THE GEOLOGICAL EVOLUTION
OF THE
NORTHERN KAMASIA HILLS
BARINGO DISTRICT, KENYA.

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of Doctor of Philosophy in the
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ABSTRACT

The Kamasia Hills are formed essentially by a line of 'en echelon' tilted blocks within the main rift valley in northern Kenya. The metamorphic basement crops out locally at the foot of the eastern fault-scarps of the range and is overlain by the thickest sequence of the late Miocene plateau phonolites so far known in Kenya. This sequence, which includes minor amounts of basic and intermediate lavas and thick sedimentary units, is described, together with that of a thick series of Pliocene basalts, trachytes and fossiliferous sediments exposed in the foot-hills to the east of the main range. Isotopic (K-Ar) age determinations from the lavas facilitate the dating of the main geological events.

Deformation is by normal faulting, associated with block tilting and fault-bounded flexuring on axes normal to the dominant fault trend. Faulting episodes are identified by consideration of stratigraphic relationships and movement on the largest faults is shown to have occurred repeatedly. Major features of the geomorphology are described and a geomorphic-tectonic history is constructed for the area.

Volcanism was mainly of the 'plateau lava' type; very few volcanic centres were found in the area but it is apparent that the western limits of both volcanic activity and minor faulting have moved towards the rift centre with time. The petrography of the lavas is summarised and fifty-one representative chemical analyses are presented and discussed. A major faulting episode in the early Pliocene which, from field relations, clearly terminated the phase of phonolite lava extrusion is shown also to define a distinct petrochemical break with respect to both the mafic and the felsic lavas. Problems of petrogenesis are briefly considered.

CONTENTS

List of Figures

List of Plates

(following in sequence after text)

Plate

Photomicrographs

Plate

List of Tables

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INTRODUCTION

(a) Location of the area, population and communications

The area mapped lies between 0°45' N and 1°00' N, and 35°37' E (approx.) and 36°00' E, comprising a total area of 400 square miles. The crest of the Kamasia Hills*, rising to over 6000 feet, bisects the area on a north-south line, flanked by the Kerio Valley on the west and by the central floor of the rift to the east.

South of the area the Kamasia rises to its maximum height of 8203 feet at Saimo and continues as a feature as far as Eldama Ravine, four miles north of the equator. A few miles north of the area the Kito Pass separates the Kamasia Hills from the hill-mass of Tiati and Ribkwo.

The area includes the whole of Ngorora Location and part of Kaboskei Location of the Tugen tribe, together with the southern corner of Ribkwo Location and the eastern edge of Loyamarok Location, both occupied by the Pokot tribe. The headquarters of the District Commissioner is at Kabarnet, twenty miles south of the area; there is a police post and a post office at both Kabarnet and Marigat.

The Tugen, in the present area, keep small numbers of livestock but are chiefly agricultural, growing millet, maize and cassava in small fields cut out of the bush, often on very steep slopes. The Pokot, in contrast, are entirely pastoral, with large herds of cattle, goats, camels and a few sheep. This distinction largely reflects the altitude, and thus the rainfall, of the areas occupied by the two tribes. Where the Tugen locations cover parts of the low dry bush the people have adopted the pastoral way of life of

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* Perhaps more correctly termed the 'Tugen Hills', but both names are published on current D.O.S. maps. 'Kamasia' is retained here to give continuity with the bulk of the previous literature on the general area.

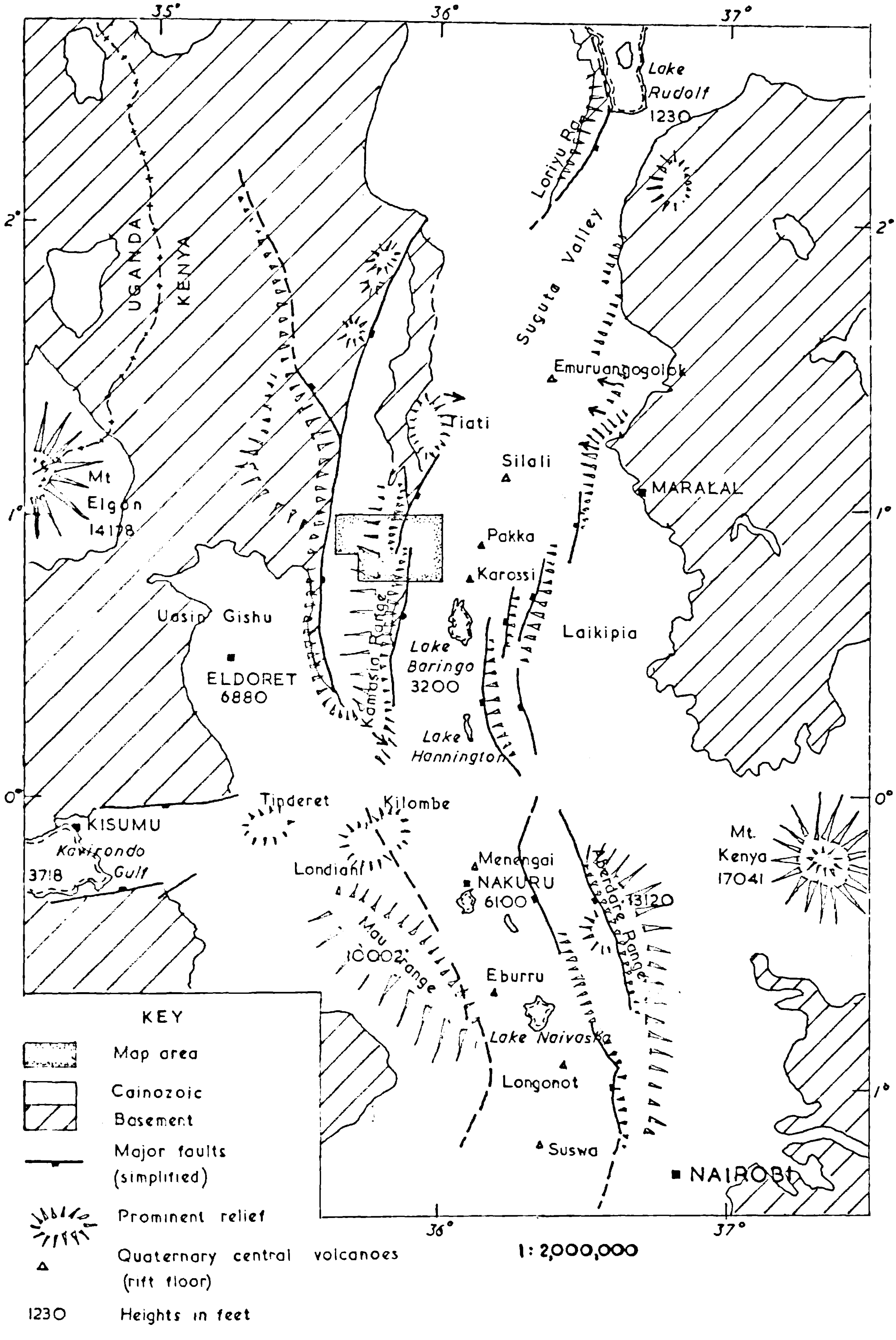

FIG. I . THE NORTHERN RIFT AND POSITION OF THE NORTHERN KAMASIA MAP AREA

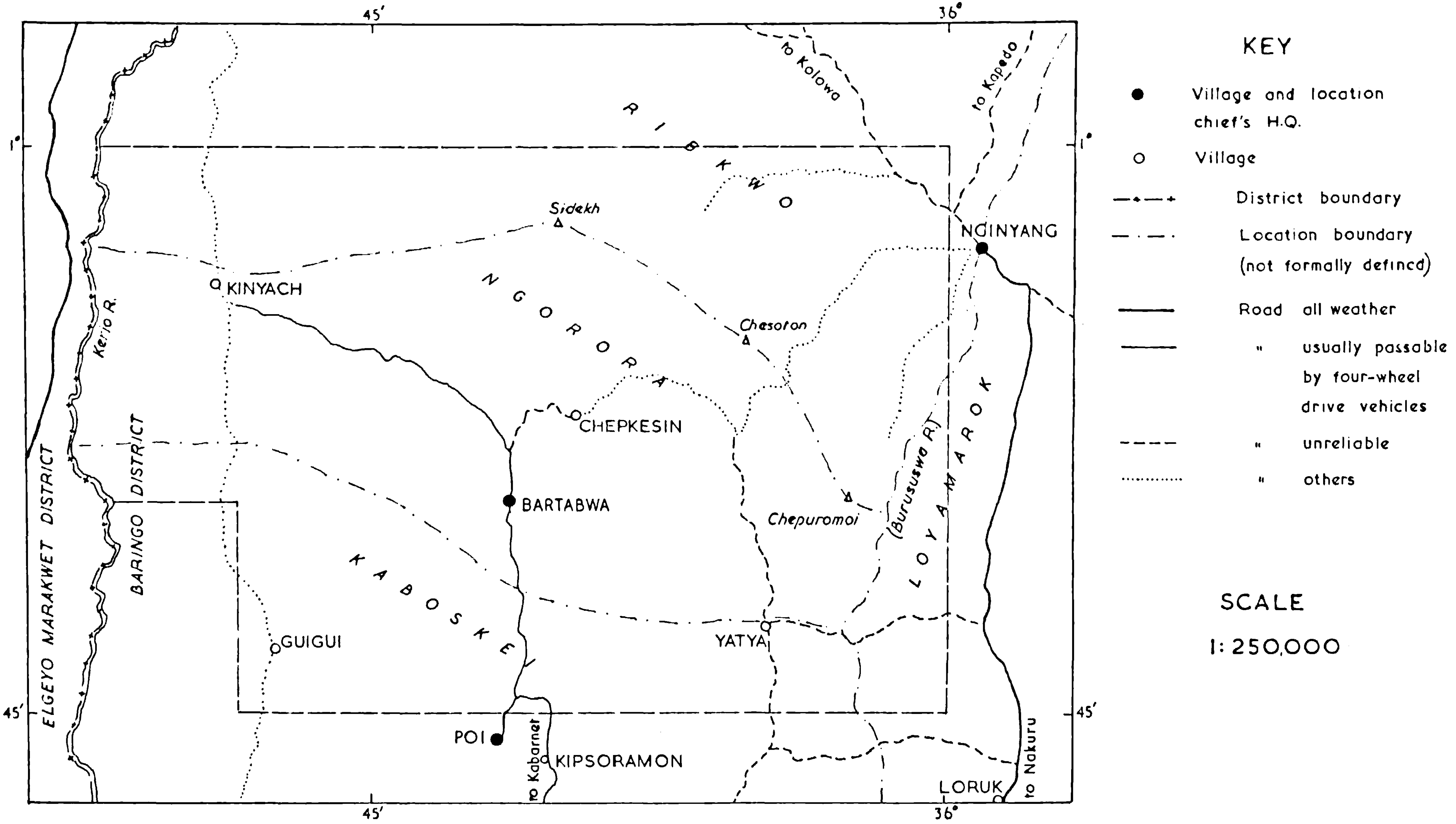

FIG. 2 ADMINISTRATION AND COMMUNICATIONS IN THE MAP AREA

their Pokot neighbours, although their traditional home is in the hills. Except for the waterless Sidekh range in the north the area is, by Kenya standards, fairly well populated.

The only really reliable road is that from Marigat to Nginyang which runs parallel to, and two or three miles to the east of, the eastern boundary of the area (fig. 2). The Kabarnet-Bartabwa road is usually passable in all weathers by four-wheel drive vehicles but the other tracks shown on the map are difficult and hardly ever repaired by local initiative. Supplies for many local shops and markets are transported by donkeys.

(b) Climate, vegetation and fauna

The climate closely reflects the variations in altitude of the area. There are no rainfall recording stations in the area but by observation and extrapolation from figures obtained from further south (Walsh 1969) the highest parts of the area receive 40"-45" per annum, while the Nginyang area (2800') is judged to have less than 25" per annum. Rainfall usually occurs in two periods: the 'long rains' from March to May and the 'short rains' in November and early December but they are notoriously unreliable.

Shade temperatures rise to more than 90° F. in the lowest areas with night temperatures falling to 60° F., but conditions are generally cooler in the hills, night temperatures often falling to 45° F.

The overall environment is dry bush country with large trees only on water courses, but there is a striking vertical biological zonation, especially in the flora, which is (with at least one notable exception) independent of the geology. The exception is a type of tree, characterised by a very straight trunk and branches arranged in semi-pendant tiers, which is entirely restricted to outcrops of trachyte or trachyphonolite at below 4500 feet altitude. Lacking any more specific botanical studies in the area the writer can only record that after some time in the field he was able to estimate altitude to within 300 feet (at some levels) simply by the aspect of the vegetation. Grass probably formerly covered most of the area but has been almost completely destroyed by over-grazing in the lower areas, where soil erosion is proceeding rapidly.

Bird species also showed vertical zonation, many species e.g. touraco, red-cheeked cordon-bleu, red-headed weaver and the larger hornbills being restricted to the hills, while francolins, buffalo weaver, many raptors and large ground birds such as the ground hornbill and kori bustard are more typical of the low dry bush. The Baringo area generally is famous for its abundant bird-life.

Large animals are scarce over most of the area, but Grant's gazelle may be seen on the plains and greater kudu in rocky hill areas of the Pokot country. Most of the indigenous carnivora are common, with the exception of lion. (One vagrant lion was speared in the area while the writer was working there.) Pygmy antelopes (dik-dik, klipspringer) and other small mammals are abundant. In the bush and riverine forest of the Kerio Valley large animals, including elephant and buffalo, are reported to be plentiful; in view of its lack of geological interest the writer did not closely examine that area.

(c) Drainage and water resources

The crest of the Kamasia is the watershed between drainage eastwards to the Burususwa River (which becomes the Suguta further north) and westwards to the Kerio River which is the western boundary of the area mapped (fig. 3). The Kerio is the only large permanent stream in the area and its tributaries at Guigui and Kinyach also have a permanent flow. In the hills the Bartabwa river, fed by streams from the Rimo plateau, flows as far as the foot of the main escarpment for most of the year, and springs occur on the escarpment at the junction of pervious lavas with underlying sediments, especially near Chepkesin.

Although numerous watercourses occur in the low country to the east

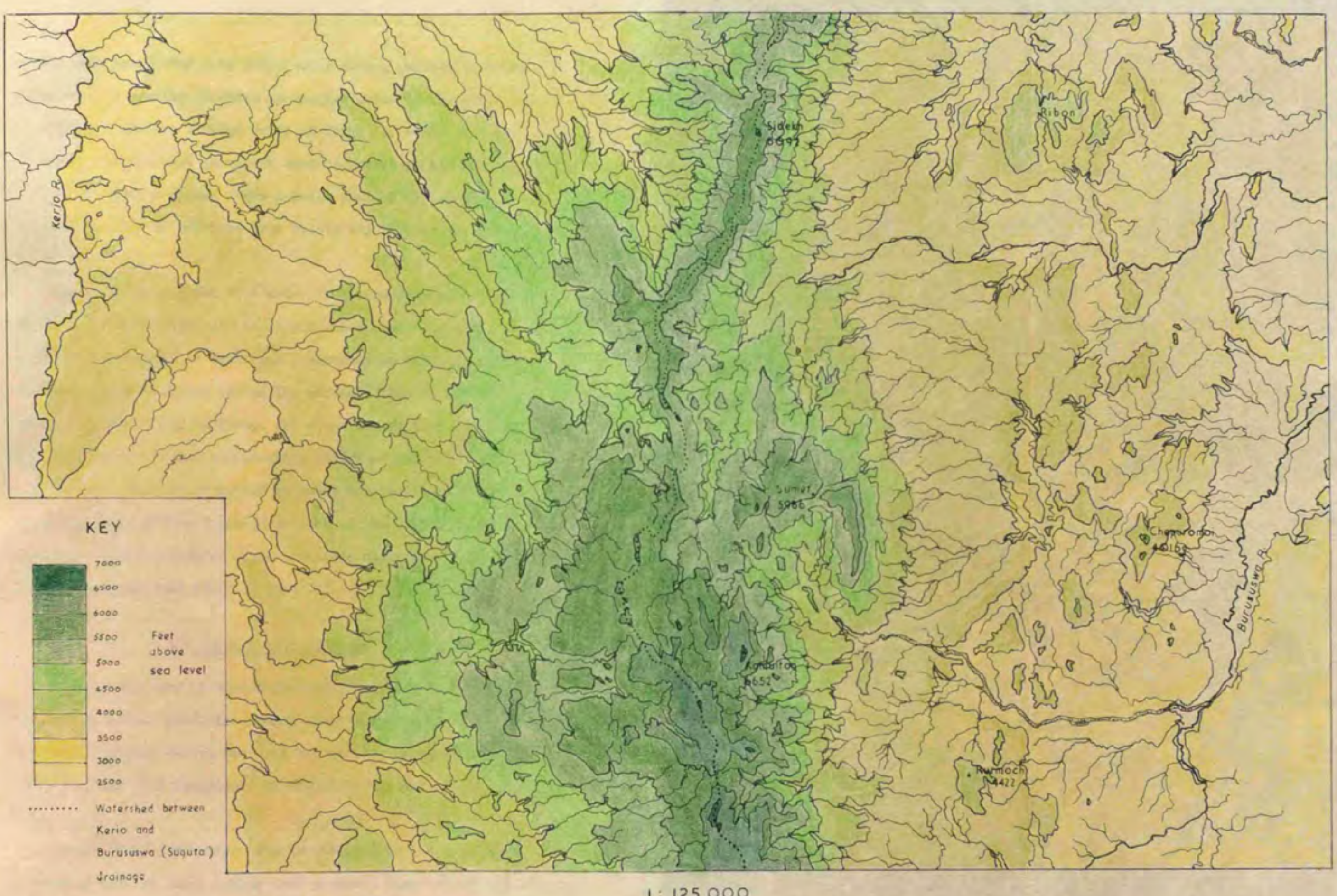

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FIG. 3 RELIEF AND DRAINAGE OF THE NORTHERN KAMASIA HILLS of the main scarp they only carry water during periods of heavy rain and water is more usually obtained by digging wells in the river beds. There is sometimes surface flowing water at Yatya for weeks at a time during the rains but the only permanent surface source in the low country is at Kisitei where a spring feeds a large pool in the gorge. At Nginyang water can always be obtained from relatively shallow excavations in the sandy river bed.

Observations suggest that water is always flowing at the bottom of of the channel alluvium of the larger water-courses and the occurrence of surface or near-surface water can frequently be related to the presence of natural rock barriers across the streams; this is certainly the case at Kisitei, Kukur and Nginyang. It seems likely that sub-surface dams would be the best water-conservation technique in this area.

The rock barriers referred to above are the result of a remarkable superimposition of the drainage pattern on the structure in the east of the area. The development of the drainage system and related erosion surfaces is discussed fully in Part III.

(d) Conduct of field-work

Mapping was done on aerial photographs (scale 1:35,000 approx.) supplied by D.O.S. and subsequently transferred to the two 1:50,000 maps which largely define the area boundaries. These are sheets 90/2 (Bartabwa) and 20/1 (Kapsowar) of series Y 231, D.O.S. 1:50,000 map of Kenya.

In the field information was transferred to the base map by inspection and the final copies were prepared using radial-line plotter and 'stereo-sketch' instruments.

The topographic survey was carried out using a telescopic alidade, supplemented by dual-control aneroid traverses (with J.S.C. Sceal). The network of height data thus established was later intensified by photogrammetry, enabling contours to be drawn at intervals of 100 feet for the whole area.

The field work was done in two field-seasons, from September 1966 to April 1967 and February to August 1968. A total of fourteen months, including short vacations and some laboratory work at University College, Nairobi, was spent in the field.

Localities are defined in the text by four- and six-figure map references where place-names are insufficient. Specimen numbers, e.g. 2/162, in the text correspond to numbers in the field notebooks, the prefix '2' referring to mapping area '2' of the EAGRU project. (Note that the second number is a specimen number only and does not correspond to a locality number.)

Specimens, thin-sections, field-slips and field notebooks are housed in the Geology Department, Bedford College (University of London).

(e) Previous work

Virtually no previous geological work has been done in the present map area, but the Kamasia Range has been known since the earliest geological investigations.

Joseph Thomson crossed the Kamasia near Kabarnet in 1883 and reported (Thomson 1885) that the range was composed of crystalline metamorphic rocks, which mistake Walsh (1969, p.4) charitably suggests was the result of confusing his notes with those made elsewhere.

The structure and succession in the Kamasia as shown by Gregory (1921, p.108) is substantially correct in outline.

Bailey Willis (1936) describes the general Baringo area but mistakenly attributes the Kerio Valley to a largely erosional origin, whereas it is now clear that it is a tectonic valley with a very large displacement on the Elgeyo Fault, as originally shown by Gregory (op.cit.).

V.E. Fuchs (1950) attempted a synthesis of Pleistocene events in the Baringo area but the results are largely erroneous simplifications. In the course of the field-work involved D.J. MacInnes visited the north-eastern corner of the present map area. He appears to have walked westwards from Nginyang as far as the basalt-capped outliers of Kaperyon Formation sediments at Motimyput (2806); the sediments were attributed to the 'Kamasia sediments' as, at that time, were all sediments in the Baringo area.

The section given by Shackleton (1950), from observations by J. Scott, shows the tectonic dip-slope of the Kamasia, with its surface of trachyte lavas.

McCall et al. (1967) elucidated the stratigraphy of the 'Kamasia lake beds' of Gregory (op.cit.) which were defined as the Chemeron Beds and the Kapthurin Beds (see Martyn 1969).

The quarter-degree sheet between Kabarnet and Eldama Ravine was mapped for the Kenya Geological Survey by Walsh (1969), but the subsequent mapping of Martyn (op.cit.) and Lippard (Ph.D. thesis in preparation) has shown that Walsh's map is inaccurate in several important respects.

The present mapping programme by the East African Geological Research Unit (EAGRU), directed by Professor B.C. King, was initiated by J.E. Martyn in 1965. Martyn (1969) mapped the area immediately to the south of that described in the present thesis, where the succession is essentially the same as that established by Martyn. The area to the north was mapped by Mason and Gibson (1957) but has since been remapped by M.P. McClenaghan. The areas to the west and east of the present area have now been mapped by S.J. Lippard and J.S.C. Sceal respectively, and systematic mapping is continuing throughout Baringo and south Turkana.

(f) Geological setting

The Eastern, Kenya or Gregory Rift is essentially a tectonic trough, averaging 30 miles (45 km) in width and extending between 2°S and 2°N;

beyond these latitudes its nature becomes more diffuse. Total vertical displacement reaches a maximum of about 12,000 feet (3.6 km) but the trough is largely filled by Cainozoic volcanics which also thinly mantle the flank plateaux.

The boundaries may be simple single faults, series of 'fault-steps' (often arranged 'en echelon'), or fractured monoclinal warps. The limits of both faulting and the associated volcanism have migrated towards the centre of the rift with time. There is marked tilting of the plateaux away from the rift shoulders, but it should be noted that the rift occurs across the crest of a general up-warp, often referred to as the 'Kenya dome'. The effect of this can be seen even on the rift floor which falls from about 6000 feet at Nakuru to 2000 feet at the Suguta valley in the north and at Lake Magadi in the south.

The Kamasia Range may be thought of either as a huge tilted block within the rift, or as the intermediate block between a double western rift boundary, of which the Elgeyo Fault is one component and the Kamasia scarp-faults the other. North of 0°30'N hardly any volcanic or tectonic activity has occurred west of the Kamasia scarp-faults in the last 8 million years, except for a major rejuvenation of the Elgeyo Fault in the Quaternary.

Figure 4 is a true-scale cross-section of the rift at 0°45'N (the southern border of the present thesis map) showing the relation of the Cainozoic volcanics to the tectonic setting.

As Baker et al. (in press) have observed, the volcanics within the rift (only) may be divided into certain major groups. These are listed on the left below, while on the right is the present writer's suggested numerical notation for the groups:

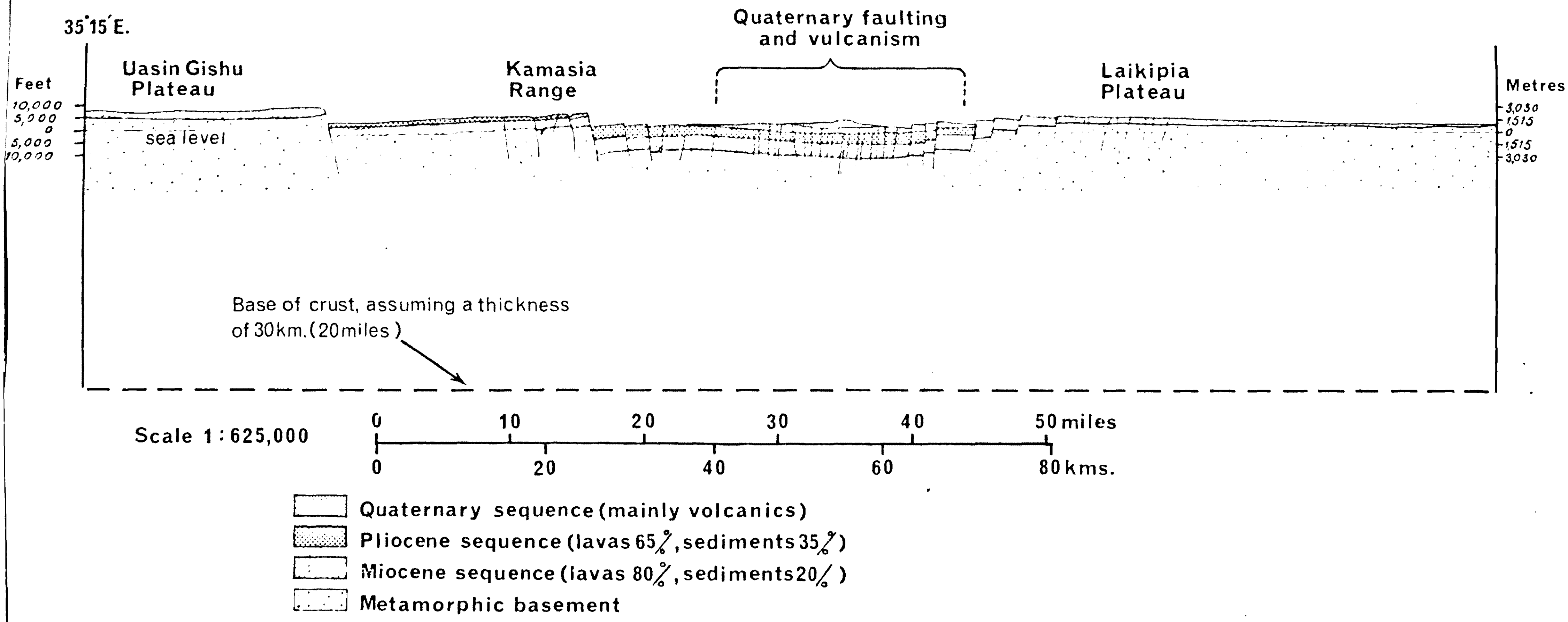

FIG. 4 TRUE SCALE STRUCTURAL SECTION OF THE KENYA RIFT VALLEY AT LAT. 0°45'N
(Only major faults and fault belts shown)

Baker et.al.	Chapman	
U.Pliocene-Pleistocene: trachytes	Volcanic group V	(b) Quaternary trachyte/ basalt volcanoes (a) Quaternary flood lavas, mainly trachytic
	Volcanic group IV	Multi-centre trachyte 'shields'
M.Pliocene: basalts	Volcanic group III	
U.Miocene-L.Pliocene: phonolites, local trachytes	Volcanic group II	
L. & M.Miocene: basalts	Volcanic group I	

The proliferation of local formation names has reached the stage when the use of such names in literature or discussion must always be accompanied by explanations (often lengthy) as to their relative stratigraphic position. The advantage of the numerical system suggested here is that a rock unit may be referred to as, for example, 'group IV trachytes' and be instantly placed within the general stratigraphic framework.

It should be noted that the rock types listed are only those typical of the individual groups and do not exclude other types from any group.

The placing of sediments within this system is usually easily decided by stratigraphic relationships such as unconformities.

The groups are lithostratigraphic units and do not therefore necessarily bear a strict chronological relationship to each other.

In figure 4 'Miocene' is approximately equivalent to groups I and II, 'Pliocene' to group III and 'Quaternary' to group V. Group IV is absent at this latitude, as also is group I on the Kamasia, unless it is represented by a thin basic intercalation occurring in group II. Only group II has any significant extent beyond the confines of the rift.

PART I: STRATIGRAPHY

The oldest rocks in the area are the rocks of the metamorphic basement exposed in a small outcrop at the foot of the main scarp in the extreme south of the area. This is the northern end of the more extensive outcrop mapped by Martyn (1969). The rocks are hornblende-gneisses often with a dense network of intrusive granitic or granodioritic veins up to 2 feet thick. Foliation of the metamorphic rocks strikes WNW-ESE, dipping steeply northwards. The metamorphic basement rocks of the area as a whole are thought to be part of the 'Mozambique Belt', in which isotopic dates of metamorphism and later intrusions range between late pre-Cambrian and Ordovician (Cahen & Snelling 1966, p.29).

The metamorphic basement is directly overlain by the base of the Cainozoic succession; there is nothing resembling the 'Kamego Formation' of Martyn (1969, pp.18-22). The complete Cainozoic succession is shown in figure 5. It will be seen that volcanic group I is absent from the area (unless represented by the Noroyan Formation), groups II and III are well represented but groups IV and V, elsewhere very thick, are represented in this area only by a single lava flow in each case, with the addition of the Lokwaleibit basalts.

The chief interest of the Kamasia succession lies in the great thickness of the group II plateau phonolites, and in the fact that about half of the total succession, including fossiliferous sediments, can be placed in the Pliocene, the status of which system in southern Africa has hitherto been in some doubt.

(a) Volcanic group II - Tugen Hills Group

It was proposed by Martyn (op.cit.) that all those formations (with the exception of the Kamego Formation) above the metamorphic basement and below the widespread unconformity beneath the Kabarnet Trachyte

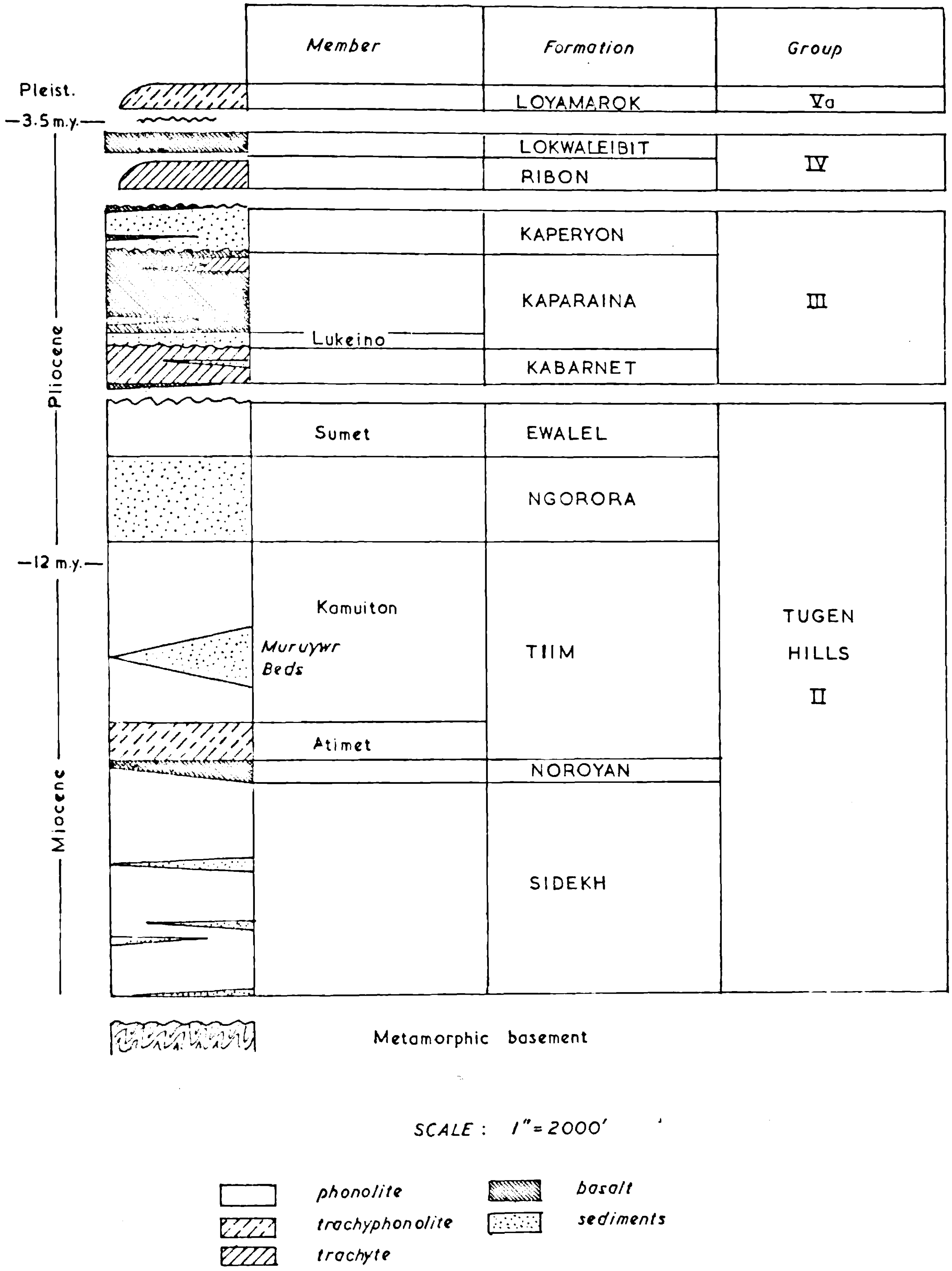

FIG. 5 THE STRATIGRAPHIC COLUMN

should compose the Tugen Hills Group. The formations of the group are chiefly lithologically distinctive phonolite lavas, but thin undersaturated basic lavas also occur and thick sedimentary formations form a considerable proportion of the upper part.

The group is the approximate equivalent of the 'plateau phonolites' of Baker et al. (in press), and thus of the writer's 'group II', which occurs over large areas of the Kenya plateau but the total thickness (6500') in the present area is greater than that seen anywhere on the plateaux or Rift shoulders; it seems that phonolites both older and younger than the bulk of the plateaux successions occur in the Kamasia. Regional correlation and radiometric ages are further considered in a concluding section (Part If).

The 'Saimo Phonolites' of Martyn have been renamed 'Sidekh Phonolites' (q.v.) and Martyn's Tiim Phonolites have been subdivided into members which satisfy all the criteria for being elevated to formations. However the formational rank of the Tiim Phonolites is retained for the present to minimise confusion.

1. Sidekh Phonolites Formation

(i) Phonolites

This is the Saimo Phonolites Formation of Martyn (op.cit.). The formation has been renamed chiefly because the Saimo section is relatively thin (fig. 7) compared to that on the Sidekh range on the present map and also because 'Saimo' as a formation name is also used by Martyn for a separate formation of basanitic lavas.

The formation has been divided for mapping purposes into two subdivisions: in the lower flows, comprising from three to seven phonolites and intercalated shales, the porphyritic flows lack biotite phenocrysts; in the upper flows, two in the south, four or five in the north, biotite phenocrysts are conspicuous in the porphyritic flows. The investigation of the stratigraphic significance of phyric biotite was made at the suggestion of Dr. L.A.J. Williams, in whose classification of East African phonolites (Williams 1968) the 'Mara' and 'Kericho' types are separated by the absence and presence, respectively, of phyric biotite; this is essentially a splitting of Prior's (1903) original 'Losaguta' type. No 'big-nepheline' phonolites ('Kapiti' type, Neilson 1921, Williams 1968) occur in the Kamasia succession. (See also Part IVh.)

The phonolites are dark blue-grey, green or purple rocks, very fine-grained or aphanitic with a characteristic rather brittle conchoidal fracture. Deep weathering to a whitish (?kaolinitic) rock occurs at the tops of flows, but a thin pale patina is present on the rock in most exposures. Scattered altered nepheline phenocrysts are usually visible, with laths of fresh feldspar, in the porphyritic types. Biotite is prominent in porphyritic types in the upper flows. The nephelines may be, in exceptional cases, up to 10 mm. in length but are usually less than 5 mm.; in contrast to the fresh water-clear nephelines in the Tiim and Ewalel phonolites (q.v.) those in the Sidekh Phonolites are invariably turbid and altered. Phenocrysts are well scattered, not more than two or three of all types being visible in the average (1") thin-section, and these phonolites are not nearly as porphyritic as chemically similar types from the Laikipia escarpment (Sceal, Ph.D. thesis in preparation).

The formation totals 2300 feet at the southern border of the area, this thickness including 250 feet of sediments. The phonolites are thick (250-300 feet) massive flows usually with weathered tops and brecciated bases. The central part of each flow is relatively more resistant to erosion and spurs on the southern (Kamuiton) escarpment have, for this reason, a stepped appearance, accentuated in places by the sedimentary intercalations. In the northern outcrop there is much less intra-formational weathering of the flows, which occur in greater number than in the south. The effect on the topography is to produce a much smoother slope profile on the Sidekh scarp, lacking the crags and steps of the southern outcrop. It should, however, be stated that tectonic and erosional history are also important factors in this respect.

The base of the formation is only seen in the extreme south of the area but the formation is here thicker than on the Saimo scarp a few miles to the south (Martyn op.cit.). McClenaghan (op.cit.) records 4000 feet of the formation resting on the basement immediately north of the present area, and has shown that there, the lower flows are overlapped by the biotite-bearing upper flows which rest directly on the basement on the western side of water-shed. Although most of the upper flows are, in fact, aphyric the lowest biotite-phyric flow (2/322), which is probably also the most porphyritic phonolite in the whole of the Tugen Hills Group, is an extremely distinctive mapping horizon.

In figure 7, in considering thickness variation, the Noroyan formation is coupled to the Sidekh Phonolites because Martyn (op.cit., fig. 22) implies that in the Saimo area the upper phonolite of the 'Saimo Phonolites' and the basic lavas of the Kapkiai Tephrite : Saimo Basanites are to some extent mutually exclusive; it is possible that a similar relationship exists between the Sidekh and Noroyan formations of the present area.

(ii) Sediments

The sediments of the southern outcrop occur in three main horizons: the basal sediments (Chepkuno grit & breccia and Tinyérinyér Beds of Martyn, op.cit., pp.25-27) are assumed to occur above the basement in the extreme south, although they were not located in the southernmost stream sections during a joint survey by Martyn and myself. The green shales occurring at the extreme foot of the scarp below Kamuiton can probably be ascribed to the Tinyérinyér Beds of Martyn to which they bear a strong lithological resemblance, consisting almost entirely of green tuffaceous shales and reddish mudstones with green reduction spots. In the Bargetyo River thin lenticular mudflake conglomerates occur within the mudstones. The exposed thickness is here between 50 and 20 feet.

The middle sedimentary unit, of green tuffaceous shales, represents the lower part of the Aimeno Shales and marls of Martyn (op.cit., pp.27-29). This is very thin (20-30 feet) and was not recognised in the central part of the southern outcrop. A similar unit again occurs near the base of the scarp below Kamuiton at about the same horizon.

The upper sediments compose the thickest of the three sedimentary units and are the bulk of Martyn's Aimeno shales and marls. They consist of 160-200 feet of predominantly green shales, siltstones and thin-bedded whitish porcellanous mudstones. In the southernmost river-section the lower part of the unit is predominantly red in colour and includes a purple-red structureless agglomerate with lapilli and blocks of pumice, phonolite and welded tuff up to one foot across in a fine-grained matrix. An apparent steep (45°) eastward dip was observed at one exposure of red structureless tuff but this may have been an exfoliation effect. If it is a true dip it is possible that the outcrops represent a small local ash-cone in the sedimentary basin.

The typical green shales of this unit outcrop in the Noroyan River area of the northern outcrop but thin rapidly northwards and are not seen in the main Sidekh range, where the only clastic rock is a very thin horizon of agglomerate in the lower flows.

No evidence of euxinic or saline conditions, of the type described by Martyn (op.cit., p.28) was seen in the present area.

In view of the correlation between sedimentary thicknesses and tectonic relief (fig. 17) in the cases of the Muruywr Beds and Ngorora Formation the writer is sceptical of Martyn's assertion that during the period of the Sidekh and Tiim phonolites the Saimo area, (including the Kamuiton area on the present map), was 'one of subsidence and sediment accumulation' (op.cit., p.59). It is very probable that the Sidekh Formation sediments, only exposed at present in what are virtually two-dimensional sections in tectonically 'high' areas, have much thicker counterparts concealed on the down-faulted side of the main scarp faults, and are analogous in this respect to the younger sediments of the group.

2. Noroyan Formation

A formation of basaltic lavas persisting throughout the outcrop of the Tugen Hills Group in the area. The most southerly tongue of the formation extends south of the present area as the 'Kapkiai tephrites' of Martyn (op.cit., pp.29-30).

Petrographically these lavas are very similar in many respects to rocks described by Martyn as 'analcite basanites' and 'analcite tephrites', in the 'Saimo basanites and tephrites' and the 'Kapkiai tephrites'; but in view of the fact that the groundmass plagioclase is predominantly less calcic than An_{50}, both in the rocks described by Martyn and in those of the present area (fig. 53), the writer prefers the terms 'analcite-hawaiite' and 'analcite-mugearite' (see Part IVa). They are usually dark grey to black, fine-grained occasionally glassy rocks, with phenocrysts of pyroxene sometimes very abundant and (less commonly) plagioclase visible in hand-specimen. Olivine phenocrysts are rarely seen.

The formation attains its maximum development on the Charkum range and is well exposed in the Noroyan River and its tributaries, whence the name is derived. In this area it is 350 feet thick and may be subdivided into four units:

(i) The most conspicuous petrology is a porphyritic analcite-hawaiite occurring at the base. Phenocrysts are chiefly of augite (black in hand-specimen) up to 7 mm. across, and less abundant olivine. Phenocrysts are most abundant in the lower part of the unit and olivine, in particular, is difficult to find except in the most porphyritic petrologies.

(ii) A black sparsely porphyritic rock of resinous appearance occurs above the pyroxene-phyric basal type in the Noroyan area (2/282).

(iii) A middle unit of feldspathic petrology is characterised by sub-trachytic texture. Pyroxene phenocrysts are rare. This division probably consists of at least two flows since in the Chepbaiwa River south of the Noroyan a rubbly vesicular horizon occurs within the succession of this type.

(iv) Occurring in the Noroyan River and on Atimet the highest part of the formation in this immediate area is an analcite-trachymugearite (2/284,285). In the field this rock is greenish with sub-trachytic texture and was initially identified as a facies of the overlying trachytoid phonolite (c.f. Joubert 1966, p.35), but seen in thin-section its affinities are with the underlying analcite-hawaiites and analcite-mugearites. This rock forms the summit immediately north of the Atimet col, which is thus the most northerly outlier of the Noroyan formation on the main watershed.

The highest point of the formation in the Chepbaiwa River is an analcite-hawaiite resembling the rock of the Kamuiton scarp outcrops. The small phenocrysts are of augite and rare olivine. However, this petrology is not seen further north, where the analcite-trachymugearite is overlain directly by the Atimet Trachyphonolite. Thus, if the southern correlation with the Kapkiai tephrites of Martyn (see below) is correct it appears that the base of the Atimet Trachyphonolite (basal Tiim Formation of Martyn) oversteps gradually on to progressively older units as it is traced northwards along the range.

The sequence described above suggests both an eruptive sequence of progressively more salic magmas and, in the lowest division, some crystal settling within one unit. There is no evidence to suggest an intrusive origin, whereas the contacts with weathered and brecciated phonolite below and above respectively, as well as the vesicular horizon within the sequence, are positive indications of an extrusive origin for the whole series.

From Atimet the main outcrop continues north-eastwards down the Chemoigut River where the formation is thinner but still comprises a basal pyroxene-phyric petrology overlain by a sparsely porphyritic type. It was not followed north of 0°58'N. but McClenaghan (op.cit.) did not observe it north of 1°00'N.

In the southern outcrop along the Kamuiton scarp a single unit 150 feet thick is present, underlain locally by a thin band of green shales. The rock is dark when fresh with small pyroxene phenocrysts, and occasional rare olivine phenocrysts in hand-specimen (2/237). On weathering the rock acquires a pale buff patina on which the dark pyroxenes stand out in relief. The rock is well jointed and breaks into roughly rhombic blocks on weathering.

Of the two basaltic formations on the Saimo scarp only the Kapkiai tephrites reaches the southern border of the present area (Martyn op.cit.). Martyn records fine-grained phonolites between the Kapkiai tephrites and the base of the Tiim Formation but in the present area the Atimet Formation rests directly on the basaltic rock and no intercalation of other lithologies was found within a quarter of a mile of the northern boundary of Martyn's map. The base of the unit rests on the weathered top of the underlying phonolite. In the Chepkokel River section there crops out a trachymugearite (2/239) of the type which occurs extensively in the north.

The Saimo Basanites of Martyn (1969) are in an equivalent stratigraphic position to the Noroyan Formation (fig. 6) from which, however, as far as the evidence from present exposure goes, they are a distinctly separate lithosome. The rocks in the Saimo Basanites have a much higher colour index than the average Noroyan lava, and even include types with no feldspar (Martyn op.cit., pp.205-207).

The Elgeyo Basalts of Walsh (1969) are also in a similar stratigraphic position to the Noroyan, lying between the phonolites of the Elgeyo

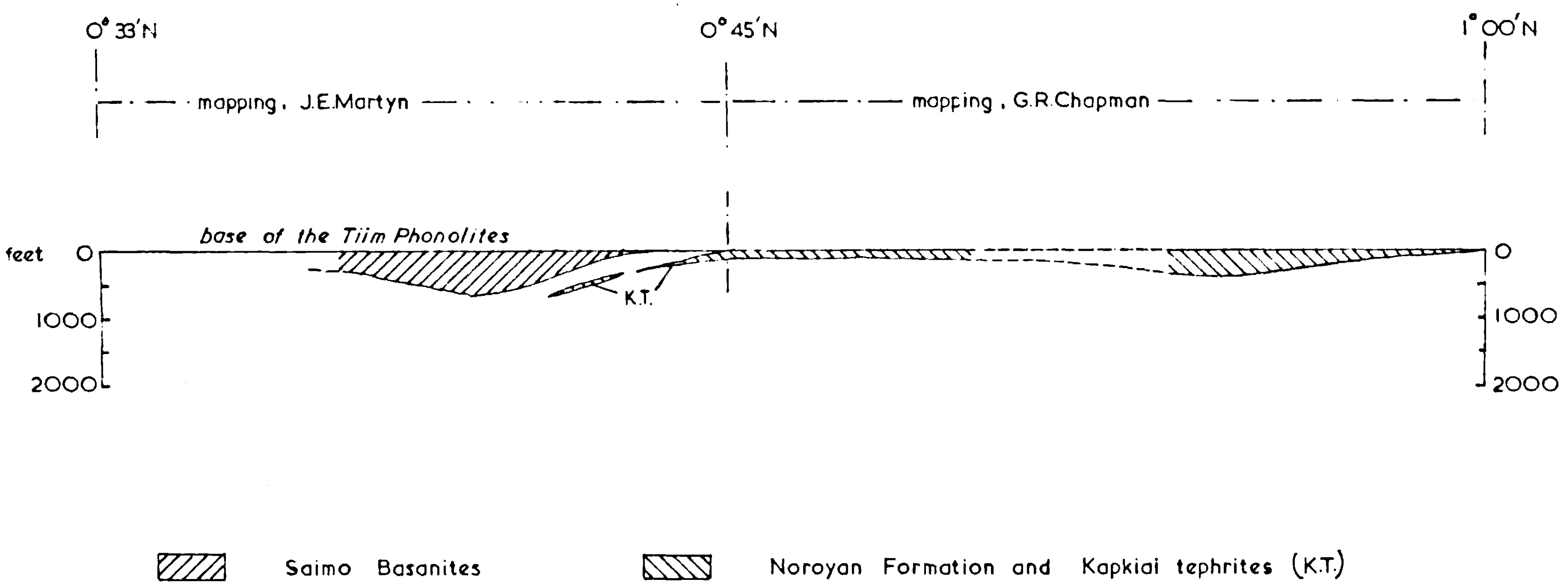

FIG 6 STRATIGRAPHIC RELATIONSHIP OF THE SAIMO BASANITES AND THE NOROYAN FORMATION

Escarpment (largely correlated with the Tiim Phonolites of the Kamasia) and the metamorphic basement. The Elgeyo Basalts are largely agglomeratic but are petrographically similar to the Noroyan lavas (Lippard op.cit.).

3. Tiim Phonolites Formation

In the present area this formation is subdivided into the Atimet and Kamuiton members, the latter containing a locally thick sedimentary unit, the Muruywr Beds. The chief interest of the formation lies in the fact that both petrography and isotopic dates indicate its approximate equivalence to the phonolites of the Elgeyo Escarpment and Uasin Gishu plateau (fig. 8).

The Sidekh and Tiim formations together make up a constant thickness (4000 to 5000 feet) from the northern to the southern edges of the map. However, whereas in the south this thickness is composed of both formations in equal amounts, in the north the Sidekh accounts for over 80% of the section and the Tiim is reduced to about 800 feet (fig. 7).

The southward increase in thickness of the Tiim is continued beyond the southern border of the map and on Tiim mountain itself the formation may be 5000 feet thick (Martyn op.cit., p.34). Northwards from the northern boundary the Sidekh Phonolites have been eroded from the Kito Pass area, but further north still their stratigraphic position is occupied by the Sigatgat complex whence McClenaghan (op.cit.) suggests some of them may have originated.

(i) Atimet Trachyphonolite Member

In hand-specimen this rock is a very distinctive green type, often with a strong fissility due to 'trachytic' texture, and is distinctly coarser-grained than the usual phonolites of the Tugen Hills Group. The coloration is very strong and may even be a bright pistachio-green, often with a variolitic texture - this type is well exposed in the Chepkokel River section. Near the base and the top large calcite amygdales

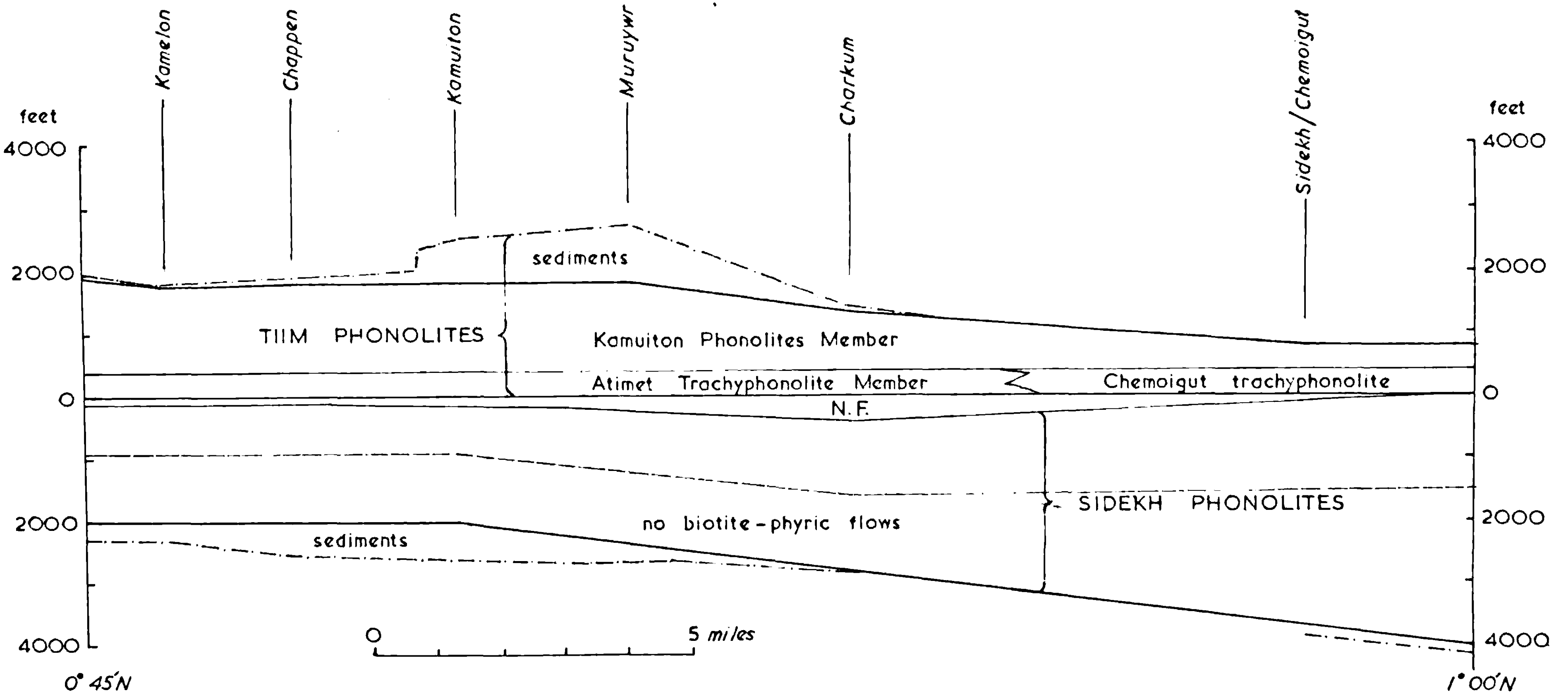

FIG. 7 NORTH-SOUTH THICKNESS VARIATIONS IN THE LAVAS OF THE TIIM, NOROYAN (N.F.) AND SIDEKH FORMATIONS. (Sediments shown only as addenda, not in correct stratigraphic position)

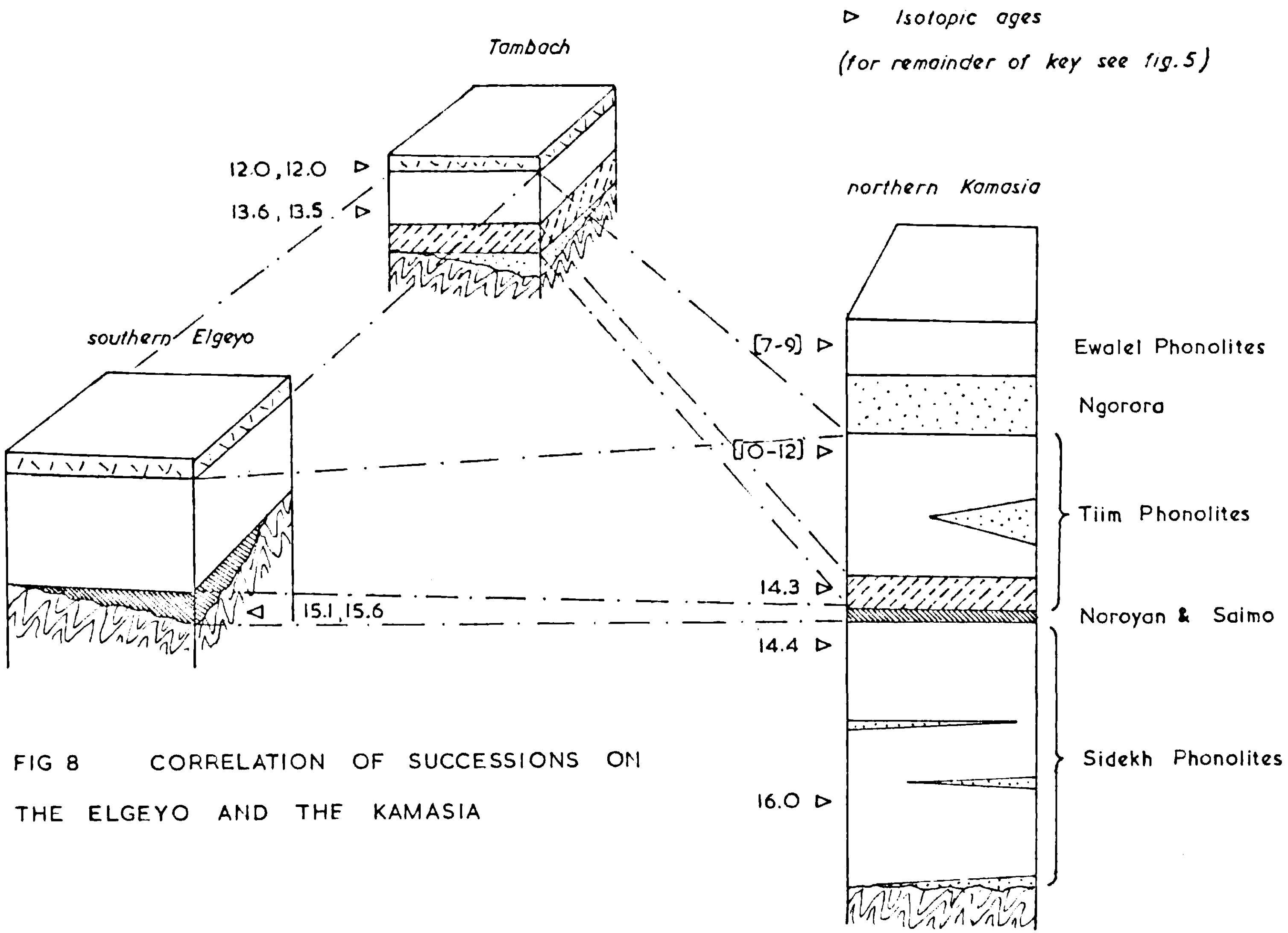

FIG 8 CORRELATION OF SUCCESSIONS ON THE ELGEYO AND THE KAMASIA

are present and the rock is often brecciated and weathered whitish. A black fine-grained facies also occurs near the base and the top and sometimes appears to occur as broad veins in the coarser-grained rock.

The Atimet Trachyphonolite usually averages 400 feet in thickness and forms the more rugged parts of the main escarpments and some impressive waterfalls. In the Chepkokel River section the fissility is pronounced to a degree where it resembles horizontal bedding, but it is frequently not at all obvious in the field. Northwards along the Charkum range the Atimet Member crops out progressively higher up the escarpment, finally forming the summit of Atimet hill. It can be traced most of the way down the dip-slope of Atimet but it is not seen at the head of the Chemoigut River. This termination is obvious both in the field and on aerial photographs and is expressed as a distinct step on the dip-slope. Along the Chemoigut River its place in the succession appears to be taken by the Chemoigut Trachyphonolite (see below).

The chief interest of the Atimet lava lies in its correlation with the flow above the basal phonolite flow on the Elgeyo Escarpment at Tambach, also an aphyric 'trachytoid phonolite', or phonolitic trachyte (fig. 8). The writer has compared specimens and sections collected by S.J. Lippard (Ph.D. thesis in preparation) from the Elgeyo with the Atimet rock and the resemblance is striking (see also Part If). Furthermore, the north and south limits of the trachytoid lava in the two areas match very closely. (The Atimet continues as basal Tiim Phonolites Formation well into the Saimo area, Martyn pers.comm.). Since this correlation was first suggested an isotopic (K/Ar) age determination of 14.3 ± 0.5 m.y. has been obtained for the Chemoigut lava (below). The flow above the basal flow at Tambach had been previously dated at 13.6 ± 0.6 and 13.5 ± 0.3 m.y. (Bishop et al. 1969, p.683).

Chemoigut Trachyphonolite

As mentioned above, in the Chemoigut River area the typical Atimet

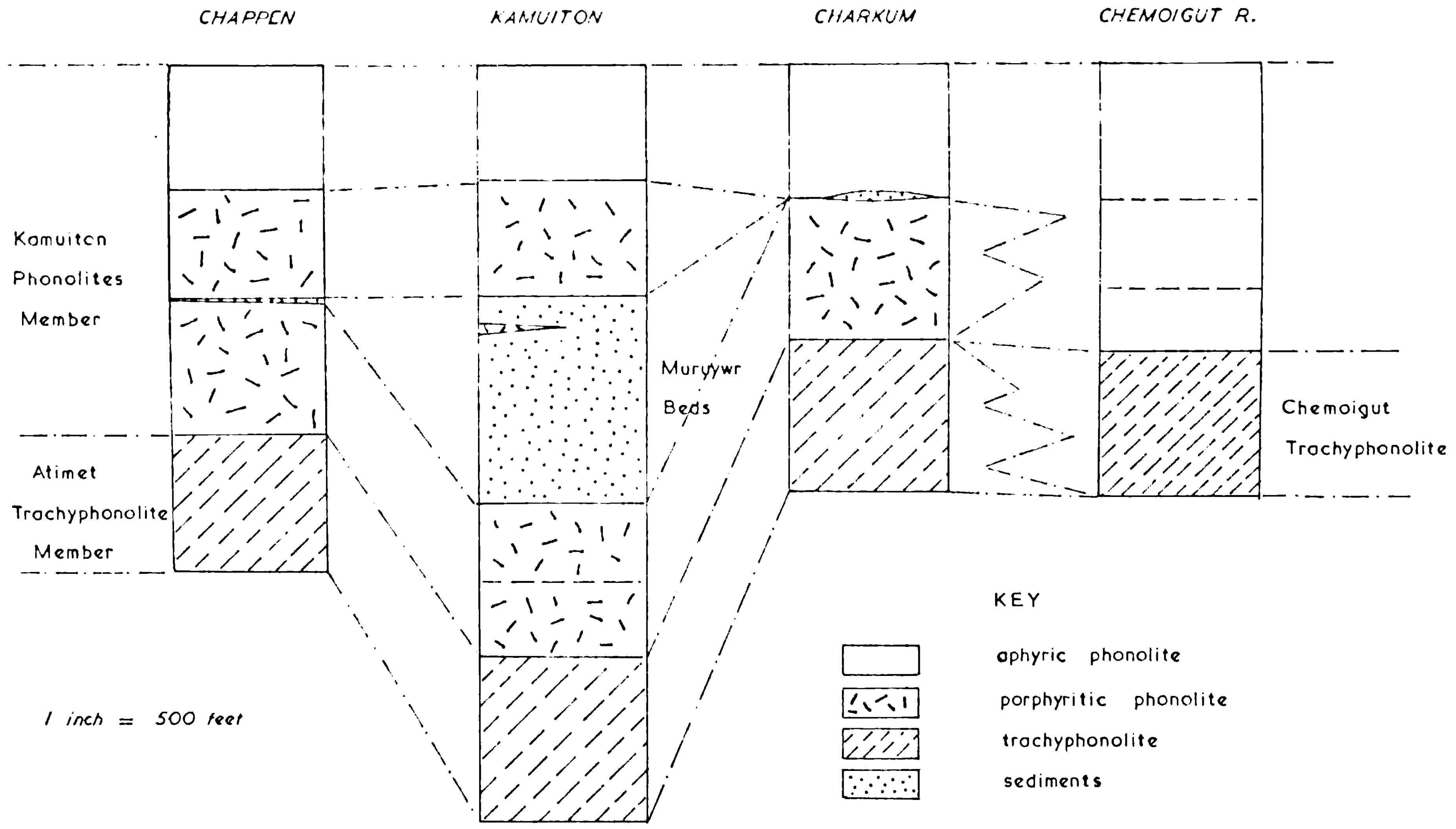

FIG. 9 SECTIONS IN THE TIIM PHONOLITES FORMATION

rock is absent, but the horizon between Noroyan Formation and aphyric phonolite of the Kamuiton Member is occupied by another distinctive petrology, having more in common with the Atimet than with the true phonolites. This lava is dark grey in colour, coarser in grain than the flinty true phonolites, with well-scattered large feldspar phenocrysts. It is extremely hard. This unit forms the lower (300-450 feet) very steep part of the hillside above the river; features suggesting thin layering of the unit can be seen on the aerial photographs but no topographic or lithological evidence of this could be seen in the field.

(ii) Kamuiton Phonolites Member

The member comprises up to five porphyritic and aphyric phonolite flows and a locally thick sedimentary unit, the Muruywr Beds. It is equivalent to most of the Tiim Phonolite Formation of Martyn (op.cit., pp.34-41) and probably also to the upper phonolites of the Uasin Gishu plateau (see Part If).

The member is best exposed below Kamuiton peak where it totals 2000 feet of which 750 feet is represented by the Muruywr Beds. Southwards the phonolites maintain this thickness but the sediments thin to a few feet. In the north-west the sediments are absent and the member is represented by 500 feet or less of aphyric phonolite in the Chemoigut River exposures.

The porphyritic phonolites are dark green or blue-grey fine-grained or aphanitic rocks characterised by small sanidine nepheline and biotite phenocrysts, the nepheline being usually unaltered and water-clear, e.g. 2/264. Pale green 'diopsidic augite' phenocrysts are seen in thin-sections (2/331, 2/267).

Calcite occurs throughout and the lowest flow has elongated amygdales of calcite and analcite.

The highest flow, which forms the summit of Kamuiton where it is

300-350 feet thick and persists over the extent of the outcrop is a very fine-grained aphyric phonolite usually showing convoluted ('rhyolitoid') banding (pl. 6).

Lower phonolite flows

Sections in the member are well exposed in the steep stream valleys below Kamuiton. No gross lithological features could be used to subdivide the lava between the Atimet Trachyphonolite and Muruywr Beds. There is no trace of weathering, brecciation, vesicularity etc. within the unit; however, the distinction between the lowest exposures, showing only feldspar phenocrysts and large amygdales and calcitic veins, and the upper horizons with abundant feldspar, nepheline and biotite phenocrysts, indicates that more than one flow is probably present in this part of the succession.

Between Kamuiton scarp and Terenin a 30 foot thick phonolite flow with sanidine, nepheline and biotite phenocrysts occurs within the upper part of the Muruywr Member. It is not seen north of Kamuiton but southwards it continues into the middle of the thin section of Muruywr Beds below Terenin. It is not distinguishable around Chappen where the Muruywr Beds are very thin - it either dies out or passes into the main phonolite sequence in that area.

Muruywr Beds

These sediments crop out only in the main escarpment between the southern boundary of the area and Sumet where exposure is truncated by the main scarp faults. A small lens of sediments on the Charkum range is tentatively ascribed to this unit. The Muruywr Beds thicken from less than 10 feet near Kamelon to 900 feet in the Muruywr section itself, 500 to 600 feet of this thickening being due to movement on a single fault during deposition of the sediments (fig. 10).

The thickest and best exposed section occurs below Muruywr peak on

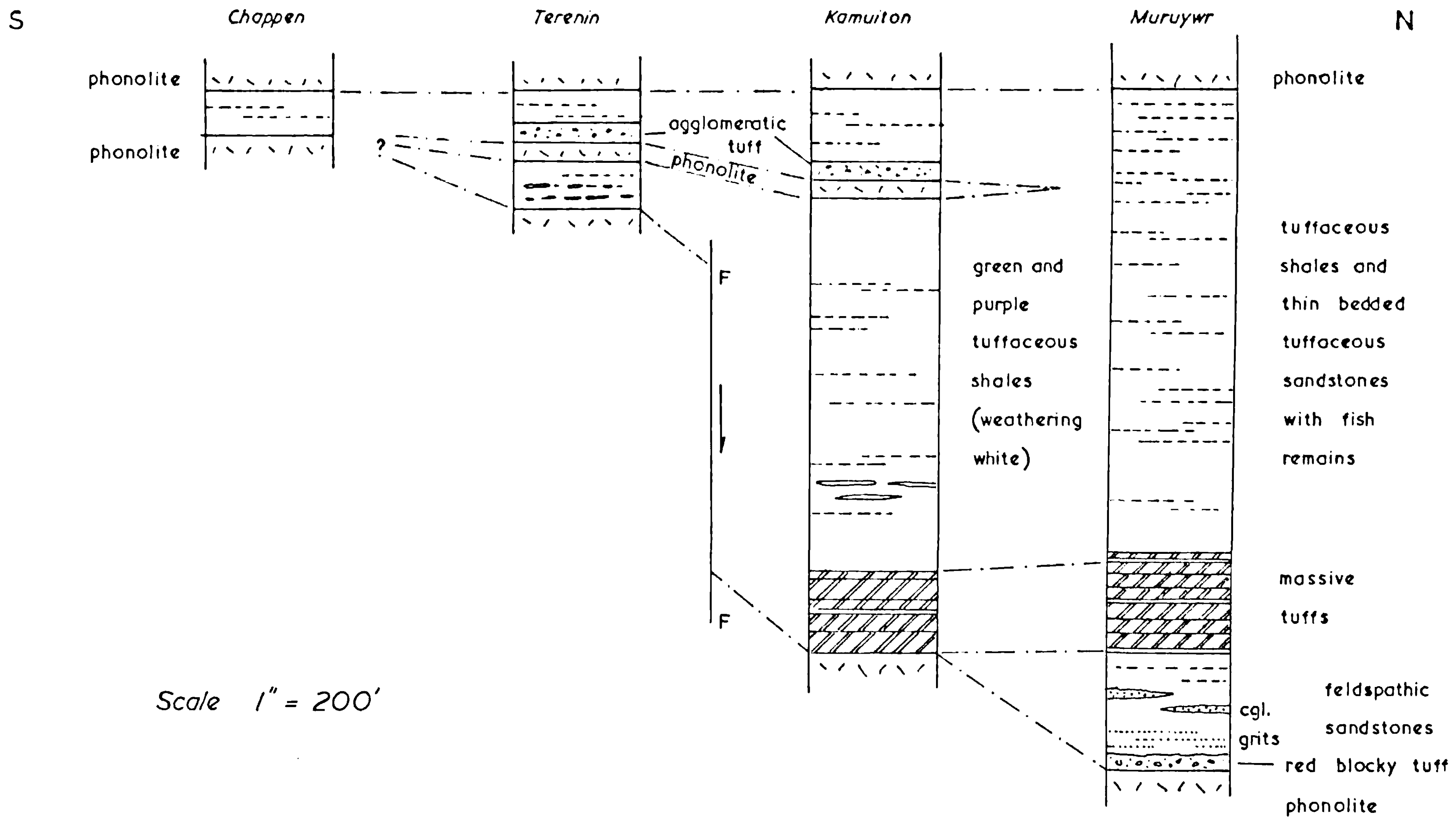

FIG. 10 SECTIONS IN THE MURUYWR BEDS

the long interfluve between the Porgopol (Panwa) and Chepkokel Rivers where the succession is repeated by a large SW-NE fault (Sumet 'B' Fault). The most typical facies are well-bedded tuffs and tuffaceous sandstones and shales but considerable variation occurs. Near the base a massive red tuff with blocks of phonolite crops out on the interfluve and is also exposed in the Porgopol River where, however, it lacks the red coloration, being a normal buff-yellow colour. The basal beds here are also characterised by more epiclastic sediments such as feldspathic sandstones. Also well seen in the Porgopol River section, but less well exposed on the ridge, are several thick (10'-11') beds of massive part-silicified calcitic yellowish tuff. In the Chepkokel section the lowest Muruywr facies seen is a massive 10 foot green lapilli-tuff in a more or less welded condition. In the section to the east of the Kamuetyo Fault three horizons of conglomerates and cross-bedded grits, in units between 2 and 6 feet thick, occur in the middle of the succession in a general sequence of red or cream tuffaceous shales.

The upper part of the unit is generally less variable with laminated to thin-bedded tuffaceous shales and sandstones. When exposed in freshly eroded stream sections the shales are usually green or purple in colour but outcrops on ridges and bare slopes are commonly a buff-yellow colour, probably due to alteration of their pyroclastic component to clay minerals on exposure to prolonged weathering. The phenomenon was also noted by Martyn (pers.comm.) in the tuffaceous shale horizons within the Saimo Phonolites. The shales often have depositional structures such as ripple cross-lamination, and ripple-marked bedding-planes occur below Kamuiton. Worm-casts were also found (2/281). The arenaceous units are locally very rich in fish remains in the form of disarticulated and fragmental bones; one siliceous nodule was found enclosing better-preserved remains of the head region of a fish (2/266). The only larger fossil found was a ingle crocodilian vertebra (2/304) from the thin tuff-bed in the Terenin section.

The Muruywr Beds are not well exposed on the Kamuiton scarp itself, cropping out as short isolated stream sections, but a continuous section of 750 feet is seen in the most northerly tributary of the Terenin River (150890). The basal beds here are the thick massive flinty tuff units described above, lying directly on grey sparsely porphyritic phonolite. These are overlain by alternating massive tuff units up to 2 feet thick and tuffaceous shales, but the bulk of the succession is composed of monotonous purple and green shales. About 100 feet below the top of the section the sequence includes a thin (25') porphyritic phonolite flow overlain by a green lapilli-tuff.

Below Terenin knoll, three-quarters of a mile to the SSW of the thick succession described above, the Muruywr is represented by a maximum of 150 feet of shales and tuffs which includes the thin porphyritic phonolite flow of the thick section. The unmistakeable basal massive tuffs of the northern sections are completely absent; tuffaceous shales, and tuff beds up to 2 feet thick comprise the dominant facies, but in one stream exposure (143887) a massive purple blocky tuff containing blocks of green lapilli-tuff up to 2 feet by 1 foot, crops out separated by a vertical fault from porphyritic phonolite. It is obvious that the thin Terenin succession represents only the top part of the thick northern succession, as shown chiefly by the absence of the thick basal tuffs and continuity of the included thin phonolite flow in both successions. The NW-SE fault running parallel to, and about 1000 feet south of, the long stream exposures of the Terenin tributary is the only agency available to account for this spectacular decrease in thickness of the sediments and the writer concludes that it was active before and during deposition of the Muruywr Beds, restricting the bulk of deposition to its NE (downthrown) side (see fig. 10).

Post-depositional structures provide supporting evidence for tectonism coeval with deposition: in the Porgopol section the thick-bedded tuffs show large slump structures including zig-zag folds with amplitudes of several feet. In the Terenin area massive tuff units among tuffaceous shales are commonly extremely boudinaged, individual boudins often being well separated from each other (figs. 11,12). In the thin Terenin section in particular the sediments are extremely deformed and disturbed.

Isolated very small exposures of silicified tuffaceous shales are seen around the foot of Chappen and Kamelon indicating the continuity of the northern sediments with the more extensive exposures mapped by Martyn, seen in the road between Kipsoramon and Poi.

In terms of their overall aspect, the mixed facies of the Muruywr Beds show an interesting transition between the low-energy environment shales of the Sidekh Phonolite Formation and the high-energy fluviatile facies of the Ngorora Formation. In addition the thickness variations provide a close parallel to the better exposed succession of the Ngorora (fig. 17).

Upper phonolite flows

A further 700 feet of phonolite lies above the Muruywr Member on Kamuiton. This thickness is divided between two and possibly three flows: the lower part is porphyritic (feldspar, nepheline and biotite), and the upper a non-porphyritic flow-banded rock, mentioned above. A pale-weathering horizon can be distinguished about half-way up the steep scarp, and above the 200 foot waterfall where the Chepkokel River drops over the upper phonolites below Koitimim a thin horizon of silicified shales crops out in the stream bed on about the same horizon. Within these shales occurs a horizon of distinctive knobbly siliceous concretions (2/265).

Within the lower part of the upper flow the normal porphyritic petrology is accompanied by a type containing, in addition to feldspar and nepheline, pale green euhedral pyroxene phenocrysts, seen only in thin sections (2/331); it seems that, at least in the Kamuiton section, the upper porphyritic unit comprises at least two flows. The long gorge below Koitimim exposes 400 feet of the aphyric phonolite which is obviously an indivisible unit.

Essentially the same succession of upper phonolites, nearly 1000 feet

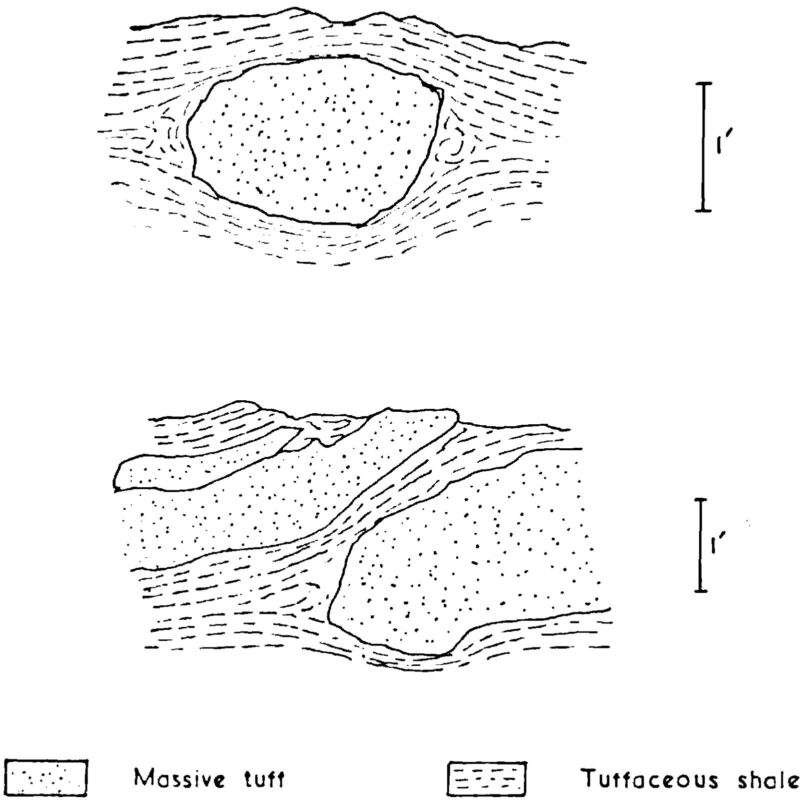

FIG. 11 BOUDINAGE (?) IN THE MURUYWR BEDS (FROM A FIELD SKETCH AT 144879)

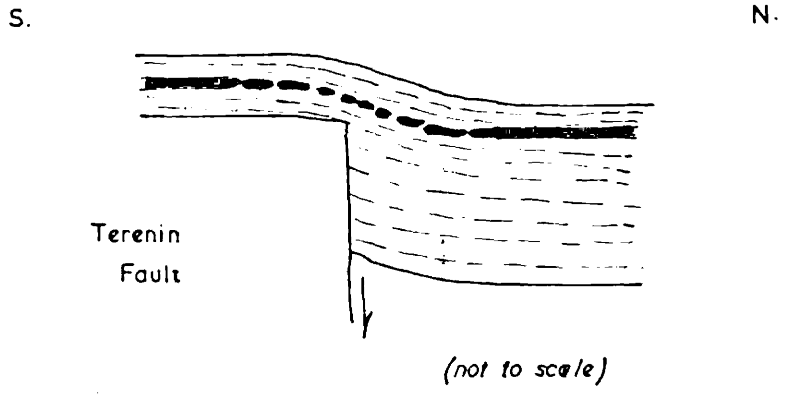

FIG. 12 HYPOTHETICAL ORIGIN OF THE MURUYWR BEDS BOUDINAGE FEATURES

thick, form the peaks of Chappen and Kamelon but with the absence of the thin silicified shales. Where the Kabarnet trachyte oversteps Ngorora Formation on to the Kamuiton Phonolites near Terenin a deep but irregular white weathering zone, very similar to that in the Sumet Phonolite (p. 33), occurs in the phonolites.

The upper Kamuiton phonolites are the lowest rocks exposed at the foot of the scarp below Chepkesin. Here again the lower sections are in porphyritic phonolite but the bulk of the section exposed is in aphyric phonolite; in fact the tortuous gorge of the Kiptoisarorr River below Kabarsero exposes the best section in this top phonolite, and the convoluted rhyolitoid banding is very well developed here (pl. 6). Thin sections of this and other banded phonolites (2/256) show the banding to be formed by alternating feldspathic and mafic (aegirine) layers 1 mm. to 2 mm. thick; it is presumably a flow phenomenon. A very similar texture is illustrated by McCall (1964, pl.24, fig.5).

On the Charkum range the Kamuiton Member totals only 800 feet, comprising a lower porphyritic phonolite overlain by the aphyric phonolite. If the thin lens of tuffaceous sediments exposed locally in the scarp above the headstreams of the Noroyan River represents the Muruywr Beds, the phonolites of the area can be attributed to both the lower and the upper group. Adding strength to this conclusion, the lower (porphyritic) phonolite of Charkum resembles the lower flow of the Kamuiton section in the abundance of phyric biotite and the presence of amygdales with euhedral analcite and calcite (2/309).

800 feet of steeply dipping Kamuiton phonolites crop out as a triangular inlier at the junction of the Chemnakoi and Simniyon faults. Both thickness and petrologies resemble those of Charkum, a lower porphyritic phonolite being succeeded by an aphyric banded phonolite, the two forming a distinct double topographic feature. In the field the angular discordance between the Tugen Hills Group and the Kabarnet trachytes is perhaps

seen most clearly in this area, the steeply-dipping phonolite of the inlier contrasting with the near-horizontal Kabarnet trachytes to the south and west.

In the most northerly outcrops, along the Chemoigut River, the member consists of less than 400 feet of aphyric phonolite, between the Chemoigut trachyphonolite below and the sediments of the Ngorora Formation above. The member has not been recognised in the field as a separate entity north of the area.

In the south of the area Martyn (op.cit.) has recorded a total thickness for the Tiim Phonolites exceeding Kamuiton and Atimet members together, and it seems that in the Saimo-Tiim area additional lavas occur both above and below the lateral equivalents of those of the present area.

4. Ngorora Formation

This formation consists of waterlaid sediments of mixed pyroclastic and epiclastic origin, up to 1200 feet thick, with an interesting assemblage of fossil vertebrates (faunal list in Part Ig). The following account is the joint work of the writer and W.W. Bishop, and follows the account already published (Bishop and Chapman 1969), but with expanded sections on the Poi and Kapkiamu units, and on the environmental interpretation.

The formation as originally mapped was virtually confined to the present map area. However, it is apparent that a single sedimentary lithosome with complex facies variations occupies the horizon between the Tiim and Ewalel formations throughout the length of the Kamasia Range, and the 'Kapkiamu shales' and 'Poi tuffaceous sandstones' of Martyn (1969, pp.42-48) are now included in the Ngorora Formation.

(i) Type area facies

The type section (fig. 13) is at Kabarsero (1699) north of Chepkesin village. Here, the sequence totals over 1200 feet in thickness; it rests on the flow-banded aphyric phonolite which is the top flow of the Kamuiton

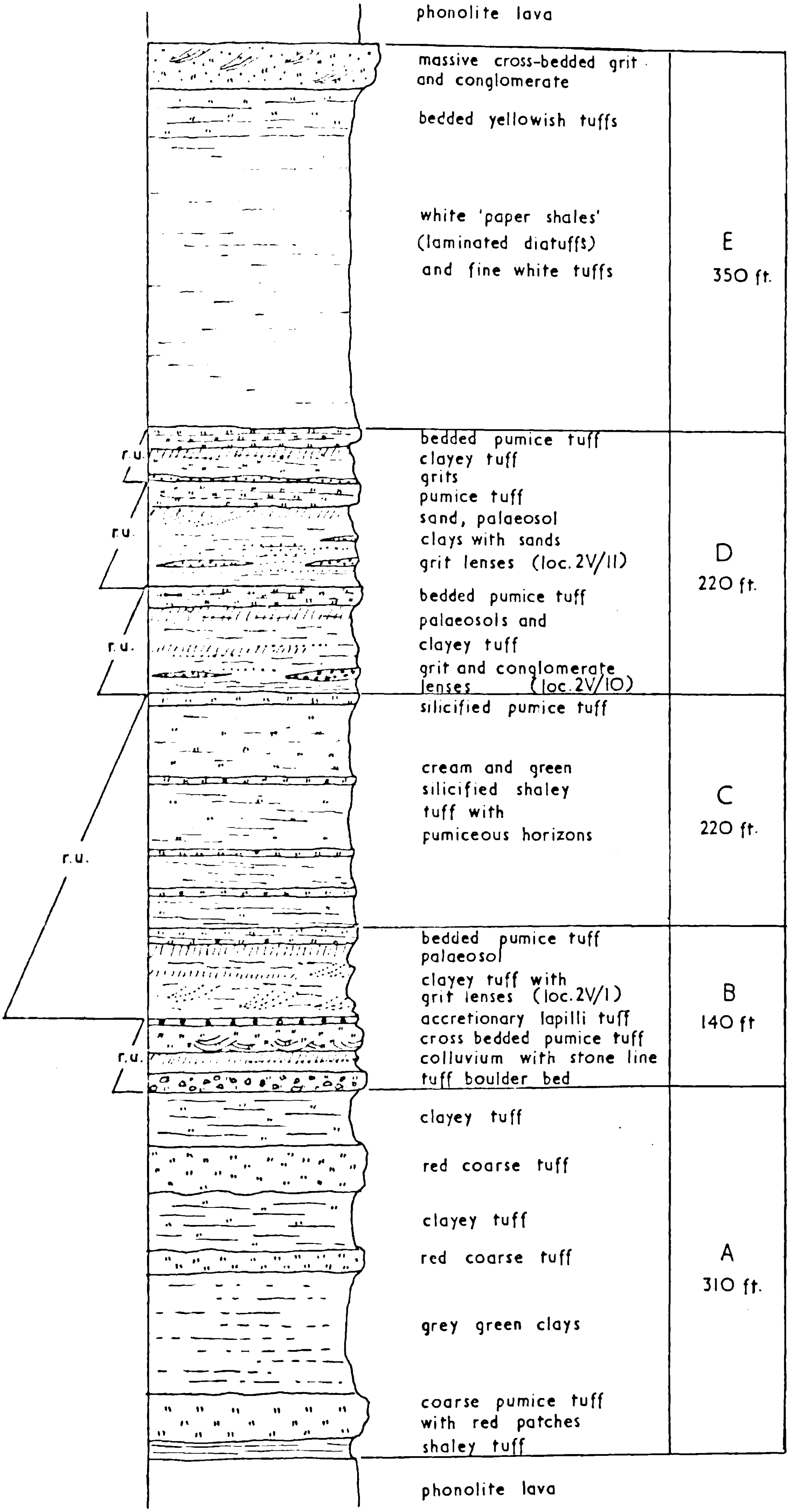

FIG. 13 TYPE SECTION OF THE NGORORA FORMATION AT KABARSERO

r.u. = rhythmic unit

Phonolites Member of the Tiim Formation throughout the area and is overlain by the Sumet Phonolites (Ewalel Formation). Isotopic ages from these phonolites suggest an age of between 9 and 11 million years for the Ngorora (see Part I f).

Five main lithological divisions are recognized in the type-section (fig. 13):

A - variable bedded tuffs, tuffaceous clays and grit* lenses. The outstanding beds are massive tuffs with lava blocks which occur near the top and the base of the subdivision. These are stained red in patches but the red coloration is not as persistent in the type area as at other localities.

B - ferruginous pebbly grit and a prominent bed with tuff-boulders mark the base of this division. Above these beds sedimentation is in the form of alternations of current-bedded grits, sands and clays with bedded pumice tuffs and tuffaceous silts. As rhythmic sedimentation is typical of division D also, a standard bipartite unit is illustrated (fig. 14) and described in more detail:

> The lower part of this generalized unit shows a decrease upwards in the number of grit bands and in overall grain size. Vertebrate fossils are concentrated in the conglomerate and grit lenses and are often very abundant. Bones and teeth show a variable degree of rolling but normally are well preserved. (The principal fossil mammal horizons are indicated in Figure 13 but fragments of fish occur in sandy beds throughout the sequence.) Well preserved chelonian remains occur more generally in the silts and clays of the middle of the unit. These are succeeded by glutinous clays containing kunkar and occasional rootlet casts. These clays are characteristic of palaeosols produced by the weathering of tuffaceous silts. Sedimentary

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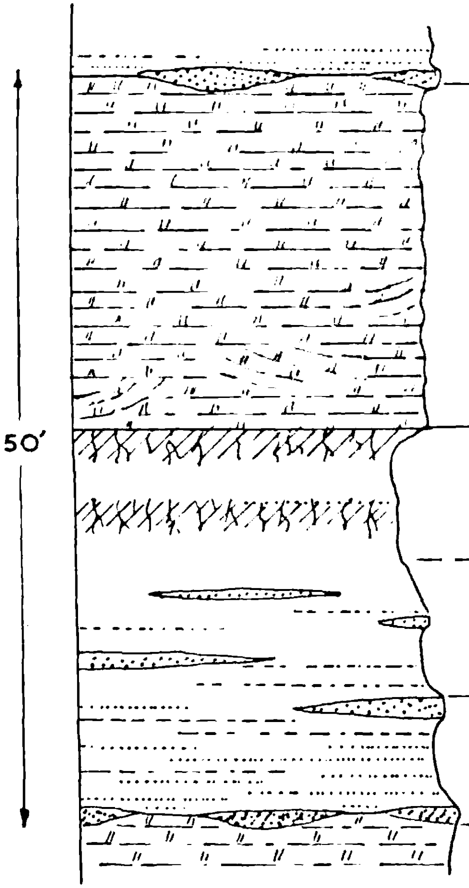
* 'Grit' is used as a convenient term to denote characteristic coarser feldspathic/lithic sandstones.



LITHOLOGY AND FOSSILS	*INTERPRETATION*
Fine to medium grained thin-bedded pumiceous tuffs often silicified. Rare cross bedding. Plant remains.	Off-shore lacustrine deposition. Pumice and plants possibly transported by floating.
Clays with kunkar, rootlet casts and 'stone lines'.	Fluvio-paludal environment culminating in emergent land surface with palaeosols (upper clays).
Clays and silts. Chelonian remains.	
Sands and conglomerate lenses with mammalian remains.	

FIG. 14 GENERALISED RHYTHMIC UNIT, NGORORA FORMATION

dykes of silicified angular pumice tuff also occur marking infilling of open cracks on land surfaces. The dykes invariably terminate at one of the palaeosol horizons.

The upper part of the unit is composed of thin-bedded pumice tuffs, occasionally showing trough cross-bedding but typically very evenly bedded and fine-grained with a sharply defined base (see fig. 14). These strata usually form cliffs. The fine-grained sediments are frequently silicified to a brittle porcellanous rock with chert bands. Fragments of wood and fruits occur in the tuff above Loc. 2V/11. The top of the bedded tuffs is often cut by channels containing the basal grit and conglomerate of the succeeding unit. This feature is well shown below Loc. 2V/1 where the fossil bearing deposits lie in channels which have cut through a massive accretionary lapilli-tuff producing pot-holes and water-worn blocks.

C - this is essentially the upper part of the rhythmic unit of Loc. 2V/1. It has been mapped separately to facilitate the study of thickness variations. It consists of cream and green well-bedded tuffaceous silts exhibiting variable silicification and containing five coarser pumiceous horizons.

D - comprises three rhythmic units of which the lower two contain the fossil localities 2V/10 (named the 'Charnel House Grit'), 2V/11 and 2V/13. The top of the sands and clays of Loc. 2V/11 is marked by a thin, 1½ inch (40 mm.) but laterally persistent pebble bed. This and the underlying sands were subjected to minor faulting and fissuring before the deposition of the overlying bedded tuffs.

E - white diatomites and finely laminated diatomaceous and tuffaceous silts occur at the top of the sequence in the Chepkesin-Kabarsero area. Above this sequence is a prominent massive cross-bedded grit and conglomerate overlain by a thick tuffaceous silt; the grit and conglomerate make a prominent cliff above the road south of the old Chepkesin village.

Sections of the formation exposed on the crest and dip-slope of the Sidekh range, three miles to the west of Kabarsero on the upthrown side of the Kito Pass Fault (2000 foot throw) are only 100-150 feet thick. Also, a progressive thinning is observed when the formation is traced south-southwestwards from Kabarsero towards Kamuiton where the section is only 245 to 250 feet thick. Thicker sections are again seen as the outcrop is traced north-westwards from Bartabwa towards the Kerio. In short, there is everywhere a close correlation between the thickness of the formation and structural relief (fig. 17). Detailed sections have subsequently been measured and logged by W.W. Bishop.

It is true to say that the massive red tuffs everywhere characterise the basal horizons and that a general increase of fine-grained well-bedded lithologies occurs upwards.

At the southern end of the Kamuiton outcrop there occurs a thin bed of calcarenite which gives a strong bituminous smell when broken; it is used by the local people to prepare a medicine. Martyn records a very similar lithology from near Cherial.

Wherever the base and top are seen, the formation rests conformably on the top flow of the Kamuiton Phonolites Member (Tiim Formation) and is overlain conformably by the Sumet Phonolite (Ewalel Formation). Within the limits of the preliminary observations there seems to be no significant intra-formational unconformity.

(ii) Kapkiamu shales and Poi tuffaceous sandstones

The Kapkiamu shales (Martyn op.cit., pp.42-43) are, in the present area, confined to the large southern outcrop in the Poi valley. (However, similar shales also form a thin horizon near the base of the Kamuiton outcrop.) They are very thin bedded and laminated green and cream shales, some horizons with abundant fish remains. Overlying the shales are the Poi tuffaceous sandstones of Martyn (op.cit., pp.43-48); these are sandy tuffs and tuffaceous sandstones, much more even in grain size and more evenly bedded than the arenites of the Ngorora type-section area. Some very thick (6 feet) and persistent beds occur.

Although Martyn gave both the above two lithologies formation status there is no natural division to be made in the succession. This is apparent both in the field and in Martyn's 'Poi tuffaceous sandstones type section' (Martyn 1969, fig. 15) of which at least half the thickness is shown as being composed of tuffaceous shale.

There also appears to be a lateral transition between the Ngorora type-section facies and the Poi tuffaceous sandstone facies. This becomes apparent as the Ngorora outcrop is followed north-westwards from Bartabwa towards Kinyach, where the bulk of the unit is composed of bedded tuffs of the 'Poi-type', although coarse channel-grits are also present.

Finally, there is a striking correlation between the lithologies shown by Martyn in the Ngeringerowa section of the Poi tuffaceous sandstones (Martyn 1969, fig. 16) and the lithologies of the type-section of the Ngorora at Kabarsero.

The overall picture is clearly that the facies characterised by channel conglomerates, grits, clays and palaeosols (e.g. Kabarsero, Ngeringerowa) occurs along the crest of, and to the east of, the main range and is replaced westwards by the less variable 'Poi tuffaceous sandstones' facies of Martyn's type section; the Kapkiamu shales are older than the other facies and, in their typical development, restricted, as Martyn says, to the embayment outcrops in the Poi and Kapkiamu areas.

The result of all this is that the present writer would prefer to extend the Ngorora Formation to include the 'Poi' and 'Kapkiamu' units of Martyn, thus abolishing the 'Kaboskei sub-group' of the latter author.

(iii) Environment

Preliminary examination of cross-bedded structures, imbrications and channel orientations in the type-section (Kabarsero) facies suggests sediment transport from between north and east. This appears to preclude derivation from the Kamasia itself but thickness variations in the sediments show that the range was obviously a positive tectonic element within the basin of deposition.

Figure 15 shows the overall synthesis for all facies. The diagrams are largely self-explanatory but general asymmetry of the rift at this time is suggested by a mass of circumstantial evidence including evidence of the size and age of the Kamasia and Elgeyo faults (see Part IIf) and the abundance of minor unconformities within the relatively thin Laikipia succession (Sceal, Ph.D. thesis in preparation). The result of the asymmetry was probably, as shown, to place the watershed on the west at the crest of the Elgeyo and, in the east, at some distance to the east of the Rift margin. This is in fact the general position to this day, but there is also evidence, in the Amaya trachyte outcrops (Sceal op.cit.), of long erosional valleys in the Laikipia in the Pliocene also.

The deposition of the Kapkiamu shales may have been localised by contemporaneous movement on the Cherial Fault, forming a semi-circular basin, bounded on the west by the west-facing fault scarp.

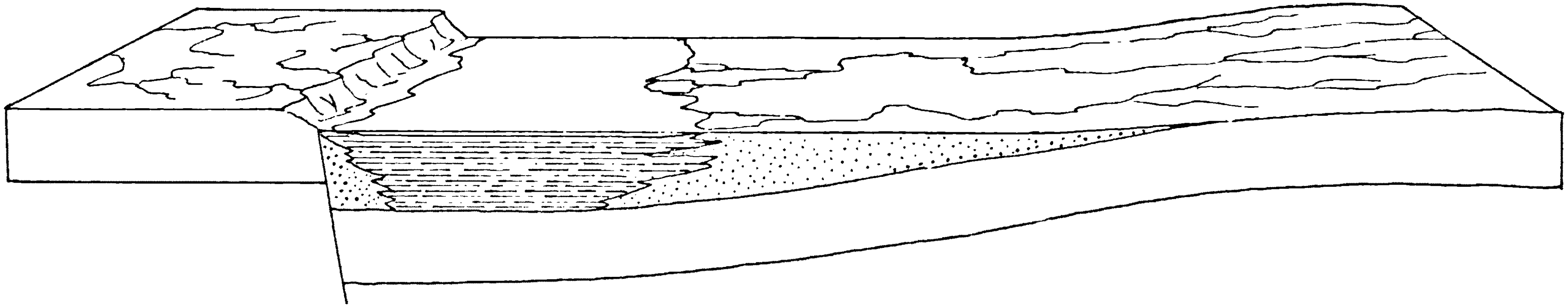
A tectonic explanation is also favoured for the rhythmic units of the type-section. This is shown diagrammatically in figure 16. The faults shown do not represent actual faults; the diagram is designed to show, in a general way, how sporadic faulting (which must have occurred to govern the overall thickness variability) might cause the observed sequence of lithologies:

Given an established sedimentary lithosome with a near-planar surface:

(a) Movement occurs on the western fault, causing tilting of the basin floor and emergence of lake sediments with consequent channel erosion and deposition of coarse epiclastic sediments.

(b) Slight persistent movements on the eastern faults, tending to negate the previous tilting, are resulting in the progressively lower energy environments of swamps and alluvial plains with

(a) Idealised



(b) Actual (in part, hypothetical)

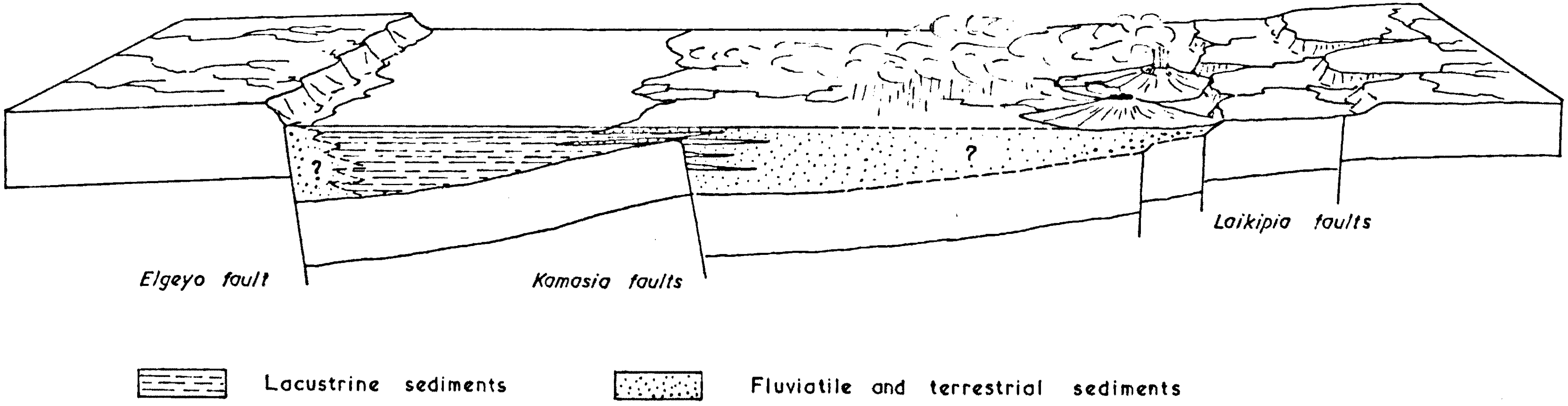
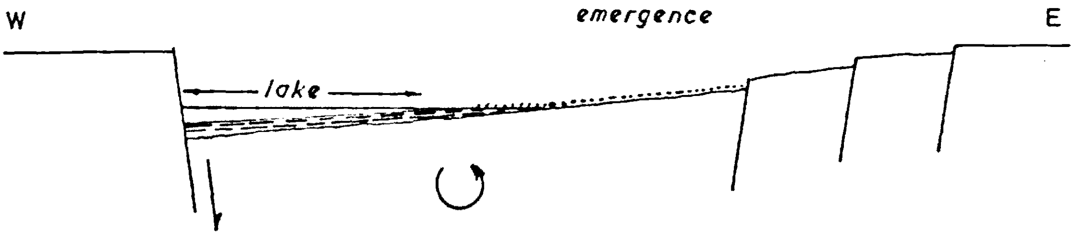
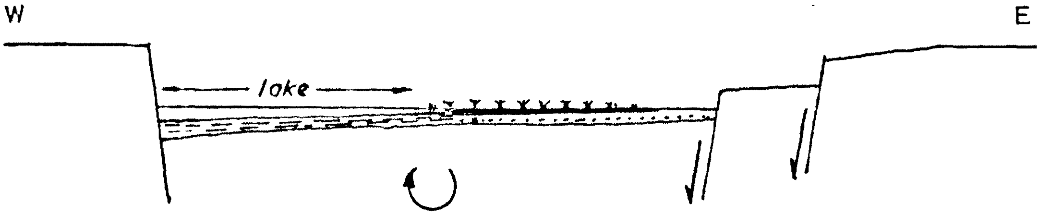


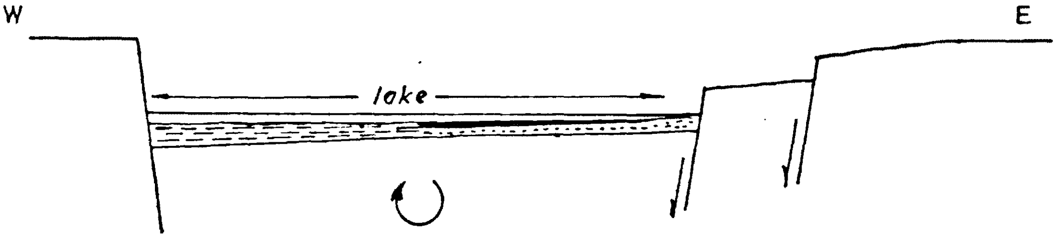
FIG. 15 RECONSTRUCTION OF THE DEPOSITIONAL BASIN OF THE NGORORA FORMATION



(a) Rapid tilting, emergence of lake bed, channel erosion in the east



(b) Slow tilting in reverse direction, fluvial plains and marsh in east



(c) Tilting continues, lake transgresses eastwards. Sequence then returns to (a).

FIG 16 TECTONIC MODEL FOR THE NGORORA FORMATION RHYTHMIC UNIT deposition of silts and clays and development of palaeosols. Occasional incursions of primary tuffs occur.

(a) and (b) together produce the lower (sand/clay) part of the rhythmic unit.

(c) Continued faulting on the eastern side causing rapid transgression of lake waters across the alluvial plains; deposition of the pumiceous pyroclastics of the upper part of the unit in still-water conditions. The wood and fruit in these sediments, and also the pumice fragments, would have been able to float to some distance from the shore. No mammalian fossils were found in this upper part of the unit.

Divisions C and E of the type-section represent more stable periods of lacustrine deposition, the laminated diatomaceous tuffs of E, in particular, indicating an episode of tranquil lake conditions which was eventually terminated with the deposition of the conglomerate and grit at the top of the sequence.

5. Ewalel Phonolites Formation (Sumet Phonolite Member)

In the present area the Sumet Phonolite is the highest unit of the Tugen Hills Group seen and is the only representative of the Ewalel Phonolites of Martyn (op.cit., pp.52-55) which are much thicker, with sedimentary intercalations, further south.

Notwithstanding the maximum thickness of the Sumet Phonolite of 800 feet on Sumet mountain, there is no indication of any division into separate flow-units, but it is possible that the formation at its thickest represents several pulses of nearly contemporaneous lava extrusion. Where the base is seen, it overlies the Ngorora Formation with perfect conformity.

There is very little petrologic variation over the greater part of the outcrop; the rock is commonly dark green in colour, with small phenocrysts of sanidine and nepheline, the latter averaging 2 mm. in size. The rock has a very distinctive 'freckled' appearance due to poikilitic aggregation of groundmass mafics. This feature defines the rock as within the 'Kamasia-type' phonolite of Prior (1903).

On the dip slope of the Charkum range in the north-west of the area, and in the Poi embayment in the south (Chepware River exposures) a slightly different petrology occurs, finer-grained than the type, with only rare micro-phenocrysts of feldspar and nepheline (2/290). In the Chepware River there are outcrops or extremely brecciated phonolite of this type (2/310); to the south Martyn (op.cit., pp.51-52) has recorded brecciated phonolites associated with the Kaption intrusive complex but no intrusive relationship could be proved in the present area, and these petrologies are included for mapping purposes with the Sumet Phonolite.

Rather exceptionally among the salic lavas of the area the Sumet Phonolite often shows good spheroidal weathering. It also has the ability to form vertical-faced bluffs typified by the peaks above Muruywr, and to a much greater extent in the Kaption embayment south of the area.

In addition to the extensive outcrops on the main range the Sumet Phonolite also occurs as an inlier at Yatya in the axis of a fault half-dome (see Part IId). Here the phonolite is of the typical freckled variety (2/211). The top 40-50 feet has been deeply weathered to a soft whitish rock which is overlain by the sharply defined base of the lowest Kabarnet trachyte (pl.11). This white weathering is also extensively developed on the dip-slope outcrops in the main range, especially on the scarp above the Chemoigut River where the writer was surprised to find that the white horizon prominent in aerial photographs was not a development of sub-Kabarnet sediments. It is, however, absent from the outcrops on the crest of the range and Sumet itself; other evidence (Part IId) shows that these areas stood up as hills above the sub-Kabarnet erosion surface and it is likely that here the weathering products were removed by down slope movement practically as soon as they were formed. No trace of bedding or other structure was seen in the weathered material.

On the dip-slope it is common to find the Sumet 'feather-edging' out beneath the Kabarnet trachytes, despite the demonstrable feature-forming capability of the phonolite at the present time, and over large areas the Kabarnet trachytes lie directly on the Ngorora Formation.

In view of the widespread planar erosion of the highest Tugen Hills Group formations it is unlikely that the complete thickness of the Sumet Phonolite is anywhere preserved, but the great thickness in the Sumet mesas probably approaches the original maximum.

(b) Source of the 'plateau' phonolites

It has long been assumed that the 'plateau phonolites' were erupted from fissures either on the shoulders of the developing rift (McCall 1967, p.98) or on the crest of the 'Kenya dome' prior to any rift faulting (Baker 1965, p.2, Williams 1969, p.61). The remarkable thickness of these phonolites exposed in the Kamasia, the bulk of which is both older (Sidekh Phonolites) and younger (upper Tiim and Ewalel Phonolites) than the comparatively thin succession on the Rift shoulders, shows that rift faulting preceded the earliest phonolites and that the latter must have sources within the Rift. The extreme scarcity of phonolite dykes, anywhere, and the presence of phonolitic extrusive centres such as Sigatgat (McClenaghan op.cit.), Kaption (Martyn op.cit., pp.48-52) and smaller central sources on the eastern side of the Rift (Sceal op.cit.) together with the microfoyaite plugs of Turkana (Joubert 1966) appear to the writer strongly to indicate central sources for some, if not most, of the phonolites.

Superficially, the great north-south extent of the phonolite suggests linear sources, but the detailed mapping in the present area and on the Elgeyo Escarpment (Lippard op.cit.) has shown that individual identifiable units extend no further in a north-south direction than they do east-west, and have complex interdigitating relationships with other units which replace them in a succession which maintains overall constant thickness.

This situation is exemplified in the present area by the relationship between the Sidekh and Tiim formations (fig. 7), and the correspondence between north-south extent of the Atimet Trachyphonolite on the Kamasia and the equivalent unit on the Elgeyo. Lippard (op.cit.) has shown that the phonolite capping the Elgeyo consists of many different units often with definite north-south limits; furthermore as the succession on the Elgeyo thickens towards the south it appears to pass laterally into a succession dominated by pyroclastics, just as the Sidekh Phonolites on the Kamasia thicken to the north and appear to pass into the pyroclastics of the Sigatgat and Tiati areas.

So, to the fissure source hypothesis the writer adds the alternative model of very large, very low-angle phonolite shield volcanoes of which the rift shoulder flows are the extreme flanks, and whose major sources lie well within the present rift and are mostly concealed beneath later rocks. Figure 18 is a diagrammatic representation of the postulated situation. The actual slope of the volcanic piles, judged from the varying thickness of the Sidekh and Tiim units, would be 3^{o} or less. This is extremely low, in fact a lower angle than the basaltic shield volcanoes of Hawaii, but in view of the apparent extreme fluidity of the plateau-phonolite lava in East Africa, the figure is not unreasonable. There is, in any case, no reason why the 'shields' should not have been completely flat, if flows were being erupted from different centres simultaneously to form a composite 'plateau' succession.

Figure 17 also illustrates the point that the water-laid sediments associated with the two major phonolite units are thickest on the flanks of the postulated shield volcanoes (although the thickness in the Tiim Formation sediments is partly due to tectonic causes), and are entirely absent from the thicker part of the Sidekh Formation where, as described, there is hardly any inter-flow weathering, implying shorter intervals between successive flows.

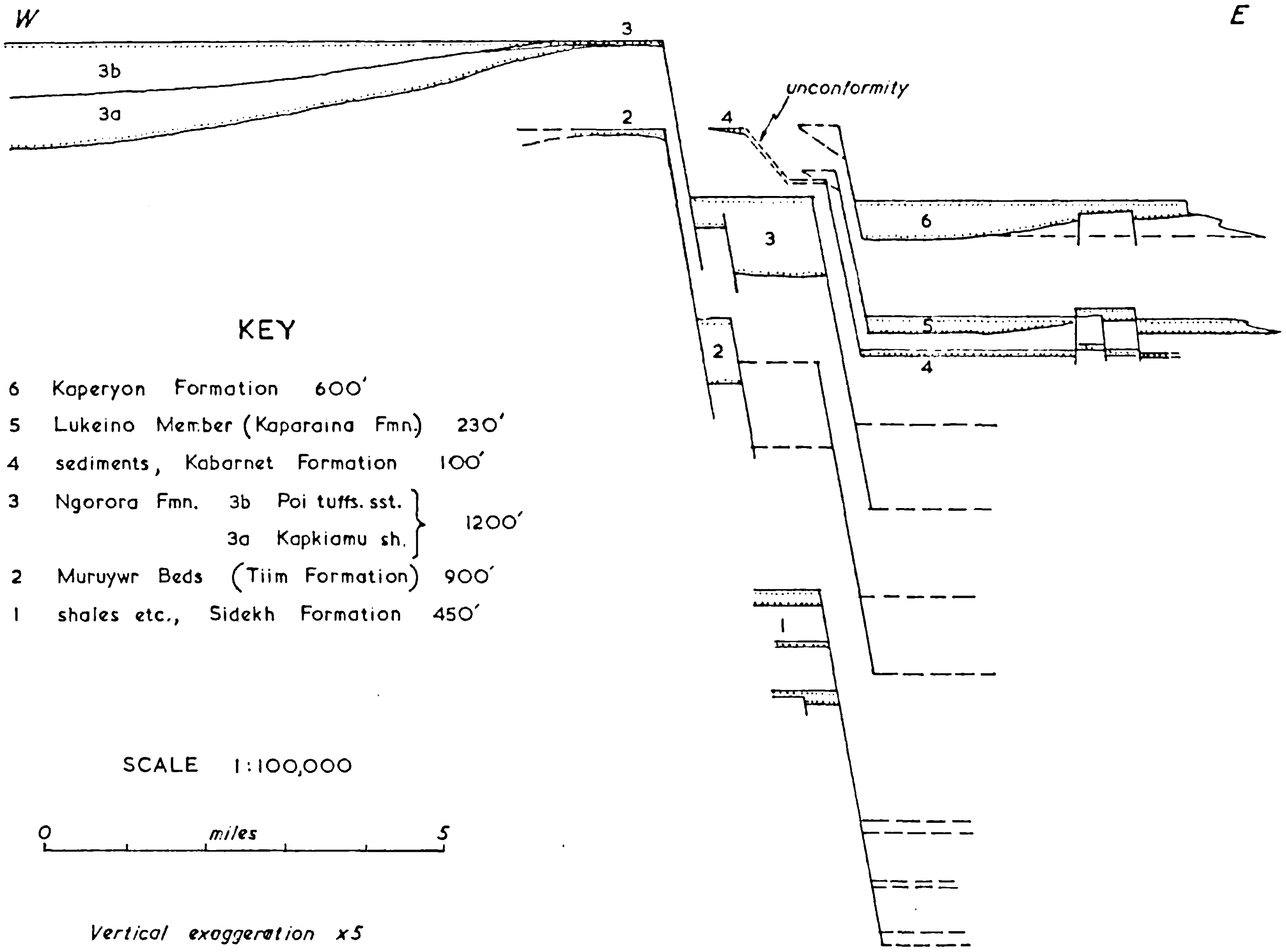


FIG. 17 TECTONIC CONTROL OF SEDIMENTARY THICKNESSES (Tilting and overstep not shown)

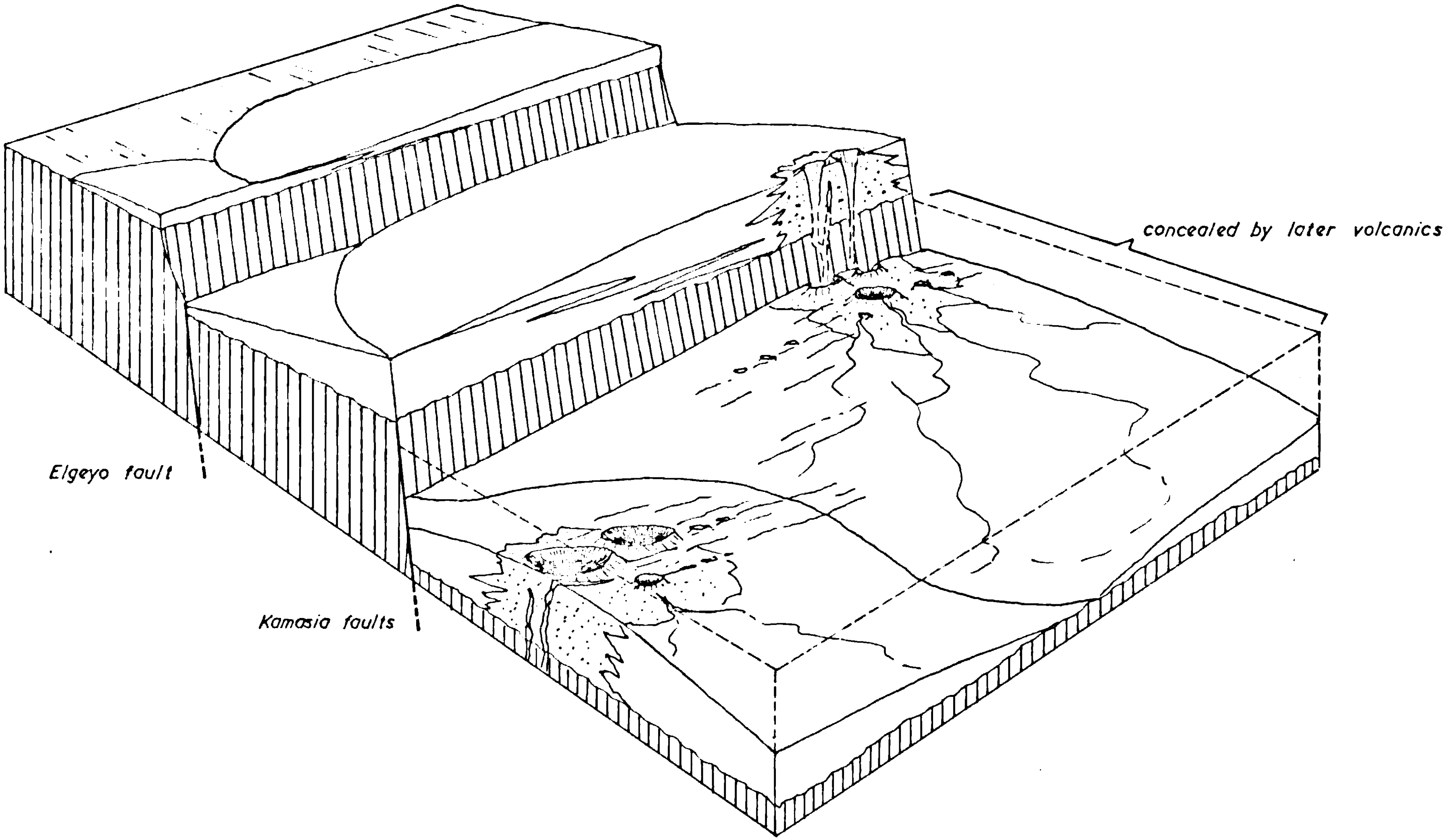


FIG. 18 HYPOTHETICAL RECONSTRUCTION OF THE GROUP II PHONOLITE FORMATIONS AS FLAT SHIELD VOLCANOES

(c) Volcanic group III - Pliocene basalt/trachyte group

1. Kabarnet Trachytes Formation

The formation is mainly composed of a remarkably uniform series of flood trachytes which form the greater part of the dip-slope of the Kamasia Range between 0°15'N and 1°00'N, and occurring also as faulted inliers to the east of the main range. Their original extent cannot have been less than 700 square miles.

Minor amounts of basalt occur beneath the trachytes and sediments are intercalated within the latter.

(i) Lokwetmoi basalt and Mukur basalts

A single flow of basalt crops out beneath the trachyte of the Mokhungo syncline (1497). The rock is mainly fresh with very sparse small feldspar phenocrysts. In the river gorges on the western limb of the outcrop good columnar jointing is seen. The basalt appears to be conformable with the trachyte and oversteps the underlying Sumet Phonolite and Ngorora Formation, but is very limited in extent.

To the east of the Mukur gorge (2410), north of Ribon there occur basalts which, from aerial photograph interpretation, appear to dip beneath the Kabarnet trachyte of the gorge. Lithologically they are very similar to the Kaparaina basalts, with both porphyritic (plagioclase/olivine) and aphyric types. McClenaghan (op.cit.) has mapped all the basalts in the Cheptopokwa River outcrop as belonging to a unit named 'Barpelo Basalts' which underlies the Kabarnet trachytes. However, the present writer's structural interpretation of this area confines the sub-trachyte basalts to a relatively small outcrop at the mouth of the gorge, and assigns the rest to the Kaparaina Formation (see Part IId).

(ii) Trachytes

The Kamasia dip-slope was first recorded by Maufe (1908) and the trachytes were first mentioned by J. Scott (in Shackleton 1950, p.372). The formation was named by Walsh (1969, p.24) after the small town of Kabarnet, and the name was first recorded by Baker (1965, p.6) and by Williams (1965, p.37). The trachytes have since been mapped to the north of Kabarnet by Martyn (1969, pp.71-78) who showed conclusively that Walsh was incorrect both in placing them too high in the succession and in assuming that they were erupted near Kabarnet and flowed down the dip-slope. In fact the Kamasia dip-slope is of entirely tectonic origin and the Kabarnet trachytes lie below the Kaparaina Formation on the east (down-throw) side of the main Kamasia faults. In the present map area, in particular, as well as forming the dip-slope the trachytes are widely exposed in a series of faulted inliers in the general area of outcrop of the Kaparaina Formation. Recent mapping by Lippard (Ph.D. thesis in preparation) has shown that the trachytes also continue far to the south of their limits as mapped by Walsh.

Lithologically the Kabarnet trachytes show a monotonous similarity over the whole of the map area: they are micro-porphyritic soda-trachytes, greenish in colour, with a strong fissility due to orientation of the feldspar laths. In hand-specimen they are essentially non-porphyritic but in the north-west of the area the presence of sparse small phenocrysts (2-3 mm.) of Carlsbad-twinned sanidine serves to distinguish these trachytes from the very similar Ribon Trachyte. Abundant large (10-15 mm.) tabular sanidine phenocrysts occur exceptionally in a thin local flow near Yatya.

The Kabarnet Trachytes Formation rests unconformably on underlying formations but on the present map they overstep beyond the Ngorora Formation in a very limited area. In general the trachytes lie on a fault-repeated succession of Sumet Phonolite and Ngorora Formation. At one point only, near the road two miles south of Bartabwa, the lowest trachyte lies on the top Kamuiton Phonolite. Westwards from their eastern outcrop-margin on the top of the range the trachytes thicken very suddenly and the mapping showed that the upper of the two main flows just overlaps the lower.

The trachytes continue to thicken towards the Kerio valley, being at least 500 feet thick at Atyar and over 750 feet in the valley of the Sergothwa. This is less than the maximum thickness of 1100 to 1200 feet recorded by Martyn (op.cit., p.71) in the Erón valley. At least three flows are present in the Kinyach area, 'flow three' overlapping 'flow two' about 1½ miles from the foot of the dip-slope. Thus, the two flows present on the higher part of the dip-slope are flows 'one' and 'three' of the Kinyach area.

Tops of flows may be identified by vesicularity and brecciation but the mapping of individual flow outcrops on the dip-slope was done almost entirely on photogeological evidence, erosion scarps of the separate flows being very clear on the aerial photographs. No sediments occur associated with the trachyte succession anywhere on the dip-slope.

At Yatya the basal Kabarnet trachyte rests with apparent conformity on typical Sumet Phonolite. The total thickness of the formation here is 600 feet but of this 150 to 200 feet is represented by sediments between the two main flows. Locally between Yatya and Sibillo a third flow, of very porphyritic trachyte, occurs at the top of the succession, capping distinctive white tuffaceous sediments. This succession forms the south-east corner of Rurmoch mesa and is repeated by faulting at the extreme southern edge of the area (2483). It is not clear whether the sporadic occurrence of these units is due to primary distribution or to the sub-Kaparaina unconformity. The upper main flow forms the wide mesa on which Rurmoch peak stands, and terminates above the Yatya river as a vertical two-hundred-foot cliff overlooking an extensive area of land-slip.

In the fault-arch inliers of Tegit and Chepirimor only one trachyte is seen, its total thickness being not less than 500 feet, but below Kokwomur yellow-brown bedded tuffs are seen apparently lying beneath the trachyte. The huge mass of Kokwomur (fig. 35) rising seven hundred feet from the surrounding valley is composed entirely of trachyte. A large area of exfoliation sheets is seen on the eastern face and this, together with the absence of recognizable flow-units, gives this hill the superficial appearance of a plutonic body or extrusive cumulo-dome. However, the Kisitei gorge section shows the lithology to be no different from that of the dip-slope sheets; the fissility dips steadily at 30-40 degrees to the north-west and in the eastern end of the gorge solid lava is overlain by trachytic breccia. When viewed from any distance to the east the whole hill is seen to have a regular planar top dipping to the NNE (pl. 12), i.e. concordant with the tectonic dip of the southern inliers. It is accordingly interpreted as a 'single-ended' horst composed of one extraordinarily thick and massive flow (see Part IId).

Northwards from Kisitei the trachyte forms a low asymmetric ridge at the northern end of which, at Mpesida, fossiliferous sediments dip off the trachyte on WNW-ESE strike, i.e. normal to the regional fault pattern but, again, concordant with the general tectonic attitude of the trachyte inliers.

At Mukur, on the northern edge of the area, a gorge remarkably similar to that at Kisitei cuts through the Kabarnet formation, here at its most tectonically complex development. Vertical bluffs of trachytic breccia/agglomerate form the eastern mouth of the gorge and this lithology is continued for 300 yards upstream on the south side. However, more normal trachyte lithologies predominate, fine-grained with scattered small (3 mm.) sanidine phenocrysts. At the big loop in the central section of the gorge thinly-bedded pale brown tuffaceous sediments occur, dipping vertically on a north-south strike. A few yards to the west they are again seen dipping steeply westwards beneath a relatively thin (40-50 feet) trachyte flow. In this final (western) section of the gorge the dip again changes abruptly and thin trachyte flows overlie buff-yellow fine-grained bedded tuffs dipping at 40° to the south-east. It is obvious that in this area the Kabarnet has been very strongly disturbed by faulting and tilting. This fact has a bearing on the overall structural interpretation of the Mukur area as a whole (see Part IId).

The inlier of Kabarnet trachyte in Kaperyon Formation on the Chepkesin road (2299) is interpreted as Kabarnet only on gross lithology. The discontinuous outcrop of Kabarnet along the foot of the main scarp is the result of dragging on the large scarp faults. The trachyte dips very steeply (up to 70°) and the tectonic cause is proved by the occurrence, between trachytes, of fine-grained water-laid tuffs (184993) also dipping east at the same angle. This fault-drag effect is best seen in the Mokhungo-Noroyan River area, where the combination of regional westward dip and steep eastward dip due to drag on the southern end of the Kito Pass Fault has produced a topographically expressed syncline in the trachyte (see Part IId).

(iii) Sedimentary intercalations

These are almost entirely restricted to the successions exposed in the eastern inliers and comprise two main facies associations: (a) epiclastic-feldspathic with fossil vertebrates, and (b) pyroclastic, generally unfossiliferous.

The fossiliferous facies is well exposed at Kasigoryan, one and a half miles north-west of Yatya. Here, over 90 feet of silts, sandstones, feldspathic tuffs, argillaceous pumice-tuffs and one lens of fine conglomerate are exposed. In overall lithology these sediments resemble the finer-grained facies of the Ngorora Formation. At Kasigoryan the most prominent bed is the lens of cross-bedded fine conglomerate or grit of phonolite and tuff pebbles and feldspar clasts. This bed, 40 feet in exposed extent, with a maximum thickness of 4 feet, is well indurated by iron oxides and where the underlying softer sediments have been removed by erosion large bones can be seen projecting from the base of the conglomerate. Vertebrate fossils are also found in the fine-grained silts and sandstones, fish, crocodile and chelonian remains being often concentrated in very thin beds of limonitic feldspathic sandstone.

The argillaceous tuffs are often silicified to a porcellanous rock, as in the Ngorora Formation.

The Kasigoryan locality is unique in that only here can the fossiliferous sediments be shown conclusively to lie between trachyte flows. At the two other main exposures of this facies, Cheparain in the south and Mpesida in the north, the exact relationships within the Kabarnet Formation are obscured by overstep of younger rocks, tectonism and landslip.

At Mpesida 100 feet of the fossiliferous facies is seen dipping steeply to the NNE off the trachyte mass and is overlain with apparent conformity by the Kaperyon Formation (fig. 21). From this locality the name 'Mpesida Beds' was first suggested for these fossiliferous sediments, but is is preferable to refer to them as 'Mpesida facies', since stratigraphic correlation between exposures is dubious. At Mpesida the sediments resemble those at Kasigoryan, but conglomerates are absent. Fossils are abundant but only reptile and fish remains were found in situ. The matrix of some of the larger mammalian bones is a green porcellanous chert. Near the junction with the trachyte the sediments are very much disturbed and sheared. Mpesida shares with the other outcrops the presence of anomalous trachyte-capped knolls within the outcrop of the sediments. These either indicate the presence of strong intra-formational unconformity or, more probably, are the eroded remnants of ancient landslips.

The Mpesida facies occurs again at Cheparain, south of Rurmoch, where the relationship between sediments and trachytesis again uncertain, but there is much disturbance of the former. Among the usual lithologies very small-scale faulting (100 mm.) occurs in thin-bedded horizons. At this locality the Mpesida facies is overlain by non-bedded primary pumice-tuffs, at least 80 feet thick, containing abundant remains of trees (trunks and ?roots) in position of growth. Some of the trunks are up to one foot in diameter. Most of the plant remains have been calcified but a few are beautifully preserved in silica (2/216); the latter are common as boulders in the stream-bed up to half a mile downstream from the exposure.

The Cheparain tuffs are atypical of the pyroclastic facies, which is more usually water-laid and well-bedded. In point of fact the bedded tuffs are the most common lithology of the whole sediment group, a point which was overlooked in the field due to the greater interest of the fossiliferous Mpesida facies. The pyroclastic facies occurs at Mukur, below the trachyte at Kokwomur, at various localities in the south and is most widely exposed to the west of Yatya where bedded pumice-tuffs and pumice-lapilli agglomerates occur in a slightly faulted succession with trachyte. The Mpesida facies, well-developed at Kasigoryan, is not seen here and is possibly the lateral equivalent of the pyroclastic facies.

However, there is no doubt that at Cheparain the primary pyroclastics overlie the Mpesida facies and are themselves overlain by a very fine-grained thin-bedded white tuff, exposed beneath the trachyte on the south-east corner of the Rurmoch mesa.

The most westerly outcrop of Kabarnet sediments is on a small knoll on the lower mesa of Sumet. Here 15 feet of sediments comprising, from the bottom, grey bedded tuffs, pumice-agglomerates and yellow argillaceous tuffs crop out on the north-west side of the knoll (182950) which is capped by large blocks of trachyte, presumably representing the remains of a higher flow. This outcrop is significant in enabling a correlation to be made between the lowest flow at Yatya, demonstrably overlain by sediments, and the single flow of Sumet and Mokhungo. While they may not be the same flow (however, in view of the extent of flows on dip-slope, they probably are), it is possible to say that the sedimentary horizon may be extrapolated to a position between the two main flows of the upper dip-slope.

Environment

The similarity of the Mpesida facies to the Ngorora Formation type-section facies has been noted; the analogy can be extended to a comparison of the typical Kabarnet pyroclastic facies with the Poi tuffaceous sandstones. However, in the Kabarnet sediments there is no obvious spatial relationship between the different facies as there is in the Ngorora. A further interesting feature is that in the thickest sections observed in both Kabarnet sediments and Ngorora Formation, at Cheparain-Rurmoch and Kabarsero respectively, the top of the succession is dominated by similar white laminated tuff lithologies.

It follows that the Kabarnet sediments indicate an environment similar to that of the Ngorora Formation, but with less powerful and widespread fluviatile deposition. The present conditions around Lake Tilam, below Pakka volcano on the plains of the rift centre represent a similar situation: a volcanic plain floored by lavas has been slightly faulted allowing alluvial deposition over the whole surface and, to a greater thickness, in fault-bounded depressions. If minor explosive volcanism were prevalent at the present time much of the alluvium would naturally be of pyroclastic material, as it is in the Kabarnet sediments. The presence in the latter of epiclastic conglomerates and 'grits', together with the remains of aquatic vertebrates, indicates a more permanent fluviatile regime in addition to the redistribution of local pyroclastics.

2. Kaparaina Basalts Formation

This formation comprises basal fossiliferous sediments (the Lukeino Member), a large number of basalt flows and, in the upper part, prominent flows of trachyte. It attains a maximum thickness of 1200 feet in the thesis area where it accounts for most of the geological map to the east of the main scarp faults. In that area the outcrop forms a gentle faulted anticline, which is a simple continuation from the Kaparaina range (from which the formation was first proposed by Martyn in 1966) to the south. Both Martyn (op.cit., p.80) and Lippard (Ph.D. thesis in preparation) have found outliers of Kaparaina basalts on Kabarnet Trachyte on the crest of the Kamasia between Kabartonjo and Tenges, but the formation is not seen to the west of the main scarp faults in the present area. On the northern edge of the present area the Kaparaina is overlain by the lavas and tuffs of the Ribkwo volcanic complex and no definite correlations have yet been made with other formations further north.

(i) Lukeino Member and Rurmoch Dolerite

A sedimentary member characterized by certain distinctive lithologies but varying greatly in both facies and thickness (fig. 19).

From the southern border of the area to the Tegit inlier there is a distinctive basal facies, comprising bedded fossiliferous epiclastic and pyroclastic lithologies with an abundance of ferruginous cementation and alteration. The lowest beds are reddish-brown feldspathic sands with many limonitic concretions and 'boxstones'. These can be shown at the Kapgoyo locality (208899) to lie with slight disconformity on faulted trachytes and sediments of the Kabarnet Formation. The red sands strongly resemble the present-day weathering products of the trachytes and the sands are accordingly ascribed to the same process. These ferruginous basal beds continue to the south of the area and Martyn (op.cit., p.230) gives chemical analyses showing that they are certainly trachyte weathering products with, compared to fresh trachyte, a decrease in SiO_2; increase in Al_2O_3, iron oxides and H_2O; the red coloration is caused by free Fe_2O_3.

In the area west of Rurmoch the red sands are succeeded by similar but poorly bedded yellow-brown sands, consisting chiefly of decomposed lava débris; again, ferruginous veins and concretions occur. These are overlain locally by a bedded white siderite/calcite rock, probably replacing the white diatomaceous lithology which occurs as thin beds

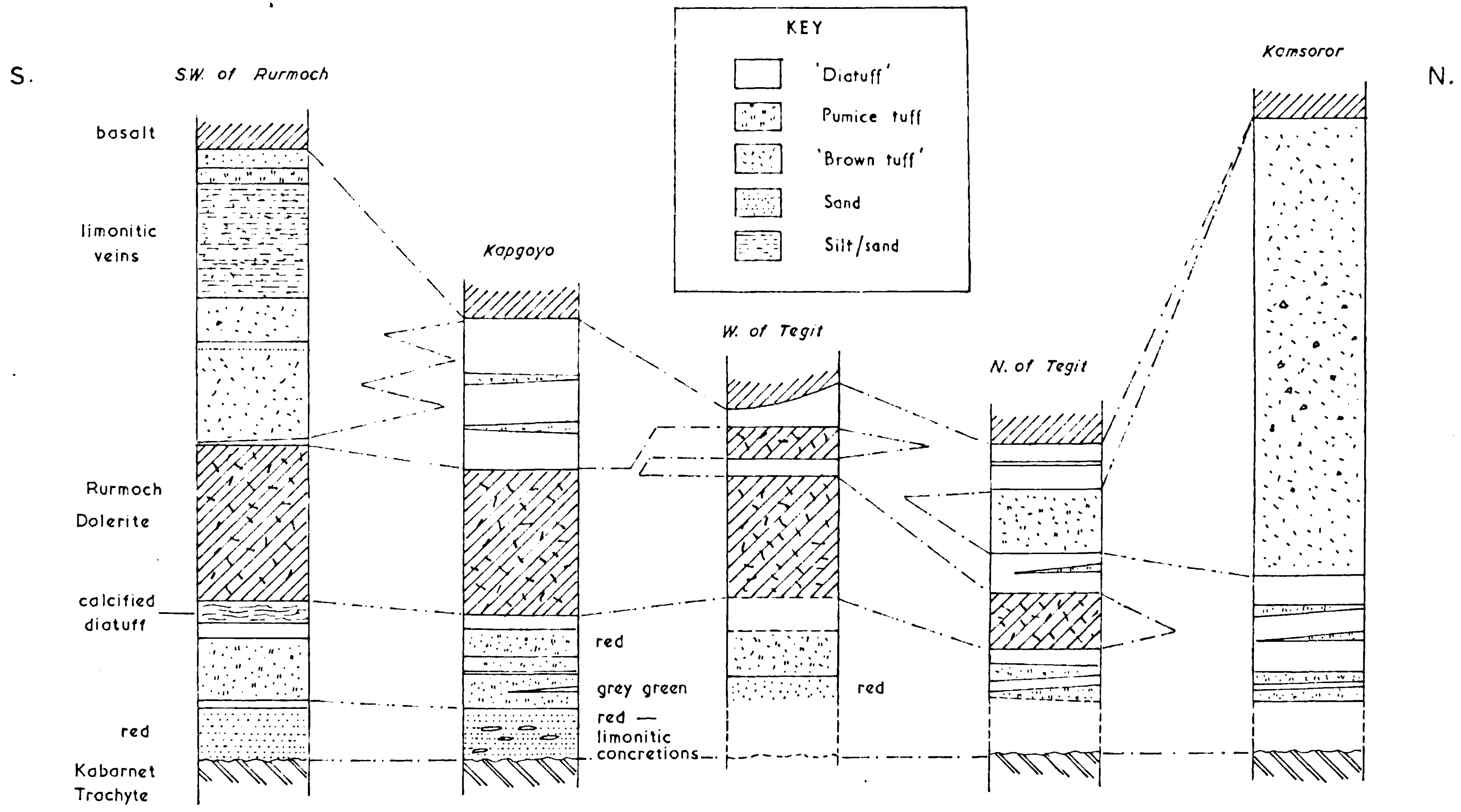


FIG 19 SECTIONS IN THE LUKEINO MEMBER AND THE RURMOCH DOLERITE (1" = 50')

throughout the whole member. At Kapgoyo the red sands are overlain by grey, green and yellowish fine sands and silts rich in vertebrate remains, hippo being especially abundant.

The basal beds are not well exposed further north but the typical red silts and 'diatuffs'* are seen in the road to the north-west of Tegit, and the yellow-brown weathered tuff in contact with Kabarnet trachyte on the west side of Tegit is also interpreted as basal Lukeino.

Rurmoch Dolerite

This unit usually divides the lower ferruginous/epiclastic beds of the Lukeino Member from the upper predominantly tuffaceous facies. The rock is a porphyritic dolerite, large feldspar phenocrysts in 'trachytic' orientation being prominent but with pyroxene and olivine commonly also present. The groundmass is usually fine/medium-grained and ophitic but in the Tegit area a feldsparphyric variety with fine-grained ground-mass comprises the upper part of the unit. The rock displays good spheroidal weathering which together with the abundance of large phenocrysts facilitates field recognition.

On Rurmoch peak itself basalts total 400 feet in thickness but here aphyric petrologies appear both above and below the feldsparphyric dolerite. The lower aphyric unit is probably the basalt dividing the Lukeino Member in the Sibillo area to the south where the feldsparphyric dolerite is absent (Martin op.cit., fig. 30). The feldsparphyric dolerite has a thickness of 150 feet on Rurmoch and thins very gradually northwards to a poorly-exposed section of 15 to 20 feet north of Tegit.

In the section in the upper Kobuluk River (248943) and west flanks of Tegit, two feldsparphyric units (not separated on the map) are seen within the Lukeino Mekber. The writer suspects that this unit may in

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* Various argillaceous well-bedded whitish sediments occurring in many formations are comprised of both primary volcaniclastic material and biogenic silica in the form of diatoms; hence 'diatuff' - a 'sack' term.

fact be entirely intrusive in view of the porphyritic doleritic texture, lateral persistence with very gradual thinning and sudden appearance of two separate units near Tegit, suggesting splitting-up of the intrusion near its extremities. However, in the rare exposures where the contact with sediments can be seen there is no sign of a chilled upper margin, discordant contacts, or baking of the country rock. On the other hand neither is there any of the marginal vesiculation, autobrecciation and weathering which characterises extrusive flows, and an intrusive theory of origin is generally more satisfactory.

Above the Rurmoch Dolerite in the south a further 110 feet of sediments occurs, composed largely of a brown ferruginous friable rock containing weathered lava fragments and feldspar crystals. This is sometimes well-bedded in units 6 inches to 1 foot thick. It appears to be a polygenetic rock, but derived chiefly from extreme weathering of basaltic lapilli-tuffs. It crops out well to the south of the thesis area in the region of the Kaichurot volcanic centre where it passes into basaltic agglomerate (Martyn pers.comm.). It is seen again in the lower beds around Tegit and returns in force in the Kisitei area where it contains a high proportion of pumiceous tuff and some blocks of trachyte. Sections up to 10 feet in thin weathered tuff lithology occur also in the Chepkow river valley in the east.

The most northerly exposure of Lukeino Member is the bedded brown tuff of the upper Kateli River, attributed to this member entirely on lithological evidence, in a tectonically complex situation. (At Mpesida, south of the brown tuff section, the pre-Kaperyon surface was on Mpesida facies of the Kabarnet sediments, dipping northwards; presence of the basal Kaparaina further north is thus not unlikely.)

Figure 19 shows that the sudden increase in thickness of the Lukeino Member in the north and south is associated with the occurrence of the brown tuff lithology.

Within the brown tuffs occur thin beds of 'diatuff', green and grey tuffaceous silts, rare feldspathic sandstones and pumice-lapilli agglomerates. In the central Kapgoyo-Tegit region the upper beds are dominated by well-bedded sub-aqueous lithologies; white massive diatomites (2/244) and diatomaceous paper shales are particularly characteristic.

Diatomaceous sediments and bedded green tuffs and silts also occur around Kokwomur and Kisitei but are subordinate to the brown tuffs. In the Kisitei area beds of calcified tuff occur 200 yards south of the drift, dipping steeply away from the trachyte. In thin section these are seen to be composed of calcite (90%) replacing fibrous pumice, with relict unaltered plagioclase crystals.

At the confluence of the two main branches of the Kobuluk River (248943) aphyric fine-grained basalt lies on eroded white paper-shales. This may be only a local unconformity but it is possible that a discontinuity at this level would account for the absence of Lukeino Member around the foot of Kukwaderr. Since the Lukeino does occur on top of the Yatya fault-arch structure, around Tegit (although thinner) and in the Chepkow valley to the east of the fault-arch belt it is likely that it was in fact continuous over the whole area and entirely preceded basalt extrusion. This contrasts with the situation further south where Martyn postulates a lake basin bounded by the Kamasia escarpment in the west and dammed by early lavas of the Kaichurot centre in the east. Martyn (op.cit., p.83) records boulders of 'Saimo Phonolites' (Sidekh Phonolites) in a 'piedmont facies' below the Saimo escarpment, proving that at the time of Lukeino deposition throw on the Saimo Fault already amounted to 3000 feet, giving an escarpment at least 1500 feet above the basin of deposition.

True lacustrine conditions certainly existed at times in the present area, and evidence of sub-aqueous deposition occurs regularly throughout the succession. Abundance of hippo among the fossils of the basal beds adds further to the environmental picture.

(ii) Basalts

Between 20 and 30 basalt flows make up the bulk of the Kaparaina Formation in the present area. Martyn (pers.comm.) recorded up to 40 flows in the formation in the Kaparaina Range to the south. The following types can be distinguished in the field:

1. Porphyritic - common plagioclase and olivine and rare pyroxene phenocrysts: This is the most typical porphyritic type and is black in colour when fresh; it is often referred to in the writer's field notebooks as the 'Kateli type' since it was first encountered in the Kateli River section. The density of phenocrysts varies - phyric pyroxene is absent from the more sparsely porphyritic varieties.

2. Porphyritic - very abundant phenocrysts of olivine, augite and plagioclase: Distinctly more phenocrysts than the 'Kateli type' and very fresh; the overall colour in hand-specimen is paler than the 'Kateli' type. The type is very rare, and was observed at only two localities, one just to the east of Chemolingot hill, the other near the base of the basalts in the Yatya river section.

3. Feldsparphyric: Large (up to 15 mm.) plagioclase phenocrysts in a fine-grained grey groundmass. Other phenocrysts are rare or absent. This type is less common than the 'Kateli type'. Certain of the Rurmoch Dolerite lithologies resemble this type in the field but are distinguished in thin section by the abundant ophitic brown augite.

4. Aphyric, fine-grained: These include olivine-basalts, basalts and rare hawaiites. In total bulk they equal the porphyritic types. The type is often deeply weathered to a pink, purple or pale grey colour and in the hawaiite (identifiable only in thin section) may have a sub-trachytic fissility.

5. Sparse small phenocrysts, fine-grained, fissile: This type comprises hawaiites and mugearites, and is relatively rare. They rather resemble

dark trachytes in hand specimen, but are distinctly heavier. Thin-section examination suggests that the Kamsoror rock (mugearite), at least, may be of hybrid origin.

6. Aphyric, fine/medium grained: Only one example is known of this type, from near the base of the formation in the Kamsoror-Chepochom area. It is, in the field, noticeably coarser in grain-size than most basalts and thin-section examination shows it to have a doleritic (ophitic) texture. It was not possible to determine the field relationship of this rock but the Nginyang Basalt (Part Ic) proves that ophitic textures can be found in surface flows as well as in sills. It is an unusually hard rock.

Individual flows vary from 10 to 40 feet in thickness; they cannot be traced laterally with certainty for any great distance. For this reason flows were not mapped individually within the Kaparaina Formation, but the map indicates outcrop features, from both photo and field observation, which serve to elucidate the structure in certain areas.

Many flows become very vesicular and amygdaloidal near their tops, amygdales being usually filled by calcite.

Polygonal jointing is often well-developed (pl. 19).

Development of red 'bole' between flows, particularly well seen in the Cheptopokwa River section, is evidence for considerable time intervals between flows; in the Kateli River section 40 feet of bedded red earthy sediments occurs between flows, presumably representing the contemporaneous reworking and deposition of weathered basalt. This bright red intra-basalt weathering coloration, caused by free ferric oxide, is in contrast to the brown hydrated oxides typical of the Lukeino brown tuffs, the sub-Kaperyon surface and present day weathering products.

Deep weathering is a feature of the Kaparaina generally and in this respect they differ from the other basalts of the local Tertiary succession.

An almost rainbow-like range of red, purple, greenish and blue-grey colours occur at exposures giving rise to soils of the same hues which become extremely glutinous in wet weather. To some extent this is due to contemporaneous intra-flow weathering, as described, but it can be ascribed chiefly to the length of time for which the Kaparaina has been exposed to erosion, when compared to the older basic lavas, exposed only in the swiftly retreating scarp slope, and to the younger basalts.

Spheroidal weathering is best developed in the porphyritic 'Kateli' types where on land surfaces it may exceptionally result in weathered-out spheres up to 4 feet in diameter (pl. 21). The porphyritic and coarser-grained basalts are more resistant to recent erosion generally, while fresh specimens of the fine-grained types are more difficult to obtain.

(iii) Trachytes

Porphyritic trachytes form an estimated 8-10 per cent by volume of the formation exposed in the map area, occurring at or near the top of the visible succession. They are characterised by conspicuous rhombic phenocrysts of anorthoclase although aphyric types also occur, for example in the outcrop to the west of Tegit.

The flows can be divided into two groups, associated with two centres marked by trachyte intrusions: the more northerly of the two centres is the prominent 'puy' of Chepochom. One of the most prominent landmarks in the area, this is a quartz-trachyte plug intruded into the lower basalts of the Kaparaina. (Quartz occurs to the extent of 7-8 per cent as lacunae in the groundmass (2/62).)

The bluff to the west of the main peak is capped by fine-grained trachyte over trachytic agglomerate of a total thickness of 100 feet. This is interpreted as a vent agglomerate, probably faulted down from its original position.

No intrusive contact can be demonstrated for either the main peak trachyte or the agglomerate, the flanks of the hill being covered by scree, but the overall morphology and anomalous position of the rock, in addition to its distinctive petrology defy any explanation other than intrusion.

Petrographically the Chepochom rock can also be matched with the trachytes cropping out on the plain to the west of Nginyang and on the hill Adonyasas; this group commonly contain a little quartz as groundmass lacunae, together with biotite and common hornblende. The most conspicuous mafic mineral in both the Chepochom rock and the flows is a pale green 'diopsidic augite' occurring as corroded phenocrysts with a brownish rim.

The southern group of trachytes are, in contrast, either saturated types, or undersaturated types with a little modal nepheline represented by turbid pseudomorphs rimmed by mafics (2/146). These attain a maximum thickness (2, possibly 3, flows) of 300 feet on Chepuromoi, where a pointed buttress on the western face of the hill is also interpreted as a plug, in this case much finer-grained than the Chepochom rock.

Forming, as they do, some of the highest members of a deeply eroded succession it is difficult to estimate the original extent of these trachytes but it is probable that the hill-masses of Ketan and Chepuromoi owe much of their resistance to erosion to the local presence of trachyte flows related to the Chepuromoi plug. Trachytes also outcrop extensively near the top of the Kaparaina succession around Sibillo (Martyn op.cit., p.90) where they are overlain by further basalts (this relationship cannot be proved in the present area). From their overall sporadic occurrence it is unlikely that the trachytes of the Kaparaina were ever remotely comparable in extent to those of the Kabarnet Formation.

(iv) Stratigraphy of the lavas

The lavas of the Kaparaina show a maximum thickness, in observed section, of 900 feet in the hill-mass of Chepuromoi where the top 300 feet comprises two thick trachyte flows. Presence of the Lukeino Member below this pile is indicated by the extensive exposures of sediments in the Chepkow

River one mile to the north-east. The base of the Lukeino Member is not seen but extrapolating from the observed thickness of 250 feet (including Rurmoch Dolerite) to the west of Tegit the total thickness of the Kaparaina Formation here is not less than 1200 feet. Martyn (op.cit., p.86) records a maximum of 2500 feet in the basalts of this formation.

A red basaltic agglomerate occurs at the base of the Chepuromoi succession and a similar rock outcrops east of Kisitei, beneath Nakipurat hill. This, together with a thin pumice-tuff on Chepuromoi and fine agglomerate beneath the Kamuiton scarp are the only pyroclastics of any significance within the basalt succession.

The Chepuromoi group of trachytes may be traced westwards across the flat-topped hills around Ketan to the plain below Sumet where the highest lava seen is a non-porphyritic trachyte underlain by 600 feet of basalts and Lukeino Member. The latter, divided by the Rurmoch Dolerite, comprises at least half of this thickness and it is apparent that there is a considerable decrease in thickness of the lavas in this area. Similarly sediments make up at least one third of the 900 foot Kaparaina succession to the west of Rurmoch; in this latter area the lavas are porphyritic 'Kateli' type and aphyric basalts, trachytes being absent. The thickness of basalt here is thus comparable to that below the trachytes on Chepuromoi.

In the southern half of the area the first basalt above the Lukeino Member is a very fine-grained aphyric type; at the big loop of the Kobuluk River south of Tegit this rests on an eroded surface of diatomaceous paper-shales (see p. 47).

Accompanying the rapid facies change of the Lukeino Beds northwards from Tegit to the Kisitei area is a change in the basal lava: at the Kamsoror waterfall (usually dry) is seen almost the entire thickness of a sparsely porphyritic mugearite (2/125) with good 'colonnade and entablature' columnar jointing. This rock rests on thin-bedded brown tuffs of the Lukeino Member and also crops out as a low ridge between Chepochom and Kokwomur. The petrology of this lava is matched very closely, both by thin-section examination and chemical analysis (Part Vb), with that of two mugearite dykes in the Kisitei gorge 1½ miles to the north-east.

A doleritic basalt (type (6), above) lies above the Kamsoror mugearite and also crops out by the road below the lower bluff of Chepochom. This is possibly another intrusive unit similar to the Rurmoch Dolerite from which it differs in completely lacking phenocrysts.

The base of the basalts is not identified north of Kisitei. The basalts of the Kateli River plains are porphyritic ('Kateli') types and purple aphyric types, some of the latter being very amygdaloidal, with calcite amygdales. On the east of these plains occur several outcrops of trachyte.

The basalt occurring below the Kaperyon Formation along the Cheptopokwa River on the northern boundary of the area resemble the Kaparaina basalts in all respects and are allocated to that formation by the writer. However, McClenaghan (Ph.D. thesis in preparation) considers them to be below the Kabarnet Formation. The basalts in the mouth of the Mukur gorge certainly appear to be below the Kabarnet trachytes. While conceding that previous workers in the Rift have often confused Tertiary basalts of widely different ages the writer would stress that this area should not be considered in isolation, and considers that the structural synthesis of the area demands a fault to the east of Mukur, downthrowing Kaparaina Formation on the east against Kabarnet Formation on the west. The arguments are elaborated in Part IId.

(v) Associated dykes

There are remarkably few dykes associated with the outcrop of the Kaparaina basalts in the present area, and all occur between Chepuromoi and Kisitei.

The basic/intermediate dykes are all aligned NW-SE or NNW-SSE, which is also the trend of some minor faults in the area. There is little positive evidence to connect them with the Kaparaina basalts, but since the two mugearite dykes of Kisitei are chemically identical to the basal mugearite flow of the Kaparaina at Kamsoror (258997) the association of the other, more basic, dykes on the same trend with the formation seems likely. With the exception of a hawaiite dyke, also near Kamsoror, the remaining basic dykes are all basaltic and usually deeply weathered. A prominent feldsparphyric basalt dyke cutting Kabarnet sediments at Cheparain (2284) may have been connected with the feldsparphyric Rurmoch Dolerite.

Thick trachyte dykes occur on Chepuromoi, two aligned E-W and a third, in the Kobuluk River, trending NNW. The latter is a quartz-rich trachyte, quartz occurring as subhedral microphenocrysts, totalling 15% of the rock.

A remarkable phonolitic type rock (2/113) crops out in the Kobuluk River on the same NNW trend as the basic dykes. In thin section it is seen to be composed of a dark brown glassy vesicular matrix with common large euhedral phenocrysts of ?nepheline replaced by clear analcite. No comparable rock was seen anywhere else in the area.

3. Kaperyon Formation

(i) Sediments

A formation of dominantly pyroclastic sediments, well-bedded and water-laid in the south-west, with diatomites, becoming massive and subaerial to the north-east. MacInnes (in Fuchs 1950, p.163) saw the Kaperyon outcrop near Mpesida and recorded it as 'Kamasia lake beds'. There is also a reference (op.cit., p.164) to what may be Chemolingot hill, which is composed of Kaperyon Formation capped by Ribon Trachyte.

The type section (fig. 20) is on the prominent mesa of Chesoton to the west of the Kokwomur trachyte mass. Here, 480 feet of sediments, including three thin basalts, was measured above the weathered basaltic detritus of the underlying Lukeino Member.

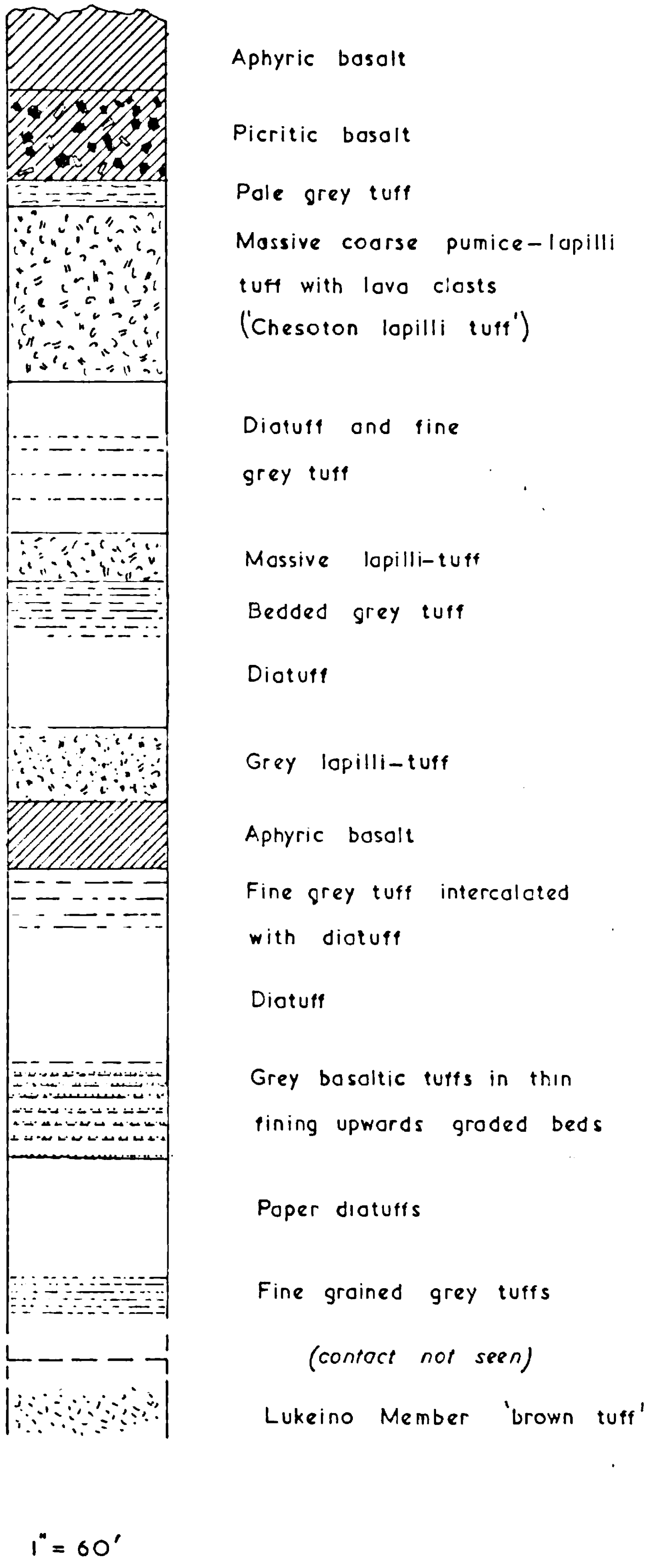

FIG. 20 KAPERYON FORMATION : SECTION ON CHESOTON MESA

The base of the Kaperyon is usually a disconformity. At Chesoton it oversteps the basalts of the Kaparaina on to the Lukeino Member of that formation; in the Mukur area it rests on Kabarnet trachyte, and at Mpesida it rests with apparent conformity on the sediments of the Kabarnet Formation. It would seem that considerable movement and subsequent erosion occurred on the line of fault-arches after the Kaparaina lavas and before deposition of the Kaperyon.

Where the base of the formation lies on basalt there is often a transition from slightly weathered basalt through 'in situ' basalt débris to reworked and bedded basalt weathering products, making the base of the formation difficult to define accurately. On the other hand where the basal Kaperyon rests on trachyte or sediments there is a characteristic basal succession marked by a red-purple earth-bed, cross-bedded greenish tuff and thin diatomites (figs. 21,22). In addition to these lithologies there is, at the Mpesida river localities, a very thin ($\frac{1}{2}$") ostracod limestone (2/27) 5-20 feet above the base (depending on persistence of the other basal beds). At the Mpesida Kabarnet sediments type locality it may be located almost immediately below the lowest thin dolerite sill (fig. 21).

Lithologies in the Chesoton section are divided among 'diatomites', thin water-laid basaltic tuffs and coarse lapilli-tuffs, giving a predominantly grey and white aspect to the succession. The most prominent horizon is a 15 foot thick lapilli-tuff, with basaltic lapilli and scoria up to 1 inch across, which forms a prominent vertical cliff around the hillside. This bed is referred to as the Chesoton lapilli-tuff; it is a good mapping horizon and may easily be traced in the Kaperyon area to the east where it demonstrates the most striking feature of the Kaperyon Formation, namely the change in facies to the north-east (fig. 23). At Likwen the Chesoton lapilli-tuff overlies thick (but very disturbed) diatomites, as in the Chesoton section, but is overlain by a further thickness (60-80 feet) of bedded pumice-tuff, which lithology also becomes

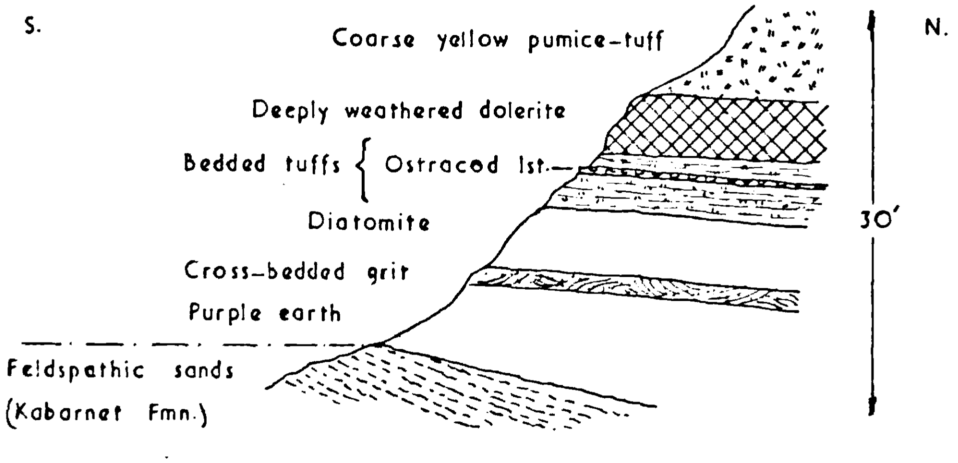

FIG. 21 BASE OF THE KAPERYON FORMATION AT MPESIDA

(FIELD SKETCH AT 275055).

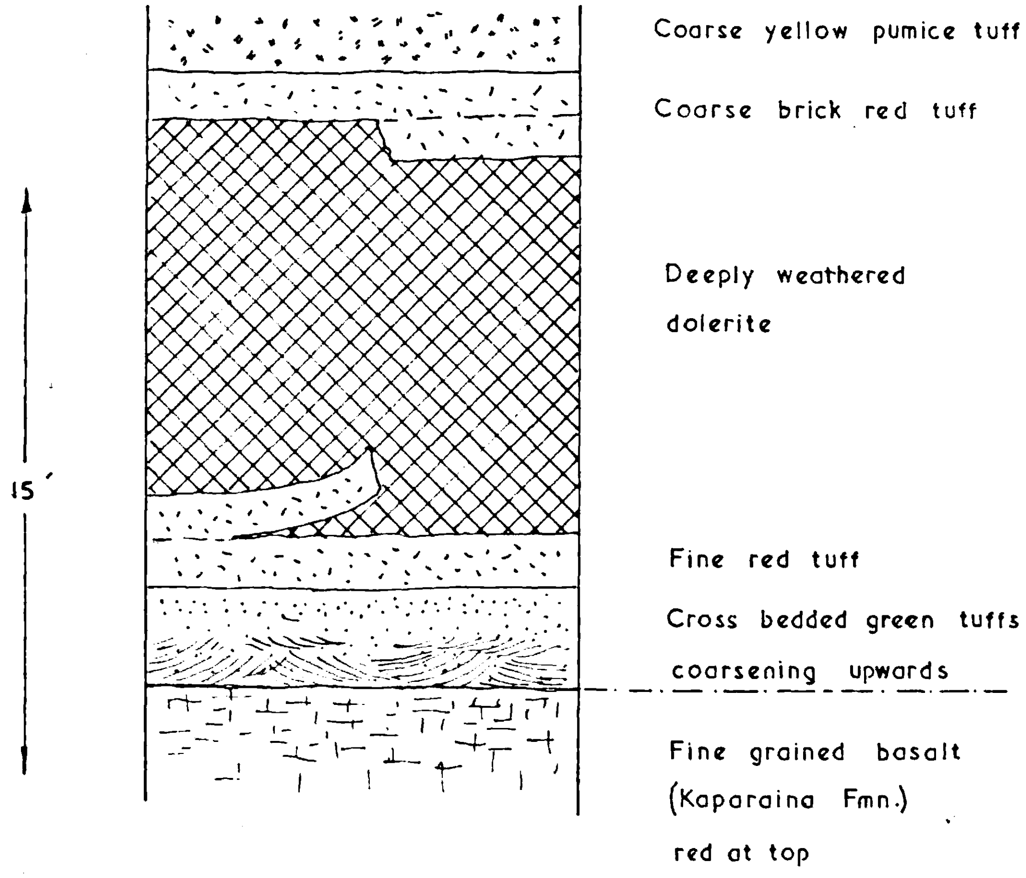

FIG. 22 BASE OF THE KAPERYON FORMATION NORTH OF RIBON (FIELD SKETCH AT 282092)

predominant below the lapilli-tuff as the latter is followed northwards. In addition the lithology of the lapilli-tuff itself alters northwards, the volume of basaltic clasts being gradually augmented by pumice and sanidine crystals.

The southern, or Chesoton, facies persists everywhere as the basal facies of the Kaperyon, even though, as below the northern spur of Ribon, it may only be represented by a single diatomite bed. In the Ribon area the basal diatomite/basaltic tuff facies averages 2 to 20 feet in thickness, the diatomaceous beds often thoroughly silicified to tabular chert, and is overlain by up to 300 feet of coarse poorly-bedded yellow pumice-tuff, composed of fibrous pumice lapilli averaging $\frac{1}{4}$ inch in diameter. In the head-streams of the Kateli River bands of scoria and lava blocks up to 2 inches in diameter occur in the pumiceous facies, and are again seen, widely scattered, in the tuffs below the Katokomta welded tuff to the east. However in the most north-easterly outlier of the Kaperyon, on Chemolingot mesa, large lava blocks of basalt and tuff, in a pumiceous matrix, make up 5 to 10 per cent of the 300 foot succession exposed below the trachyte of the summit.

Silicification, as noted above, is a feature of the Kaperyon sediments and apart from the common whitish chert of the Ribon area, oolitic and pisolitic cherts occur in the upper part of the succession on the Kaperyon plain; there also occur thin limestone beds apparently of diagenetic origin, representing replacement of pumice by calcite, often with relict feldspar crystals (2/101, 2/169). At least 200 feet of water-laid pumice-tuffs overlie the Chesoton lapilli-tuff in the Kaperyon plains and the total thickness in this area is thus not less than 680 feet.

The basin of deposition of the Kaperyon is interpreted as having received clastic material from both an area of persistent basaltic activity to the south and from explosive trachytic sources in the north; the basaltic tuffs are often very thinly bedded and well graded in fining-

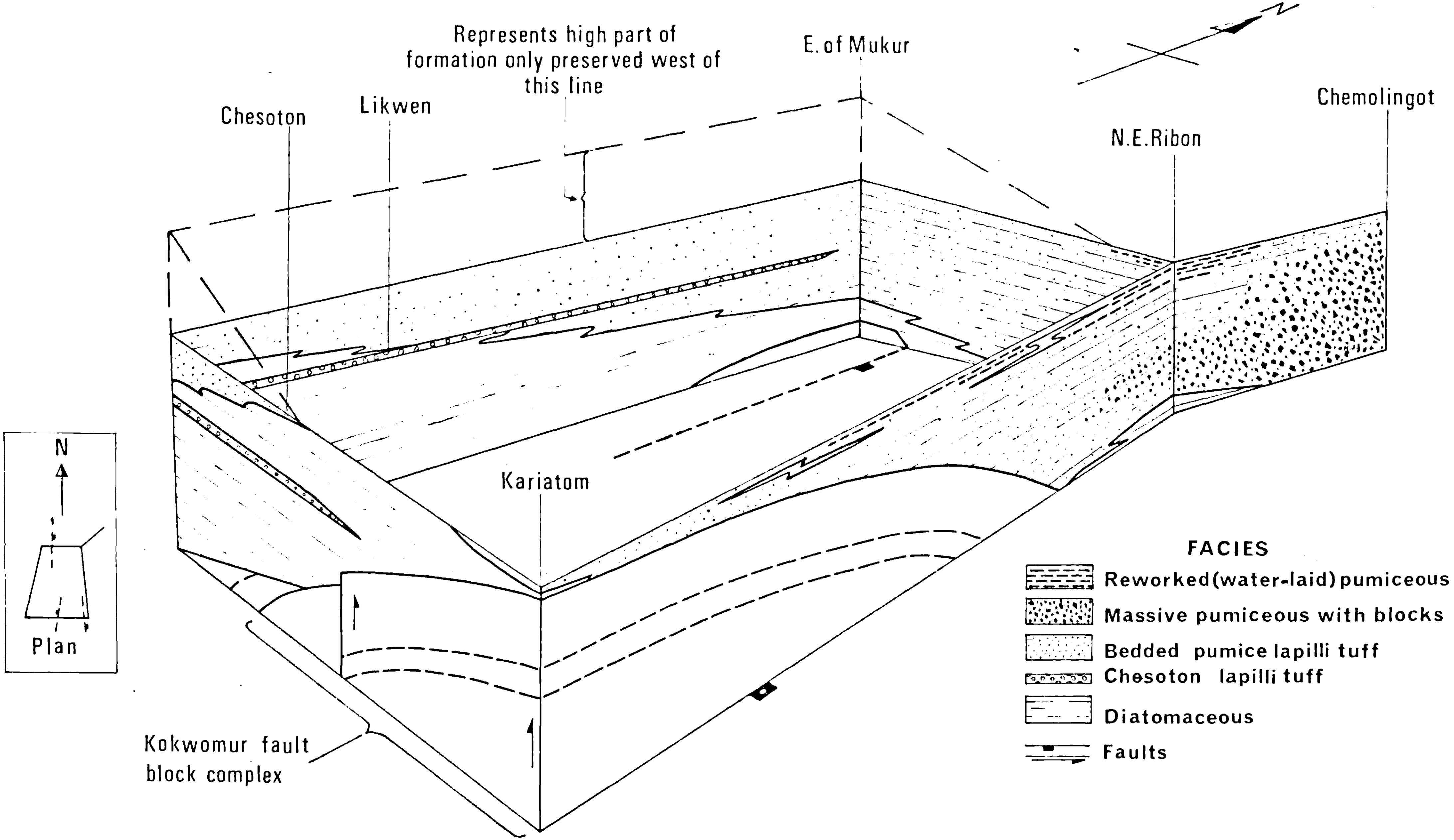

FIG. 23 KAPERYON FORMATION — FACIES DISTRIBUTION

upward units of only ¼ inch thickness (2/161) indicating intermittent, though mild, fall-out from basaltic ash-clouds. This explosive activity was probably the forerunner to the succeeding extrusion of basaltic lavas. In addition authigenic diatomites make up a maximum of 40-45 per cent of the formation in the south-west. To the north and north-east, however, violently explosive trachyte activity predominated, almost certainly in the area of the Ribkwo volcanic complex, and contributed the pumiceous component and large blocks. The basalt blocks of Chemolingot are regarded as the result of the early Ribkwo gaseous activity blasting through the demonstrable basaltic substratum of that volcano.

Although in the west and north thicknesses of the Kaperyon are everywhere comparable, a sudden thinning occurs due east from Chesoton. North-east of Chepochom the Kaperyon thins from over 400 feet to only 10 feet of bedded pumice-tuffs exposed between the Kaparaina basalts and overlying Katokomta welded tuff (= Ribon Trachyte). It would seem that either relict relief or continued uplift on the fault-arch belt restricted deposition in this area (fig. 23). A tiny outlier of diatomite to the east of Kariatom, if correctly ascribed to the Kaperyon, marks the most westerly occurrence of the southern facies.

Northwards from the present area, the Kaperyon Formation interdigitates with, or is overlain by, the Ribkwo trachyte (McClenaghan, Ph.D. thesis in preparation). The blocky tuffs of Chemolingot thin rapidly between two trachytes; north of the Kaperyon plain the sediments are overlain by a trachyte which has formed an extensive landslipped area. Here the sediments are more epiclastic in nature and McClenaghan has found in them the only vertebrate fossils so far known from the Kaperyon Formation.

(ii) Basalts

On Chesoton the Kaperyon is both underlain and overlain by olivine-basalts, apparently conformable with the sediments. The basal basalt and the lower of the two capping basalts are distinctive having large numbers of fresh olivine phenocrysts (2/163, 2/174) and in this respect differ markedly from both the Kaparaina basalts and the Lokwaleibit basalts. The summit basalt of Chesoton, forming a prominent knoll on the plateau surface, is a fine-grained aphyric type.

Apart from a very small outcrop (258051) west of Mpesida and a medium-grained lava, or sill, in the west on the Kiptoisarorr River, no basalts are seen in the Kaperyon plain itself and the local presence of these lavas capping the soft sediments is almost certainly the cause of the Chesoton outlier.

The capping basalts may be the most south-westerly representatives of the Lokwaleibit basalts (q.v.) but the petrologic similarity of the basal basalt and capping olivine-phyric basalts and obvious concordance of the lavas with the sediments indicates that they are more intimately associated with the Kaperyon than with the younger Lokwaleibit flows which post-date the Ribon Trachyte.

Environment

The significant features of the Kaperyon sediments are the evidence for true lacustrine conditions (diatomites and ostracod bands) and predominance of pyroclastic material. Evidence of fluviatile conditions, a feature of the older formations, is absent and it seems that at this time the basin of sub-aqueous deposition was cut off by both tectonic and volcanic activity from the main line of rift-floor drainage.

Movement on the Kito Pass and Sumet faults has affected the Kaperyon Formation; there is a general absence of piedmont detritus in the western outcrop of these sediments, with the sole observed exception of a bed of trachytic cobbles close to the fault-dragged trachyte in the scarp below Kabarsero (fig. 32). Thus, although the Sumet and Kito Pass fault-scarps, in a much subdued form, may have delimited the basin of deposition, they contributed little to the Kaperyon deposition, and the present scarps are largely due to post-Kaperyon movement.

(iii) Yepkarat Dolerite Sill

This intrusive unit has an extensive outcrop within that of the Kaperyon Formation. It invariably occurs near the base of the sediments and can thus be considered as an integral part of the Kaperyon stratigraphy.

In hand-specimen the rock is distinctly coarser than the average basalt with rare feldspar phenocrysts and white amygdales. The abundant olivine is also seen in the hand-specimen and altered zeolites sometimes speckle the rock.

The sill attains its maximum observed thickness of 50 feet at Yepkarat (218078). Here it is underlain by laminated 'diatuffs', typical of the lower Kaperyon, and overlain by coarse pumice tuffs. The fine-grained lower margin of the dolerite has incorporated fragments of baked 'diatuff', and the normally yellowish tuffs at the upper margin have been altered to a reddish colour. The upper margin is also finer-grained and has a very sharp contact with the tuffs, with none of the vesicularity, brecciation and weathering associated with flows. At Yepkarat a narrow more deeply eroded zone in the centre of the sill appears to divide it into upper and lower units. The only obvious difference between the two parts is that small feldspar phenocrysts are slightly more common in the upper part.

In the southern part of its outcrop the sill is poorly exposed but only the fine-grained facies occurs suggesting that the unit is thin in this area (the broad outcrop on the map is largely the result of the very low angles of dip). The isolated oval outcrop, bisected by the Kiptoisarorr River, is of a similar lithology to the type-Yepkarat. It occurs simply as a capping to a low mesa and its relationship to the main Yepkarat outcrop is not known.

The sill, sometimes split into two or more separate units, occurs extensively near the base of the Kaperyon where it is preserved beneath the Ribon Trachyte. It is seldom more than 10 feet thick in this area and is often deeply weathered and friable throughout its thickness. Although the intrusive origin of the unit can be inferred in the type-section by the nature of the upper and lower contacts it was only in one exposure on the north-west side of Ribon that it could be seen to have a local transgressive relationship to the sediments (282092) (fig. 22).

On the low ground to the north of Ribon the dolerite is very deeply weathered and was in fact originally mapped as a pyroclastic. However some excavation reveals spheroidal cores of more or less solid dolerite in the decomposed material.

The sill also occurs as two thin units near the base of the Kaperyon at Mukur (fig. 21), and numerous very thin (50 mm.) sills and connecting dykes are seen in the tuffs between Motimyput and the main Ribon Trachyte.

The dolerite outcrop does not continue very far north of the northern boundary of the map. The emplacement of the Yepkarat Dolerite must have preceded the pre-Ribon faulting of the Kaperyon since it has obviously been faulted and tilted with the latter formation, and was considerably eroded before the extrusion of the Ribon Trachyte.

The two dolerite sills in the present area and that described by Patterson et al. (1970, p.919) from Lothagam appear to be the first substantial basic sills recorded from the East African Tertiary. In fact, basic sills are probably much more abundant than this suggests, but are difficult to recognise in the predominantly volcanic sequence.

(iv) Dykes

The few basaltic dykes which intrude the Kaperyon Formation occur to the north and west of Ribon, and have a north-south trend. Two small dykes on the same trend cut the Kaparaina basalts and trachytes of Adonyasas and may be of post-Kaperyon age.

All the dykes are aphyric, finely vesicular and deeply weathered. None is more than 2 feet thick.

(d) Volcanic group IV - Plio-Pleistocene trachyte group

1. Ribon Trachyte

In the north-east corner of the area are several outliers of a dissected trachyte flow associated with the Ribkwo volcanic complex (trachytes and phonolitic trachytes).

The rock is a microphyric soda-trachyte, microphenocrysts of sanidine being set in a groundmass of sanidine, aegirine, aenigmatite and typical poikilitic mossy arfvedsonite. It is dark green, when fresh, and fissile.

The largest remaining outlier forms the plateau of Ribon (Riribon); the trachyte is inferred to rest unconformably on the Kabarnet trachytes and sediments of Mukur and the Mpesida area in the north and south respectively but where the base is seen, e.g. on the north-eastern spur (the 'elbow'*) the lava lies more or less conformably on the Kaperyon Formation; however, in a stream section on the northern edge of the plateau the base of the trachyte is seen dipping at 45° to the south-west cutting across horizontal bedded tuffs. This is taken to indicate some incision of the '3700 foot surface' (see Part IIIb) before the extrusion of the trachyte.

In the valley between the Elbow and the main plateau the eastern side is in Kaperyon Formation capped by trachyte but the opposite side of the valley is in trachyte (the 'Honey-rock trachyte'). A zone of brecciated trachyte separates fine-grained columnar-jointed trachyte from the sediments, which includes laminated 'diatuffs', dipping steeply (40°) away from the contact. It was at first believed that this trachyte was up-faulted Kabarnet Formation continuing from the Kisitei mass, but petrology, the columnar jointing typical of Ribon, and photogeological evidence of the colour of the outcrop show its true affinities to be with the Ribon Trachyte. It is assumed to be a down-faulted block of the latter (see fig. 24), but the breccias and eastward-dipping sediments remain rather puzzling.

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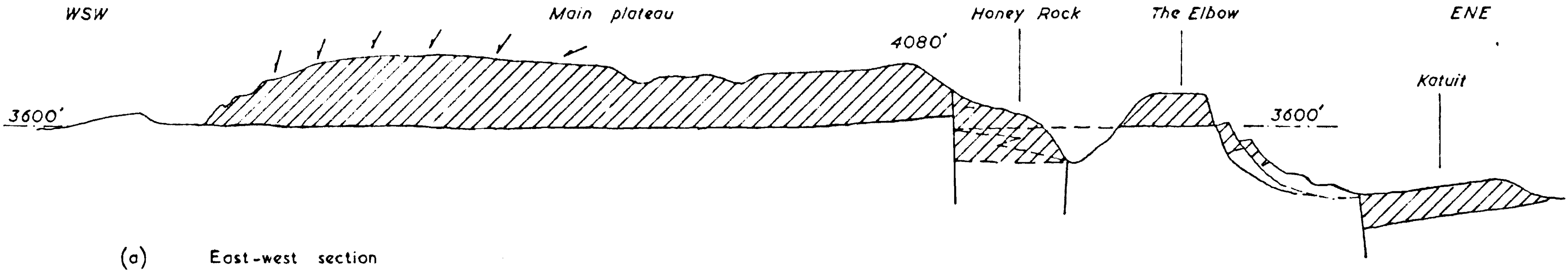
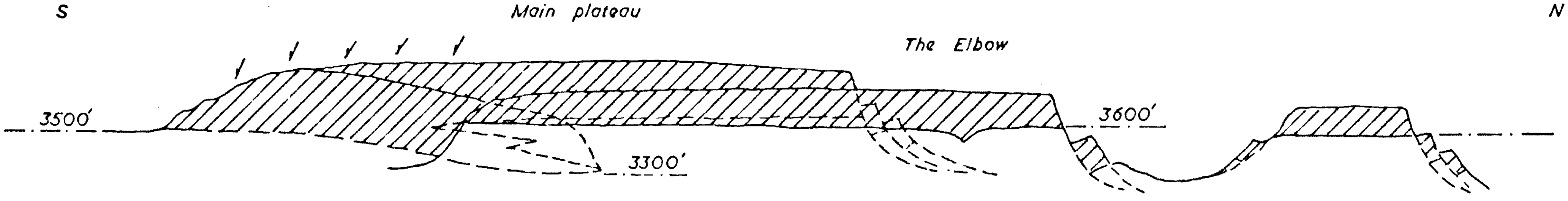
* The local name of this ridge means 'the elbow'.



(a) East-west section



(b) North-south composite section

Scale 1 : 25000, vertical exaggeration x2.   / Dip of fissility, where regular.

FIG. 24 SECTIONS OF THE RIBON TRACHYTE PLATEAU

The base of the trachyte is at 3600-3700 feet in the north falling to 3500 feet in the south and south-west (fig. 24) but as noted, trachyte is seen much lower at 3300 feet in the Honey Rock. A small fault separates the Elbow from the main plateau but west of this there has been little or no tectonic disturbance since the lava was extruded. That the level surface of the plateau in this area is at about 4000 feet is entirely fortuitous and has nothing to do with the '4000 foot summit-level' recognised elsewhere (Part IIIb). Cliffs in trachyte nearly 200 feet high occur in the north but the maximum thickness of the flow is nearer 400 feet (fig. 24).

The most remarkable feature of the plateau surface is a series of sub-concentric ridges in the southern and western area, deeply etched out by stream erosion. This pattern is the expression of a strong fissility which in these areas dips at 70° towards the margin of the outcrop. This feature, by analogy with Quaternary trachyte flows elsewhere in the Rift, is interpreted as a flow phenomenon showing that the lava originated on, or to the north of, the present plateau; the relatively un-eroded southern and western margins, closely paralleled by the fissility, almost certainly mark the furthest extent of the flow. In the north, by contrast, the Cheptopokwa river and (to the north of the map) the Chepanda river have removed large areas of trachyte and Kaperyon Formation, leaving steep-sided outliers which are very susceptible to landslipping of the 'rotational slip' type. Thus on the north and east margins of Ribon vertical trachyte cliffs overlook a series of parallel slip-cuestas composed of lava and underlying sediments, producing topographic and geologic chaos (Part IIIc).

An elongate outlier on the northern margin of the map is at the same level as Ribon, as is also a large mesa* to the north-west, entirely surrounded by a wide zone of slip-cuestas (McClenaghan, Ph.D. thesis in preparation).

To the north-east of the main plateau the mesa of Chemolingot and

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* A singularly suitable word since it is also used in Swahili for 'table'.

the low escarpment of Katuit are the eroded remnants of a down-faulted and westward-tilted strip of Ribon Trachyte. Both these outcrops show good columnar jointing of the lower part of the lava overlain by a structureless portion and at Chemolingot the base of the lava and contact with underlying blocky tuffs of the Kaperyon can be examined in detail.

The lowest few feet of the Katuit outlier has a eutaxitic microcrystalline texture which grades upwards into normal homogenous trachyte lava. Where the succession is again seen half a mile to the south in the Kateli River the eutaxitic rock (the 'Katokomta ignimbrite') and the underlying pumice-tuffs are identical to those below the trachyte of Katuit but the lava itself is absent, the ignimbrite being overlain directly by Lokwaleibit olivine-basalts. The ignimbrite, although only 2½ feet thick, can be traced southwards as far as the latitude of Chepochom where the whole Kaperyon sequence is reduced to 10 feet between the Kaparaina and Lokwaleibit basalts. It can be traced northwards from Katuit and Chemolingot for 3½ miles (McClenaghan op.cit.); it appears that homogenous trachyte and the ignimbrite are in this case the results of the same eruptive event, the more mobile ignimbrite unit travelling well beyond the limits of the lava. Compound units of this type have been described by McCall from Menengai (McCall 1964, p.1188).

The Lokwaleibit Basalts, mentioned above, occur on the south-eastern margin of Ribon capping Kaperyon Formation at the same level as the Ribon Trachyte and within the same structural block, i.e. no intervening faults. The explanation is thought to be that the thin mobile basalt flows flowed around the margins of the thick trachyte flow and in this part of the succession the two lavas are thus mutually exclusive. It can be seen, therefore, that the southern limit of the trachyte can be continued to the north-east by a line separating Ribon, the Elbow and Katuit from the outcrops of Lokwaleibit Basalts to the south-east (fig. 25).

The source of the Ribon Trachyte may be the trachyte plug at Marsapit,

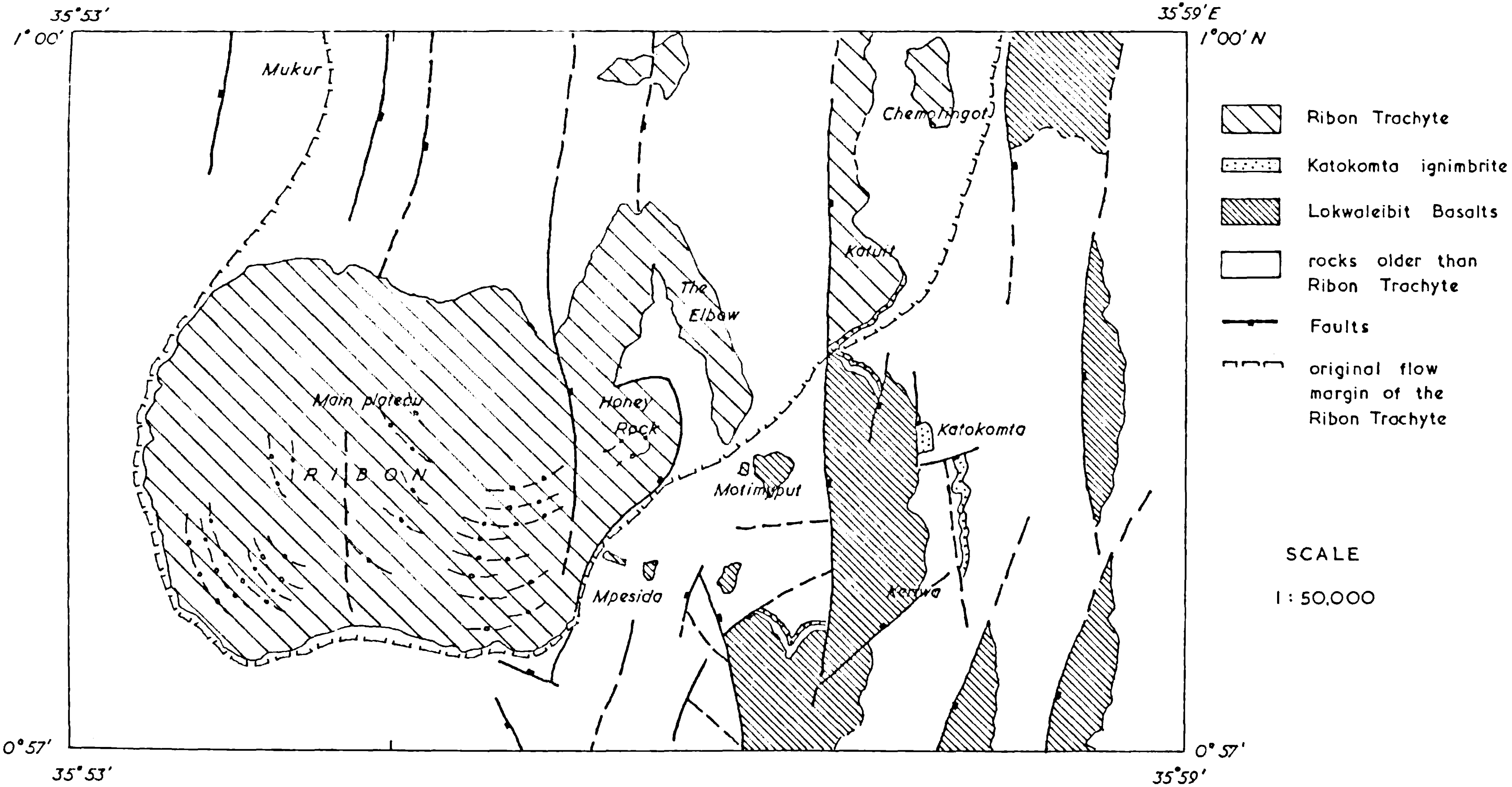

FIG. 25 THE RIBON AREA, SHOWING ORIGINAL BOUNDARY OF THE RIBON TRACHYTE FLOW

3½ miles due north of Ribon near the Kito Pass road (McClenaghan op.cit.). Lava erupted from a source in this position would naturally flow south down the gently-sloping flanks of the Ribkwo trachytic pile. All the Ribon Trachyte outliers are to the south of Marsapit and there is petrologic similarity although in the local context there is not strong evidence either way.

The Ribon Trachyte and Katokomta ignimbrite represent the most southerly manifestation of the trachytic eruptions of the Ribkwo area. In particular the southward extension of the ignimbrite allows some correlation of Ribkwo events with the succession further south.

A recent isotopic (K-Ar) age determination (Snelling, unpublished) gives the age of the Ribon Trachyte as 3.7 ± 0.2 m.y. This is in complete accord with the geological evidence and other age determinations in the area (Part If). However another determination, for the Chemolingot lava, gives an age of 4.9 ± 0.2 m.y. which is unacceptable if that trachyte is to be correlated with the Ribon trachyte. The writer is inclined to give more credence to the younger age, not only on stratigraphic grounds but also because some difficulty was experienced in obtaining an unweathered specimen of the Chemolingot rock, whereas the Ribon specimen is extremely fresh.

2. Lokwaleibit Basalts

A formation of basalts named by McClenaghan (op.cit.) from the Lokwaleibit River area where they are seen to lie on, and are faulted with, the trachytes of the Ribkwo pile.

To the east and south-east of the Ribon Trachyte the Kaperyon Formation is capped by thin olivine-basalt flows which increase in number and thickness eastwards. The basalts are of two types: a fine-grained olivine-basalt with scattered calcite amygdales and rare feldspar phenocrysts and a strongly porphyritic type with feldspar, olivine and augite phenocrysts.

In the Mpesida River - Kateli River area to the east of Ribon two (possibly three - the summit knoll is broken-up lava) basalt flows cap the hill Motimyput, the lower being non-porphyritic, the upper two strongly porphyritic with feldspar, olivine and augite phenocrysts in about equal proportion. On the two isolated hills to the south, above Mpesida, a non-porphyritic basalt caps diatomaceous tuffs of the Kaperyon Formation.

Porphyritic basalt lies directly above the Katokomta ignimbrite at Katokomta. Porphyritic basalt also caps the ridge of hills running south from the Kateli River to Kariatom, usually underlain by a non-porphrytic type, but it is uncertain how much of the succession of at least four flows on this ridge should be ascribed to the Lokwaleibit basalts and how much to Kaparaina basalts. The interpretation shown on the map is based largely on topographic field evidence of an apparent angular disconformity between the almost horizontal summit-knoll, comprising the upper two flows, and underlying basalts with a pronounced westward dip. A steep westward dip is, however, seen in undoubted Lokwaleibit basalts in two tilted fault-cuestas to the east of the Chemotyn River (3003, 3103); here, an upper porphyritic basalt and a lower aphyric type overlie cindery pumiceous tuffs of the Kaperyon Formation in the fault-repeated outcrops. These two ridges, together with the Kariatom ridge mentioned above, must be the 'three lava-fault ridges' crossed by D.G. MacInnes on his traverse westward from Nginyang (Fuchs 1950, p.163).

On the hill of Nakipurat where the Chemotyn River breaks through the Kariatom ridge (290028) after debouching from Kisitei gorge, a section in coarse cindery tuffs is capped by two aphyric, rather weathered and slaggy purple lava flows, but to the south the equivalent of the tuff is difficult to trace in the continuation of the ridge, although the capping of Lokwaleibit basalts is easily recognised by the erosion pattern. The capping of porphyritic basalts of the Lokwaleibit on the very thin pyroclastics of the Kaperyon Formation in the area to the north-east of Chepochom are the most southerly recognised outliers of these lavas. It is possible that the very highest flows of Adonyasas and Cheporomoi are of this age but neither of those hills shows the characteristic erosion pattern of the younger basalts.

Where, as in the Kariatom area, the Lokwaleibit basalts rest directly on the petrologically identical Kaparaina Basalts, or on very thin and therefore usually concealed Kaperyon Formation, the characteristic lobate erosion pattern of the younger lavas was used to define their boundaries in photogeological interpretations.

The Lokwaleibit basalts were probably fissure eruptions fed by the occasional basaltic dykes seen to cut Kaperyon Formation in the Ribon area. These basalts attain their maximum observed thickness of 400 feet, representing eight flows, to the north-west of Nginyang (McClenaghan, pers.comm.) where successive flows have overlapped against the Ribkwo trachyte pile and have been strongly faulted with the trachyte. It is possible that the main basalt source was to the north-east of the present map area.

(e) Volcanic group Va - Quaternary lavas group

1. Loyamarok Trachyphonolite Formation

A single flow of trachyphonolite impingeing on the eastern border of the map is the only representative of the Quaternary volcanics in the area. It forms a thickly-bushed gently east-dipping low escarpment or plateau known as Loyamarok (Loiyamarok) from which both the administrative location and the geological formation are named.

The rock is aphyric, dark green when fresh, usually with a trachytoid texture. Vesicular and flow-banded petrologies are common on the surface of the plateau.

The western margin of the formation forms an escarpment reaching a maximum height of 300 feet in the south, which figure also indicates the maximum known thickness of the lava. The peculiar lobate topography of the scarp, little modified by erosion, suggests that this margin approximates to the original limit of the flow. Ill-defined pressure-ridges seen in the south on the aerial photographs are parallel to the outcrop margin and indicate a source near, or to the east of, the south-eastern corner of the map. Just to the north-east of the point at which the boundary of the trachyphonolite runs off the map near Adonyasas a curious palmate lobe in the scarp is interpreted as being caused by mobile lava having broken through a largely-solidified flow-front. A remarkable feature of this lobe is the gently inclined east-west natural causeway connecting it to the top of the plateau by way of a pass in the main escarpment edge.

The base of the Loyamarok Trachyphonolite declines from 3300 feet in the extreme south (Martyn 1969) to 2800 feet near Nginyang, a distance of 16 miles. This is a slope of less than half a degree and probably represents the original slope of the Nginyang erosion surface (see Part IIIb) across which the lava flowed. The base is presumed to be everywhere planar, but is only seen exposed at Alotakok where the Yatya road crosses the Burususwa. Here the base of the trachyphonolite is seen resting on 15 inches of yellow tuff, resting in turn on weathered purple aphyric basalt of the Kaparaina Formation. Other geomorphic evidence (Part IIIb) suggests that this lava post-dates the development of the drainage system and has diverted the original west-to-east drainage northwards in the natural gutter of the present Burususwa valley.

The thickness variation of the lava as indicated by the height of the marginal scarp is only observable in the north-south direction: it thins rapidly in the south (Martyn op.cit., p.134) and more gradually in the north. At Nginyang the low feature is concealed by floods of younger basalts.

The present average dip of the surface of the lava is about 1 degree in a north-easterly direction. This is thought to be due in part to the

original slope of the Nginyang surface, in part (the most dubious factor) to thinning away from the source and in part again to a component of gentle easterly tilting associated with the Quaternary Rift-centre faulting.
Two north-south faults occur between the map-edge at the Nginyang-Marigat road; they have throws of no more than 15-20 feet but the fault scarps, associated with gullies at the foot, are so completely uneroded that their topographic prominence is greatly disproportionate to their geological significance.

An isotopic (K-Ar) age of 0.5 m.y. for the trachyphonolite confirms its youth. It is interesting in providing an example of an undersaturated salic lava flow comparable in thickness, though not in extent, to the phonolites of the Miocene-Pliocene Tugen Hills Group.

2. Nginyang Basalt

This unit is not on the area of the map, since it lies 1½-2 miles east of the north-east corner, but was mapped by the writer in the field and is described here to complement its inclusion in the petrological section of this thesis.

The basalt is a thin flow which has apparently flowed through the gap between the northern end of the Loyamarok Trachyphonolite flow and the trachyte inliers of the Nginyang trig-station hill. After breaking through to the Burususwa it obviously flowed down the valley of that river and its present extent approximates to its original limits.

It has a very distinctive diktytaxitic texture, and is much paler grey than the average basalt. This type occurs extensively among the Quaternary lavas of the area as a whole (Martyn 1969, p.137; Sceal, Carney, Griffiths, pers.comm.) but is never seen, without any known exception, among the older basalts of the Pliocene and Miocene successions.

(f) Regional correlation and isotopic (K-Ar) ages

All available K-Ar ages from the Kamasia succession are plotted against the stratigraphic column in figure 26 to give an approximate time-curve for accumulation. Details of the isotopic ages are given in table . It will be seen that, with one exception, all determinations are on salic lavas with high potassium contents.

Tugen Hills Group (Volcanic group II)

The isotopic ages for this group emphasize the conclusion from stratigraphic considerations that the group II phonolites in the Kamasia cover a greater time-span than those on the Rift shoulders. Figure 8 illustrates the correlation of the Kamasia succession with that on the Elgeyo Escarpment. The date of 14.3 ± 0.5 m.y. for the basal flow of the Tiim Phonolites, a distinctive trachyphonolite (2/315), is comparable to the dates of 13.6 ± 0.6 and 13.5 ± 0.3 for the flow above the basal flow on the Elgeyo at Tambach* (MB/8, Bishop et al. 1969, p.683); in the latter the basal flow is also a trachyphonolite.

Basaltic lavas and pyroclastics occur between the phonolites and the basement on the southern Elgeyo (Walsh 1969, p.15), and on the Kamasia directly underlie the dated trachyphonolite. These basalts can probably be correlated with the widespread group I Miocene basalts in Turkana (Joubert 1966) and on the eastern side of the northern rift (the Samburu Basalts of Shackleton 1946, Baker 1963, McCall 1967). Thus, the basic lavas in the Tugen Hills Group may, in fact, represent a thin intercalation of group I. However they are underlain by a further considerable thickness of phonolites, very similar to those above the basalts. These are the Sidekh Phonolites from which two K-Ar ages are available, of 14.4 ± 0.5 and 16.0 ± 0.6 m.y. These ages are quite acceptable on stratigraphic

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* Correct position of the dated flow (MB/8) determined by S.J. Lippard.

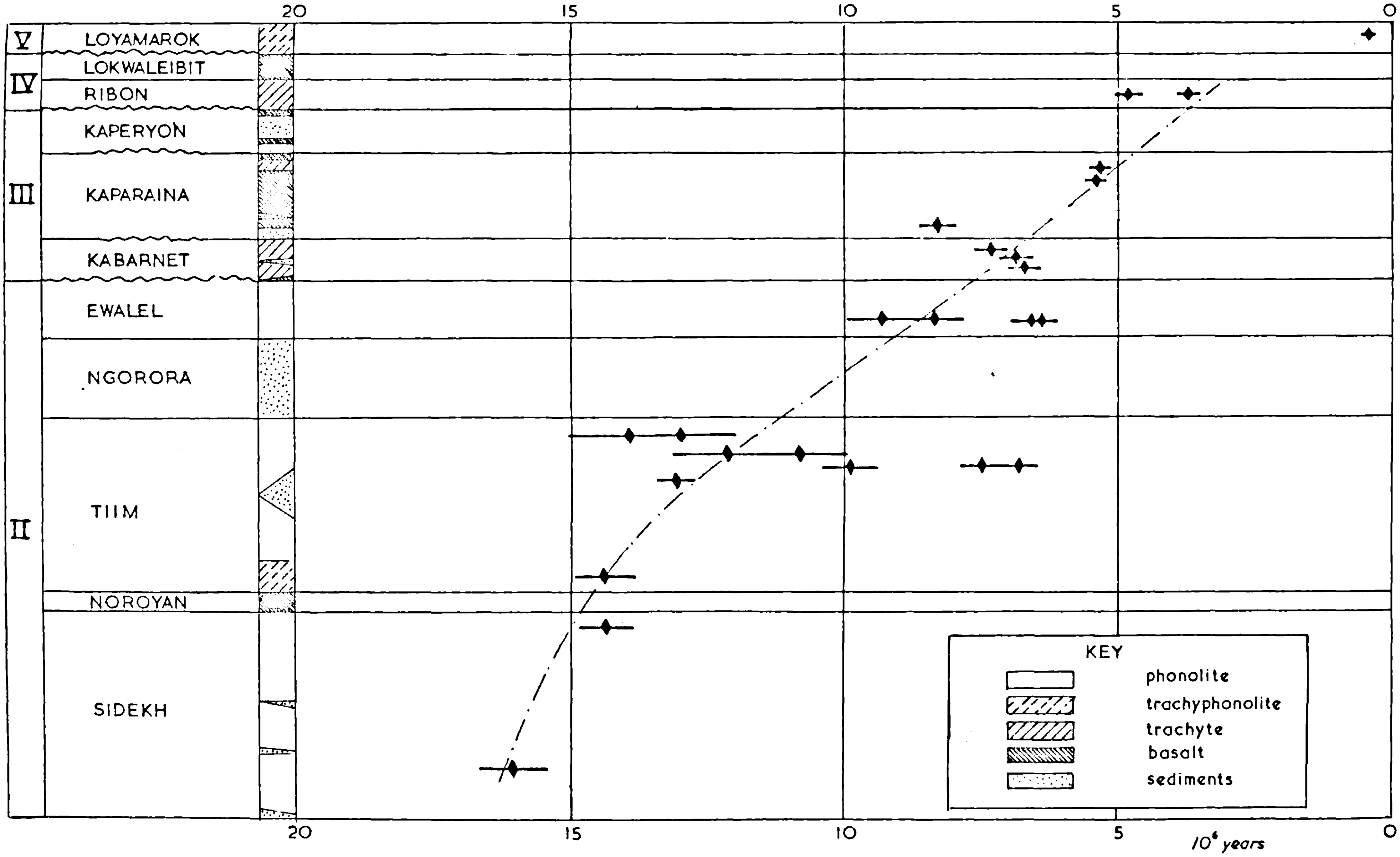


FIG 26 ISOTOPIC (K-Ar) AGES FROM THE KAMASIA SUCCESSION

grounds and it appears that in this area the lowest group II phonolites are roughly synchronous with some of the group I basalts of other areas. In the Kito Pass and Tiati areas (McClenaghan op.cit.) basalts do occur beneath the Sidekh Phonolites and become thicker northwards into Turkana (Webb op.cit.).

Of the remaining Tiim Phonolite ages, those from the Kamuiton Phonolites Member of the writer's area (WB/10, WB/12), of 11 to 13 m.y., are within the accepted range of the 'plateau phonolites' (group II), as also is 1/368 (13 m.y.) from near Kabarnet. However the ages of JM/474 and JM/346 are unacceptably low in view of the Kabarnet Trachyte ages (q.v.) from much higher in the succession. The anomalies may be caused by secondary calcite and zeolites which tend to occur in all these older phonolites.

The dated samples of the Ewalel Phonolites are all from the Sumet Phonolite Member in the Chepkesin-Yatya area. Although this unit appears to be a single thick (600') flow, there is some disparity in the dates. WB/11 is obviously too low (possibly due to high gas pressure in the extraction line - J.A. Miller, pers.comm.), but 2/214 and WB/13 indicate a possible age between 7 and 9 m.y.

The palaeontologically important Ngorora Formation (Bishop and Chapman 1970) is thus dated at between 11 and 9 m.y., which age appears to be supported by the fossil vertebrate evidence from the formation.

Volcanic group III

Kabarnet Trachytes

In view of the eminent mappability of this formation the close grouping, with small quoted errors, of the isotopic ages is especially useful. The rocks are leucocratic lavas composed chiefly of sanidine, with very little alteration or secondary mineralization, and the dates are regarded as very reliable.

Although they rest directly on the Tugen Hills Group over most of the Kamasia, at the extreme north and south of their outcrop the Kabarnet Trachytes form a tongue within the basalts which more usually overlie them. In the southern Kamasia (Lippard, Ph.D. thesis in preparation) and north of Tiati (Webb, op.cit.) the group III basalts lie directly on the Tugen Hills Group; it therefore seems more reasonable to include the Kabarnet Trachytes with group III rather than to place them on their own, particularly as trachytes again occur near the top of the basaltic sequence (see below).

Kaparaina Formation

This formation is composed chiefly of basaltic lavas but, fortunately, intercalated trachytes are available for sampling near the top of the formation. The age of 2/125, a mugearite at the base of the sequence, is obviously too high, possibly because of the low potassium content of the rock. The trachytes (M5, 2/227) are from widely separated localities but the rock is petrographically distinctive and the dates are thought to be reliable. They coincide with the oldest isotopic ages for the overlying Ribkwo complex (McClenaghan op.cit.).

Other 'plateau' basalts in the rift which should be included in group III are the Laikipian Basalts (Shackleton 1945), the Tirioko basalts (Webb op.cit.), basalts west of Baragoi (Baker 1963) and, in the Magadi area, Singaraini Basalt. It is also apparent that the Simbara series of the Aberdares falls into the same time range (Baker et al., in press). The basalts of the Loriyu Plateau at the southern end of Lake Rudolf may also belong to this group (Rhemtulla 1970, p.67).

Volcanic group IV

Ribon Trachyte

This is a single flow of trachyte and the disparity between the dates of 2/22 and 2/79, from separate outcrops, is unfortunate. The writer is inclined to place more credence in the age of 2/22 (3.7 ± 0.2 m.y.) since it was a very fresh specimen while difficulty was experienced in obtaining an unweathered specimen from Chemolingot hill, the locality of 2/79. Also, the older date does not seem to give enough time between it and the Kaparaina trachyte dates for deposition of the Kaperyon Formation and the subsequent faulting and planation which clearly preceded the Ribon lava.

The Ribon Trachyte is the most southerly outlier of the Ribkwo trachytic pile, one of a number of group IV multi-centre trachytic volcanoes in south Turkana which include the Tirr Tirr trachytes (Baker 1963) and many other complex centres (McClenaghan op.cit., Webb op.cit., Weaver, Ph.D. thesis in preparation). Isotopic ages of these trachytes in the EAGRU mapping area range from 3 to 5 m.y. (Snelling, unpublished).

Volcanic group Va

Loyamarok Trachyphonolite

The isotopic age of JM/52 is compatible with stratigraphic and geomorphological evidence. This lava may be equivalent to part of the Dispei-Lake Hannington phonolites of McCall (1967); those lavas form a complex sequence, older than the Quaternary central volcanoes, but not yet resolved in detail.

TABLE I ISOTOPIC AGE DETERMINATIONS

(All results are whole rock determinations)

K-Ar ages of the Tugen Hills Group (Volcanic group II)

Sample		Locality	Formation	Age
2/214	(1)	Yatya	Ewalel (Sumet) Phonolites	7.1 ± 0.4
WB/11	(2)	Chepkesin	Ewalel (Sumet) Phonolites	6.7 ± 0.7 6.6 ± 0.7
WB/13	(2)	Kamuiton	Ewalel (Sumet) Phonolites	8.4 ± 0.8 9.3 ± 0.9
WB/12	(2)	Kamuiton	Tiim (Kamuiton) Phonolites	12.9 ± 1.3 13.4 ± 1.4
WB/10	(2)	Kabarsero	Tiim (Kamuiton) Phonolites)	12.1 ± 1.2 10.8 ± 1.0
JM/474	(2)	Ngeringerowa	Tiim Phonolites (upper)	7.54 ± 0.52 6.80 ± 0.51
JM/346	(2)	Kipchebor R.	Tiim Phonolites (upper)	9.84 ± 0.47 9.97 ± 0.48
1/368	(1)	Kiplapal R.	Tiim Phonolites (middle)	13.0 ± 0.4
2/315	(1)	Chemoigut R. (Sidekh)	Tiim Phonolites (basal)	14.3 ± 0.5
3/514	(1)	Chepanda Hills	Sidekh Phonolites	14.4 ± 0.5
2/217	(1)	Kamuiton scarp	Sidekh Phonolites (lower)	16.0 ± 0.6

(1) N.J. Snelling (unpublished)
(2) J.A. Miller (unpublished)

K-Ar ages of the Kabarnet Trachytes (Volcanic group III)

Sample		Locality	Formation	Age
JM/734	(1)	Lelyan	Kabarnet Trachytes	7.1 ± 0.3 7.3 ± 0.3 7.3 ± 0.4
2/210	(2)	Yatya	Kabarnet Trachytes (base)	6.8 ± 0.2
1/714	(2)	Lelyan	Kabarnet Trachytes	6.7 ± 0.3

(1) J.A. Miller (Baker, Williams & Miller, in press)
(2) N.J. Snelling (unpublished)

K-Ar ages of the Kaparaina Formation (Volcanic group III)

2/227	(1)	nr. Tegit	trachyte, Kaparaina Formation	5.3 ± 0.2
M5	(1)	Chepanda R.	trachyte, Kaparaina Formation	5.4 ± 0.2
2/125	(1)	Kamsoror	mugearite, basal Kaparaina Formation	8.2 ± 0.4

(1) N.J. Snelling (unpublished)

K-Ar ages of the Ribon Trachyte (Volcanic group IV)

2/22	(1)	Ribon	Ribon Trachyte	3.7 ± 0.2
2/79	(1)	Chemolingot (Nginyang)	Ribon Trachyte	4.9 ± 0.2

(1) N.J. Snelling (unpublished)

K-Ar ages of the Loyamarok Trachyphonolite (Volcanic group Va)

JM/52	(1)	Loruk	Loyamarok Trachyphonolite	0.558 ± 0.560 ±

(1) J.A. Miller (unpublished)

(g) Palaeontology

1. Vertebrates

The writer is grateful to Mr. A. Hill for preparation of the following faunal lists:

TABLE II

Ngorora Formation

PISCES			*Clarias* sp. *Tilapia* sp.
REPTILIA	Chelonia	Pelomedusidae	*Pelusios* cf. *sinuatus*[1]
		trionychid	
	Crocodilia		
AVES		Ciconiidae[2]	
MAMMALIA	Primates	Hominoidea	? hominid
		Cercopithecoidea	
	Carnivora		
	Proboscidea	Gomphotheriidae	
		Deinotheridae	*Deinotherium* sp.
	Hyracoidea		Sp.nov.
	Perissodactyla	Chalicotheriidae	
		Tapiridae	
		Rhinocerotidae[3]	*Chilotherium* sp. *Aceratherium* sp. ? *Brachypotherium* sp.
	Artiodactyla[4]	Suidae	
		Hippopotamidae	
		Giraffoidea sp.	
		Giraffidae sp.	
		Boselaphini	? *Protragocerus* sp.
		Tragelaphini/ Boselaphini sp.	
		Cephalophini/ Boselaphini sp.	
		Caprinae/ Alcelaphini sp.	

'Mpesida Beds' (Kabarnet Formation)

PISCES	Siluriformes		cf. *Clarias/Clarotes* sp.
REPTILIA	Chelonia	trionychid	
	Crocodilia		
MAMMALIA	Proboscidea		*Stegotetrabelodon orbus* (Maglio)
	Perissodactyla	Equidae	? *Hipparion (Stylohipparion)* sp.
		Rhinocerotidae	
	Artiodactyla	Hippopotamidae	
		Bovidae	

Lukeino Member (Kaparaina Formation

REPTILIA	Chelonia	trionychid	
	Crocodilia		
MAMMALIA	Proboscidae	Gomphotheriidae	
	Perissodactyla	Equidae	*Hipparion (Stylohipparion)* sp.
	Artiodactyla	Suidae	*Nyanzachoerus tulotos*
		Hippopotamidae	
		Reduncini sp.	
		Antilopini sp.	

(Identification supplied by: 1. Mr. A. Wood; 2. Dr. A.C. Walker; 3. Dr. D.A. Hooijer; 4. Dr. A. Gentry.)

In addition to the above lists, abundant fish remains and a single crocodilian vertebra have been recovered from the Muruywr Beds (Tiim Phonolites Formation); in these sediments there occur similar facies to the Ngorora fossiliferous facies, and it seems likely that further search for fossils in the Muruywr Beds would be worthwhile. McClenaghan (op.cit.) located fossiliferous sediments, alleged to be Kaperyon Formation, near the Chepanda River, but no vertebrate fossils were found in that formation in the present area.

Within the above assemblages, the oldest, from the Ngorora Formation, shows significant differences from the other two: the Ngorora assemblage has a generally older aspect, particularly with regard to the perissodactyls, which include a chalicothere and a tapir. Equid remains were not found, but are recorded from the two younger assemblages. 'Hippo' remains in the Ngorora are the oldest recorded, anywhere, but are very scarce, in contrast to their abundance in the younger assemblages.

The '? hominid' recorded is a molar tooth crown described by Dr. L.S.B. Leakey (in Bishop and Chapman 1970, p.917) as having some affinities to Kenyapithecus and some to both Australopithecus and Homo.

Fish remains are common as disarticulated bones but Martyn (1969, p.43) found small (80-100 mm.) complete Tilapia specimens in the Kapkiamu Shales (Ngorora Formation).

The Chemeron Formation (McCall et al. 1967, Martyn 1967, 1969) and the Aterir sediments (Webb, Ph.D. thesis in preparation), which have yielded rich vertebrate faunas, are both younger than the units with fossiliferous assemblages in the present area.

The Kamasia succession would be ideal for the application of a strict stratigraphic investigation of the fossil vertebrates. However at present the 'treasure-hunt' technique is still being applied by the majority of palaeontologists in East Africa with resulting chronic uncertainty as to time relationships among geographically separated assemblages. However, taphonomic and palaeoecological studies in Baringo and Turkana being conducted by Mr. A. Hill and Mr. C. Fowler, directed by Dr. W.W. Bishop, may at least help to identify the environmental factor when considering evolutionary significance of the fossil assemblages.

2. Invertebrates and plants

Fossils other than vertebrates are scarce in the present area. Fruit and leaves occur in the Ngorora Formation and in situ tree remains occur in a tuff in the Kabarnet Formation (see p. 42). Diatoms are found in the diatomites and 'diatuffs' of the Lukeino Member and Kaperyon Formation but have not been studied in detail beyond noting that the two units appear to have distinctly different diatom assemblages.

Algal limestone masses occur on the plain of the 'Nginyang surface' south-west of Adonyasas. It is not certain whether these are intercalated in the Kaparaina basalts or of recent origin. If the latter, it seems that the Burususwa valley may at one time have been a shallow lake. Similar algal limestone masses have been found (W.W. Bishop, pers.comm.) on the surface of the Kapthurin Beds outcrop near Lake Baringo.

A thin (15-20 mm.) ostracod limestone occurs near the base of the Kaperyon Formation in the Mpesida area, and McClenaghan (op.cit.) also records gasteropod limestone from this formation. Gasteropod shells were found in recent calcareous tufa in the present area.

PART II: STRUCTURE

(a) Introduction

The structure and tectonic history of the map area cannot be considered in isolation and the writer has drawn freely on the findings of his colleagues, particularly of J.E. Martyn (Martyn 1969), for the purpose of illustration. The writer is well acquainted with the adjacent area, mapped by Martyn, having accompanied the latter in the field, and by reason of the general road network of the Kamasia area.

The Kamasia Range is essentially a tectonic feature, relatively little modified by erosion, formed by large dip-slip movements on dominantly north-south trending faults. The general structure of the Kamasia and the Elgeyo Escarpment was correctly shown by Gregory (1921, p.108) but several later writers have drawn wrong conclusions from less cursory investigations. The metamorphic basement is exposed on the up-throw side of the largest faults but it hardly rises to a level of 5000 feet, less than its average altitude on the Elgeyo Escarpment at this latitude; hence the range must still be considered to be downthrown relative to the western shoulder of the Rift if one assumes that the depression always has been entirely tectonic in origin.

Parity in topographic relief between the range (8203 feet at Saimo) and the shoulders is caused largely by the much greater thickness of Cainozoic layered rocks on the former. This diminution of structural relief by stratigraphic accumulation is a significant effect in the Baringo section of Rift (fig. 4) and probably also in other areas where the thickness of the Cainozoic rocks is not known.

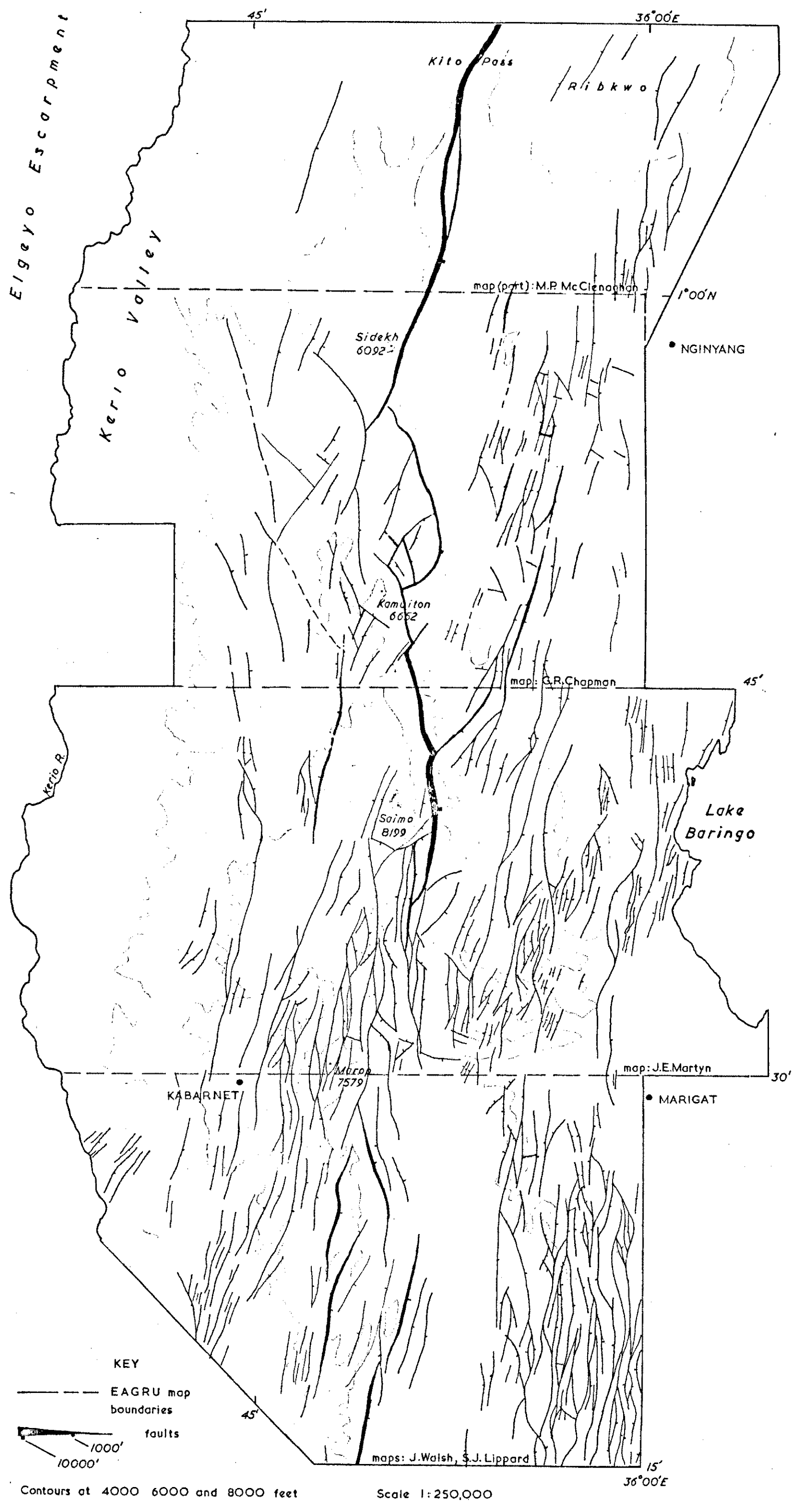


FIG. 27 KAMASIA RANGE : FAULTS AND RELIEF

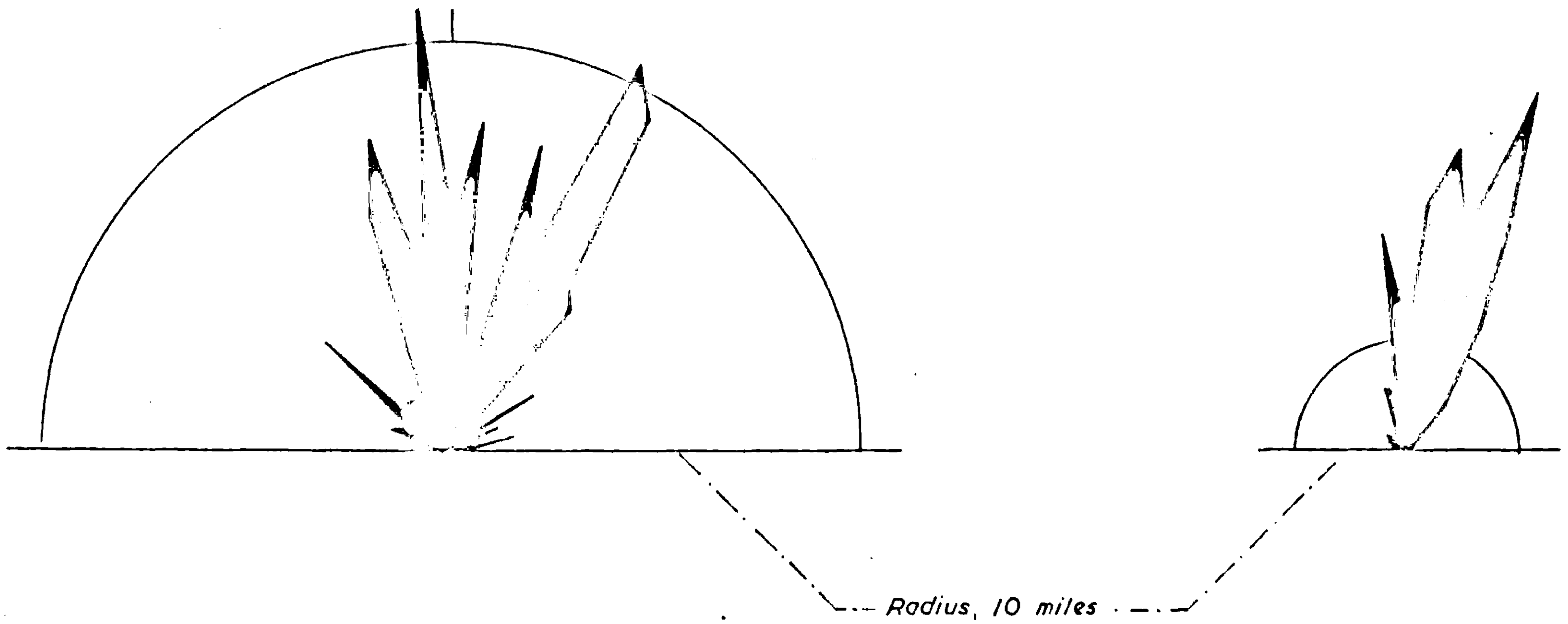
(b) Faults and fault-trends

The map of the faults in the present area (fig. 27) shows the dominance of the NNE-SSW trend to the east of the main range while the main scarp faults, in the south, run almost north-south, with some abrupt divergence in the centre of the area. On the main range and the dip-slope a number of NW-SE trending faults occur. The rose diagrams (fig. 28) emphasize the NNE-SSW trend but it should be stressed that such diagrams show only total length of faults, regardless of throw; many faults of quantitatively insignificant length have very large throws as, for example, in the Sumet area.

The NNE-SSW fault trend is the predominant structural feature between Lake Baringo and Lake Rudolf and reflects the whole orientation of the Rift between these latitudes. It is the prevailing direction of strike of the basement foliation in the Kito Pass-Kolowa area immediately north-west of the present map area (McClenaghan op.cit.) It is suggested that faulting must be at least greatly facilitated by a coincident direction of basement strike, if not actually controlled by it. However, the north-west foliation of the basement gneisses in the small area on the present map is truncated by the Saimo Fault, and Martyn (op.cit.) confirms that this relationship is maintained to the south along the whole outcrop of the Saimo basement inlier.

With regard to the NW-SE fault trend Martyn has pointed out that in many northern areas of Kenya to the west of the Rift the basement is cut by pre-Cainozoic faults trending in this direction (Miller 1956; Jennings 1964; Walsh 1966, p.29; Joubert 1966, p.44; Williams 1966).

Unfortunately, scarcely any fault-planes are well exposed in the present area but those that are confirm the perpendicular relationship between fault-plane and strata observed by Martyn (op.cit., pp.168-172). Sections on the map are drawn, with a few exceptions, on the assumption of this relationship. In the result, it is noteworthy that faults in



(a) West of, and including, the main scarp faults

(b) East of the main scarp faults

FIG. 28 ROSE DIAGRAMS OF FAULT ORIENTATION (Total fault length) horizontal strata, assumed to be vertical, often map out as much straighter lines than those assumed to be dipping (at angles up to 75°). Indirect evidence of fault-plane dip is given by fault-drag structures which indicate dips of 60-70 degrees on the Sumet Fault where the faulted strata are dipping at 20 degrees in the opposite direction.

(c) Structural contour maps

Two structural contour maps have been drawn for the base of the Sumet Phonolite, and for the Kabarnet Formation. Individual features illustrated by these maps are described in the appropriate section of the text, but some general features are noted here:

Firstly, with regard to the methods used: extrapolation in the case of the Sumet Phonolite map involved the assumption of no angular disconformity between the Sumet Phonolite and the underlying succession, apart from the effect of the observed thinning of the Ngorora Formation at the crest of the range. In the Kabarnet map a similar assumption was made of the relationships between Kaparaina and Kabarnet formations; in this case there is, in fact, evidence of slight unconformity, but this is not thought to have a significant effect. The area shown as never having been covered by Kabarnet 'flow 1' was determined by the overlap of 'flow 2' on 'flow 1' in the west, projection of the Kabarnet datum to an intersection with the Sumet datum on the Sidekh dip-slope, and the observed relationship on Sumet mountain. However some doubt remains about the central area around Bartabwa: possibly 'flow 2' crossed the range at this point (but this complicates stratigraphic reconstructions on Sumet); possibly 'flow 1' crossed but was considerably eroded after tilting before the arrival of 'flow 2'.

The results emphasize above all that one cannot, at least with regard to the Cainozoic rocks, think of the tectonics simply in terms of 'blocks' or 'block-tilting', except when considering two-dimensional models or sections. The contours show that although the structure is dominated by faulting, plastic deformation is much more in evidence in this area than descriptions of African rift tectonics usually suggest. Much of the folding may be superficial and brittle deformation may well be more pronounced in the metamorphic basement, but the evidence of the largest faults shows that large-scale flexuring associated with fractures also affects the basement as, for example, on the Saimo Fault which, with a displacement of nearly 4 km., must be a major crustal structure (figs. 37,38). The 'half-dome' and 'fault-arch' structures between Yatya and Mukur are also considered to be deep-seated in origin, but, at the end of the scale, the very steep dips on the down-throw side of the major faults are almost certainly relatively superficial fault-drag effects associated with the presence of thick sedimentary formations in the sequence.

(d) Description, by area

1. The main range

Comparison of topographic and tectonic maps shows that the Kamasia watershed runs practically due north-south and is oblique to the prevailing fault trend. It is for this reason that the range, although a distinct physiographic entity, has west-facing scarps formed by a series of staggered faults which relay the major displacements 'en echelon'. Baker (1958) has described small-scale 'en echelon' faulting with 'ramps' from the Magadi area and King (1970) has recognised this pattern on a large scale as characteristic of the East African rift system as a whole. The present map shows the overlap of two such major fractures, the Saimo Fault (Martyn op. cit.) and the Kito Pass Fault. By judicious choice of route it is possible to walk from the foot of the range in the north of the area to the crest of it in the south without crossing a single fault. The structure along which this theoretical journey would be undertaken is suggested in the field by the outcrop of the Kabarnet trachyte and became known as 'The Gangplank'.

Similar structures are well developed on the eastern side of the Rift in the Ol Arabel river area (Carney, Ph.D. thesis in preparation).

The map cross-sections show the variety of structures in the main range. This includes simple single fault-scarps, as at Sidekh, tilted steps, as in the Sumet area, and asymmetric horsts, as at Kamelon. This last structure is continued southwards as the 'Saimo Horst' of Martyn (op.cit., p.160); its nature is not obvious as there has been no movement on the western boundary fault ('Cherial Fault' of Martyn) since the extrusion of the Kabarnet Trachytes and the fault is largely concealed by those lavas. A number of other small faults of pre-Kabarnet age are exposed in the deeply incised valleys of the dip-slope in the south. By contrast the dip-slope of the Sidekh range in the north is scarcely faulted at all and this area attains the same tectonic relief as the south with shallower angles of dip ($< 10^{o}$). Dips in the Tugen Hills Group attain a maximum in the central/southern part of the map where faults are most numerous. The dip in the Kamuiton section of the main scarp approaches 20 degrees at a maximum and it can clearly be seen to decrease southwards towards Saimo. At the northern and southern ends respectively of the Saimo and Kito Pass faults there is a distinct swing in the strike from the general north-south direction towards the faults accompanied by an increase in dip. The Kapitan inlier of Kamuiton Phonolites is formed by the relative up-faulting of a triangular block at the right-angle intersection of two large faults.

Martyn (op.cit., p.160) states that: 'All the older faulting of the dip-slope region is superimposed on a gentle upwarp which culminates in the north of the area .... The overall uplift is of the order of 2,000 feet. Its culmination coincides with the Saimo Horst to the east ....'. When Martyn's map and the south-west corner of the present map are examined in detail there is found to be positive evidence against this interpretation: the base of the Ewalel Phonolites is at about the same level at Kapchomuswo

(3 miles north of Kabarnet), Kapkiamu and Poi along a NNE-SSW line, 17 miles in length. The overstep of Kabarnet Trachytes on to the Ngorora Formation ('Poi' and 'Kapkiamu' formations of Martyn) occurs mostly well down the dip-slope and is the result of pre-Kabarnet faulting, particularly on the group of north-south faults running through Kaption, and subsequent erosion. However, the overstep of trachyte on to the shaley lower lithology ('Kapkiamu shales') of the Ngorora west of Chappen on the present map is genuinely caused by flexure but of a much more local nature than that envisaged by Martyn: the base of the Kabarnet Trachytes is at the same altitude on either side of the Poi embayment but the base of the 'Poi tuffaceous sandstones' rises by 700 feet in three miles along a north-south line from near Poi to the Chepkusum River on the writer's map; the regional dip in this area is very slight but south-west dips were recorded in the field. This local upwarping is believed to be associated with a north-west trending fault concealed beneath the trachytes of the southern Rimo plateau. This fault is a necessary postulate to explain the rapid change from the near horizontal lower Ngorora sediments west of Chappen to the faulted and tilted Ewalel Phonolites around Bartabwa.

The importance of this correction lies in the emphasis it places on the apparent independence of the Saimo fault-arch structure from the contemporaneous (pre-Kabarnet) structures of the dip-slope. Also, Martyn's view of a regional up-warp in this area is in contradiction to the writer's idea (which Martyn accepts, op.cit. p.162) that the Cherial Fault was active during deposition of the Ngorora, providing a subsiding fault-bounded basin in which accumulated the thick 'Kapkiamu shales' and 'Poi tuffaceous sandstones' of the type areas.

With regard to the Cherial Fault, Martyn (op.cit., p.161) suggests that its maximum throw is about 3000 feet, at Rort. Neither the structure nor the thickness of the Tiim Phonolites is known here and the figure is an estimate largely based on the known thickness of 5000 feet in these phonolites on Tiim itself. Rort is equidistant from Tiim and the southern edge of the writer's map where the Tiim Phonolites are only 2000 feet thick. It is considered that the 3000 feet maximum throw is therefore probably an over-estimate by at least 1000 feet.

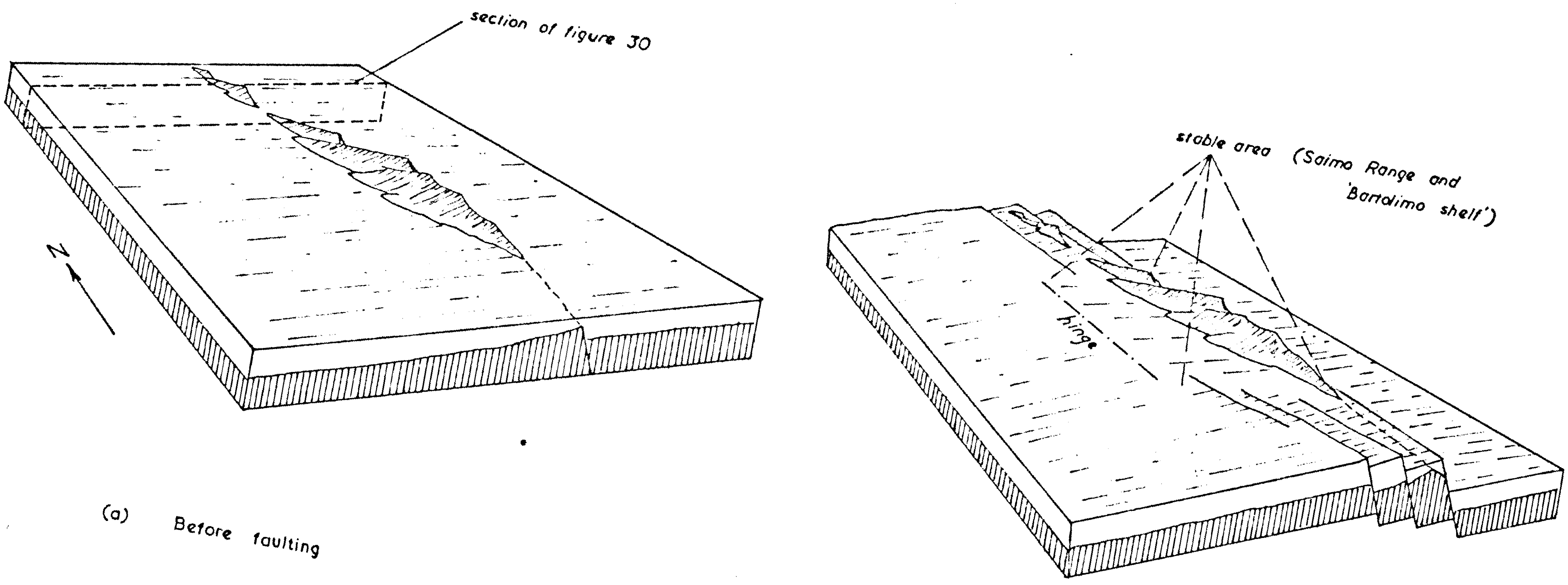
2. The dip-slope

The present western slope of the Kamasia Range is an extensive planar surface on the Kabarnet Trachytes with an average slope, on the present map, of 3½ degrees due west. It is clear that this surface is frequently the top of a single trachyte flow from top to bottom of the slope. Walsh (1969, p.25) believed these trachytes to have been erupted from a source on the crest of the Kamasia and to have flowed down the western slope; however Martyn (op.cit., pp.76-78) summarizes the positive tectonic and geomorphic evidence against this view and also the negative evidence of the absence of any observed source for the lavas and concludes that the slope is entirely tectonic in origin, i.e. it is a true dip-slope, as shown by Shackleton (1951, fig. 5). The writer agrees with Martyn; briefly, the geomorphic evidence consists of the disturbance of the drainage pattern on the trachytes by fairly recent tilting (see Part IIId) and on the Elgeyo Escarpment by rapid tectonic deepening of the Kerio Valley. The Kabarnet Trachytes are much lower in the Kamasia succession than Walsh realized and have been extensively down-faulted to the east of the main range where their total thickness is comparable to that in the Kerio valley on the west of the range. Above all, it is unlikely that a series of low viscosity flood lavas could occur consistently at a certain stratigraphic level over 700 square miles had they not been erupted on to an essentially level land surface.

The trachytes thus certainly form a true tectonic dip-slope as first shown by Shackleton (1951, fig. 5) who postulated a curved fault-plane for the Elgeyo Fault to accommodate the rotation of the Kamasia 'block'. The tilt in the central (Saimo) section of the Range is not, however, directly related to movement on the main Kamasia faults but the dip-slope has dropped like a trap-door hinged on a line well to the west of the watershed (figs. 29,45) and involving the Elgeyo Fault alone. The most significant feature leading to this conclusion is not the independence of the dip-slope from the older structures, as Martyn suggests, but an extensive area of horizontality in the trachytes where they butt against the western flanks of the summit ridge at an altitude of just above 6000 feet. This feature, named for convenience the 'Bartolimo shelf', is best seen from Kabartonjo looking northwards along the range, when the angular discordance between the Tugen Hills Group phonolites dipping at 12-15 degrees and the horizontal trachytes is very striking (pl. 3). On the present map area the shelf is represented in the lobe of trachytes between Atyar and Kamuiton, south-southwest of Bartabwa. As well as the east-west horizontality, which is obvious in the field, plotting the altitude of the Kabarnet Trachytes on a north-south section shows that between Tirimionin and Bartabwa (Saimo and Muruywr on figures 37 & 38) the shelf dips at less than 1 degree to the north. The writer's conclusion is that the Bartolimo shelf, 24 square miles in area (pre-erosion), has suffered hardly any deformation since extrusion of the trachytes and is therefore a stable reference datum for considering all post-Kabarnet earth-movements in the area.

North of Bartabwa and south of Kabartonjo the shelf passes into areas were tilting has involved the Kabarnet Trachytes; the transition is shown in the Atyar area by the steepening of dip in the trachytes east of the horizontal lobe.

The original boundary of the trachyte lava field, marked by the intersection of the dip-slopes on the trachyte and the Sumet Phonolite, is again seen west of Atimet. Here, its altitude is 5300 feet, but rotation of the Sidekh range dip-slope as a whole about an axis close to the watershed would restore the trachyte to a horizontal position at about 6000 feet.



(a) Before faulting

(b) After faulting

FIG. 29 POST-KABARNET TRACHYTE FAULTING (DIAGRAMMATIC) ON THE MAIN RANGE BETWEEN 0° 35′N AND 0° 55′N

Separate evidence for the stability of the Saimo Horst is seen in the dips of the older phonolites in the main scarp: if, as suggested, the horst has not been tilted since the extrusion of the Kabarnet Trachytes, whereas to the north and south the trachytes have been involved in tilting, there should be a relative increase in dip of the Tugen Hills Group rocks in the latter areas when compared to Saimo. This is precisely what is seen in the Saimo scarp; the dip increases gradually from 12 degrees below Saimo summit to 20 degrees in the Muruywr area where the trachyte on Sumet dips at 8 degrees and southwards from Saimo it increases more rapidly to over 30 degrees at Tiim (writer's interpretation of Martyn's map - it can also be clearly seen from the Marigat-Kabarnet road). The stratigraphic relationships within the trachytes also suggest slight tilting of the dip-slope and possibly some movement on the Sumet 'A' Fault during extrusion of the trachytes (fig. 30).

In the map area only one large fault affects the trachytes on the dip-slope. This is the Kapitan fault, movement on which has increased the average dip of the trachytes on the up-throw side to 6 degrees (sections D-D' and, by fault-drag, caused the local shallow syncline of the western Rimo plateau on the down-throw side.

The drainage pattern on the dip-slope picks out a number of minor lineations of presumed tectonic origin. They seem to be parallel to the two main range fault directions in the south but towards Kinyach, where they are very clear on aerial photographs, their alignment changes to WNW-ESE. There is no observable displacement on these lineations and they are possibly major joints.

In the south of the area the dip-slope has a slight convexity, as described by Martyn, but in the north the slope is planar and becomes concave in the Kinyach area. Kinyach village stands close to the axis of a shallow syncline plunging to the south, maximum dip in the western limb approaching 2 degrees. The structure is thought to be due to a large-scale drag effect on the Elgeyo Fault. The Kerio River flows at the foot of the western trachyte escarpment and cuts through spurs of trachyte in a few places. The trachytes crop out within one mile of metamorphic basement outcrops near Koitilial, thus restricting the Elgeyo Fault to within that distance of the foot of the escarpment.

3. The Elgeyo Escarpment

Mapping did not extend beyond the Kerio River but a photogeological study of the Elgeyo Escarpment shows that one can practically lay a ruler along the sharp break in slope at the foot of the escarpment. This may support the conclusion from the evidence of the dip-slope trachytes (above) that the fault lies very close to the solid outcrops of basement and that there has been relatively recent movement. On the other hand the straightness may simply be the result of the fact that the basement strike is perfectly parallel to the fault and dips steeply towards the valley.

The steep lower part of the escarpment rises from about 4000 feet to 7000 feet where gentler slopes commence on the phonolites. A throw of about 3000 feet is adequate to account for the dip-slope of the Kamasia by the 'trap door' theory.

4. Sumet

(i) West of the scarp-faults

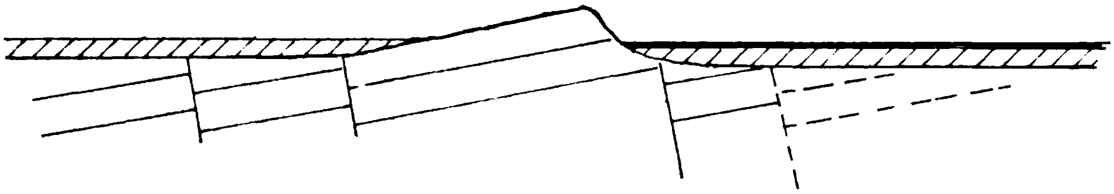
The trachyte-capped table mountains of Sumet are both topographically and tectonically intermediate in position between the dip-slope and the eastern foothills. Dips in both the Tugen Hills Group and the Kabarnet Trachytes are steeper (20^{o} and 8^{o} respectively) than the average for the dip-slope due to the involvement with main-scarp post-Kabarnet faulting.

The southern edge of the higher mesa ('High Sumet') has an altitude only a few feet short of 6000 feet and is thus at a comparable level to the Bartolimo shelf. In view of the tilting of Sumet this may be coincidence rather than an indication of stability, but with the Bartolimo shelf in mind the relationship between the trachyte and the Sumet Phonolite on the western edge of the mesa is interesting: an indented ridge of Sumet Phonolite falls from a 6000 foot peak north-eastwards towards Chepkesin; the trachyte butts against the eastern slope in the south but overlies the phonolite in the north. North of the main phonolite ridge there is a small hill of phonolite entirely surrounded by level trachyte, apparently a small steptoe in the trachyte lava field. The conclusion is almost inescapable that the trachyte/phonolite contact here represents the same 'high-water mark' of the flood-lavas as that seen at the top of the dip-slope.

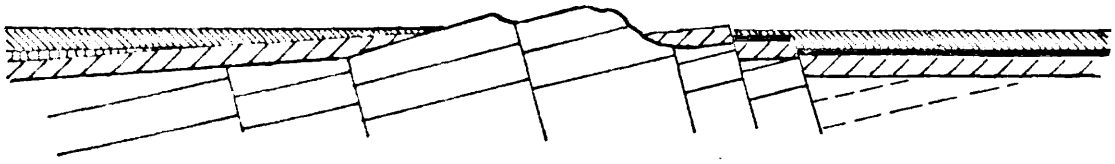
In the long lower mesa ('Low Sumet') both the Kabarnet Trachytes and the Sumet Phonolites have a north-south strike and the trachyte dips west at over 10 degrees. There is a small outlier of sediments and indication of an overlying second trachyte flow.

These observations all suggest that at the time of their extrusion the trachytes on Sumet were effectively 'in front of', i.e. to the east of, the main Kamasia scarp. The latter was declining northwards as an eroded 'gangplank' of which the High Sumet phonolite ridge and steptoe was the most northerly salient.

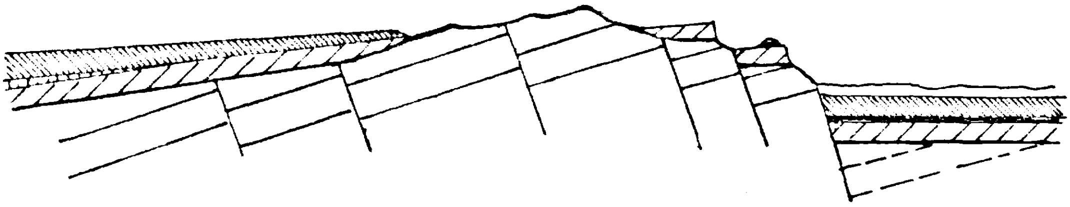
Consideration of the fault-throws supports this interpretation: If the Panwa Fault had moved since the Kabarnet Trachyte it would have increased the throw on the north-eastern part of the Sumet 'B' Fault, relative to the south-western section of that fault. However, the Sumet 'B' Fault shows the same displacement (900') in both Kabarnet Trachyte and Tugen Hills Group along its whole length. Pre-Kabarnet Trachyte movement on the Saimo Fault is necessitated by the angular unconformity and overstep on the crest of the range; it thus appears that at the time of extrusion of the trachyte the Saimo and Panwa Faults (the latter including its north-westerly continuation below High Sumet) were already well developed while both Sumet 'A' and Sumet 'B' largely, if not entirely, post-date the trachyte (fig. 31).



(a) Arrival of flow '1' and sedimentation in the east



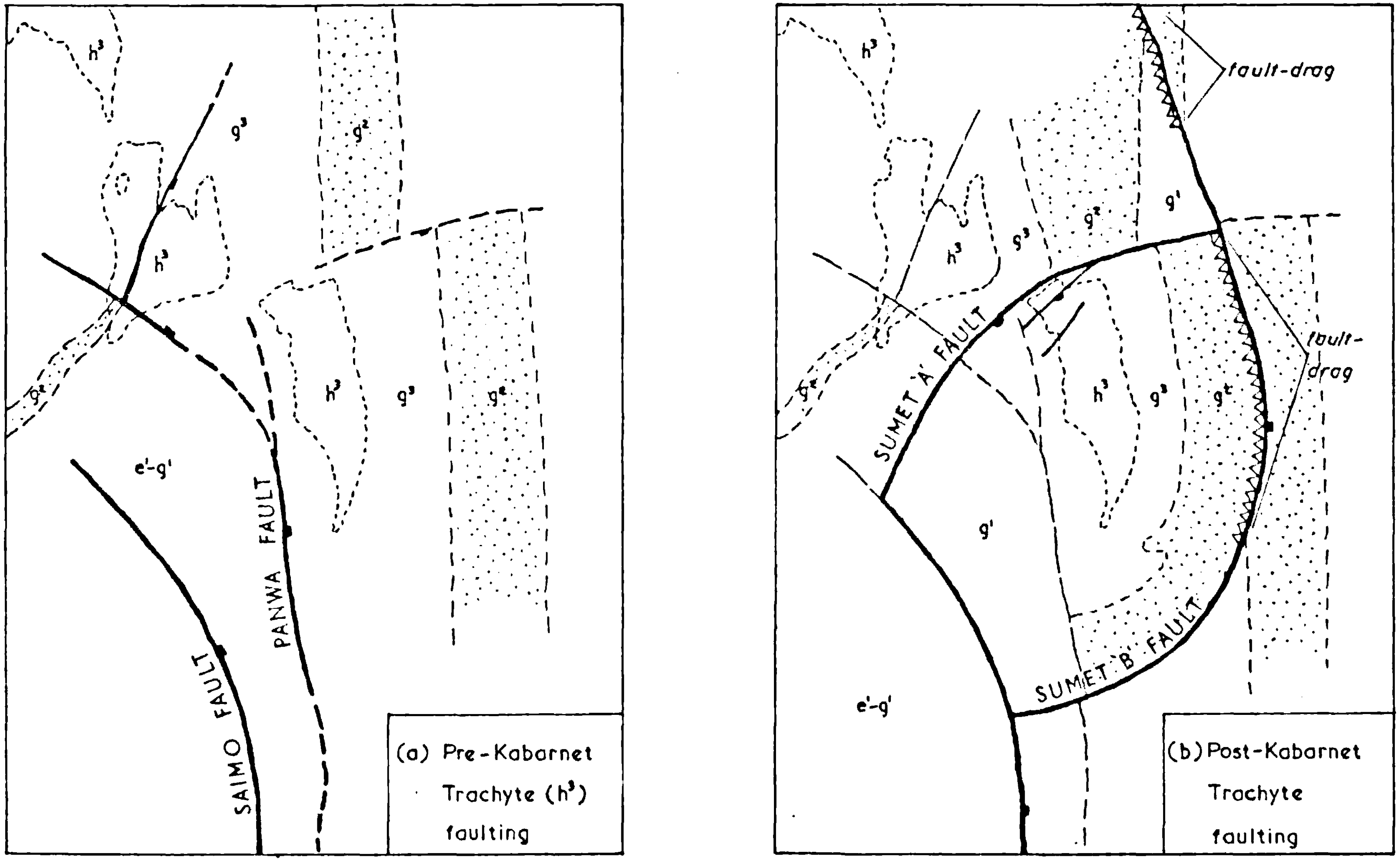
(b) Faulting and tilting arrival of flows '2' and '3'



(c) Present situation

▨ *Flow 1* ▥ *Flow 2* ▭ *Sediments* ▩ *Flow 3*

FIG. 30 EFFECTS OF FAULTING AND TILTING ON THE KABARNET TRACHYTES IN THE SUMET AREA



SCALE 1:80,000 approx.

FIG. 31 SUMET AREA — HISTORY OF FAULTING AND POSTULATED CORRELATION OF FAULT DRAG WITH NGORORA FORMATION (g^2)

(ii) Fault-drag

The Sumet Fault scarp appears, along most of its length, to have a facing structure of Kabarnet Trachyte at its foot (fig. 32). Exposures in narrow gorges on the scarp show that in fact this trachyte, with intercalated sediments, is dipping west at about 50 degrees. Although the actual contact between trachyte and the phonolite of the scarp is not seen, mapping shows that the plane of contact must dip east at an angle of between 60 and 70 degrees; the sediments and phonolite of the scarp dip west at 20 degrees. There is no doubt of the tectonic origin of the structure and a fault-drag effect is the most probable explanation.

Although a certain amount of drag occurs on all the major faults the extreme developments of it are restricted to situations where the Kabarnet Trachytes overstep the older succession and on the downthrow side of a fault lie or can be inferred to lie on the Ngorora Formation sediments. It seems that either the relative incompetence of the sediments or a flattening of the fault dip within them (see Lahee 1929), or both, causes the anomalous deformation of the overlying trachyte. In the case of the Sumet Fault stratigraphic considerations show that most of the movement is post-Kabarnet Trachytes and on the upthrow side the trachyte lies on the 1200 foot type-section of the Ngorora Formation.

The discontinuity of the fault-dragged trachyte along the fault can be explained by assumption of some movement on the eastern part of the Sumet 'B' Fault before extrusion of the trachyte. Such movement would displace the outcrops on the sub-Kabarnet surface and subsequent oblique transection of the offset outcrops by the Sumet 'A' Fault (fig. 31) would, if the correlation between fault-drag and trachyte overstep on to sediments is correct, have the observed effect. Thus, south of the Chemagin River the trachyte on the Sumet 'A' fault-line would have overstepped as far as the Kamuiton Phonolite and there would be no drag. South of the Sumet 'B' Fault the abrupt re-appearance of fault-dragged trachyte may be caused by

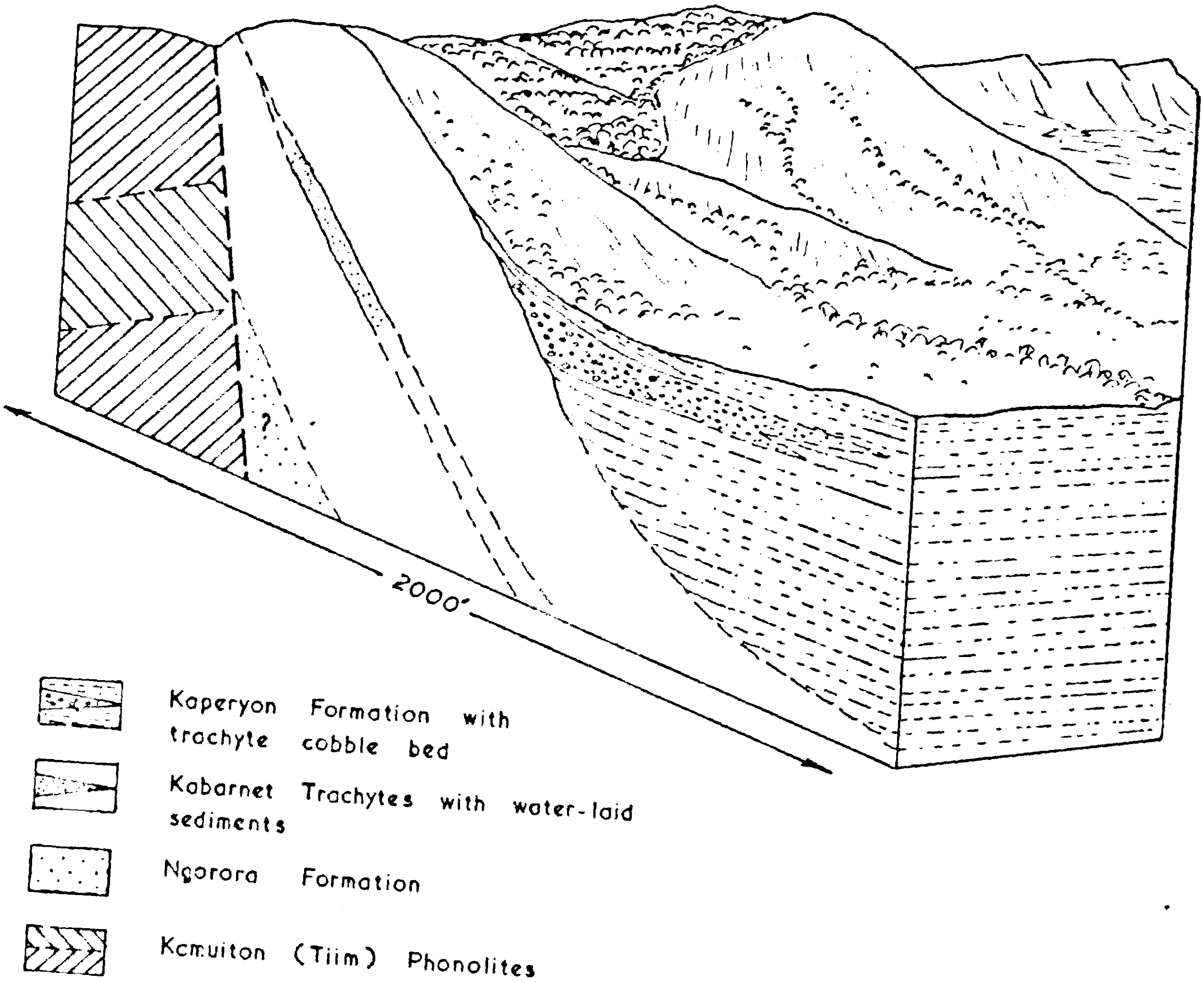


FIG. 32 FAULT-DRAG IN KABARNET TRACHYTES NEAR THE CHEMAGIN RIVER (Based partly on a field sketch looking N.E. from 198975)

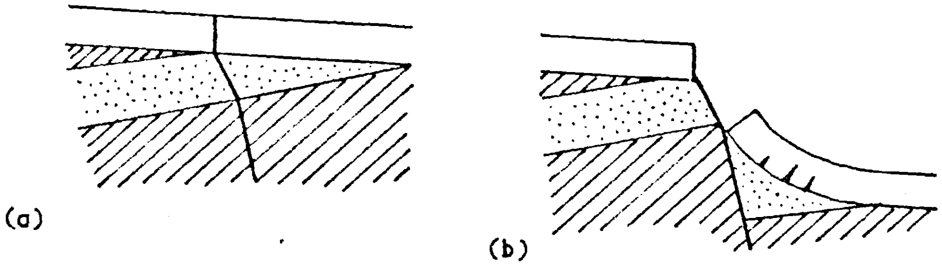


FIG. 33 HYPOTHETICAL EXPLANATION OF FAULT-DRAG

the abrupt appearance of Ngorora sediments beneath the trachyte as the Sumet 'A' Fault crosses the Sumet 'B' Fault.

Southwards the fault-drag effect dies out as the Sumet 'A' Fault swings westwards across the strike, as one would expect on the above hypothesis. Northwards the fault-drag trachyte passes into the trachyte on the upthrow side of the fault with no break.

Following this same Kabarnet Trachytes outcrop southwards along the southern end of the Kito Pass Fault another interesting example of fault-drag occurs in the Mokongho area where it forms the 'Gangplank'. Here the regional westerly dip of the trachyte is reversed as it is dragged on the fault to form a small nearly symmetrical syncline, well expressed topographically. The obvious drag is thus related to post-Kabarnet movement, as on the Sumet Fault; however mapping revealed in the underlying Sumet and Ngorora formations a similar but more pronounced structure the limbs of which are overstepped by the Kabarnet trachyte. In this case pre-Kabarnet movement caused Sumet Phonolite, overlying thick sediments, to drag on the fault. The resulting structure was then planed off before the arrival of the trachyte and the later phase of fault movement.

Other fault-drag effects are seen on the Saimo Fault, where Kaparaina basalts and sediments dip steeply eastwards near the fault, on the Kapitan fault and around the up-faulted inliers of Kabarnet Trachytes in the eastern foothills. The Kinyach syncline may also, as suggested, be due to fault-drag on the Elgeyo Fault; in this area the trachyte also lies directly on the Ngorora Formation at the extreme north-west of the map.

5. Eastern foot-hills - the fault-domes and fault-arches

In the foot-hills, on the eastern half of the map, faulting is concentrated in a belt of country five miles wide characterised by 'dome and basin' structures of the type introduced by Martyn (op.cit., pp.176-177). To the west of this belt faulting is conspicuously absent in a broad area at the foot of the main scarp. Exposure is good in this area and structure is also clear on aerial photographs; there is no possibility that any but very minor fractures have been overlooked. To the east of the fault-belt, on the other hand, it is quite possible that faults were missed in the outcrop of the Kaparaina Basalts near the Burususwa River.

The fault-belt also approximately defines the crest of an anticlinal structure which is, in effect, a continuation of the 'Kaparaina Uplift Zone' of Martyn (op.cit., pp.173-176). A large component of dip in the structure is a result of the tilting of fault-blocks, as described by Martyn, but that some of it is genuine flexure is well shown in the hill-mass of Chepuromoi: here nearly horizontal lavas form the western and central parts of the hill while features formed by thin basalts and one thin trachyte are seen to be dipping east at increasing angles, up to 10 degrees, down the eastern side. When viewed from some distance to north or south this gentle flexure is extremely clear.

Dips in both limbs of the flexure reach a maximum of 12-15 degrees (at Yatya, plate 11 , and Kamsoror near Chesoton) and are thus comparable with the dips of the older succession on the main range. These are measurements on Kabarnet and Kaparaina formations - dips in younger rocks are invariably less, again inviting comparison with the main range.

In a narrow belt along the axis of the flexure there is no east-west dip component and east-west sections show apparently horizontal horsts and graben (sections B-B',C-C'). However, the structures in this belt have a pronounced north-south plunge, i.e. flexures on east-west axes (sections F-F',G- erosion of which has caused the series of Kabarnet inliers along its length; the structure of these inliers is discussed in greater detail below. North of Kokwomur the general pattern is modified by later westward block-tilting to the east of the axial line, in the region of Keriwa.

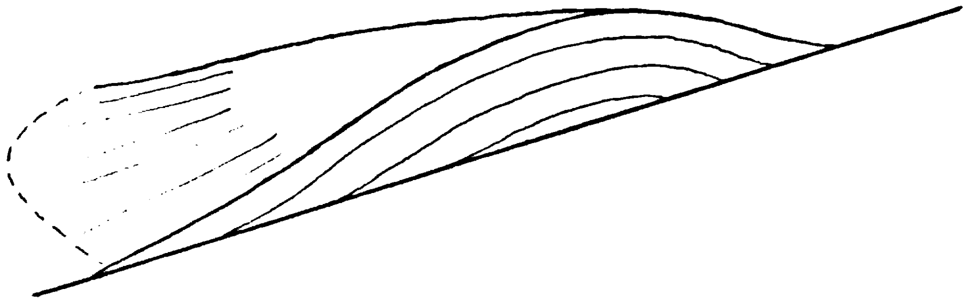
An ideal 'normal' fault has finite length, the throw being zero at the ends and at a maximum somewhere in between. Strata on the up-throw side will thus form a 'half-dome' (de Soutter 1964, p.123) with a complementary 'half-basin' on the down-throw side. Such ideal structures appear to be best known from oil-fields, in weakly deformed strata where there is abundant quantitative evidence of structural morphology (Shelby 1951). In the present area this type of structure is exceptionally well developed and is obvious from field mapping as well as being topographically expressed. The structure of the three main Kabarnet Trachyte inliers is shown in simplified block-diagrams (fig. 34).

(i) Yatya

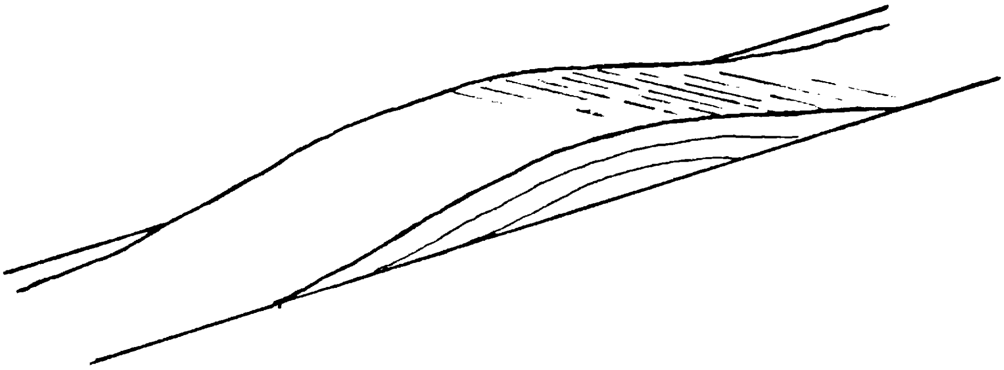
This structure best conforms to the ideal half-dome truncated by a fault. In fact the Yatya structure is bounded by two faults but the fault crossing the river immediately east of the village is the larger of the two, with a maximum throw of at least 900 feet; Sumet Phonolite is exposed on the up-throw side, the only inlier of the Tugen Hills Group east of the main Kamasia scarp in this area. The structural contours clearly show the half-dome which has been accentuated at the culmination near the village where trachyte is seen dipping south-west at 45 degrees on the hill above the dukas. The average dip is however in the order of 10-12 degrees in directions between south-west and north-west. Since no structure is seen within the phonolite outcrop it is not possible to say whether there was tilting of the older rocks before the extrusion of the Kabarnet Trachyte as on the main range.

The Lukeino Member and the basalts of the Kaparaina Formation are broadly conformable with the Kabarnet Formation but mapping shows that there was certainly some minor faulting of the latter prior to the deposition of the Lukeino Member.

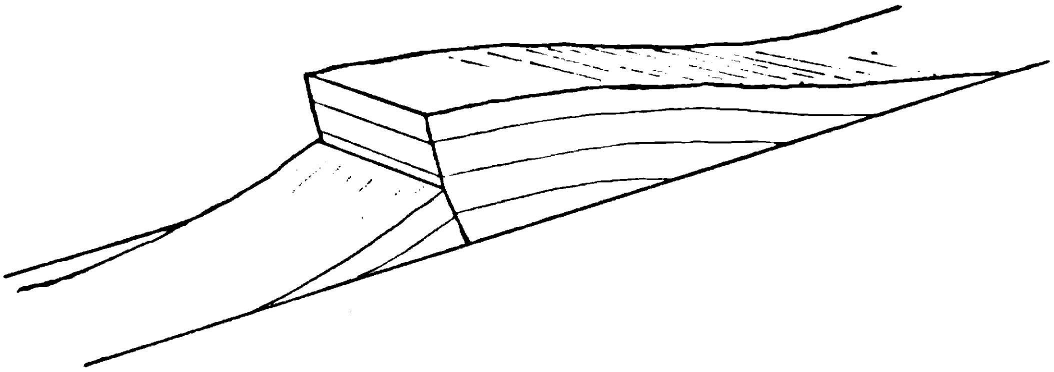
It is also apparent that the half-dome structure has been modified by collapse of the northern and southern flanks along ESE-WNW faults perpendicular to the main boundary fault. Thus the trough defined by the long cliff north of Rurmoch and the escarpment north of Kasigoryan represents a



(a) Fault half-dome e.g. Yatya



(b) Fault-arch e.g. Tegit



(c) Fractured fault-arch e.g. Kokwomur

FIG. 34 TYPES OF MINOR FAULT FLEXURE

reversal of structural relief. The Kaparaina outlier of Rurmoch occupies a slight sag on the southern flank of the half-dome.

Structures around Cheparain on the southern edge of the map are extremely complex, with the bifurcation of the two Yatya faults producing separate horsts of trachyte between outcrops of Kaparaina. Just south of the border of the map one of the western faults of this group produces an ideal half-dome only one mile in diameter (Martyn,op.cit., p.176); the same fault continues southwards to a junction with the Saimo Fault.

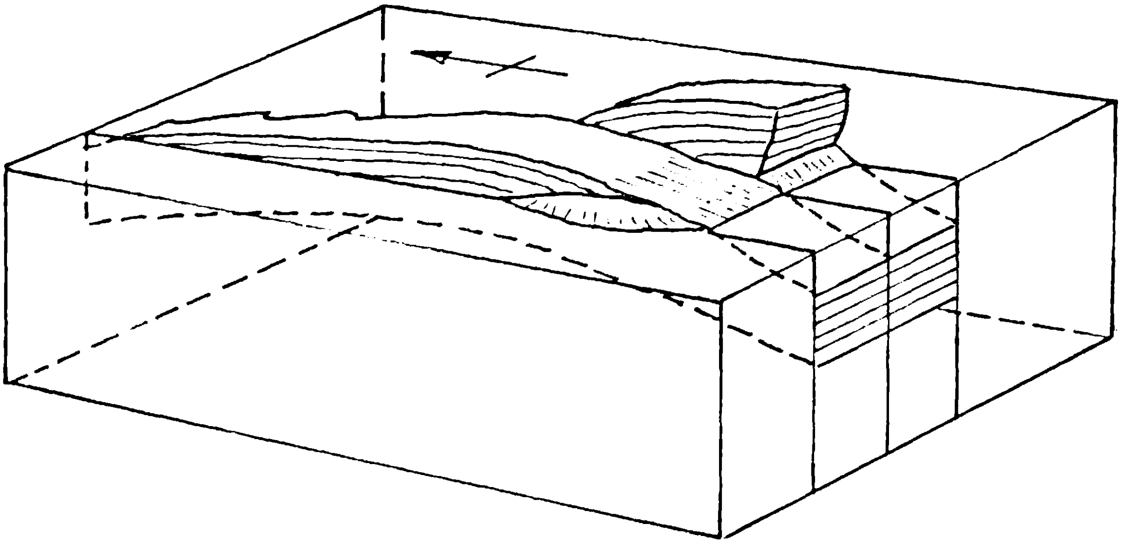
Unfortunately structures on the downthrow side of the Yatya Fault are not clear but there is a general dip to the west in the basalts. South-east of Yatya a long whale-back horst of Kabarnet trachyte continues to the south of the map and in the north plunges beneath the alluvium of the Yatya river; there appears to be no east-west dip in the horst but basalts to the east of it are seen in river sections to dip gently to the east.

(ii) Tegit and Chepirimor

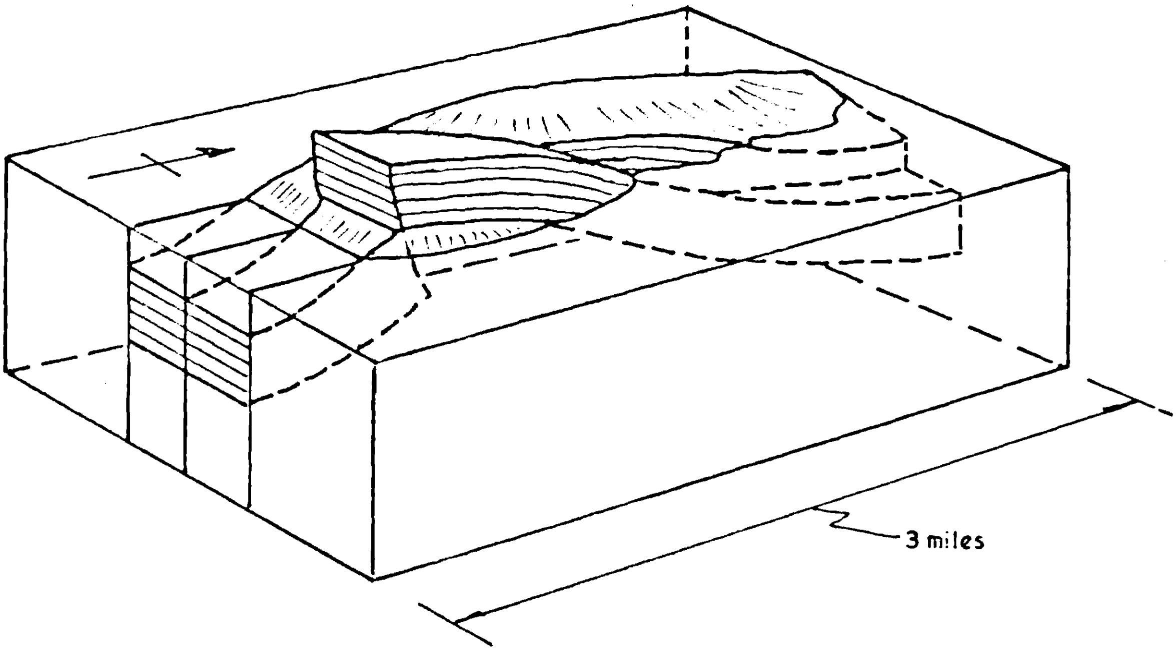
This double structure is defined in east and west by faults but the trachyte plunges beneath basalts and Lukeino Member at the north and south ends of the inlier. The structure is clearest in Tegit where it is perfectly expressed in the topography (pl. 14). The view of Tegit and the other inliers from the Sumet scarp led the writer to compare them to a school of whales surfacing in a choppy sea (of eroded basalts). The east and west margins are near-vertical fault scarps between which the arch is practically concentric, the steepest plunge, of 10-12 degrees, occurring at the north and south ends. Steep dips do however also occur in the flanking sediments on the western side; this is probably due to fault-drag. The Tegit arch is judged to have no east-west dip component but the Chepirimor section has a slight dip to the west.

(iii) Kokwomur

This is the most spectacular of the three main structures (pl. 12) and the most complex. The interpreted structure is explained in figure 35.



(a) From the south-west



(b) From the south-east

FIG. 35 STRUCTURE OF THE KOKWOMUR–KISITEI FAULT-ARCHES

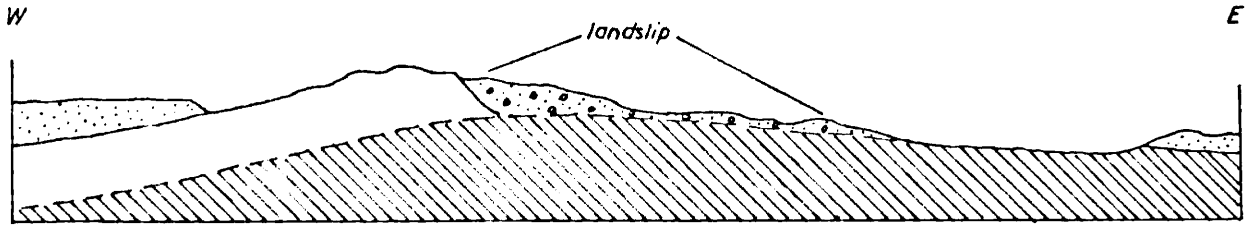
There is no direct evidence that the ESE-WNW fault at the southern end is in fact a reverse fault; it is inferred to be so firstly because the Kokwomur mass is an anomalous tectonic 'high' compared to the surrounding terrain and secondly a reverse fault is more compatible with the inferred stress field of the fault arches (see Part II(e)3).

The crest of the Kokwomur block dips evenly northwards at 5 degrees for 600 yards before the dip steepens abruptly near Kisitei where Lukeino Member sediments on the plain dip at up to 70 degrees away from the trachyte. The remainder of the trachyte inlier is more subdued in relief and is bounded by a NNW-SSE fault on its western side. Again from topographic evidence, the main area of the Kabarnet inlier has a fairly shallow dip to the NNE (fig. 35) but at Mpesida, the type section in the Mpesida facies sediments shows northward dips of up to 45 degrees.

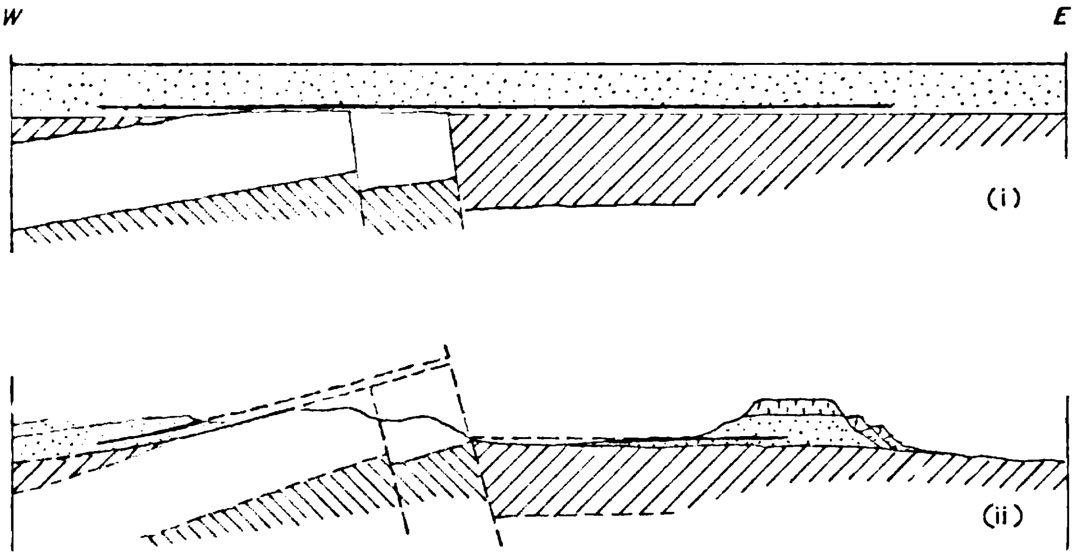
(iv) Mukur

The Mukur outcrop on the northern edge of the map is the southern end of a long escarpment of Kabarnet Trachyte extending for four miles to the north before the outcrop curves west to meet the Kito Pass Fault (McClenaghan op.cit.). On the western side of the trachyte ridge the Kaperyon Formation, in the type area, overlies the trachyte and dips to the west at up to 10 degrees. From topography, the trachyte also appears to dip west but more steeply; exposures in the Mukur gorge show dips up to 90 degrees in trachytes and intercalated sediments. East of the gorge the Cheptopokwa River section exposes strongly faulted basalts. Photo-geology strongly suggests that near the mouth of the Mukur gorge some of the basalts dip steeply west and pass underneath the trachyte but the contact is not exposed in the field.

The writer's structural interpretation of the area is shown in figure 36. The differing attitudes and altitudes of the Kaperyon outcrops require a fault to the east of the Mukur gorge, a continuation of which (the fault) is concealed beneath the Ribon Trachyte; the differing substrata of the Kaperyon require an unconformity expressed as either simple



(a) After McClenaghan, (PhD thesis in prep.) grid line 130.



(b) By present author, grid line 105.

SCALE 1 50,000 vertical exaggeration x2

▨	Ribon Trachyte
—	Yepkarat Dolerite
░	Kaperyon Formation
▨	Kaparaina Basalts
☐	Kabarnet Trachytes
▧	basalts (Barpello basalts of McClenaghan)

FIG. 36 TWO INTERPRETATIONS OF THE MUKUR AREA

overstep of older tilted rocks with negligible previous faulting or overstep of a fault-repeated succession. The first explanation is favoured by McClenaghan (op.cit.) who interprets all the basalts to the east of Mukur as older than the Kabarnet Trachytes - these are the Barpello Basalts of McClenaghan. The writer holds the second view and has mapped only the basalts in the mouth of the gorge as older than the Kabarnet Trachytes, on the west of the postulated fault, and the remainder as Kaparaina Basalts. The differing interpretations are shown in figure 36.

The writer thus sees the situation as closely analogous to that at Yatya, with the substitution of basalt for phonolite and the addition of a cover of Kaperyon sediments on the western flank of the structure. The chief objection to this hypothesis appears to be that there is no positive evidence of the existence of a large fault (neither is there at Yatya), and that at the northern end of the Kabarnet outcrop near the Chepanda River (McClenaghan op.cit.) the fault system is difficult to visualize. On the other hand the objections to McClenaghan's hypothesis are many but the chief are two; the suggested structure is incompatible with that mapped to the south and the necessary scarp retreat and planation of at least two trachytes plus sediments before Kaperyon sedimentation is far greater than any observed elsewhere, even on the main range.

In summary: the Kaparaina Uplift Zone of Martyn is continued northwards as a faulted anticlinal structure where its axis is characterised by fault-bounded flexures of the type described by Martyn in his 'Dome and Basin Province'. The two 'provinces' are thus impossible to separate in the present area. The crest of the flexure is relayed by 'en echelon' NNE-SSW faults so that it runs parallel to the main Kamasia Range which is also oblique to the fault trend. North of the present map the flexure, as a strongly faulted feature, disappears beneath the Ribkwo trachytic pile (McClenaghan op.cit., Webb op.cit.) but it is probable that at least the eastern flank of Ribkwo is partly a tectonic slope related to the same general structure.

6. Loyamarok

The few faults shown on the Loyamarok plateau are certainly the only fractures present and in terms of throw, which is less than 20 feet in individual cases, even these are relatively insignificant. The fault-scarps are virtually untouched by erosion and have narrow gullies at their feet; these ravine features are suggested by Martyn (op.cit., p.179) to be collapsed tension fissures by analogy with similar features in Iceland (Neilsen 1929, Bodvarsson and Walker 1964). A spurious impression of strike-slip movement is given by the apparent lateral off-setting of stream courses by these faults; in fact, both right-lateral and left-lateral 'displacements' can be seen on the same fault and the effect is due simply to differential stream erosion along the faults. Although the Loyamarok faults obviously belong to Martyn's 'zone of Late Pleistocene to Recent faulting' they are not nearly as closely spaced as those around Lake Baringo and it seems that the eastern edge of the present map is the approximate western limit of the intense Quaternary fault-belt of the centre of the Rift.

It is uncertain whether the easterly slope of the Loyamarok Hills is an original feature or whether it is of tectonic origin. However the general slope of the 'Nginyang surface' (Part IIIb) on which the lava was extruded is certainly less than the slope of the lava surface (1^{o}) and probably an original slope of the lava surface away from its source has been augmented by subsequent tilting.

(e) Mechanisms

1. Introduction

Deformation in the Kamasia is chiefly by dip-slip movements on high-angle fault-planes; nowhere is there seen any significant strike-slip component (but see Martyn, op.cit. pp.167,170). These are rarely simple gravity displacements but involve a considerable degree of rotation of both strata and fault-planes, giving rise to what appears in east-west sections to be a 'tilt-block' system. As a broad generalisation the Range as a whole can be thought of as a block rotated between the Elgeyo Fault and the Kamasia scarp faults, but the down-faulted eastern foothills must also be considered part of the same belt of positive tectonic relief. The north-south plunge of the major structures is associated with the 'en echelon' arrangement of the large faults.

Normal faults are usually assumed to have steep, but not vertical, dips but it seems that in the Kamasia the majority of the large faults originated as vertical fractures, their present inclination being the result of rotation; Martyn (op.cit. p.168) has suggested that in a pile of layered rocks consisting largely of competent lavas a horizontal tensional stress will result initially in vertical fractures rather than in conjugate shear sets. This is in particular more likely to occur at shallow depths and on the surface. There is no evidence of the behaviour of the fault-planes at depth but in the case of 'tilt-block' geometry it can be postulated that the fault-dips steepen with depth, extension due to faulting gradually being replaced by plastic flow; if the tension is produced by large-scale crustal arching then the tensional stress will decrease downwards in any case - a situation illustrated by Cloos's clay model on an inflated balloon (Cloos 1930), described below. On the other hand it is conceivable that superficial vertical fractures are completely replaced at depth by conjugate shear sets. There are in fact strong indications that the faulting observed in the Cainozoic rocks may in some cases be antithetic to larger fractures in the basement and that basement faults may be considerably modified when transmitted upwards through the younger rocks. Such modification may well include the flattening of fault-dips in the less competent sedimentary formations, as described by Lahee (1929), which could be a major factor in the origin of the prominent fault-drag structures of the area.

The east-west stratal extension due to faulting and rotation has been calculated as approximately 300 m. over a distance of 35 km., or less than one per cent. This, however, is a minimum figure since it is based on observed throw only; rejuvenation of faults was a common feature in the tectonic history and it is possible that far greater displacements occur at depth, particularly in the east of the area where the older succession is concealed. Again, the basic assumption is made that the faults originated as vertical fractures perpendicular to bedding, displacement being caused by rotation or 'block-tilting'. If in fact the initial fractures were not vertical the subsequent extension would be considerably greater than suggested. However, even allowing for these possibilities the total extension is unlikely to exceed 1 km. at a generous estimate. The sum effect of block tilting was likened by Martyn to the leaning of books on a shelf but such an analogy only suffices in two dimentions or in situations where blocks are conveniently separated from one another along strike by cross-faults. In the Kamasia, however, it is more accurate to speak of tilted strips with pronounced north-south plunge between 'en echelon' faults; such a pattern can be explained by a unified theory of deformation of the area.

2. Models

(i) Clay and paper models

In an attempt to reproduce in model form the half-domes and fault-arches of the eastern foothills the writer made 'en echelon' cuts in cartridge paper and applied simple tension at right angles to the cuts; arching occurred on axes parallel to the tensional stress combined with overall tilting of the fault-bounded strips. The strips have a plunge direction parallel to the fault, i.e. normal to the regional tilting. The most familiar example of this pattern is the material known as 'expanded metal', used in, among other things, loudspeaker and ventilation grilles.

The following points are noted in the paper model: displacement of the strips occurs on planes normal to the surface, and this relationship is maintained at all angles of tilt - i.e. as strain is increased the tilt of the strips increases, dip of the faults decreases with increased displacement and extension occurs; the amount of displacement on a fault is roughly proportional to its length; the displacement and tilting is usually all unilateral and as a result no horsts or graben are produced. It is also obvious that a secondary compressive stress is being applied along the length of the strips as a direct result of the primary tensional strain.

It is equally obvious that such a model has very little validity since the strength of the material used is far too great for the scale of the model. This being so, the analogy would be swiftly abandoned but for the fact that much careful experimental work, notably the well-known experiments of Cloos (1929, 1930, 1930a, 1932, 1939) and similar investigations by Baine and Beebe (1954) using soft clay of the correct model strength, showed that 'en echelon' normal faults can be produced by a tensional stress. (Hubbert (1951) and others have used sand because it has a lower internal friction than clay.) Cloos was primarily concerned to reproduce graben structures; bearing in mind that the actual major rift systems of the Rhine, Red Sea and East Africa occur across up-domed regions the most satisfactory of Cloos's model graben was that produced by arching a clay cake over an inflating balloon; this produced a graben (of width approximately equal to the thickness of the clay) which was bounded by 'en echelon' faults (Cloos 1930, 1939) and the shoulders of which sloped away from the graben at angles steeper than the 'regional' convex balloon surface. In this model the faults had a high angle of dip and steepened downwards, finally dying out before reaching the base of the clay cake.

In other models Cloos produced conjugate sets of relatively low-angle faults on a stretched rubber plate (1930) and downward-flattening curved faults in clay mounted on two boards.

The main result of the experiments of Baine and Beebe was 'en echelon' faults associated with tilting: a clay cake was mounted on the extensible planar surface of a rubber sheet, the clay being contained by two 'half-boxes', one fitting inside the other. Briefly, the tensional stress produced a set of 'en echelon' faults the dips of which decreased (with resultant increased tilting of fault-bounded strips) with increasing throw, in a precisely similar manner to that of the writer's paper model. Faults tended all to throw in the same direction and the authors appear to attach some significance to the fact that no graben were formed but this, in the writer's view, can probably be ascribed to the entirely unilateral stress application.

The overall conclusion, from consideration of these various clay models, is that for the purposes of examining the geometry of the situation the paper model is a reasonable equivalent which may be very conveniently produced in a matter of seconds with a sheet of cartridge paper and a razor blade.

(ii) Eastern foot-hills model

The paper model shares with the clay model of Baine and Beebe the fact that it is difficult to produce horsts and graben since once faults have started throwing in a certain direction then this direction determines that of all subsequent displacements. Horsts and graben may however be produced either by applying a slight transcurrent component to the fault system or, equally significantly, by ensuring that the tensional stress is nearly perfectly bilateral i.e. both margins of the sheet moving equally relative to the substratum on which they lie; in the latter case opposing sets of fault-scarps face each other across a central strip, or strips, which buckles on axes normal to the faults producing, in different cross-sections, both horsts and graben along its undulating length. This is exactly the form of the Yatya-Tegit-Kokwomur area along which the Kabarnet Trachyte inliers record the crests along the buckled strips. As in the model, stratal dip and fault-throw are in opposite directions on either side of the buckled strip. The second major significant point about this feature is that dilation must occur along the strip where the dip direction changes; that this must be so can be seen from the fact that the displacement of the central strip is entirely vertical (both upwards and downwards, in contrast to the 'keystone' idea) while on either side there is extension and bulk movement away from the strip by tilting. It is therefore not surprising that nearly all the dykes in the map area and at least two trachyte plugs occur along this strip, although admittedly many are not parallel to the faults and the total number is few. However, when the axial strip is followed southwards into the 'Kaparaina uplift zone' of Martyn (op.cit.) it is found to contain an extremely dense dyke swarm associated with a basaltic extrusive complex in the Kaichurot area, where over 90 per cent of the dykes are parallel to the faults. Also, when the strip is extrapolated northwards from the present map its extension would pass directly through the complex central focus of the Ribkwo trachytic complex. A fault-arch structure similar to Tegit has been mapped by Webb (Ph.D. thesis in preparation) north of Tiati, where the main Kamasia faults are replaced by a faulted monocline, and here again there occurs a group of intrusive (trachytic) masses in the Cheptumet hill-mass.

Although dyke-swarms associated with major crustal flexures are well-known, e.g. the east Greenland swarm (Wager and Deer, 1938) and, closer to the present area, the Nyasaland dyke-swarm (Dixey 1956), it is unlikely that the Kamasia eastern foot-hills flexure is large enough to be an analogous structure; the writer believes the main cause of the intense local dyke injection to be the change from west-dipping 'en echelon' fault strips to east-dipping strips with the attendant median geometric dilation.

The structure of the eastern foot-hills has been dealt with at some length at this stage partly due to the chronological order of the writer's theorising and partly because of the suspicion that this zone of relatively complicated structures is in fact just as significant as the larger and more obvious main scarp structures; in various experiments it has been found difficult to reproduce such a structure, which is clearly associated with igneous activity far more than are the large main scarp faults.

(iii) Main scarp faults model

Extending the expanded metal analogy from the fault-arch zone of the foot-hills to the main scarp faults is an obvious step since the arching on these faults, while not as conspicuous in the field as that in the smaller structures, is at once apparent in north-south sections (sections H-H', I-I').

The Kito Pass Fault starts near Bartabwa and its throw increases northwards as far as the Kito Pass; towards Tiati it appears to die away (McClenaghan op.cit.) and is replaced, as related, by a faulted monocline. It can, in fact, be argued that on the present map the northward increase in throw is caused entirely by the discordance between the fault direction and regional strike, but the subsequent northward decrease is not accompanied by any corresponding major change in direction.

The Saimo fault system starts in a complicated way with the Sumet faults and the main Saimo Fault increases in throw to the south, eventually exposing the metamorphic basement on the up-throw side below Saimo summit. South from Saimo the arch declines but is terminated, more abruptly than in the north, by Martyn's 'Tilted Block Province' (i.e. an area of more steeply tilted 'blocks').

To conform to the ideal pattern suggested by the model these faults should show a comparable amount of down-throw to up-throw, i.e. the fault-face should approximate to a bilaterally symmetrical figure. That this is the case should be suspected simply from a quick inspection of the maps since the outcrops of the youngest sedimentary formations - the Chemeron and Kaperyon formations on the down-throw sides of the Saimo and Kito Pass faults respectively - coincide with the limits of maximum tectonic relief on the up-throw sides of the faults. However, the Kamasia stratigraphy is known in sufficient detail to allow a reasonably accurate estimate of the position of certain concealed datum horizons on the down-throw side of the Saimo Fault. Thus in figures 38 (present time) and 37 (c. 7.0 m.y. B.P.) are plotted the vertical and lateral limits of displacement on the fault. The diagrams show that the Saimo fault-plane is roughly symmetrical at the present time but that all the post-Kabarnet Trachyte movement, amounting to half of the total, has been down-throw alone, the up-throw side having remained relatively stable, as described (p. 86).

A remarkable series of 'half-basins' occurs in the Kaparaina and Chemeron formations at the foot of the Saimo scarp, from the Toluk valley in the present area as far as Kipcherere in the south. These form part of Martyn's 'Dome and Basin Province', of which the domes have already been considered; the basins are essentially a modification of the major depression which preserves the Chemeron Formation and were probably caused by a space problem: if the downward movement of the major structure were halted due to lack of space the incipient north-south compression could be expressed as a series of minor flexures, rather than as one large one (fig. 41). (Note that half-basins matching the half-domes of Yatya and Mukur would hardly be expected since these structures face the axial strip which deforms almost independently of the flanking sets of tilted strips.)

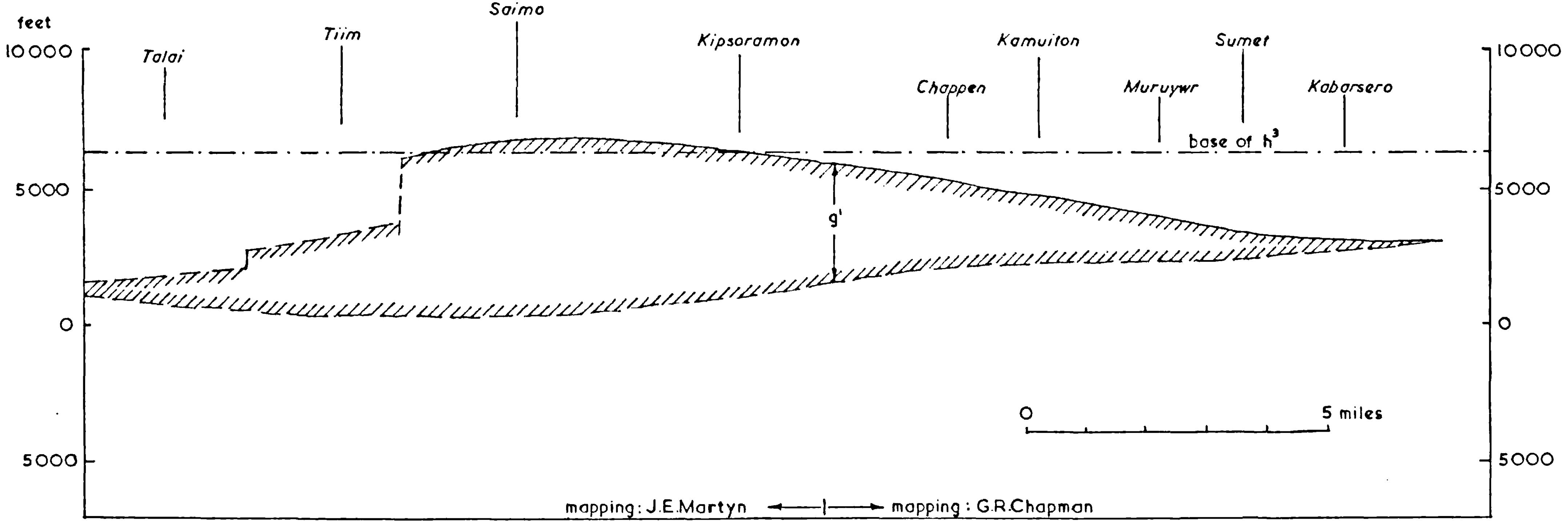


FIG. 37 SAIMO FAULT — VERTICAL DISPLACEMENT OF THE BASE OF THE TIIM PHONOLITES (g') AT THE TIME OF EXTRUSION OF THE KABARNET TRACHYTES (h^3) (Based on two sections on eastings 16 & 21)

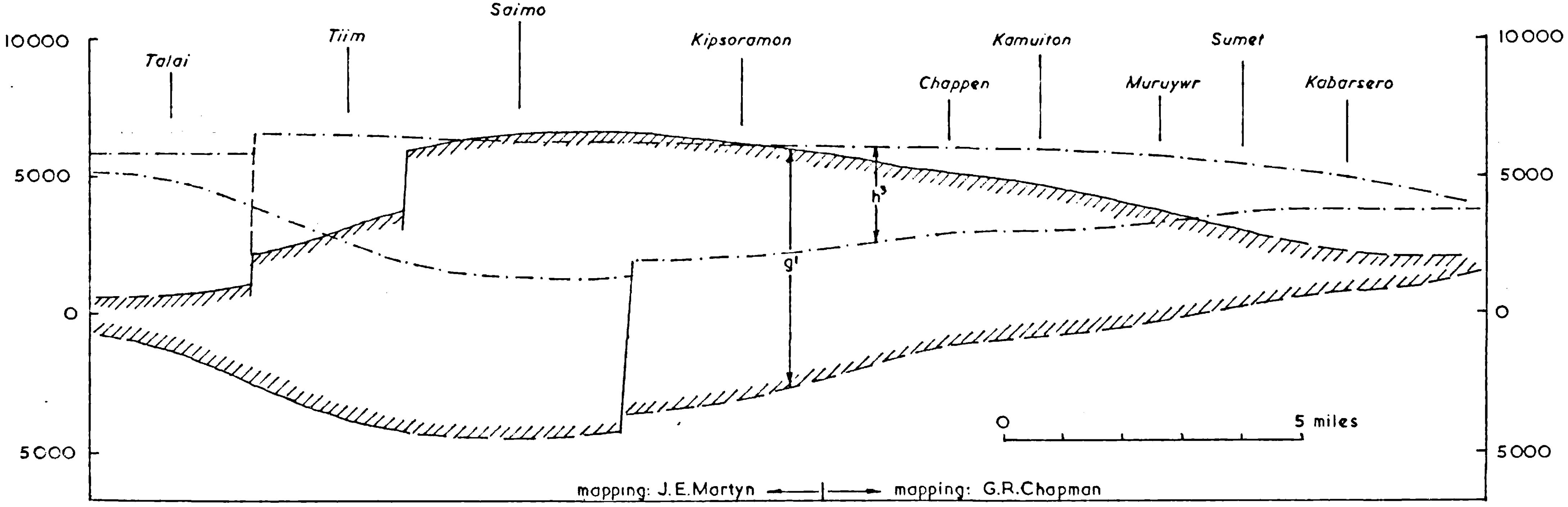


FIG. 38 SAIMO FAULT — VERTICAL DISPLACEMENT OF THE BASE OF THE TIIM PHONOLITES (g') AND THE BASE OF THE KABARNET TRACHYTES (h³) (Two north-south sections on eastings 16 & 21)

On the up-throw side of the Saimo and Kito Pass faults the change in direction and degree of dip at the north and south terminations respectively has been remarked. That most of this increase occurred after the arrival of the Kabarnet Trachytes seems to be proved beyond doubt in the case of the Saimo system but it should be noted that this geometric modification is bound to occur at the ends of an ideal fault-arch (consider a faulted plunging fold). The abruptness of the change of attitude in both cases is probably due to the small amount of overlap of the two faults; although this amounts to about seven miles, it represents less than a third of the length of either fault. An alternative explanation in the case of the Kito Pass Fault is strongly suggested by the structural contours: the Kito Pass and Kapitan faults may represent the surface expression in the Cainozoic rocks of a major fracture in the basement which has not been perfectly continued into the former. Thus the major fault has possibly split as it was transmitted upwards through the less competent lavas and sediments which may, in part, be warped across the deep fault.

3. Stress system

The suggestion (above) of discordance between basement structures and those in the Cainozoic rocks points to a major problem encountered when considering the origins of observed structures: that is, the extent to which the structures are (a) primary features of the upper part of the crust, (b) discordant deformation of the Cainozoic cover by such primary structures and (c) entirely superficial features such as slumping and fault-drag. These genetic categories do not necessarily bear any relation to the size of the structures. However, a dislocation of the magnitude of the Saimo Fault (4 km. maximum throw) must surely fall into category (a) and since this fault is geometrically compatible with an origin by tensional stress, with a secondary north-south compressive component, the writer feels justified in assuming this stress-field for the whole area and to a considerable depth in the crust.

The postulated stress arrangement thus differs significantly from that described by Anderson (1951) for normal faults. Anderson places intermediate and least principal stresses in the horizontal plane and maximum stress (gravity) vertical. Structures in the present area, in particular those of the fault-arch strip in the foot-hills, show clearly that a horizontal compressive north-south stress was greater than gravity, aided undoubtedly by the near-surface position of the structures. The writer proposes the stress system shown in figure 39 . This is the same as Anderson's system for strike-slip faults but in this case the faults are parallel to the greatest principal stress and in theory negligible strike-slip displacement occurs. This situation comes about because the positive component is the east-west tension of which the compression is largely a secondary result - largely, but perhaps not entirely since, as Holmes (1965, p.1065) pointed out, the floor of a major rift valley, on subsiding, must be thrown into compression along its length due to the shortening of an arc of the earth's circumference.

At this point one could return to the experiment of Baine and Beebe and reasonably argue that their model showed 'en echelon' faulting without any evidence of shortening parallel to the faults. In point of fact the Baringo structures are of measurably greater amplitude than those of the model: the throw/length ratios of faults in the model ranged from 1/25 to 1/40, whereas the Tegit ratio is 1/17 and the Saimo ratio 1/12.

It is concluded therefore that a regional tensional stress field of the type postulated has produced the observed pattern of deformation which also shows the effects of a compressive component normal to the tension. The compression can be adequately explained as the direct result of the primary tensional strain, but it may also be caused by a regional Rift-floor compression as described by Holmes, or again a slight

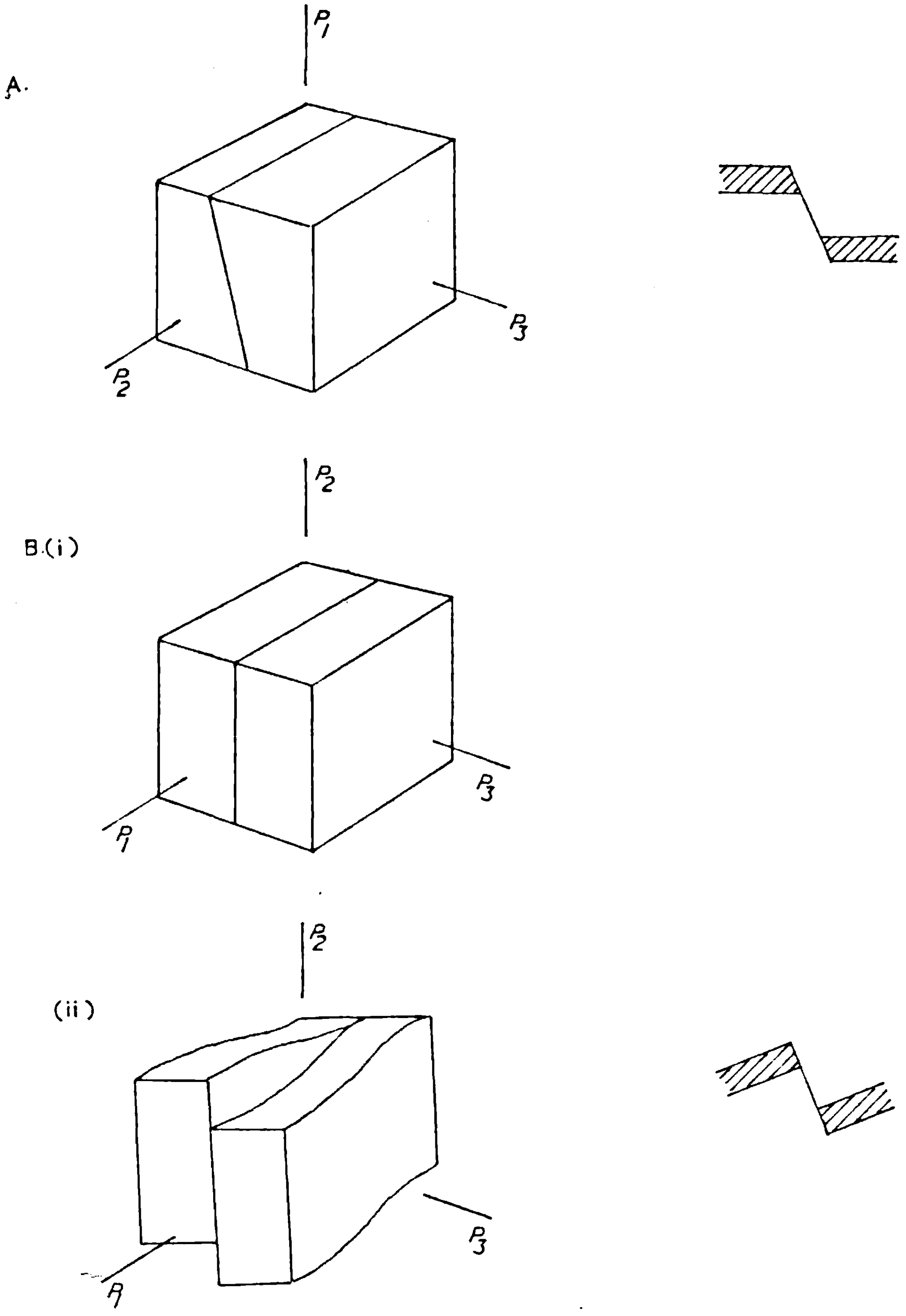


FIG. 39 STRESS DISTRIBUTION IN NORMAL FAULTS A. Tension/gravity displacement. B(i)&(ii). Tension displacement in the Kamasia Range (P_1 P_2 and P_3 are greatest intermediate and least compressive stress axes respectively) Note, in B(ii), flexure on axes parallel to P_3 and rotation of blocks

strike-slip component could produce the same results (see below). It should be emphasized that in fact many of the smaller faults must be simple gravity 'adjustments' to the primary structures and cannot be explained by the main hypothesis, e.g. the E-W faults in the Tegit fault arch.

The above explanation is, however, by no means complete - one outstanding problem is the simple question of why the main scarp faults in preference to any others should have developed to their present magnitude in their present positions. Secondly there is the interesting parallelism between the main range and axial fault-arch belt in the eastern foothills. Both structural belts are relayed by 'en echelon' faults oblique to their general trend.

4. Regional considerations

(i) General

The line of major faults marked by the Kamasia scarp must imply a major structure in the crust, but of a markedly different character to the Elgeyo Fault which seems to be one single simple vertical displacement. The Kamasia, by contrast, appears to be caused by the great exaggeration of a number of structures which are also seen on a much smaller scale to be the characteristic features of the area as a whole. A major dip-slip fracture of the crust would presumably cause a single great fault scarp on the Kamasia line as it has on the Elgeyo - and it is not likely that the huge 'en echelon' Kamasia displacements are simply the result of diffraction of such a single deeper fault. While it is true that the range as a whole is depressed relative to the Elgeyo, a considerable amount of positive upward arching certainly occurred, on the Saimo Fault at least, in the first major episode of faulting and it is likely that any proven upward movement is the result of the faulting rather than of any generalised 'belt of uplift' as suggested by Martyn (op.cit. p.157 & fig. 52). Martyn postulated such a situation particularly in the case of the Tiim area of 'tilt-blocks' which he regarded as the result of the collapse of a great upwarp. The writer prefers to regard these structures as the result of faulting antithetic to a deep concealed southern extension of the Saimo Fault, i.e. essentially a faulted monocline over a deep-seated fault. This type of situation is well illustrated by one of Cloos's clay models (Cloos 1930, fig. 8). South of Martyn's 'Tilted-block province' the Kamasia scarp is again composed of a number of large 'en echelon' faults, down-throwing to the east (Lippard, Ph.D. thesis in preparation).

A possible explanation is sought in a slight transcurrent component of movement. It should be stressed immediately that there is no physical evidence whatsoever for strike-slip movement on individual faults; on the other hand it is apparent that a regular line of large 'en echelon' normal faults in the same orientation and displacing in the same direction must cause a slight transcurrent movement of the two plates on either side of the line due simply to the shortening effect parallel to the faults (fig. 40). A simple experiment with the paper model well illustrates this: the 'faulted' paper was attached at either side to separate but contiguous cardboard plates; the 'en echelon' cuts in the paper were distributed evenly over the surface but on moving apart the cardboard base-plates not only were the usual tilted fault-arches produced in the paper but it was impossible to eliminate a transcurrent movement along the contact of the base-plates and the largest faults occurred above this contact. This transcurrent movement was of about the same amount as the overall extension normal to the fault-traces but less than a quarter of the dip-slip movement on the master faults. The writer is uncertain whether to apply the corollary of this effect, and postulate a deep seated transcurrent displacement (as well as the regional tension) causing the great Kamasia en echelon displacements or whether the original route to this hypothesis was in fact nearer the truth i.e. the possibility that a single fault will grow to a size where the secondary compressive stresses produced

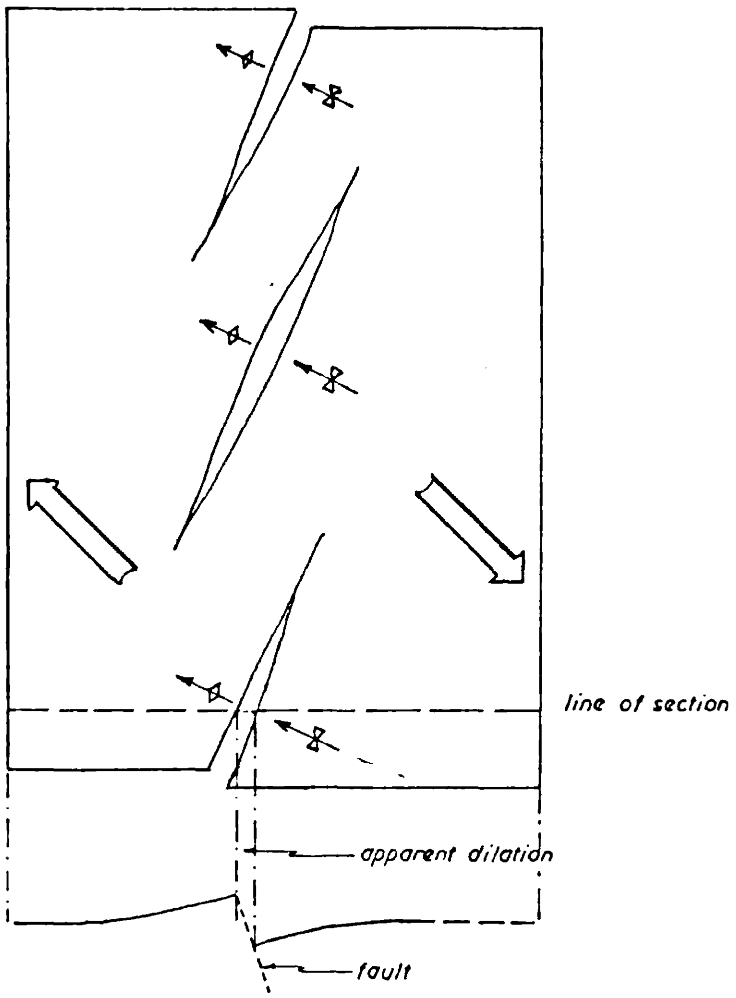
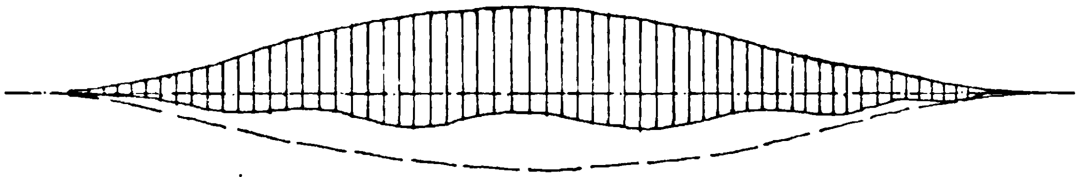
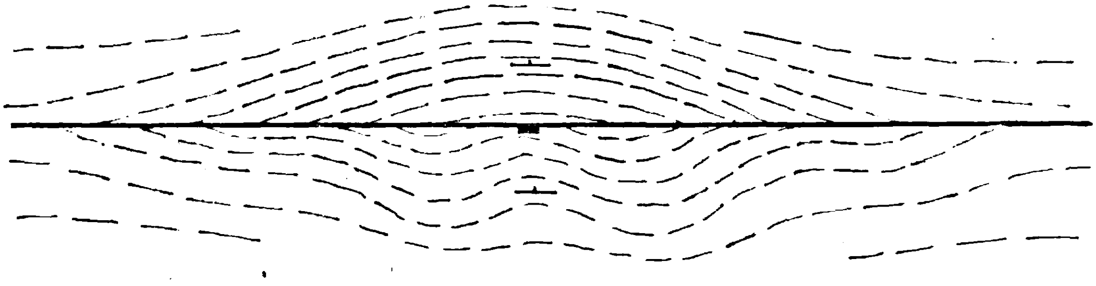


FIG. 40 'EN ECHELON' DIP-SLIP FAULTS AND LATERAL DISPLACEMENT OF THE AFFECTED PLATE



(a) Front elevation of fault displacement



(b) Plan view of fault with structural contours

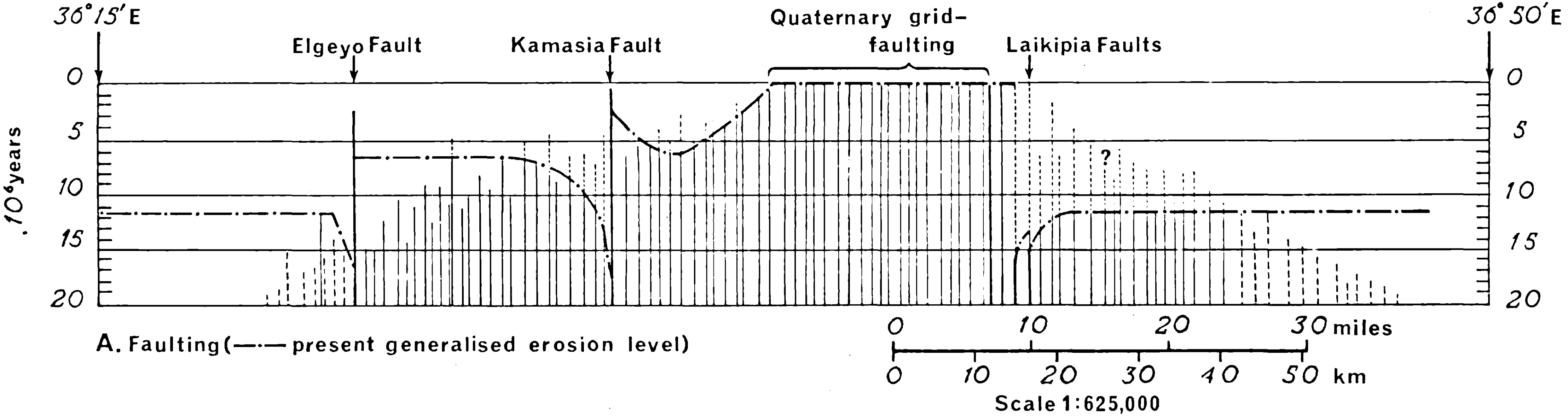
FIG. 41 ORIGIN OF THE 'HALF-BASINS' AT THE FOOT OF THE SAIMO FAULT-SCARP will be sufficient to propagate more displacements on the same trend. The Kamasia Range is perhaps too long and persistent a feature for the second suggestion to be very likely, and some recourse must be made to deep-seated controlling structures. (Note that it is not suggested that the actual orientation of the faults is caused by the deep transcurrent movement.)

As a tailpiece to the above tentative hypothesis two points arise: the suggested movement in the Kamasia is right-lateral but the 'en echelon' faults in the Laikipia area on the other side of the Rift are in an opposing arrangement i.e. suggesting a left-lateral movement. Geophysicists would, it seems, be happy with strike-slip movements on the East African rift system (see McKenzie 1970) but it is worth emphasizing again that as far as the evidence for the last 15 million years goes, any actual strike-slip movement has been negligible in comparison to the dip-slip displacements.

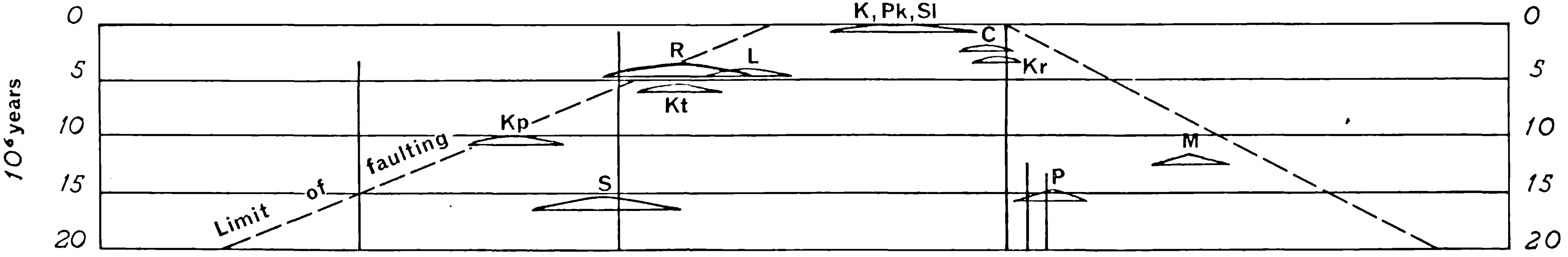
(ii) Migration of faulting

In Baringo, as over the whole length of the Rift, both faulting and vulcanism appear to have migrated towards the centre of the Rift with time (McCall 1967, p.101; Baker 1965, p.4). However, the writer does not entirely agree with the view often stated (Baker op.cit., p.4) that the Quaternary faults in the Rift centre are more closely spaced than older faults. In fact the detailed mapping of the Kamasia (Martyn 1969, Lippard Ph.D. thesis in preparation, and present map) indicates that very closely spaced faults of small displacements also occur in the older strata - this is particularly noticeable where erosional windows in unfaulted strata expose older strongly faulted successions e.g. in the eastern outcrops of Chemeron Formation (Martyn op.cit., map). Lippard (op.cit.) has mapped very closely spaced faults in the group II phonolites in the southern Kamasia and Carney (Ph.D. thesis in preparation) has shown that fairly close faulting also occurs in the Rumuruti Phonolites of the Laikipia plateau. It seems that the late Quaternary faults have attracted more attention since they form conspicuous uneroded scarps whereas minor faults of earlier age are only identified by detailed investigations.

It thus seems that in the Kamasia area the western limit of close faulting has migrated eastwards with time. Figure 42 shows that the fault pattern seen in a section across the Rift through the present map area can be explained by the intersection of the present erosional level - relative to time-stratigraphy - with a regular hypothetical surface representing the migration of faulting with time. Thus although Baker (op.cit.) suggests that faults with progressively closer spacing with time are correlated with progressively higher levels of magma generation in the crust, the writer is very doubtful of the premise that faulting has become more closely spaced at all. However recent largely unpublished geophysical (seismic) work does seem to indicate anomalies in the upper crust below the Rift centre and one observable feature of the late Quaternary fault zone is possibly significant: without exception, other workers (e.g. Baker op.cit., McCall 1967, Martyn 1967) have stated that this zone is 'median' or 'central'. This is not so; examination of published maps (Baker 1958, 1963; McCall 1967; Thompson & Dodson 1963) shows that the zone of recognized late Quaternary faults is by no means central relative to the major Rift boundary faults, but in fact 'cuts the corners' of the great kink in the Rift direction centred on Nakuru (fig. 43). Both the zone and individual faults trend much more nearly north-south than the faults of known earlier age. This is particularly well-shown in the Lake Hannington area (McCall 1967). This suggests, at least, that the directional controls on faulting have altered with time, and if one postulates control by basement structures to explain the major fault trends, it cannot be denied that the Quaternary fault trend tends



A. Faulting (—·— present generalised erosion level)



B. Volcanic centres or complexes

Ch: Chepchuk, K: Karossi, Kp: Kaption, Kr: Karau, Kt: Kaichurot, L: Lomelo, Pk: Pakka
P: postulated phonolite centre, R: Ribkwo, S: Sigatgat, Sl: Silale, M: Murgomul

FIG. 42 *Space/Time Distribution of Faulting and Volcanism, Baringo Section of the Kenya Rift Valley*

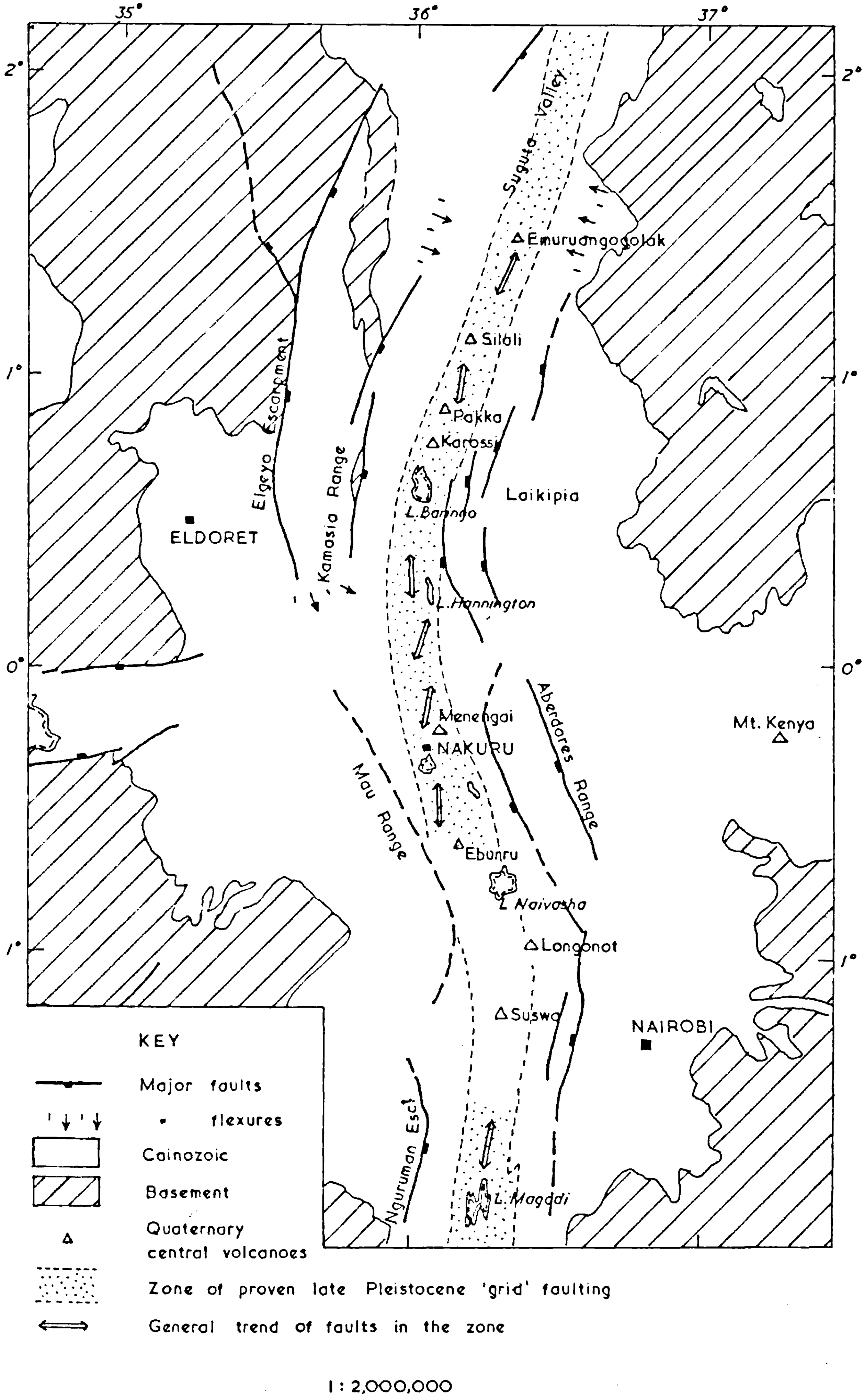


FIG 43 THE 'MEDIAN' QUATERNARY FAULT BELT IN THE KENYA RIFT

to support the idea of actual crustal separation put forward by some geophysical workers (e.g. Girdler et al., 1970). It cannot, however, be emphasized too strongly that the figures for amount of separation in the last 15 million years often suggested - 30 km. by McKenzie (1970) is one of the more conservative estimates - have no support whatsoever in the geological evidence. In North Baringo phonolitic and intermediate centres known to be older than the plateau phonolites (11-13 m.y. - Bishop et al., 1969) have been found within four or five kilometres of the Quaternary fault zone and central volcanoes (Sceal, Ph.D. thesis in preparation; Golden, Ph.D. thesis in preparation). The writer's view, in summary, is that there may be crustal separation, but that it can be only slight and relatively recent in age.

(f) Chronology of faulting - a summary

Stratigraphic relationships examined in detail, combined with radiometric dates from the felsic lavas, have enabled the faulting in the Kamasia to be dated with some accuracy (fig. 44). The evidence for relative ages and amounts of movements is described in Part I; the present section simply summarises the conclusions, with some comments on the regional significance.

Earth movements before the group II phonolites in the Kamasia are indicated by basement topography in the Kito Pass area (McClenaghan op.cit.) and sediment thickness variations in the Saimo section (Martyn 1969, p.25 & fig. 10). At a later stage the deposition of the Muruywr Beds and the Ngorora Formation was affected by coeval fault movement and large-scale tilting (see fig. 17) amounting to over 1000 feet of relative subsidence in the case of the Ngorora. However, no major unconformities occur within the Tugen Hills Group in the north and central Kamasia and movement appears to have been continual but spasmodic.

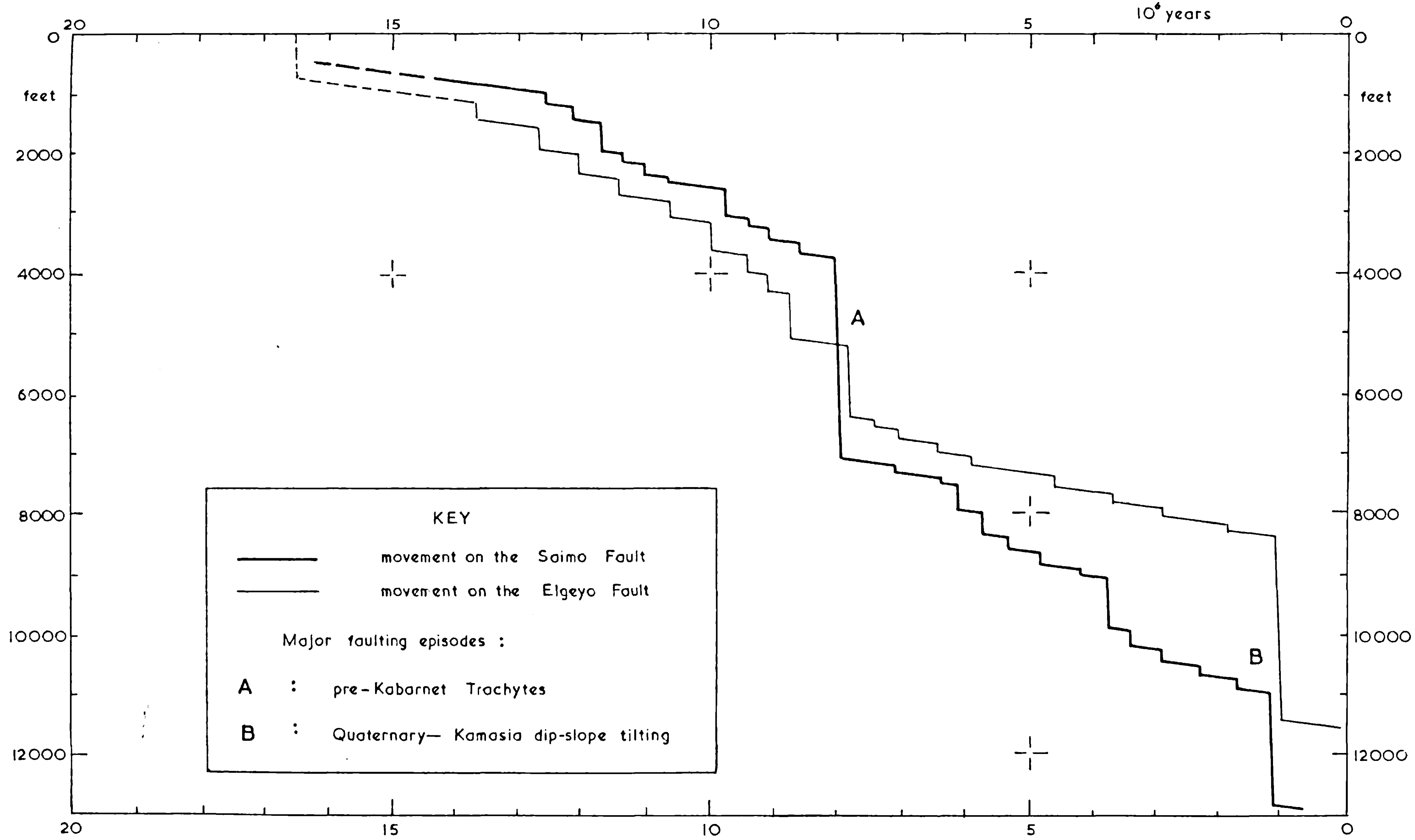


FIG. 44 SAIMO AND ELGEYO FAULTS — AN APPROXIMATE TIME SCALE FOR INFERRED MOVEMENT

The major faulting episode which preceded the Kabarnet Trachytes caused the most striking geological feature of the main range in the unconformity between the trachytes and the Tugen Hills Group and the relict topography in the latter. This episode can be fairly closely dated at between 8 or 9 million years (K-Ar dates from the Sumet Phonolite) and 7 million years (K-Ar dates from the Kabarnet Trachytes - see Part If). Martyn (op.cit., p.183) describes its age as middle Pliocene and claims that it is not represented elsewhere in the Rift; the writer suspects that it is, in fact, that faulting episode usually described as late Miocene/early Pliocene and known from several areas (Kent 1944, Baker 1965, McCall 1967). The event is usually ascribed to that age because it affects the late Miocene phonolites of the Rift shoulders but is demonstrably earlier than Pliocene volcanics within the rift. In the Kamasia, however, both radiometric and palaeontological evidence (Bishop and Chapman 1970) shows that the plateau phonolites range well up into the Pliocene and the faulting episode has to be dated accordingly. The nearest described correlative event is the 'First major faulting episode' of McCall (1967, p.93) in the Lake Hannington area. Although McCall dates this episode as Miocene or early Pliocene, subsequent K-Ar determinations date the Thomsons Falls Phonolites, which McCall says almost certainly pre-date the faulting, at 6.2 to 6.7 million years. If McCall's conclusions and the radiometric dates are correct the first Laikipia faulting may even be younger than this major Pliocene movement in the Kamasia.

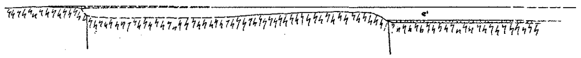
Slight main scarp faulting probably occurred during accumulation of the Kabarnet Trachytes (fig. 30) and there is sedimentological evidence (Martyn 1969, p.83 & fig. 31) for movement on the Saimo Fault during deposition of the basal member of the Kaparaina Formation, which in the present area seems to have been restricted by this faulting to the area east of the main scarp.

The bulk of the movement in the fault-arch and half-dome belt followed the Kaparaina Formation and preceded the Kaperyon, and is therefore dated at about 5 million years (dates from trachytes high in the Kaparaina). The overstep of the Kaperyon on to Lukeino Member of the basal Kaparaina and the angular discordance of the two formations are best seen near Chesoton. On that hill, the gently west-dipping Kaperyon overlies more steeply dipping (20°) Kaparaina basalts and tuffs, well exposed at the waterfall of Kamsoror. Further movement occurred which also tilted the Kaperyon Formation to the west of the fault-arch belt; this preceded a period of planation on the resultant surface of which the Ribon Trachyte (3.7 m.y.) was extruded. In this pre-Ribon movement must be included the faulting of the Kaperyon at Mukur and probably considerable movement on the Kito Pass Fault.

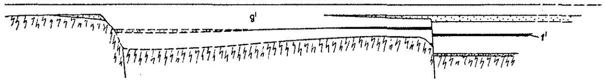
Post-Ribon faulting in the map area is seen in the set of faulted tilt-strips east of the main Ribon plateau. The largest of these faults has a throw of 700-800 feet.

The faulting in the Loyamarok Trachyphonolite is, obviously, younger than the 0.5 m.y. age of that lava, and from the uneroded appearance of the fault scarps is judged to be very young indeed.

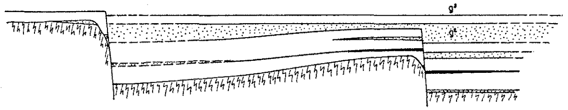
In the present area there is little direct evidence for the age of the later movements on the main scarp faults. Fault-drag occurs in both the Kaparaina and Kaperyon formations on the Saimo, Sumet 'A' and Kito Pass faults, there are huge but ill-defined facets on the spurs of both the Kamuiton and Sidekh scarps and distinct profile-breaks in most of the streams on the former range. Martyn (op.cit., fig. 61) dates a major movement of the Saimo Fault at about 1.5 million years, occurring after deposition of the Chemeron Beds; the geomorphology of the dip-slope of the main range suggests that it received its present tilt at about the same time. Presumed synchronous faulting on the opposite



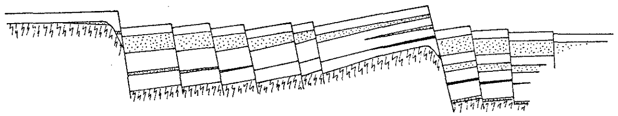
(a) Early rift faulting and extrusion of the Sidekh Phonolites 14 m.y.



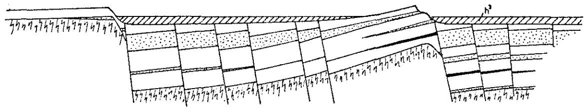
(b) Extrusion of Tiim Phonolites and sediments, and Uasin Gishu phonolites. 11 m.y.



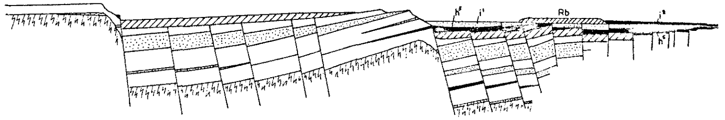
(c) Continued faulting, deposition of Ngorora Formation and Ewalel Phonolites 8 m.y.



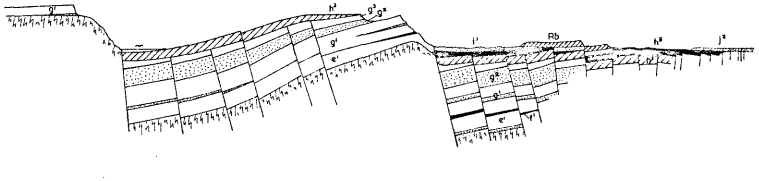
(d) First major faulting episode 8 m.y.



(e) Extrusion of Kabarnet Trachytes 7 m.y.



(f) Continued faulting, extrusion of Kaparaina Basalts. Faulting and deposition of Kaperyon Formation. Faulting, planation and extrusion of Ribon Trachyte and 'Lokwaleibit basalts 3.5 m.y.



(g) Second major faulting episode. Tilting of the dip-slope. In the east, minor faulting, planation and extrusion of the Loyamarok Trachyphonolite. Late Pleistocene grid faulting Present

Vertical exaggeration x2·25 Key as for map and figure 5

FIG. 45 DIAGRAMMATIC SYNOPSIS OF THE TECTONIC-GEOMORPHIC EVOLUTION OF THE NORTHERN KAMASIA HILLS (eastern) side of the Kaparaina anticline affects lavas dated at 1.5 to 2.0 m.y., above the Chemeron Beds, but unconformably overlain by the Kapthurin Beds and the Lake Baringo Trachyte (0.23 m.y.). Martyn suggests that the Kapthurin Beds are the products of the erosion resulting from the major fault rejuvenation.

The size of this major movement of the Saimo Fault is gauged from the absence of basement pebbles in the Chemeron Beds, although the metamorphic rocks are exposed up to 1500 feet above the foot of the scarp at the present time (Martyn op.cit.). The movement may tentatively be correlated with the 'second major faulting episode' of the Lake Hannington area (McCall 1967, p.97) which produced the facing structure of Lake Hannington Phonolites on the scarp above the lake. Clearer indication of the age of the faulting in that area would be given by radiometric dates, as yet unavailable, for the lavas in question.

The section in figure 45 illustrates both the faulting episodes and the general morphological evolution of the range in the map area.

(g) Relationship of faulting and volcanicity

Distribution of the main volcanic sources in the Kamasia area supports the generally accepted observation that the limits of both faulting and volcanism have migrated towards the centre of the Rift, where the Quaternary activity is concentrated. Very small amounts of Quaternary basalts are exceptions to this generalisation: Pleistocene basalt flows occurred in the eroded flanks of the Ribkwo complex (Webb op.cit.) and in the eroded Pliocene (?) succession in the hills east of Silale (Golden pers.comm.). However, as figure 42 shows, no major centres are known outside the limits of closely spaced faulting, although at any one stage they may have been fairly generally distributed in space within those limits.

Within the generalisation, it is significant that volcanism in the Kamasia does not seem to be associated with individual faults, however large, but can be correlated with faulted flexures such as the Kaparaina Range and the area around and to the north of Tiati. A possible explanation for this association lies, as suggested, in the necessary extension which for geometric reasons cannot be expressed by the faulting in those areas.

With regard to the faulting-volcanicity relationship in time, Martyn denies any significance in the fact that major faulting occurred after the accumulation of the Tugen Hills Group and again after the Kaparaina Basalts. Kent (1944) claimed that faulting terminated episodes of volcanicity but he invoked the compressional hypothesis of rift formation to explain this. The present writer's conclusion is that east-west tension, not compression, was certainly the main tectonic control in the Kamasia but that faulting does indeed terminate eruptive episodes and that this is adequately explained by the tensional theory: it is agreed that a regional tensional stress will facilitate igneous intrusion, particularly dyke injection (Anderson 1942) with consequent extrusion of lavas. (The plateau phonolites are usually supposed to have been extruded from fissures and a large proportion of the basalts certainly were.) Relief of the stress by faulting should therefore have the reverse effect and intrusion would be inhibited; the greater the strain, the more complete is the cessation of igneous activity, a long period of erosion or sedimentation intervening before the next evidence of volcanism. This latter effect was noted by Kent (op.cit.) and it is best exemplified in the present area by the near-planation of the sub-Kabarnet surface following the first major faulting.

The first major faulting episode also suggests a correlation between tectonism and petrochemistry. That the faulting was accompanied by deep-seated events, possibly pressure changes, in or below the crust is surely indicated by the distinct change in chemistry of the lavas erupted subsequently, which form a basalt-mugearite-trachyte association in contrast to the older undersaturated association dominated by phonolites (see Part V). One might expect a similar change to have accompanied the Pleistocene faulting which involved movements on the main scarp faults of magnitude equal to those in the earlier episode. No such change is obvious, but recent wet chemical analyses (Carney, pers.comm.) strongly suggest that many of the Quaternary 'Nginyang-type' basalts (Martyn op.cit., p.137) are alumina-rich and more siliceous than the earlier types (but still falling in the 'alkalic' field).

PART III: GEOMORPHOLOGY

(a) Early morphological evolution

Figure 45 illustrates the overall morphological and tectonic evolution of the ranges in the present area.

As Martyn shows (op.cit., fig. 22), the greater part of the time span of the Tugen Hills Group is recorded by the intercalated sediments and inter-flow weathering horizons. Thus it is that the sediments record the fault movements, which were, at least in the later stages, considerable, but it appears that never at any stage (apart from the early scarp restricting the lower Sidekh flows near Kito Pass) was there any topographic barrier to the spread of the phonolite flows. Accumulation continually kept pace with tectonism and at any one time the landscape would have given little hint of the concealed structure. However at about 8.0 m.y. B.P. the faulting accelerated and the Kamasia finally appeared as a physiographic entity (fig. 45(d)).

The first major faulting episode produced relief on the main scarps amounting initially to at least two thirds (1500 to 2000 feet) of the present amount. The overstep of Kabarnet Trachyte on to Tiim Phonolite suggests that the initial scarp must have been considerably reduced in height by the time the trachyte was extruded. Despite the close proximity of the isotopic data for Sumet Phonolite and Kabarnet Trachyte, considerable erosion occurred between the two lavas. This involved, chiefly, the near planation of most of the area of the present dip-slope, even though this was composed of phonolite overlying sediments in tilted fault-blocks. The surface so formed - essentially a pediplane - contrasted strongly with the residual ridge (inselberg) along the crest of the range. A present-day analogy can be seen in the area to the south-west of Nginyang where inselbergs, e.g. Adonyasas, of Kaparaina Basalt rise abruptly from a surface cut across the same faulted and tilted formation.

Where the sub-Kabarnet surface is cut across phonolite, the lava is often deeply weathered to a soft whitish rock, composed chiefly of ?kaolinite. This is well exposed at Yatya; on the main range it occurs extensively about half-way down the dip-slope. It is noteworthy that nothing resembling laterite or red soils is ever seen preserved beneath the Kabarnet Trachytes, although laterite occurs extensively on the Uasin Gishu Plateau and red soils on the higher parts of the Kamasia. In fact the weight of the evidence now overwhelmingly suggests that most of the red soils on the Kamasia and in the Timboroa area represent a time span extending into the earlier Quaternary (near Timboroa they lie on the Quaternary Eldama Ravine Tuffs) and their extent can in fact be closely correlated with those areas receiving at present more than 40 inches of rain per annum which means, in effect, those areas with an altitude of 7000 feet plus. If the 'Bartolimo shelf' of Kabarnet Trachyte does, as suggested in Part II, preserve the original attitude and altitude of the trachytes, then the original altitude of the sub-Kabarnet surface must have been less than 6000 feet; this altitude, being within the Rift, would almost certainly have been too low, and therefore too dry, for laterite formation. It can be argued (King, pers.comm.) that the lateritic weathering products were removed by erosion consequent upon the faulting in the Kamasia. If this occurred it is difficult to understand how the red soils, now seen on the Saimo range, were preserved on the deeply dissected topography while being absent from the near-planar surface beneath the trachytes. None of the younger sedimentary units in the succession shows evidence of being derived by erosion of lateritic areas with the exception of the late-Pleistocene Kapthurin Beds which are predominantly red-brown in colour, as also is most of the present alluvium.

Sediment deposition associated with the Kabarnet Trachytes was in the present area entirely confined, probably by minor faulting, to the area east of the main range; the complete absence of rocks younger than the Kabarnet Trachyte on the main range or the dip slope indicates that spasmodic fault movement continued to keep pace with accumulation and restricted it to the area east of the main scarp. However, Kaparaina Basalt certainly occurs in the crest and extensively on the dip-slope of the range in the south (Martyn 1969, Lippard op.cit.); it is not impossible that the basalts did spread to the dip-slope in the north but have since been entirely removed by erosion.

Minor unconformities between Kabarnet and Kaparaina, and Kaparaina and Kaperyon formations record the continued tectonic activity in the eastern foothills and the fault-arch belt but there is no evidence that actual topographic features existed in this area until a major faulting episode in these areas between 5 and 4 m.y. B.P. The subsequent geomorphological history of the area to the east of the main scarp has been examined in some detail.

(b) Topographic development of the eastern foot-hills

1. General

The two salient features of the present topography are the superimposition of the main E-W rivers on the fault-arches and horsts at Yatya, Kisitei and Mukur, and the near-horizontal base of the Ribon Trachyte on a surface cut across all formations between the Kabarnet Trachytes, Kaparaina Basalts and Kaperyon Formation.

The remarkable relationship of main streams to structure - at each of the localities mentioned above they cut across the highest parts of the structures - led to the search for the surface on which the drainage was initiated. In the first place it was observed that a number of the highest peaks east of the main scarp had heights very close to 4000 feet.

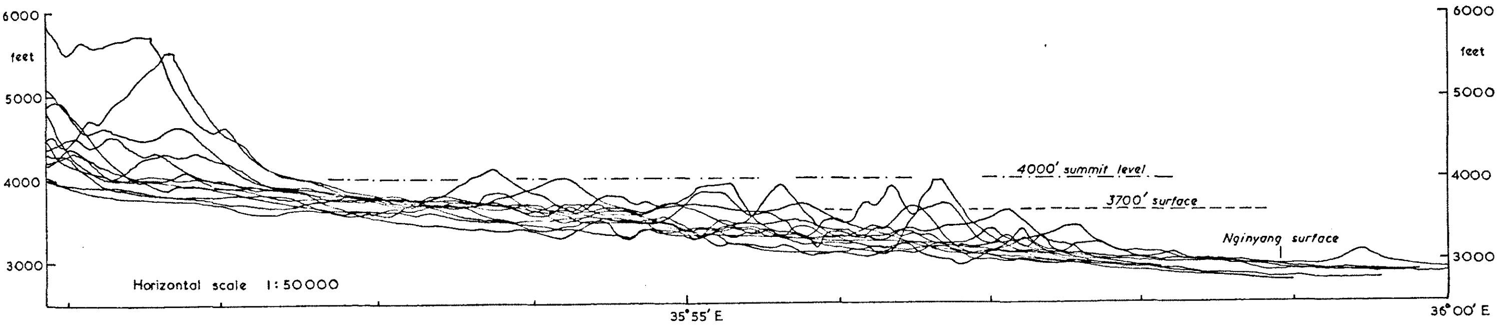


FIG. 46 SUPERIMPOSED EAST-WEST TOPOGRAPHIC SECTIONS ACROSS THE EASTERN FOOT-HILLS (see figure 48)

This is in fact the average height of the break in slope at the foot of the main scarp, but the summit level is maintained eastwards, as the river valleys become deeper (fig. 46). Of six summits within a few feet of 4000 feet, one is in Kabarnet Trachyte, four are in Kaparaina Formation (two lower, two upper trachytes and intrusive equivalent) and one in Kaperyon Formation. (The surface of the Ribon Trachyte is also close to 4000 feet but this, as will be clear, is fortuitous.)

The '4000 foot summit-level' is suggestive but it is in fact a lower surface, between 3800 and 3500 feet, which can be more convincingly demonstrated by a variety of methods based on the topographic map.

2. Projected-profile model

Following the methods of Barrell (1920) and Bates (1939) a projected profile model of the Bartabwa sheet (1:50,000 sheet 90/2) was constructed. The method involved subdividing the map into E-W strips, for which purpose the 1 km. grid lines were used, and determining the highest contours within the strips at one tenth of an inch intervals along their lengths. The points obtained were plotted on 1/10" graph paper (vertical exaggeration is x4), the points joined, graph paper glued to cardboard and the profile cut out with a modelling knife. The twenty-eight profiles were then mounted, at the correct horizontal interval in a slotted wooden base.

The result shows rather well, in the writer's view, the presence of two surfaces: the bulk of the foot-hills area is composed of a dissected surface at between 3800 and 3500 feet. The Ribon Trachyte, the base of which is at an altitude of 3500-3600 feet, preserves part of this surface, and is outlined in red on the profiles. The other prominent surface is at 2800-3000 feet and, unlike the higher level, is as obvious in the field as on the model; this is designated the 'Nginyang surface', across which advanced the Loyamarok Phonolite, also outlined in red.

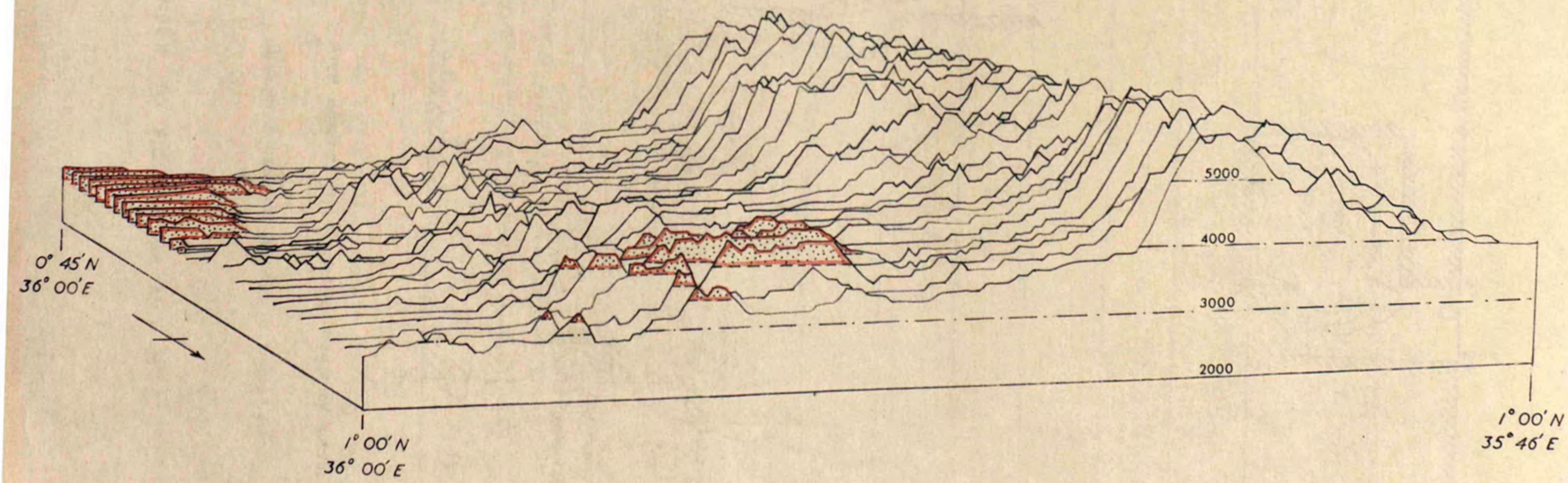


FIG. 47 DRAWING (FROM A PHOTOGRAPH) OF THE PROJECTED PROFILE MODEL ▨ : Ribon Trachyte (centre) and Loyamarok Trachyphonolite (left)

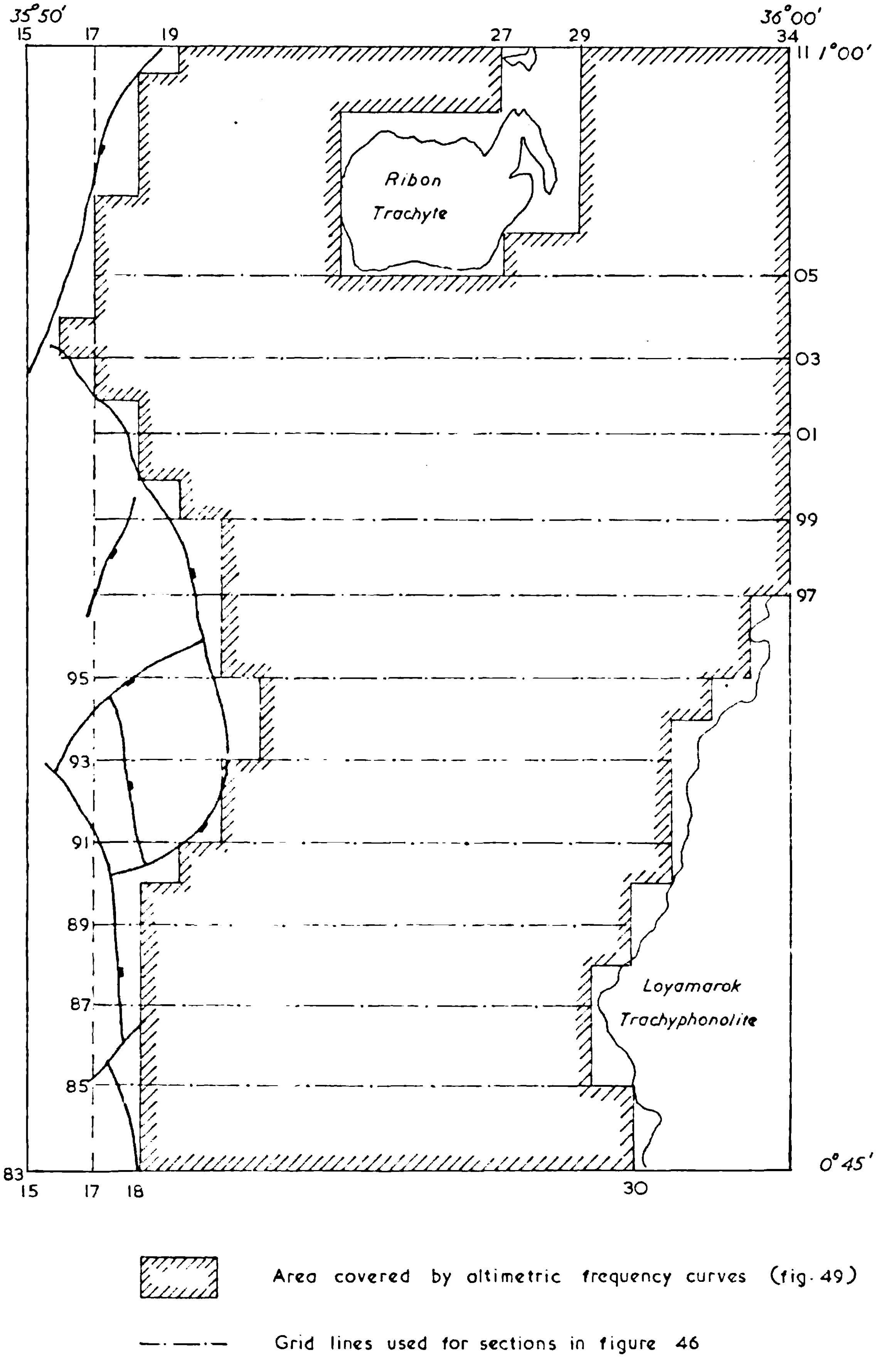


FIG. 48 MAP INDEX TO FIGURES 46 AND 49

3. Altimetric frequency curves

Two types of altimetric frequency curve were plotted (fig. 49). In the one type the number of closed-contour sediments at varying altitudes was plotted; in the other, 'spot elevation' method, the highest contour in each grid square was found, and the frequency of the different altitudes plotted. (In both cases the area studied (fig. 48) was only that to the east of the main scarp fault and excluding the areas of the Ribon Trachyte and Loyamarok Phonolite since their surfaces are original flow surfaces, not erosion surfaces.) Both curves have a strong peak at 3700 feet and the grid-squares altitudes curve has a peak at 2900 feet representing the recent Nginyang surface. The latter is not shown, obviously, on the closed-contour summit curve since that method is for indicating dissected surfaces only.

There is thus strong evidence for a local surface between 3800 and 3600 feet but designated, for convenience, the '3700 foot surface' on which, it is probable, the present drainage lines were established and on to which the Ribon Trachyte was extruded at about 4 m.y. B.P. The 4000 foot summits may be remnants of a still earlier surface and presumably stood above the lower surface as inselbergs. It is noteworthy that no through E-W streams cross the Kaparaina Range to the south of the present area, and it seems probable that this feature was already established as a ridge at the time of the 3700 foot surface.

The faulting episode which affects the Ribon Trachyte and Lokwaleibit basalt in the north-east of the map area by lowering base level in the Rift centre presumably caused the rejuvenation of the major streams which became impaled on the exhumed horsts and fault-arches of Kabarnet Trachyte. The rapid incision of the rivers was accompanied by a more general retreat of the hill slopes from east to west forming the 'Nginyang surface' which is effectively the present local base-level of erosion. It may be emphasized that, in contrast to the lava-plains east of Nginyang, the Nginyang

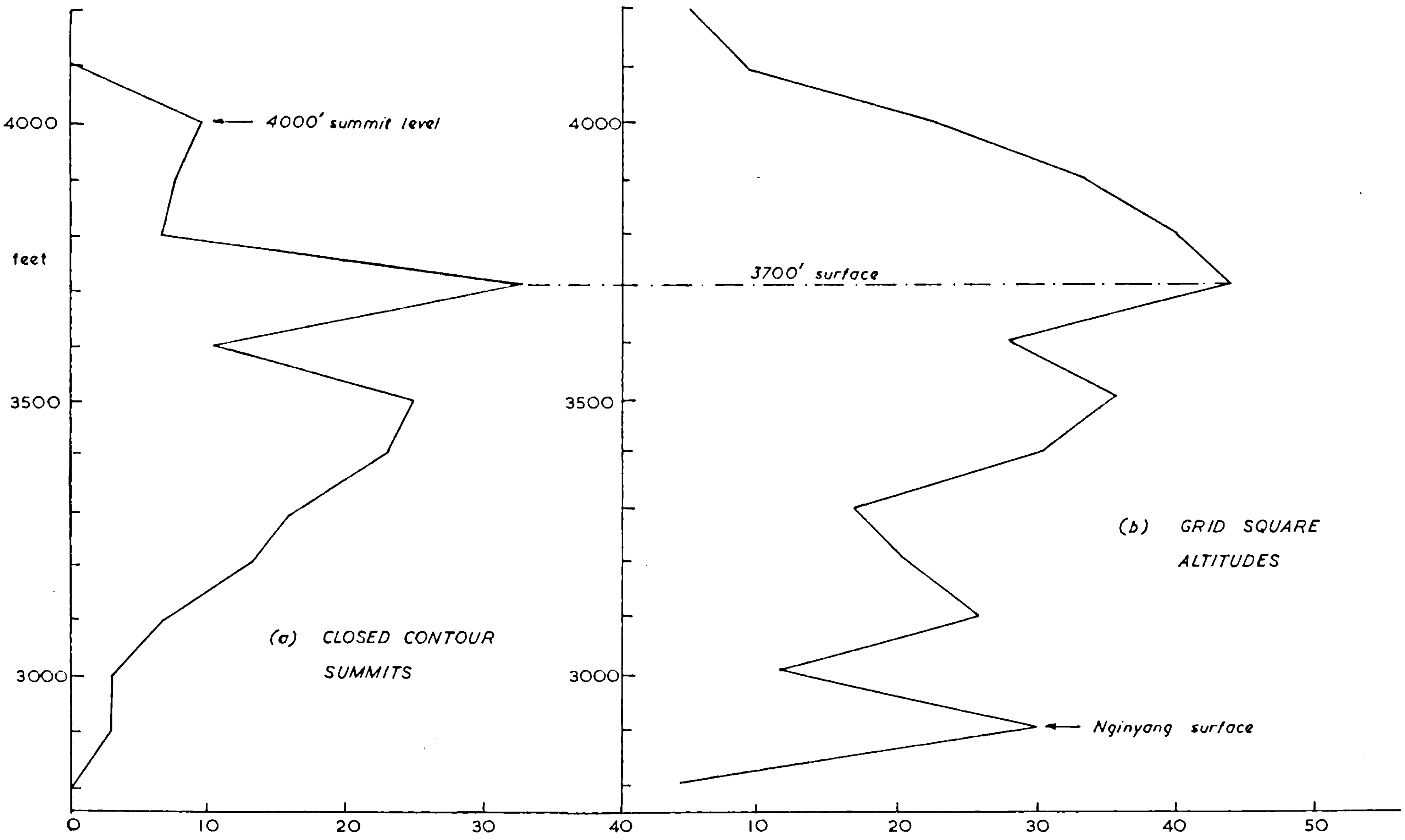


FIG. 49 ALTIMETRIC FREQUENCY CURVES (see figure 48)

surface is a true erosion surface cut across faulted and tilted basalts and trachytes with very little surface débris. The area around Adonyasas and Chepuromoi provides a classic example of the inselberg and pediment type of landscape with sharp breaks in slope at the foot of the hills, 'pediment passes' and surface run-off carried in a multitude of small radiating rills and gullies.

Had the Loyamarok Phonolite advanced a few miles further to the west it would have completely concealed the Nginyang surface and it does in fact almost butt against the older eroded hills at Chepuromoi. The lava has diverted the west-east drainage to the north along the flow-front in the present Burususwa River. The sharp break in stream profile entailed in this diversion is evidenced by the grain-size of the débris in the stream beds: the sandy bed of the Burususwa can be used as a very reasonable road (for land-rovers) southwards from Nginyang to the southern edge of the map, whereas progress is drastically slowed by the coarse cobbles and boulders encountered as soon as one turns off into any of the major tributaries.

4. Present processes

The longitudinal profiles of the trunk streams between the scarp foot and the Burususwa have in general very even gradients whereas their local tributaries, in the foothills, have strong concave profiles and in many places are threatening to capture, by headward erosion, their parent stream (fig. 52). It is suggested that the explanation for this cannibalistic behaviour is that the shape of the profile of the trunk stream has been inherited from the ancient '3700 foot surface'; although rejuvenation has occurred, increased load, due to subsequently increased erosion of the main range, and evidenced by the wide braided channels, has prevented later alterations to the profiles by down-cutting. The small local tributaries on the other hand, unencumbered by débris from the main range, are eroding vigorously. Good examples are seen near Yatya: a small stream south of and parallel to the main stream is very close to capturing the latter a few hundred yards upstream from the village; similarly, another right bank tributary, at Kapgoyo three miles northwest of Yatya, has headstreams at a distinctly lower level than the bed of the main stream only four hundred yards away. (These differences in level cannot be seen on the topographic map but are clear on the aerial photographs where their existence was proved by parallax techniques on the stereometer.)

(c) Development of the main range

The drainage on the main range and dip-slope reflects, in general, the overall structure much more closely than that in the eastern foothills, even to the extent that the Bartabwa river follows the slope of the tectonic 'gangplank' between the Saimo-Sumet and Kito Pass fault systems.

However, time-correlation of morphogenetic events on the main Kamasia scarp with those in the foothills is difficult and involves apparent contradictions: there is good evidence (see Part II) that the Saimo fault system moved considerably at about 1.0 m.y. B.P. and that the bulk of the movement was downthrow alone; however any large movement on the main scarp faults in the present area would surely have affected the '3700 foot surface' which is dated by the isotopic ages of the Ribon Trachyte at no younger than about 4 million years. No such disturbance is evident - the Ribon Trachyte is still a horizontal plate, except at its eastern margin where it has been down-faulted. On the other hand, the deeply incised main streams of the Kamuiton scarp, interrupted by waterfalls at the same level but on different substrata, together with large facets on the spurs, seem to indicate a rejuvenation of the Saimo Fault, at least, at a fairly recent date. The smaller streams, while lacking the waterfall knick-points and deep incision, often have a distinct break in profile at about 5000 feet, e.g. the stream immediately east of Kamuiton summit.

Large waterfalls on the Panwa, Chepkokel, Terenin and Bargetyo rivers are at 4700, 4600, 4800 and 4800 feet respectively, at horizons between the top of the Sidekh Phonolites and the base of the Muruywr Beds. The foot of the present scarp is at about 4000 feet at which height the '3700 foot surface' and the 4000 foot summit level converge, and it thus appears that there has been recent rejuvenation of the Saimo Fault in the order of 800 to 1000 feet.

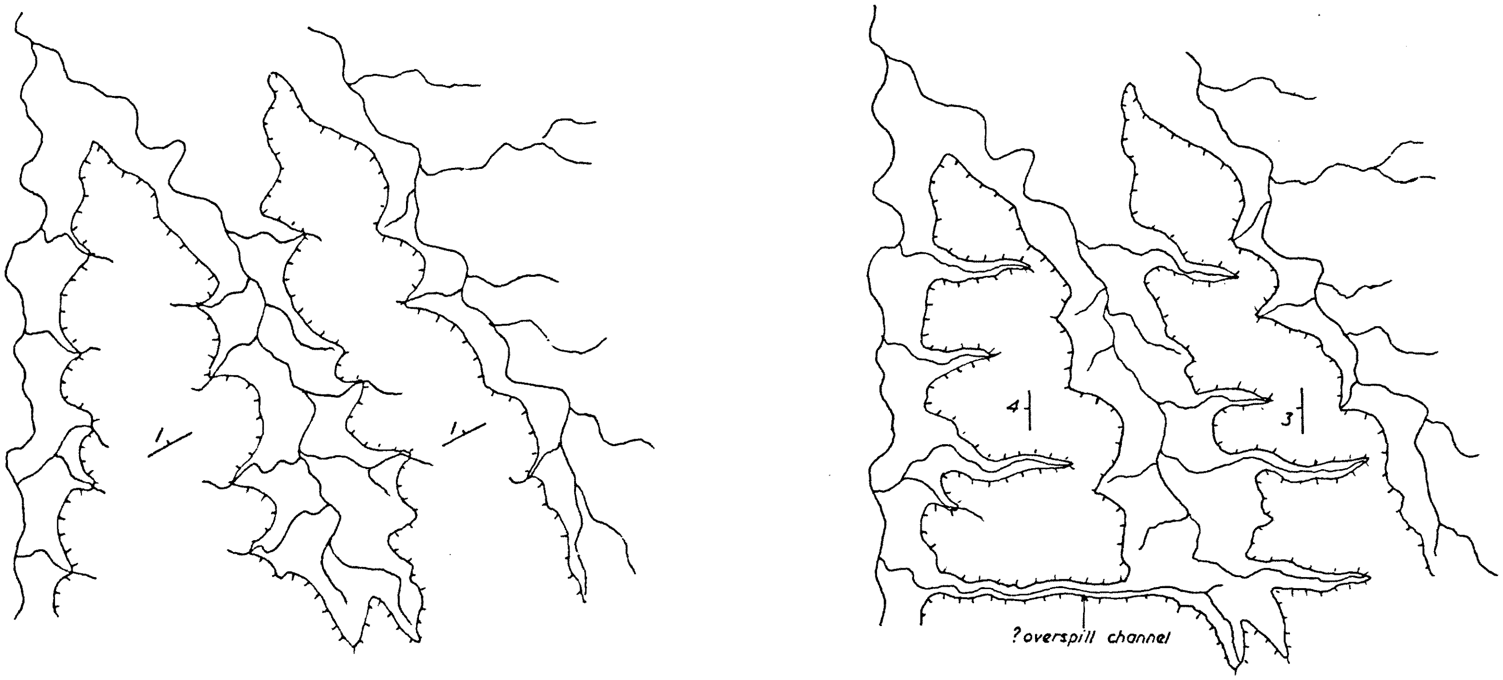
In the present area the southern and northern parts of the main range show striking physiographic contrasts: the southern area (the Kamuiton range) has been deeply dissected by powerful streams flowing eastwards down the scarp, and as a result the watershed lies well to the west of the topographic crest of the range, marked by the summits at 6500 feet plus, and is likely to advance, by stream capture, even further west. In the north the Sidekh Range has only shallow and even dissection of the scarp slope, but the dip slope, in complete contrast to that in the south and centre, has been very deeply dissected indeed, as shown by the northwesterly trend of the outcrop pattern. A possible explanation is that whereas in the south the main scarp has a long history of rejuvenation and erosion but the present dip-slope is of fairly recent date (1.0 m.y. B.P.), in the north the opposite is the case: the Sidekh Range as a tectonic feature must be of considerable age and the dissection of the dip-slope possibly dates from the first major faulting episode; the present scarp, however, is largely the product of Quaternary fault movement with the result that the drainage of the main Sidekh Range has with its multitude of small equidistant streams a distinctly 'young' appearance.

(d) Development of the dip-slope

The predominant trend of the streams on the trachyte dip-slope was, at one time, NW-SE, parallel to that preserved in the north by the

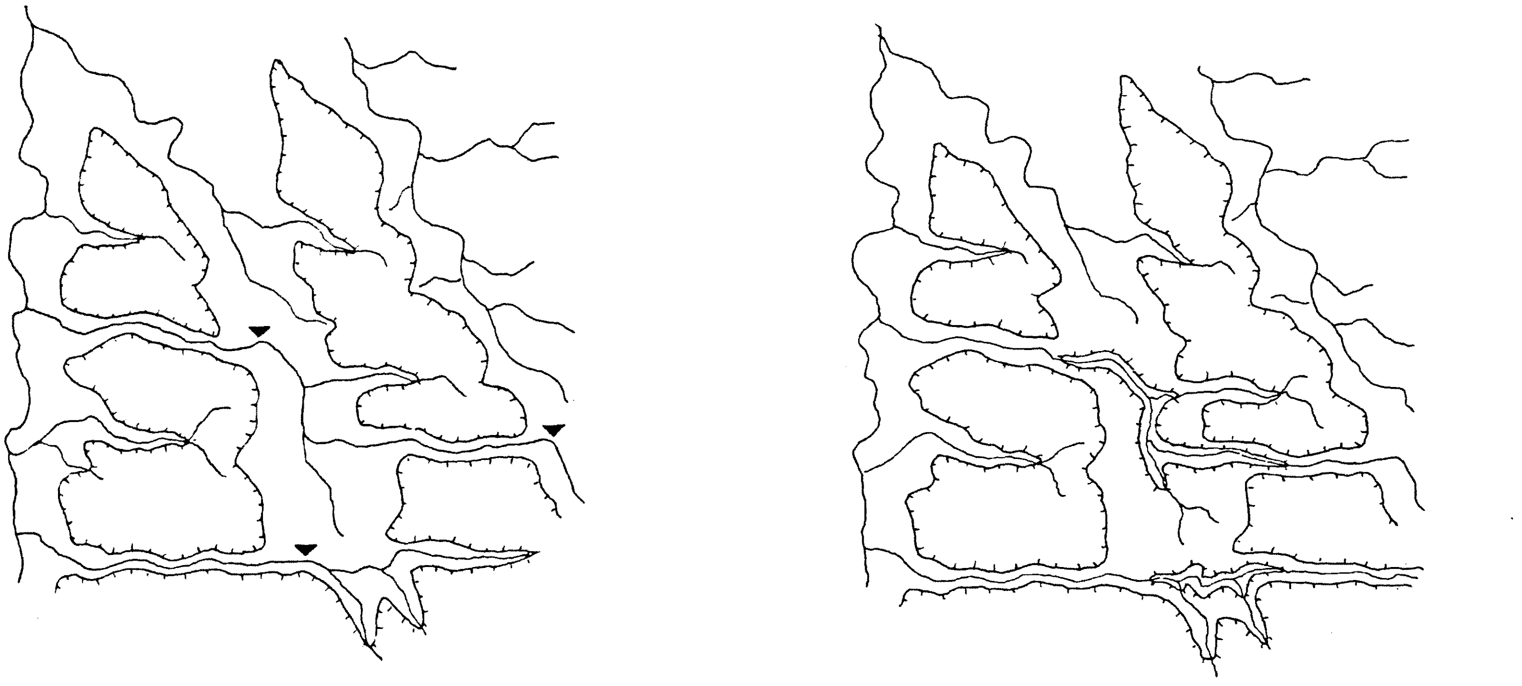
Chemoigut and Simniyon rivers. Very few visible faults follow this trend and its presence on the homogenous trachyte surface as well as on the outcrop pattern of the Tugen Hills Group in the north make its explanation difficult. A regional slope may be postulated but the extraordinary parallelism of the streams must surely indicate some structural control in addition.

The present drainage on the trachyte dip-slope has a trellised pattern of which the components are the ancient north-westerly trend, the younger westward lines down the present dip-slope and other roughly north-south lines controlled by faults. The main streams are often deeply incised and older valleys have been abandoned at higher levels. This is even better seen in the area to the south of the present map and is well illustrated by Martyn (1969). In the southern areas there are invariably prominent knick-point waterfalls where the plateau streams plunge into their incised lower valleys. This was explained by Martyn as due entirely to the Quaternary tilting of the dip-slope, but it is obvious that such tilting could only cause increased erosion along the whole length of a stream and would not cause knick-points. Knick-points would be caused by a sharp base-level lowering but there is no evidence for this in the Kerio Valley. The evidence in the present areas for an older north-west trending system which has been taken over by streams flowing more directly westward suggests the explanation shown in figure 50. Steepening of the dip-slope in a westward direction caused stronger erosion by the west-flowing subsequent tributaries of the old streams. The former cut back until they captured the original trunk streams. Knick-points originated at the points of capture, then migrated further up the system, possibly effecting further captures and incision of the main streams. (If the Sidekh Range was also tilted at this time it is likely that the streams in that area were already too deeply incised to be greatly affected by the change in regional slope (see above).)



(a) Before Quaternary tilting

(b) Quaternary tilting : headward erosion by new consequent streams



(c) Capture of original consequents.
▼ : knick points

(d) Migration of knick points, causing incision of original valleys

FIG. 50 DEVELOPMENT OF THE DIP-SLOPE DRAINAGE (DIAGRAMMATIC)

In the south-west of the map the erosion of the trachyte has revealed the underlying phonolites and extensively exposed Ngorora Formation, in a large embayment. This is the most northerly of a series of such valleys (Martyn 1969) and the writer agrees with Martyn in ascribing their formation, following initial river erosion, largely to landslipping, of trachyte on the sediments, around their margins. The undulating floor of the embayment is nearly everywhere mantled by trachyte débris, often in the form of huge, apparently in situ, unbroken masses.

The Kerio Valley is floored by very gently-sloping alluvial plains with few well-defined water-courses. North of the area the Kerio plains form a broad pediplain surface which slopes gently up to a sharp break in slope at the western foot of the Tiati range. This has been designated the 'Kerio surface' by Webb (op.cit.) and provides, perhaps even better than the 'Nginyang surface', an example of the type of landscape covered by the floods of Kabarnet Trachyte at an earlier date. The flat floors of the Chemoigut and nearby streams on the northern edge of the map are the most southerly finger-tips of the Kerio surface; it is here at an altitude of 3800 feet, tempting tentative correlation with the '3700 foot surface' to the east of the range.

(c) Landslip

In areas where competent lavas overlie sediments slumping of the rotational type is common. It is best developed on the margins of trachyte plateaux such as Ribon where the Ribon Trachyte rests on Kaperyon Formation, near Yatya (Kabarnet Trachyte on Mpesida Beds) and extensively on the dip-slope wherever the Kabarnet Trachytes rest directly on the Ngorora Formation.

In cross-section (fig. 51) the slumping produces a series of tilted blocks, of which those furthest from the plateaux may have been rotated

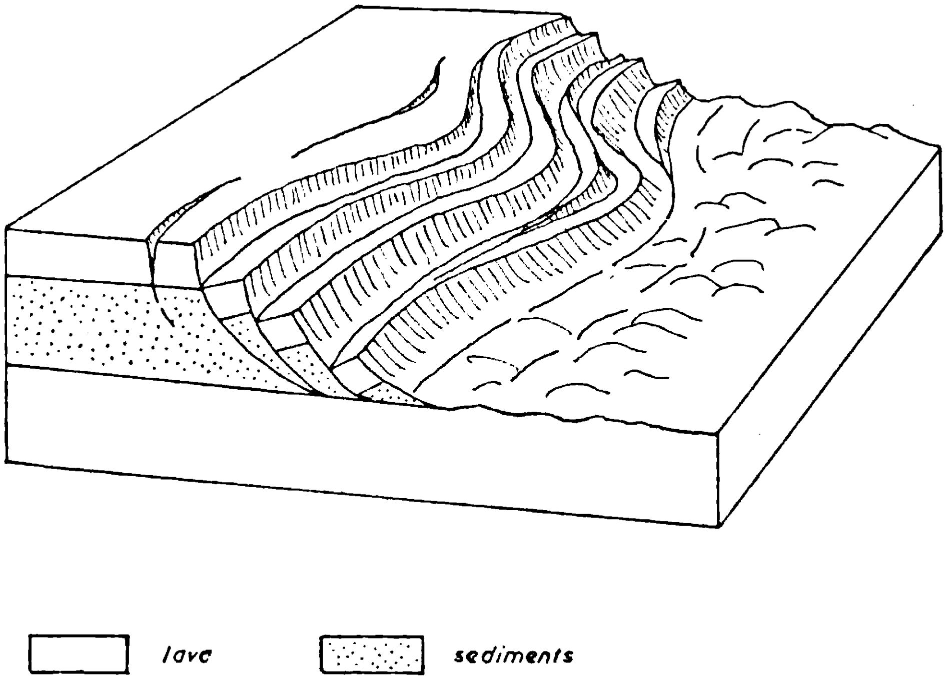


FIG. 51 LANDSLIP, SHOWING 'SLIP CUESTAS'

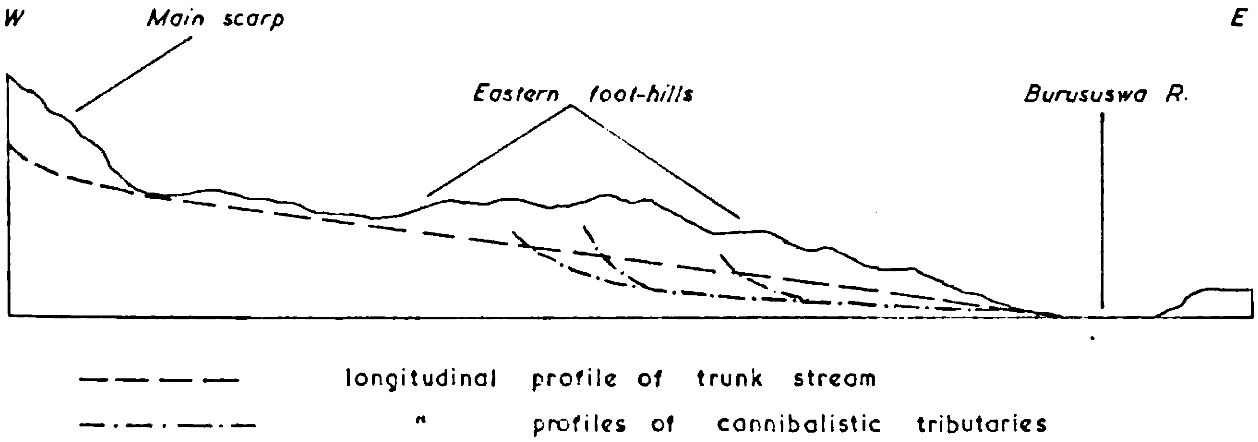


FIG. 52 CANNIBALISTIC TRIBUTARIES ON THE TRUNK STREAMS IN THE EASTERN FOOT-HILLS (Diagrammatic section with great vertical exaggeration)

to the vertical. In plan, the slips compose a series of parallel ridges, or 'slip-cuestas', the trace of which closely follows the outline of the remnant plateaux. It is assumed that the slip-cuestas furthest from the plateaux are the oldest and that tension cracks close to the edge of the plateaux indicate incipient new slumps. Where the superincumbent lava is more than a thin capping, or where the strata dip down-slope, or both, the slip tends to be chaotic, rather than in the form of slip-cuestas.

Vital to the movement of slip-cuestas appears to be the presence of space into which the 'toe' of the slip can advance. For example on Ribon, although slumping occurs extensively on the northern and eastern sides, it is absent from the narrow north-south valley in the east of the plateau presumably because there is no room for a slump to slide into, the two sides of the valley there forming an inverted structural arch.

PART IV: PETROGRAPHY

Presentation of the petrographic data largely follows the scheme adopted by Harkin (1960) in his account of the Rungwe volcanics. In particular, the rock nomenclature and tabulated thin-section descriptions are based on Harkin, with appropriate modifications. The Rungwe memoir is the most comprehensive petrographic account of an East African volcanic province and comparisons with the Rungwe rocks, in particular, are made throughout the present work.

(a) Nomenclature

BASALT	:	plagioclase (average $>$ An$_{50}$) augite and ore essential.
OLIVINE-BASALT	:	basalt with total olivine $>10\%$.
PICRITIC BASALT	:	basalt with olivine and augite phenocrysts together totalling 30% but total feldspar not less than 30%.
FELDSPARPHYRIC BASALT	:	basalt with phyric plagioclase $>30\%$.
DOLERITE	:	basaltic mineralogy but medium grained texture. Usually ophitic.
HAWAIITE	:	basaltic mineralogy but plagioclase averaging between An$_{50}$ and An$_{30}$.
MUGEARITE	:	basaltic mineralogy but plagioclase $<$ An$_{30}$.
ANALCITE-HAWAIITE ANALCITE-MUGEARITE	:	hawaiite and mugearite with primary analcite $>10\%$.
NEPHELINE-HAWAIITE	:	hawaiite with nepheline $>5\%$.
TRACHYMUGEARITE	:	('Benmoreite') plagioclase (ave. $<$ An$_{30}$) and alkali feldspar each between 1/3 & 2/3 of the total.
ANALCITE-TRACHYMUGEARITE	:	(?'Tahitite') trachymugearite with primary analcite $>10\%$.
TRACHYTE	:	alkali-feldspar $>$ 2/3 of the total.

ALKALI-TRACHYTE : trachyte with alkali mafics prominent.

QUARTZ-TRACHYTE : trachyte with accessory quartz.

QUARTZ-ALKALI-TRACHYTE : ('Pantellerite') alkali-trachyte with accessory quartz.

PHONOLITIC TRACHYTE : trachyte with nepheline up to 10%.

TRACHYPHONOLITE : trachyte with nepheline between 10 and 15%.

PHONOLITE : trachyte with nepheline >15%. Usually very fine-grained or aphanitic.

These definitions are based on thin-section descriptions alone; the available chemical data allows some refinement of the classification. Thus the basalts and olivine basalts, which have without exception an 'alkalic' mineral composition, comprise the 'alkali basalts' of Yoder and Tilley (1962) and 'alkalic basalts' (< 5% modal olivine) and 'alkalic olivine-basalts' (> 5% modal olivine, < 5% normative nepheline) of Macdonald and Katsura (1964). There is no indication, from either petrography or petrochemistry, of tholeiitic or calc-alkaline affinities in any rock examined.

The name 'hawaiite' (Iddings 1913) is adopted as proposed by Macdonald (1960) for alkalic basalts characterised by andesine, rather than labradorite. Both hawaiites and mugearites occur throughout the province but have invariably been described previously as 'andesites' and 'trachyandesites'. The Rungwe 'andesites' and 'trachyandesites' (Lehmann 1924, Harkin 1960) are also alkalic rocks, more appropriately termed 'hawaiite', 'mugearite' or 'trachymugearite' (see below).

The mugearites generally fall into the chemical range of mugearites from Skye (Harker 1904), New Zealand (Benson and Turner 1940) and Hawaii (Macdonald 1968) but very few have the textural characteristics of the Skye rocks. The 'trachymugearites' are the 'benmoreites' of Tilley, Yoder and Schairer (1965) and the 'mugearite-trachytes' of Macdonald (1968). Of the three available names the writer prefers 'trachymugearite', as adopted by Martyn (1969) for certain lavas from the present petrographic province.

The undersaturated basic-intermediate lavas from the Noroyan Formation present a nomenclatural problem which, to the writer's knowledge, has not been much discussed in the literature. Similar rocks from the Saimo area were described by Martyn as 'analcite-basanites' and 'analcite-tephrites'; these rocks have a much higher colour index than the Noroyan varieties but the feldspar is in most cases andesine. The terms 'analcite-hawaiite' etc. appear to be the least cumbersome and most accurately informative of the names available (see Williams, 1964).

The prefix 'alkali-' in the case of the trachytes would seem to be superfluous to the extent that, by definition, all trachytes are strongly alkaline rocks. However, in Kenya, the term is in general use (e.g. Baker 1958) to denote peralkaline trachytes with an abundance of sodic mafic minerals.

The adoption of 15 per cent as the definitive lower limit of modal nepheline in 'phonolites' (as distinct from 'trachyphonolites') differs from the more normal use of the 10 per cent limit. In fact the 15 per cent division is the most, if not the only, natural boundary in the whole group of the felsic differentiates, a distinct chemical hiatus occurring between the 'Phonolites' and the 'trachyphonolites', whose lower nepheline limit is still defined at 10 per cent modal nepheline.

In Kenya the phonolites (sensu lato) have unique terminological problems with long histories, to be discussed in a later section.

(b) Mineralogy

1. Plagioclase feldspars

Plagioclase compositions were determined by extinction angles using Michel-Levy's method and combined Carlsbad-albite twins. Compositions in the Noroyan Formation average $< An_{50}$, while those in the younger basalts average $> An_{50}$. Compositions become difficult to determine in the more felsic types especially where interstitial alkali feldspar is present, and it is suspected that in intermediate rocks such as the trachymugearites the groundmass feldspar may be potash-oligoclase. Plagioclase phenocrysts are usually strongly zoned from calcic labradorite and often show good oscillatory zoning. Twinning is usually Carlsbad/Albite. As in the Rungwe rocks tabular glomerophyric plagioclase sometimes shows cruciform intergrowth.

2. Alkali feldspars

The alkali feldspar of the salic rocks seems to be sanidine more commonly than anorthoclase although, again, groundmass determinations are difficult. Normative feldspar proportions indicate compositions very close to Or_{37} in the majority of cases, with some of the older phonolites being more variable in both directions.

Sanidine is definitely more common than anorthoclase as phenocrysts, but the latter, as rhombs, is dominant in a few of the older phonolites and in the trachytes of the Kaparaina Formation where in aphyric types it may also compose the groundmass. Anorthoclase is distinguished by polysynthetic, often cross-hatched, twinning and patchy extinction. Sanidine phenocrysts are usually laths which are simple Carlsbad twins. Low 2V angles also indicate sanidine.

3. Pyroxenes

In the basaltic rocks there is a distinction between the augites of the Noroyan Formation and those of the younger lavas. In the older rocks the component phenocryst (often glomerophyric) is a pink-brown or purple augite in which $\{100\}$ and $\{010\}$ dominate the prism form $\{110\}$, giving nearly rectangular basal sections; in the less basic differentiate of this formation the phyric augite is sometimes a very pale green in colour. In the younger basalts the augite is a pale buff colour and $\{100\}$, $\{110\}$

and {010} are equally developed, giving equidimensional octagonal sections often somewhat corroded; in contrast to the abundant phenocrysts of the older lavas, phyric augite never exceeds other phenocrysts in the younger lavas and may be rare or absent from rocks with common plagioclase and olivine phenocrysts. Simple and hour-glass zoning is seen and simple twinning is not uncommon in the Noroyan lavas.

Groundmass augite is commonly in the form of short prisms. In the less basic lavas of the Noroyan Formation these may be greenish in colour.

Ophitic augite occurs in the dolerites of the Rurmoch and Yepkarat sills. The colour is a more intense brown than in the basaltic lavas of the same age. Sub-ophitic augite also occurs in the Nginyang Basalt (not on the map) which, however, is quite definitely a surface flow.

The commonest pyroxene of the felsic lavas is aegirine-augite. Crystals are frequently zoned outwards to compositions closer to aegirine; the aegirine content is gauged by increase in the intensity of the green colour and of pleochroism, and also very low extinction angles. Micro-phenocrysts in the trachytes are commonly very ragged, being surrounded by 'spongy' rims in which pyroxene poikilitically encloses ground-mass nepheline, a feature also noted in the Rungwe rocks (Harker op.cit.). Groundmass sodic pyroxene is in the form of shreds and poikilitic patches, often intimately associated with a blue-brown sodic amphibole.

Harkin records the frequent occurrence of 'aegirine' and 'aegirine-augite' cores in titanaugite of the basaltic lavas but this was not seen in any rock from the present area. (Martyn, however, records 'diopsidic' cores in augite from an ankaramite of the Saimo Basanites Formation and the writer has observed green cores in pink augite in an intermediate rock collected by J. Sceal from the Laikipia Escarpment.)

Phyric pyroxene in the Tugen Hills Group phonolites described as diopsidic augite, in the tables, is probably ferro-hedenbergite (I.L. Gibson, pers.comm.), but aegirine-augite is common in the ground-mass.

The phenocrysts resemble the augites of the Tugen Hills Group basaltic lavas in the weak development of the {110} form. Similar 'diopsidic augite' phenocrysts, as attenuate prisms, also characterise the trachytes of the Kaparaina Formation, where the anorthoclase appears to have monopolised the available sodium. The mineral also occurs, but is very rare, in the Kabarnet Trachytes.

4. Aenigmatite

This mineral is rarely absent from the groundmass of the felsic rocks, and overall it is probably the most abundant mafic mineral in those types. It is characterised by intense absorption and pleochroism in very dark brown and reddish-brown. Harkin (op.cit.) states that it is difficult to distinguish this mineral from kataphorite-type amphiboles, but the intense colour seems to be distinctive in the Kamasia lavas.

5. Amphiboles

Alkali amphiboles are common in the felsic rocks where a number of varieties are present. It almost invariably occurs interstitial in the groundmass and optical determinations are very difficult. Examination of the literature and discussion with colleagues suggests that in these circumstances, identification tends to be somewhat subjective.

The writer follows Martyn in tentatively naming the alkali amphiboles on the general aspect of the pleochroic schemes. Thus, amphiboles with blue-brown colour are referred to arfvedsonite and is the commonest variety in the trachytes. Red-brown and yellow-brown colours identify kataphorite which is the commonest type in the Tugen Hills Group phonolites with the exception of the Sumet Phonolite (Ewalel Formation) where poikilitic arfvedsonite is nearly as abundant as aegirine-augite. Kataphorite also occurs in mugearites and trachymugearites of the Kaparaina and Noroyan Formations. An amphibole occurring as rare micro-phenocrysts in a quartz-trachyte of the Kabarnet is identified by an intense indigo-blue colour as riebeckite.

Common hornblende occurs as sparse micro-phenocrysts in some quartz-trachytes of the Kaparaina Formation.

Prismatic phenocrysts of a strongly pleochroic (red-brown, brownish-yellow, pale yellow) amphibole are common in the Noroyan Formation. Extinction angles are always close to zero. Simple twinning is present. The crystals invariably show strong resorption rims of ore and augite and are frequently entirely resorbed, leaving 'ghosts' in the form of the original prisms but composed entirely of ore grains. A mineral which seems to be closely similar occurs in certain of the Rungwe rocks and was identified by Lehmann (1924) as barkevikite. However, in the Kamasia amphibole (and ? in the Rungwe mineral) $Z \wedge c$ appear to be consistently too small for barkevikite and the mineral is tentatively referred to kaersutite. This decision receives a little support in the recent description of basanites and tephrites from north of Lake Rudolf (Brown and Carmichael 1969). In those rocks a similar brown amphibole phenocryst phase occurs in the tephrites, associated with the other mineral phases seen in the Noroyan lavas. This amphibole has been analysed by the wet chemical method, and is referred to 'Ti-poor kaersutite'. An apparently similar amphibole is also described by Mason (1955) from tephrites in the Nyambeni Range; in this case it was designated 'basaltic hornblende'.

6. Olivine

Olivine does not appear to be as common in the Kamasia basaltic rocks as it is in the Rungwe equivalents, where it is 'rarely absent' (Harkin op.cit.). Phenocrysts vary from nearly perfectly euhedral to extremely rounded, and perfectly fresh to completely altered. Serpentine alteration on margins and in veins is much more common than iddingsite.

No fayalitic olivine has been found in the rocks of the present area but Martyn records it from the Ewalel Phonolites and trachytes of the Chemikilani sub-group (Quaternary) (Martyn op.cit.).

7. Feldspathoids

Nepheline is the only feldspathoid seen in the lavas of the present area, but primary analcite is also common in many nepheline-normative rocks where modal nepheline is absent. Groundmass nepheline, usually as fresh and unaltered minute prisms often poikilitically enclosed in alkali-amphibole or aegirine-augite, is abundant in all the true phonolites of the Tugen Hills Group; it is often accompanied by nepheline phenocrysts up to 5 mm. in size. The latter are commonly altered to cancrinite or natrolite in the Sidekh Phonolites but usually fresh and water-clear in the younger formations of the group.

In the Noroyan lavas normative nepheline is usually represented by primary interstitial analcite in the mode, but glassy rocks in this formation have abundant small nepheline prisms set in a matrix of glass.

In the trachyphonolites and phonolitic trachytes nepheline is present only as microphenocrysts, often altered to a brown turbid material, and rimmed by aegirine-augite and alkali amphiboles, giving an ocellar texture to the rock in thin section.

8. Quartz

Quartz occurs frequently in the trachytes of the Kaparaina Formation and associated plugs and dykes and is seen in one flow of the Kabarnet trachytes. It occurs in the flows as a very late phase forming sub-poikilitic blebs and lacunae in the groundmass, never amounting to more than about 5 per cent of the rock. In the Kaparaina trachytes the quartz lacunae tend to occur close to the rhombic anorthoclase phenocrysts; in the Kabarnet specimens its occurrence seems to be controlled by the fissility. In the trachyte of the Chepochom plug (Kaparaina age) quartz rises to nearly 10 per cent, while in a dyke cutting Kaparaina basalts in the Kobluk River quartz occurs as anhedral microphenocrysts to the extent of over 20 per cent.

9. Iron ore

Iron ore is present in all the lavas, becoming less abundant in the felsic types. In the basaltic rocks it may be very abundant, as dusty grains or well-spaced octahedra of magnetite. Skeletal plates of ore in certain basalts and dolerites are presumed to be ilmenite. Microphenocrysts occur sparsely throughout the series but attain their greater size (0.5 mm.) in the Tugen Hills Group phonolites; as in the Rungwe rocks the microphyric ore of the phonolites often includes apatite or even has associated apatite microphenocrysts, and often occurs with them at the centre of glomerophyric clumps of pyroxene.

Haematite occurs in the Kaparaina trachytes, possibly as an alteration product. Indeterminate hydrated iron oxides are found in all rocks.

10. Biotite

Biotite is sparsely distributed: in the Sidekh and Tiim formations of the Tugen Hills Group it is not uncommon as microphenocrysts in the phonolites. In this situation it is invariably strongly resorbed and altered to aggregates of iron ore. Coloration is strong, with yellow-brown to deep red pleochroism.

As a groundmass constituent it occurs in some of the quartz-bearing trachytes of the Kaparaina where it is associated with common hornblende, in the absence of the more usual aegirine-augite and alkali amphiboles. It also occurs in small amounts in the feldsparphyric basalts, hawaiites and mugearites of the Kaparaina and more commonly in the Noroyan intermediate rocks. In all the basic-intermediate rocks the biotite is a very pale variety and in the Noroyan Formation, at least, an analogy may perhaps again be drawn with the Korath lavas (Brown & Carmichael op.cit.) where the groundmass mica is identified as phlogopite.

11. Apatite

Apatite occurs throughout the assemblage, and reaches microphyric proportions in some of the Tugen Hills Group phonolites, where it may be very pale pink in colour.

12. Other minerals

Analcite is a common accessory and, as mentioned, reaches signifiaant proportions as a late primary phase in the Noroyan lavas. It is also common in vesicles in all rocks, often occurring as euhedral crystals lining amygdales.

Zeolites are common, but are seen spectacularly developed in voids in the Yepkarat dolerite where natrolite, thomsonite, scolecite and gmelinite have been identified, and others are probably present also. It is also common as a cementing matrix mineral in the coarser epiclastic rocks in the sedimentary formations.

Calcite is abundant as a secondary mineral, following analcite in infilling vesicles and occurring as dilational veins in the Tugen Hills Group phonolites. Calcite tuffs also occur in the younger rocks, where pumice and other material has been completely replaced leaving relict crystal clasts in a nearly pure calcic matrix.

Chlorite is common in the basic lavas, associated with glass serpentine and zeolites.

Glass is an important matrix component in glassy varieties of the Atimet Trachyphonolite where it is pale green and isotropic, and in glassy nepheline-hawaiites in the Noroyan Formation where it is khaki-brown. It is common in all basic rocks, often as cryptocrystalline patches with faint birefringence. Primary tuffs are commonly glassy with calcite in the 'honeycomb' vesicles of the fibrous pumice.

In a comparison with the Rungwe assemblage, certain minerals are notably absent: in particular, whereas only one feldspathoid (leucite) is not seen in the Rungwe rocks, only nepheline occurs in the Kamasia rocks. This reflects the generally more undersaturated nature of the Rungwe Association. Sphene has not been observed in the rocks from the present area but the writer has seen it as a common microphenocryst in a melaphonolite collected by S.J. Lippard in the southern end of the Kamasia. (Lippard (pers.comm.) believes this rock may be part of the Tinderet association.)

(c) Tabulated thin-section descriptions

Fifty-seven thin-section descriptions of representative lavas are presented in tabular form, with more general description in the text itself.

Although relative abundance of groundmass constituents is indicated for the mafic minerals, feldspar is always the dominant constituent in the trachytes and phonolites and in the basic lavas the mafic:felsic ratio is hardly ever greater than 1. Percentages and relative proportions are approximate estimates only.

Abbreviations used are:

P : plagioclase
S : sanidine
F : anorthoclase
N : nepheline
O : olivine
A : augite
AeA: aegirine-augite
Ae: aegirine

Use of lower case, e.g. p, s etc., indicates microphyric or groundmass constituents.

In the first column of each table (sample numbers) the letter A indicates that an analysis is included in Part V (tables 15-23), the letter P indicates that a photomicrograph is included, and the letter R that the rock has been radiometrically dated (table 1). When rocks from two or more separate formations are included in one table the relevant map symbols, e.g. (g^3) may also occur in the first column.

Table 3: NOROYAN FORMATION

Spec. No.	Rock type	PHENOCRYSTS (max. size in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	OLIVINE	AUGITE	PLAGIOCLASE	OTHERS	OLIVINE	AUGITE	PLAGIOCLASE	ORE	OTHERS	
2/285	analcite-trachy-mugearite	5-10% P+p= a	none	diopsidic a .75 long prisms and brown .4 short prisms	P rare 3 laths An$_{30}$ p An$_{30}$	ore sparse .2	none	.05 ave. pale green a and AeA prisms and grains	.3 ave laths An$_{20-30}$ (n balsam -?K-oligoclase)	.02 ave common	analcite kataphorite glass calcite K-feldspar	sub-trachytic texture
2/254 P	glassy nepheline-hawaiite	7% a > others p = amphibole	none	a common .6 pink-brown short prisms	p sparse 1.5	? kaersutite sparse .7 resorbed long prisms ore sparse .25 grains	none	.1 + sparse pale brown prisms	.1-.4 thin laths An$_{40}$	.02 ave. octahedra	nepheline (15%) clear prisms brown glass (70%)	g/mass is glass with f/spar microlites & nepheline
2/237 A	hawaiite	5%	none	a sparse .6 very pale brown glomerophyric	none		.1 sparse fresh	.03-.15 abundant pale brown prisms	.1 ave. laths and grains An$_{45}$	.07 ave. grains & octahedra	calcite analcite glass apatite biotite	very basic rock calcite veins amygdales
2/239 A	analcite-mugearite	5% a=P= amphibole > o	o rare 2 totally serpentinised	a sparse .7 very pale brown	P sparse 2+ corroded	kaersutite 1.5+ resorbed with ore grains	none	.05 ave. sparse colourless to pale green-brown	.06 laths overgrown by K-feldspar	.01-.02 abundant grains	biotite analcite K-feldspar calcite glass	distinctive intergranular texture
2/343	ankaramitic analcite-hawaiite	15-20% A > others	O rare 2 in hand specimen	A common 2.5 pale brown	none	ore .25 common	rare .03	.03-.15 abundant brown prisms	.04-.2 thin laths An$_{45}$	.04 ave. common grains & octahedra	analcite glass zeolites	A up to 10 common in h/specimen

Table 4: NOROYAN FORMATION

Spec No.	Rock type	PHENOCRYSTS (max size in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	OLIVINE	AUGITE	PLAGIOCLASE	OTHERS	OLIVINE	AUGITE	PLAGIOCLASE	ORE	OTHERS	
2/327	hawaiite	10-15% o > A + a	common 1 fresh serpentine veins rounded	A sparse 2.5 very pale brown	none		rare .07 fresh	.02-.05 prisms	.05-.15 laths An_{45}	.02-.06 abundant grains & octahedra	analcite glass chlorite ?biotite	
2/329 A	analcite-hawaiite	5% a > others	o rare 1.3 largely replaced by serpentine & calcite	a sparse 1 very pale brown	p rare 1.3 laths	kaersutite .5 almost completely resorbed ore .3	none	.03-.06 colourless pale brown grains & prisms	.15 ave. laths An_{45}	.01-.03 common grains & octahedra	biotite analcite calcite K-feldspar ?nepheline glass	sub-trachytic texture
2/340 A	analcite-hawaiite	10% a > P	none	a common .75 pale pink-brown & pale green	P sparse 2.5 fresh euhedral laths An_{40-50}	ore .4 octahedra ?amphibole replaced by ore grains	none	.1 ave. pale green-brown prisms	.15 ave. laths An_{40}	.02-.05 common grains & octahedra	analcite biotite apatite glass chlorite	
2/341 A	analcite-hawaiite	10-15% a > others	none	a common .7 pale pink-brown	p sparse 1.8	kaersutite 1 strongly resorbed ore .2 sparse	none	.02-.06 colourless to green-brown ?Ae rare	.2 ave. laths An_{45}	.02-.04 common grains	analcite calcite chlorite glass apatite	sub-trachytic texture
2/334	analcite-hawaiite	10-12% p > a	none	a sparse 1 pale brown	p sparse 1.7 An_{45-50}	amphibole .2 rare resorbed ore .2 octahedra	none	.02-.05 colourless to green-brown	.1-.25 thin laths An_{45}	.02 ave. grains common	analcite calcite biotite glass	good trachytic texture

Table 5: BASALTS - KAPARAINA FORMATION

Spec. No.	Rock type	PHENOCRYSTS (max size in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	OLIVINE	AUGITE	PLAGIOCLASE	OTHERS	OLIVINE	AUGITE	PLAGIOCLASE	ORE	OTHERS	
2/16 A	basalt	5% p >o	o sparse .2 completely serpentinised		p sparse 1 corroded plates	ore rare .2	.01 rare altered	.01-.02 colourless grains & prisms	.02-.25 short laths An_{60}	.01-.02 abundant dusty grains		zeolite patches & calcite veins
2/46 A	basalt	5%			p sparse 1 long laths		.02-.3 fresh & iddingsitised	.02-.2 very pale brown prisms	.02-.25 laths An_{60}	.03-.08 abundant octahedra	serpentine chlorite	
2/49	feldsparphyric olivine basalt	45% P+p > others O+o > A+a	O rare 6 o common 2 subhedral serpentinised and iddingsite	A sparse 6 a sparse 1.5 pale pink-brown resorbed	P common 4 p common 2 short laths & plates An_{60-65}	ore rare .2	.1-.3 common largely serpentinised	.04 ave. colourless prisms & grains	.05-.25 laths An_{50}	.02-.1 abundant grains & octahedra	serpentine chlorite glass	
2/104 P	olivine-basalt	20-25% O+o > others P+p > A+a	O common 3.5 o common 2 fresh very rounded	A sparse 5 corroded a rare 1 very pale brown	P rare 5 p sparse 1		.05-.2 common serpentinised	.04 ave. very pale brown grains and prisms	.1-.75 slender laths An_{60}	.15 ave. common skeletal & poikilitic	serpentine glass zeolites	
2/156b A	olivine-basalt	20% P+p > o	o sparse 1.5 subhedral serpentinised		P common 4 p rare 2 plates An_{60}		.05-.2 strongly serpentinised	.04-.08 pale purple-brown grains & prisms	.05-.2 laths An_{55}	.05 ave. well-spaced grains & octahedra	chlorite serpentine	fluidal g/mass

Table 6: BASALTS - KAPARAINA FORMATION

Spec. No.	Rock type	PHENOCRYSTS (max. size in mm)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	OLIVINE	AUGITE	PLAGIOCLASE	OTHERS	OLIVINE	AUGITE	PLAGIOCLASE	ORE	OTHERS	
2/10 P	olivine-basalt	35% P+p > O+o > A+a	O sparse 2.5 o common 1.5 serpentinised	A rare 2 a sparse 1 pale brown corroded	P abundant 2.5 corroded plates An$_{55-60}$		.05-.2 abundant strongly serpentinised	.02-.1 colourless prisms	.05-2 laths An$_{60}$	.2 skeletal plates well-spaced	chlorite glass zeolite serpentine calcite	ore is distinctive
2/70	olivine-basalt	45% P+p= others O+o= A+a	O,o 2.5 common fresh subhedral	A,a common 2.2 pale mauve-brown A euhedral a corroded	P abundant 8 An$_{60}$ p abundant 2.2 laths		.05-.2 common rounded fresh	.05 ave. colourless pale brown prisms	.06-.2 laths An$_{60-65}$	.05-.1 abundant grains & octahedra	zeolite glass	high mafic content very fresh
2/128	basalt	10% P>p			P common 3 p sparse 2 plates An$_{60-65}$		?rare totally serpentinised	.02-.1 very pale brown grains & prisms	.1-.5 laths An$_{55}$	.02-.1 abundant grains & octahedra	glass serpentine chlorite biotite apatite	
2/130 P	feldspar-phyric basalt	45-50% P+p > others O+o > A+a	O rare 2 o sparse .5-2 almost completely serpentinised	A rare 2.5 a rare .5 very pale brown	P abundant 20 complex zoning p abundant 2 An$_{55-60}$		rare totally serpentinised	.01-.04 colourless prisms	.05-.1 laths An$_{55}$	.02 ave. abundant dusty grains	glass serpentine chlorite calcite biotite (rare)	large P abundant g/mass very fine-grained

Table 7: KAPARAINA FORMATION - BASIC/INTERMEDIATE LAVAS

Spec. No.	Rock type	PHENOCRYSTS (max. size in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	OLIVINE	AUGITE	PLAGIOCLASE	OTHERS	OLIVINE	AUGITE	PLAGIOCLASE	ORE	OTHERS	
2/143	mugearite	5%			P rare .4	ore sparse .15	none	sub-ophitic sparse pale brown to colourless	.2 ave. laths and plates An_{20-30}	.03 ave. abundant grains & octahedra	chlorite glass calcite alk.f/spar	strong trachytic texture
2/6	hawaiite	5%			p rare 2	ore rare .3 octahedra	none	.04 ave. colourless grains & prisms	.15 ave. laths An_{45}	.02-.1 abundant grains & octahedra	chlorite glass ?biotite	sub-trachytic texture
2/123	olivine-hawaiite	15% o > others	o common 1.4 rounded almost totally serpentinised	a sparse 1.5 fresh but rounded	p sparse .5 deeply corroded & rounded		.05-.1 common largely serpentinised	.03 ave. colourless grains & prisms	.05-.25 laths An_{45-50}	.03 abundant grains & octahedra	serpentine chlorite (analcite calcite in amygdales)	amygdaloidal dyke-rock
2/71 A	mugearite						?none	.05-.35 common green-brown prisms	.05-.5 laths & plates zoned An_{20-30}	.03-.08 common octahedra & grains	brown glass (abundant chlorite)	large range in g/mass grain-size. dyke-rock
2/125 A P	mugearite	5% p > others			p rare 1+ zoned plates	ore rare .4 f rare 1.5 corroded rhombs	.05 rare serpentinised	.05-.2 common pale brown prisms	.04-.15 laths & plates An_{20-30}	.02-.08 common octahedra & grains	glass kataphorite calcite	probably a hybrid rock trachytic texture

Table 8: BASALTS - LOKWETEMOI (h^2), KAPERYON (i^1), LOKWALEIBIT (i^2) AND NGINYANG (k^1) FORMATIONS

Spec. No.	Rock type	PHENOCRYSTS (max. size in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	OLIVINE	AUGITE	PLAGIOCLASE	OTHERS	OLIVINE	AUGITE	PLAGIOCLASE	ORE	OTHERS	
2/136 (k^1) A	doleritic olivine-basalt	5%			P rare 2.5		.15-.8 abundant rounded fresh	.6 ave. sub-ophitic plates pink-brown	.2-1 laths An_{60}	.2 ave. common thin plates	serpentine glass	micro-vesicular doleritic flow
2/53 (i^2)	olivine-basalt	15-20% o = p > P	o common .6 partly serpentinised		P rare 3 plates An_{65} p common .5 plates An_{60}		.05-.2 abundant rounded part-serpentinised	.05 ave. pale brown grains & prisms	.15-.5 laths An_{55-60}	.1 ave. common octahedra	serpentine calcite zeolites (in rare amygdales)	sub-fluidal g/mass p
2/162 (i^1) A	picritic basalt	45% O = A = p P < others	O common 3 fresh subhedral	A common 4.5 euhedral very pale brown	P sparse 6 p common 1.5 laths An_{70}		.15-.3 common partly serpentinised	.1 ave. very pale brown grains & prisms	.1-.5 laths An_{65}	.03-.2 common octahedra & poikilitic	serpentine chlorite calcite glass	strongly porphyritic
2/174 (i^1)	olivine-basalt	25-30% O + o > A+a+p	O common 3 o common 2 euhedral fresh	A sparse 3.5 a rare .4 subhedral pale brown	p rare .8 plates An_{65-70}		.1-.2 common partly serpentinised	.08 ave. very pale brown prisms	.15-1 slender laths An_{55-60}	.05-.15 common grains & poikilitic	serpentine calcite zeolite glass	sub-fluidal g/mass p
2/344 (h^2) A	olivine-basalt	5% o > p	o rare .25 fresh euhedral		p rare 1.3		.04 ave. common largely serpentinised	.05 ave. pale brown grains & prisms	.1-.15 laths An_{60}	.1 ave. skeletal plates	serpentine chlorite zeolite glass calcite	rare calcite amygdales

Table 9: DOLERITES - RURMOCH SILL (D^1), YEPKARAT SILL (D^2), AND KAPARAINA FORMATION (h^5)

Spec. No.	Rock type	PHENOCRYSTS (max. sizes in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	OLIVINE	AUGITE	PLAGIOCLASE	OTHERS	OLIVINE	AUGITE	PLAGIOCLASE	ORE	OTHERS	
2/100 (D^2) A P	zeolitic olivine-dolerite						.15-.6 abundant fresh rounded	.5-3 ophitic pale brown-purple plates	.4-1.5 laths An_{60}	.2-.5 common skeletal crystals	serpentine analcite mesolite ?gmelinite	medium-grained - zeolites in cavities
2/119 (D^2) A	olivine-dolerite	5%			p sparse 1.6 plates & laths		.1-.6 abundant fresh rounded	.4-2 ophitic purple-brown plates	.3-1 laths An_{60}	.05-.2 skeletal plates	analcite calcite	medium-grained zeolites scarce
2/317 (D^1) P	olivine-dolerite	20% p = 0	0 common 2.5 fresh subhedral serpentine veins		P common 3 slightly corroded An_{65}		.1 ave. abundant largely serpentinised	1 ave. ophitic pale purple-brown plates	.2-.6 laths An_{55-60}	.05-.15 abundant octahedra	calcite analcite zeolites serpentine glass	
2/165 (D^1)	feldspar-phyric dolerite	40%			P common 6 fresh plates An_{60-65}		none	1 ave. ophitic pale purple brown plates	.15-.4 laths An_{60}	.1 ave. skeletal plates	calcite glass zeolites	
2/173 (h^5) A	doleritic olivine-basalt						.1-.25 abundant rounded fresh o = a	.3-.75 sub-ophitic plates strong pink brown	.2-.7 thin laths An_{60-65}	.25 ave. abundant thin plates	calcite zeolites	distinctive ore intensely coloured augite

Table 10: TRACHYTES - RIBON (Rb) AND KABARNET (h^3) FORMATIONS

Spec. No.	Rock type	PHENOCRYSTS (max. size in mm.)				GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	FELDSPAR	PYROXENE	OTHERS	ALKALI FELDSPAR	PYROXENE	AMPHIBOLE	ORE	OTHERS	
2/22 (Rb) A P	alkali-trachyte	45-50% s >AeA	s abundant 1 short laths and plates	AeA common .4 prisms zoned out to Ae		.03 fine granular	AeA sparse nucleated mossy on AeA p/crysts	?arfvedsonite rare	.01 very sparse grains	aenigmatite (abundant mossy)	s p/crysts show oblique fracture
2/79 (Rb) A	alkali-trachyte	35% s >AeA	s common .6 laths and plates	AeA common .4 very ragged prisms		.03-.15 fine granular & laths	AeA .2 shreds common	?arfvedsonite	.01 rare grains in s & AeA	aenigmatite (very abundant shreds & mossy)	difficult to distinguish phyric and g/mass AeA
2/26 (h^3) A	alkali-trachyte	30-35% s >AeA	s abundant 1.5 laths & plates	AeA rare .4 ragged prisms	turbid pseudomorphs after n .2	.05-.1 granular	AeA .01 shreds & ragged prisms	arfvedsonite rims on n pseudomorphs	.05 sparse grains	aenigmatite (very abundant shreds)	s p/crysts bent and fractured
2/298 (h^3) A	quartz-alkali-trachyte	35% s > amphibole	s abundant 1 laths		?riebeckite .2 short prisms rare	.05 laths and grains	.05 sparse green grains & shreds	?kataphorite abundant	.01 very rare grains	aenigmatite quartz (sub-poikilitic & lacunae) probably several alkali amphiboles present	trachytic texture q concentrations// fissility
2/345 (h^3) A P	alkali-trachyte	10%	s 1.5 laths and plates			.05-.15 laths	?Ae .03 ave. common interstitial & shreds	.05 sparse blue-green ?arfvedsonite	none	aenigmatite glass	strong trachytic texture

Table 11: TRACHYTES - KAPARAINA FORMATION

Spec No	Rock type	PHENOCRYSTS max. size in mm.				GROUNDMASS size in mm.					Texture and other remarks
		% of rock	FELDSPAR	PYROXENE	OTHERS	ALKALI FELDSPAR	PYROXENE	AMPHIBOLE	ORE	OTHERS	
2/62 A	quartz-alkali-trachyte	35% S/F > AeA	S/F abundant 2.5 rhombs and laths	diopsidic A common 2 long prisms brown rims	ore .15 sparse	laths .05+ and interstitial	AeA .15 altered shreds	?kataphorite arfvedsonite .02 ragged and rare prisms	.01 sparse grains	quartz sub-poikilitic & lacunae 5%	intrusive plug rock
2/117 A	trachyte	40% s>S/F >others	S/F common .5 rhombs s abundant .3 laths		Bt rare .8 ore rare .5 (haematite)	.02 + grains & laths	AeA sparse shreds	none	.01 scattered grains (with bt)	biotite .1 (common) aenigmatite (common)	
2/133 A P	quartz-trachyte	35% s/f>F >others	F common 2.5 rhombs s/f .5 abundant	none	hornblende sparse .2 ore rare .15 biotite rare .15	.03-.3 granular & laths	Ae AeA common .05 ave. prisms	hornblende .05 sparse	.01-.05 common grains	quartz 5% sub-poikilitic lacunae	glomerophyric hornblende
2/57	alkali-trachyte	30% s>S/F > AeA	S/F common 2 rhombs & plates s abundant laths	diopsidic AeA sparse 2.5 long prisms brown rims		.05-.2 laths & (rare) granular	AeA .05 ragged prisms & interstitial	arfvedsonite (blue-brown) shreds common	none	aenigmatite quartz (rare interstitial) chlorite	rock resembles 2/62 (above)

Table 12: TRACHYPHONOLITES ETC. - ATIMET (g^{1a}), CHEMOIGUT (g^{1c}) AND LOYAMAROK (j^1) FORMATIONS

Spec. No.	Rock type	PHENOCRYSTS (max. size in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	FELDSPAR	PYROXENE	FELD-SPATHOID	OTHERS	ALKALI FELDSPAR	PYROXENE	FELD-SPATHOID	ORE	OTHERS	
2/84 (j^1) A P	trachy-phonolite	20% n > s	s sparse .4 laths	AeA rare .3	n abundant .3 short prisms fresh		.05-.2 sheafs of laths & grains	Ae inter-granular common rims on n	n .02 + rare prisms	sparse .02 grains	aenigmatite (common) glass kataphorite	ocellar n micro-pheno-crysts
2/142 (j^1)	trachy-phonolite	8% n > s	s rare .7 laths		n common .05 short prisms fresh		.01-.15 grains & thin laths	AeA inter-granular and rims on n	?none	.1 common dusty grains	aenigmatite kataphorite glass	
2/224 (g^{1a}) A	glassy trachyte	5% s > n > ore	s common 1 very thin laths		?n common .2 ?zeolite pseudo-morphs	ore rare .2 octahedra	s .1-.5 needles & laths	?AeA .01 very rare inter-stitial	analcite (rare)	.01-.02 abundant dusty grains	glass 50% (pale green) calcite & analcite in veins zeolites	hyalopili-tic from top of flow q-normative
2/225 (g^{1a}) A P.	phonolitic trachyte	15% n > s	s sparse .6 thin laths		n common .25 short prisms altered ocellar		s .1-.4 thin laths	AeA common inter-stitial	n .05 rare analcite after n	haematite abundant patches	glass aenigmatite calcite zeolites	fairly coarse trachytic texture q-normative
2/315 (g^{1c}) A	trachy-phonolite	20% n > others	s sparse .8 laths glomero-phyric with n		n sparse .5 glomero-phyric fresh n altered .1 common	ore rare .25 octahedra AeA sparse .4	s .1-.4 laths	AeA .05-.15 common prisms & inter-granular	n .1 altered common	.01 com-mon dusty grains	kataphorite (abundant) prisms & inter-granular aenigmatite apatite glass	glomero-phyric micro-nodules common coarse

Table 13: PHONOLITES - TUGEN HILLS GROUP - SIDEKH FORMATION (e^1)

Spec. No.	Rock type	PHENOCRYSTS (max. size in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	FELDSPAR	PYROXENE	FELD-SPATHOID	OTHERS	ALKALI FELDSPAR	PYROXENE	FELD-SPATHOID	ORE	OTHERS	
2/217 (e^1) R	phonolite	7-10% S = N+n = a	S sparse 4.5 corroded laths	diopsidic a sparse .45 euhedral	N rare 2 n sparse mostly fresh	biotite rare 1.2 ore sparse .3	.02-.2 grains & laths	AeA common inter-granular	n .03-.06 abundant fresh prisms	.03 sparse (abundant in phyric biotite)	katapho-rite (common poiki-litic) aenigma-tite glass apatite	
2/314 (e^1) A P	phonolite	5-10% N > others	S (in hand specimen only)		N sparse 2.5 largely altered to natrolite	biotite (in hand specimen) ore sparse .5	.05-.15 grains & laths	Ae rare .15 prisms AeA common inter-granular	n .05 ave. abundant	.02 rare grains	katapho-rite aenigma-tite zeolites apatite	phenocrysts of S N Bt common in h/specimen calcite veins
2/[illegible] (e^1) P	phonolite	10% F > others N= Bt	F common 2.5 plates and rhombs corroded	diopsidic a rare .4	N sparse 2 partly altered to natrolite	biotite sparse .8 apatite .2 ore .3 sparse	.04 ave. grains some laths	AeA inter-granular	n .03 ave. abundant	.02 rare grains	katapho-rite aenigma-tite apatite zeolites	p/crysts as 2/314
2/325 (e^1) A	phonolite	5% a > others	S sparse laths 2.5	diopsidic a common .4 euhedral prisms		ore .25 sparse grains	.3 ave. laths	AeA .04 prisms & inter-granular	n .02 ave. prisms analcite inter-stitial	.01 sparse grains	aenigma-tite apatite glass	trachytic texture in relatively coarse g/mass

Table 14: PHONOLITES - TUGEN HILLS GROUP - EWALEL (g^3) AND TIIM (g^1) FORMATIONS

Spec. No.	Rock type	PHENOCRYSTS (max. size in mm.)					GROUNDMASS (size in mm.)					Texture and other remarks
		% of rock	FELDSPAR	PYROXENE	FELD-SPATHOID	OTHERS	ALKALI FELDSPAR	PYROXENE	FELD-SPATHOID	ORE	OTHERS	
2/211 (g^3) A	phonolite	35% n = s >others	S sparse 3 s abundant 1.5 laths	AeA ragged sparse	n abundant .5 fresh	ore .1 rare octahedra	s .03-.1 laths & granular	AeA poikilitic common	n .02-.05 abundant fresh prisms	.02 sparse grains	arfvedsonite kataphorite aenigmatite glass	all mafics in discreet poikilitic patches
2/271 (g^3) P	phonolite	30% s > others	S sparse 4.5 s abundant 1.5 laths & plates		n common .4 fresh		.02 granular .1-.3 laths	AeA .5 abundant zoned poikilitic patches	n .05 abundant fresh prisms	.03 ave. rare grains	kataphorite (poik.) aenigmatite ?arfvedsonite	mafics in poikilitic patches h/spec. is 'freckled'
2/231 (g^1) A	phonolite	2%			n very rare 1 corroded		s .05-.1 grains & thin laths	AeA sparse intergranular	n .05 common fresh prisms	.01 rare grains	kataphorite analcite glass zeolites	amphibole> pyroxene mostly aphyric
2/264 (g^1)	phonolite	5% n > others	S rare 2.5 s rare 1 plates		n sparse 1 fresh	biotite rare .3 ore rare .2	s .03 ave. grains & thin laths	AeA sparse intergranular	n .03 ave. abundant fresh prisms	.01 common grains & octahedra	kataphorite zeolites glass calcite	
2/331 (g^1)	phonolite	5% n > others	s rare .5 altered laths	?A rare .4 pale green non-pleochroic rounded	n sparse 2 fresh and altered	ore rare .1	.15 ave. thin laths fluidal	AeA .1 common intergranular	n .05 ave. abundant	ore .01 sparse grains	kataphorite aenigmatite calcite glass analcite	

(d) Basalts and basic-intermediate rocks

1. Noroyan Formation (Tables 3,4)

These lavas are dark grey to black analcite-hawaiites and analcite-mugearites with prominent pyroxenes, and rarer plagioclase, phenocrysts in hand-specimen. Rare olivine phenocrysts are seen in a few small specimens.

In thin section the groundmass plagioclase is seen to be andesine in the majority of sections. Plagioclase composition is plotted against frequency in the histogram (fig.58) and there is a strong peak at An_{45}, the total range being An_{15} - An_{45}. Phenocryst composition varies between An_{30} - An_{50}.

Pyroxene phenocrysts occur in every rock examined; it varies from pale brown augite in the more basic types to a pale greenish 'diopsidic augite' in the mugearites and trachymugearites. In the latter, the pyroxene colour often seems to vary between very pale brown in some crystals to very pale green in others, but no discernible pleochroism is present in individual crystals. In basal section the pyroxenes are nearly rectangular due to the dominance of {100} and {010} over the prism form {110}. Hourglass zoning is not uncommon. The pyroxenes are often glomerophyric with ore and apatite.

The most notable feature of these rocks is the presence of strongly resorbed prismatic phenocrysts of a brown strongly pleochroic amphibole, referred to kaersutite (see section IVb, above). It is more common in the less basic varieties.

Prominent in the groundmass are primary interstitial analcite and, in some types, shreds of biotite. Groundmass ore is abundant and in types with sub-trachytic texture its distribution is governed by the orientation of the groundmass feldspar laths giving a 'chain' or more graphically a 'toad-spawn' texture. Glassy types are described below.

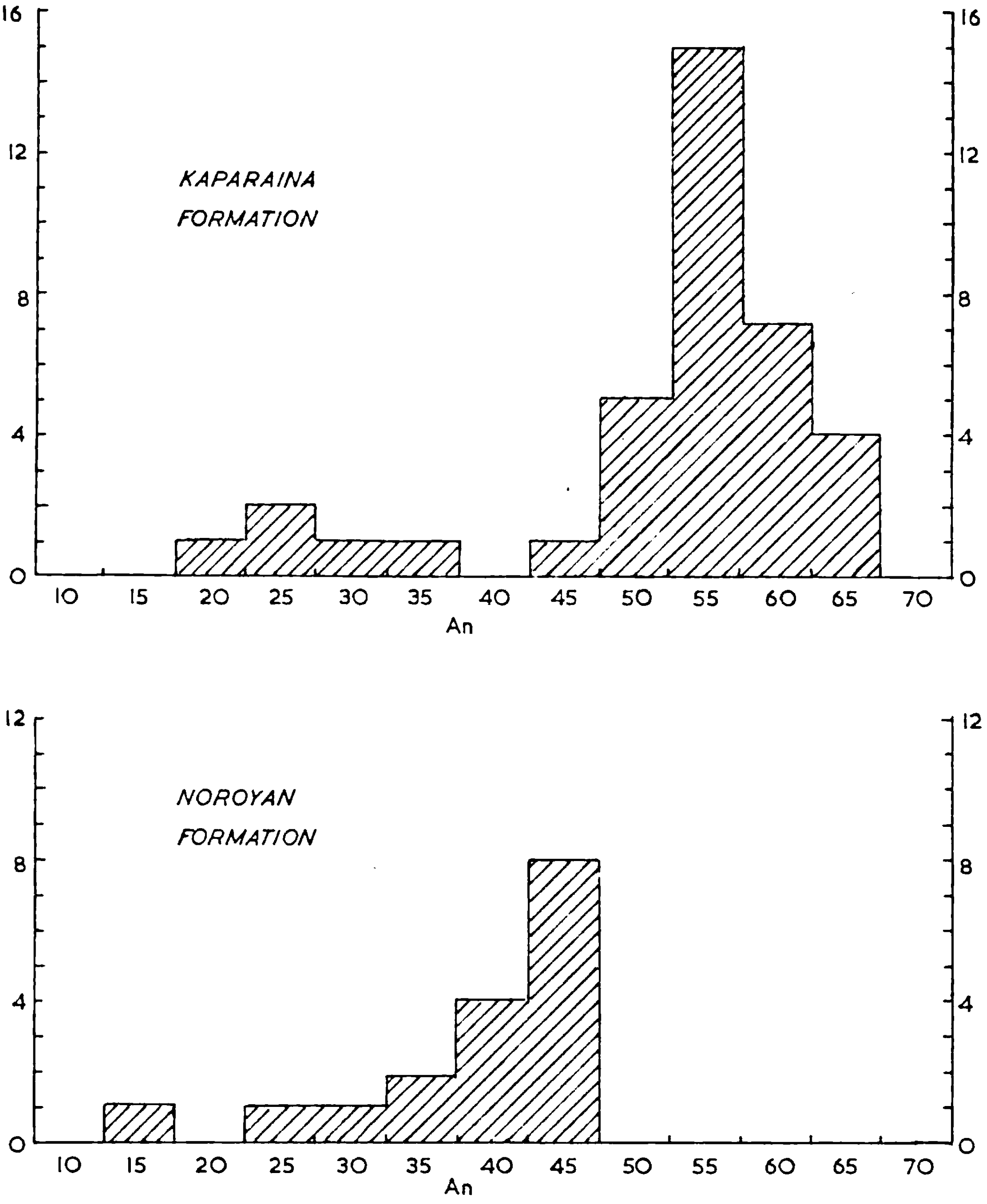


FIG. 53 GROUNDMASS PLAGIOCLASE COMPOSITION FREQUENCY IN BASALTIC ROCKS OF THE NOROYAN AND KAPARAINA FORMATIONS

The section exposed in the Noroyan River area seems to indicate the serial eruption of a differentiated sequence from ankaramitic analcite-hawaiite at the base to analcite-trachymugearite at the top. Petrography of the succession described in Part Ia (p. 15) is as follows:

(i) A unit with abundant large (10 mm.) augite phenocrysts and rare olivine, both most abundant at the extreme base (2/343).

(ii) A black glassy type (2/282, 2/254) with abundant small plagioclase (An_{40}) and nepheline crystals in a matrix of brown glass. Phenocrysts are augite, plagioclase and resorbed kaersutite.

(iii) Two feldspathic units with lower colour index and sub-trachytic texture. Kaersutite phenocrysts are more abundant than augite (2/341).

(iv) An analcite trachymugearite (2/284, 2/285), greenish in hand specimen, with trachytic texture. Phenocrysts are pale green and pale brown pyroxene and plagioclase (An_{30}). Groundmass plagioclase appears to be oligoclase, and aegirine-augite and kataphorite also occur in the groundmass.

Although the Kapkiai tephrite of Martyn (1969) appears to be a tongue of the Noroyan Formation the types described by Martyn are rather glassy and lack amphibole phenocrysts. The higher of the two basaltic units on the Saimo scarp, the Saimo Basanites of Martyn (1969) are for the most part in the same stratigraphic position as the Noroyan (see Part Ia) but differ from the latter in having much higher colour indices, feldspar being totally absent in some types. Olivine occurs in most units, but plagioclase and amphibole phenocrysts are not recorded. They are thus petrographically comparable to the basal unit of the Noroyan (2/343) in the northern outcrop of the present map.

In their most distinctive petrographic features - abundance of phyric augite, presence of resorbed amphibole phenocrysts and of primary analcite, and composition of groundmass plagioclase - the Noroyan lavas strongly resemble the Kapchererat Basalts at the base of the Tertiary succession in the Kito Pass area (McClenaghan op.cit.), the Elgeyo Basalts (Walsh 1969) and types from the succession on the Laikipia escarpment (Sceal op.cit.) including intermediate lavas from the Murgomol centre in the Amaya valley; the writer has briefly examined thin-sections of specimens collected by M. Golden (Ph.D. thesis in preparation) from the last locality; one specimen is of particular interest in that it appears from its mineralogy to be even more salic than the analcite trachymugearite of the Noroyan series.

The Murgomol complex is in a comparable stratigraphic position to the Noroyan Formation, lying beneath the main plateau phonolites (Rumuruti Phonolites, sensu lato) of the Laikipia plateau and above an older series of basalts, probably correlated with the Samburu Basalts of Shackleton (1946). Surprisingly, no analysis (apart from extreme types) is available of an average or typical rock from the widespread Miocene basalts of the northern Rift but many authors mention analcite as a constituent and describe the groundmass plagioclase as andesine (Joubert 1966, pp.34,35; McCall 1967, Baker 1963, Shackleton 1946).

2. Kaparaina Formation (Tables 5-7)

There are few remarkable features in the petrography of these rocks which compose a typical alkalic olivine-basalt-hawaiite-mugearite association of the type described from many other volcanic provinces. No indications of tholeiitic affinities are seen in any thin section examined.

Labradorite, usually zoned, is the commonest phenocryst, followed by olivine, while pale brown augite is comparatively scarce, often being somewhat corroded and resorbed. In this respect the Kaparaina rocks differ markedly from the Noroyan types where augite is the dominant phenocryst phase. The Kaparaina augites have regular octagonal basal sections in contrast to the near-rectangular sections, due to development of {100} and {010}, in the Noroyan augites. Olivine may be fresh or largely serpentinised, subhedral or very rounded (2/104). Specimen 2/104 is also unusual in that olivine phenocrysts are more abundant than labradorite.

No significant subdivision can be made of the porphyritic types listed in Part I. Types described as aphyric in hand-specimen are often found to contain sparse microphenocrysts of plagioclase in thin section (2/46). It should be noted that although in the tables phenocrysts are distinguished from microphenocrysts on the arbitrary division of 2 mm., there is usually a complete range in size.

In the groundmass of the basalts olivine is invariably present, in varying amounts; groundmass augite is slightly less or equal to plagioclase in most specimens. Groundmass plagioclase composition (determined optically to nearest 5%) in 37 thin sections examined range between An_{20} and An_{65}, but 27 fall in the range An_{50} - An_{60}, the average being An_{53} (fig. 53). These figures are a fairly close illustration of the true proportion of basalts to hawaiites and mugearites in the formation.

In the hawaiites and mugearites phenocrysts are rare or absent, with the exception of the dyke rock 2/123, in which olivine, augite and plagioclase phenocrysts occur, and are strongly rounded and corroded. Corroded and resorbed anorthoclase phenocrysts in the Kamsoror mugearite (2/125, 2/155) suggest that the rock may be of hybrid origin. The Kisitei dyke rock (2/74, 2/71) lacks phenocrysts but is chemically very close to the Kamsoror mugearite.

Trachytic or fluidal texture is prevalent in the hawaiites and mugearites e.g. the mugearite 2/143 which resembles dark trachyte in hand-specimen.

3. Other basalts (Table 8)

All basalts younger than the Tugen Hills Group are closely similar to the Kaparaina types. However, two basalts from the Kaperyon Formation on Chesoton hill are distinguished by an unusually large proportion of olivine and augite phenocrysts (2/162) in the one case and by the dominance of large olivine phenocrysts (up to 5 mm. in hand specimen) in the basal basalt (2/174). Olivine is also very abundant in the Yepkarat Dolerite (2/100, 2/119), which intrudes the Kaperyon, and in the Nginyang Basalt (2/136). There is thus a slight suggestion that basalts younger than the Kaparaina tend to be more basic than the flows of that formation. In addition in the present area no hawaiites or mugearites are known outside the Kaparaina Formation. However, the total number of the younger basalts mapped and collected is probably not sufficient to make statistically valid comparisons.

The Nginyang Basalt (2/136) is remarkable in that although it is demonstrably a Quaternary surface flow it has pronounced sub-ophitic texture and is coarser in grain size than most basalt flows.

4. Dolerites (table 9)

The younger of the two main dolerite sills, the Yepkarat Sill, is characterised by abundant analcite and several other types of zeolite. The analcite occurs to the extent of between 4 and 8 per cent on interstitial pools and as euhedral crystals along voids. Other zeolites identified include natrolite, scolecite, thomsonite and gmelinite (2/38, 2/100). Total zeolite may amount to between 10 and 15 per cent but the amount varies greatly throughout the sill.

The texture of the Yepkarat Sill is perfectly ophitic. Olivine is common. The only phenocrysts are very sparsely distributed calcic labradorite (2/119). The groundmass labradorite is usually considerably zeolitised and generally altered. Apatite needles are common.

The overall petrography has a strong resemblance to those European analcite-dolerites referred to as 'teschenites' and 'crinanites', but the writer prefers the descriptive term 'zeolitic (or analcite-) olivine-dolerite'.

The Rurmoch Sill rock differs from that of the Yepkarat Sill in relative scarcity of zeolites and abundance of phenocrysts of plagioclase (often large - up to 15 mm.) (2/165) and olivine (2/317), but the proportion of phenocrysts varies throughout the rock.

Specimen 2/173 in table 7 has been described with the other dolerites, but is in the Kaparaina sequence and may be a flow.

The majority of basaltic dykes are usually very strongly altered, showing only plagioclase crystals in a turbid brown matrix with abundant calcite amygdales (e.g. 2/168). A dyke at Cheparain to the south of Rurmoch is characterised by abundant plagioclase phenocrysts (2/234), and may have been related to the Rurmoch Sill.

A basaltic dyke in the Chepkow River is remarkable for its high proportion of small pleochroic pink augite prisms; the rock is otherwise plagioclase and brown turbid alteration products.

Dykes in the Tugen Hills Group are rather variable: a thick relatively coarse-grained dyke at the base of the Kamuiton scarp consists of labradorite laths (up to 2 mm.), calcite (30%), abundant iron ore and ferruginous alteration products (2/293). A thin basaltic dyke in the Ngorora Formation at Kabarsero has a fine-grained fluidal texture and a fairly low colour index. It is highly vesicular (2/261).

(e) Trachytes

The trachytes can be divided into two main types:

(i) Microphyric and aphyric, characterised by sanidine, aegirine-augite, arfvedsonite and aenigmatite. Quartz or nepheline may occur as a minor accessory. The Ribon and Kabarnet trachytes are almost exclusively of this type but it is rare in the Kaparaina Formation.

(ii) Macrophyric with anorthoclase and 'diopsidic augite' phenocrysts, sometimes with biotite and hornblende in place of the sodic mafics of type (i). This type is confined to the Kaparaina Formation where quartz is found as a common accessory in both types.

1. Kabarnet Trachytes (Table 10)

Sanidine is the common feldspar and occurs as both microphenocrysts and composing the groundmass. Phenocrysts are small but in the north-east of the area the presence, in hand-specimen, of sparse Carlsbad-twin sanidine phenocrysts (2-3 mm.) in the Kabarnet Trachyte distinguishes this formation from the Ribon Trachyte. In thin section the sanidine micro-phenocrysts are often bent and show oblique fracture planes (2/26). A thin local flow near Yatya is exceptional in having abundant very large (10-15 mm.) tabular sanidine phenocrysts (2/235). Pale green 'diopsidic augite' phenocrysts occur very rarely (2/114).

The groundmass texture is holocrystalline in all but one of eighteen specimens examined in thin section. The exception is specimen 2/114 where sanidine microlites, opaque with inclusions, have nucleated on larger sanidine laths in a matrix of glass, giving a distinctive stellate texture. The invariable trachytic texture is not always seen in thin section due to the orientation of the section.

In two of the sections examined the groundmass feldspar appears to be closer to anorthoclase (2/214, 2/296) than to sanidine. (The petrographic similarity of these two rocks, from 'flow 1' on the dip slope and the lowest flow at Yatya respectively, lends support to the reconstruction of events which correlates them stratigraphically.)

Aegirine-augite, arfvedsonite and aenigmatite are the typical dark minerals.

Quartz occurs in 'flow 2' of the dip slope (2/298), in which rock some microphenocrysts of an intense blue amphibole referred to riebeckite also occur.

Altered nepheline microphenocrysts rimmed by arfvedsonite are seen in the Kisitei specimens (2/26, 2/72).

2. Kaparaina Formation trachytes (Table 11)

Large rhombic phenocrysts of anorthoclase are the most striking petrographic feature of these trachytes (type (ii) above) but sanidine-phyric types also occur. In the quartz-alkali-trachytes of the northern (Chepochom - Adonyasas) group a green pyroxene, referred to as 'diopsidic augite' in the tables but possibly ferrohedenbergite, occurs as prismatic phenocrysts (2/62, 2/57). Microphenocrysts of biotite and in one case (2/135) of a strongly pleochroic green to purple-brown amphibole referred to 'hornblende' occur in certain types where sodic mafics are rare. An anorthoclase trachyte from the upper Kobluk River (2/230) is unique in the writer's collection in completely lacking phenocrysts.

Groundmass feldspar shows strong trachytic texture, but these trachytes are not as noticeably fissile as those of type (i). Aegirine-augite occurs, but is not common. In the Chepochom plug rock (2/62, 2/321), a relatively alkaline type, 'mossy' patches of aegirine-augite and alkali amphibole are found.

Quartz occurs, in both alkaline and sub-alkaline varieties, as lacunae and poikilitic patches in the groundmass. It is found in about one third of the thin-sections examined, but except in one case never comprises more than 5 per cent of the rock. The exception is a trachytic dyke in the Chepuromoi section of the Kobluk River which contains about 20 per cent quartz as angular microphenocrysts (2/144).

Altered nepheline microphenocrysts occur in the lower of the two thick flows on Chepuromoi (2/146).

3. Ribon Trachyte (Table 10)

This trachyte can be classed as type (i). In hand-specimen it is essentially non-porphyritic but in thin-section can be seen to be composed largely of sanidine microphenocrysts in a very fine-grained granular matrix. Aegirine-augite is also a common microphenocryst zoned outwards to 'spongy' groundmass aegirine of a much more intense colour. Aenigmatite in mossy patches is also common.

(f) Trachyphonolites

No natural sharp division occurs between the phonolitic trachytes (i.e. trachytes with accessory nepheline) and trachyphonolites. The latter are texturally and mineralogically simply trachytes with between 10 and 15 per cent nepheline as microphenocrysts often rimmed by sodic mafic minerals. They are the 'Kenya-type phonolites' of Prior (1904) (see below).

1. Atimet Trachyphonolite (Table 12)

In thin-section the rock has strong trachytic texture, often with kink-bands (2/225). Nepheline occurs as altered ocellar microphenocrysts rimmed by aegirine-augite. Small microphenocrysts of sanidine and a pale green pyroxene (2/255) occur sporadically.

Nepheline is absent or very rare in the groundmass, and amphibole is also scarce. A black fine-grained facies (2/224) has a felted or sub-hyalopilitic texture with bands defined by oriented feldspar microlites associated with brown glass and a green (?chloritic) mineral. Nepheline is not seen. The rock is extensively cut by dilational veins of calcite.

2. Chemoigut Trachyphonolite (2/215, table 12)

This rock is comparable in grain size to the Atimet, but the feldspar laths are randomly oriented (but the texture is not typical 'orthophyric') and the overall mafic content is higher.

Altered nepheline microphenocrysts are abundant and rare pale green pyroxenes also occur. In the hand specimen large well-scattered phenocrysts of feldspar are seen. Dark kataphorite is more abundant than aegirine-augite in the groundmass.

A peculiar feature is the presence of rounded or ovate 'micronodules' coarser in grain-size than the bulk of the rock but consisting of the same phases, i.e. sanidine, nepheline (fresh) and kataphorite.

3. Loyamarok Trachyphonolite (Table 12)

Apart from a smaller average grain size this rock is almost indistinguishable in thin-section from the Atimet rock (above). It contains abundant ocellar nepheline micro-phenocrysts and rare sanidines in a groundmass of sanidine laths, aegirine-augite, aenigmatite and kataphorite. Aegirine-augite also occurs as rare micro-phenocrysts in two sections (2/84, 2/88). In a point-count analysis of two sections (2/84, 1/51) the percentage of modal nepheline was 13.7 and 7.8 respectively. The rock may thus be described as either a trachyphonolite or a phonolitic trachyte.

4. Chemolingot

Also closely similar to the Atimet and Loyamarok lavas is the enigmatic trachytoid rock of the plain to the west of Chemolingot hill. This is in some specimens (2/107) coarser than any other trachytic rock seen in the area. In some sections (2/80, 2/157) fresh nepheline micro-phenocrysts are abundant (15%) while in others the mineral is absent. Dark green strongly pleochroic aegirine is a conspicuous mafic constituent.

(g) Phonolites

Petrographically and chemically these rocks are more distinct from the trachyphonolites than the latter are from the trachytes. They are very fine-grained, in many cases aphanitic, rocks; with large but well-scattered phenocrysts of feldspar, nepheline, biotite and pyroxene in the porphyritic types. Nepheline is abundant, as prisms, in the groundmass.

In the present area the type is confined, without exception, to the Tugen Hills Group. Apart from amounts and types of phenocrysts there is little petrographic variation throughout the group but the Sumet Phonolite has some possibly significant minor differences from the others and is described separately.

1. Sidekh Phonolites and Kamuiton (Tiim) Phonolites (Tables 13,14)

The distribution and type of phenocrysts in these units is fully described in Part I. Briefly, nepheline and sanidine occur throughout, but are in general larger in the lower Sidekh flows. Anorthoclase phenocrysts are rare (2/322). Nepheline (up to 10 mm.) in the lower Sidekh flows is commonly altered to cancrinite etc., whereas it is smaller and water-clear in upper Sidekh and Kamuiton units. Biotite is absent from the lower Sidekh Phonolites but prominent in the rest of the succession. 'Diopsidic augite' occurs more commonly in the Sidekh Phonolites than in the Kamuiton Phonolites.

Very few flows are completely devoid of phenocrysts; on the other hand there are no strongly nepheline-phyric types such as those which occur on the Laikipia side of the Rift (Sceal Ph.D. thesis in preparation) and on the southern Elgeyo-Kamasia area (Lippard Ph.D. thesis in preparation).

The groundmass is a felted or pilotaxitic mesh of feldspar microlites and nepheline prisms; trachytic texture is rare (2/325). Mafic minerals are aegirine-augite, kataphorite (often equalling the pyroxenes in abundance) and aenigmatite. In a few cases the mafics may form micropoikilitic segregations (2/209) but this is not obvious in the hand-specimen as it is in the Sumet Phonolite. The 'rhyolitoid' flow-banding in the top Kamuiton Phonolite (2/231) is seen in thin section to be caused by the concentration of aegirine-augite and feldspar into distinct fine layers. Interstitial glass and analcite occur commonly throughout.

Secondary calcite occurs throughout as veins and amygdales and generally dispersed through the rock. The lowest flow of the Kamuiton Phonolite has distinctive large elongated amygdales lined by euhedral analcite and subsequently filled by calcite (2/238).

2. Sumet (Ewalel) Phonolite (Table 14)

This unit, which appears to be a single flow, differs from the remainder of the Tugen Hills Group phonolite in a number of ways.

(i) Microphenocrysts of sanidine and nepheline are much more common (30%-40%) than in the other phonolites.

(ii) Pyroxene phenocrysts, when present, are of aegirine-augite with spongy rims of the same mineral (2/211).

(iii) A blue-brown amphibcle, referred to arfvedsonite, is prominent and may occur in place of the kataphorite of the other phonolites.

(iv) The mafics commonly occur in poikilitic patches giving the rock a distinctive 'freckled' appearance in hand-specimen.

In general petrography the rock is closer to the other Tugen Hills Group phonolites than to anything else, but in the features listed above it also has resemblance to the trachyte-trachyphonolite group. It conforms to the original 'Kamasia-type' phonolites of Prior (1903).

(h) Phonolite types in Kenya

Prior (1903) classified phonolites from Kenya into three major groups:

(a) Phonolites with large nepheline phenocrysts

- (i) Losuguta type : alkali pyriboles evenly distributed
- (ii) Kamasia type : alkali pyriboles in discrete sub-poikilitic patches.
- (iii) A type intermediate between (i) and (ii).
- (iv) A type containing sphene but no soda-amphibole.

(b) Phonolites with small nepheline phenocrysts

These are the 'Kenya type' phonolites. Microphenocrysts of nepheline occur surrounded by aegirine. Coarser in grain-size than the 'Losuguta' etc. types, and with trachytic texture.

(c) Phonolites with nepheline occurring only interstitially in the groundmass.

However, other writers (Neilson 1921, Smith 1931, 1938) re-defined the types and erected several new ones with the result that eventually use of the type names caused only ambiguity and confusion. Williams (1967) summarised the problem in a thorough and lucid review but unfortunately went on to suggest five entirely new geographically-named types.

The petrographic and chemical evidence from Baringo, including the present map area, suggests that Prior's original classification was essentially valid. In Baringo two main groups can be distinguished:

(a) Phonolites: These are porphyritic, very fine-grained or aphanitic, strongly under-saturated but often metaluminous as well as peralkaline. These conform with the 'Losuguta', 'intermediate' and 'Kamasia' types of Prior (= 'Mara' and 'Kericho' types of Williams). The affinities of the 'Kapiti' type (abundant large phenocrysts) of Neilson are obviously with this group.

(b) Trachyphonolites: Microphyric and non-porphyritic types, coarser in grain size than type (a), with trachytic texture. This type is less undersaturated, nepheline only occurs as microphenocrysts (in the coarser types the nepheline 'microphenocrysts' are not much larger than the groundmass feldspars) and usually peralkaline. This is obviously the 'Kenya type phonolite' of Prior. As Williams states, this type grades into phonolitic trachyte.

The 'Kamasia' type of Prior is well represented in Baringo by the Ewalel Phonolites in the Kamasia and certain of the flows in the Rumuruti Phonolites on the Laikipia plateau. Martyn (pers.comm.) believes that the original 'Kamasia' type specimens collected by Gregory were obtained from the Ewalel Phonolites in the Ndau River valley.

The one available analysis of an Ewalel Phonolite (2/211) shows less normative nepheline (17% as opposed to the maximum of 25%) than in some other Tugen Hills Group specimens. In addition the Sumet (Ewalel

Formation) Phonolite shows, as described in a previous section, certain petrographic features reminiscent of the younger trachytes and trachyphonolites.

It is perhaps significant that Neilson removed some of Prior's 'intermediate' and 'Kamasia' types to the 'Kenya' type and that 'Kamasia' is dropped from Williams' classification altogether. It is suggested that the reason for the demise of the 'Kamasia type' may be that after Gregory's original traverse of the area the Kamasia Range was not further mapped or investigated for the next sixty years. During this time large areas of phonolites were mapped and sampled over the rest of the volcanic province, and a collection bias, which had initially favoured the Kamasia (sensu lato) phonolites afterwards swung against them, and caused the 'Kamasia type' to fade into apparent insignificance.

The stratigraphic significance is implicit in much that has been said so far in the present work: the 'phonolites' are restricted to (and largely define) the Miocene - L.Pliocene plateau sequence; they are never found among the younger Rift floor volcanics. The 'trachyphonolites' are the typical feldspathoidal lavas of the Plio-Pleistocene Rift floor volcanism, but do also occur in the older sequence (e.g. the Atimet Trachyphonolite) in very small amounts.

Isotopic dates suggest that the phonolites at the top of the thick Kamasia succession are younger than the bulk of the phonolites on the Rift shoulders and plateaux. Petrography suggests that some of these same top phonolites may be a petrologic link between the older group and the (mainly) younger trachyphonolites. Thus although the resuscitated 'Kamasia type' may still be volumetrically insignificant the writer feels that they should no longer be neglected in any petrogenetic argument.

PART V: PETROLOGY

(a) Introduction

The writer is chiefly concerned to show that the distinct stratigraphic break in the sequence of the area, at the top of the Tugen Hills Group, is also of major importance from a petrological point of view. Lavas below the unconformity are largely strongly feldspathoidal basic and phonolitic types, while those above form an olivine-basalt/mugearite/trachyte suite. To this end the two suites are distinguished symbolically on chemical variation diagrams. Comparison with other provinces and some problems of petrogenesis are briefly discussed.

The presence of distinct 'sub-provinces' within the East African volcanic province was pointed out by Wright (1963, 1965) who distinguished between the 'Miocene phonolite sub-province', the 'Plio-Pleistocene Rift Valley sub-province', the latter dominated by trachytes and olivine-basalts, and the 'Mount Kenya sub-province'. There is strong evidence from the Kamasia that the concept of the first two of these provinces, at least, is valid. Less generalised summaries are by Williams (1965, 1969); in Williams (1969) an extremely large number of 'volcanic associations' is recognized.

Baker et al. (in press) apply the results of isotopic dating to the volcanics, and erect a rough chronostratigraphy for the major groups. These authors suggest that, considering only the sequence within the rift valley, a four-fold grouping can be made; this correlates with Wright's 'sub-province' and the present writer's lithostratigraphic groups (Roman numerals) as follows:

BAKER et al.		WRIGHT
U.Pliocene - Pleistocene	: trachytes (IV & V)	Plio-Pleistocene Rift Valley sub-province
M.Pliocene	: basalts (III)	
U.Miocene - L.Pliocene	: phonolites, local trachytes (II)	Miocene phonolite sub-province
L. & M. Miocene	: basalts (I)	(un-named northern basaltic sub-province)

(b) Petrochemistry

1. General

A total of 51 wet chemical analyses with calculated normative compositions is presented (tables 15-23). Of these, 17 are of lavas from the area to the south mapped by Martyn (1969), in which the volcanic succession is essentially the same as that in the present area.

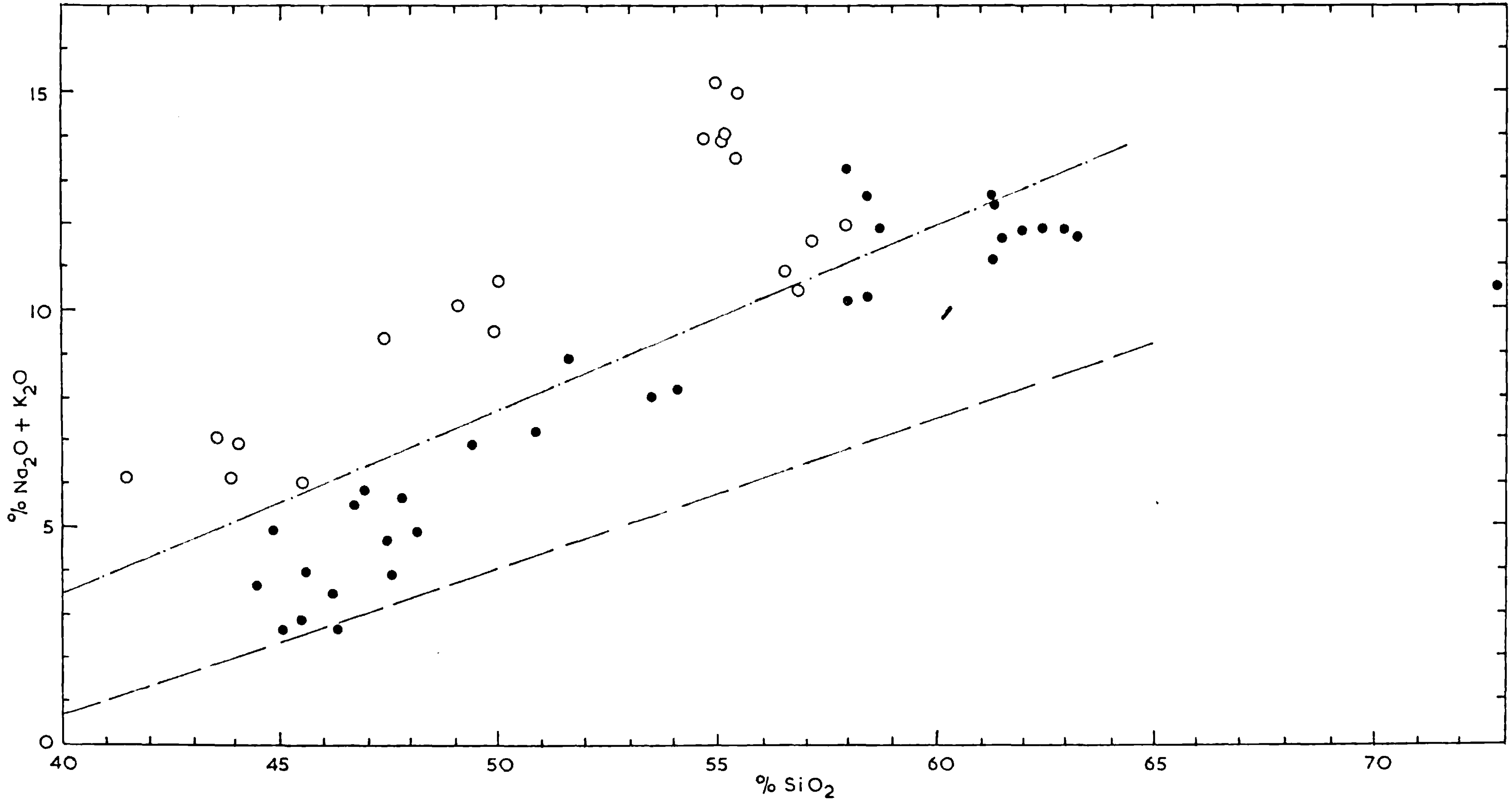
The essential distinction between the two major suites is illustrated by the plot of the rocks on the well-known alkalis/silica diagram (fig. 54). In this diagram the upper diagonal line represents that plotted by Saggerson and Williams (1964) to separate nepheline-bearing and nepheline-free rocks in the northern Tanzania 'alkaline district'. As shown this line also conveniently separates the two suites in the present area, with the exception of the trachyphonolite group which straddles it. The lower diagonal line is that defined by Macdonald (1968) dividing the 'tholeiitic' and 'alkalic' suites of Hawaii. It is perhaps misleading to characterise those rocks plotting above the upper line as 'strongly alkalic'; alkalis are more realistically expressed as a recalculated percentage of the rock after subtraction of the silica percentage. Thus the most strongly 'alkalic' rocks in the diagram, the plateau phonolites, comprise both metaluminous and peralkaline compositions, due to their high alumina percentage.

It should be stressed that in the alkalis/silica diagram the two suites indicated by the different symbols are separated entirely on stratigraphic grounds, not, as is usually the case, on a compositional basis.

Taken as a whole the alkalis/silica plot of the Kamasia rocks shows a strong resemblance to that of the Rungwe rocks (Harkin op.cit.) even to the isolated high-alkalis phonolite group and the far-flung outposts of high-silica trachytes. However when the Kamasia younger suite alone is compared with the Rungwe plot a significant difference is seen: above a silica percentage of 54, all but two of the Rungwe rocks plot on the 'nepheline-bearing' side of the Saggerson-Williams line, whereas in the same section of the Kamasia younger suite only four out of sixteen rocks occur in that field.

Comparison with other provinces eventually becomes tedious but as a generalisation the Kamasia younger suite plot in the same area as similar basalt-mugearite-trachyte associations from many other provinces, e.g. Hawaii, and can reasonably be derived by a crystal fractionation process starting with an 'average olivine-basalt'. The older suite is more problematical and not enough material is yet available (either in the field, or the laboratory) to draw many conclusions. Also, in the case of the younger suite the proportions of types plotted indicate fairly closely the actual proportions of the types present in the field. This is not so in the older suite where the phonolites, in the present area, exceed other types in volume by about 15 to 1.

The differentiation trends are also shown by a plot of the oxides against the 'solidification index' ($\frac{MgO \times 100}{MgO + FeO + Fe_2O_3 + Na_2O + K_2O}$) of Kuno et al. (1957) where smooth curves indicate continuous differentiation (fig. 55). On this diagram the long 'tail' between the centre and the left-hand side of the diagram indicates rocks with a large accumulate fraction. From this point of view other types of index are perhaps



○ group II ; ● groups III IV V ; —·—·—· separates nepheline-bearing and nepheline-free rocks in northern Tanzania (Saggerson and Williams 1964) ; — — — separates alkalic and tholeiitic suites in Hawaii (Macdonald and Katsura 1964).

FIG. 54 ALKALI : SILICA DIAGRAM OF THE KAMASIA VOLCANIC ROCKS

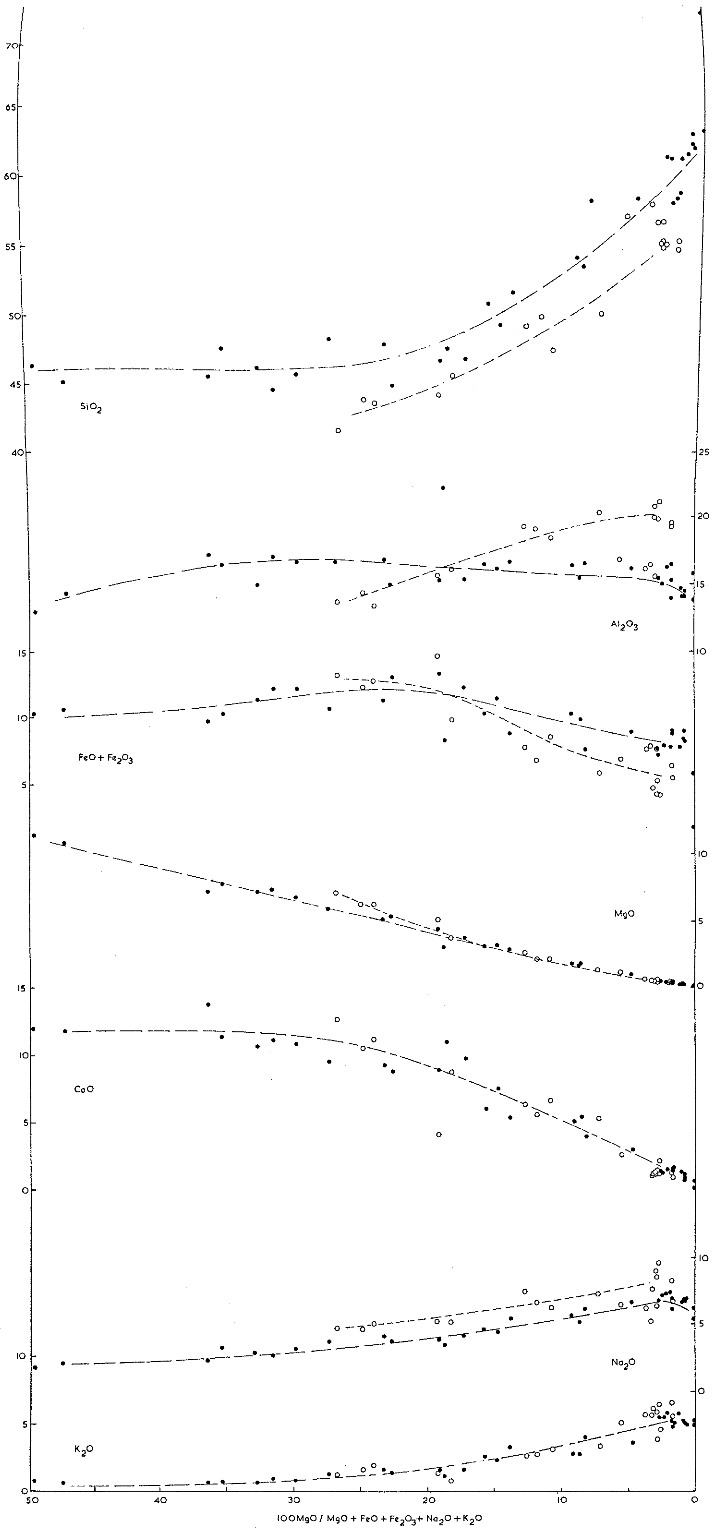


FIG. 55 OXIDE : SOLIDIFICATION INDEX VARIATION DIAGRAM OF THE KAMASIA VOLCANIC ROCKS

○ Group II ; ● Groups III IV V.

preferable, but the present one is used to facilitate comparison with other published accounts of East African rocks (Harkin 1960, Saggerson and Williams 1964).

A marked discordance between the trends for the two suites is seen in three cases.

(1) In the silica/solidification index plot the trend for the older suite is parallel to but consistently below that of the younger suite, even to the extent of dividing the trachyphonolite group.

(2) The trends for alumina cross over one another; the most basic of the older suite have a lower alumina percentage than all but the most obviously mafic-accumulatic types in the younger suite, but the trend increases steadily to the high alumina values of the Noroyan analcite-trachymugearite and the phonolites. The solitary younger suite rock plotting well above both trends is a strongly feldsparphyric 'big-feldspar' basalt from the Kaparaina.

(3) The trend for total iron diverges from the basic types to the felsic differentiates where the older suite is distinctly lower in iron than the younger suite.

The curves for the Rungwe and northern Tanzania rocks are very similar but comparison with the alumina plots is interesting: in the northern Tanzania plot the two series ('mildly alkaline' and 'strongly alkaline') also cross over, but at an S.I. value of about 5, the trend of the nepheline-free rocks dropping sharply below that of the nepheline-bearing series which for most of its length is consistently the lower of the two. In the Rungwe plot, the trend rises steadily to an S.I. value of about 7.5 and diverges sharply into two groups. With the lack of a few trachymugearites from the younger suite, and no stratigraphic distinction between suites, the Kamasia alumina trend would have looked very similar.

The Kamasia differentiation trend is also illustrated on the AFM diagram (fig. 56) which shows the relatively lower iron enrichment in the older suite. The trend of the latter is fairly close to that of the Rungwe rocks but the trend of the younger suite is more comparable to those of Hawaii, Hebrides, Mauritius etc.

The $CaO/Na_2O/K_2O$ triangular diagram is included since it illustrates perhaps better than any other the true relative abundance in the younger suite of rock types in the field. For this reason, the frequency of all analysed specimens from both suites is also plotted against a calcium/alkalis differentiation index ($\frac{CaO \times 100}{CaO + Na_2O + K_2O}$) in the histogram (fig. 58). This shows that although the usual bimodality is pronounced it is decidedly asymmetric, the curve falling fairly steadily from basalt towards mugearite, finally rising sharply to the felsic peak. (If the phonolites were represented as a true proportion the felsic peak would be more than twice as high.)

Another interesting diagram is the plot of Na_2O against K_2O. In the younger suite this shows a well-defined trend, with a gradual increase in K_2O relative to Na_2O towards the felsic end; the plots of the older suite are more scattered, but still indicate the same potash enrichment.

2. Normative analyses

The normative analyses are shown as standard CIPW norms; (a slightly revised calculation, more suitable for the rocks of the area, has since been devised by S.D. Weaver - pers.comm.).

In the younger suite normative nepheline in the basaltic rocks is, with one exception, always less than 5 per cent and decreases along the differentiation trend, mugearite and trachymugearite being slightly quartz-normative, as a rule. In the older suite basic and intermediate rocks however normative nepheline varies between 7.2 and 22.5 per cent, averaging 16.2 per cent, but no discernible pattern can be seen.

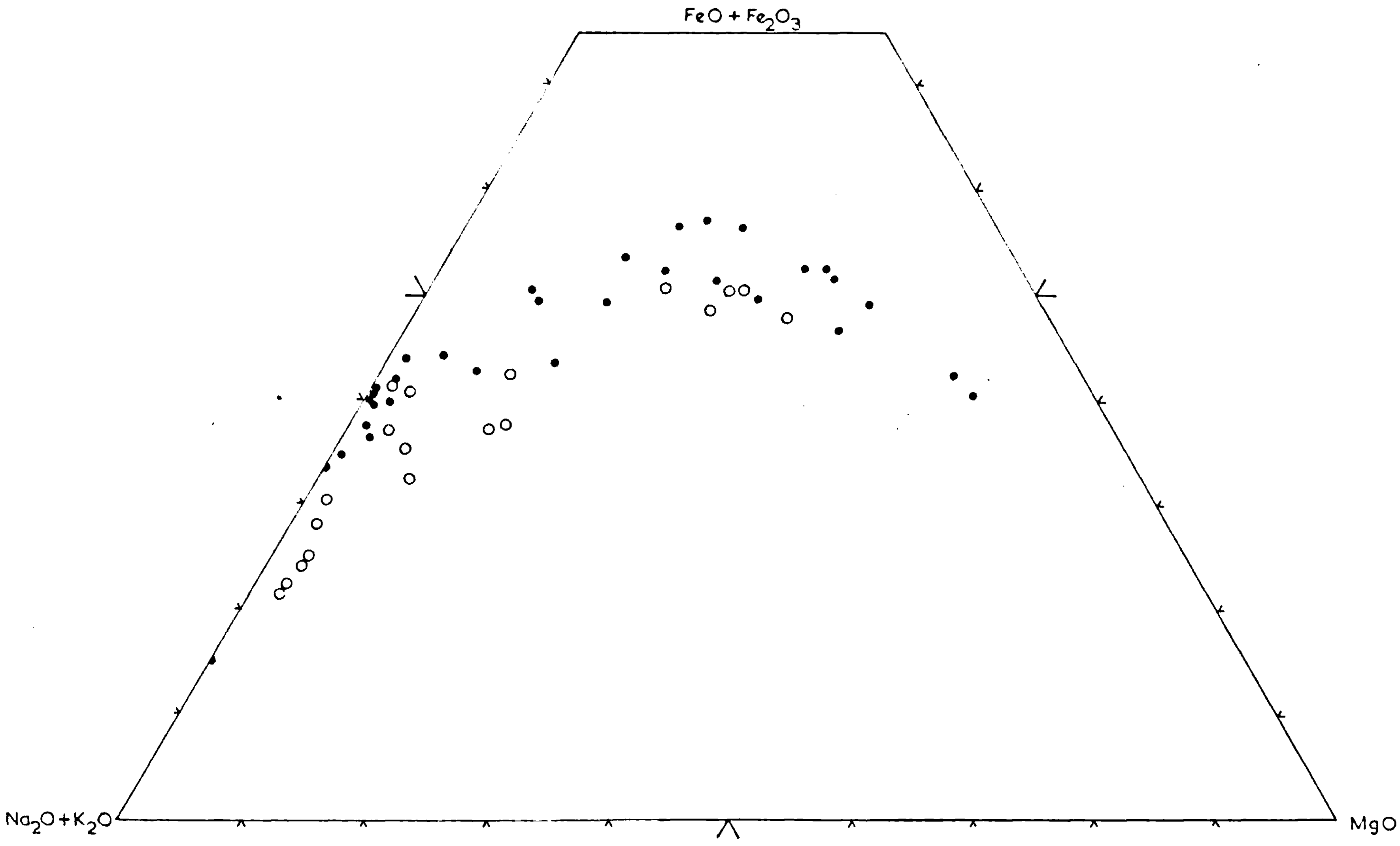


FIG. 56 AMF DIAGRAM FOR THE KAMASIA VOLCANIC ROCKS ○ Group II ; ● Groups III IV V.

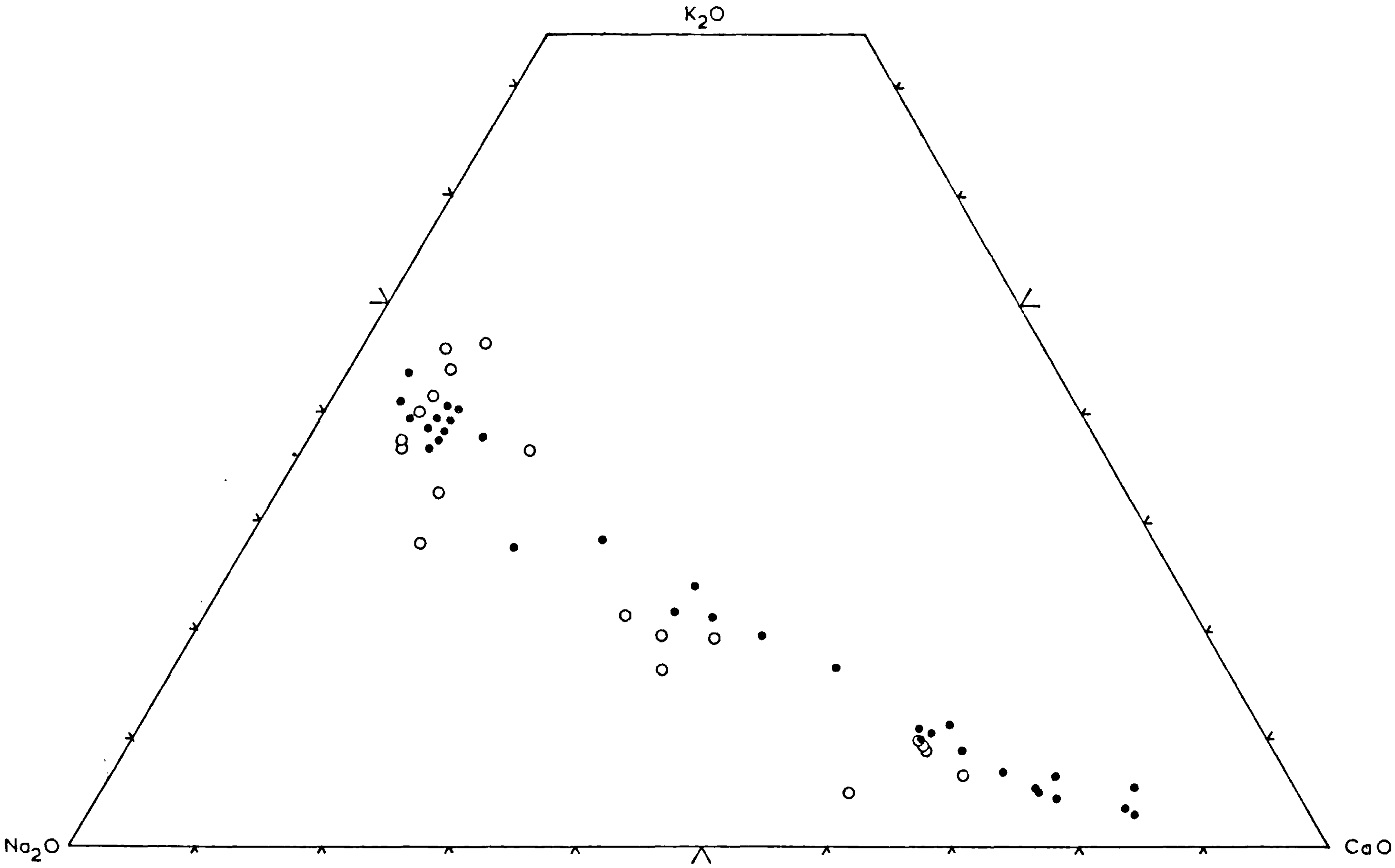


FIG. 57 CKN DIAGRAM FOR THE KAMASIA VOLCANIC ROCKS ○ Group II ● Groups III IV V,

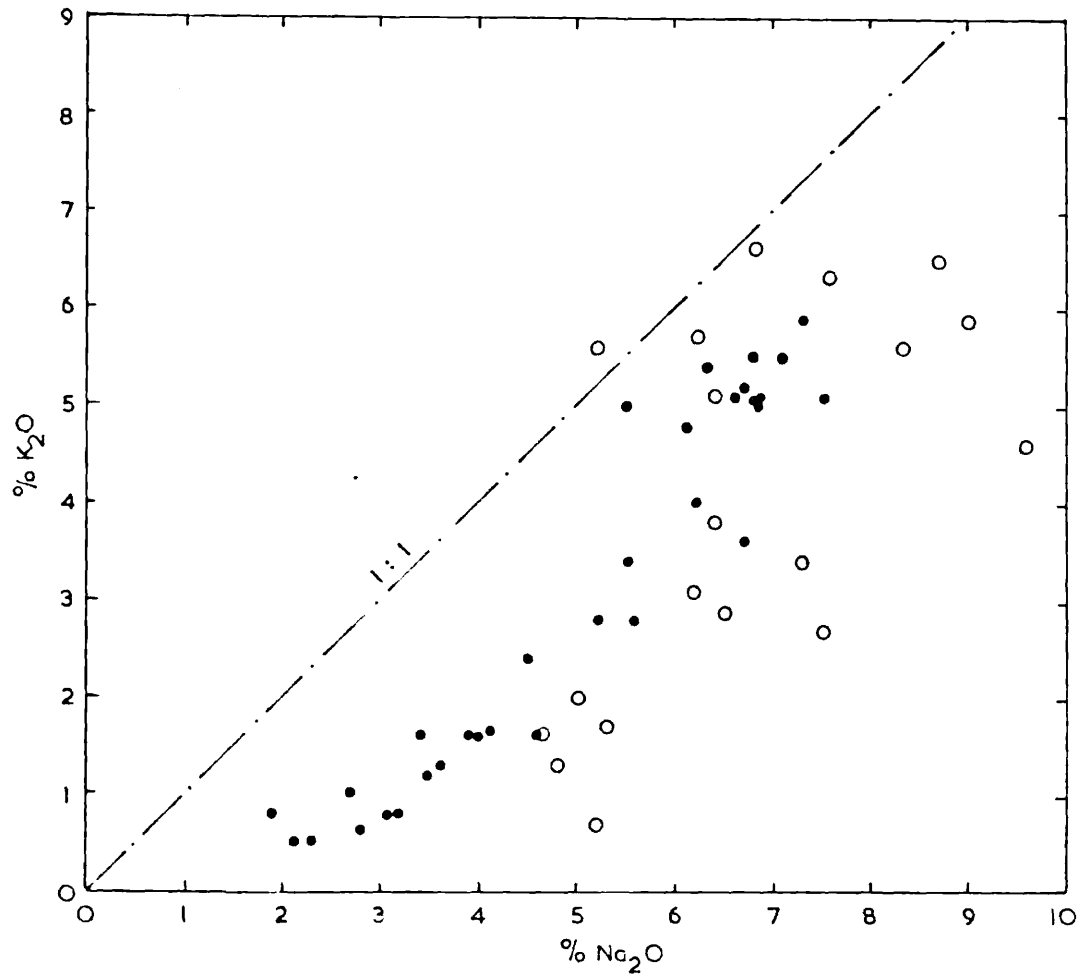


FIG. 59 ALKALI RATIO IN THE KAMASIA VOLCANIC ROCKS ○ Group II
● Groups III IV V

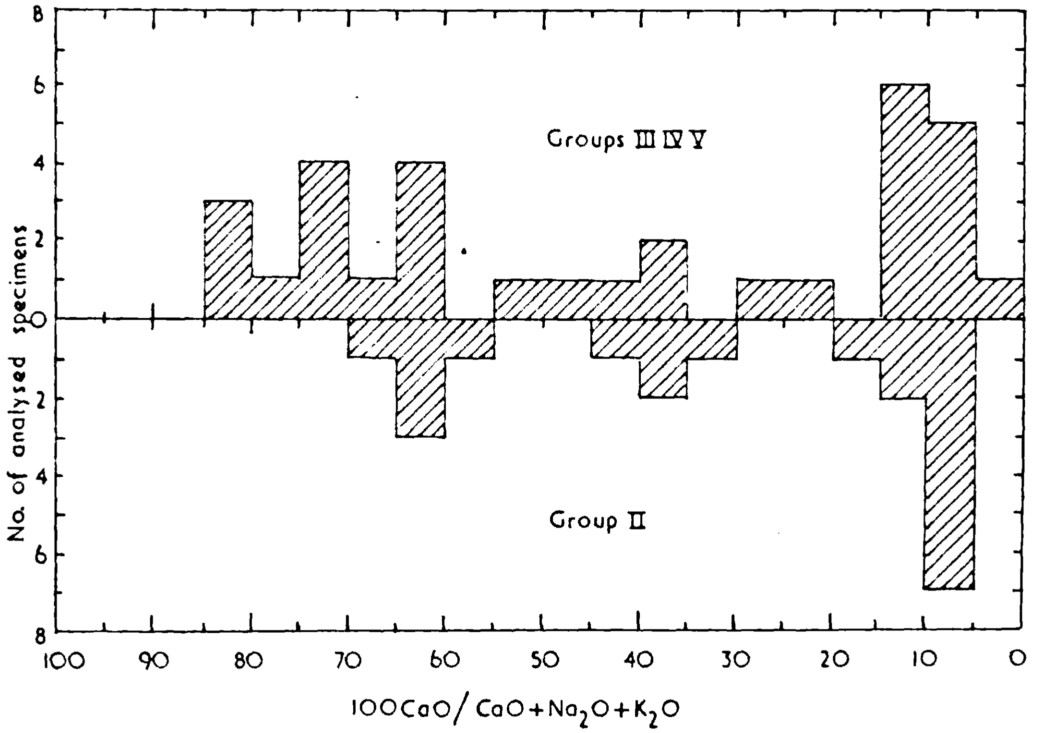


FIG. 58 FREQUENCY HISTOGRAM BASED ON THE CKN DIAGRAM (FIG. 57)

The older suite phonolites average over 20 per cent nepheline with more less than 14 per cent whereas all the trachyphonolites have normative nepheline less than 10 per cent, again emphasising the gap between the two groups. Normative quartz in the Atimet analyses is anomalous but may be caused by the alteration of the nepheline and/or occult secondary silica.

The trachytes vary from 1.4 ne-normative to 6.1 q-normative, and the exceptional comendite from the Kabarnet Trachytes (1/765) with 22.5 per cent normative quartz.

3. Tables of chemical analyses (all analyses by H. Lloyd)

Terminology of rocks prefixed '1/' is by J.E. Martyn.

When two or more formations are included within one table the analyses are arranged in ascending stratigraphic order, from left to right. Within one formation, they are arranged in ascending order of SiO_2 percentage unless otherwise stated below. An asterisk indicates that a petrographic description is also tabulated in the present volume.

Index to tables:

Table 15

1/515 : Ankaramite, Saimo Basanites Formation
1/567a : Analcite-basanite, Saimo Basanites Formation
1/609v : Analcite olivine-basalt, Saimo Bananites Formation
1/609vi : (no petrographic description) Saimo Basanites Formation

Table 16

2/237* : Hawaiite, Noroyan Formation
2/340* : Analcite-hawaiite, Noroyan Formation
2/341* : Analcite-hawaiite, Noroyan Formation
2/329* : Analcite-hawaiite, Noroyan Formation
2/239* : Analcite-mugearite, Noroyan Formation

Table 17

2/156b* : Olivine-basalt, Kaparaina Formation
1/409 : Picritic basalt, Kaparaina Formation
2/173* : Doleritic olivine-basalt, Kaparaina Formation
2/16* : Basalt, Kaparaina Formation
1/296 : Feldsparphyric basalt, Kaparaina Formation
2/46* : Basalt, Kaparaina Formation

Table 18

2/344* : Olivine-basalt, Lokwetemoi, Kabarnet Formation
1/761 : Alkali-basalt, Eron Basalts
1/858 : Olivine-basalt, Keiturwo Basalt
2/162* : Picritic basalt, Kaperyon Formation
2/100* : Zeolitic olivine-dolerite, Yepkarat Sill
2/119* : Olivine-dolerite, Yepkarat Sill
2/136* : Doleritic olivine-basalt, Nginyang Basalt

Table 19

2/71* : Mugearite, dyke in Kabarnet Formation
2/125* : Mugearite, (basal) Kaparaina Formation
1/277 : Biotite-kataphorite-mugearite, Kaparaina Formation
1/996 : Mugearite, Kaparaina Formation
1/114 : Mugearite, Ndau Mugearites
1/97 : Anorthoclase trachymugearite, Songoiwa Trachymugearites
1/99 : Anorthoclase trachymugearite, Songoiwa Trachymugearites

Table 20

2/26* : Alkali-trachyte, Kabarnet Formation
2/345* : Alkali-trachyte, Kabarnet Formation
2/298* : Quartz-alkali-trachyte, Kabarnet Formation
1/765 : Comendite, intrusive, Kabarnet Formation
2/22* : Alkali-trachyte, Ribon Trachyte Formation
2/79* : Alkali-trachyte, Ribon Trachyte Formation

Table 21

2/62* : Quartz-alkali-trachyte, plug in Kaparaina Formation
2/117* : Trachyte, Kaparaina Formation
2/133* : Quartz-trachyte, Kaparaina Formation

Table 22

2/315* : Trachyphonolite, (Chemoigut) Tiim Phonolites Formation
2/224* : Glassy trachyte, (Atimet) Tiim Phonolites Formation
2/225* : Phonolitic trachyte, (Atimet) Tiim Phonolites Formation
2/236 : Trachyphonolite, (Atimet) Tiim Phonolites Formation
2/108 : Phonolitic trachyte, Chemolingot
2/84* : Trachyphonolite, Loyamarok Trachyphonolite
1/51 : Analcite phonolite, Loyamarok Trachyphonolite

Table 23

1/596 : Phonolite, Sidekh Phonolites Formation
1/597 : Analcite phonolite, Sidekh Phonolites Formation
2/325* : Phonolite, Sidekh Phonolites Formation
2/314* : Phonolite, Sidekh Phonolites Formation
2/231* : Phonolite, (Kamuiton) Tiim Phonolites Formation
2/211* : Phonolite, (Sumet) Ewalel Phonolites Formation

TABLE 15: SAIMO ('BASANITES') FORMATION

	1/515	1/567a	1/609v	1/609vi
SiO_2	41.46	43.62	43.90	45.63
TiO_2	2.12	3.56	2.79	3.11
Al_2O_3	13.57	13.42	14.38	16.22
Fe_2O_3	6.17	5.14	4.58	3.57
FeO	6.95	7.47	7.68	6.37
MnO	0.21	0.21	0.23	0.18
MgO	6.99	6.20	6.10	3.75
CaO	12.55	11.15	10.48	8.68
Na_2O	4.82	5.02	4.55	5.18
K_2O	1.28	2.02	1.56	0.69
H_2O+	2.86	2.16	2.42	4.46
H_2O-	0.22	0.19	0.35	1.31
P_2O_5	0.64	0.52	0.54	0.45
CO_2	-	-	-	-
TOTALS	99.84	100.68	99.56	99.61

NORMS (CIPW)

	1/515	1/567a	1/609v	1/609vi
or	7.57	11.94	9.22	
ab	1.96	6.39	12.93	
an	11.62	8.12	14.21	
ne	21.03	19.55	13.85	
di	37.05	34.91	27.58	
ol	3.09	2.01	5.81	
mt	8.95	7.45	6.64	
il	4.03	6.76	5.30	
ap	1.51	1.23	1.27	
H_2O	3.05	2.33	2.75	
TOTALS	99.86	100.69	99.56	

TABLE 16: NOROYAN FORMATION - BASIC/INTERMEDIATE ROCKS

	2/237	2/340	2/341	2/329	2/239
SiO_2	44.14	47.36	50.01	49.08	49.88
TiO_2	5.18	1.90	1.42	1.70	1.73
Al_2O_3	15.69	18.54	20.35	19.32	19.14
Fe_2O_3	3.27	5.06	2.88	2.64	2.37
FeO	11.40	3.40	3.02	4.97	4.55
MnO	0.24	0.26	0.24	0.23	0.13
MgO	5.15	2.14	1.28	2.58	2.19
CaO	4.00	6.58	5.37	6.42	5.63
Na_2O	5.25	6.22	7.30	7.46	6.54
K_2O	1.69	3.07	3.40	2.68	2.91
H_2O+	1.66	3.41	3.06	2.26	2.43
H_2O-	0.21	0.67	0.60	0.28	0.55
P_2O_5	1.14	0.47	0.19	0.37	0.46
CO_2	-	0.83	0.84	0.09	1.19
TOTALS	99.48	99.91	99.96	100.08	99.70

NORMS (CIPW)

or	10.65	18.15	20.10	15.85	17.20
ab	38.28	26.02	29.86	21.59	30.45
an	12.18	13.18	12.69	11.41	14.28
ne	7.18	14.38	17.24	22.46	13.29
di	0.43	10.04	5.96	16.80	8.70
ol	15.99	0.49	2.30	2.01	3.63
mt	4.86	5.83	4.18	3.83	3.44
il	7.71	3.60	2.70	3.23	3.29
ap	2.73	1.11	0.45	0.87	1.09
H_2O	1.87	4.08	3.66	2.54	2.98
TOTALS	101.88	96.88	99.14	100.59	98.34

TABLE 17: BASALTS, KAPARAINA FORMATION

	2/156b	1/409	2/173	2/16	1/296	2/46
SiO_2	44.47	46.31	46.66	46.86	47.46	48.21
TiO_2	2.64	1.53	3.23	3.75	1.74	2.11
Al_2O_3	17.11	12.97	15.22	15.33	22.11	16.72
Fe_2O_3	2.97	3.15	3.31	5.07	2.75	3.29
FeO	9.10	7.05	10.01	7.20	5.57	7.33
MnO	0.18	0.16	0.23	0.21	0.13	0.16
MgO	7.25	12.54	4.44	3.73	2.98	5.87
CaO	11.09	11.99	8.91	9.79	10.98	9.53
Na_2O	2.74	1.88	3.94	4.05	3.45	3.59
K_2O	0.98	0.76	1.60	1.61	1.20	1.29
H_2O+	1.11	1.40	0.50	0.87	1.61	1.45
H_2O-	0.44	0.31	0.65	0.37	0.30	0.17
P_2O_5	0.35	0.19	0.42	0.64	0.29	0.32
CO_2	-	-	0.72	0.93	-	-
TOTALS	100.43	100.24	99.84	100.69	100.57	100.04

NORMS (CIPW)

	2/156b	1/409	2/173	2/16	1/296	2/46
or	5.79	4.49	9.46	9.52	7.09	7.63
ab	14.07	15.33	14.72	28.16	24.54	27.93
an	31.44	24.71	19.08	18.90	41.31	25.70
ne	4.92	0.31	10.07	3.31	2.52	1.32
di	19.15	26.73	17.76	20.45	9.23	15.79
ol	13.83	19.04	10.68	1.95	6.01	10.53
mt	4.31	4.57	4.90	7.35	3.99	4.77
il	5.02	2.91	6.14	7.12	3.30	4.01
ap	0.12	0.45	0.99	1.51	0.68	0.76
H_2O	1.55	1.70	1.15	1.21	1.90	1.61
TOTALS	100.20	100.24	93.80	99.48	100.57	100.05

TABLE 18: BASALTS, AND DOLERITES (MISCELLANEOUS - see p.171)

	2/344	1/761	1/858	2/162	2/100	2/119	2/136
SiO_2	44.76	47.84	45.48	45.11	46.16	45.57	47.64
TiO_2	3.57	2.62	1.63	1.77	1.66	2.42	1.99
Al_2O_3	15.01	16.74	17.22	14.38	14.99	16.56	16.48
Fe_2O_3	3.27	4.72	3.83	2.56	2.51	2.60	2.66
FeO	9.77	6.54	5.85	8.06	8.84	9.43	7.54
MnO	0.24	0.19	0.14	0.15	0.17	0.16	0.17
MgO	5.34	5.10	7.21	11.74	7.15	6.79	7.69
CaO	8.86	9.28	13.77	11.83	10.62	10.78	11.29
Na_2O	3.38	4.02	2.27	2.07	2.76	3.21	3.10
K_2O	1.55	1.56	0.54	0.54	0.63	0.76	0.75
H_2O+	1.39	0.88	1.24	1.55	3.74	1.29	0.42
H_2O-	0.85	0.23	0.43	0.46	0.70	0.37	0.06
P_2O_5	1.57	0.56	0.38	0.20	0.13	0.26	0.24
CO_2	0.42	-	0.20	0.11	-	0.23	-
TOTALS	99.98	100.28	100.19	100.53	100.06	100.43	100.03

NORMS (CIPW)

	2/344	1/761	1/858	2/162	2/100	2/119	2/136
or	9.21	9.22	3.19	3.19	3.72	4.49	4.43
ab	22.99	28.61	16.01	13.83	23.35	19.43	22.47
an	21.19	23.03	35.21	28.36	26.66	28.54	28.84
ne	3.02	2.93	1.73	1.99	-	4.19	2.04
di	16.13	15.50	24.46	23.28	20.56	18.99	20.67
hy	-	-	-	-	0.08	-	-
ol	11.12	6.77	8.19	20.22	14.16	13.93	12.90
mt	4.19	6.84	5.55	3.71	3.64	3.77	3.86
il	6.78	4.98	3.10	3.36	3.15	4.60	3.78
ap	3.71	1.32	0.90	0.47	0.31	0.61	0.53
H_2O	2.24	1.09	1.65	2.00	4.44	1.65	0.47
TOTALS	100.58	100.29	99.99	100.41	100.07	100.20	99.99

TABLE 19: MUGEARITES AND TRACHYMUGEARITES

	2/71	2/125	1/277	1/996	1/114	1/97	1/99
SiO_2	53.54	54.06	49.35	50.89	51.56	58.40	58.12
TiO_2	1.84	1.45	2.68	2.01	2.35	1.31	1.23
Al_2O_3	15.49	16.39	16.10	16.55	16.61	16.18	16.48
Fe_2O_3	5.85	3.87	6.44	4.33	2.75	6.78	5.86
FeO	4.10	6.38	5.04	5.84	6.23	2.07	1.74
MnO	0.22	0.27	0.16	0.17	0.28	0.22	0.18
MgO	1.67	1.88	3.18	3.21	2.87	0.95	1.59
CaO	5.36	4.97	7.53	5.95	5.33	2.85	3.93
Na_2O	5.16	5.58	4.47	4.64	5.48	6.68	6.17
K_2O	2.82	2.84	2.43	2.60	3.44	3.57	3.99
H_2O+	1.28	1.37	1.91	1.52	1.67	0.55	0.76
H_2O-	2.38	0.61	0.76	1.44	0.34	0.35	0.30
P_2O_5	0.45	0.39	0.52	0.88	0.98	0.34	0.27
CO_2	-	0.50	-	0.10	-	-	-
TOTALS	100.16	100.56	100.57	100.13	99.89	100.25	100.72

NORMS (CIPW)

	2/71	2/125	1/277	1/996	1/114	1/97	1/99
q	2.78	1.48	-	-	-	1.11	
or	16.67	17.00	14.36	15.37	20.33	21.10	
ab	43.66	50.70	35.36	39.26	36.38	56.52	
an	10.78	13.73	16.70	16.66	10.57	3.63	
ne	-	-	1.33	-	5.41	-	
di	9.10	-	13.44	5.77	7.78	5.10	
wo	0.50	-	-	-	-	0.73	
hy	-	8.20	-	4.05	-	-	
ol	-	-	1.18	3.84	6.69	-	
mt	8.48	5.46	9.00	6.28	3.99	3.59	
hm	-	-	0.23	-	-	4.30	
il	3.49	2.04	5.09	3.82	4.46	2.49	
ap	1.06	0.63	1.23	2.08	2.31	0.80	
H_2O	3.64	1.98	2.65	2.92	1.97	0.89	
TOTALS	100.16	101.22	100.57	100.05	99.89	100.26	

TABLE 20: TRACHYTES - KABARNET AND RIBON FORMATIONS

	2/26	2/345	2/298	1/765	2/22	2/79
SiO_2	61.28	61.27	62.97	72.83	61.12	61.54
TiO_2	0.75	0.72	0.66	0.56	0.67	0.70
Al_2O_3	15.46	14.99	13.95	13.84	13.88	14.56
Fe_2O_3	3.35	4.13	6.10	1.47	4.55	3.94
FeO	3.97	3.83	2.24	0.40	4.44	3.78
MnO	0.24	0.32	0.27	0.03	0.24	0.19
MgO	0.53	0.50	0.21	-	0.33	0.20
CaO	1.33	1.33	0.68	0.05	1.62	1.34
Na_2O	6.83	7.09	6.60	5.49	6.13	6.55
K_2O	5.49	5.46	5.14	5.00	4.84	5.09
H_2O+	0.68	0.31	0.78	0.18	1.26	0.43
H_2O-	0.42	0.35	0.79	0.18	1.07	0.97
P_2O_5	0.06	0.05	0.04	0.04	0.03	0.01
CO_2	-	-	-	-	-	-
TOTALS	100.39	100.35	100.43	100.07	100.18	99.80

NORMS (CIPW)

	2/26	2/345	2/298	1/765	2/22	2/79
q	-	-	6.05	22.47	4.08	1.94
or	32.45	32.30	30.40	29.55	28.62	30.08
ab	46.34	44.10	43.03	43.36	44.33	46.56
ne	1.43	1.35	-	-	-	-
ac	7.78	11.78	11.26	2.73	6.59	7.81
di	5.38	5.63	2.90	-	6.64	5.79
hy	-	-	0.74	-	2.08	2.57
ol	3.41	3.31	-	-	-	-
mt	0.96	0.07	3.18	-	3.29	1.80
hm	-	-	-	0.53	-	-
il	1.42	1.37	1.25	0.91	1.20	1.33
ap	0.14	0.12	0.07	0.09	0.03	0.02
H_2O	1.10	0.66	1.57	0.36	2.33	1.90
TOTALS	100.40	100.69	100.45	100.00	99.19	99.80

TABLE 21: TRACHYTES - KAPARAINA FORMATION

	2/62	2/117	2/133
SiO_2	61.95	63.28	62.36
TiO_2	0.69	0.41	0.69
Al_2O_3	14.53	15.94	14.02
Fe_2O_3	4.20	5.31	6.89
FeO	3.74	0.62	1.40
MnO	0.18	0.12	0.28
MgO	0.14	-	0.16
CaO	0.88	0.57	1.20
Na_2O	6.83	6.33	6.82
K_2O	5.01	5.40	5.01
H_2O+	0.71	0.93	0.54
H_2O-	1.13	0.86	0.51
P_2O_5	0.04	0.03	0.09
CO_2	-	-	-
TOTALS	100.03	99.80	99.97

NORMS (CIPW)

	2/62	2/117	2/133
q	2.06	5.60	4.94
or	29.63	31.92	29.80
ab	46.69	51.93	47.20
ac	9.75	1.43	11.48
di	3.63	-	0.88
wo	-	1.01	1.74
hy	3.80	-	-
mt	1.19	1.20	1.36
hm	-	3.99	1.28
il	1.31	0.78	1.22
ap	0.09	0.07	0.18
H_2O	1.84	1.79	1.05
TOTALS	99.99	99.72	101.13

TABLE 22: TRACHYPHONOLITES

	2/315	2/224	2/225	2/236	2/108	2/84	1/51
SiO_2	57.22	56.79	56.59	58.04	58.70	58.36	58.03
TiO_2	1.13	0.70	0.74	0.76	0.56	0.64	0.69
Al_2O_3	16.88	16.00	16.39	16.03	15.19	16.38	16.22
Fe_2O_3	2.74	3.57	5.64	4.73	5.08	4.50	4.68
FeO	4.13	4.11	2.27	2.83	3.72	3.31	3.20
MnO	0.32	0.35	0.35	0.26	0.32	0.33	0.36
MgO	1.06	0.57	0.64	0.74	0.34	0.35	0.44
CaO	2.52	1.43	1.08	1.05	1.43	1.46	1.52
Na_2O	6.37	6.44	5.21	6.20	6.75	7.48	7.26
K_2O	5.11	3.83	5.55	5.68	5.04	5.13	5.92
H_2O+	1.39	3.59	2.06	1.82	1.75	1.61	1.67
H_2O-	0.41	1.86	1.92	0.45	1.40	0.68	0.84
P_2O_5	0.21	0.08	0.04	0.02	0.02	0.06	0.05
CO_2	0.56	0.26	1.59	1.17	-	-	-
TOTALS	100.06	99.58	100.07	99.83	100.30	100.29	100.88

NORMS (CIPW)

	2/315	2/224	2/225	2/236	2/108	2/84	1/51
q	-	0.21	1.92	-	-	-	-
or	30.24	22.65	32.80	33.90	29.79	30.32	34.99
ab	45.67	54.44	44.08	54.50	46.42	41.74	33.04
an	2.32	3.41	4.95	-	-	-	-
ne	4.44	-	-	-	1.98	7.56	9.45
ac	-	-	-	1.40	6.20	6.69	9.65
di	4.44	1.31	0.12	-	6.04	5.93	6.23
hy	-	4.84	1.54	0.54	-	-	-
ol	3.33	-	-	1.14	1.36	1.24	1.65
mt	3.98	5.18	6.31	3.78	4.26	3.17	1.95
hm	-	-	1.29	1.10	-	-	-
il	2.15	1.33	1.40	1.08	1.06	1.22	1.31
ap	0.50	0.19	0.09	0.05	0.05	0.14	0.12
H_2O	1.80	5.45	3.98	2.27	3.14	2.29	2.55
TOTALS	98.87	99.01	98.48	99.76	100.30	100.28	99.94

TABLE 23: PHONOLITES - TUGEN HILLS GROUP

	1/596	1/597	2/325	2/314	2/231	2/211
SiO_2	55.35	54.88	55.22	55.35	55.12	54.72
TiO_2	0.37	0.46	0.77	0.58	0.48	0.26
Al_2O_3	19.50	19.89	21.09	20.76	19.95	19.27
Fe_2O_3	2.65	2.88	2.02	2.49	2.45	5.36
FeO	2.85	2.25	2.19	1.73	2.40	0.96
MnO	0.31	0.30	0.26	0.24	0.24	0.34
MgO	0.32	0.57	0.48	0.57	0.58	0.34
CaO	0.99	1.12	2.21	1.19	1.26	1.13
Na_2O	6.77	8.65	9.57	8.98	7.58	8.28
K_2O	6.60	6.50	4.56	5.94	6.25	5.64
H_2O+	3.37	2.91	1.41	2.20	2.78	3.09
H_2O-	0.30	0.28	0.23	0.36	0.38	0.98
P_2O_5	0.03	0.05	0.06	0.10	0.07	0.02
CO_2	1.04	-	-	-	0.68	-
TOTALS	100.45	100.74	100.07	100.48	100.22	100.39

NORMS (CIPW)

	1/596	1/597	2/325	2/314	2/231	2/211
or	39.01	38.42	26.97	35.13	36.94	33.36
ab	30.87	19.05	33.47	26.25	29.49	34.64
an	3.33	-	1.08	-	1.96	-
ne	14.31	25.50	25.12	25.52	18.77	17.83
ac	-	6.22	-	2.03	-	2.13
di	1.19	4.45	4.79	4.86	3.21	2.98
wo	-	-	1.23	-	-	0.61
ol	2.42	1.87	-	0.17	1.39	-
mt	3.84	1.06	2.93	2.59	3.55	2.38
il	0.70	0.87	1.48	1.10	0.91	0.49
ap	0.07	0.12	0.14	0.24	0.17	0.05
H_2O	3.67	3.19	1.64	2.56	3.16	4.07
TOTALS	99.41	100.75	98.85	100.45	99.55	98.54

(c) Differentiation process

An 'average olivine-basalt' was calculated for the younger suite using the chemical screen of Manson (1967). The result is the average of eight analyses, and in table 24 is shown to be closely similar to averages from the Rungwe, Scottish Carboniferous, East Otago, Hebrides and Hawaii provinces. Table 25 shows the result of subtraction calculations to derive composition, and amount of material to subtract, from the average olivine-basalt to give mugearite, trachymugearite, trachyte and quartz-trachyte. The resulting composition is close to the actual composition of a picritic basalt (2/162) from the present area and to an ankaramite (8/81) collected by S.D. Weaver from Turkana, and crystal fractionation seems to be a reasonable explanation for the origin of these lavas.

However, as is well known, the volume of felsic differentiates in the East African province (and in continental provinces generally) is disproportionately high compared to the alleged basic parents. Wright (1965) investigated the possibility of assimilation of sialic material to account for the felsic lavas, but concluded that such a process, although possible, does not nearly account for the volumes of phonolite and trachyte. Bailey (1964) has suggested that partial melting of mantle material could account for the salic lavas and backs the theory with experimental data (Bailey and Schairer 1966). In the writer's view, Bailey's theory has a totally inadequate explanation for the necessary lowering of pressure (raising of the 'Kenya dome' by lateral compression) and does not take into account the fact that basaltic magma also seem to have been available throughout the history of the province, since it is found in small quantities in the predominating phonolitic and trachytic piles as well as in basaltic formations. There is even evidence from the volcano Pakka of basalt and trachyte being erupted from the same vent (Sceal Ph.D. thesis in preparation). Finally, Harkin (1960) invoked carbonatite in the Rungwe petrogenesis. No carbonatitic rocks are known from the Rift in north and central Kenya and isotopic dates (Bishop et al. 1969, Baker et al. in press) show that the strongly nephelinic and carbonatitic centres of western Kenya and Uganda are distinctly older than the plateau phonolites of Kenya.

There is no a priori reason, as Chayes (1963) pointed out, to invoke sialic crust to explain the composition of the alkalic olivine-basalt/ trachyte association, since that association also occurs on oceanic islands. Only the proportions are different. The asymmetry of the frequency histogram (fig. 58) does not suggest mixing of two separate magmas, basaltic and felsic. The curve is similar in both oceanic and continental associations until one considers the sudden continental felsic peak, which is virtually absent in the oceanic examples. If the crust beneath the Rift has an average continental thickness (which may be thrown in some doubt by recent geophysical investigations) then the writer would suggest that the simple fact of sialic crustal thickness may be a factor: if the crust is riddled by magma chambers and channels, it may act as a gigantic still, in which progressively lighter and more felsic differentiation products work their tortuous way to the surface, until finally only the ultimate products of fractionation are erupted at the surface. Basalt only reaches the surface when episodes of extreme local or regional tension favour the formation of deep-penetrating dyke-swarms which tap the basaltic source near the crust - upper mantle region.

This idea is given some support by the actual intrusive bodies at present exposed at the surface: a fairly large number of large phonolite, micro-foyaite, syenite and trachyte plugs are known from the northern Rift (Joubert 1966, McClenaghan op.cit., Weaver op.cit., Golden pers. comm.) but virtually the only basic intrusives known are dyke swarms and thin, and rare, dolerite sills.

TABLE 24: Average Baringo olivine-basalt compared to average olivine-basalts from other provinces

	(1)	(2)	(3)	(4)	(5)	(6)
SiO_2	46.5	45.2	47.1	47.1	46.9	45.4
TiO_2	2.3	1.9	2.9	2.3	2.4	3.0
Al_2O_3	16.1	16.5	15.8	14.7	15.4	14.7
Fe_2O_3	3.5	4.0	4.0	3.5	3.9	4.1
FeO	7.5	8.7	8.3	9.0	9.8	9.2
MnO	0.2	0.2	0.2	0.2	0.3	0.2
MgO	7.4	7.8	7.4	8.7	8.4	7.8
CaO	10.9	11.2	9.4	10.2	9.6	10.5
Na_2O	3.1	2.8	3.1	3.1	2.5	1.9
K_2O	1.1	1.1	1.3	0.9	0.6	0.7
P_2O_5	0.4	0.7	0.5	0.3	0.2	0.4

(1) Average of eight olivine-basalts from the younger suite, Baringo.

(2) Rungwe (Harkin (1960) p.152)

(3) Carboniferous of Scotland (Tomkeieff 1937)*

(4) East Otago (Benson 1942)*

(5) Hebrides (Bailey et al. 1924)‡

(6) Hawaii (Macdonald (1968) p.502)

* Analysis obtained from Turner & Verhoogen (1960) pp.168 & 192.

‡ Analysis obtained from Harkin (1960) p.152.

TABLE 25: Compositions of smallest amounts of material to be subtracted from average Baringo olivine-basalt to yield more felsic lavas

		(1)	(2)	(3)	(4)	(5)
SiO_2		44.50	42.75	42.90	43.00	42.70
TiO_2		1.90	2.60	2.20	2.50	2.60
Al_2O_3		15.25	15.60	15.30	15.80	16.00
Fe_2O_3		1.40	3.20	3.45	3.30	2.85
FeO		9.40	8.15	9.25	8.40	9.10
MnO		0.30	0.20	0.25	0.20	0.25
MgO		11.10	10.70	9.50	9.40	9.60
CaO		14.00	14.25	13.60	13.35	13.80
Na_2O		1.90	1.75	2.10	2.10	2.00
Amount subtracted:		60%	73%	80%	85%	85%
				NORMS		
ab		7.3	6.1	8.4	10.7	7.3
an		33.0	34.7	32.3	33.6	34.6
ne		4.7	4.7	5.1	3.8	5.2
di	wo	15.2	15.1	15.7	13.6	14.1
	en	9.6	10.5	9.4	9.3	9.2
	fs	4.7	3.3	4.3	3.3	4.0
ol	fo	12.8	11.4	10.1	10.0	10.4
	fa	6.8	3.9	5.1	3.9	5.0
mt		2.0	4.6	5.0	4.8	5.0
il		3.6	4.9	4.2	4.7	4.9

(1) Material subtracted to yield mugearite (1/277)
(2) " " " " trachymugearite (2/125)
(3) " " " " trachymugearite (1/99)
(4) " " " " trachyte (2/79)
(5) " " " " quartz-trachyte (2/133)

(d) Summary

Evidence from the Kamasia suggests that any petrogenetic theory for the Rift volcanics must take into account the following salient facts:

(1) There is a distinct bimodality in the frequency of rock-types, with felsic types exceeding basalts. Intermediate rocks are present but scarce.

(2) Basaltic magma has been available throughout the history of the province.

(3) The most significant change in composition of lavas with time is not, as Baker et al. (in press) suggest, from basaltic to trachytic, but from strongly undersaturated to saturated or over-saturated with respect to silica.

(4) The above change is relatively sudden and, in the Kamasia at least, coincides with a major episode of Rift faulting, suggesting a connection between tectonism and magma genesis.

(5) The younger suite is almost indistinguishable from similar suites in oceanic provinces and can reasonably be derived from a basaltic parent by a crystal fractionation process. The large volume of trachytes is, however, a major problem.

(6) There have not, yet, been described any rocks with tholeiitic or calc-alkaline affinities. The 'rhyolites' and 'andesites' of Turkana are in fact pantellerites, comendites and mugearites etc. (Walsh and Dodson 1969).

CONCLUSIONS

Since, as Martyn (1969) also records, the Kamasia Range exposes the thickest and most complete sequence known in the later Tertiary of Kenya it is suggested that many observations in this relatively small area may be of general relevance to the whole Kenya Rift.

The thick group II phonolite succession immediately suggests that the source of these lavas lies within the rift rather than in the main area of the present outcrop of the rift shoulders. Isotopic age determinations show that the Kamasia sequence comprises phonolites both younger and older than those on the flanking plateaux.

The Kaparaina Basalts Formation (group III) emphasizes that there were two major episodes of basalt extrusion in the northern rift, the earlier group (I) being overlain by the group II phonolites in Turkana and on the Elgeyo and Laikipia escarpments, and the later group (III) overlying the phonolites. The two groups have already been confused in other areas and identification is likely to be difficult again in areas where they are co-extensive.

The fossiliferous sedimentary units are palaeontologically very important in that they span the former Pliocene gap in the fossil vertebrate record of Africa south of the Sahara. Furthermore they occur in a fully documented stratigraphic sequence with close control by isotopic dates.

Radiometric dating of a sequence, the stratigraphy of which is already established by mapping, has also allowed a critical assessment of the results and provided an indication of the rates of tectonism and volcanism in the area.

The tectonic control of observable thickness variations in the Ngorora Formation and the Muruywr Beds leads the writer to suspect that other sedimentary units, cropping out as thin intercalations in tectonically 'high' areas, e.g. those in the Sidekh Phonolites, may be represented by much thicker sequences in the tectonic basins, now concealed by later accumulation. The total thickness of the Cainozoic succession in this area may thus be even greater than the 10,000 feet (3 km.) demonstrable minimum. This has significant tectonic implications (see below).

Even if the Cainozoic sequence totals no more than 3 km. the base of the sequence must be depressed to a maximum of 6,000 feet (1.8 km.) below sea level in the Saimo area. This figure is comparable to the maximum elevation of the sub-Cainozoic surface of 6,000 to 7,000 feet above sea-level on the Elgeyo Escarpment (omitting the Cheringani massif which is a much older erosional remnant).

The most remarkable features of the faulting in the area are the fault-arches and half-domes, which clearly indicate a north-south compressional component complementing, and possibly a secondary result of, the regional east-west tensional stress field. These features may also be produced by a slight transcurrent fault movement but there is no evidence at all for strike-slip movement on any of the faults. East-west stratal extension is also minimal, amounting to less than 0.5 km. in the map area.

The western limits of minor faulting and volcanic accumulation have retreated eastwards with time but the major fault systems (Elgeyo, Saimo and Kito Pass faults) have been intermittently active from their probable pre-volcanic inception to the Quaternary. Had the latest movement on the Elgeyo Fault not occurred the Kamasia fault system would now appear to be the western margin of the rift; it is noteworthy that the average rift width of 45 km. is the distance between the Kamasia and Laikipia escarpments and that the area of Quaternary grid-faulting and volcanism is, at this latitude, median to those boundaries. Thus, the role of western rift-boundary has perhaps been transferred from the Elgeyo to the Kamasia and it is the former which is now anomalous.

As Martyn (op.cit.) also found, although major faulting episodes have occurred, there have also been frequent small movements on the largest faults. The Kamasia Range has been a topographic feature since the first major faulting episode (7.0 - 8.0 m.y.) and may at times since then have approached its present dimensions. However, much of the present relief is due to Quaternary fault movement.

It has been possible to demonstrate by quantitative methods the former presence of local erosion surfaces in the eastern foothills of the Kamasia, and it seems likely that much more investigation of this sort could be done in areas free from Quaternary volcanics. The presence of lavas suitable for radiometric dating would give valuable information on rates of erosion, at present an almost completely unknown factor in this area.

Although the succession would seem to indicate volcanism of the 'plateau lava' type work in adjacent areas has shown that in this region no sharp distinction can be made between 'central' and 'plateau' eruptions. For this reason it has been suggested that the group II phonolite sequence in the Kamasia may represent the flank lavas of large low-angle central complexes now concealed beneath the rift centre.

A remarkable feature of the group II phonolites is the great thickness of individual flows, up to 800 feet (240 m.) in the case of the Sumet Phonolite.

While it is true that the western limits of volcanic accumulation have moved eastwards with time, restricted chiefly by tectonic topography, there is little evidence from this area of the location of extrusive sources.

Emphasis has been laid on the distinct petrochemical break which occurs at the unconformity marking the first major faulting episode, both mafic and felsic lavas of the younger suite being more silicic than their equivalents in the older suite, and on the fact that there are two completely distinct types of 'phonolite' in the area, the more undersaturated type being entirely confined to the older suite.

From compositional considerations it is feasible to derive the intermediate and felsic rocks of the younger suite from a basaltic parent by crystal fractionation, but in both suites the very high proportion of felsic differentiates remains a major problem.

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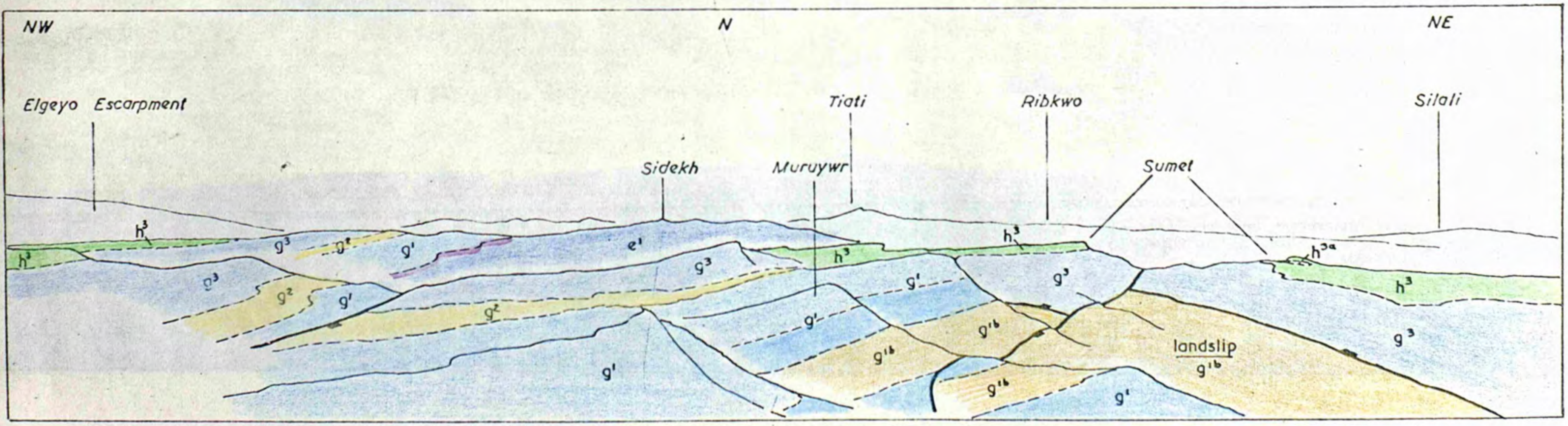
NW
N
NE
Elgeyo Escarpment
Tiati
Ribkwo
Silali
Sidekh
Muruywr
Sumet
h^3
g^3
g^2
g^1
e^1
h^{3a}
g^{1b}
landslip

PLATE I

Plate 1. The main range, north from Kamuiton.

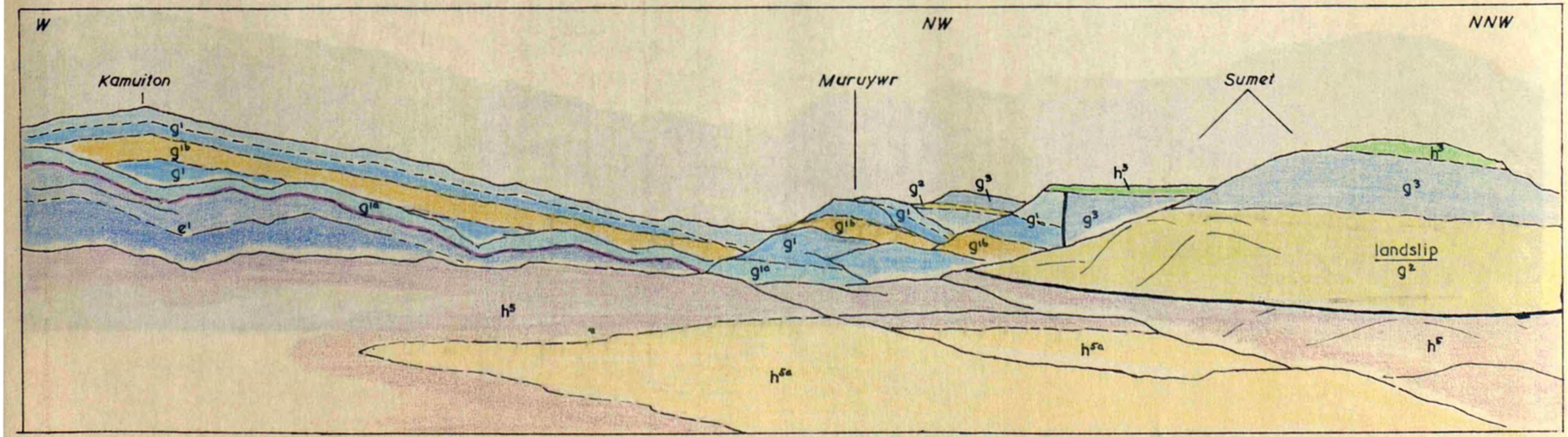
W
NW
NNW
Kamuiton
Muruywr
Sumet
g¹
g¹ᵇ
g¹
g¹ᵃ
e¹
g¹
g¹ᵇ
g¹ᵃ
g²
g¹
g³
g¹ᵇ
g¹
g³
h³
h³
g³
landslip
g²
h⁵
h⁵ᵃ
h⁵ᵃ
h⁵

PLATE 2

Plate 2. Scarps of the main range in the central area, west from near Kapgoyo.

Plate 3. Dip-slope of the Kamasia Range, south from near Atyar.

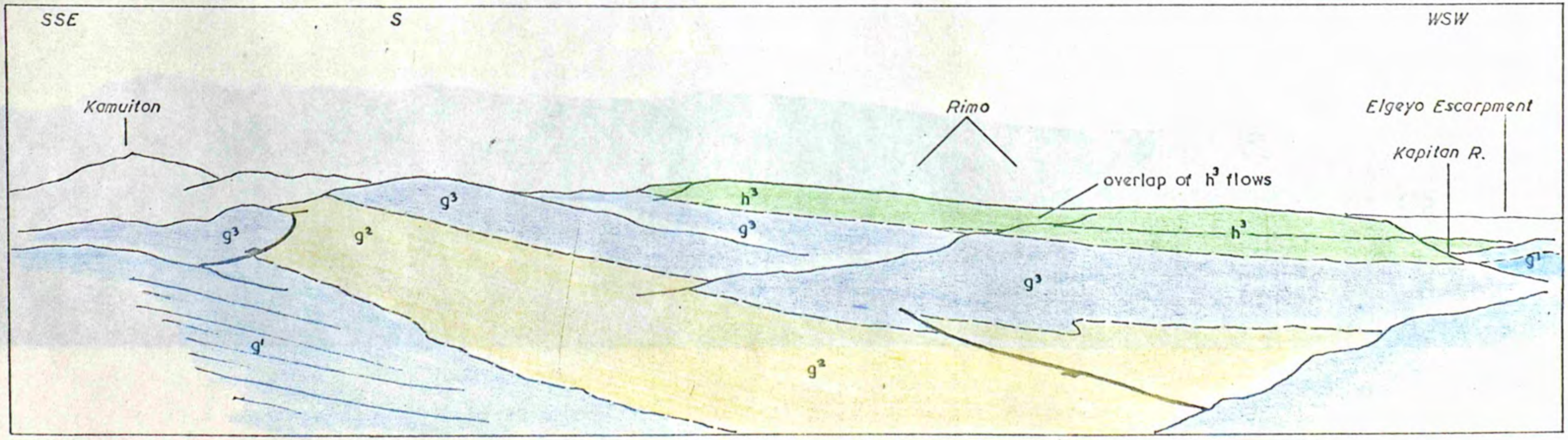
SSE
S
WSW
Kamuiton
Rimo
Elgeyo Escarpment
Kapitan R.
overlap of h³ flows
h³
h³
g³
g³
g³
g³
g²
g²
g¹
g¹

PLATE 4

Plate 4. Main range, south from Charkum.

Plate 5. Sidekh Range and Kaperyon, west from Ribon.

Plate 6 Flow-banding in Kamuiton Phonolite, Kabarsero gorge.

Plate 7 Sumet mesas from the north.

Plate 8 Rhythmic units in the Ngorora Formation, member D, Kabarsero. Cliff features are the upper (pumiceous) parts of each unit.

Plate 9 The Chepkesin grit (top of the Ngorora Formation) and Sumet (Kabarnet Trachyte capping Sumet Phonolite) from theold Chepkesin dukas.

Plate 10 Yatya - Kabarnet Trachyte overlying deeply-weathered Sumet Phonolite

Plate 11 Yatya - contact between Kabarnet Trachyte (above) and Sumet Phonolite (below)

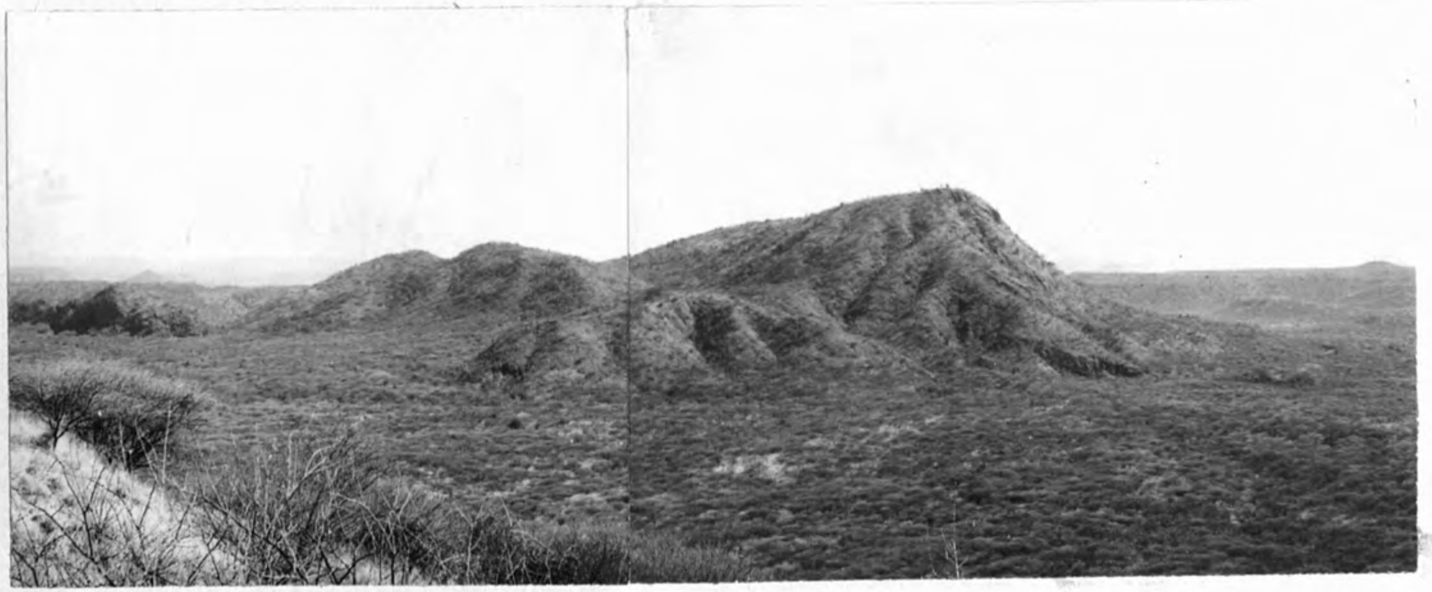

Plate 12. Kokwomur from Chesoton (see fig. 94).

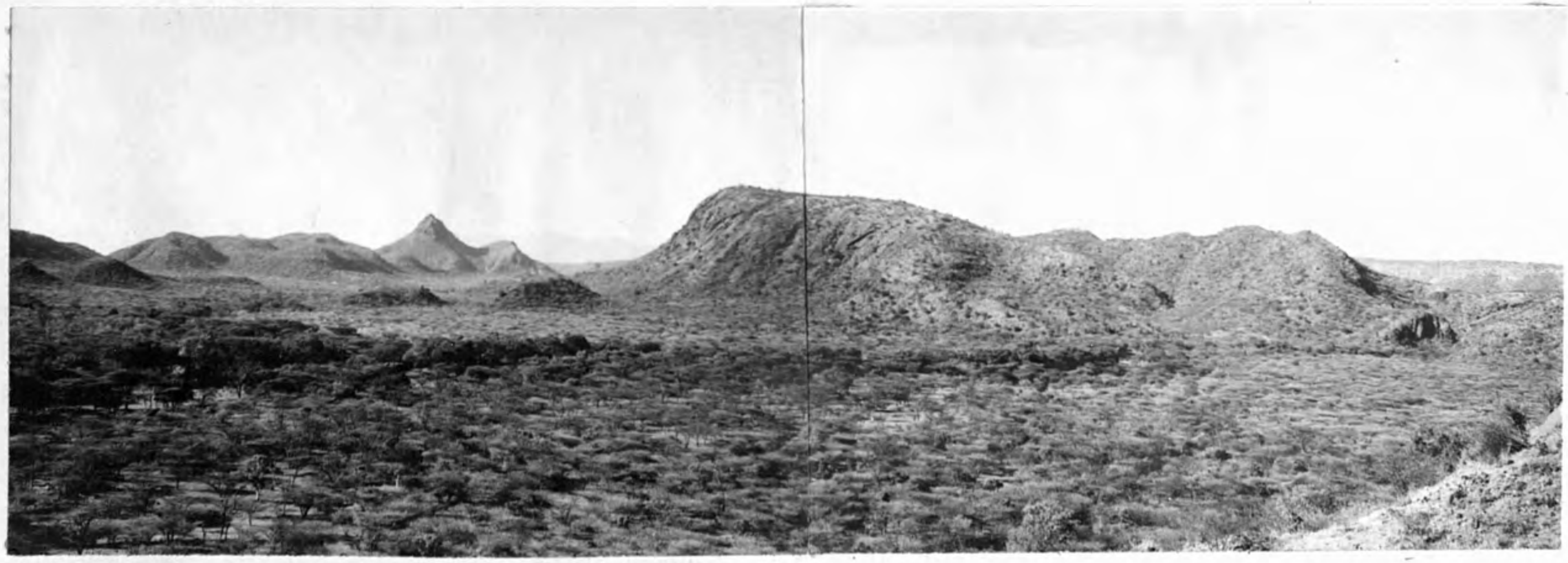

Plate 13. Kokwomur and Chepochom, south from Nakipurat.

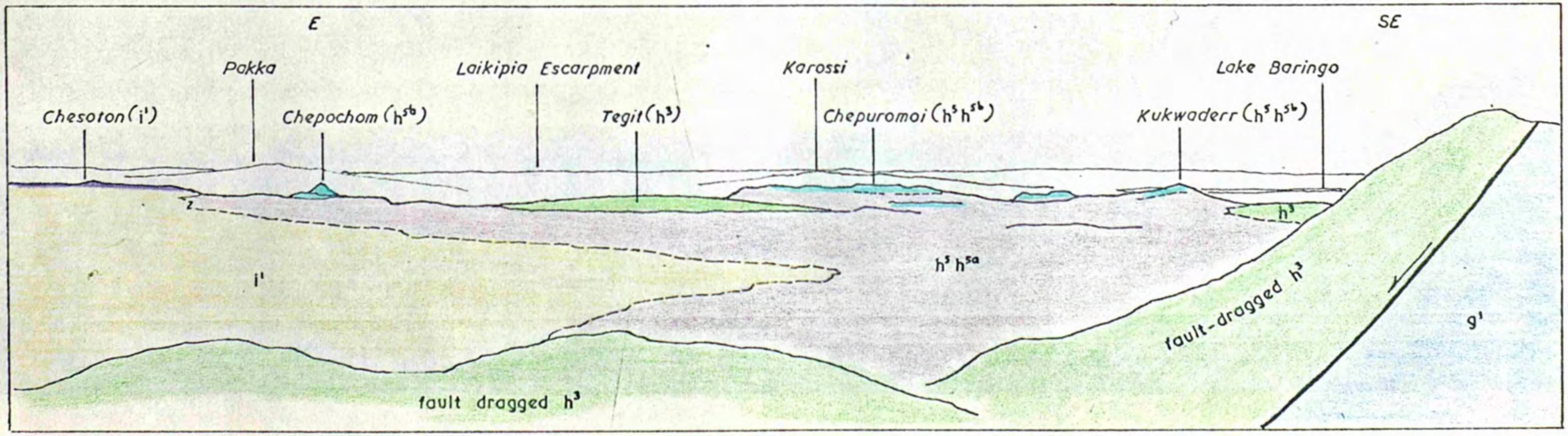
E
SE
Pakka
Laikipia Escarpment
Karossi
Lake Baringo
Chesoton (i')
Chepochom (h^{5b})
Tegit (h^3)
Chepuromoi ($h^5 h^{5b}$)
Kukwaderr ($h^5 h^{5b}$)
h^3
i'
$h^5 h^{5a}$
fault-dragged h^3
g'
fault dragged h^3

PLATE 14

Plate 14. The eastern foothills, with the Tegit fault-arch,
from the main scarp, near Chemagin River.

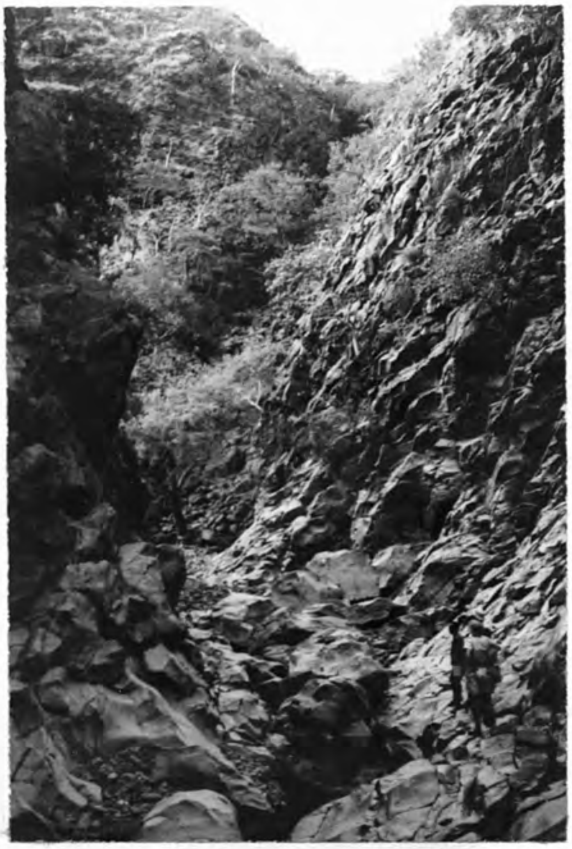

Plate 15 In the Kisitei Gorge - Kabarnet Trachyte

Plate 16 Fissility in the Kabarnet Trachyte, Kisitei Gorge

Plate 17. Chepuromoi from Cheprepei. Kaparaina basalts and trachytes.

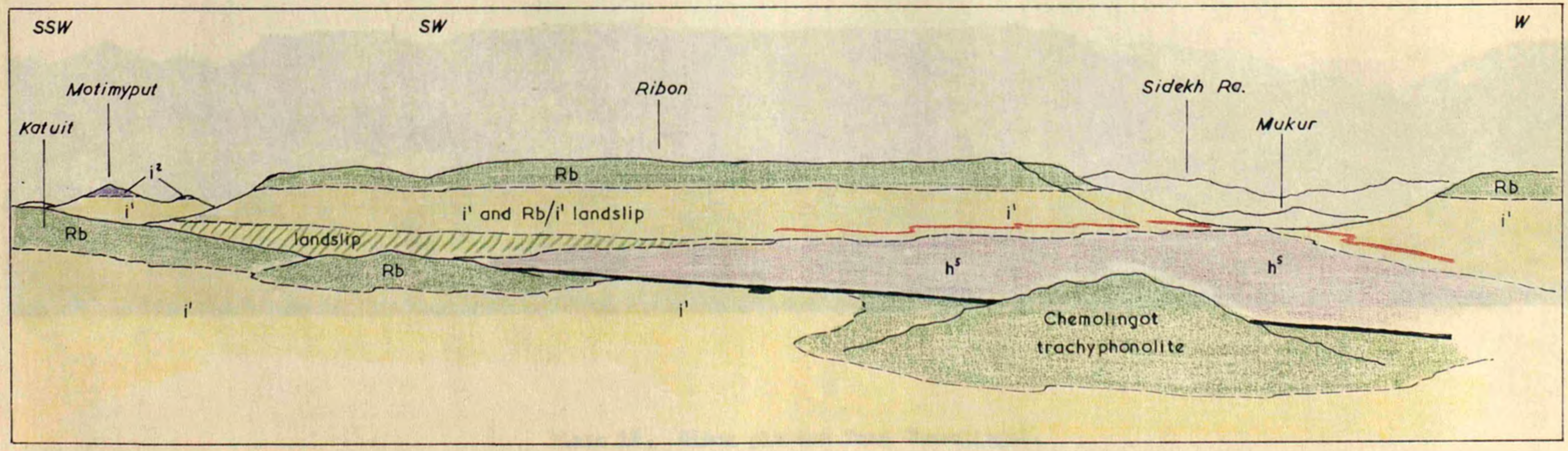
SSW
SW
W
Motimyput
Katuit
Ribon
Sidekh Ra.
Mukur
i²
i¹
Rb
Rb
i¹ and Rb/i¹ landslip
i¹
Rb
i¹
landslip
Rb
h^s
h^s
i¹
i¹
Chemolingot
trachyphonolite

PLATE 18

Plate 18. Ribon plateau from Chemolingot.

Plate 19 Columnar jointing in mugearite, Kamsoror. Bedded tuffs of Lukeino Member below.

Plate 20 Base of the Ribon Trachyte on Kaperyon Formation. (tuff with blocks) on Chemolingot

Plate 21 Spheroidal weathering in Lokwaleibit basalts, east of Nakipurat

Plate 22 The 'Nginyang surface', south from Karmosit mesa, six miles north of Nginyang

Plate 23 Ankaramitic analcite-hawaiite, Noroyan Formation, Noroyan, showing augite and altered olivine phenocrysts in an analcite-rich groundmass. x-nichols x 20 spec. 2/253

Plate 24 Analcite-hawaiite, Noroyan Formation, Noroyan, showing phenocrysts of andesine, resorbed kaersutite (dark) and augite in a fluidal groundmass texture. P.P.L. x 20 spec. 2/333

Plate 25 Glassy nepheline-hawaiite, Noroyan Formation, Noroyan, showing nepheline and andesine laths in a matrix of brown glass. P.P.L. x 50 spec. 2/254

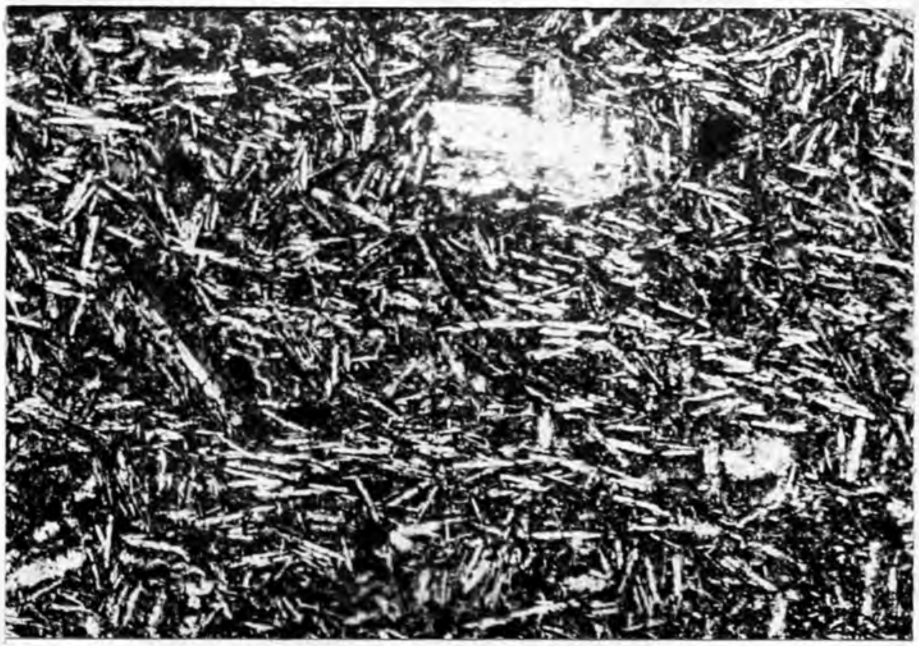

Plate 26 Analcite-trachymugearite, Noroyen Formation, Atimet, showing andesine/oligoclase phenocrysts in a trachytoid groundmass of ?potash-oligoclase and analcite. P.P.L. x 20 spec. 2/285

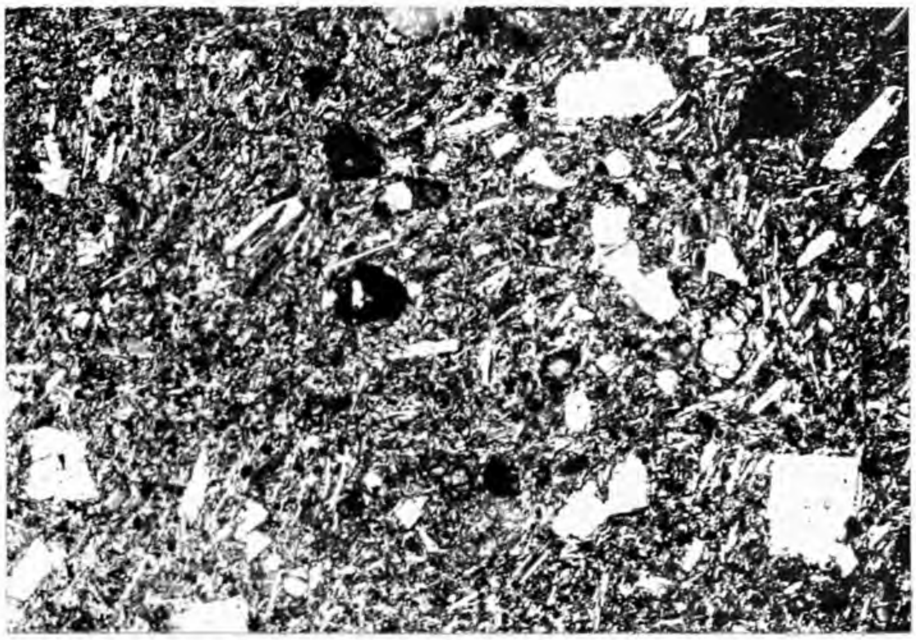

Plate 27 Olivine-basalt, Kaparaina Formation, Kateli River, showing olivine, augite and labradorite phenocrysts. x-nichols x 10 spec. 2/10

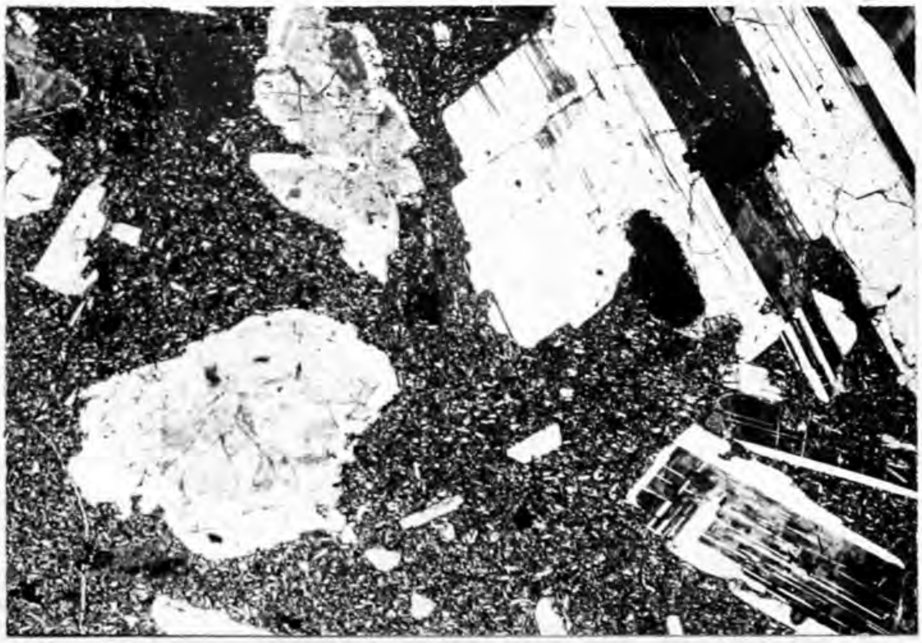

Plate 28 Feldsparphyric basalt, Kaparaina Formation, nr. Chepochom, showing large zoned phenocrysts of labradorite. x-nichols x 10 spec. 2/130

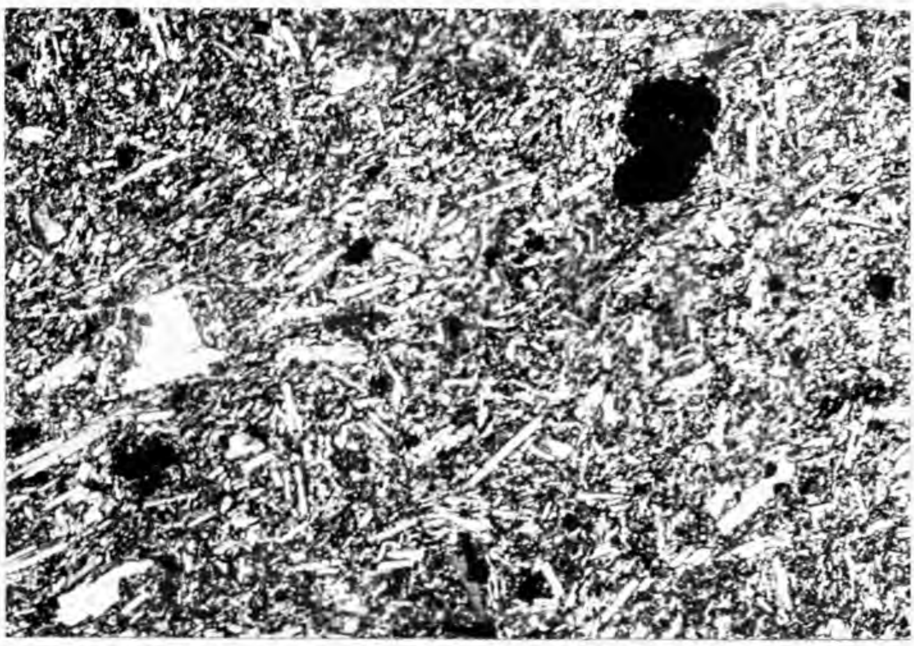

Plate 29 Olivine-basalt, Kaparaina Formation, Adonyasas, showing phenocrysts of labradorite and dark red pseudomorphs (black, top ~~left~~ right) after olivine. P.P.L. x 20 spec. 2/52

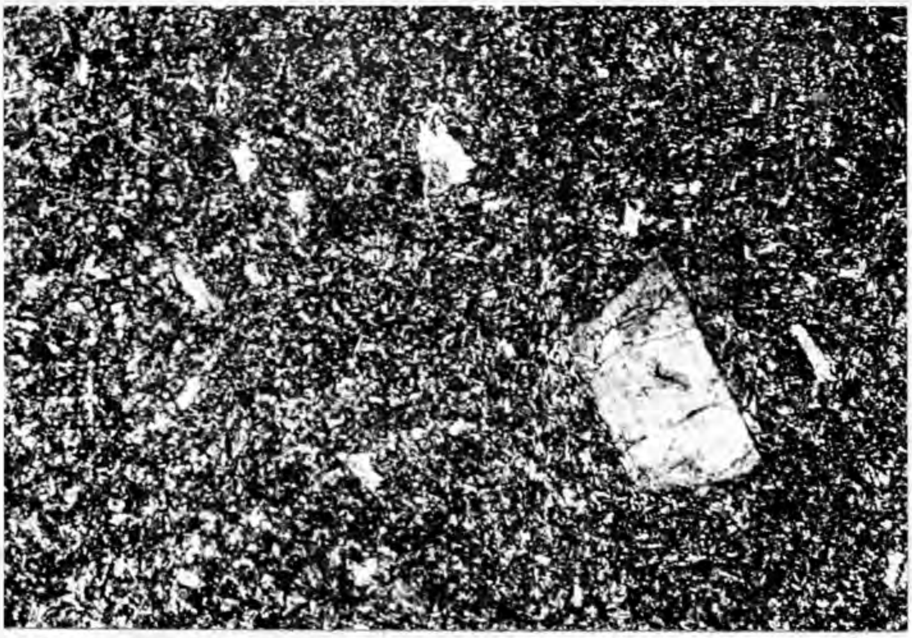

Plate 30 Mugearite, Kaparaina Formation, Kamscror, showing anorthoclase phenocrysts in a fine-grained andesine/oligoclase groundmass. x-nichols x 20 spec. 2/125

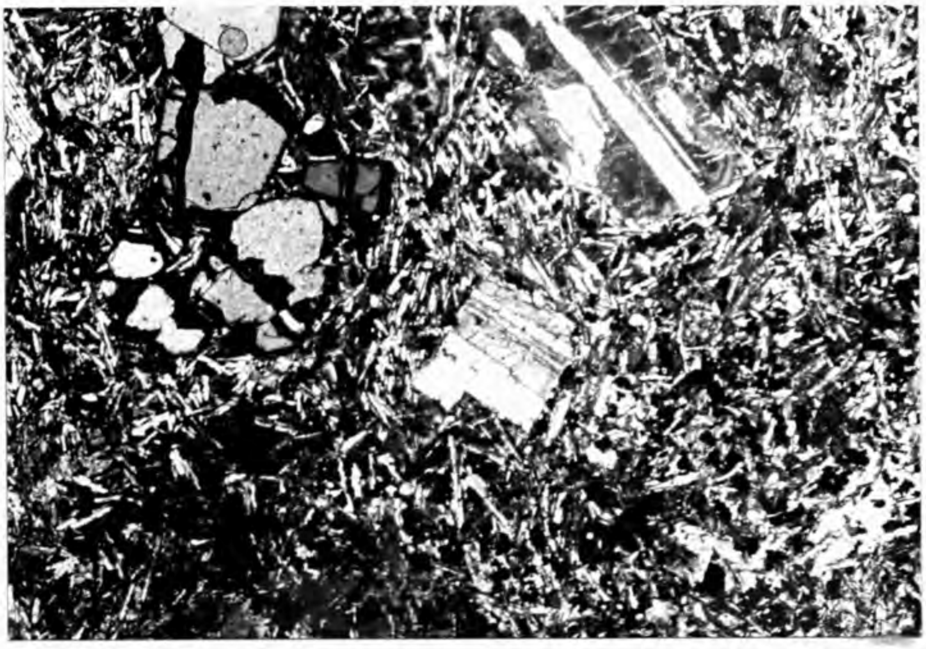

Plate 31 Porphyritic olivine-dolerite, Hurmoch Sill, nr. Tegit, showing labradorite phenocrysts in an ophitic groundmass. x-nichols x 10 spec. 2/317

Plate 32 Zeolitic olivine-dolerite, Yepkarat Sill, Yepkarat, showing ophitic texture, with analcite (dark grey, centre) and natrolite (white, top right). x-nichols x 20 spec. 2/100

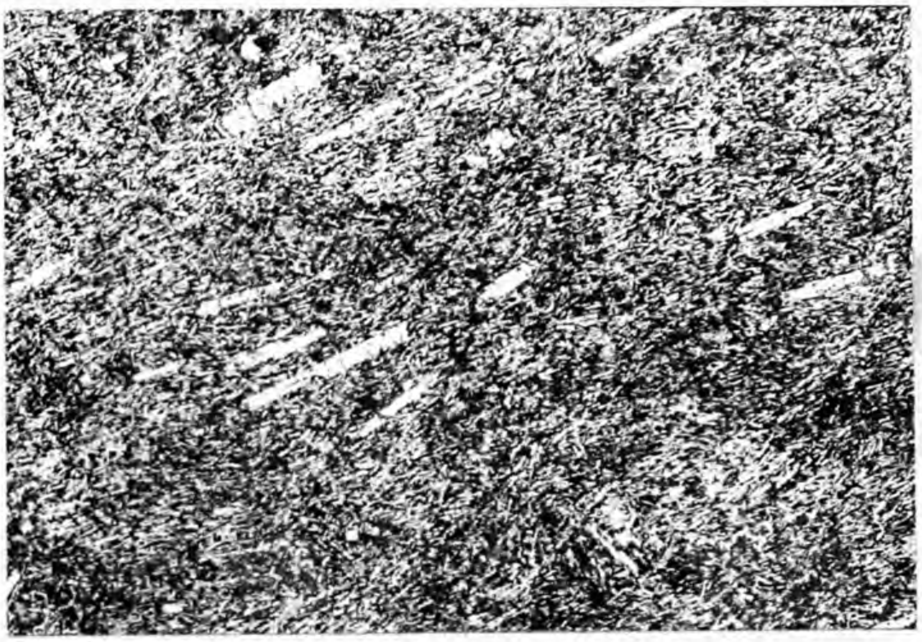

Plate 33 Alkali-trachyte, Kabarnet Formation, Mokhungo, showing sanidine microphenocrysts in a fluidal groundmass of sanidine, aegirine, arfvedsoniye and aenigmatite. P.P.L. x 20 spec. 2/345

Plate 34 Quartz-trachyte, Kaparaina Formation, Adonyasas, showing anorthoclase phenocrysts in a groundmass of alkali-feldspar and aegirine-augite with small quartz lacunae (right centre). x-nichols x 20 spec, 2/133

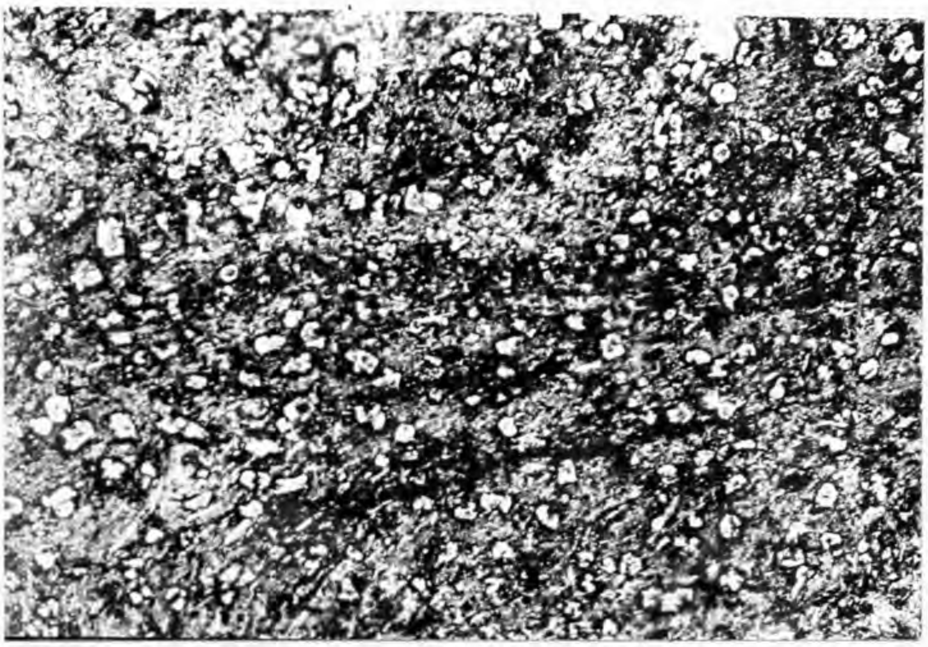

Plate 35 Trachyphonolite, Loyamarok Trachyphonolite, northern Loyamarok, showing nepheline microphenocrysts in a trachytoid groundmass. P.P.L. x20 spec. 2/84

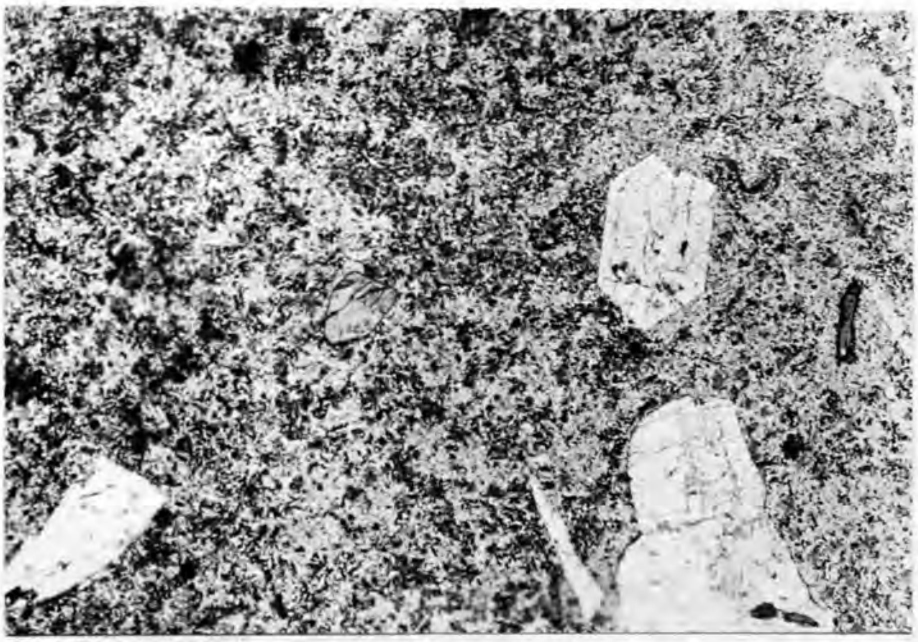

Plate 36 Phonolite, upper Sidekh Phonolites, Atimet, showing phenocrysts of clear nepheline, anorthoclase (lower left and right), biotite and green pyroxene (centre) P.P.L. x 20 spec. 2/322

Plate 37 Phonolite, lower Sidekh Phonolites, Sidekh, showing large altered nepheline phenocryst. P.P.L. x 20 spec. 2/314

Plate 38 Phonolite, Sumet (Ewalel) Phonolite, Bartabwa, showing small sanidine and nepheline phenocrysts. Typical 'Kamasia type' texture with poikilitic aegirine-augite, aenigmatite and kataphorite in the groundmass. P.P.L. x 20 spec. 2/271

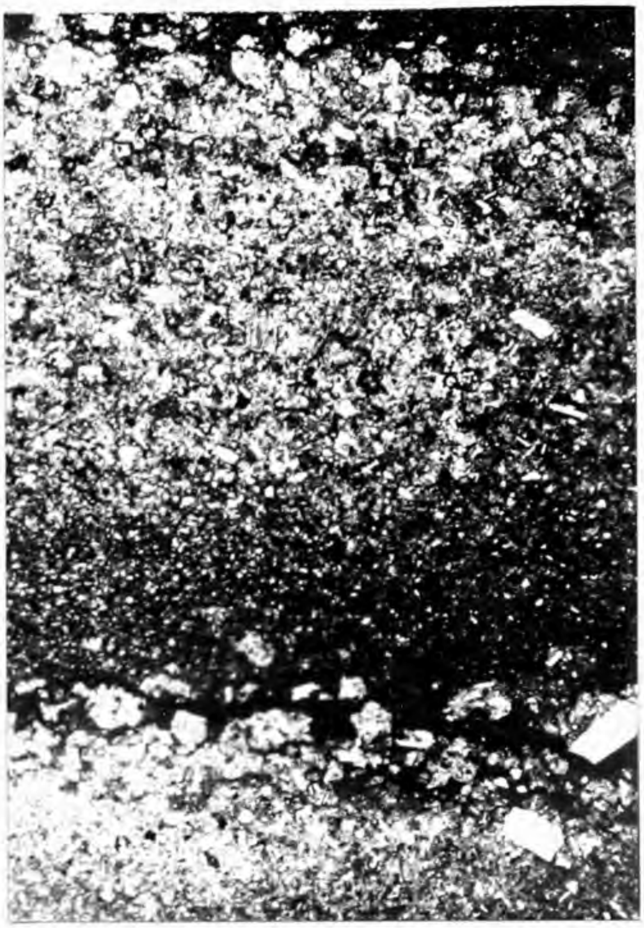

Plate 39 Graded basaltic tuff, Kaperyon Formation, Chesoton, showing glass shards, plagioclase crystals and very rare lithic (basalt) fragments in fining-upwards units. Much secondary calcite. P.P.L. x 10 spec. 2/161

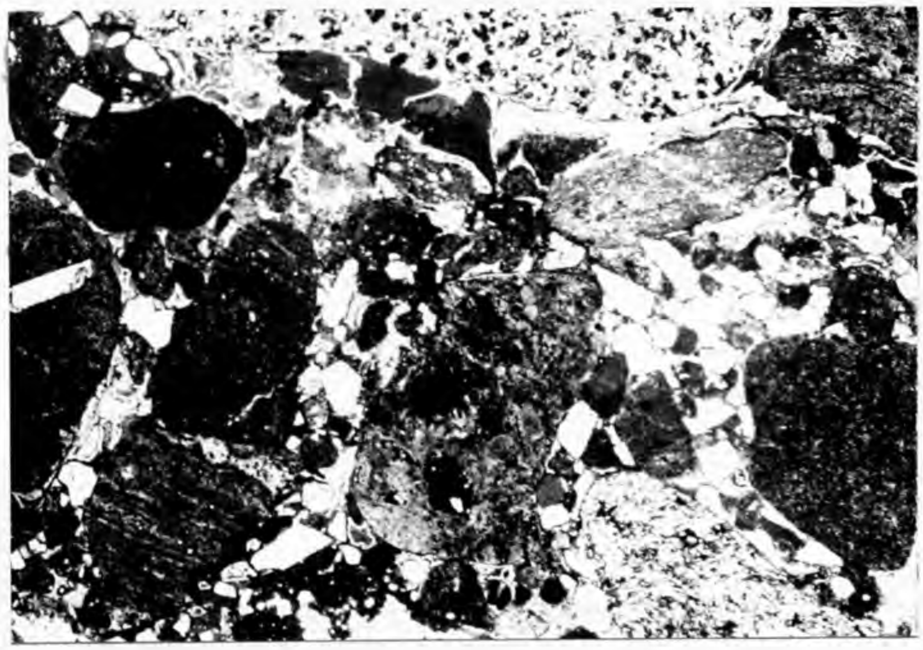

Plate 40 Conglomerate, Ngorora Formation, Chepkesin, showing pebbles of phonolite, trachyphonolite and calcified pumice, with smaller alkali-feldspar crystal-clasts in a zeolitic matrix. P.P.L. x 10 spec. 2/229