area is easily accessible.

11.10 GRAVEL

All the tributaries of the Ewaso Ng'iro and Ewaso Narok Rivers have sandy beds, providing sources of river gravel. The main component of the gravels is an iron-stained quartz sand. Various rock fragments (up to cobble-size) are ubiquitous, together with minor feldspar, garnet and ore derived from the metamorphic bedrock. Coarser, but less easily accessible, volcanic gravel is available in the steep lower courses of the rivers which descend the Laikipia Escarpment.

11.11 MARBLE

The northern part of Lobor Soit Hill (GR 2747 0575) is composed of coarsely crystalline marble. The marble is pure apart from minor amounts of chert and must have some potential as a source rock for cement. No chemical analyses have yet been carried out to determine the amount of MgO, P_2O, etc. present. However marble samples from the Mukenya area to the south have been tested and shown to be non-dolomitic.

Lobor Soit is an ideal site for a quarry as it is adjacent to a good dirt road and the marble forms a slope ideal for quarrying.

11.12 PHONOLITE

Phonolite is used in some countries, such as Czechoslovakia and Germany, for glass-making. The possibility has not been investigated in Kenya, but clearly the resources are voluminous: the desirable low-iron varieties should be available.

11.13 SILLIMANITE

Sillimanite is the major modal phase of a massive gneiss exposed immediately south of the Tura to Crocodile Jaws track at GR 2713 0597. The exposure is small and pitting is needed to ascertain the full strike length of this rock.

Jali (1983) mapped a wide band of sillimanite-gneiss within the Don Dol Gneisses of the Mukenya area (GR 267 039).

11.14 SODA

McCall's 1967 table III (pp.76–77) quoted four analyses of Bogoria lake water (columns, 3, 5, 11 and 18). He thought that in view of its depth, Lake Bogoria might suitably supply sodium monocarbonate and caustic soda. Competition from Lake Magadi, accessibility and environmental considerations are all likely to discourage such a development at present.

11.15 SULPHUR

Mason (1968) noted a sulphur efflorescence on the north-east corner of Ol Kokwe Island in Lake Baringo, covering about 185 m^2 on the side of a hill capped by a basalt flow. Grab sample assays varied from 27.4 to 76.1 per cent sulphur, and the reserves were estimated at 25 to 40 tonnes. Minor sources of sulphur also occur around several of the vents on Korosi and Paka.

11.16 VERMICULITE

A small pocket of vermiculite, after biotite, occurs in mafic gneisses close to the Ewaso Narok River (GR 2486 0505). It is likely to be of economic significance for local use only.

12 The Geochemical Exploration Programme

J. Ridgway

12.1 GENERAL DESCRIPTION

Introduction

The geochemical exploration of Degree Sheet 35 formed part of a wider reconnaissance survey covering the area between 36° and 38°E and 0° and 2°N: the following summary is applicable to the whole of the survey (Degree Sheets 27, 28, 35 and 36). Sampling was conducted concurrently with geological mapping and was largely constrained by the requirements of that exercise. Thus samples were collected chiefly, although by no means exclusively, along traverse lines dictated by geological considerations. Little or no sampling was done in areas previously mapped by the Geological Survey of Kenya or the East African Geological Research Unit (EAGRU). More detailed descriptions of the methods used and the rationale behind the geochemical survey can be found in a series of open file reports of the Overseas Programme Directorate of the British Geological Survey (formerly the Institute of Geological Sciences) (Ridgway, 1981a; 1981b; 1982; 1984). Sampling was mainly confined to areas underlain by basement rocks of the Mozambique Belt and was very sparse over most of the Tertiary and Quaternary volcanic cover.

Multi-element anomaly maps and single element plots based on decile divisions of the stream sediment data set, all at 1:250 000 scale, can be obtained through the Mines and Geological Department, Nairobi. Data from both stream sediment and pan concentrate surveys are also held in computer readable form and can be made available as print out, decile maps covering specific areas or on magnetic tape and floppy diskette media. All requests for such data should be made to the Commissioner of Mines and Geology, Mines and Geological Department, Nairobi, from whom further details are obtainable. A service charge will be made for all maps and data sets.

The sample collection programme

Two sampling media were employed in the survey; normal stream sediments and panned heavy mineral concentrates. The intensity of sampling varied according to the geology and the degree of exposure. Well-exposed areas of complex geology were subject to higher density collection than regions of extensive superficial deposits, which received little attention. Figures detailing sample densities have little meaning in this context and the pattern of collection can be seen on the summary geochemical anomaly maps for each of the four degree squares comprising the survey area. In general terms the initially recommended densities of 1 sample per 4 to 8 km^2 for normal sediments and 1 per 13 to 16 km^2 for pan concentrates were achieved, and exceeded in regions of special interest.

Stream sediments were collected by combining grab samples from 5 to 10 points within a 10 m radius of the selected site, the number of points varying according to the width of the channel. If necessary the sediments were dried before being sieved and the fine (– 80 mesh) fraction retained for analysis.

Heavy mineral concentrates were obtained by taking 2 to 5 kg of material from the sample site and panning at the base camp, where water was available, or at the Mines and Geological Department headquarters in Nairobi.

The analytical programme

The fine fraction from the stream sediment samples was analysed by atomic absorption spectroscopy, after digestion in hot 1:1 hydrochloric acid, for Ag, Ba, Co, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sr, and Zn. Initially the analyses were carried out in the laboratories of the Mines and Geological Department but for a number of reasons it unfortunately became necessary to switch to Geosurvey International Limited after approximately one quarter of the total number of samples had been processed. The effects of this change on the interpretation of the results are discussed later. Samples from the following 1:50 000 map sheets were analysed by the two laboratories: Mines and Geological Department sheets 106/1 and 106/4; Geosurvey International Limited sheets 91/2, 92/2, 92/4, 106/2 and 106/3.

With both laboratories precision (defined as twice the standard deviation of a series of replicate analyses divided by the mean and expressed as a percentage) was monitored by the submission of control samples and replicates. For the Mines and Geological Department analyses precision generally varied between 20 and 40 per cent depending on the element and concentration, the results being worst at low concentrations. Low concentrations also yielded the worst precision figures for the Geosurvey data but monitoring charts of the type advocated by Thompson and Howarth (1973) show that for most elements the precision is better than 20 per cent, the chief exceptions being Pb and Li. A precision level of 20 per cent is adequate for geochemical exploration purposes and even where the figure is higher, examination of simple element concentration maps shows that the stream sediment chemistry reflects the geology with a fair degree of accuracy and there is therefore no reason to doubt the reliability of the data. Further details on the precision of the analytical results can be found in Ridgway (1981b; 1982 and 1984).

Pan concentrates were analysed by X-ray fluorescence methods in the Department of Geology at the University of Nottingham, UK. The elements determined were As, Ba, Bi, Co, Cr, Cu, Fe, La, Mn, Mo, Nb, Ni, Pb, Sn, Sr, Th, Ti, U, V, W, Zn and Zr. Because of the small amounts of concentrate usually available it was not possible to monitor the precision of the XRF programme by using replicates, but the laboratory claims a figure of better than 8 per cent at the 100 ppm level for all the elements determined.

Interpretation

Fine-fraction stream sediments

Interpretation relied heavily on the use of plots of log concentration against probability (Lepeltier, 1969; Sinclair, 1976) to determine threshold values, above which concentrations can be considered to be anomalous and possibly related to mineralisation. This approach was supplemented by the examination of maps showing the spatial variation in concentration of each element.

Because of the complexity of the geology in the survey area the data were grouped according to the dominance of one or more of a number of lithological units in the drainage basin upstream from the sample site before commencing the generation of log concentration/probability plots. The lithological units were chosen in consultation with the mapping geologists and are described briefly below.

The greater part of the area covered by the geochemical survey is underlain by rocks of the Mozambique Orogenic Belt. These are chiefly metasediments of probable middle to late Proterozoic age which have undergone polyphase metamorphism accompanied by widespread anatexis. The present metamorphic grade is almost uniformly of the upper amphibolite facies. Six significant groupings have been recognised in the basement in this area (letters in parenthesis are codes used in later tables and text):

Don Dol Gneisses (D)—medium- to coarse-grained, banded, quartz-feldspar biotite gneisses with some hornblende gneiss and a few thin metasedimentary intercalations of marble, graphite gneiss, garnet gneiss and metaquartzite.

Ol Doinyo Ng'iro Gneisses (O)—medium- to coarse-grained, banded, biotite gneisses with major metasedimentary intercalations of marble, graphite gneiss, garnet gneiss, sillimanite garnet gneiss and metaquartzite.

Loroki Gneisses (KL)—quartzofeldspathic gneisses, sometimes carrying muscovite, and minor, banded, biotite gneiss. Highly leucocratic with little biotite, but common zircon and magnetite/ilmenite. Variably migmatised.

Migmatites (M)—coarse-grained quartzofeldspathic migmatites with some mafic hornblende-rich varieties and garnet-bearing types. Generally massive, heavily veined and pegmatised. Muscovite occurs in the pegmatites.

Metabasic and meta-ultrabasic pods (MBU) not obviously related to the Siambu or Korr Complexes.

Quartzofeldspathic gneiss and granite gneiss (QG).

Tertiary and Quaternary volcanics overlie the basement and are particularly extensive on the eastern shoulder of the Rift Valley and in the southern part of the region. Four groupings have been recognised in the volcanics, only two of which are represented on Degree Sheet 35:

Phonolites and phonolitic trachytes (P)—extensive flows of Miocene age found along the eastern shoulder of the Rift Valley and on the northern slopes of Mount Kenya.

Basalts and associated undersaturated rocks of Miocene to Pliocene age (SO)—extensive thin flows on the eastern rift shoulder (Samburu Basalts).

In addition to the above a small group of undifferentiated sediments has been defined.

Mafic and felsic intrusions of various ages are found throughout the basement but are generally of too limited extent to form useful divisions for the purposes of the stream sediment exploration programme.

After separation of the data into results produced by the Geosurvey laboratory and those emanating from the Mines and Geological Department laboratories, the above groupings were used to generate threshold values applicable to the whole of the surveyed area (Table 7). Thus, depending on the relationship between the areal distribution of the lithological groups and the time the samples were processed each division may have one or two threshold values per element. This does not affect the appearance of the summary multi-element anomaly maps for the four degree sheets. On these the anomalies are plotted in a standardised form (Govett and Galanos, 1974) using the formula:

$$\frac{(\text{Anomaly} - \text{Threshold})}{\text{Threshold}} \times 100$$

Results equal to the threshold level were regarded as anomalous and given the standardised value of 1.

The practice, frequently adopted in the absence of well-defined inflection points in the log concentration/probability curves, of regarding the top 2.5 per cent of high values as being anomalous has not been followed

Table 7 Threshold (upper) and background (lower) levels in relation to drainage basin lithology groups (see text for explanation of letter codes) and analysing laboratory

Drainage Basin Lithology	Zn	Pb	Ni	Co	Mn	Cu	Sr	Ba	Li
All data									
QG	150	20	50	40	3000	80	155	500	19
	41	1	14	12	468	18	32	118	5
O	100	16	70	50	1200	60	—	—	—
	45	1	17	15	438	23	33	132	5
MBU	100	—	1000	—	2000	170	250	—	—
	38	1	21	17	453	23	36	130	5
KL	150	20	70	35	1600	45	250	350	22
	44	2	15	12	476	15	39	107	6
Mines									
D	200	30	100	50	2500	40	600	300	30
	30	10	21	16	555	13	71	86	2
M	80	21	35	28	2000	30	200	205	26
	35	10	18	16	629	13	59	88	4
P	100	40	100	26	3000	25	350	300	10
	46	17	27	16	1257	12	75	135	2
SO	120	30	50	51	4000	—	700	400	20
	52	12	25	20	972	16	100	132	3
Geosurvey									
D	110	40	60	35	2000	—	150	400	—
	41	1	15	14	427	17	27	103	3
M	125	20	40	70	—	55	135	350	30
	42	1	15	13	422	19	30	103	5
P	200	40	40	50	5000	—	160	500	—
	69	4	10	14	1184	13	31	161	7
SO	200	15	70	70	—	60	190	500	—
	62	2	14	16	752	17	63	181	7

Under 'All data' samples from each group were analysed almost exclusively by either the Mines Department or Geosurvey laboratory. Where no threshold value is given the log concentration versus cumulative frequency graph indicated the presence of only one population. Figure 1 shows the relationship between 1:50 000 map sheets and analysing laboratory.

here. Threshold values have been defined only where significant changes in slope at high concentration levels could be identified.

For the maps showing the areal variation in element concentration the data from the two analytical sources were separately divided into decile groupings for the individual element concentration ranges and the decile intervals plotted as variable sized symbols.

In assessing the significance of the anomalies it should be borne in mind that they are not all necessarily related to occurrences of economically important minerals. Analytical interferences, secondary environmental effects and concentrations in 'non-economic' minerals may singly or in combination give rise to anomalous results for some elements. Detailed consideration of these factors is beyond the scope of this report but some of the more obvious possible effects are worthy of comment.

Background absorption can lead to large errors when AAS methods are used to measure low concentrations of an element in geochemical samples (Fletcher, 1970; Foster, 1971). In the present survey Pb, Co and Ni could have been affected but the low threshold levels for Pb in some lithological groups make anomalies in this element the most likely to be spurious. Ca and Fe are two of the most important interfering elements and care is needed in the evaluation of Pb anomalies where Fe concentrations, marbles or calcrete are prominent in the catchment area.

'Scavenging' by Fe/Mn oxides can preferentially concentrate a number of elements and give rise to anomalies unrelated to mineralisation. Mn oxides are probably more efficient scavenging agents than those of Fe (Chao and Theobald, 1976). Co, Zn, Ni and Cu have all been reported to be affected, whereas Pb commonly is not (Levinson, 1974; Carpenter and others, 1975; Whitney, 1981). Nowlan (1976), however, considers Pb to be weakly scavenged. Low-level anomalies in the above elements in association with high Mn values are the most suspect, but it should be remembered that some mineral deposits are accompanied by enhanced levels of Mn.

Erosion of ultramafic rocks can give rise to anomalies in Ni, Co and Cu because of their characteristically high content of these metals. Calcrete deposits might be enriched in strontium and produce low-level anomalies, particularly in flat-lying plains and areas of poorly defined drainage.

Pan concentrates

A number of factors can contribute to variability in the analytical results from a pan concentrate exploration programme. Among these factors are the selection of the collecting site in the stream, the depth of collection, the consistency of the degree of panning and the 'nugget effect' in the fraction selected for analysis. Given the size of the present survey, the time allotted for completion and the difficulties of panning in a semi-arid environment it was not possible to significantly reduce the variability inherent in the methodology.

Interpretation at this stage has relied on the identification of anomalous samples from scatter plots of individual element concentrations against the combined concentration of Ba and Sr; this latter factor being introduced as a rough measure of the degree of panning. Thus relatively low values of an element might be considered anomalous if high values of Ba + Sr indicate a poor degree of concentration of heavy minerals. Threshold levels for the pan concentrates are shown in Table 8.

As with the fine-fraction stream sediments, anomalies in pan concentrates are not necessarily directly attributable to the presence of ore minerals. Many of the elements determined in this survey are found in small quantities in common rock-forming and accessory minerals. If any of these minerals occur in quantity in the concentrates anomalies in a variety of trace elements could result.

Table 8 Threshold levels for pan concentrates established from examination of scatter plots of individual elements against combined Ba and Sr values

Element	Threshold	Element	Threshold
As	12	NB	250
Ba	2000	Ni	250
Bi	5	Pb	50
Co	110		Ba + Sr > 2500: 10
	Ba + Sr > 600: 70	Sn	50
	Ba + Sr > 1300: 40		Ba + Sr > 1000: 25
Cr	3500	Sr	900
Cu	70	Th	800
La	2000	Ti*	33
Mn	1.9	U	60
	Ba + Sr > 2000: 1.0	V	2300
Mo	45	W	50
	Ba + Sr > 1500: 35	Zn	900
	Ba + Sr > 2400: 10		Ba + Sr > 700: 500
		Zr	1750

* Values in % MnO and TiO_2

Predicted mineralisation

Neither the Mozambique Belt nor the East African Rift volcanics contain many significant recorded mineral deposits.

However, a wide variety of mineral deposits could occur in a complex metamorphic terrain and metasediments, metavolcanics, acid and basic intrusives are all present within the Project area. Thus ores related to igneous, metamorphic, sedimentary and surficial environments may be present in some form. Base and precious metals, tin, tungsten, chromium, niobium/tantalum, rare earths, uranium and pegmatitic deposits are all possible targets for the exploration programme.

In the volcanic areas carbonatite and kimberlite intrusions and a variety of vein deposits associated with faults and volcanic centres could be present.

Minor amounts of economically interesting minerals such as beryl, mica, chromite and corundum, along with indications of Ag, Au, Bi, Cu, Mn, Nb and rare earth mineralisation, have been noted in the Project area.

12.2 RESULTS FOR DEGREE SHEET 35

Fine-fraction stream sediments

A summary map of the anomalies is given in Figure 25. In the following discussion the anomaly numbers refer to those on Figure 25. some details of the numbered anomalies are given in Table 9.

Pan concentrates

Pan concentrate anomalies are shown on Figure 26. They are restricted to the northern half of the sheet with one prominent group in the north centre, in an area previously mapped by EAGRU but sampled because of the presence of an alkaline igneous complex.

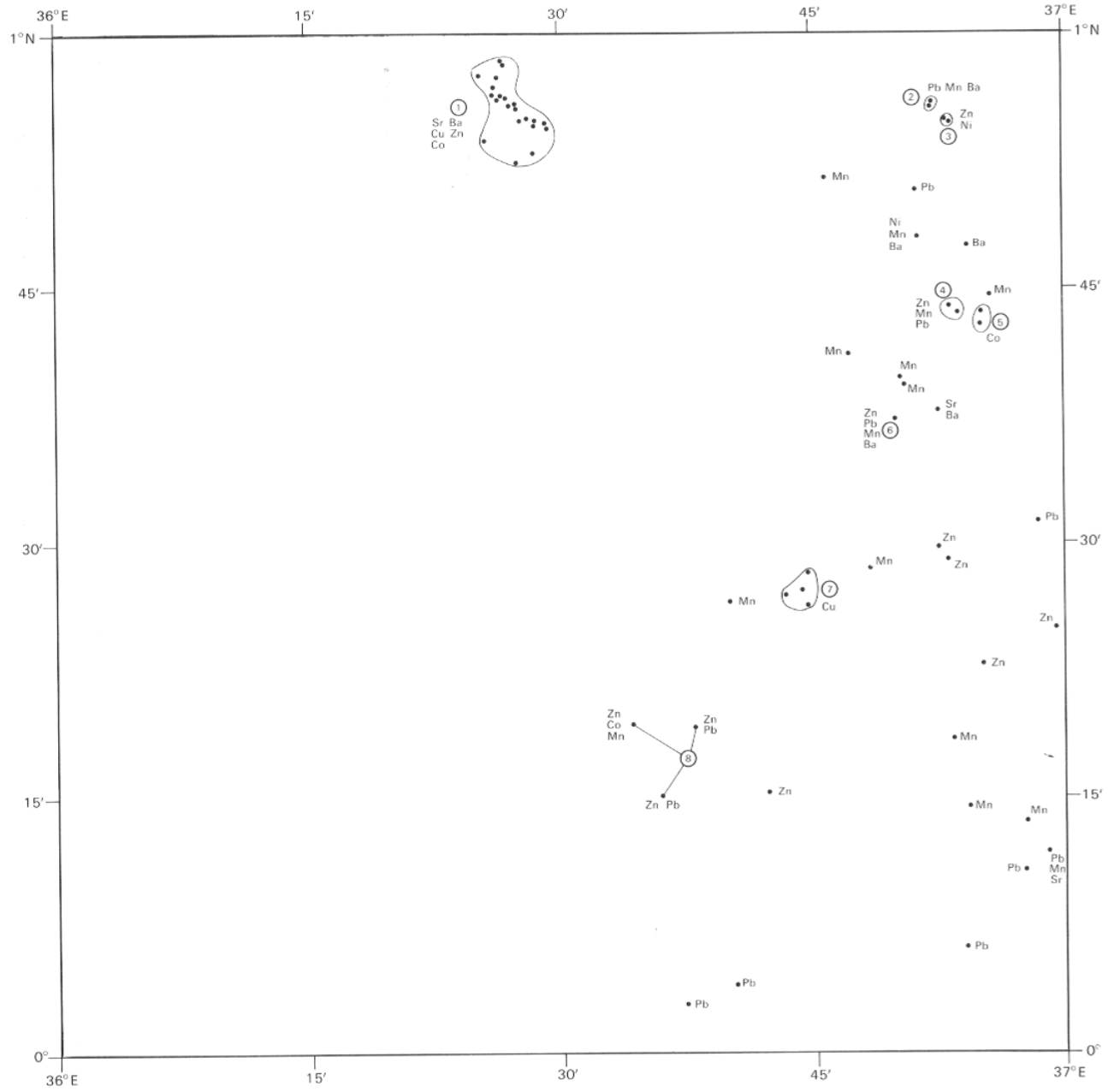


Figure 25 Anomalies in – 80 mesh stream sediments

Comments on the anomalies

Throughout the area there are scattered stream sediment Mn anomalies and in the southern half isolated Zn and Pb anomalies occur. The majority of these anomalies are found in flat-lying country containing a number of seasonal swamps. Cattle ranching is widespread. Secondary environmental factors related to precipitation in sluggish streams and at the margins of swamps (e.g. 8) may be responsible for the majority of the high values but contamination from agricultural activities and human habitation may also contribute. Three pan concentrate samples have high levels of Fe and Mn oxides along with Ba, Mo and slightly enhanced Pb. They also occur in flat-lying plain areas and are probably the result of secondary precipitation and adsorption. A pan concentrate Mo anomaly associated with a stream sediment Mn high is considered to have a similar origin.

The Sr, Ba, Zn, Cu and Co anomalies of 1 have corresponding pan concentrate anomalies of a relatively low level in Co with some anomalous Sr, Cu, V and Zn values. The Co in pan concentrates becomes anomalous chiefly because the relatively high Sr + Ba values have been used as an indication of the degree of panning (see Table 8) and is thus of little significance in this situation. High levels of Nb, La, Ti, Zr, etc, which might have been expected from an alkaline complex such as is known to occur in the area, are absent.

Stream sediment anomalies 2 and 3 have no accompanying pan concentrate anomalies but are spatially related to a major fold closure in gneisses in the Loroki forest area. No samples were collected upstream of either anomaly group. Anomaly 3 has gneisses of group QG in the drainage basin: use of QG thresholds would lower the Zn and enhance the Ni standardised anomaly values. Zn,

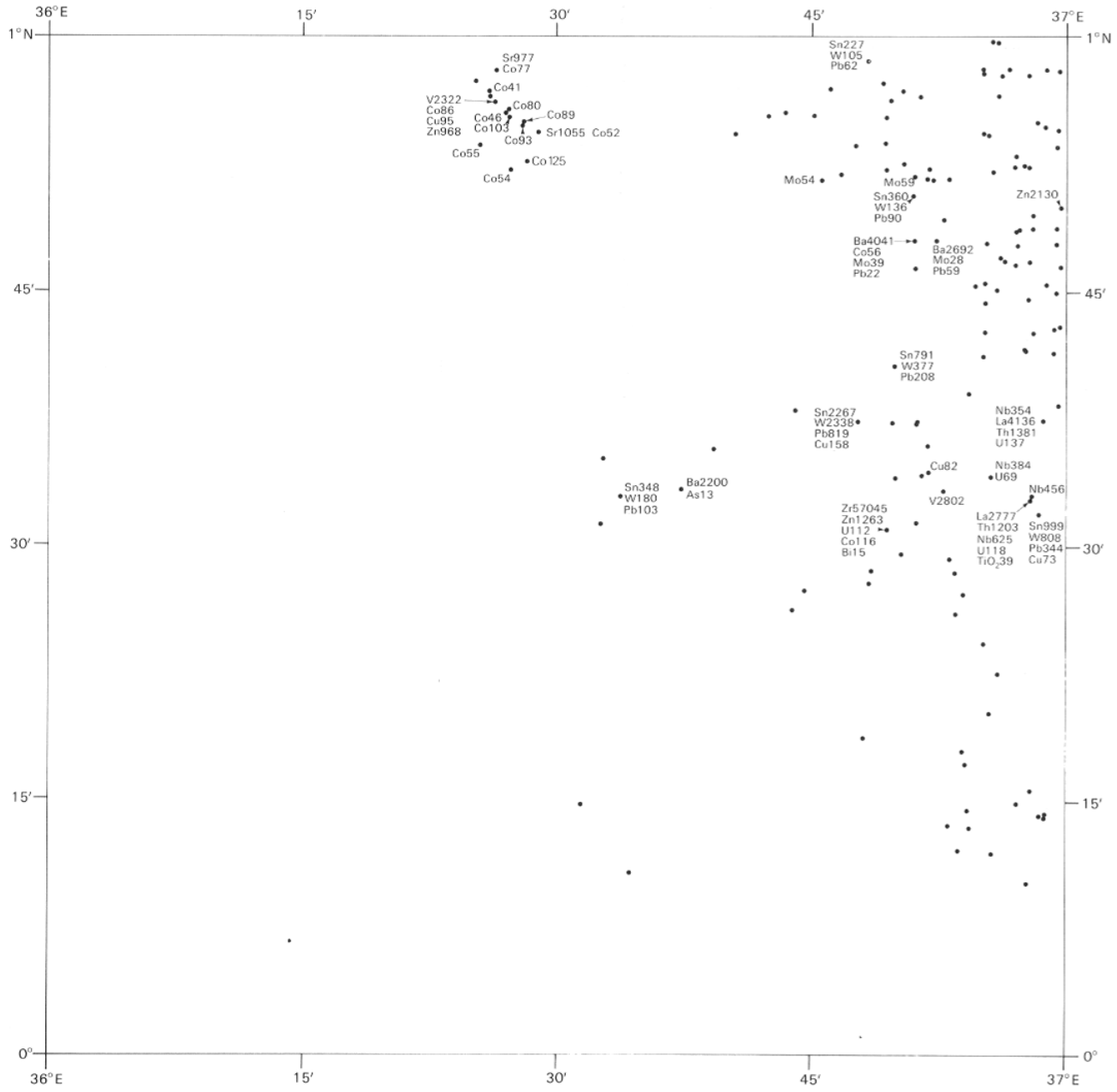


Figure 26 Anomalies in pan concentrates

Pb, Mn, Ba and Li are all generally high in the area.

Anomalies 4, 5 and 6 are all at low levels and based on the threshold levels of the undifferentiated gneiss group (X). These thresholds are the lowest for the basement groups and the anomalies are probably of little significance.

The Cu anomalies of 7 occur where streams draining phonolites encounter an area of Don Dol Gneisses with basic intrusions and may be associated with the latter. Ni levels are also relatively high in the same small area.

In the central part of the eastern margin of the sheet two pan concentrate anomalies in Nb, La, Th and U (Figure 26) occur in an area of Don Dol and Ol Doinyo Ng'iro Gneisses. A Sn, W and Pb pan concentrate anomaly, with minor Cu, is found in the region and has an associated stream sediment Pb high in the drainage basin. The Don Dol Gneisses on the western margin of Degree Sheet 36, immediately to the east, also contain a number of Nb anomalies and the presence of mineralised pegmatites and/or veins seems possible.

The five other Sn, W, Pb anomalies on Sheet 35 are scattered and in areas dominated by volcanic rocks. They may originate from small inliers of basement or perhaps from heavy mineral accumulations in the sediments which underlie the Miocene phonolites.

Summary

The geochemical exploration programme in Degree Sheet 35 has indicated a number of areas where further investigations are merited. The four areas which are considered to be of the greatest interest are listed below:

1 Despite the lack of pan concentrate anomalies to complement those in the fine-fraction stream sediments the area around the alkaline complex indicated by anomaly group 1 still seems worthy of further exploration since alkaline rocks are known to

host a variety of mineral deposits including rare earths, Nb/Ta minerals, phosphate, apatite, baryte and (rarely) Cu.

2 The Nb, La, Th, U anomalies in the Don Dol Gneisses at the eastern margin of the sheet are also interesting, particularly since they form part of a larger area of Nb anomalies which extends into Degree Sheet 36.

3 No specific region is defined by the scattered Sn, W, Pb pan concentrate anomalies, only one of which can be directly related to the basement. Investigation of their origin may be worthwhile, but the possibility that the anomalies arise from substitutions in minerals such as sphene, zircon or magnetite should not be overlooked.

4 Anomalies 2 and 3, from stream sediments draining the Loroki Forest area, are not backed up by pan concentrate highs but their location near the head of their respective drainage basins and the presence of a major fold closure upstream suggest that they may merit some attention. The Loroki Forest region on the adjacent sheet to the north (Degree Sheet 27) also gives rise to a number of anomalies.

These conclusions are based on a preliminary examination of the data; further study may reveal more information on the possible origin of the anomalies and indicate other areas of interest.

Table 9 Summary of the main stream sediment geochemical anomalies

Anom. No.	Elem.	D.B. Lith.	Thr. Value	Values ppm	Values standard	No. of Samps.
1	Sr	SO	190	207–1030	9–442	12
	Ba		500	538– 955	8– 91	5
	Cu		60	63– 104	5– 73	6
	Zn		200	221– 349	11– 75	6
	Co		70	74	6	2
2	Pb	QG	20	34– 80	70–300	2
	Mn		3000	4200	40	1
	Ba		500	800	60	1
3	Zn	OB	100	138– 190	38– 90	2
	Ni		70	79–100	13– 43	2
4	Zn	X	80	95	19	1
	Mn		1500	1570	5	1
	Pb		10	10	1	1
5	Co	X	27	29– 37	7– 37	2
6	Zn	X	80	94	18	1
	Pb		10	11	10	1
	Mn		1500	2120	41	1
	Ba		240	260	8	1
7	Cu	P	25	27– 32	8– 28	4
8	Zn	P	100	123– 274	23–174	4
	Pb		40	59– 73	48–174	2
	Mn		3600	4540	51	1
	Co		26	31	19	1

Notes
Anom. No. refers to the numbered anomalies in Figure 26, Elem. = element, D.B. Lith. = drainage basin lithology, Thr. Value = threshold value, standard. = standardised anomaly value, No. of Samps. = number of anomalous samples.

Anomalies 1 to 6—analyses by Geosurvey International Limited.
Anomalies 7 and 8—analyses by Mines and Geological Department.

13 Water resources

Much of the area, except for parts of the Rift in the north-west, is well supplied with water from perennial rivers, dams and boreholes: in the course of this survey a general deterioration in the condition of dams and boreholes has been noted in many parts of the area, which is likely to lead to future problems if it remains unchecked. As no test pumping has been performed on a regular basis in recent years, no modern data on groundwater conditions are available. Regional potential for improved water resources development is considerable, and is needed to support the ranching industry. Figure 27 shows a fair density of boreholes over the Laikipia Plateau and in the

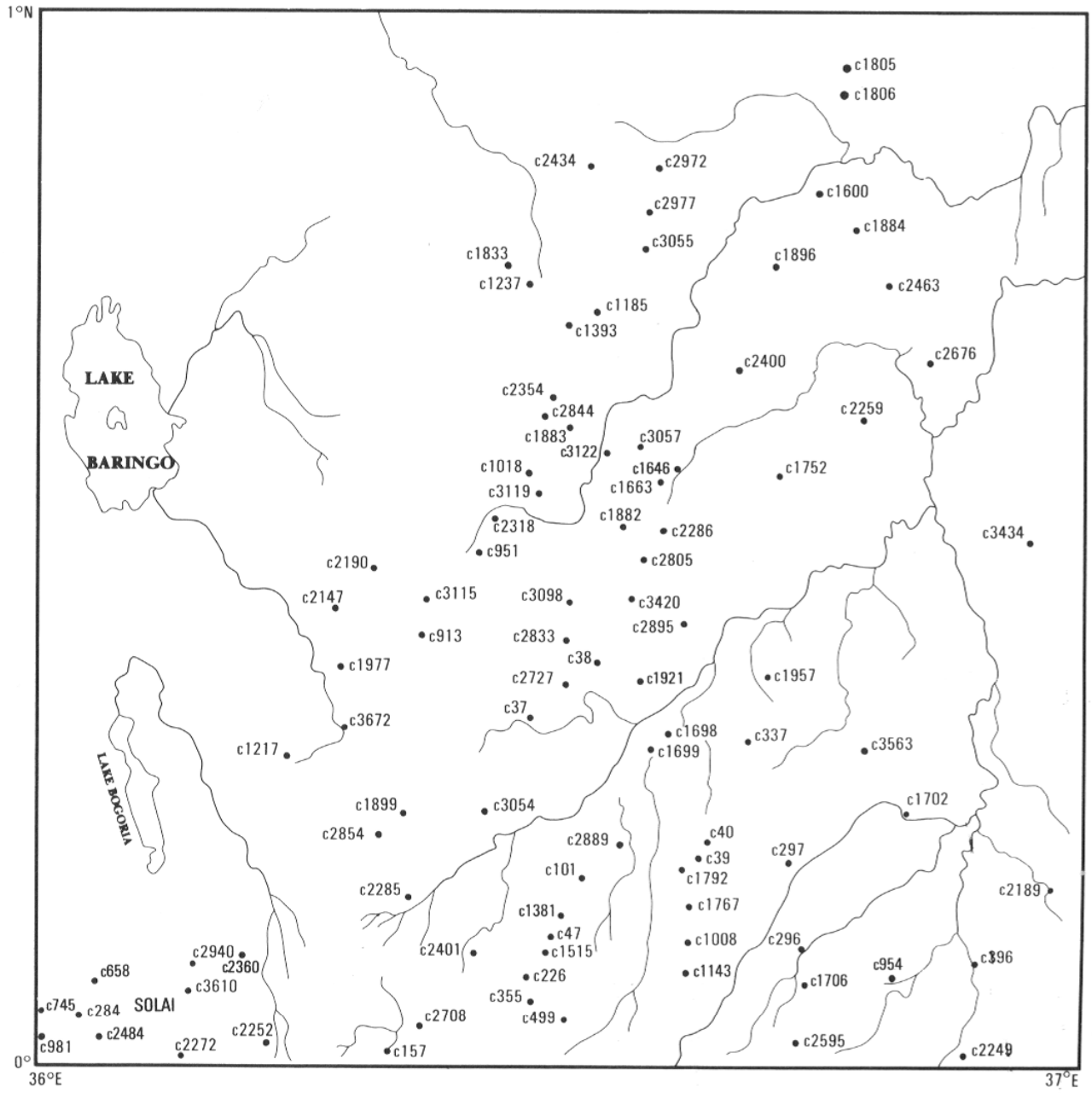


Figure 27 Boreholes in the Solai–Laikipia area

south: however the data, compiled from Ministry of Water Development files in 1986, are unlikely to be complete.

The average annual rainfall varies from 1140 mm south-west of Nyahururu to less than 500 mm in the north-east. The height of the 'rest level surface' varies in the same general direction between c.2500 and 1500 m above sea level (Bristow and Temperley, 1964), although the forested Karisia Hills in the extreme north-east are well-watered. It is convenient to consider the three main physiographic zones separately for the purposes of describing the water resources:

1 In the 'uplands' of the Ewaso Ng'iro River Basin, founded on the Proterozoic metamorphic rocks, water requirements for the local Samburu population are largely met by the main river, using buckets: no pumping is carried out. No dams have yet been constructed along its length.

That part of the Ewaso Ng'iro catchment which occurs in this area was included in a comprehensive investigation of the water resources of the entire Ewaso Ng'iro Basin undertaken in 1958–61 (Roberts and others, 1962).

On the interfluves (even on the high ground) the more permeable gneisses and connecting fracture zones may provide aquifers.

If a supply is needed for the growing settlement at Ol Doinyo Ng'iro, near the graphite prospect, the most likely source rock for drinkable groundwater is the marble immediately to the east.

2 On the Laikipia Plateau the Rumuruti phonolites are, fortunately for the ranching industry, an excellent source of groundwater over much of the area. Boreholes seem to provide the most reliable supplies: water is reticulated through pipe systems from the well heads to widely dispersed tanks and troughs.

Yields from the Rumuruti phonolites fall somewhat to the east: however, Bristow and Temperley (1964) carried out a general survey of the hydrogeology of central Laikipia and concluded that 'many times the present number of boreholes could be drilled before depletion would set in'. Following Sykes (1934) they consider that 'old land surfaces', marked by weathered zones and fossil soils, are the principle aquifers, forming thin stratiform bodies sandwiched between lavas, locally giving rise to springs: for example, along the Ol Keju Losera valley where the Sukuta lol Marmar spring emerges from near the base of the Middle Rumuruti (Lower Ewaso Narok) phonolites, and the Sukuta Mugie spring located at the bae of the Upper Rumuruti (Marmanet) phonolites; both sites are also related to major joint swarms trending ENE.

The springs seeping from the Lower and Middle Rumuruti phonolites/basement interface in the Kirimun area provide a permanent source of water fit for human consumption.

The groundwater on the plateau is slightly saline, with a higher fluoride content than in the Marmanet Forest area.

To the south of the main plateau, the Thomson's Falls phonolites are a poor source of groundwater: Bristow and Temperley (1964) ascribe this to their poor permeability and the absence of intercalated weathered zones. However, McCall (1967), noted that boreholes in the Sattima Fault Zone east of Nyahururu yielded copious water supplies. Boreholes into the Laikipian Formation basalts have also often proved disappointing, because they rarely tap the 'water rest level'.

Many small earth dams have been constructed across the rivers on the plateau, providing reservoirs, which, except in the north, dry out only during prolonged periods of drought.

Swamps such as the Ewaso Narok swamp and the Pesi swamp near Rumuruti, have resulted from a combination of impermeable lava at the surface and centripetal groundwater drainage, perhaps conditioned by broad warping. The Narok swamp covers a total area of 20 km^2: drainage proposals, and the irrigation possibilities for the Pesi swamp were discussed by Roberts and others (1962, pp.267–277).

3 In the Rift Valley, rainfall and the availability of permanent water in the rivers away from Lake Baringo decrease generally towards the north.

Bristow and Temperley (1964) postulated that, although on the central Laikipia Plateau the 'water rest level' declines towards the north-east, much groundwater discharges in the opposite direction, due to channeling in fossil valleys on the sub-Miocene surface which is tilted westwards: such water would eventually drain into the Rift Valley and supplement groundwater reserves, in particular under areas like the Loboi Plain and the Mukutan–Komol Basin.

Rivers flowing off the Laikipia Escarpment, such as the Ol Arabel and the Mukutan, tend to lose much of their surface water into escarpment fault zones, and also into the alluvial gravels soon after they debouch on to the rift floor. Therefore the groundwater potential of the alluvial zones of the Amaya Embayment and the Mukutan–Tangulbei Basin should be considerable. Although the groundwater of the Loboi Plain is somewhat saline, the Perakera (Tigeri) River which drains part of the southern Tugen Hills is used for an irrigation scheme over the western part of the plain.

Sceal (1974) noted in the northern part of the rift that permanent water was available in the rivers at Nginyang, Tangulbei and in the upper Amaya but not in the lower Amaya below the Locheria Kosowa gorge. Between Paka and Korosi the Komol River often dries up completely below the water holes at Tapogh; 10 km to the west the river course ends in Lake Tilam, which for much of the year is a dry pan.

14 Geothermal energy

The successful exploitation of geothermal resources at Olkaria, on the south side of Lake Naivasha, is currently being followed up by the national geothermal exploration project, carried out by the Kenya Ministry of Energy and Regional Development in conjunction with UNDP and the British Government. That project is investigating the Kenya Rift Valley from Lake Magadi in the south up to Silali Volcano in the north. The Lake Bogoria area has, amongst other target areas, some priority for investigations, also the Solai graben to the south. It is therefore inappropriate here to expand on the geothermal potential of the area, as much new information is likely to become available in the near future, which would radically supersede any statement that can be made now on the basis of previous investigations.

Hot springs, fumaroles and geysers occur extensively in the Lake Bogoria area (Plate 11, Figure 28) particularly around the Mwanasis Peninsula (85–98°C) and at Emsos to the south (37°C), also sodium bicarbonate type springs occur at Maji ya Moto and Loboi to the west. Steam ascends around the margins of the lake, mixing with the lake water and warm groundwater sources, thus generating hot springs. McCall (1967) also noted the hot springs beneath the Solai Escarpment, and on Ol Kokwe Island at Soro (see inset to 1:250 000 map): he quoted an analysis for the latter which indicated that the source was essentially lake water. However the spring (91°C at the surface) has a high chloride content, suggesting a deep source at about 180°C. Steam jets occur in the Komol valley south of Paka, and at Nakapron, and Sceal (1974) recorded 16 other fumaroles arranged broadly in two belts trending N and NNE across the summit of Paka. The hot spring at Kutwa, to the east, suggests that the Mukutan Basin is also prospective.

Glover (1972) collected a large number of water and steam samples from the Lake Bogoria area and concluded from his analytical data, comparing with the Olkaria and Eburru areas further south, that 'a relatively large and homogeneous body of warm (35°C) water lies under much of the area, discharging at Emsos, Maji ya Moto, Loboi, Kipkongor ...'; he recommended that initial drilling be carried out in the Mwanasis Peninsula area, which seems to be the main source area for steam. The gas there has a high carbon dioxide content, with some methane and hydrogen sulphide, and the lake water is enriched in Na_2CO_3, chlorine and fluorine. The chloride/sulphate ratios of the warm springs around Solai

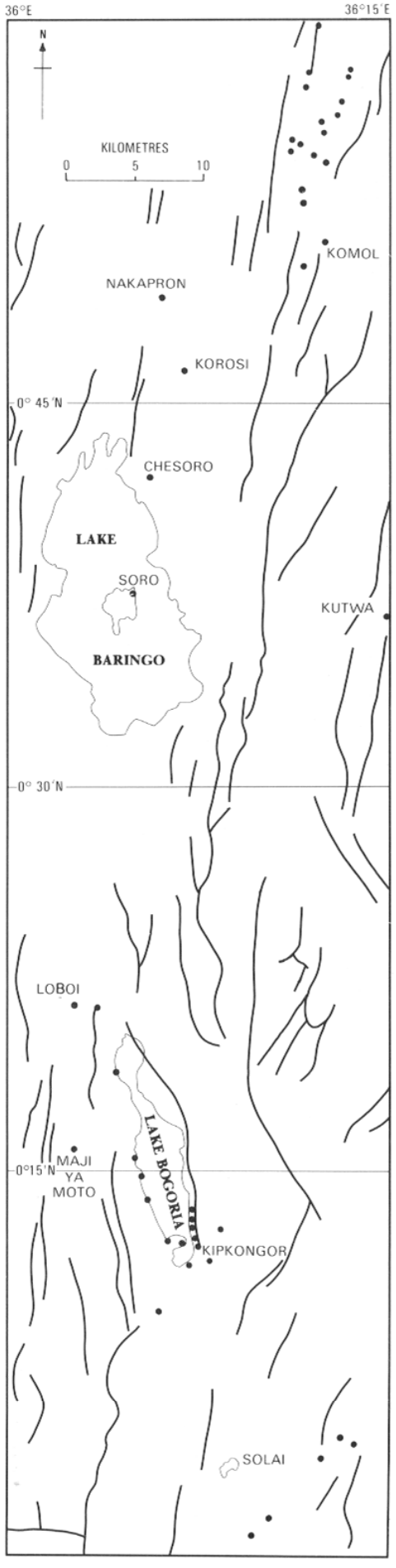


Figure 28 Hot springs and steam jets in the Baringo–Bogoria sector of the Rift Valley

vary somewhat: to the east they tend to be low, to the west chlorine is higher, but the indications are that temperatures at depth are not likely to be high.

In 1970 a joint exploration project (United Nations Development Programme and East African Power & Lighting Co Ltd) carried out an aerial infra-red imagery survey in the Lake Bogoria area, which did not locate any additional 'hot spots' on the ground (Noble and Ojiambo, 1976): also lake bottom temperatures were taken, and 1 m depth temperature surveys were carried out on the west side of the lake; a DC dipole resistivity survey showed a high conductance area in the centre of the lake, and high resistivity anomalies on either side in areas with surface thermal activity.

On the Laikipia Plateau further east springs are not significantly warm: Key (1986b) recorded a temperature of about 27°C for the spring water at Mamasoie, in the Kirimun area.

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