THE GEOLOGY OF THE TIATI HILLS,
RIFT VALLEY PROVINCE, KENYA.

Thesis presented for the degree of
Doctor of Philosophy in the University of London.

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ABSTRACT

The area lies between the Kerio and Suguta Rivers in southern Turkana. Metamorphic basement rocks are exposed along the axis of an anticlinal arch which is overlain by a succession of volcanics and associated sediments, up to 2,000 ft. (610 m.) in thickness west of it, and up to 11,000 ft. (3,400 m.) east of it.

A basal grit formation passes up into basalts dating from 16·6 m.y., which are then overlain unconformably by a thick succession of phonolites. The latter constitute the Tiati Hills east of the basement inlier. The phonolites are succeeded by basalts which are in turn overlain by a group of large trachyte central volcanoes, consisting of trachyte lavas and subordinate pyroclastics, including welded tuffs, erupted from multi-centre source zones. Minor basalt eruptions are the last manifestation of volcanic activity older than the shield volcanoes of the axial zone. The latter are only represented in the present area by the distal portions of airfall tuff showers erupted from them.

Structurally, the older eruptions are related to a monocline active at first to the west of the present watershed, but migrating steadily eastwards with time. In this manner, east of the basement arch, the volcanics become younger towards the centre of the developing rift valley. The younger volcanics are cut by normal faults trending generally north-northeastwards.

A wide range of rock types is present, including basanitoids, basalts, mugearites, phonolites and trachytes among the lavas, and pumice tuffs and welded tuffs among the pyroclastics. The basic and salic lavas are present in approximately equal volume, and together are far more abundant than intermediate lavas. Their alkalinity decreases generally with time. The distribution of each major stratigraphic unit is related to inferred cycles of magmatism.

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CHAPTER 1

GENERAL INFORMATION AND INTRODUCTION

1. Situation and Access

The area is situated in Baringo and South Turkana Districts, Rift Valley Province, Kenya. It dovers 356 square miles (920 sq.km.) and lies between latitudes 1°15'N and 1°29'N, and longitudes 35°41'E and 36°10'E, Fig. 1.

The area is bounded on the east by the road to Lake Rudolf. Two motorable tracks leading off from this enter the area, one by way of the Kito Pass, and a second to beyond Akoret.

For the purposes of mapping, regions lying far from the roads can be reached by donkey safaris.

2. Physiography

The area can be divided physiographically into three regions, Fig. 2.

(a) the Suguta lowlands
(b) the Tiati Hills and Ribkwo Hills
(c) the Kerio lowlands.

The north-flowing Suguta and Kerio Rivers are permanent in the latitude of the present area, but become semi-permanent nearer Lake Rufolf. They are at heights of about 2,200 ft. O.D. for the Suguta, and 3,000 ft. O.D. for the Kerio. The ground between them rises to over 7,000 ft. O.D., the highest point being Tiati at 7,718 ft. O.D.

There is an overall correlation between volcanic history and topography. Former volcanoes, although dissected to varying degrees, are still identifiable as topographic units.

(a) The Suguta lowlands occupy a relatively small part of the area. The Suguta rises at Kapeddo, a few miles south of the area. Its valley at this latitude is not very wide, being bounded to the east by the Pleistocene volcano Silali, and to the west by the Ribkwo

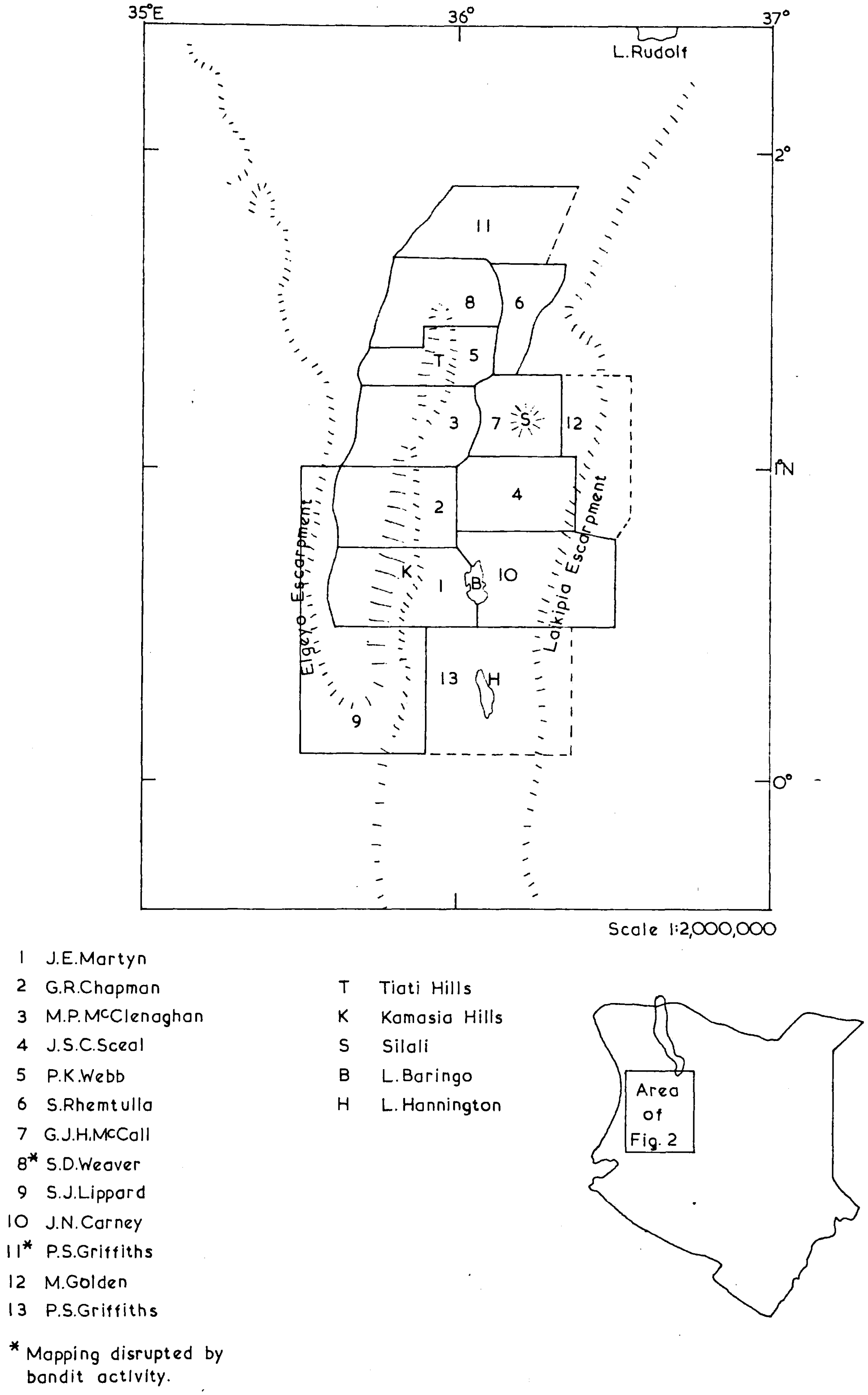

FIG.1. E.A.G.R.U. Research areas.

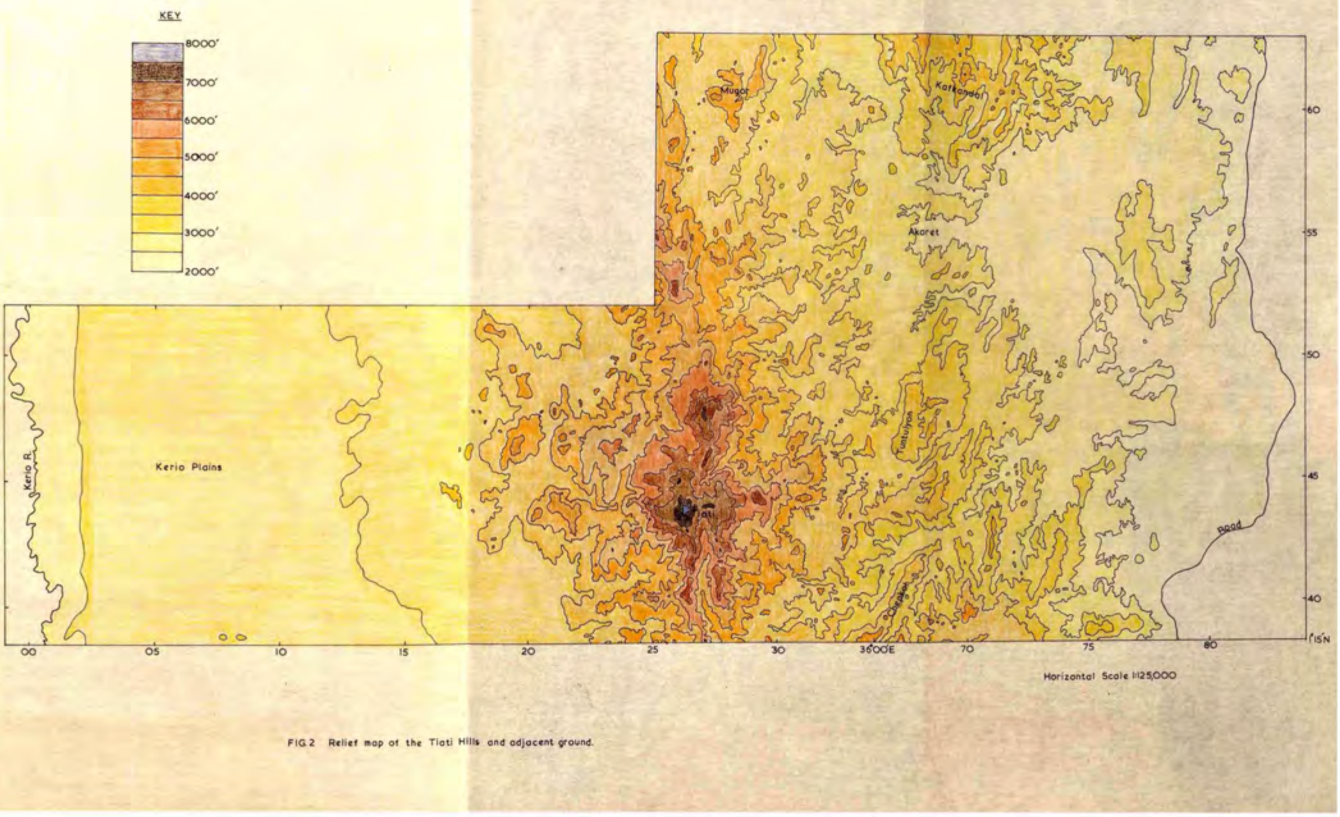

FIG. 2 Relief map of the Tiati Hills and adjacent ground.

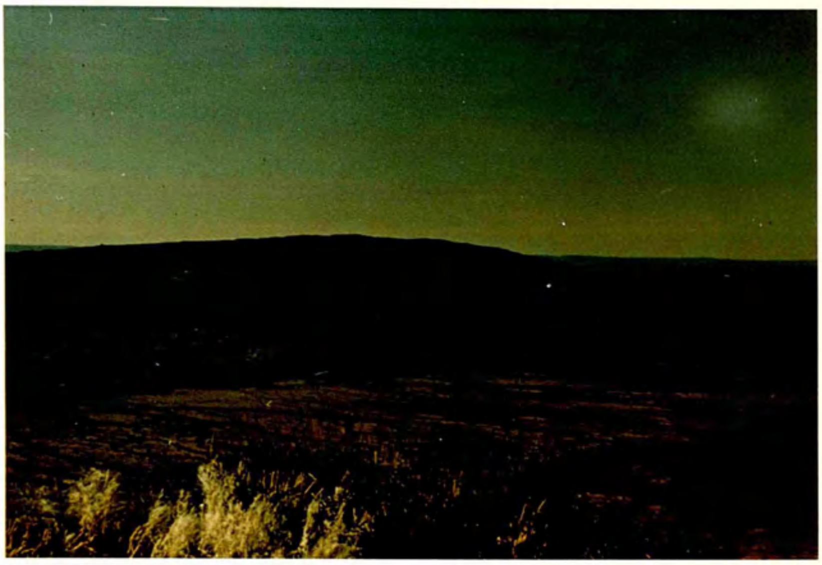

PLATE I: Silali and the Suguta flats, from Lokitet.

PLATE II: Chebelo from Lokitet.

The flat interfluves are strewn with a thick mantle of rock waste into which are cut one or two terrace levels.

Nearer the Tiati foothills, rock outcrops occur more frequently, and the Kerio lowlands take on a greater degree of relief. Residual hills are present, the highest being Pukaleh, the summit of which is 450 ft. (140 m.) above the surrounding plains.

3. Drainage

The present day drainage pattern is discussed in Chapter 4. In this section, the maintenance and distribution of flow will be discussed.

The Kerio and Suguta are the only permanent rivers in the present area.

The Suguta is fed by hot saline springs at Kapeddo, and at Lorusio, in the southeast corner of the present area, where a water temperature of 72°C was recorded. It is also fed by cooler, non-saline springs at Kapeddo, and during the rainy season by run-off from the Nginyang and Amaya Rivers, among others.

The Kerio is fed by hot springs at its source in the Metkei Forest, and by run-off from tributary streams draining the Elgeyo Escarpment and cooler areas west and south of the main trunk stream. Its water is cooler than that of the Suguta, and much more sediment-laden.

The area is drained exclusively by tributaries of these two rivers, none of which is permanent, because of the seasonal nature of the rainfall. While the larger tributaries are flowing, they have tremendous erosive and transport capacities, and can move at speeds up to 15 m.p.h. (24 k.p.h.), although they may only flow for several days or even hours. During periods of such flow, the river replenishes the water level in its own channel deposits.

Away from rivers, water is confined to closed system rain catchment pools on bare rock, or to occasional springs. The latter are confined to areas of basalt, where the basal rubble of basalt flows acts as an aquifer, and are more or less permanent. Such springs are maintained by percolating groundwater, are non-saline, and may have deposits of travertine associated with them.

4. Climate

The climate is of the semi-arid savannah type, with a strongly seasonal distribution of rainfall. The annual rainfall is between 15 ins. and 25 ins. (38 cm. and 64 cm.) per annum, falling mainly in November and December - the short rains, and from April to July - the long rains. Temperature depends on altitude, ranging from 115°F (recorded 3.00 p.m. January 1968) on the Suguta lowlands to 50°F or below near Tiati summit.

5. Flora and Fauna

The flora depends on rock type and local climatic variations due to relief, but has been modified by overgrazing and soil erosion. The whole area below 5,000 ft. O.D. is characterized by a sparse thorn bush cover and immature soils deficient in organic material. The Suguta lowlands support only occasional grass and thorn bushes. Their gravelly character changes at Lorusio, where the soil is impregnated with salts from the hot springs, and a tough spiky grass thrives.

Over 5,000 ft. O.D., Euphorbia candelabrum appears, and above 6,500 ft. O.D. patches of dense deciduous forest occur.

The banks of the larger rivers are fringed with thin strips of riverine forest. This is especially true of the Kerio and its larger tributaries. The Kerio plains themselves have a thick cover of the 'wait-a-bit' thorn bush.

The original fauna has been much reduced by the poaching and grazing of the local people, and lion and leopard are now very rare.

Elephant, rhinoceros and hippopotamus no longer exist in the area, though their presence in the recent past is indicated by the number of place names referring to them.

Large herds of Grant's gazelle inhabit the Suguta plains and adjoining lower ground, together with occasional oryx and ostrich. Great kudu are found in the hills, while hyaena, hunting dogs and buffalo inhabit the dense bush of the Kerio lowlands.

Small mammals are abundant throughout the area, together with various reptiles and a flourishing insect life.

6. People

The area is inhabited by the Pokot and Turkana tribes, the boundary between them running southeast-northwest along the Akoret road. Both tribes lead a very frugal semi-nomadic existence, living almost entirely on the blood, milk and meat of their cattle, camels, sheep and goats. The availability of water for stock determines these people's movements, and even their continued existence. Nevertheless, they have steadfastly refused most attempts to better their lot. Cultivation is minimal, but includes maize, tobacco and sorghum.

Overgrazing is a serious problem, but they refuse to restrict the size or movements of their herds of stock.

To outsiders, they are generally friendly and cooperative, Plate III, except for the Pokot in the Kerio valley. Swahili is spoken throughout most of the area.

7. Introduction

This section serves to introduce the geology of the area, and to put it into a regional context. Previous and current work will then be discussed.

The author's area is situated in the Rift Valley at a latitude

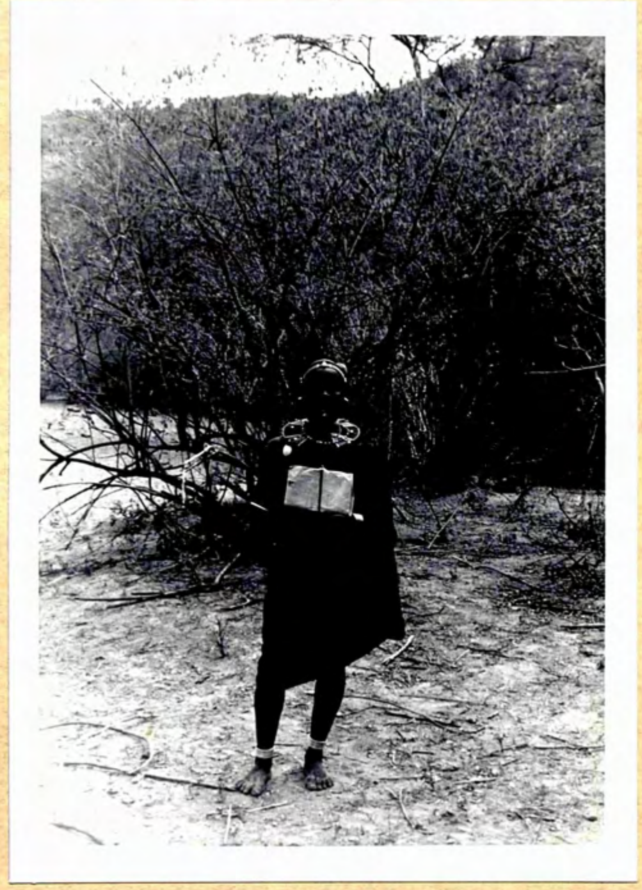

PLATE III Jerikan, a friendly and cooperative Pokot where the rift valley as a whole is widening and showing an increasing diversity of structures, Fig. 3. Between Nairobi and Nakuru, the rift zone is not more than 40 miles (65 km.) wide. Northwards, it opens out, so that at 0°30'N complex fault blocks occupy the rift floor, with a volcanic history more complicated than that of the shoulders. This trend continues northwards, and at 2°00'N the rift zone is about 90 miles (145 km.) wide.

Throughout its length, the rift floor has had a complex history, but there is often an approximate bilateral symmetry about a central zone. This zone is a feature which extends from Lake Magadi to Lake Rudolf, and is the site of the most recent volcanic activity, particularly marked by the large central volcanoes. Examples of these are Suswa, Menengai, Paka, Silali and Emuruangokolok, nearly all of which have calderas.

The rift margins themselves may be a single fault, a series of step faults, or a monoclinal downwarp.

The author's area makes a transect from near the Elgeyo Escarpment, the western edge of the rift zone, to the axial zone. The symmetry about the axial zone is only approximate, since there are no counterparts of the Kerio valley or Tiati Hills east of the Suguta.

The area consists essentially of a north-south trending arch, in the eroded core of which is exposed a crystalline metamorphic complex. This is overlain by a volcanic sequence much thicker and more variable east of the arch than west of it.

A variable basal succession is present, consisting of grits and tuffaceous sediments. In the west, the earliest volcanic activity is basaltic, separated from the overlying phonolites by an unconformity. There is then an extended period of erosion before the eruption of the Chepkowagh Mugearite. East of the arch, both basalts and phonolites

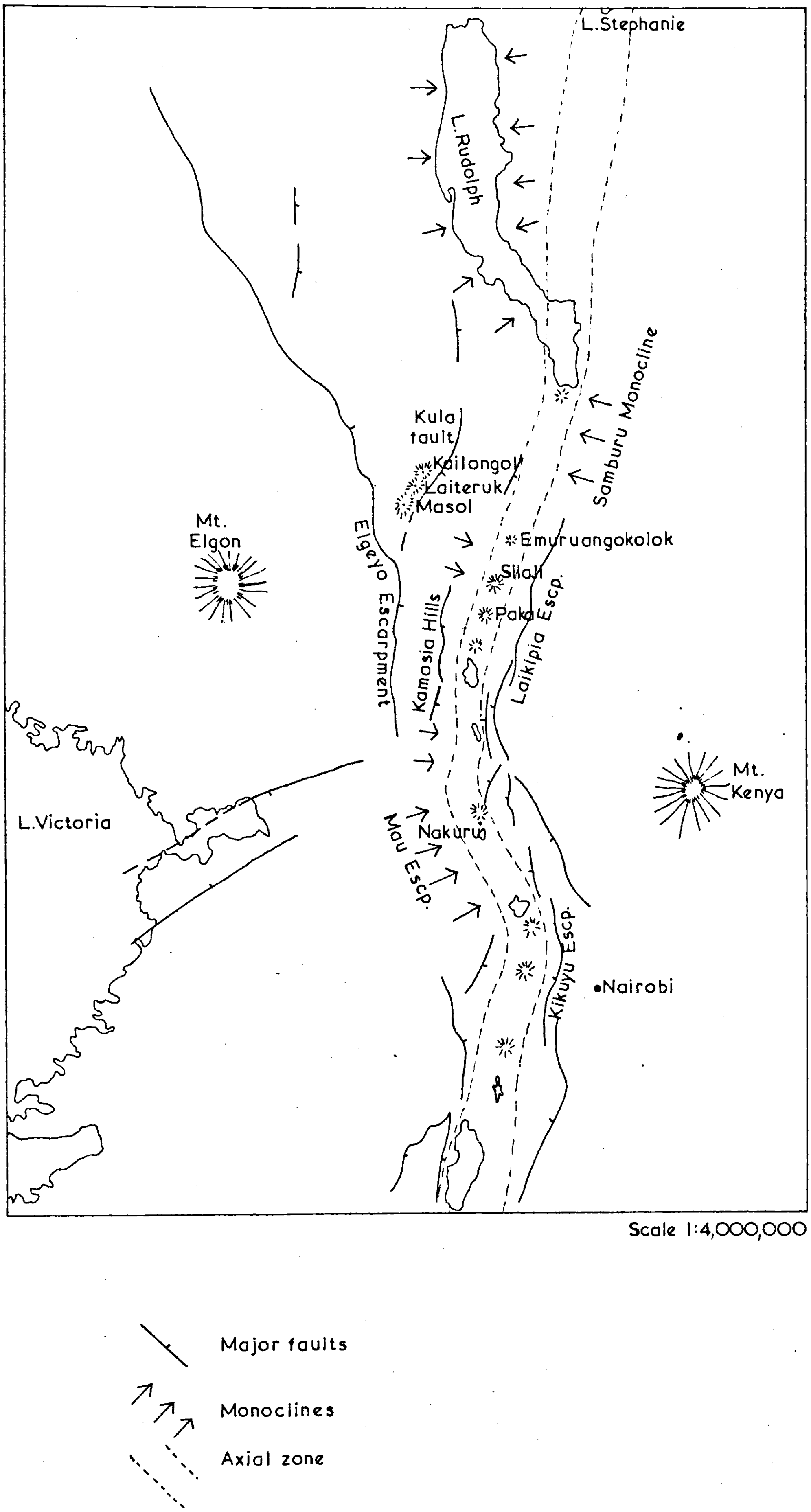

FIG. 3 The Kenya Rift Valley

are much thicker. The phonolites are then overlain by formations not present west of the arch. The earliest of these is the Tirioko Basalts which overlies various formations in the Tugen Hills Group.

Overlying the Tirioko Basalts is a series of trachytic strato-volcanoes in which welded tuffs are prominent. Variable thicknesses of sediment are present, some of which contain vertebrate fossil remains. Scattered flows of olivine-basalt were erupted from centres on the eastern fringes of these volcanoes, marking the end of activity outside the central zone.

The most recent volcanic deposits in the present area are associated with the axial zone central volcanoes Silali and Emuruangokolok, and consist principally of thin pumice deposits.

The structure of the area is not complicated, and is related to tilting of the region east of the basement arch, on the Tiati Monocline. Faulting occurs predominantly on a northnortheast trend, but northwest-southeast trending faults also occur.

Planar (or nearly so) erosion surfaces occur in the area. The regional significance of these surfaces is dealt with in Chapter 3.

Petrochemistry is discussed in Chapter 6. Until then, it suffices to say that throughout the history of the area, contrasting magmas have been available for eruption, closely associated in space and time. Olivine-basalts are common as are the highly differentiated trachytes and phonolites, but lavas of intermediate composition are rare.

8. Previous Work

The Kenya Rift Valley was traversed and explored by early explorers such as Teleki, Van Hohnel and Joseph Thompson.

J.W. Gregory, in 1896, crossed the Tugen Hills, south of the present area, and collected specimens which were described by Prior (1903). Gregory's observations were later published (1921) in

"The Rift Valleys and Geology of East Africa".

Bailey Willis (1936) describes the Kamasia Range and the Kerio Valley, ascribing an erosional origin to the latter.

Other workers have paid attention to the Lake Baringo Basin, involving much discussion of the sediments to the west of the lake.

Further north, Glenday & Parkinson (1926 & 1927) studied the metamorphic rocks and lavas northeast of the present area.

Champion (1937) made many observations on the geology of Turkana. The rocks he collected were described by Campbell-Smith (1938). Fuchs (1939) suggested that the initiation of the Kerio valley dates back to Miocene times, and noted that it may have been ponded up by lavas at one time.

Dixey (1948) discussed the geology and erosion surfaces of Turkana.

The Loperot area, north of the present area, was mapped by Joubert (1966). He records igneous activity in the Turkana Grits.

Rhemtulla (1970) describes the Loriyu Plateau, northeast of the present area, and gives evidence for its being a faulted block. He briefly mentions volcanics further south, which relate to and pass into those in the present area.

The only previous work in the present area is by Mason & Gibson (1957), who carried out a reconnaissance survey of the ground west of Tiati. McCall (unpublished paper) examined Silali, and briefly refers to the Ribkwo Hills.

9. Current Work

The East African Geological Research Unit, under the directorship of Professor B.C. King, is currently investigating a large area in the rift valley, Fig. 1. Northward extension of this area has had to be halted because of bandit activity.

Geophysical investigations have been carried out in the rift valley by a team from Birmingham and Leicester Universities, but results are not yet available.

CHAPTER 2

STRATIGRAPHY AND GEOLOGICAL HISTORY

PART 1: THE METAMORPHIC BASEMENT

This has only received cursory attention in the present study. It forms part of the Mozambique orogenic belt of eastern Africa in which the dominant structures were determined by an orogeny dated at 500-600 million years.

It outcrops in a roughly north-south strip, 4 to 5 miles (6½ to 8 km.) wide, between the Tiati Hills and the Kerio river, Fig. 4. Most abundant are biotite gneisses (5/352)* in which the essential minerals are quartz, oligoclase, microcline, biotite and muscovite in that order. Hornblende gneisses also occur, together with occasional hornblende-rich bands.

The gneisses are often garnetiferous. In the hornblende-gneisses, the garnets may have kelyphitic rims (5/370), Plate IV.

The basement appears to represent a metasedimentary assemblage. Marbles and pure quartzites are absent, but occur further to the west (Mason and Gibson, op.cit.) and to the north (Joubert, op.cit.). The original sediments were probably quartz-rich siltstones.

In the Cheptokol River at 158462, thin ptygmatic quartzo-feldspathic veins occur in the gneisses, connecting with leucocratic bands in the gneiss, and crosscutting the foliation of the immediately adjacent country rock. The veins vary from sharply defined to diffuse impregnations.

At 094491 in the Ngeleyo River, a cross-cutting dyke-like body about 10 ft. (3 m.) wide was recorded. It is schistose, consists almost entirely of biotite and hornblende, and is considered to be a basic dyke involved in a later phase of deformation.

Entirely later than the deformation is a phase of pegmatite intrusions. These form irregular cross-cutting bodies rarely more than 15 ft. (5 m.) wide, and consist almost entirely of quartz and

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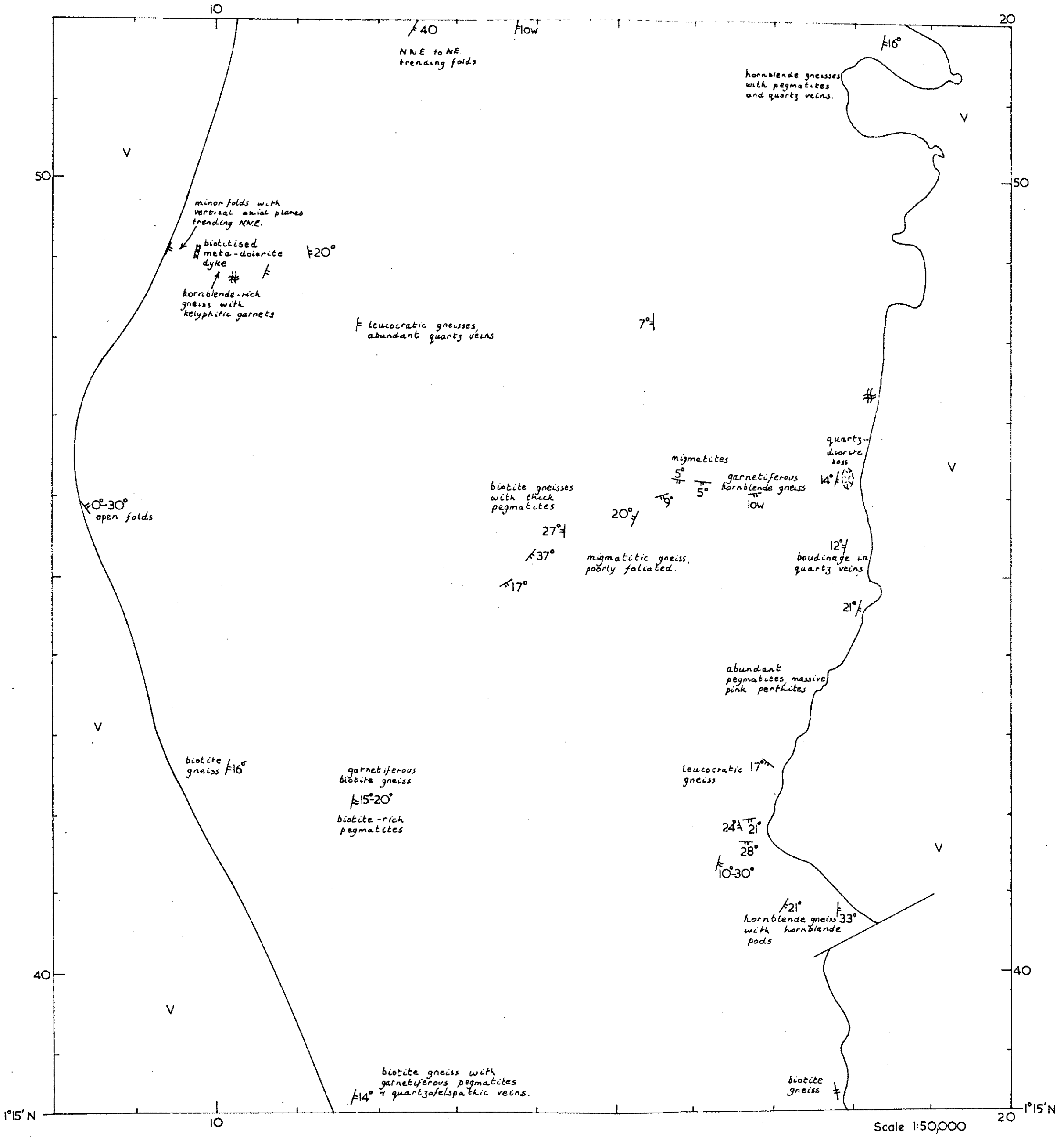
* See Appendix A, for specimen localities.



KEY

V Volcanics and sediments

⟋ Foliation, strike and dip

⟋ Foliation, dip variable

Foliation, horizontal and undulating

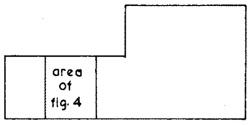


FIG. 4 Geology of the Basement.

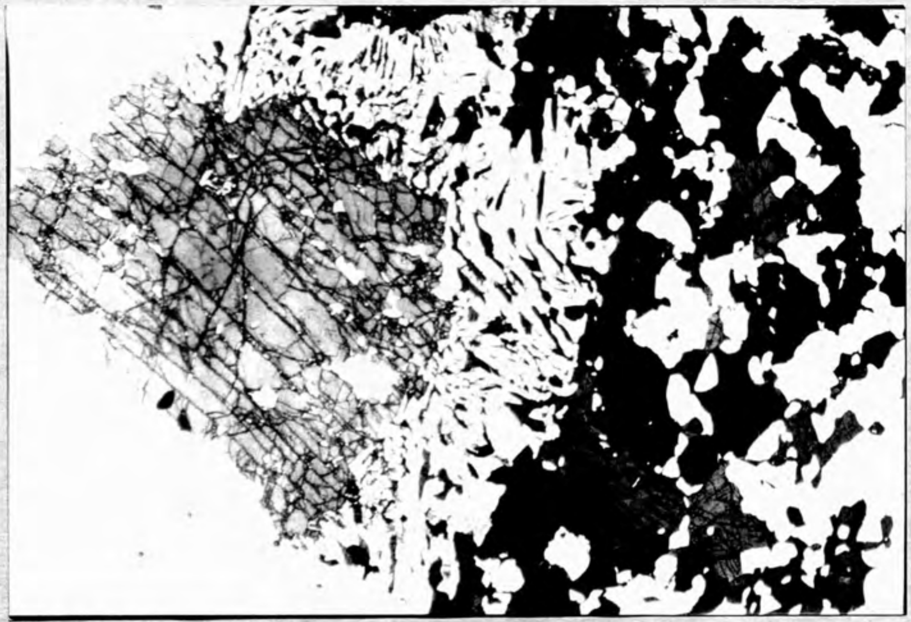


Plate IV Garnet porphyroblast with reaction rim, 5/370.

perthitic feldspar, together with rare magnetite. Graphic intergrowths of quartz and feldspar were occasionally seen.

At 178463, there is an intrusion of quartz diorite. The rock has an igneous texture in thin section, but is foliated in the field (5/389). It is composed of feldspar (70%) - calcic oligoclase to andesine; pale green diopsidic augite (15%); quartz (10%); apatite, biotite and magnetite (5%).

Structure in the Basement

The structure is dominated by the foliation which dips eastsoutheast at angles usually less than 30°. Mason and Gibson (op.cit., p.28) state that the foliation is parallel to the original bedding and that folding is isoclinal.

The foliation has itself been involved in open folds of large amplitude. Minor structures, though present, are rare. No faulting was detected in the basement.

The oldest rocks overlying the basement are less than 30 m.y. old. There is thus a major unconformity above the basement, representing a time interval of about 500 m.y. During this time, the East African region was subjected to repeated uplift and erosion. The later cycles of erosion were not complete, so that whereas in some parts of Kenya, the earliest volcanics were erupted on to a peneplain, in other parts the sub-volcanic surface had considerable relief.

PART 2: THE CAENOZOIC AND QUATERNARY ROCKS

Introduction

The Caenozoic and Quaternary formations in the present area are divided by the basement outcrop into two disconnected parts.

West of the arch, the basalts of the Kapchererat Formation dip westwards. East of the arch, they dip eastwards. Very few basalt dykes were found between the two parts of their outcrop.

Further, the basalts east of the arch are over 3,800 ft. (1150 m.) thick. West of the arch, they are about 1,500 ft. (460 m.) thick.

For these two reasons it is inferred that the source of the basalts lay east of the arch. The same reasoning applies to the phonolites of the Tugen Hills Group.

The inference is that the Kolloa and Tugen Hills Groups were involved in tilting to the east by 8^{o}-10^{o} while westwards there was a downwarping towards the present position of the Elgeyo Escarpment. The basement arch is the result of these opposing directions of tilt. It may be noted that a similar pattern of arching is seen in the Kamasia Range to the south, in an uninterrupted succession of volcanics.

A. Caenozoic and Quaternary rocks west of the arch

At least 3,000 ft. (920 m.) of strata are present, although individual formations vary considerably in thickness. The succession is summarized in Fig. 5.

A1. KOLLOA GROUP

1. Turkana Grits

These are predominantly coarse-grained quartzo-feldspathic sediments. The youngest horizons are tuffaceous. To the west of the basement arch they range in thickness from 0 ft. in the south to 800 ft. (250 m.) in the north, their maximum development in the entire area.

The Turkana Grits outcrop widely beyond the present area, notably in South and North Turkana, but also on the eastern side of the rift valley. They were ascribed to the Jurassic by Murray-Hughes (1933), the Trias by Arambourg (1935), and late Mesozoic or early Tertiary by Mason and Gibson (op.cit.). Fuchs (op.cit.) considered that they

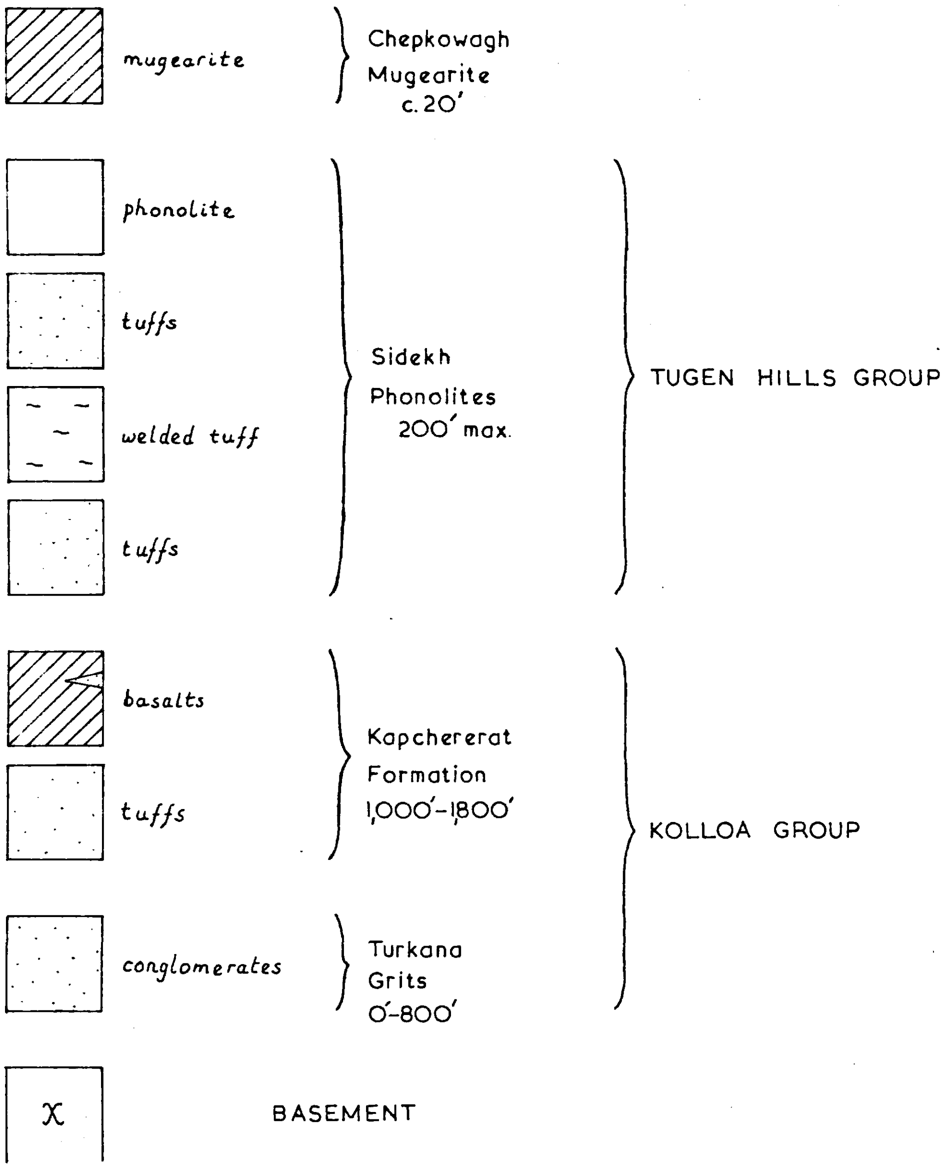


FIG. 5 Succession West of the Basement Arch.

were Oligo-Miocene in age on fossil plant and structural evidence. Joubert (op.cit.) concludes that they are Lower Miocene in age, since at Loperot they contain Dinotherium hobleyi.

Mason and Gibson (op.cit.) distinguished between two sedimentary formations in the author's area: (a) The Turkana Grits of wholly pre-volcanic age, and (b) The Tiati Grits, occurring within the early volcanics. The present writer has found their mapping to be incorrect, and their establishment of these formations doubtful.

In the Chepkowagh River, basement-bearing gravels and pebble beds pass up into tuffaceous gravels and then into tuffs with bands of basement pebbles. The author has placed the top of the Turkana Grits where the amount of volcanic material exceeds the amount of basement material.

The Turkana Grits rest on a weathered surface of basement. At 093491 the old land surface is exposed, fresh gneiss passing up into a rotted weathered horizon about 4 ft. (1.3 m.) thick before the basal beds are encountered. These are very coarse, but pass rapidly up into gravels in which only a few pebbles exceed 4 cm. in diameter.

The sediments are commonly composed of well-rounded pebbles of quartz and feldspar derived from the basement (5/351, 5/363). Chalcedony and calcite are common matrix minerals. Detrital grains of garnet, and flakes of biotite and muscovite occur, but are rare.

The finer-grained rocks sometimes show current bedding indicating derivation from the north and east. The author infers that the Turkana Grits were derived from the rising western edge of the rift, but that there were additional sources of material within the region of the present rift valley. They were deposited in a subsiding basin as a coalescence of piedmont fans and torrent bedded gravels.

Finer-grained deposits accumulated at the same time in temporary lakes. Thinly bedded siltstones were recorded from an outlier of the Turkana Grits at 107493.

There has been much discussion concerning the nature of the sub-Miocene erosion surface in Kenya. In the present area it was at least undulating, as indicated by the various outliers of Turkana Grits on top of the basement arch. This is dealt with in detail further on.

2. Kapchererat Formation

This outcrops widely west of the arch, in a continuous north-northeast trending belt. The lower part of the succession consists of laminated tuffs, while the upper part is composed of basalt lavas. The formation is 1,800 ft. (550 m.) thick in the north of its outcrop, but is probably less than 1,000 ft. (300 m.) thick in the south.

The tuffs are well sorted laminated reworked pyroclastics. They vary in colour from purple to orange, pink, yellow and white, and range from silt to sand grade. Large clasts are rare except for pebbly layers near the base, where they pass down into the Turkana Grits. In the extreme south of the area, where the Turkana Grits are absent, there is a coarse, tuffaceous, gravelly basal bed, about 6 ft. (2 m.) thick (5/355). It contains abundant small pebbles of both basement material and altered lava. Its matrix is brownish and ferruginous.

Derivation, or at least reworking, by currents from the northeast is indicated by current bedding at 066433.

In thin section, the tuffs show much permeation of the matrix by a reddish ferruginous material. Lava fragments are always altered, rendering the mafics unidentifiable, and feldspar only identifiable as such. Calcite is common in the matrix, together with secondary zeolites (5/353). Crystal fragments, commonly feldspar, are present, derived possibly from both volcanics and basement. Quartz grains, almost certainly from the basement are seen in 5/368, from near the base of the tuffs.

Overlying the tuffs are basalts, about 1,500 ft. (460 m.) thick in the north, but thinning to nothing southwards, where they are locally missing. They dip 8°-12° to the northwest.

The basalts occasionally show ropy surfaces, and are often characterized by plagioclase phenocrysts up to 2½ cm. long, sometimes in sub-parallel arrangement. The majority of the basalts are olivine-bearing. Basanites are present (5/365) in which analcite occurs as an interstitial primary mineral.

The basalts occur as thin continuous flows, probably erupted from fissures. This is especially true of the continuous outcrop of basalts in the western extremities of the area. Basaltic agglomerates at 077403 and 093389 indicate that there were also individual eruptive centres.

At Kei Pa So, 300 ft. (92 m.) of well sorted massively bedded white or cream-coloured sandstones are intercalated in the basalts. They consist of quartz and feldspar grains in a chalcedonic matrix (5/373). The sandstones thicken northwards, presumably towards their source, which is thought to have been the fault block west of the Kula Fault, Fig. 1 and Fig. 3, now occupied by the hills Masol, Laiteruk and Kailongol. It is inferred that movements on this fault initiated both sedimentation and volcanism during Kapchererat Formation times, so that both facies interdigitate.

In the south of the area, the basalts were largely removed by erosion before the eruption of the Sidekh Phonolites, so that the basal tuffs of the latter rest on tuffs of the Kapchererat Formation. On Kwaisagat East, 60-70 ft. (18-21 m.) of basalts are present below the basal tuffs of the Sidekh Phonolites, whereas basalts are absent on Kwaisagat West.

A2. THE TUGEN HILLS GROUP

1. The Sidekh Phonolites

This formation outcrops in a thin continuous strip near the Kerio River, and dips westnorthwest at 7^{o}-8^{o}. Further outcrops occur on the southern margin of the area, and on the two Kwaisagat hills. On Kwaisagat West, it reaches its maximum thickness of 200 ft. (61 m.), Fig. 6.

The lower tuff member and welded tuff are missing on Kwaisagat East. This was possibly determined by the contemporary topography. It is inferred that the lower tuff and welded tuff were erupted around the base of a residual basalt hill, and that the eruptions of the upper tuff member and phonolite covered it completely. The Sidekh Phonolites have also been involved in an anticline in the immediate vicinity, Fig. 7.

In squares 0639 and 0740, the lower tuff member is less than 25 ft. ($7\frac{1}{2}$ m.) thick, and in square 0538, the lower tuff and welded tuff are absent. Beneath Chebolotyolot and Kasowan, the upper tuff member rests directly on tuffs of the Kapchererat Formation.

These variations in thickness and distribution may be original, or due to contemporaneous erosion, or both.

Both the upper and lower tuff members are pink in colour, massively bedded, and internally structureless (5/356). They consist of lithic and pumice lapilli in a lithified, tuffaceous, fine-grained matrix. Biotite flakes are nearly always present, together with fragments of sanidine. Alteration is ubiquitous, causing much secondary zeolitisation and permeation of the matrix by disseminated ferruginous material.

The welded tuff is not more than 20 ft. (6 m.) thick. It is dark greenish brown to khaki in colour, flow banded, very compact and hard. It contains abundant lithic lapilli, and biotite, nepheline,

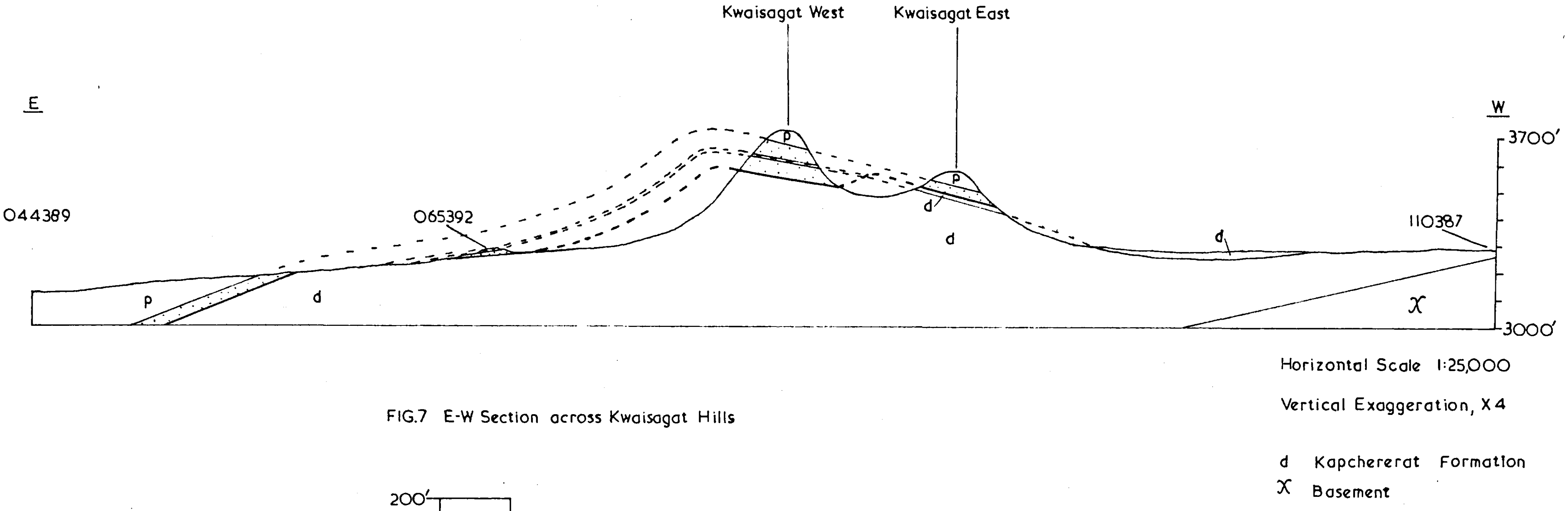


FIG.7 E-W Section across Kwaisagat Hills

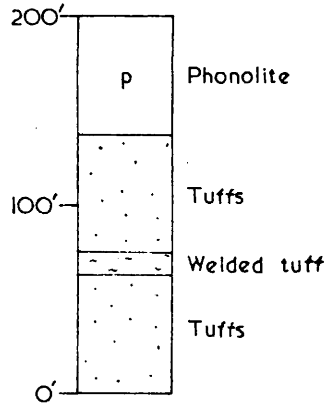


FIG. 6 Succession in Sidekh Phonolites, Kwaisagat West.

and feldspar are identifiable in hand specimen.

Near the Kerio, it forms an ill-defined feature trending north-northeast, but is well exposed in each large stream section. It is welded throughout its vertical extent. Specimen 5/366 shows flattened shards with frayed ends.

The phonolite is black with a greenish tinge, fine-grained, compact, and has an almost flinty feel and fracture. Freshly broken surfaces may have a waxy lustre. In hand specimen, biotite and nepheline are visible. The latter is altered to fibrous zeolites in 5/348. Sanidine, biotite and pale green diopsidic augite phenocrysts are also present. In all specimens, there is much recrystallisation in the groundmass.

A3. INTRUSIONS OF UNCERTAIN AGE

Two small outcrops of olivine phyric basalt occur, in squares 0440 and 0543, specimens 5/349 and 5/361 respectively. Their intrusive relationship, however, is only inferred. Although they are unlike any of the basalts in the Kapchererat Formation west of the arch, they are very similar to basalts low in the Kapchererat Formation east of it. They may thus be outliers of lava flows erupted simultaneously with the tuffs, but the field relationships do not favour this interpretation.

They intrude tuffs of the Kapchererat Formation, but their upper age limit is unknown.

In square 0339, there is a circular plug of coarsely porphyritic nepheline microsyenite, 1,500 ft. (460 m.) in diameter. It cuts the upper tuff member of the Sidekh Phonolites, and almost certainly cuts the phonolites but this is not proven. Specimen 5/346 is described in Chapter 5.

During and after the deposition and eruption of the sediments and volcanics of the Kolloa and Tugen Hills Groups, the area west of the arch was tilted towards the west. Faulting occurred on a northnortheast to northeast trend.

Subsequently the area was subjected to a long-continued period of erosion, reducing the area between Tiati and the Elgeyo Escarpment to a mature, almost flat plain, referred to subsequently as the Kerio Surface. Residual hills such as Pukaleh and Kei Pa So project above it. McClenaghan (Ph.D. thesis in preparation) reports that this surface truncates the Ngorora beds, which are 8 to 9 m.y. old. It is more fully described in Chapter 3.

A4. THE CHEPKOWAGH MUGEARITE

There are two outcrops of this, 2,000 ft. (610 m.) apart on the north bank of the Chepkowagh River. The larger of the two gives rise to a flat-topped feature, rising about 30 ft. (9 m.) above the level of the surrounding plains. The smaller outcrop (5/360) is of identical lithology, namely a plagioclase-phyric mugearite, in which the phenocrysts are in parallel alignment, and the groundmass is pale greyish.

The outcrop in the Chepkowagh River is interpreted as a large dyke from which lava was erupted on to the Kerio Surface, the larger outcrop being a remnant of this. Neither the original extent nor the thickness are known, since the base is not exposed.

Since eruption of the mugearite, rejuvenation has caused some slight incision of the Kerio Surface. At Cheptokol, there is a knickpoint 30 ft. (9 m.) high, Plate V. Between the road and the Kerio, terraces are developed along the major rivers. Fig. 8 shows the inter-relationship of the terraces, the Chepkowagh Mugearite, and the Kerio Surface.

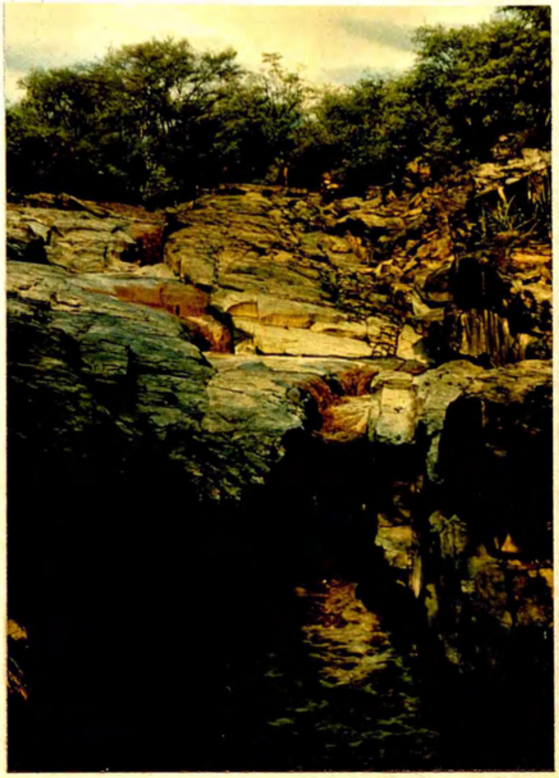


PLATE V Knickpoint at 159462, Cheptokol River.

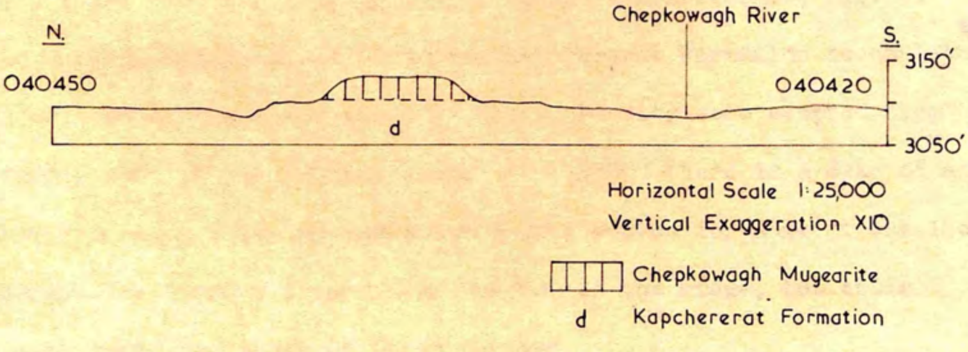


FIG. 8 Relations of Chepkowagh Mugearite to Kerio Surface.

B. Caenozoic and Quaternary Rocks on Top of the Arch

The Turkana Grits and both tuffs and lavas of the Kapchererat Formation are present as scattered outliers overlying basement.

The Turkana Grits occur as outliers in squares 0949 and 1049, where they are represented by quartzofeldspathic gravels, with siltstones in square 1049, see p.12 . They outcrop at 134439, where 3 ft. (1 m.) of coarse gravels with cobbles of basement material underlie tuffs of the Kapchererat Formation. In square 1545, there is a restricted outlier of tuffaceous grits.

These small outliers serve to indicate that the surface on which the early volcanics and sediments accumulated was undulating, and not planar.

Basalts of the Kapchererat Formation outcrop in a belt of outliers between Pukaleh and Singelel, and there is a small cluster of outliers around 170440. In each outlier, the basalts rest directly on basement gneisses, without any intervening sediments or tuffs. These basalts are mainly augite-phyric.

At Pukaleh, the sub-volcanic surface is at a height of c.3,750 ft. O.D. and rises to about 3,800 ft. O.D. near Singelel. The same surface occurs at a height of c.3,400 ft. O.D. at 134439 and in square 1049, i.e. about 350 ft. lower. From these data it is reasonable to infer that the sub-volcanic surface on top of the present arch was marked by a ridge trending roughly westsouthwest-eastnortheast, Fig. 9. The Turkana Grits and tuffs of the Kapchererat Formation accumulated in hollows on the lower ground. Later, basalts were erupted from sources east of the present arch. At 172500, there is a dyke of augite phyric basalts which probably acted as a source for some of the local lavas. The basalts flowed over the top of the ridge, but their extent north and south of it is unknown.

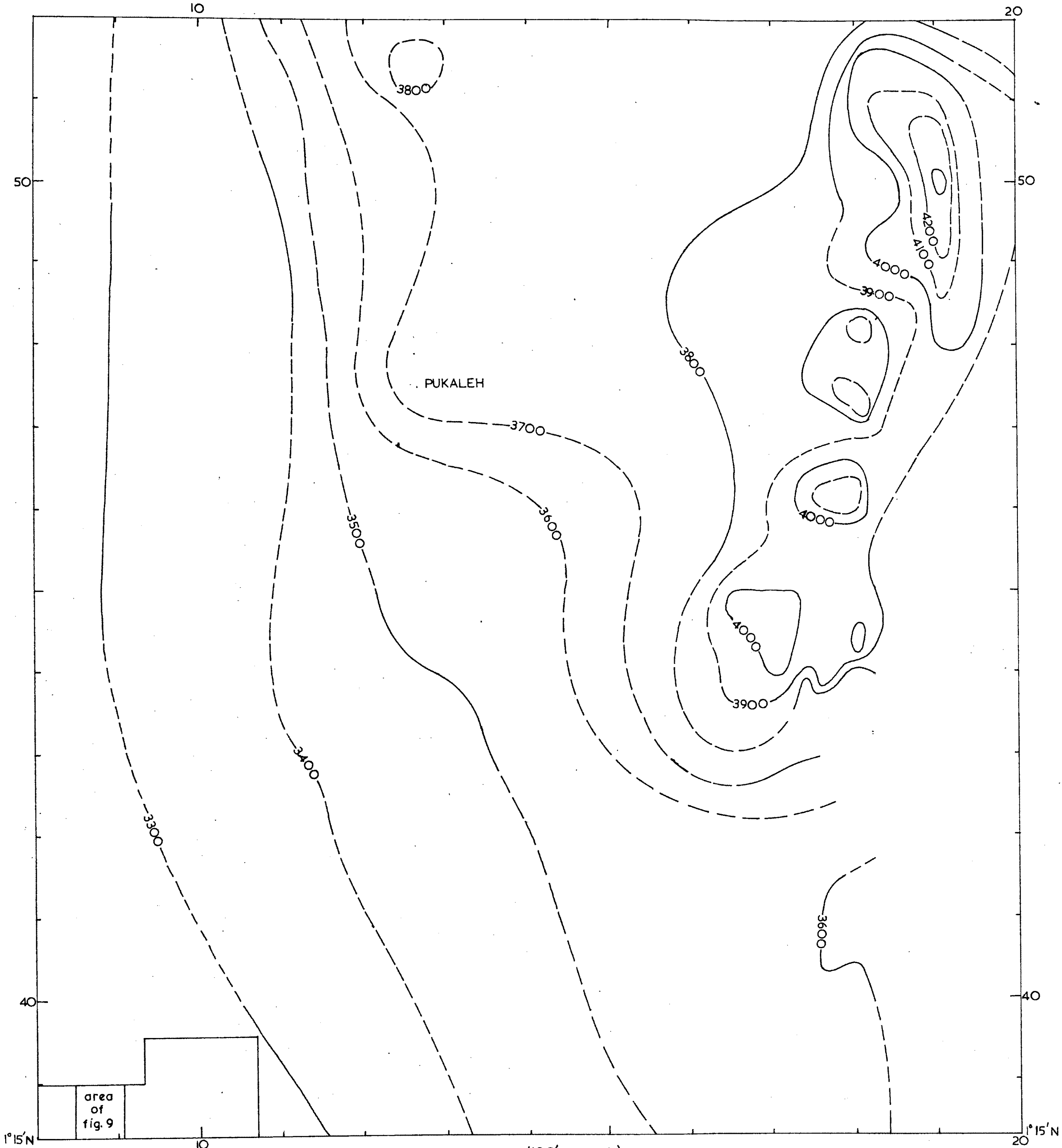


FIG. 9 Contoured map of sub-volcanic surface (100' intervals)

C. Caenozoic Rocks East of the Arch

Introduction

Fig. 10 illustrates the relationships between the successions west of, on top of, and east of the basement arch.

The whole succession east of the arch is about 11,000 ft. (3,400 m.) thick. The earliest activity occurred in middle Miocene times associated with an active zone which represents the northward continuation of the Saimo and Kito Pass fault systems. This active zone subsequently developed into a downwarp referred to as the Tiati Monocline.

Later volcanic activity occurred along northnortheast trending belts, which are situated progressively eastwards of one another. In this manner, the youngest volcanics occur adjacent to the axial zone of the rift, and are overlain only by the Middle to Upper Pleistocene volcanics of the axial zone central volcanoes.

These belts are remarkably continuous in a north-south sense.

C1. THE KOLLOA GROUP

1. Turkana Grits

These are present up to 400 ft. (120 m.) thick, in two widely separated stream sections. Elsewhere, Kapchererat Formation basalts rest directly on basement gneisses.

They are represented by coarse quartzofeldspathic gravels with a purple tuffaceous matrix, and finer-grained sandstones, and are generally well stratified and well sorted.

The thickest exposure is in the Kapunyan River, square 1840, where 400 ft. (120 m.) of gravels are exposed, dipping northeast at up to 21°. To the south, they are cut out by a fault, and are probably overstepped by basalts of the Kapchererat Formation. Near

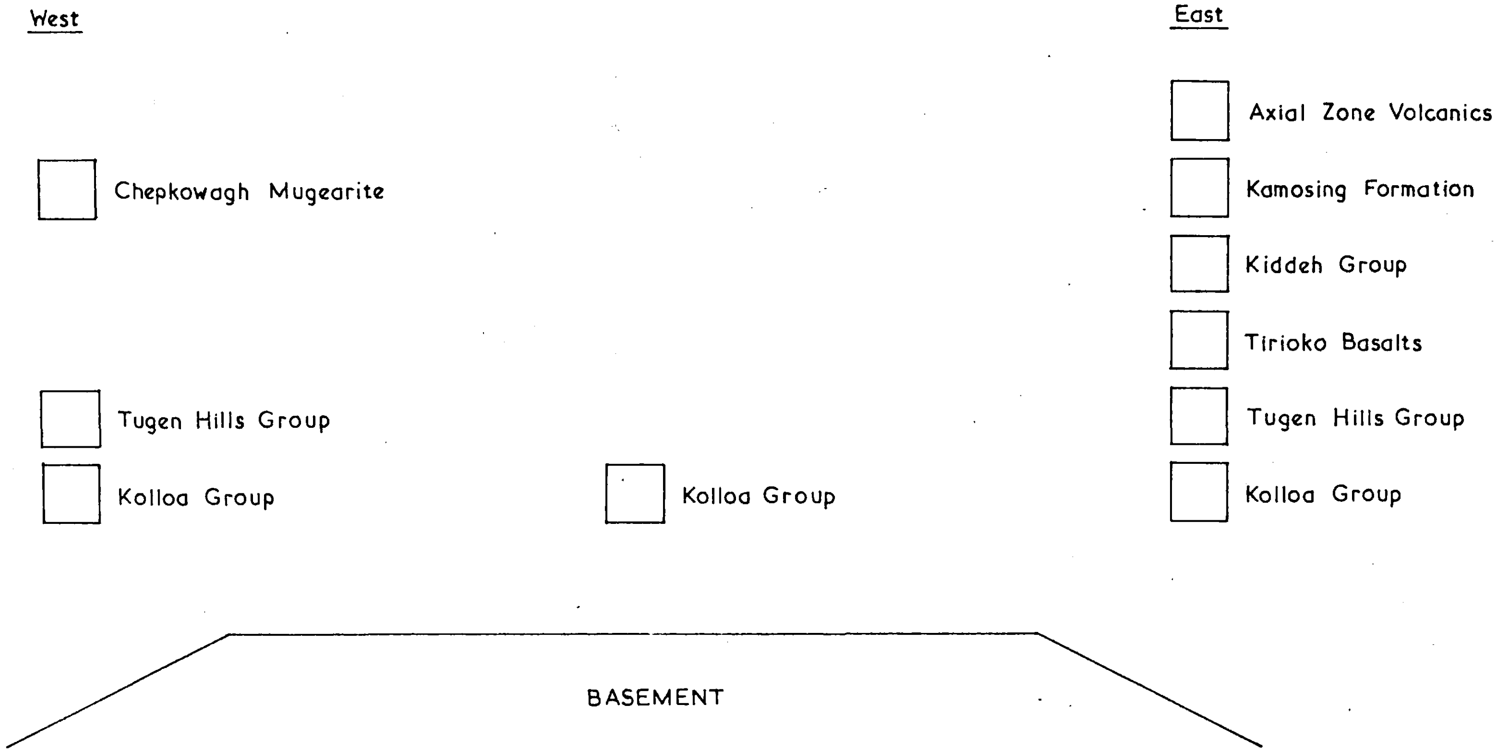


FIG. 10 Comparison of successions West of, on top of, and East of the basement arch.

this outcrop, in square 1641, there are two small outliers of Turkana Grits consisting of coarse conglomerates in a purple tuffaceous matrix, and resting on a more or less level rotted surface of gneiss. These were almost certainly continuous with the main outcrop in the Kapunyan River.

The sub-Turkana Grit surface in this locality is shown in Fig. 11.

At the two outliers, the sub-Turkana Grit surface, inferred to be of Miocene age, is almost coincident with the Kerio Surface.

The Turkana Grits are not exposed south of this but are represented by 5-10 ft. ($1\frac{1}{2}$-3 m.) of tuffaceous sandstone in McClenaghan's area, only a mile south of $1^{o}15'$N, which that author assigns to the Kapchererat Formation (McClenaghan, op.cit.).

Just outside the present area, there is a further outcrop of the Turkana Grits in the Chepkirial River in square 5218. They are probably less than 30 ft. (9 m.) thick, but the section shows basement passing through a weathered zone into tuffaceous sandstones and gravels. The last named contain pebbles of bluish-black basalt, so that basalts must have been erupted before or during the deposition of the grits. In this section, the Turkana Grits pass rapidly up into massive purple tuffs of the Kapchererat Formation, which are then overlain by basalts.

In this area, the Turkana Grits are confined to local depressions. Their present altitude is dependent not only on subsequent earth movements, but also the original topography.

It is inferred that the outcrops in the Kapunyan and Chepkirial Rivers are related to the presence of the basement ridge, p. 18.

2. Kapchererat Formation

This is at least 3,800 ft. (1150 m.) thick, reaching a maximum at about $1^{\circ}17'$N. It is composed almost entirely of basalt lavas, pyroclastics and other lavas occupying only a small proportion of the total volume.

It rests on a basement surface which is undulating but not of great relief. At 177438, the basal lava assumes the original surface, dipping east at 30°, the steepest recorded dip for the sub-basalt surface. Around Singelel, the basalts rest on a gently dipping basement surface, becoming horizontal westwards.

The main outcrop of the basalts east of the arch is composed of regular flows which probably erupted from fissures and individual volcanic centres, now represented by sporadic outcrops of agglomerates and pyroclastics.

It is difficult to derive a 3-dimensional model of the sub-basalt surface, since it outcrops in a fairly straight north-south line. That it has some relief is indicated around 177438, where Fig. 12 is a representative cross-section. At this locality, the basal lava is a buff coloured aphyric trachyte (5/380), in which the fissility is parallel to the upper and lower surfaces of the flow. Between this locality and the Cheptokol River, the fissility becomes vertical, and may be associated with a fissure or similar source. This trachyte is overlain in turn by aphyric and augite-phyric lavas, which also occur as outliers immediately to the west, and are thought to have been originally connected with the main outcrops as indicated in Fig. 12.

The trachyte mentioned above also outcrops in the Kapunyan River overlying the Turkana Grits, where its fissility dips southeastwards at 19°, although this may not be the attitude of the upper and lower surfaces of the flow.

The Turkana Grits and the basal trachyte are both overstepped by the basalts, and in turn some of the older basalts are overstepped by younger flows.

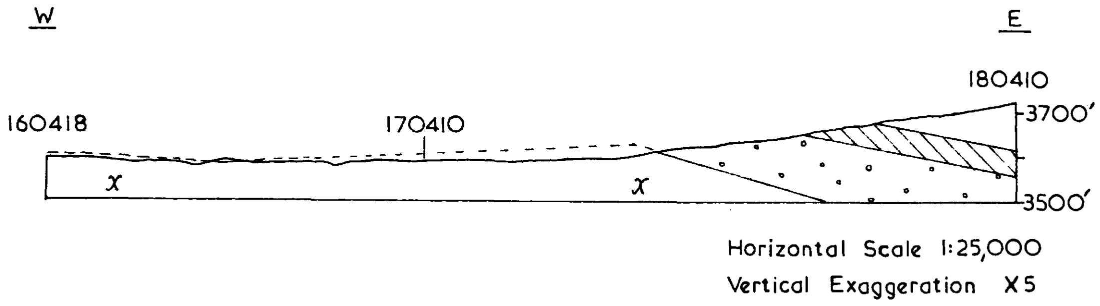


FIG. 11 Sub-volcanic surface in Kapunyan River.

KEY, FIGS. 11 & 12

- ⁞ Augite-olivine-phyric basalt
- ☐ Aphyric basalt
- ⁚ Basaltic tuffs
- ▧ Trachyte
- ∘ Turkana Grits
- χ Basement

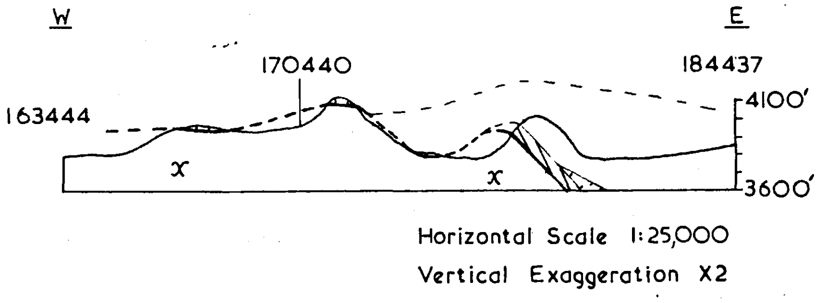


FIG. 12 Sub-volcanic surface near Cheptokol.

Petrographically, the Kapchererat Formation basalts exhibit a range of texture and mineralogy, see Fig. 13. Representative specimens are described in Chapter 5. There is a range from basanites and olivine basalts to trachytes and mugearites. The two last named tend to occur nearer the base of the formation than the top. South of the Cheptokol River, the plagioclase-phyric basalts may occur anywhere in the succession, whereas north of it they are strongly concentrated at the top of the succession.

South of the Kapunyan River, the Kapchererat Formation is affected by the Kerio surface, and exposures are restricted to stream sections. In square 1838, unevenly dipping tuffs are prominent. Similar pyroclastics also occur in the Cheptokol River, and again in the Chepkirial River, above the Turkana Grits, where the succession is shown in Fig. 14.

North of the Meriigun River, the lower part of the succession is composed mainly of bluish-black aphyric basalts, overlain by olivine-augite-phyric basalts, although there is usually some interdigitation between the two. Plagioclase phenocrysts occur sporadically in this part of the succession, but increase greatly in number in the upper part of the succession, where augite and olivine phenocrysts are rarer.

The outliers on basement, nearest to Singelel, are of aphyric basalt, while those further west are olivine-augite-phyric. It is inferred then that these were erupted in the same order as the lavas of the main outcrop, and that the olivine-augite-phyric lavas flowed westwards, overlapping the slightly older aphyric basalts, Fig. 15.

Extending this inference further westwards, it is probable that the basalts west of the basement arch are stratigraphically equivalent to the lithologically similar plagioclase-phyric basalts in the upper part of the Formation east of the arch, though they may not have been directly connected.

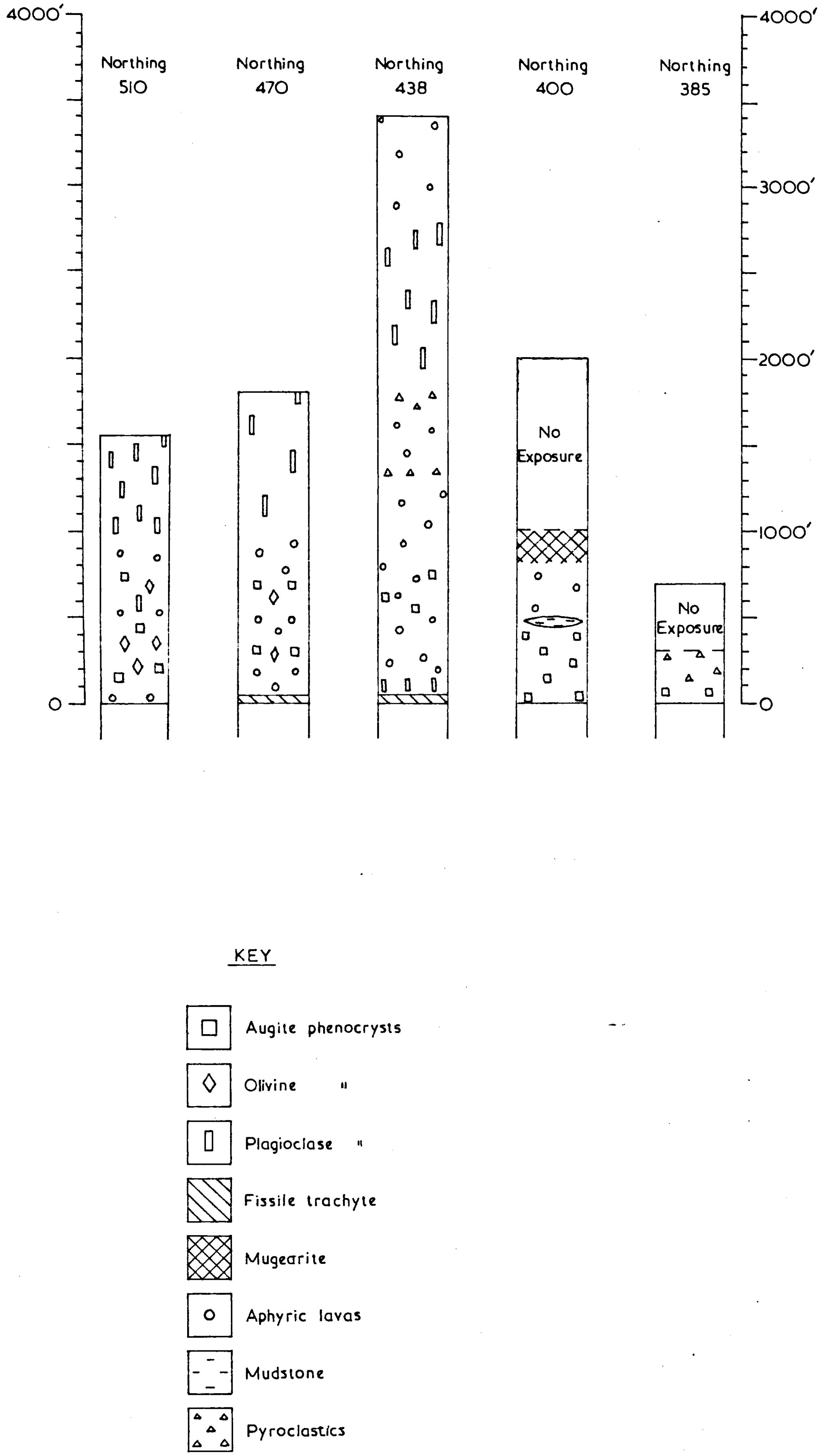


FIG.13 Variations in the Kapchererat Formation east of the basement arch.

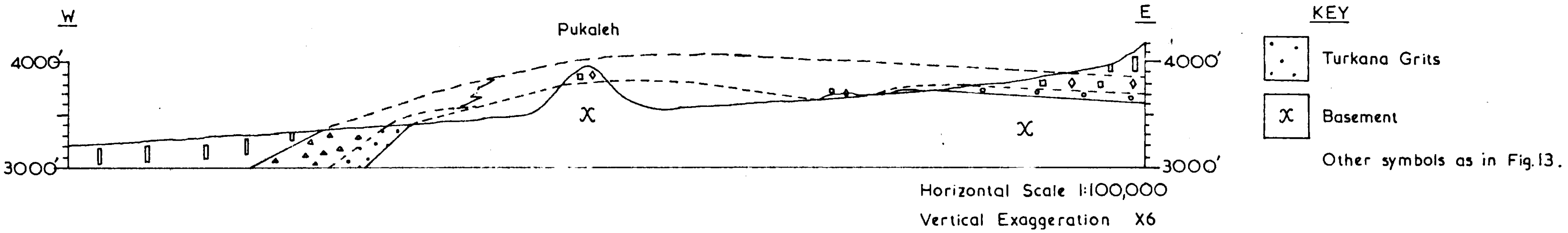


FIG. 15 Relations among outcrops of Kapchererat Formation across the basement arch.

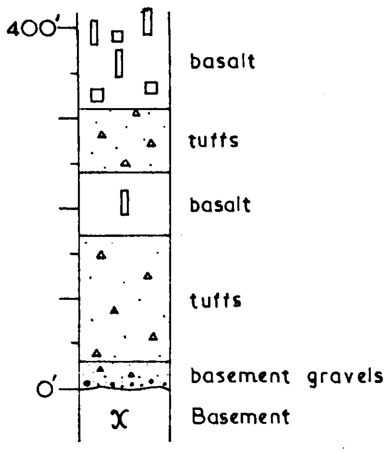


FIG. 14 Section in Chepkirial River, squares 1852 & 1952.

Alteration is common throughout the Formation, and affects each type of lava. Alteration is particularly advanced where the basalts are overlain by the Tugen Hills Group, and it seems that there was a period of erosion and weathering before its eruption. Mafic minerals are often altered to brownish or black disseminated ferruginous material. Olivine is almost always undergoing alteration to bowlingite or black iron ore along fractures. Zeolites are common, with radiating habit in vesicles, or as fibres obliterating groundmass feldspar, particularly in the more silica-rich varieties.

The volcanic episode responsible for the accumulation of the Kapchererat Formation ended before the eruption of the earliest lavas of the Tugen Hills Group. The waning stages of activity are represented by veins of fluorspar which occur north and east of Singelel, in the Meriigun River, and also in the extreme south of the area, in square 1638. The fluorspar is usually pale buff in colour, to greenish, bluish, or rarely colourless. The veins, which are generally ramifying with diffuse margins, cut the basement and the Kapchererat Formation, but not the Tugen Hills Group.

The cessation of volcanic activity was followed by a period of erosion, and possibly faulting. The contact between Kapchererat Formation and Tugen Hills Group from 210420 to 214440 is almost a straight line on the map, although it covers considerable relief. It appears to be an east-facing fault scarp against which was erupted the Tugen Hills Group. This is also traceable north of the Cheptokol River, though it is not such a distinct feature.

3. Karu River Basalts

East of the main watershed, there is a fault controlled inlier in which 900 ft. (270 m.) of eastward dipping olivine basalts are exposed. They are overlain by the Tugen Hills Group, and are separated from it by a deeply weathered surface.

The basalts in the field are bluish-black in colour, and do not have prominent phenocrysts (5/232). Basaltic boulder beds occur sporadically in the lavas.

The base of the formation is not seen, and so their correlation with the Kapchererat Formation is only tentative.

C2. THE TUGEN HILLS GROUP

This is a 4,000 ft. (1200 m.) thick sequence dominated by trachytes, phonolites and associated pyroclastics. The Group outcrops along the hills of the main watershed as far north as 1°24'N, where it is concealed by the Tirioko Basalts. Further north, it is again exposed in the Kewarr Horst.

The order of formations within the Group is summarized in Fig. 16.

1. The Tiriomim Volcanics

This formation is the lowest of the Tugen Hills Group east of the watershed. It rests nearly everywhere on an eroded and weathered surface of basalts of the Kapchererat Formation. The Singelel trachytes overstep basalt to rest directly on basement, in square 1951.

It varies greatly in thickness, from about 200 ft. (63 m.) at Singelel, to 3,000 ft. (910 m.) and possibly more in the extreme south of the area. It is composed mainly of 3 coalesced shield volcanoes, but also comprises several outliers mainly of trachyte.

The 3 shield volcanoes are Chepachaghom, Kaparerr, and the Sigatgat Hill Complex. Only parts of the second and third occur in the present area. Kaparerr continues into the mapping area to the north, and Sigatgat Hill to the south, see Fig. 17.

(a) Chepachaghom Volcano

This is a trachyte volcano roughly circular in plan, and about

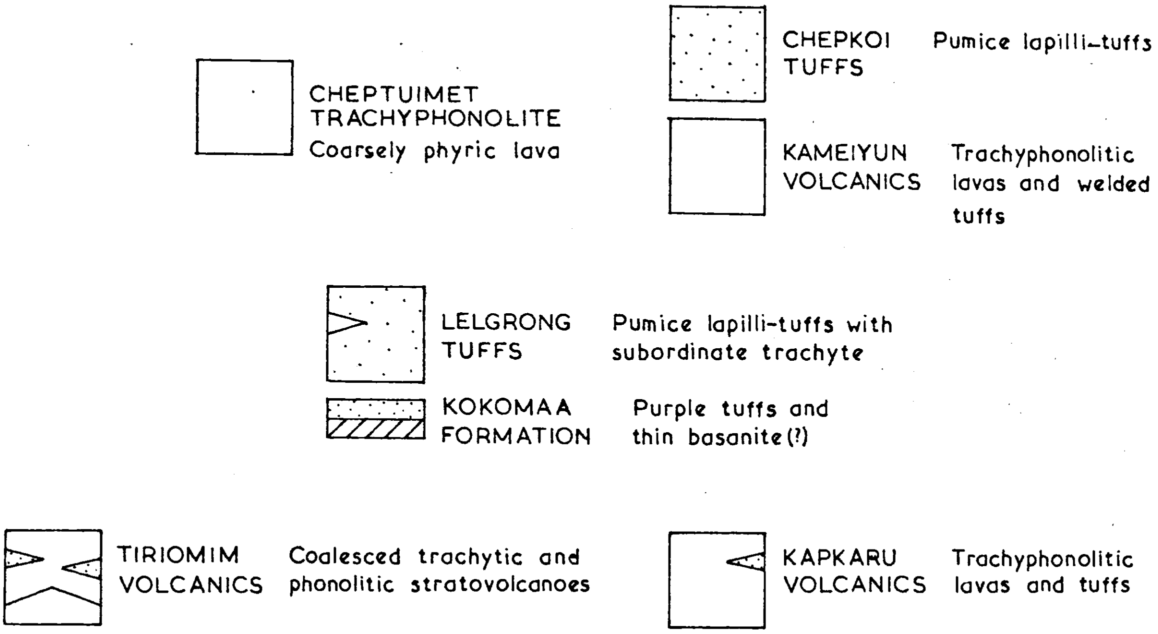


FIG. 16 The Tugen Hills Group

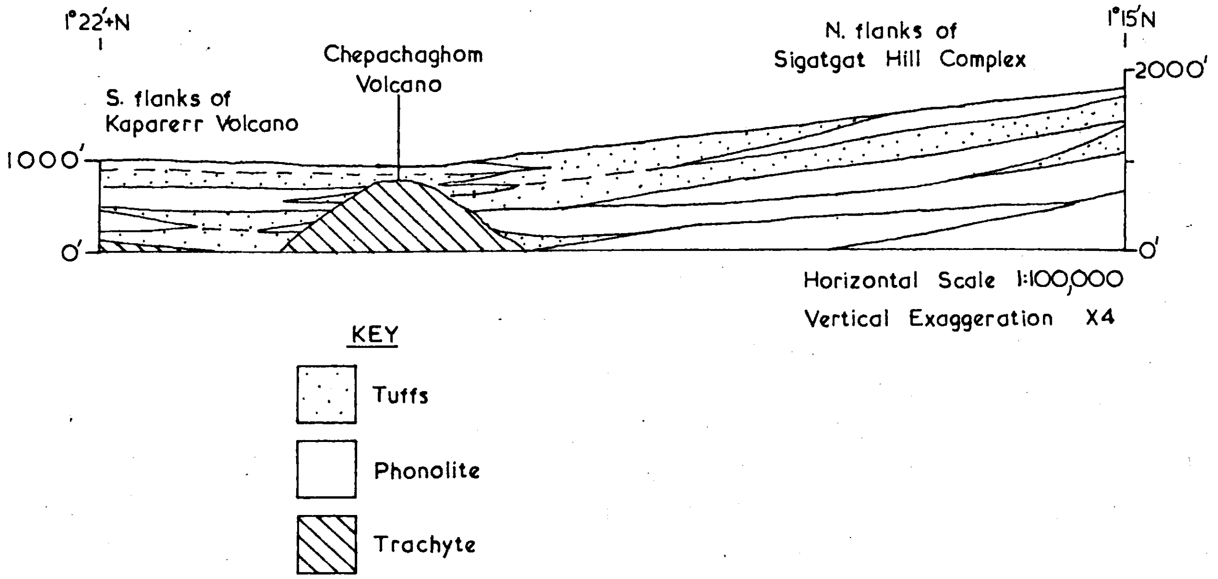


FIG. 17 Relations among shield volcanoes in the Tiriomim Volcanics

2½ miles (4 km.) in diameter. Some 800-1,000 ft. (240-300 m.) of lavas are present. The main vent appears to have been located around 207477, where massive agglomerates are exposed in the Meriigun River. The agglomerates are composed of angular fragments of trachyte up to 5 cm. across, in a comminuted groundmass of the same material. The whole assemblage has been bleached and altered.

Overlying the agglomerates are thick flows of porphyritic trachyte, such as 5/401, from the hill Chepachaghom, which is anorthoclase-phyric. Similar trachytes occur ½ mile west of Chepachaghom. East of Chepachaghom, the agglomerates pass up into alternating trachyte lavas and agglomerates, which may in fact be block lavas. In square 2347, trachytes and phonolites interdigitate, and it is not clear whether the phonolites are assignable to the Chepachaghom volcano, or to a younger eruptive centre.

There is certainly interdigitation between the lavas and tuffs of the Sigatgat Hill Complex, and those of Chepachaghom. In square 2146, Chepachaghom agglomerates pass both upwards and laterally into a trachyte/tuff/phonolite sequence which thickens rapidly southwards.

Trachyte dykes cut the Chepachaghom volcano, as do two plagioclase-phyric basalt dykes petrologically similar to those which cut lavas of the Kapchererat Formation. No basalts of this type occur either in or on top of the Chepachaghom volcano.

Other intrusive bodies cutting the Chepachaghom volcano are described in Chapter 5.

(b) Kaparerr Volcano

Only the southern flanks of this volcano are represented in the present area. They are composed principally of phonolites and tuffs. The phonolites are typically black with a greenish tinge, fine-grained, with a flinty texture and rather waxy lustre. They show flow banding which is occasionally contorted. Biotite and nepheline phenocrysts are often visible in hand specimens. The flow banding is seen in thin section to be caused by the alternation of mesocratic and leucocratic layers. The mesocratic layers are composed principally of aegirine, alkali feldspar and analcime, while the leucocratic layers are extremely rich in analcime (5/433 and 5/437).

The lowest exposed member of the Kaparerr volcano is a fissile sparsely feldsparphyric trachyte.

The tuffs are white to cream, occasionally purplish, generally fine-grained to medium-grained, and are sometimes closely laminated. Pumice lapilli and agglomeratic tuffs are also common. At 231494 xenoliths of basalt are abundant, while at 245497, the tuffs contain xenoliths of earlier tuff.

A fissile aphyric trachyte (5/444) overlies the phonolite on Kiptugun. It consists wholly of a subtaxitic plexus of sanidine laths and interstitial aegirine. No quartz-bearing lavas were found in this volcano.

Southwards, the Kaparerr Volcanics interdigitate with the Sigatgat Hill Complex. The sequence beneath the Kokomaa Formation in square 2246 is composed of alternating phonolites and thin tuffs and lapilli tuffs. Locally, they dip up to 30° eastwards.

Alteration has not greatly affected the lavas of the Kaparerr volcano. The tuffs on the other hand are always altered to some degree, rendering them rather turbid and irresolvable in thin section.

(c) Sigatgat Hill Complex

This is a large phonolitic volcano, the central complex of which occurs in McClenaghan's area (op.cit.). The northern flanks extend into the present area, being about 3,000 ft. (910 m.) thick at $1^{\circ}15'$N, and thinning northwards to less than 1,000 ft. (305 m.) at about 1°20'N, where they interdigitate with the Kaparerr volcano.

The lithologies are very similar to those of Kaparerr, but the lavas are usually more extensively altered.

The phonolites are greenish-black when fresh, very fine-grained and show flow banding which is frequently contorted. In the fresh condition, nepheline phenocrysts may be recognized, together with sanidine and sparse biotite flakes. The phonolites are commonly weathered to a whitish or cream coloured rock in which the flow banding is still distinct. In such rocks, the nepheline phenocrysts are replaced by fibrous natrolite.

Such weathering may extend only partly into a flow, or it may affect many tens of feet of phonolite, so that whole flows are reduced to whitish material. Examples of this occur at 237393, where there is a waterfall 80 ft. (24 m.) high, developed on weathered phonolite. Massive weathered phonolites also occur at 229429, and in the Cheptokol valley, between 223443 and 238453 where they give rise to narrow gorges marked by frequent rapids.

Fissile, feldsparphyric trachytes (5/408) are present as thin flows, but do not contribute greatly to the total volume.

Pyroclastics make up about one third to one half of the total volume of eruptives. They are mainly fine-grained tuffs, many of which are partly welded (5/414), especially near the base of the Complex. Lithic lapilli tuffs are also present, but pumice lapilli are not common in the northern flanks of the Sigatgat Hill Complex. The tuffs range in colour from white to purple and pale greenish.

Thin trachyte and phonolite dykes intersect the tuffs and lavas (5/404).

In the present area, the Sigatgat Hill Complex rests on an eroded surface of the Kapchererat Formation. Between 1°15'N and 1°17'N, this is very badly exposed where it has been affected by the

Kerio Surface. North of the Kapunyan River, the contact is seen to be nearly vertical in places. As for the Chepachaghom centre, it is inferred that the lavas were erupted against an eroded fault scarp.

In part, though, they have flowed eastwards over the fault scarp. At Chepcholongi, square 2144, the earliest lavas dip eastwards at 40°. Even when the eastward tilting of 10° associated with the Tiati Monocline, p. 11, is reversed, the basal lavas must originally have dipped eastwards at 30°. Therefore they must have flowed down the basalt scarp, and not against it. These earliest lavas are massive buff coloured altered phonolites and are overlain by thick black flinty phonolites. These are in turn overlain by another series of altered phonolites, which outcrop in the Cheptokol River between 223443 and 238453, and in which dips both east and west of up to 20° are recorded. Further, an agglomerate forming a feature at 222449 dips eastwards at 22°.

It is probable then that some of the northern flank deposits of the Sigatgat Hill Complex were derived not only from the central vent complex, but from smaller peripheral centres.

Reference has already been made to the alteration in the lavas. The alteration is greatest in the extreme south of the area, its effects diminishing steadily northwards. At 1°18'N, the phonolites retain their black colour. At 1°16'N, phonolites occurring within the Lelgrong Tuffs are not altered. It is possible then that the alteration took place before the eruption of the Lelgrong Tuffs, and that it is associated with emanations of volatiles from the main vent complex. The purple coloration in the tuffs is thought to be of a similar origin.

Some of the tuffs in the Kaparerr Volcano, particularly those near the base, are the same purple colour. The phonolites, however, are not as altered as those of the Sigatgat Hill Complex, and it is possible that the alteration is caused solely by circulating groundwater.

(d) Trachyte outliers

These include the outliers at Singelel; a small outlier at 184444; and an outlier at 192470.

The Singelel trachytes consist of two flows, each about 50 ft. (15 m.) thick. The lower of the two is the more extensive, and dips at about 10° northnortheast. In the Chepkirial River, it is an agglomeratic autobreccia. In several places, the lower flow unit oversteps basalts of the Kapchererat Formation to rest directly on basement. It is a sparsely feldspar-phyric trachyte (5/423). The original mafics are altered to ferruginous material, and the feldspar is undergoing alteration to minute fibres of zeolite (?). Quartz is present as interstitial anhedra, probably secondary.

The upper flow unit is confined in extent to Singelel itself, and dips northnortheast at about 30°. It was not examined in thin section but is identical in hand specimen to the lower flow unit.

The small outlier at 184444 is a phonolitic trachyte (5/381), in which phenocrysts of nepheline (?) pseudomorphed by a brownish secondary aggregate occur in a subtaxitic groundmass composed mainly of sanidine and aegirine.

The outlier at 192470 is a trachyte flow about 50 ft. (15 m.) thick (5/391). It is not fissile, and weathers out as rounded boulders. In thin section it is seen to be rather coarse-grained, and aphyric. It is extremely leucocratic, consisting almost wholly of alkali feldspar laths. Some of these show fine lamellar twinning and may be close to anorthoclase.

The presence of trachyte dykes occurring between the outliers and the main outcrop of the Tiriomim Volcanics indicates that the latter were formerly continuous across the present outcrop of the Kapchererat Formation east of the arch.

The Kewarr Horst is a fault bounded inlier in the north of the area. In it, phonolites, tuffs and feldspathoidal trachytes are exposed. These are lithologically similar to rocks of the Tiriomim Volcanics and are considered to be laterally equivalent. Its structural significance is considered in Chapter 3.

2. The Kapkaru Lavas

These consist of at least 1,500 ft. (460 m.) of phonolitic lavas and subordinate pyroclastics. They outcrop in a northeast-southwest trending belt about 3 miles (5 km.) in length and rarely more than 1 mile (1.6 km.) wide, between the main watershed and Chepkoi.

In the southwest of their outcrop, they overlie the weathered surface developed on the Karu River Basalts, dipping eastwards at about 10°. They consist mainly of greyish lavas, occasionally fissile, visibly crystalline in hand specimen, and sparsely feldspar-phyric. Thin sections reveal the presence of zeolitized phenocrysts of nepheline and/or sodalite, with well developed coronae of aegirine and reddish brown pleochroic amphibole (5/226).

Agglomerates are occasionally interbedded with the lavas (5/227), in which fragments of fine-grained flow banded trachytic lava up to 3 ins. long occur in an altered tuffaceous matrix. Pumice lapilli are also present.

In the hill Kapkaru, square 3140, there is a considerable thickness of pumice lapilli tuffs within the Kapkaru Lavas, but this is the only notable development of pyroclastics.

The mode of eruption of the Kapkaru Lavas is not known. No vents were found, but there are a few trachytic dykes at 332402 and about ½ mile upstream in the Karu River.

There appears to have been some erosion of the Kapkaru Lavas before the eruption of the Lelgrong Tuffs which overlie them. In the Karu River, at about 307393, the Lelgrong Tuffs overstep Kapkaru Lavas on to Karu River Basalts. There is further evidence at 312396 and 322415, where the Lelgrong Tuffs dip westwards at 5^{o}-10^{o} off an earlier topography developed on the Kapkaru Lavas.

The base of the Lelgrong Tuffs and the unconformity below it are dealt with in the section on the Lelgrong Tuffs, p. 32.

3. The Kokomaa Formation

This Formation is about 100 ft. (30 m.) thick, and of very limited distribution. It occurs in square 2246, on the western slopes of Kokomaa, and at 231442. The succession at Kokomaa is shown in Fig. 18.

The basal member rests on a tuff/phonolite succession of Tiriomim Volcanics. It is a non-porphyritic olivine-basalt, black, fine-grained and non-vesicular in hand specimen. In thin section 5/417, it is seen to be a sub-ophitic analcite-basanite, rather coarse-grained, with about 5%-10% of interstitial analcite. The overlying tuffs are purplish to pale violet in colour, fine-grained, well laminated and fairly compact. The whole assemblage dips eastwards at 18^{o}, and is overlain by the Lelgrong Tuffs, which in the Cheporon River directly overlie Tiriomim Volcanics, Fig. 18 model I.

It is considered possible that the Kokomaa Formation is laterally equivalent to the Saimo Formation in Martyn's area (Martyn 1969, p.23), and to the Noroyan Formation in Chapman's area (Chapman, Ph.D. thesis in preparation). This is shown in Fig. 23, where comparison is also made with the succession on the Elgeyo Escarpment.

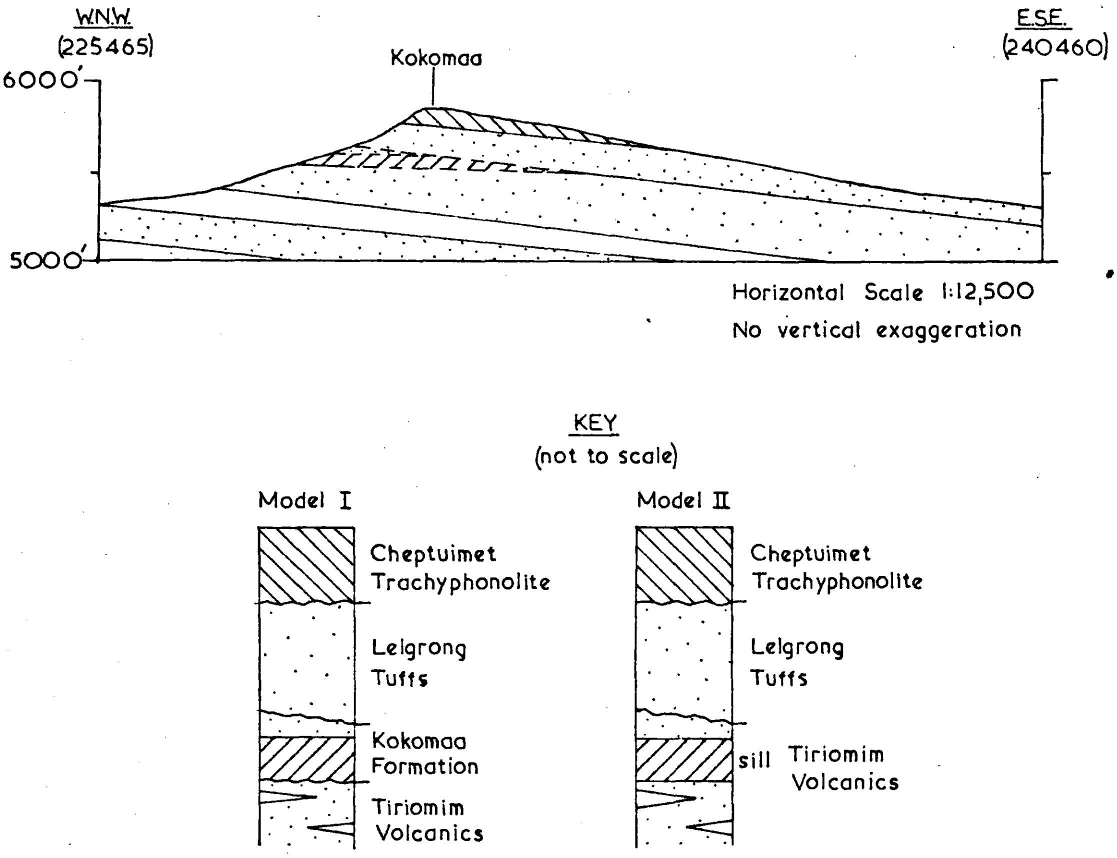


FIG. 18 The Kokomaa Formation

Chapman (personal communication) suggests that the lava member is in fact a teschenite sill, and compares specimen 5/417 with specimens of dykes from the Noroyan Formation. The purple tuffs above it are then not basaltic tuffs, but tuffs of the Tiriomim Volcanics rendered purple by metasomatism associated with the intrusion of the sill, Fig. 18 model II.

4. The Lelgrong Tuffs

This is the most extensive formation in the Tugen Hills Group, being over 3,000 ft. (910 m.) thick, and covering about 20 sqare miles (52 sq.km.). It is composed mainly of pyroclastics, including regularly stratified pumice lapilli tuffs, finer grained tuffs with lithic lapilli, and laminated ash beds. Agglomerates are uncommon, as are welded tuffs.

The formation overlies the Tiriomim Volcanics in the west, and the Kapkaru Lavas and Karu River Basalts in the east. The nature of the unconformity below its base in the east has already been discussed, p. 31.

Its base west of the main watershed is a little more complex. In the extreme south of the area, there is no break between the Sigatgat Hill Complex and the Lelgrong Tuffs, and phonolites are present in both. The base of the latter formation is more or less arbitrary, but is put below the first agglomerates. At this level also, pumice lapilli tuffs, scarce in the northern flank of the Sigatgat Hill Complex, become abundant.

North of $1^{\circ}17'$N, the distinction between Lelgrong Tuffs and Tiriomim Volcanics is clearer, since there are no phonolites in the former. The basal deposits of the Lelgrong Tuffs tend to be agglomeratic, and dip generally eastwards at up to 25°, but usually less than 10°.

North of 1°18'N, the Lelgrong Tuffs rest on varying members of the Tiriomim Volcanics and the Kokomaa Formation, the basal deposits occasionally banked at up to 40° against older volcanics, e.g. at 241471 and 238468.

The formation is composed mainly of tuffs and pumice lapilli tuffs, but coarser lithologies are present. Coarse agglomerates, with boulders of altered lava up to 2 ft. (.6 m.) across form conspicuous features west and south of Tiati, but are not found east of the main watershed.

At 246460, thick welded tuffs form a waterfall 30 ft. high, and at 242462, there is a violet tuff containing blocks of welded tuff of the same colour.

In the bulk of the tuffs, pumice and lithic lapilli are abundant. The lithic lapilli are mainly of greenish and greyish lava, often partly altered (5/234A). Lithic lapilli of nepheline-syenite are also common (5/234B). Pumice is always altered and completely devitrified. In the finer grained lithologies, fine scale grading is sometimes present (5/430), which may indicate the existence of temporary lakes. Grading has, however, been recorded in wholly sub-aerial tuffs (Dawson,1962, p.354). Thin paper shales occur at 319520, interbedded in tuffs. In thin section, the finer grained lithologies are seen to be composed of very fine-grained rather turbid unidentifiable material. Small angular fragments of feldspar are present, but no diatoms were found in any of the specimens examined.

Rain drop lapilli were found at scattered localities, 5/236 at 253470.

East of Cheptuimet, a fissile trachyte lava flow is intercalated in the tuffs. This has flowed southwards, terminating at 286469. Apart from numerous small intrusives, no other lavas occur within the Lelgrong Tuffs.

The formation as a whole dips eastwards at up to 22° east of the main watershed, but at generally lower angles west of it, where dips to the west and north are also recorded. It is inferred that the Lelgrong Tuffs had numerous sources, although an east-west section tends to assume the form of a large tilted shield-like cone, see Fig. 19.

The greatest thickness coincides with the topographic low in the Tiriomim Volcanics, between the Kaparerr Volcano and the Sigatgat Hill Complex. Southwards and northwards, the Lelgrong Tuffs are thinner. In square 2650, the Tirioko Basalts overstep Lelgrong Tuffs on to Tiriomim Volcanics. They reappear, however, and are still present beneath Tirioko Basalts north of the present area.

Numerous dykes intersect the Lelgrong Tuffs, including phonolitic and trachytic dykes west of the main watershed, and trachytic and basaltic dykes east of it.

West of the watershed, there is a well marked concentration of trachytic dykes in and around square 2546, extending in a northnortheast trending belt 3 miles (5 km.) long. They are usually not very fissile, but have prominent feldspar phenocrysts. Specimen 5/435 contains abundant small pseudonephelines. Two thick dykes of non-porphyritic leucocratic trachyte occur in square 2545.

Other dykes are described in Chapter 5.

The summit of Tiati is a trachyphonolite plug, recognizeable from many miles away. The margins are fine-grained and have a crude sheet jointing parallel to the walls. Specimen 5/136 shows sodalite microphenocrysts.

The Hill Kelan (square 2741) is a small intrusive complex. It consists of a central neck of fissile phonolitic trachyte (5/237) which has been brecciated to an agglomerate by upward streaming gases.

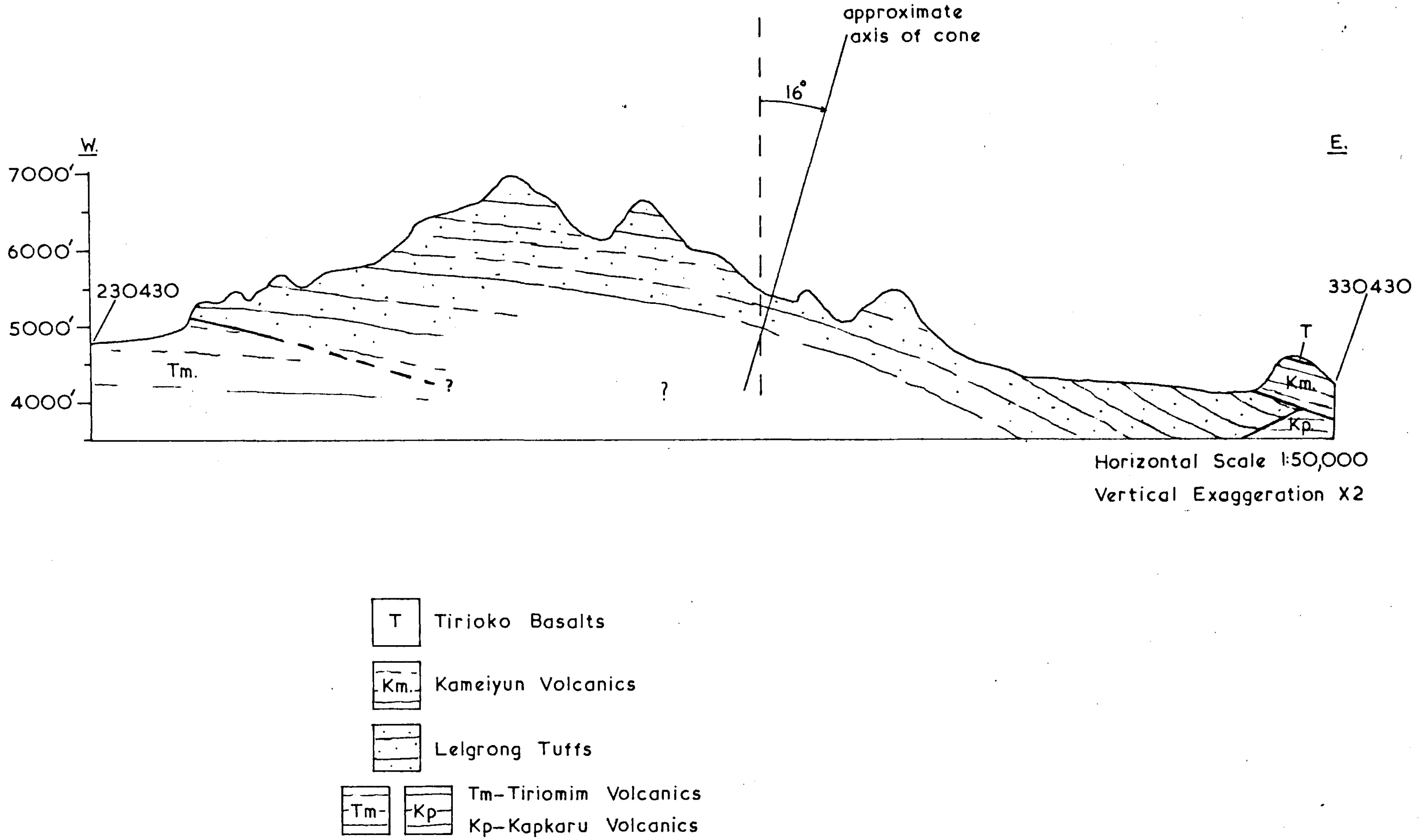


FIG. 19 Section across the Lelgrong Tuffs.

The walls of the pipe are irregular, and there are apophyses of both trachyte and brecciated country rock. The agglomerates contain xenoliths of country rock such as olivine-basalt.

East of the main watershed, numerous basaltic dykes cut the Lelgrong Tuffs and Kameiyun Volcanics. These are inferred to be feeders for the overlying Tirioko Basalts, and will be considered in that section.

5. The Kameiyun Volcanics

This formation is at least 500 ft. (150 m.) thick, and is composed of trachyphonolites and pyroclastics, including welded tuffs. It outcrops in a roughly north-south belt 8 miles (13 km.) long and rarely more than 1 mile (1.6 km.) wide. The outcrop is continuous as far north as 1°20'N, but north of this is confined to a series of inliers, where its base is never exposed.

South of 1°20'N, it rests mainly on Lelgrong Tuffs, but at 324420, oversteps these on to older Kapkaru Volcanics. Throughout the outcrop, the formation generally dips eastwards, but westward dips are recorded in the Waldagh River. The succession thickens and diversifies northwards, and it is inferred that the Kameiyun Volcanics were derived principally from this direction.

The formation consists in the south of flow banded dark green and grey trachyphonolites. Specimen 5/140 contains both nepheline and sodalite and is dark green to black with a rather flinty texture. Specimen 5/141 is a fissile, visibly crystalline lava, which contains abundant small phenocrysts of sodalite and nepheline. Pyroclastics are also present including welded tuffs and non-welded, white, laminated tuffs. The welded tuffs are greenish, fine-grained and have highly contorted flow banding (5/143 and 5/144). Small xenoliths are abundant, as are sanidine crystals and occasional biotite flakes. Such welded tuffs are always altered, so that no undevitrified glass is present. The larger crystal fragments are invariably rounded, while smaller ones are more angular.

North of about 1°18'N, thin agglomerates appear, and the proportion of pyroclastics increases. The trachyphonolites are interbedded with lapilli tuffs and welded tuffs. At 324463, a pumice lapilli tuff with rounded bombs of unaltered glass up to 7 cm. across was recorded. Specimen 5/335 shows that the glass is pale brown in thin section, with perlitic fractures. It contains sparse feldspar microlites and a few biotite laths and large sanidine grains. The pyroclastics are generally altered, rendering the groundmass very turbid. Hydromuscovite (?) was identified in 5/314, which also contained sanidine and anorthoclase fragments, and a single large flake of dark brown biotite.

North of 1°20'N, much of the Tugen Hills Group is concealed by the Tirioko Basalts. Inliers of lavas and tuffs as far north as 1°23'N are assigned to the Kameiyun Volcanics. Nevertheless, the relationship between the Kameiyun Volcanics and the Cheptuimet Trachyphonolite is not clear. The low ridge Kepsetan (square 2951) is a coarsely porphyritic non-fissile lava, lithologically identical to the type Cheptuimet Trachyphonolite.

The inliers of trachyte in square 3148 and at 298503 are, however, fissile and only sparsely porphyritic, and are interpreted as belonging to the Kameiyun Volcanics.

It is suspected that the Cheptuimet Trachyte is younger than the Kameiyun Volcanics, and that Kepsetan represents a lava that flowed eastwards, abutting against a topography developed on the older volcanics.

It is also evident that there was much erosion of the Kameiyun Volcanics before the eruption of the Tirioko Basalts, but that will be considered in the section on the Tirioko Basalts.

6. The Cheptuimet Trachyphonolite

This formation is over 1,500 ft. (460 m.) thick, and consists almost wholly of a few flows of coarsely feldsparphyric non-fissile trachyphonolite. It overlies the Lelgrong Tuffs unconformably, and probably the Kameiyun Volcanics as well.

In the north face of Cheptuimet, agglomeratic tuffs are exposed, indicating that the main mass of Cheptuimet is composed of more than one flow, though the individual flows are not expressed in the present day topography. Specimen 5/324 from Cheptuimet itself is characteristic. The feldspar phenocrysts are honey-coloured and glassy, and in thin section are seen to be sanidine. Fairly fresh nepheline phenocrysts also occur, and pale green augite phenocrysts. Nepheline is not obvious in the groundmass. Specimen 5/336 from Gaako contains anorthoclase. The thick trachyphonolite on top of Kokomaa (5/418) is very similar. The outlier at Molingot is composed of two flows, fissile in hand specimen. Specimen 5/337 from the upper flow has phenocrysts of sanidine, anorthoclase and nepheline.

The trachyphonolite hill Chesitoi, Plate VI, is very steep-sided, with a north-south trending axial ridge. It may be intrusive, although no contacts are exposed to prove this. It is lithologically similar (5/326) to the type Cheptuimet Trachyphonolite, but contains sodalite in place of nepheline.

Fig. 20 is a contoured map of the base of the Cheptuimet Trachyphonolite. The highest of the present day outcrops is Molingot (square 2943) and it is considered therefore that the Cheptuimet Trachyphonolite was derived, at least in part, from the south. Such a source may have been Kelan, or even the plug at the top of Tiati.

Additional sources may have been the concentration of dykes between Cheptuimet and Kokomaa, on Chesitoi. The latter is a distinctive steep-sided hill. Although no contacts are exposed, it

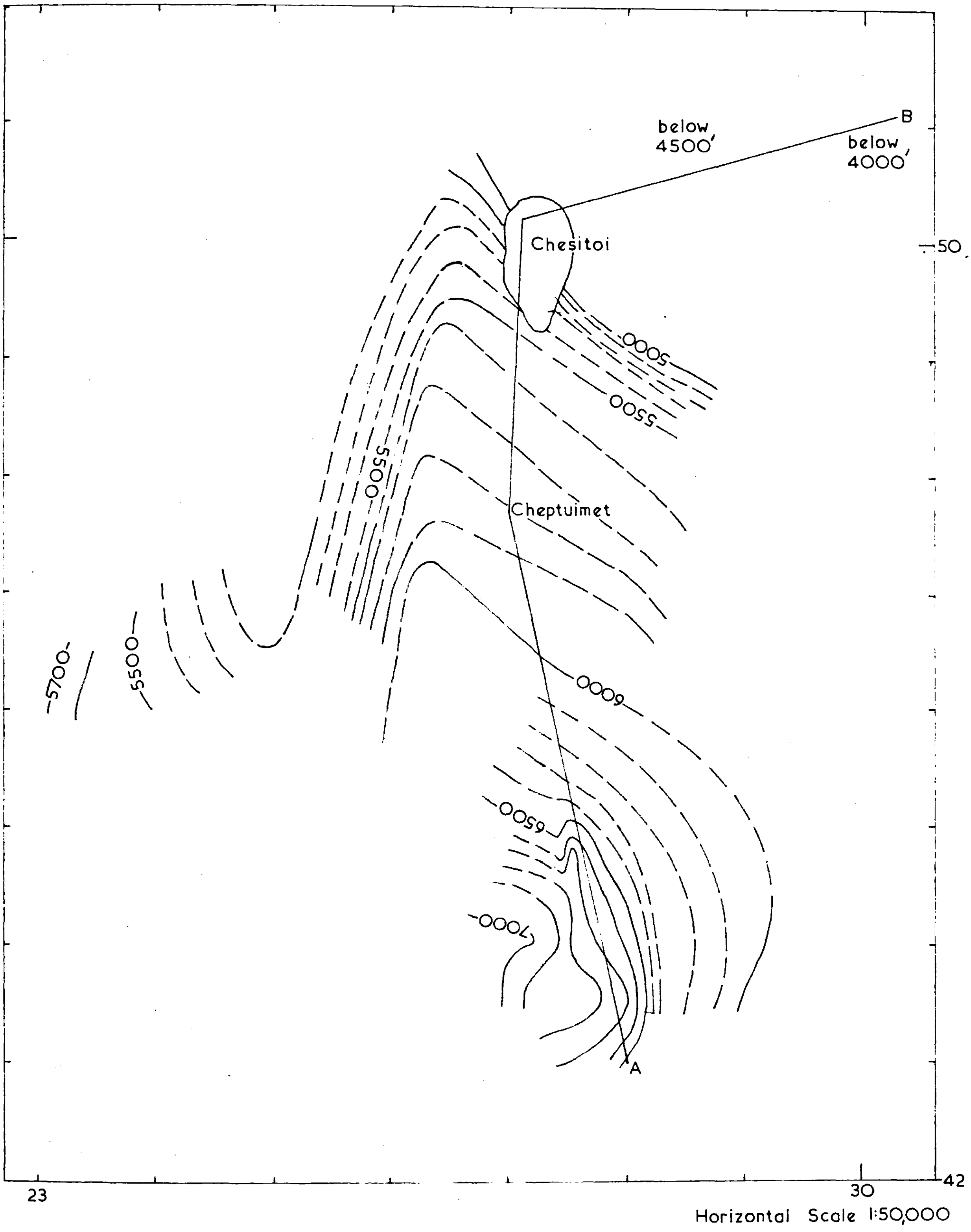


FIG. 20 Base of the Cheptuimet Trachyphonolite.

resembles a plug, and may be situated on a source, above which accumulated a cumulodome of very viscous magma (Van Bemmelen, 1949, pp.197-198). It may thus have served as a source for the lava of Kepsetan (see below), but unless flow took place uphill, it could not have given rise to the lavas in Cheptuimet, where the sub-surface is inclined upwards away from Chesitoi. There may, alternatively, be a further source between Serkoit and Cheptuimet, to account for the great thickness of lava there.

Kepsetan is thought to be part of this formation. It is the topographically lowest representative, and is thought to be a lava that flowed eastnortheast from either Cheptuimet or Chesitoi on to the eroded Kameiyun Volcanics. Fig. 21 is a section from 290513 to 313502.

Fig. 22 is a schematic representation of the Cheptuimet Trachyphonolite illustrating the relationships among the structure, lithology and possible modes of eruption of the various parts of the formation.

7. The Chepkoi Tuffs

This formation is about 600 ft. (185 m.) thick, and occurs in the east and southeast of the outcrop of the Tugen Hills Group. It overlies both the Kameiyun Volcanics and Kapkaru Volcanics, but its relationship to the Cheptuimet Trachyphonolite is unknown.

They dip eastwards at angles of up to 15°. Throughout their outcrop, they consist mainly of rather monotonous pumice lapilli tuffs, generally well bedded but poorly sorted. Occasional agglomerates are present, and a welded tuff in a fault controlled inlier in square 6842. At 339413, the tuffs are graded and show slumping and flame structures, which may indicate a sub-aqueous environment of accumulation.

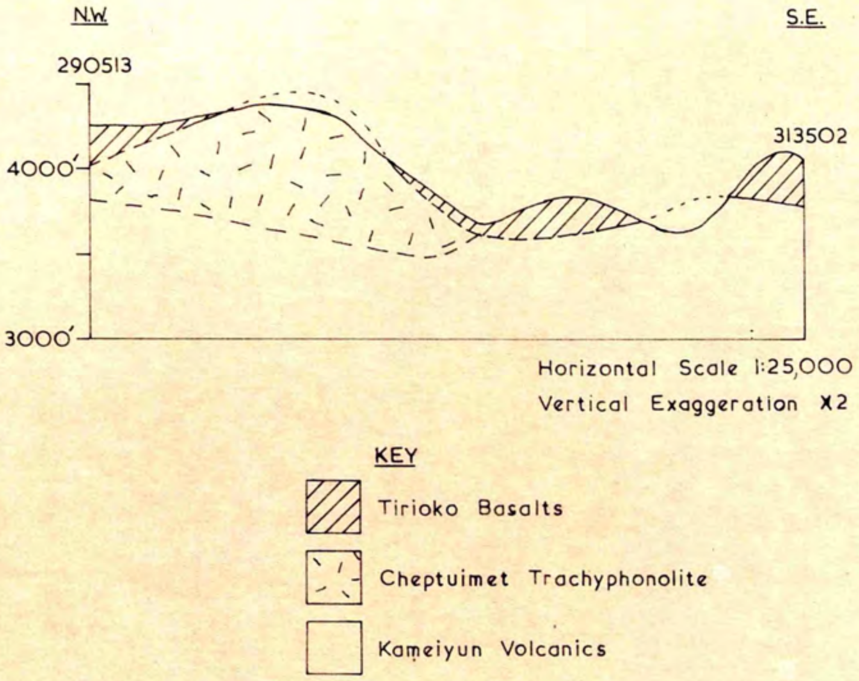


FIG. 21 Supposed relationship of Kepsetan to Kameiyun Volcanics.

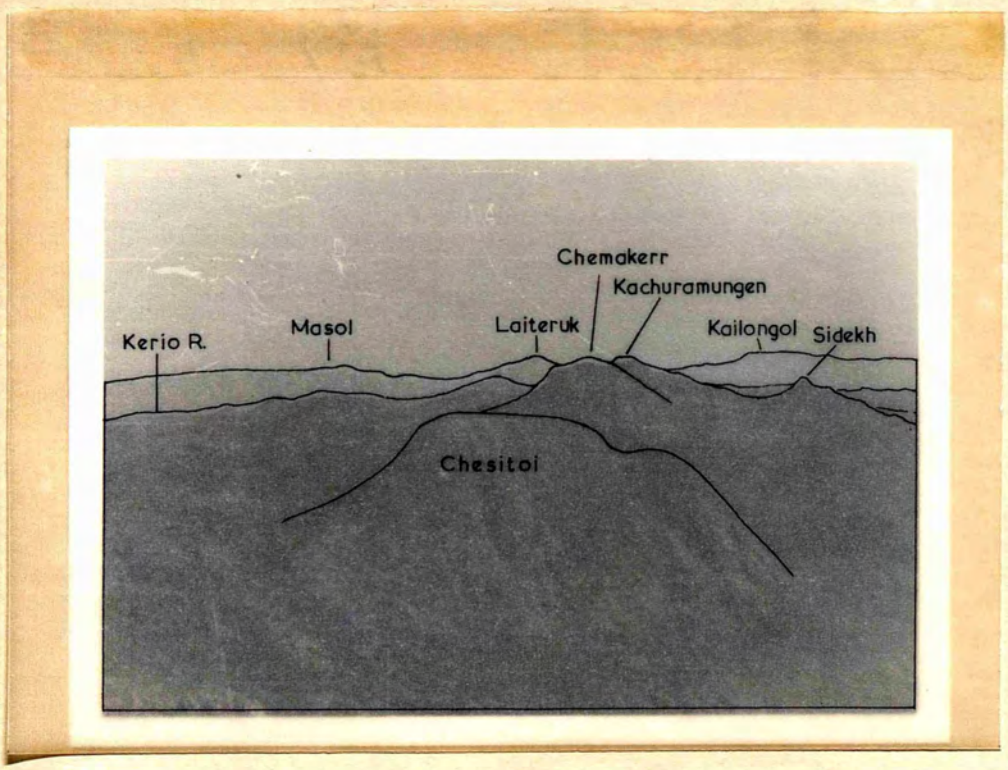


PLATE VI Chesitoi from Cheptuimet.

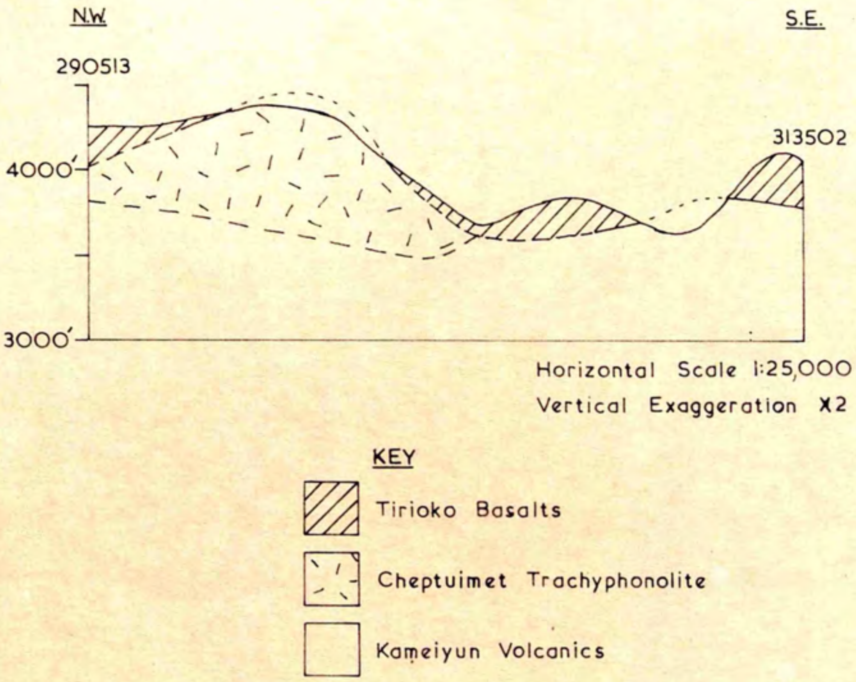


FIG. 21 Supposed relationship of Kepsetan to Kameiyun Volcanics.

PLATE VI Chesitoi from Cheptuimet.

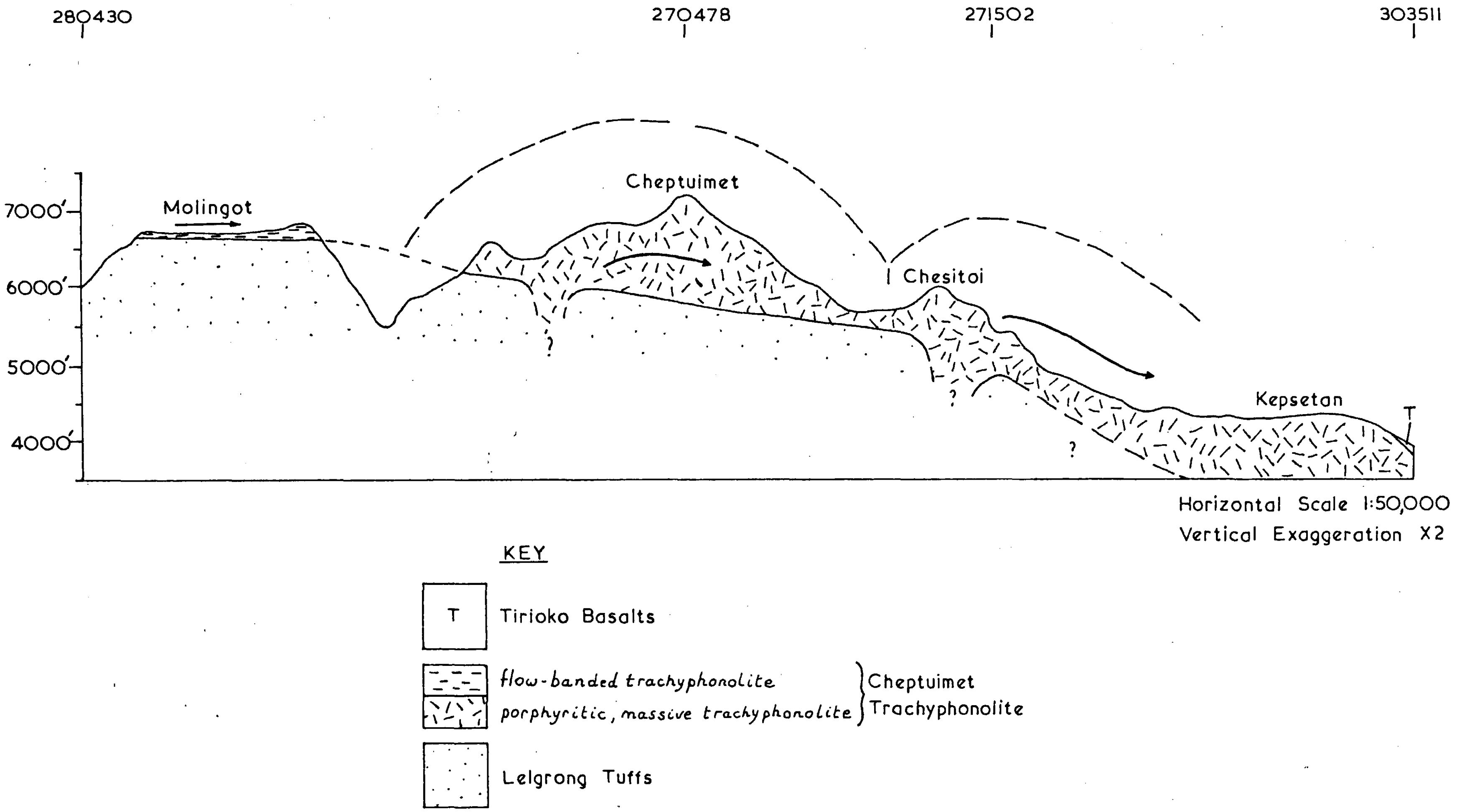


FIG. 22 Relations among the structure, lithology and mode of eruption of the Cheptuimet Trachyphonolite.

Lithologically, they are very similar to the Lelgrong Tuffs, and in McClenaghan's area, where the two are in direct contact, they are not divisible.

West of the watershed, there are no counterparts of the Kameiyun Volcanics or Chepkoi Tuffs. In this respect, the Tiati Volcanic Complex is asymmetrical, and indicates that activity was shifting eastwards towards the centre of the rift valley.

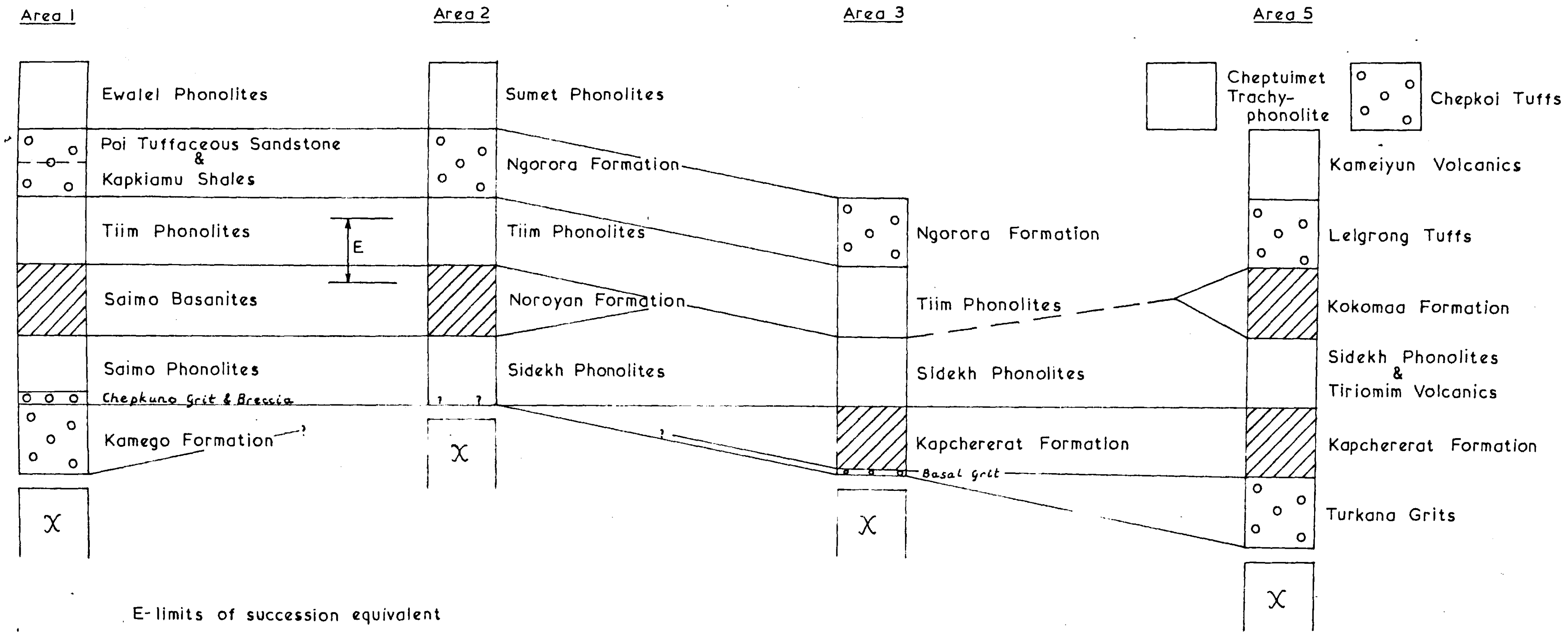
The overlying Tirioko Basalts, however, were erupted over a very wide area, and the Mugor Trachytes have their greatest development almost along the main watershed. Hence there is no precise correlation between the change in locus of activity and time.

Correlation and comparison of the Kolloa and Tugen Hills Groups with other areas

The term Tugen Hills Group was proposed by J.E. Martyn (op.cit.) and groups together the formations in his area composed principally of phonolite lavas. Considerable thicknesses of epiclastic sediment also occur, as well as up to 800 ft. (250 m.) of basanites.

Martyn's formations are traceable through Chapman's area (Fig. 2) and into McClenaghan's area (Fig. 2). In the latter, the erupted units are more irregular in form than in areas further south, and correlation may only be approximate. Fig. 23 indicates the relationships among the various formations.

The basement is overlain in Martyn's area by two sedimentary successions. The Kamego Formation is thought by that author (op.cit., p.22) to be older than the Turkana Grits. He equates the overlying Chepkuno Grit and Breccia (the basal member of the Tugen Hills Group) with the Turkana Grits (op.cit., p.64). In Chapman's area, the base of the phonolites is not exposed. In McClenaghan's area, c. 6 ft. (2 m.)



E-limits of succession equivalent
to Tugen Hills Group on
Elgeyo Escarpment

FIG. 23 Lateral Relationships in the Tugen Hills Group.

of tuffaceous grits overlie basement, followed up by the basalts of the Kapchererat Formation. Martyn (op.cit., p.64) correlates these grits with the Chepkuno Grit and Breccia, and McClenaghan accordingly placed the Kapchererat Formation in the Tugen Hills Group.

The present author, however, feels that the Kapchererat Formation is of sufficient size and distinct lithology for it to be raised to group status. Accordingly, the term Kolloa Group has been used, and includes the Turkana Grits and Kapchererat Formation.

The Kapchererat Formation thickens from 0 ft. at 1°7'N to at least 3,700 ft. (1130 m.) at 1°17'N, and occupies a position analagous to the Samburu Basalts on the eastern side of the Rift Valley.

The Saimo phonolites thicken northwards from Martyn's area, and are equated by McClenaghan with the lower part of the Sigatgat Hill Complex, which may in part be their source. In Martyn's and Chapman's areas, the Saimo and Sidekh Phonolites consist of flood type lavas erupted probably from dispersed fissures and small centres, but thickening towards Sigatgat Hill. In the present area, the equivalents of these formations are the Tiriomim and Kapkaru Volcanics, a coalescence of shield volcanoes, in which the proportion of pyroclastics is much higher than in their equivalents further south. Furthermore, there are no intercalations of epiclastic material in the Tiriomim or Kapkaru Volcanics, neither is there much weathering on individual flow tops as there is in the Saimo Phonolites, and so it is inferred that eruptions proceeded almost continually in the present area.

As regards the Saimo Basanites, Martyn considers that these form a large, low angle shield-like volcano, with their thickest accumulation in his area. From there, they thin northwards into Chapman's area, and are absent from McClenaghan's area, but may be represented in the present area by the Kokomaa Formation.

It is not possible to correlate formations in the upper part of the Tugen Hills Group in areas to the south with those in the present area. The eruptive pattern changes completely and there is no continuity between the formations.

There are also important structural differences between the northern and southern parts of the region occupied by the Tugen Hills Group, see Chapter 3.

C3. THE TIRIOKO BASALTS

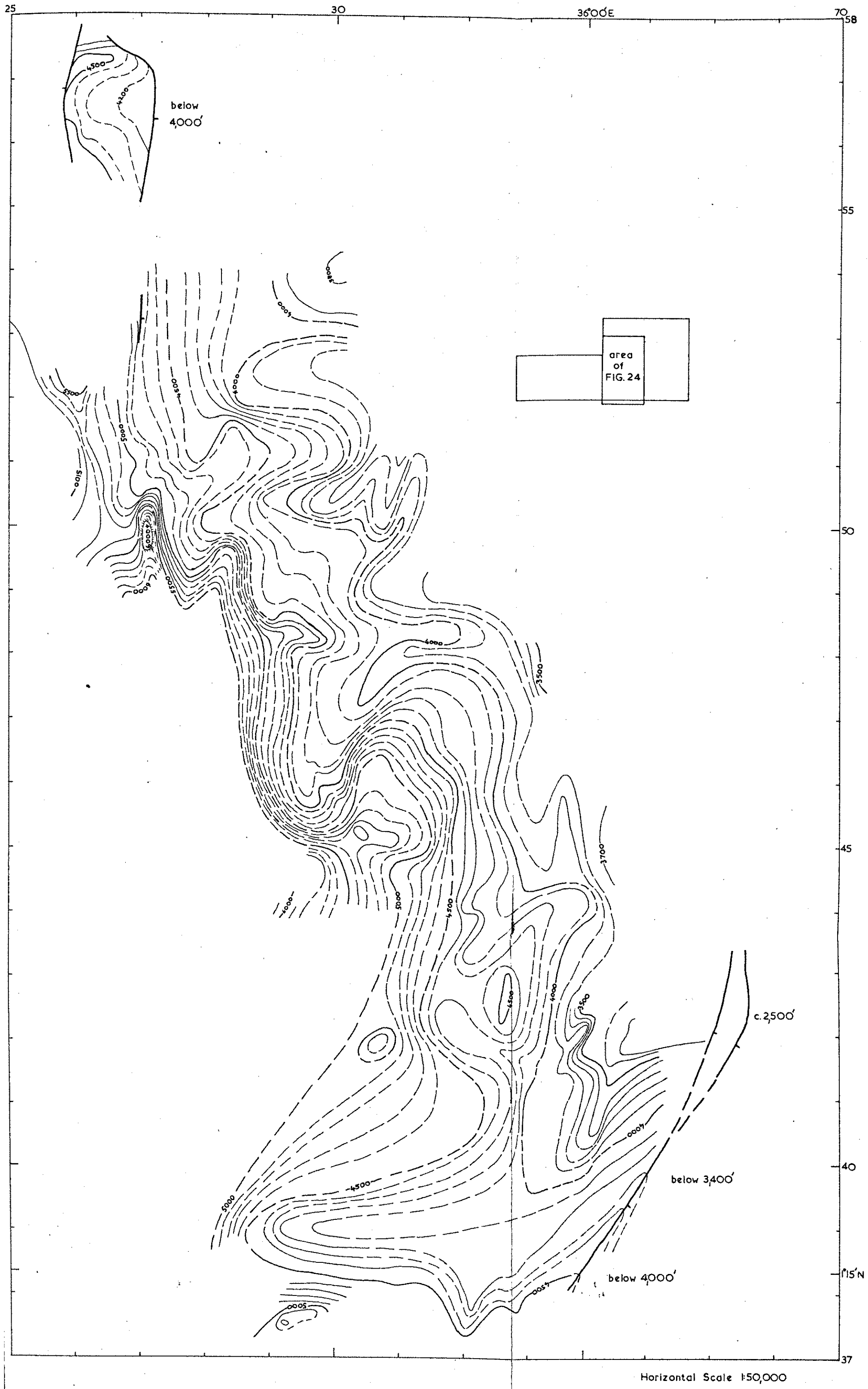
This is a widespread formation, composed almost entirely of basalt lavas, totalling over 1,000 ft. (300 m.) in thickness. There are minor developments of pyroclastics, and trachytes and mugearites occur near the top of the formation.

At Chepkoi, only 80 ft. (25 m.) of basalt is present, but the formation is probably over 1,000 ft. (300 m.) thick at the latitude of Akoret. It thins slowly northwards into Weaver's area (Fig. 1). Dips are generally eastwards to northeastwards.

Following the build-up of the Tiati volcanic complex, there was a quiescent period during which erosion of the tuffs and phonolites took place, and the Tirioko Basalts now overlie the Tugen Hills Group unconformably. In part, this older landscape has been exhumed by present day erosion. Its existence is indicated by the many outliers of basalt between Tiati and Chepkoi, occurring at different heights. The sub-Tirioko Basalt surface is shown in Fig. 24.

Red soils are occasionally developed on the surface, particularly on the Lelgrong Tuffs. At 308512, a stream section shows basalts resting on weathered trachytes via a westward dipping thin earthy boulder bed.

East of Chesitoi and Gromot, pre-Tirioko Basalt formations occur as inliers both in stream valleys and on the interfluves, indicating



Horizontal Scale 1:50,000

FIG 24 Sub-Tirioko Basalts Surface.

the undulating nature of the sub-basalt surface. Further, in square 2938, a basalt flow occurs at 4,100 ft. O.D., in continuity with the main outcrop on Chepkoi which is at c. 4,800 ft. O.D. This indicates the existence of a valley at least 700 ft. (215 m.) deep.

The present attitude of the base of the formation and the differances in thickness are partly controlled, however, by tectonism. This includes pre-Kiddeh Group faulting, and post- Ribkwo Volcanic Complex uplift about an east-west axis at 1°13'N, referred to in Chapter 3.

Throughout the outcrop, the volume of pyroclastics is low, and the occurrence of numerous dykes suggests that the lavas were erupted mainly from fissures. The dykes are easily visible on the aerial photographs where they cut the Lelgrong Tuffs, and occur as high as 6,000 ft. O.D. at 269449.

Pyroclastics do occur, however, fairly low in the formation, but are only developed to any extent north of 1°22'N. They include beds of lapilli between flows, but more commonly are irregular horizons of agglomerates with spindle bombs, occasionally up to 3 ft. (1 m.) in diameter. Around 283551, outward dips in such agglomerates indicate the presence of a cinder cone. The agglomerate is coarsest in the centre of the outcrop, passing upwards into finer material, and thence into basalt lava.

The outliers around Mechwet (square 3045) appear to belong to a dissected cone, Plate VII and Fig. 25. Mechwet itself consists of a coarse spindle bomb-bearing agglomerate. To the immediate northwest are basalt lavas dipping away from the agglomerate. This assemblage is interpreted as a vent agglomerate with associated lava flows. The agglomerates at Kapusyuin overlie rocks of the Tugen Hills Group, and are thought to have been erupted on to the flanks of the basaltic cone. Similarly, the basalt lava between Mechwet and Kapusyuin is thought to be a lava erupted on to the eastern flank of the cone.

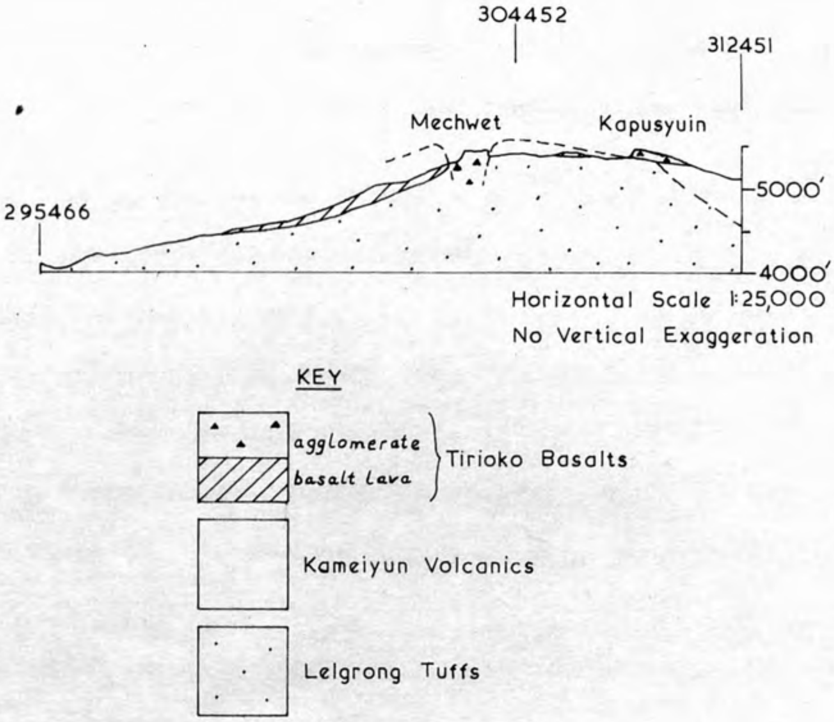


FIG.25 Reconstruction of Mechwet cone, Tirioko Basalts.

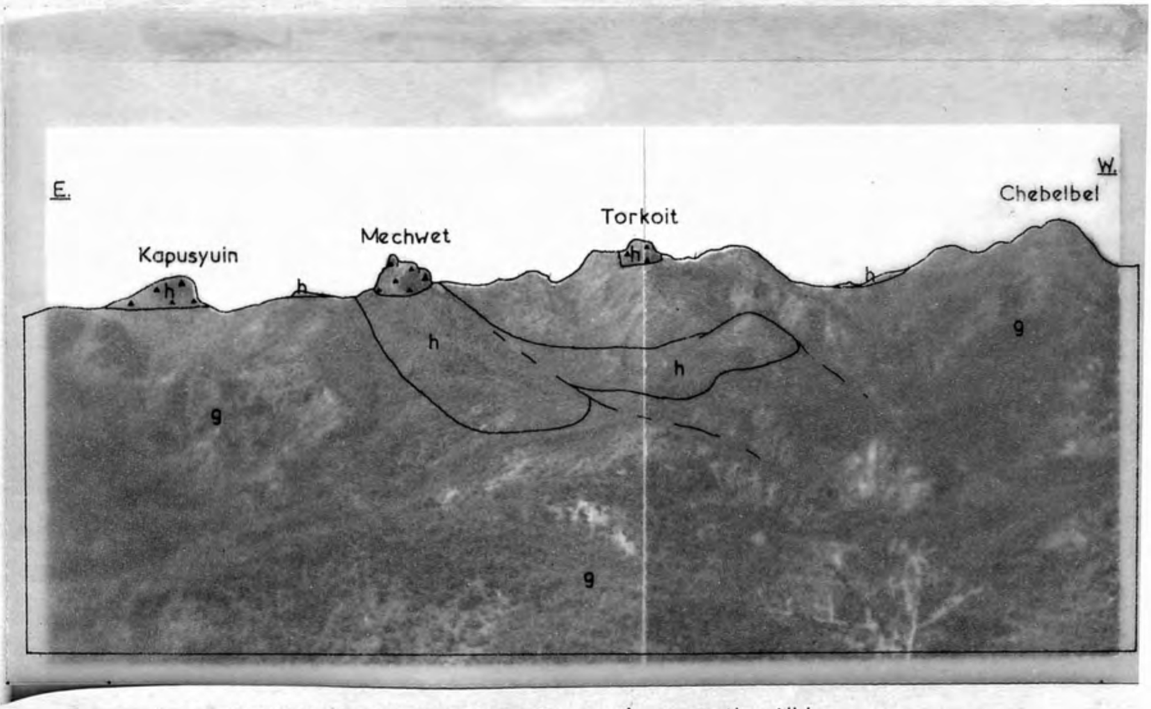


PLATE VII Mechwet and Kapusyuin from the N.W.

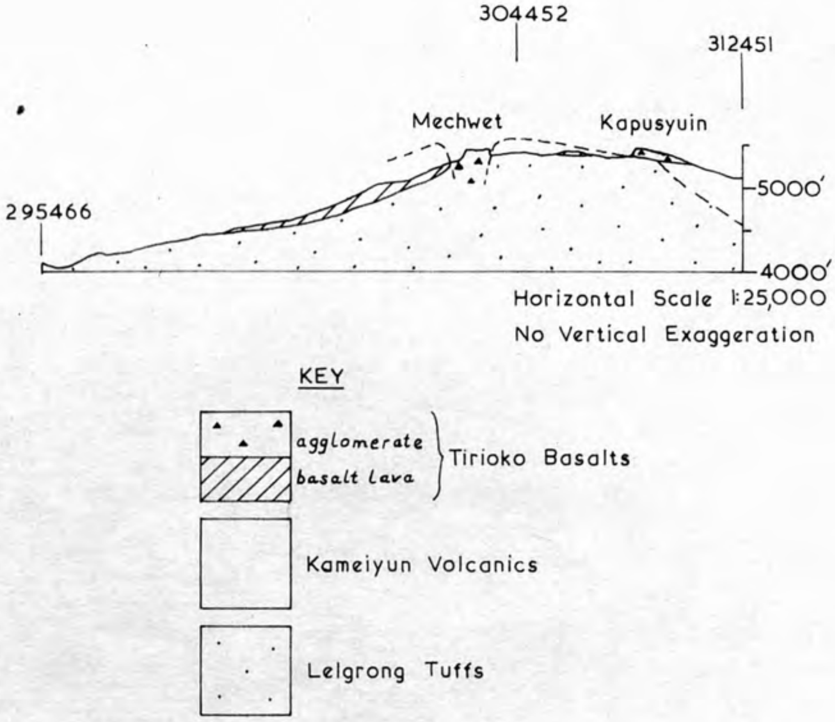


FIG.25 Reconstruction of Mechwet cone, Tirioko Basalts.

PLATE VII Mechwet and Kapusyuin from the N.W.

There is also an outcrop of agglomerate at Torkoit, square 3045, which occurs at a higher altitude than either of the others mentioned above, and is not thought to have been connected with the same cone.

The Tirioko Basalts immediately east and west of Chesitoi consist mainly of purplish earthy beds containing abundant rounded boulders of porphyritic trachyte derived, it is thought, from Chesitoi. This facies is well exposed at 297497, where the matrix is seen to consist of basaltic cinder and ash, altered to an earthy material. The boulders of trachyte are well rounded, and up to 3 ft. (1 m.) across. At this locality, the deposit has weathered out as earth pillars, Plate VIII.

At 278509, similar deposits have thin basalt lavas intercalated, indicating their age.

It is considered that during the local eruptions of the Tirioko Basalts, Chesitoi was a steep-sided hill undergoing active erosion, and that the rounded boulders of trachyte are derived from it.

The lavas in the formation vary greatly in character, although nearly all of them are olivine-bearing. The fullest sequence is at Akoret. Variations northwards and southwards are expressed in Fig. 26.

(a) Microphyric unit. Phenocrysts are generally small, and are mainly olivine. Augite is sometimes present, but plagioclase only rarely so. Aphyric lavas are common. In hand specimen, the lavas are mostly fine grained, bluish or black and only sparsely vesicular. They are mostly quite fresh, excepting the olivine phenocrysts, which are always altered to some degree. Occasionally, areas of basalt are completely altered to reddish, yellowish or white secondary products by alteration, e.g. at 326619. An intensely, but laterally restricted, altered zone occurs at 339558, on the southern extremity of the Ka'at fault, and is also colinear with a narrow zone of basaltic dykes at

PLATE VIII Earth pillars, near Chesitoi.

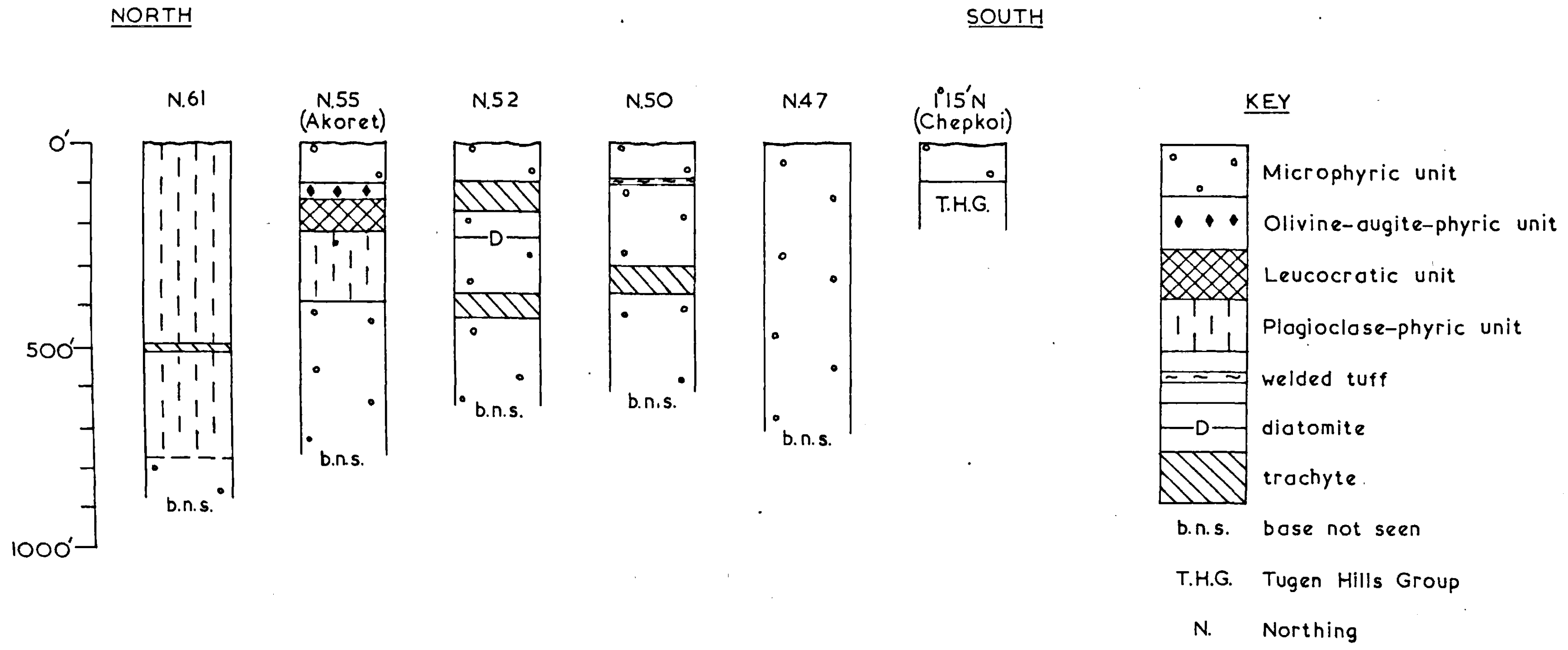


FIG. 26 Variations in the Tirioko Basalts from North to South between 36°00′E & 36°03′E.

337554.

Basalt lavas within the microphyric unit are described in Chapter 5.

About 2 miles (3.2 km.) westsouthwest of Akoret, 3 trachyte flows are intercalated within the Tirioko Basalts. Specimen 5/152, the youngest of the 3 flows, has anorthoclase, occurring both as phenocrysts and in the groundmass. It is worth noting that trachytes in the Kaparaina Basalts (a formation roughly the same age as the Tirioko Basalts) in Martyn's area (op.cit., p.90) are similarly anorthoclase-bearing. The trachyte from the Tirioko Basalts differs, however, in that it contains alkali amphiboles, while those in Martyn's area (op.cit., p.96) contain diopsidic augite.

At 690519, a 2 foot (.6 m.) thick diatomite is intercalated in the basalts. It is rather shaly, but very light and almost pure white. The diatoms are shown below, Fig. 27. They are morphologically distinct from those in the Aterir Beds, q.v. p. 74.

The rocks in the microphyric unit dip mainly northeastwards. The earliest lavas overlying the Tugen Hills Group dip fairly steeply eastwards, varying according to the local nature of the sub-basalt surface. Beneath the flank deposits of the Ribkwo complex, they dip northeastwards at about 9°. West of Kafkandal, they dip eastnortheast or eastwards, usually at less than 10°. Immediately west of Mugor (square 2760), the basalts are involved in an upwarp about a north-south axis so that in the northwest of the area, dips are westwards at up to 5° - see also Chapter 3.

(b) The Plagioclase-phyric unit thickens northwards from nothing in square 6854 to about 400 ft. (125 m.) at 1°28'N. The lavas are usually greyish or purplish, with abundant glassy tabular plagioclase phenocrysts up to 2 cm. long, often in subparallel alignment. Ropy

Relative abundance

Form (a)	c. 90%
Form (b)	c. 5%
Others	c. 5%

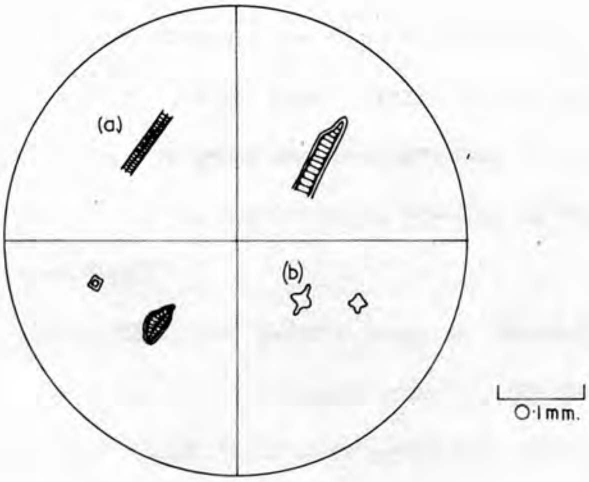


FIG. 27 Diatoms from the Tirioko Basalts

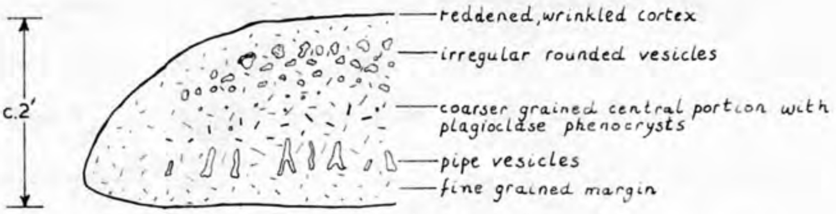


FIG. 28 Section through pahoehoe 'toe', plagioclase-phyric unit, Tirioko Basalts.

PLATE IX Pahoehoe toe, plagioclase-phyric unit, Tirioko Basalts.

surfaces and pahoehoe toes are common, see Fig. 28 and Plate IX. The lavas examined in thin section (5/278) have olivine in the groundmass, and large concentrically zoned plagioclase phenocrysts.

A thin fissile trachyte is intercalated in basalts of this unit beneath Kafkandal, square 6661.

The plagioclase-phyric lavas are rather prone to alteration. The phenocrysts alter along the (010) cleavage causing fracturing in the adjacent groundmass, and large fresh hand specimens are difficult to obtain. In thin section, the mafics are seen to be largely altered to secondary ferruginous material.

(c) The Leucocratic unit is of limited distribution, occurring only immediately east of Akoret, and is less than 100 ft. (30 m.) thick. At 687543, the field relations show that it is an intercalation within the microphyric unit. It is very distinctive in the field and together with the plagioclase phyric unit, enabled the detection of strike faulting east of Akoret.

At 708551, a stream section shows at least 3 distinct flows, each about 20 ft. (6 m.) thick.

In hand specimen, the lavas are usually fresh, aphyric, buff or brownish, fine-grained, with a compact, non-fissile texture. Vesicles are commonly large, ovoid, with smooth walls, and are concentrated near the base of the flows, where they are often filled with calcite.

In thin section, these lavas are seen to consist largely of feldspar, and colourless augite and magnetite, and are quite fresh. Both trachytic and mugearitic types occur.

(d) The olivine-augite-phyric unit is also of very limited distribution, and is laterally equivalent to lavas in the upper part of the microphyric unit, see Fig. 26. It overlies the mugearite unit in squares 7055 and 7054 and occurs as two small outliers at 693547 and 703552. To the south and north of its outcrop, it is overlain by later trachytes, and eastwards by the Tumungir Basalt. It is thought, however, to be older than the Tirioko Basalts between Kamungechot and the edge of the Ribkwo complex flank deposits.

It is lithologically distinctive in hand specimen in that it contains abundant olivine and augite phenocrysts. The groundmass is black and fine-grained, and only sparsely vesicular.

Lavas within this unit are exceptionally prone to alteration, and are altered to a thick bole where they outcrop from beneath the Kafkandal and Kamungechot trachyte complexes, e.g. at 709553 and 704544. At the latter locality, the basalts are reduced to a reddish-violet earthy material in which remain fresh augite phenocrysts.

(e) Basalts younger than the olivine-augite-phyric unit. This covers all the basalts older than the Tumungir Basalts, between Kamungechot, Tuntulyon and the western limits of the Ribkwo Volcanic Complex. They occur as far north as the southern limits of the Kafkandal complex, but their southern limit is not precisely known, where they become indistinguishable from the Tumungir Basalt.

They are lithologically similar to basalts in the microphyric unit, including both porphyritic and non-porphyritic types. In thin section, both intergranular and ophitic texture is recognized. As in the microphyric unit, plagioclase-phyric lavas are rare.

Post Tirioko Basalts Events

After the eruption of the Tirioko Basalts, there was an extended period of erosion and faulting, so that the trachytic volcanoes of the Kiddeh Group overlie the basalts unconformably. Reddened weathered zones are preserved beneath the trachytic complexes at Chepkoi, Kamungechot and Kafkandal, where they are developed on aphyric, olivine-augite-phyric and plagioclase-phyric basalts respectively. Thick red boles are also preserved on top of the basalts at several localities up to 3 miles (5 km.) west and northwest of Akoret. These occur at 3 different levels, and indicate successive rejuvenation of the local drainage.

Faulting also occurred during this quiescent period, so that both the Ribkwo and the Kafkandal complexes were erupted against fault scarps. The Chepkoi fault throws eastwards about 700 ft. (215 m.) at 1°15'N. This fault is well exposed in 3 dimensions in the Kamosing valley, but is not exposed in the Chemukol valley. Fig. 29 is a section through Chepkoi. The trachytes of the Ribkwo complex are not affected by the fault.

North of 1°19'N, the Ribkwo Complex is affected by faults with throws of less than 150 ft. (46 m.), which are in line with the Chepkoi fault, and are considered to be its northward extension.

Another concealed fault trending north-south is suspected at about 36°03'E. This is the Chemartos Fault, named after some hills beneath which it is inferred to pass.

If the eastward dipping sub-Ribkwo surface on the downthrow side of the Chepkoi fault is extrapolated eastwards, it would occur at about 2,000 ft. O.D. at 36°03'E. At this longitude, however, there are several inliers at approximately 3,000 ft. O.D., of what are considered to be Tirioko Basalts, at 718449, 720459, and in the Chemukol valley in squares 7148 and 7248, see Fig. 30.

It is possible therefore that there is a fault, with a throw of about 1,000 ft. (305 m.) to the west, along 36°03'E. However, its calculated magnitude depends on inferences as to the downward slope of the sub-Ribkwo surface east of the Chepkoi Fault. In the Kamosing River, this is about 10°, but if it flattens out eastwards, the difference in the theoretical and the actual elevations of the surface at 36°03'E becomes less, and could be entirely erosional, and not

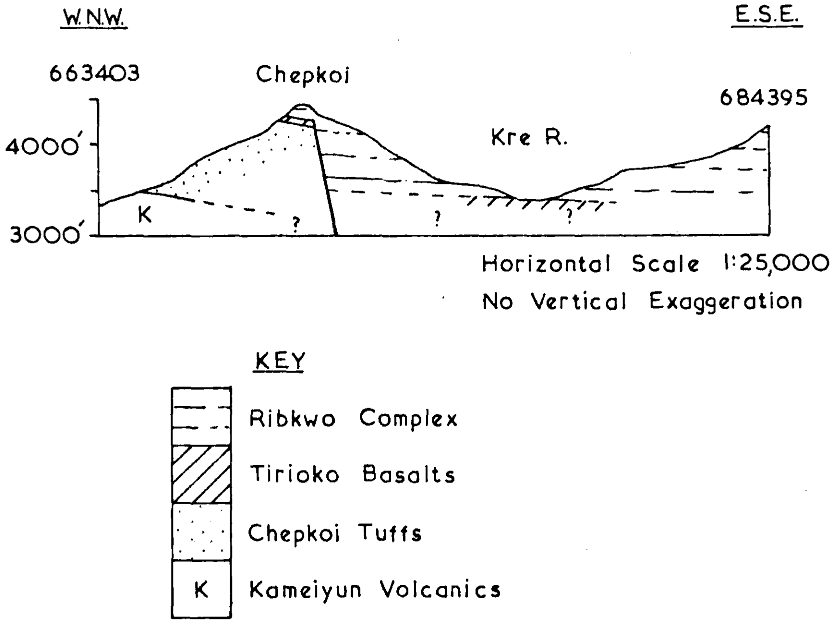


FIG. 29 Section showing Chepkoi Fault.

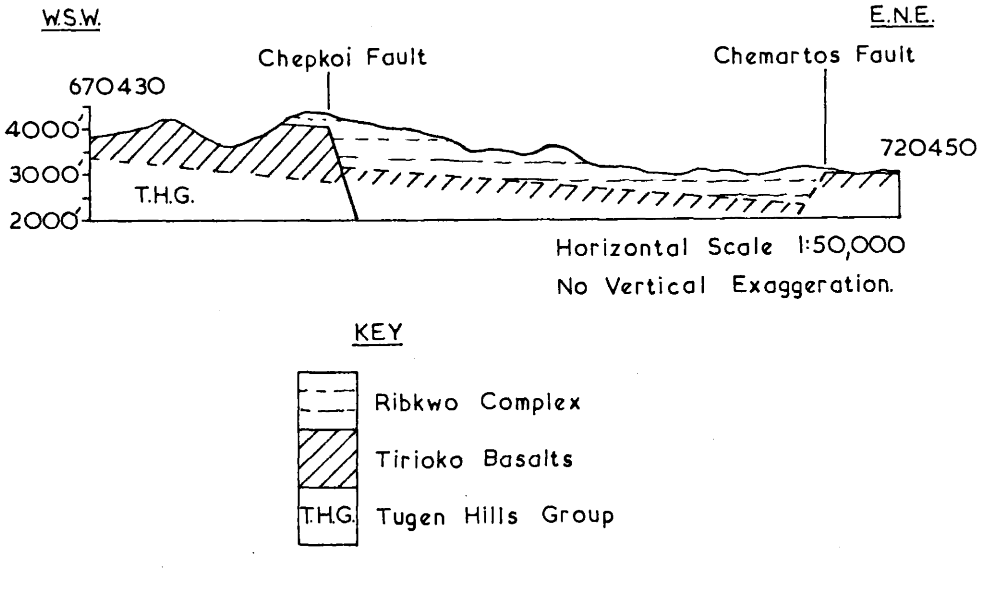


FIG. 30 Section showing Chepkoi and Chemartos Faults.

fault controlled.

The Ka'at Fault displaces the Tirioko Basalts beneath the extreme western edge of the Kafkandal Complex. It trends about N10°E, and is thought to extend as far south as 1°24'N, where dyke intrusion and alteration of the basalts have taken place along it. At 1°26'N, it brings plagioclase-phyric basalts into contact with older basalts of the microphyric unit. The fault scarp produced by it must have been somewhat eroded by the time the Kafkandal complex was being formed, since at 671604, a trachyte flow crosses the line of the fault without being displaced at its top or its base. A $\frac{1}{2}$ mile (0.8 km.) to the north, the locally oldest trachytes flowed southeastwards over a fairly degraded fault scarp, at 672613. As with the Chepkoi Fault, the Ka'at Fault does not displace the lavas of the trachytic complex overlying it.

Fig. 31 is a map of the top surface of the Tirioko Basalts.

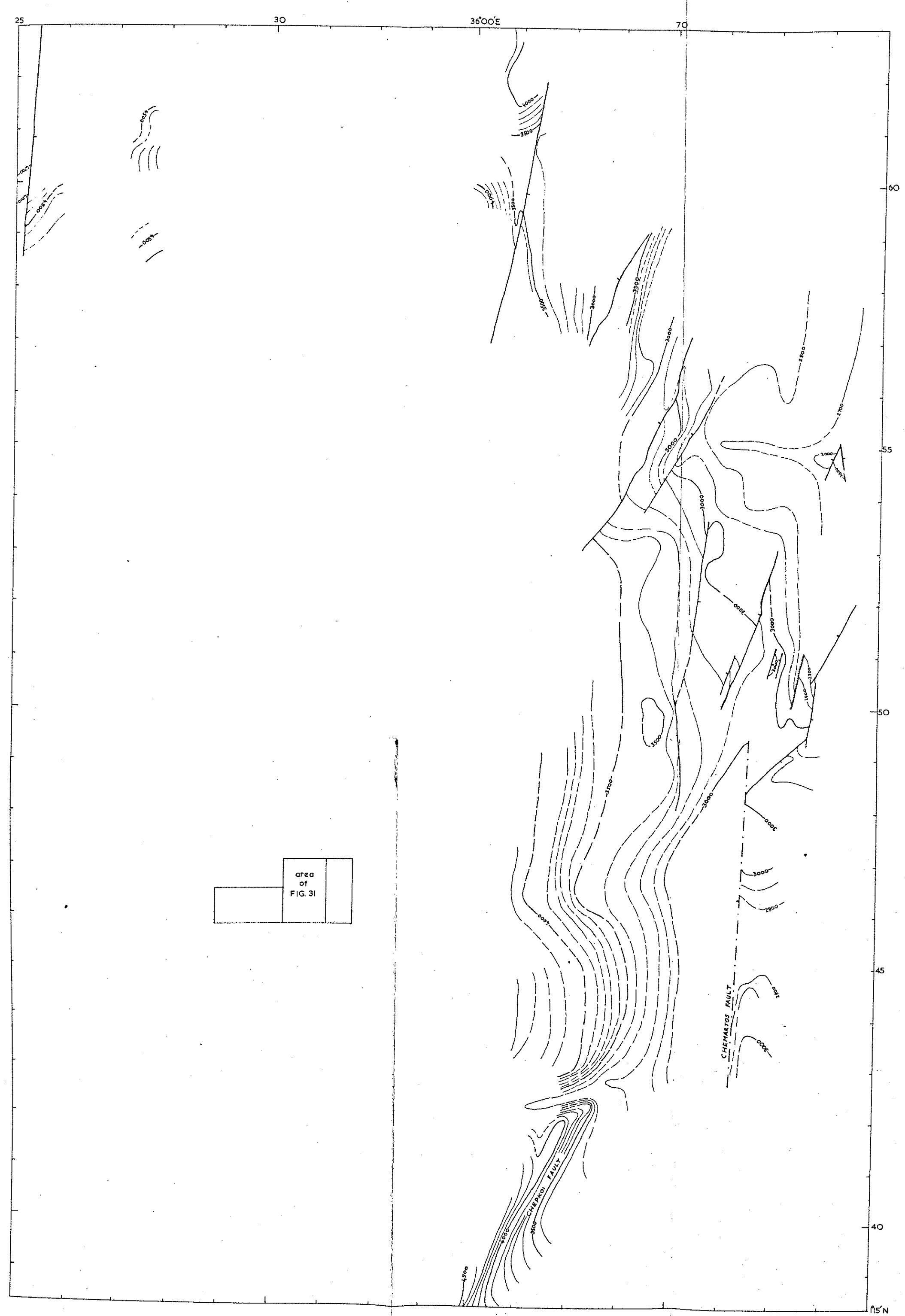
C4. THE KIDDEH GROUP

Introduction

This comprises, in the author's area, several different trachytic complexes. The Ribkwo, Nasaken and Kafkandal Complexes are recognizeable as volcanoes, while the Mugor Trachytes are essentially coalescences of fissure eruptions.

Outside the author's area, trachytic complexes laterally equivalent to the Kiddeh Group occur as far north as 2°N, and as far south as 0°10'N. South of 1°5'N, the complexes are discontinuous and widely separated, but north of this they increase in number, overlapping and interdigitating. Lateral relationships are sometimes obscure, and unconformable contacts may become conformable laterally.

The Kafkandal complex started erupting c. 5.8 m.y. ago, the oldest date being 5.9 ± 0.3 m.y. (Weaver, Ph.D. thesis in preparation). The



Horizontal Scale 1:50,000

FIG. 31 Contoured map of base of Kiddeh Group.

youngest date in the author's area, for the whole group, is 2.6 ± 0.2 m.y., from a specimen in the Nasaken Volcanics. The Oliyamur Volcano, in Rhemtulla's area, see Fig. 1, is younger than this, and is the youngest known complex in the Group or its equivalents.

The lateral relationships between the various complexes within the group are summarized in Fig. 32.

1. The Mugor Trachytes

This formation is about 200 ft. (61 m.) thick, consists of disconnected outcrops of trachyte flows, and includes associated dykes. It occurs in the northwest of the area, and probably thickens in that direction. The trachytes are gently arched about a north-south axis at 35°56'E, so that in the east of their outcrop they dip northeastwards, but dip northwestwards on the western edge of the present area. This arch is in line with the Kewarr Horst, and is probably associated with the Tiati Monocline (see p. 94).

Eastwards, the Mugor Trachytes are indistinguishable from the lower trachytes of the Kafkandal Complex, lithologically or structurally and are thus inferred to be similar in age. The thick trachyte on Kogh Pa Meyos (square 3359) is in structural continuity with the Kafkandal Complex.

Associated with the Mugor Trachytes is a linear swarm of trachyte dykes, trending slightly west of north, and extending from Chesitoi to Mugor.

The majority of the trachytes are feldspar-phyric and fissile in hand specimen, and are usually silvery or greyish. Specimen 5/248 contains quartz as either a late stage primary or secondary mineral. Specimen 5/302 from Kogh Pa Meyos contains pseudonephelines, and sodalite is recorded from 5/325. The majority of the specimens, however, contain neither quartz nor feldspathoid.

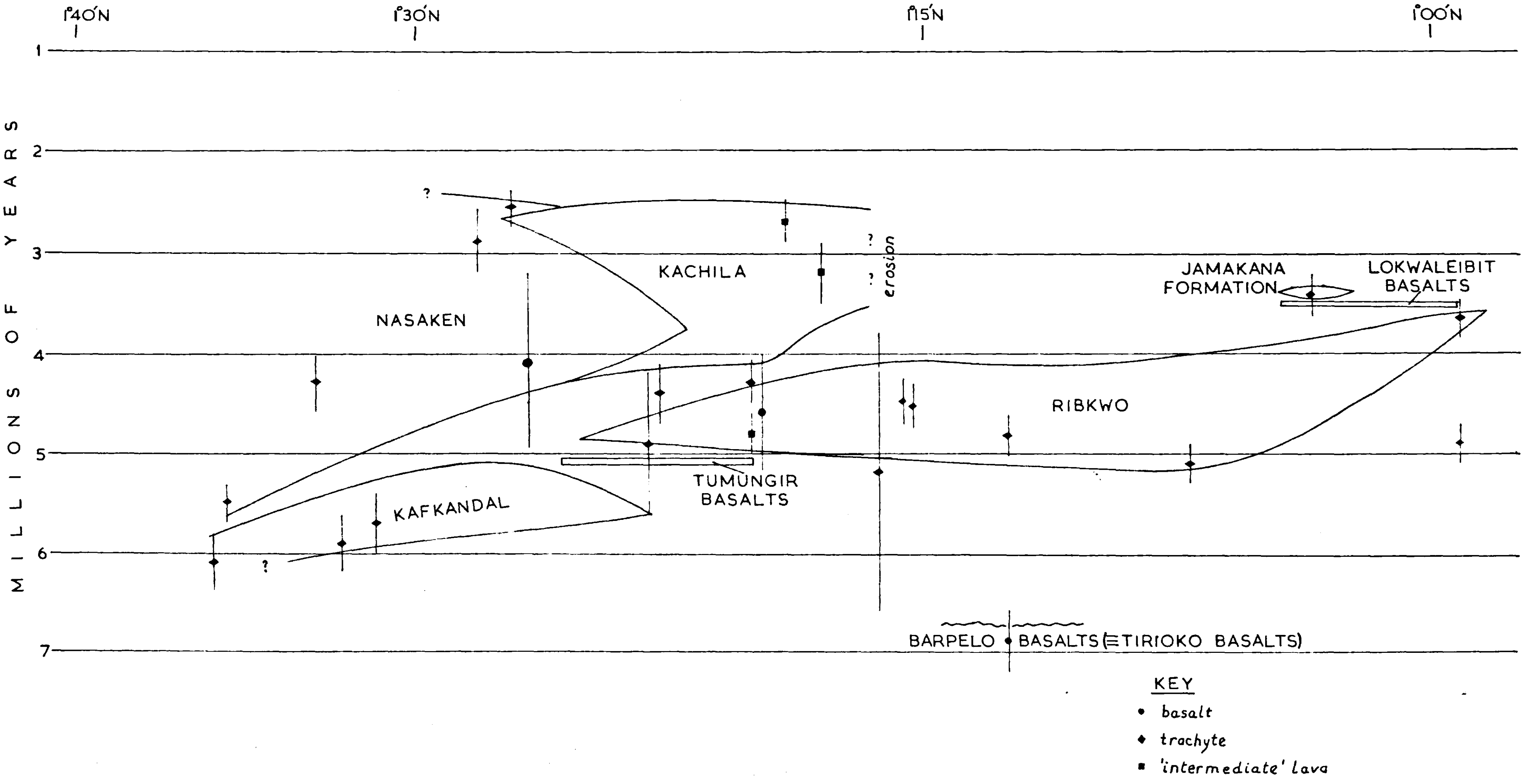


FIG.32 Age relationships among complexes in the Kiddeh Group.

In thin section, the feldspar phenocrysts are seen to be mainly sanidine, as are the groundmass feldspars. The principal mafics are aegirine and both blue and brown pleochroic amphiboles. Phenocrysts of pale green diopsidic augite are occasionally present.

Alteration does not greatly affect the trachytes, although in some cases the mafics are replaced by a brownish ferruginous material, and there is a little zeolite in the groundmass.

Pyroclastics are absent except for a thick silvery or whitish agglomerate beneath the trachyte at Mugor itself. This consists mainly of whitish or silvery comminuted trachytic material in which are large blocks of trachyte and basalt xenoliths near the base.

2. Kafkandal Volcanic Complex

This is the oldest of the recognizeable volcanoes in the Kiddeh Group. Its present outcrop is approximately circular, roughly 5 miles (8 km.) in diameter, but the original size must have been much greater, since erosion has cut back the flanks on the east, south and west sides. To the north, the flanks are concealed by younger rocks of the Nasaken Complex.

The Kafkandal Complex in the present area consists of two units, the Ngapawoi unit, and the Epong unit, which overlies the former unconformably. In Weaver's area, the even younger Moru Angitak unit passes conformably up into rocks of the Nasaken Complex. About 2,000 feet (610 m.) of volcanics are present in the entire complex.

The trachytes generally are not feldspathoid bearing, although pseudonephelines are present in lava at the base of the complex. Quartz is present in trachytes higher in the complex, and throughout much of the Nasaken Complex (Weaver, op.cit.), where feldspathoids are absent. Pyroclastics are abundant, especially in the Epong unit, and include lapilli tuffs and welded tuffs.

(a) The Ngapawoi Unit

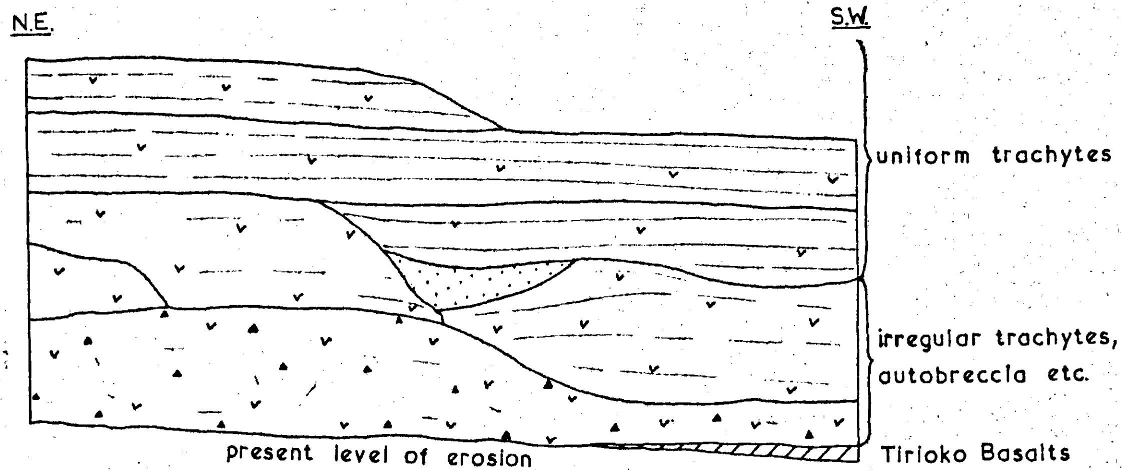
This unit outcrops over the southern and western parts of the complex, in the present area. The eruptions were initially from dispersed centres. Higher in the unit, eruption was from fissures, so that a broad, low angle shield was formed.

The early centres are exposed at the base of the complex, in the cliff-like sections on the south and west sides of the complex. Associated with these centres are thick, short fissile trachyte flows, and block flows. Intercalations of pumice tuffs occur, and irregular intrusive masses of trachyte. One such centre is exposed in square 6662, in the west-facing cliffs which mark the present edge of the complex, and another at 695589, in a river section. At both these localities, the earlier trachytes are overlain by younger flows erupted from fissures, Fig. 33.

In the southwest part of the complex, the later Ngapawoi trachytes directly overlie the Tirioko Basalts, so that there are no irregular central type eruptives beneath the uniform lavas, Fig. 34.

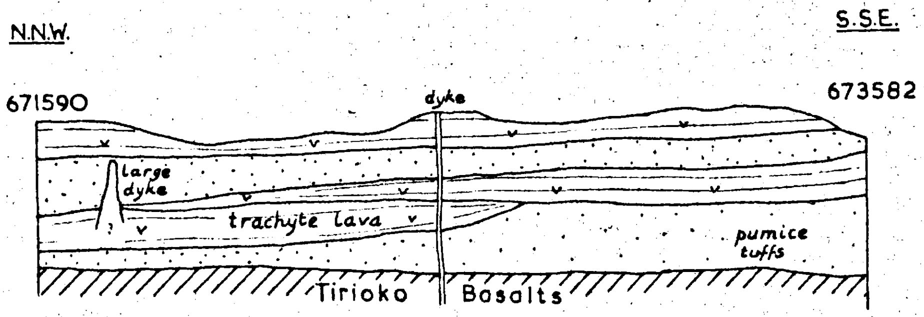
Structurally, the Ngapawoi unit represents a large shield-like volcano, with approximately radially outward dips, Plate X, that has been tilted eastwards by 8°-9°. The steepest dips in the unit are accordingly in the southeastern corner, where trachytes dip about 20°-25° east to southeast. Erosion has largely removed the western flanks of the volcano, so that only a small part of the present outcrop still dips to the west or northwest. Fig. 35 compares the present day structure with the inferred original form, after reversing the eastward tilt.

The lavas in the Ngapawoi unit are all trachytes, phonolites and basalts being absent. Feldspathoid, replaced by brownish zeolite (?) is present only in 5/250. Quartz is present in a few lavas as a



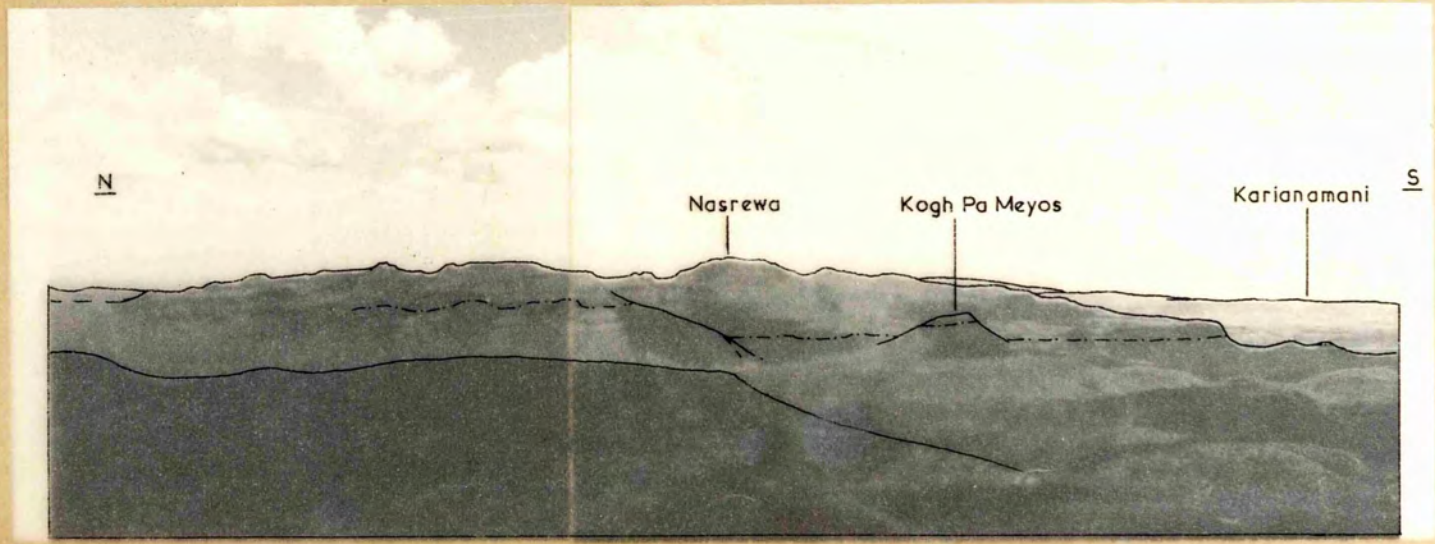
Length of section c.1000'
Approximately true vertical scale

FIG. 33 The Ngapawoi unit at 695590, from a field sketch.



Length of section 3,000'.
Vertical Exaggeration c.X2

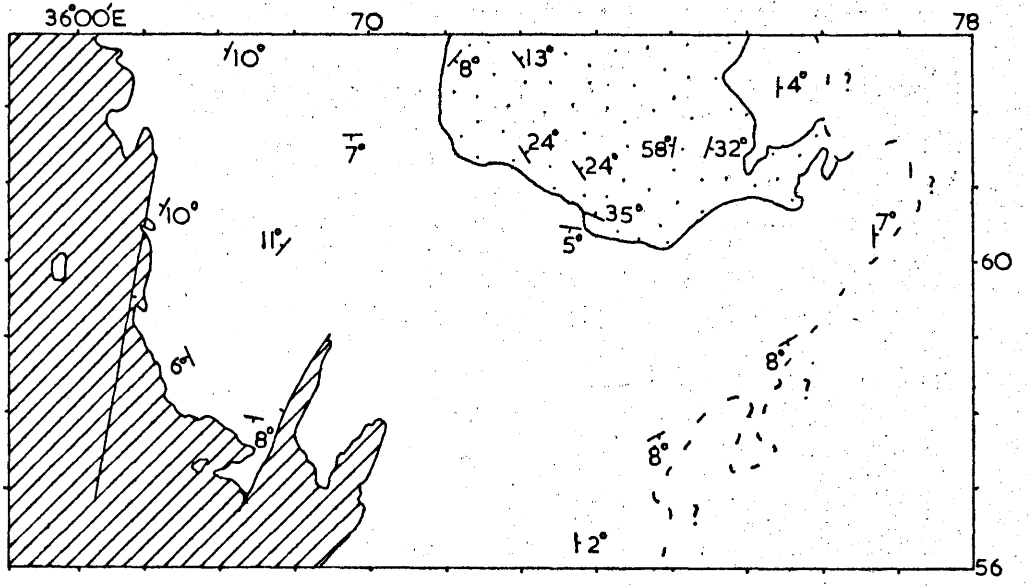
FIG. 34 Ngapawoi unit, southwest Kafkandal, from a field sketch.



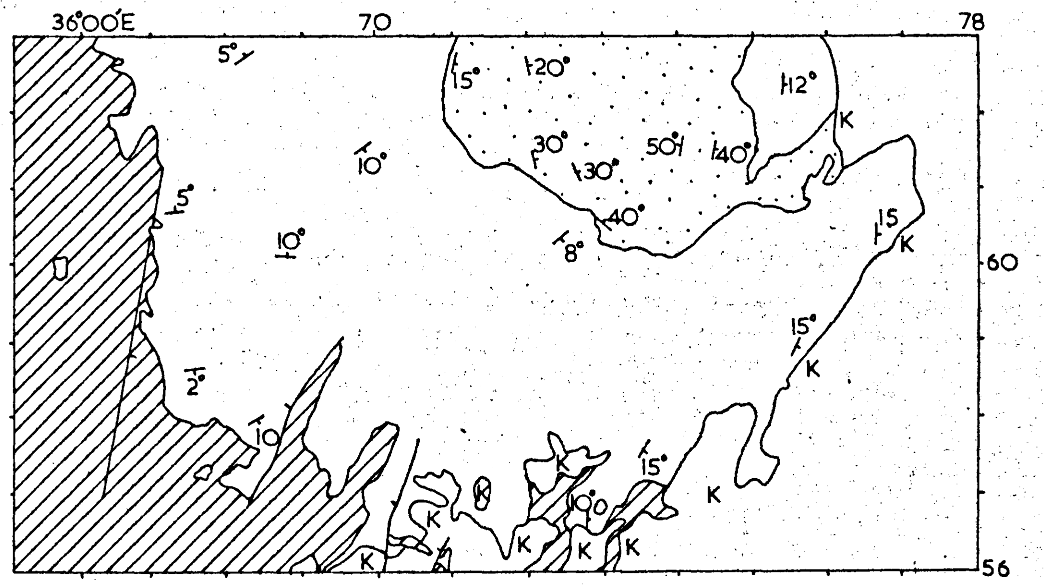
—·—·—· Contact between Kafkandal Complex and Tirioko Basalts.

PLATE X Kafkandal from Mugor.

PLATE X Kafkandal from Mugor.



a. before tilting



b. present day structure

Horizontal scale 1:100,000

KEY

K Post-Kafkandal Complex volcanics

∴ Epong unit } Kafkandal Complex

☐ Ngapawoi unit } Kafkandal Complex

▨ Tirioko Basalts

FIG.35 Effects of eastward tilting on Kafkandal Complex.

secondary or late-stage primary mineral.

Most of the trachytes are fissile, but in some, the groundmass feldspars do not show taxitic texture. The lavas are usually porphyritic, commonly feldspar-phyric, but fayalite (?), diopsidic augite and an unidentified yellow mineral also occur as phenocrysts. Alkaline amphiboles and aegirine are common as mafic minerals. The trachytes occasionally have glassy bands and streaks (5/252), parallel to the planar flow structure.

Pyroclastics are mainly restricted to pumice tuffs, containing abundant feldspar and occasional diopsidic augite fragments, altered trachytic lapilli, and comminuted ash and pumice, rarely undevitrified. Welded tuffs are only occasionally present.

(b) The Epong Unit

This unconformably overlies the Ngapawoi unit. The contact between the two is more or less circular in the author's area, but its continuation into Weaver's area is obscured by volcanics of the Nasaken Complex, Fig. 36.

The form of the visible portion of the unit, the high proportion of pyroclastics within it, and its steeply inward dipping western and southern margins indicate that it is probably a crater, the formation of which led to the evisceration of the Ngapawoi shield.

The walls of the crater are steeply inclined inwards on the western and southern margins of the unit. The pyroclastics dip inwards at up to 40°. In the eastern part of its outcrop, the Epong unit overlies a trachyte mass which is inferred to belong to the Ngapawoi unit. This is apparently not the eastern margin of the crater, as the tuffs only dip at a low angle to the west, consistent with a position more or less in the centre of the crater. The inferred extent of the unit beneath the Nasaken volcanics is shown in Fig. 36.

The proportion of pyroclastics in the unit is high. The commonest rock type is a white pumice lapilli-tuff, frequently containing abundant fragments of feldspar. Welded tuffs, commonly less than 15 ft. (4.5 m.) thick are also present. Trachyte lavas are present, particularly in the upper part of the unit, overlying the pyroclastics.

In the western part of the outcrop of the unit, the earliest deposits are white and yellow pumice tuffs, overlain by several flows of trachyte. These flowed eastwards over the steep western margin of the crater, presumably from a source outside of it, and interdigitate with the pyroclastics in it, Fig. 37. Within the crater, an early cone with outward dips is seen in a stream section in square 7461 buried by the pyroclastics, Fig. 37.

The trachyte lavas erupted on to the pyroclastics have since been affected by small landslips and superficial faults.

3. The Kamungechot Volcanics

This is a small outcrop of trachytic lavas and tuffs about 2 miles (3 km.) south of Kafkandal, overlying the Tirioko Basalts, and overlain by the Tumungir Basalt. It is not recognizeable as a centre, and was probably formerly continuous with the Kafkandal Complex. The two outcrops are in fact almost connected via the outcrops of trachyte at 708561, 708558 and 708551. These three outcrops are all seen to overlie the Tirioko Basalts, either the olivine-augite-phyric or the leucocratic member.

The Kamungechot Volcanics are probably not more than 200 ft. (61 m.) thick. They are principally trachytes, but thin welded tuffs and lapilli-tuffs are also present. Specimen 5/287 has sparse sanidine phenocrysts and abundant small yellow phenocrysts, similar to lavas from the Ngapawoi unit of the Kafkandal Complex.

There are two trachyte bodies at 708540 and 709538, that dip at

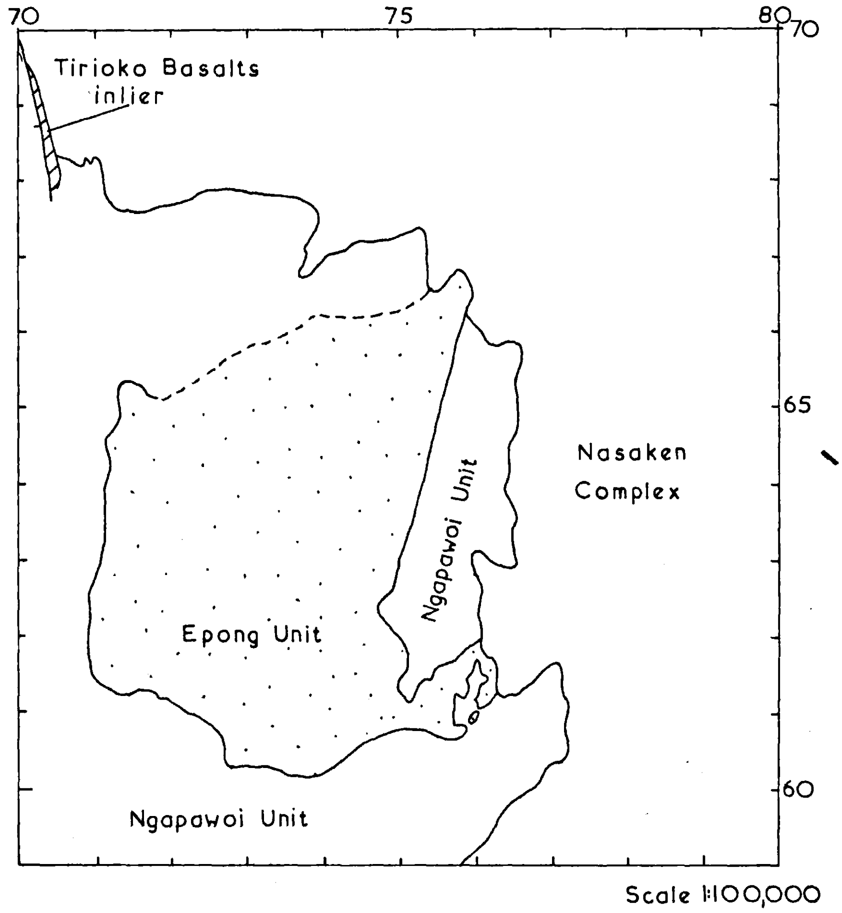


FIG.36 The Epong unit.

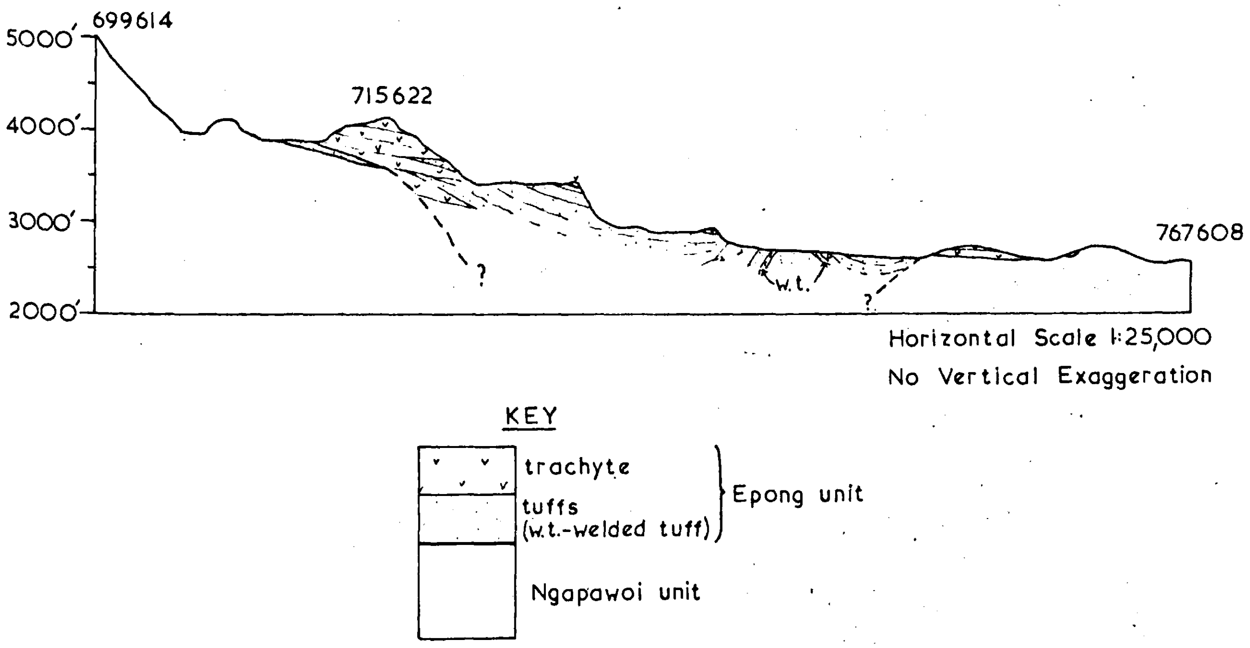


FIG. 37 Section across Epong unit.

60° southeastwards. Their northwest contact is marked by reddening of the basalts, but not the southeast contact. It is not certain whether they are dykes related to the Kamungechot Volcanics, or whether they are steeply inclined trachyte flows in the Tirioko Basalts. The latter alternative appears more likely.

4. The Tumungir Basalts

These were first distinguished on the southern edge of Kafkandal, where they rest upon the eroded flanks of that complex. Southwards, they overlie the trachytic volcanics at Kamungechot, overstepping these to rest discordantly on Tirioko Basalts, with a weathered surface between the two. Three flows are distinguishable on Tumungir - Kongo. The lower flow has moderately abundant olivine phenocrysts, while the upper two flows are not very porphyritic. They are each only about 15 ft. (4.5 m.) thick, and dip very gently eastnortheastwards. The lavas are black, non-vesicular, and fresh and unaltered.

South of the Chepsawach River, some of the Tumungir Basalts are olivine-phyric, but are mainly aphyric, and it appears that only the upper flows are present. South of $1^{\circ}22'$N, possibly two flows are present, and it is not entirely certain how far east these extend, beneath the Ribkwo Complex.

The Ribkwo Complex is younger than the Tumungir Basalts, this relationship being seen in the northern end of Tuntulyon, Fig. 38.

At 691519, the Tumungir Basalts are distinguished from the Tirioko Basalts by the steeper dip of the latter. Further south, the difference in dip is not so obvious. Nevertheless, the Tumungir Basalts are thought to be still present, represented probably by a single flow. Fig. 39 shows the interpretation of the section in squares 6850 and 6849.

At 683487, there is a poor exposure of trachyte which is thought

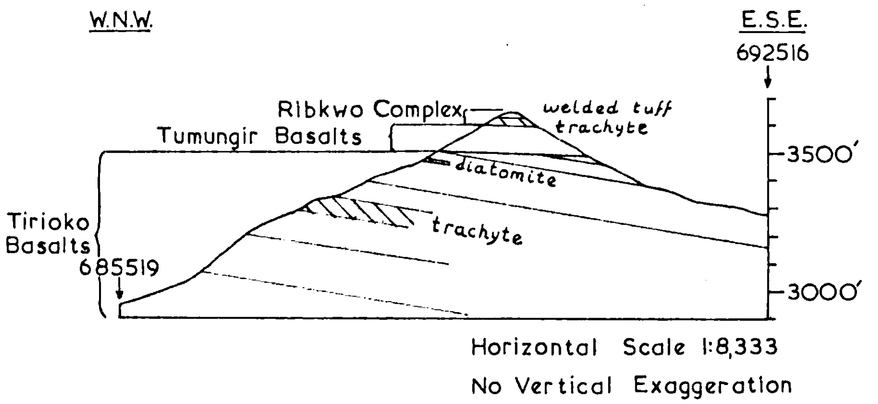


FIG. 38 Section at Tuntulyon.

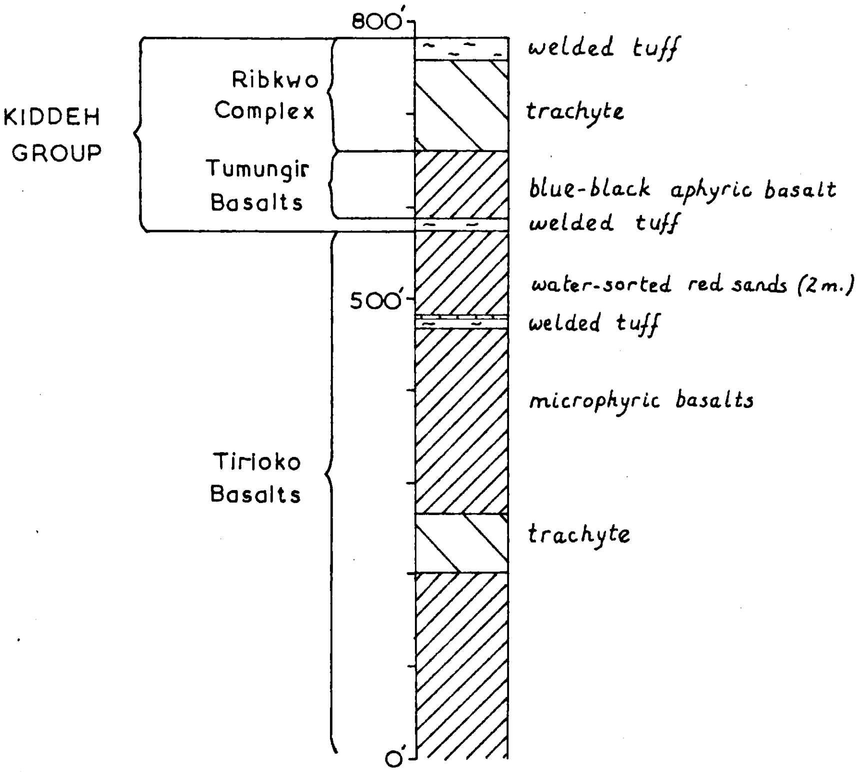


FIG. 39 Interpretation of succession between 673503 and 683493.

to be beneath the Tumungir Basalts, and to overlie the Tirioko Basalts, and thus to be of the same age as the welded tuff at 683501, and the same age therefore as the Kafkandal Complex and Kamungechot Volcanics.

Eastwards the extent of the Tumungir Basalts is difficult to assess.

They are present immediately south of Kafkandal as far east as 36°04'E, at 732567. South of this locality, they are apparently absent, and the basalts beneath the welded tuff of the Ribkwo Complex between squares 7252 and 7254 belong to the Tirioko Basalts. South of square 7252, olivine basalts appear within the basal flows of the Ribkwo Complex, further complicating the relations.

Apart from the three lava flows within this formation, there is a limited outcrop of pyroclastics on Tumungir Udei. At 691561, a grey tuff 5 ft. (1.5 m.) thick, welded in its central portion, occurs beneath the basalt. At 700558, an agglomeratic horizon 15 ft. (4.5 m.) thick occurs, containing spindle bombs and scoria in a crudely stratified matrix. It forms a distinct feature, continuous over half a mile (0.8 km.).

5. The Ribkwo Volcanic Complex

Introduction

This is a large trachytic shield volcano, at least 2,500 ft. (760 m.) thick, of approximately elliptical form. It measures at the present day about 30 miles (48 km.) by 10 miles (16 km.), being elongated in the north-south direction. Erosion has reduced its extent on the western and eastern sides, but the complex retains very nearly its original extent on the southern and northern flanks.

The lavas are mainly trachytes, but mugearites and occasional olivine basalts are also present. Pyroclastics are abundant, and include welded tuffs.

Stratigraphy

The structures of the complex change greatly from the central zone into the flanks, making precise correlation difficult among the various eruptive units.

Nearly all of the central zone is contained in McClenaghan's area. Within this zone, he recognizes 13 central units (RBC_1 - RBC_{13}) of mainly irregular form, and often of no great lateral extent. The adjoining flank zone is then subdivided into 7 units, generally stratiform, and often of considerable lateral extent. McClenaghan equates the central and plateau units as shown in Fig. 40.

The correlation between these and the present writer's 4 units is also shown. Before considering the history of the complex in the present area, mention will be made of the structure of the complex as a whole.

Two principal parts are recognized: the central zone and the flank zone.

The central zone is almost entirely confined to McClenaghan's area. It consists of a series of tuffs and trachytes of generally irregular form. Welded tuffs are uncommon. Trachyte lavas appear to have been fairly viscous at the time of emplacement. The pyroclastics are mainly white or cream coloured pumice tuffs. Dykes, plugs and less regular intrusive bodies are common.

The flank zone is characterized by regularly stratified deposits, Plate XI, erupted both from sources associated with the central zone and from dykes occurring on the immediately adjacent flanks. The frequency of dykes decreases systematically away from the central zone.

Within the central zone in contrast to the flanks, faulting is either absent or not recognizeable. In the present area, the faults are all normal faults trending northnortheast, reflecting the regional trend of the rift as a whole.

McCLENAGHAN's AREA		PRESENT AREA
Plateau units	Central units	KARIAMANGRO UNIT
VII		
	13 12	LOKITET UNIT
		tilting
VI V IV III		KABLATON UNIT Includes RBP_{II} & RBC_{11}
II	11	
I	10 9 8 7 6 5 4 3	RIBKWO MAIN SHIELD Includes RBP_{I} RBC_{1} & RBC_{8}
	2 1	

FIG. 40 Comparison of stratigraphy of Ribkwo Complex in McClenaghan's and present areas.

PLATE XI Ribkwo Complex northern flanks, from 717606.

Generally, it seems that the central and flank zones were formed by simultaneous eruptions, but of a different nature and environment.

The history of the complex in the present area will be dealt with in the following order:

(f) Kariamangro Caldera
(e) Lokitet crater
(d) Tilting
(c) Kablaton unit
(b) Ribkwo main shield
(a) Nature of sub-Ribkwo surface.

Fig. 41 illustrates the general disposition of each of the major units. and the extent to which erosion has modified the complex.

(a) Nature of sub-Ribkwo Surface

The surface on which the Ribkwo Complex rests is one of considerable relief, some of which is undoubtedly the effect of earlier and contemporary movements. Mention has already been made of the Chepkoi (p.47) and Chemartos (p.47) faults, and the inferred presence of the trough between the two. There is evidence of erosion and dissection of these fault scarps before the eruption of the Ribkwo Volcano. At 672422, there is a small outcrop of fissile sodalite-phonolitic trachyte, at 3,300 ft. O.D. The trachytes north and south of this are at 4,000 ft. - 4,200 ft. O.D., implying the presence of a river valley about 800 ft. (245 m.) deep, traversing the Chepkoi fault scarp.

The cross sections, Fig. 42, indicate the differences in form of the sub-Ribkwo surface, from north to south.

The erosion which affected the Tirioko Basalts also affected the Kafkandal Complex, so that the northernmost welded tuffs of the Ribkwo Complex rest on a pediment cut back into the southern flanks of Kafkandal, see Fig. 43 and Plate XII.

It is worth noting that this pediment was formed before the

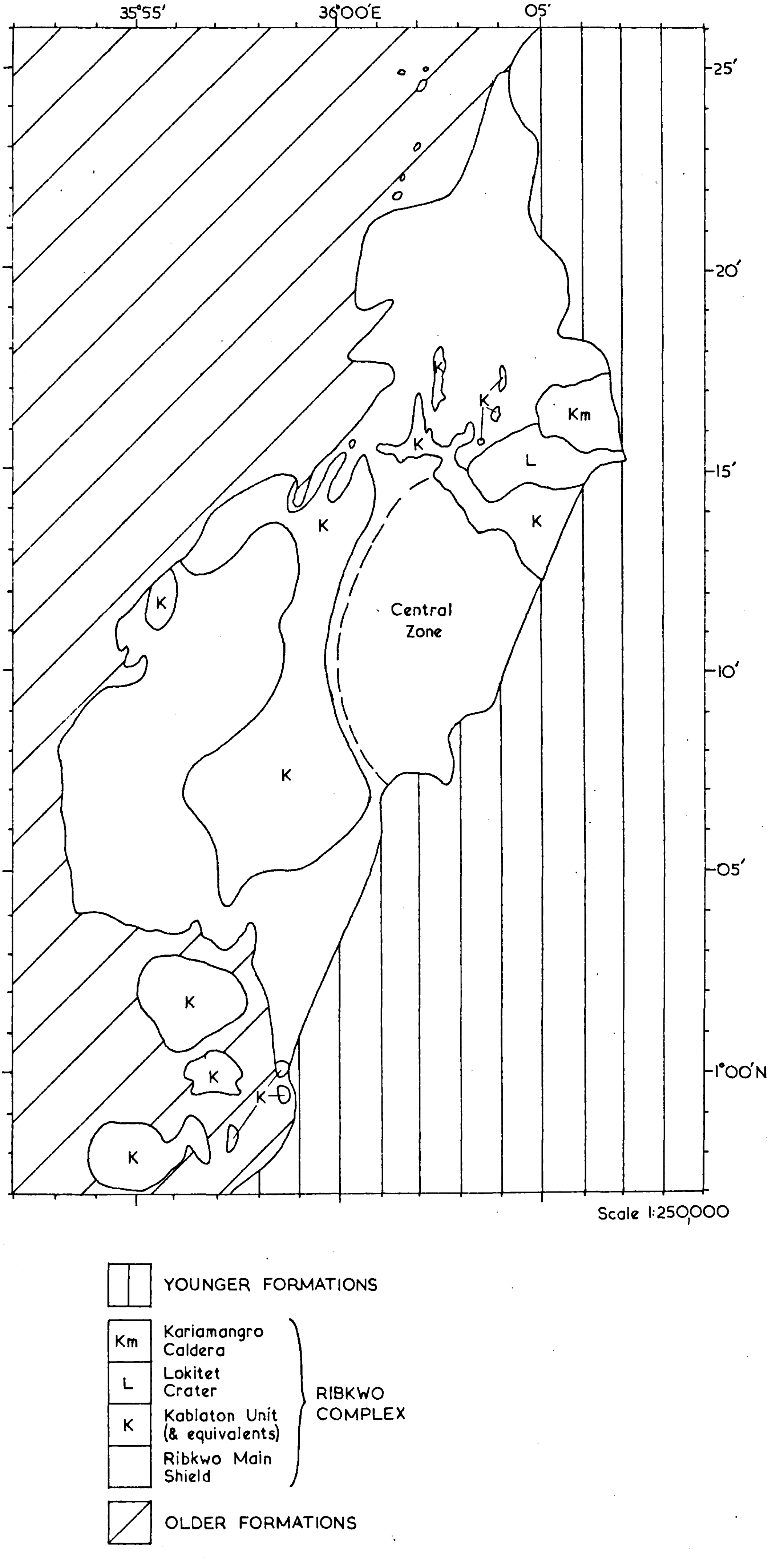


FIG. 41 The Ribkwo Complex

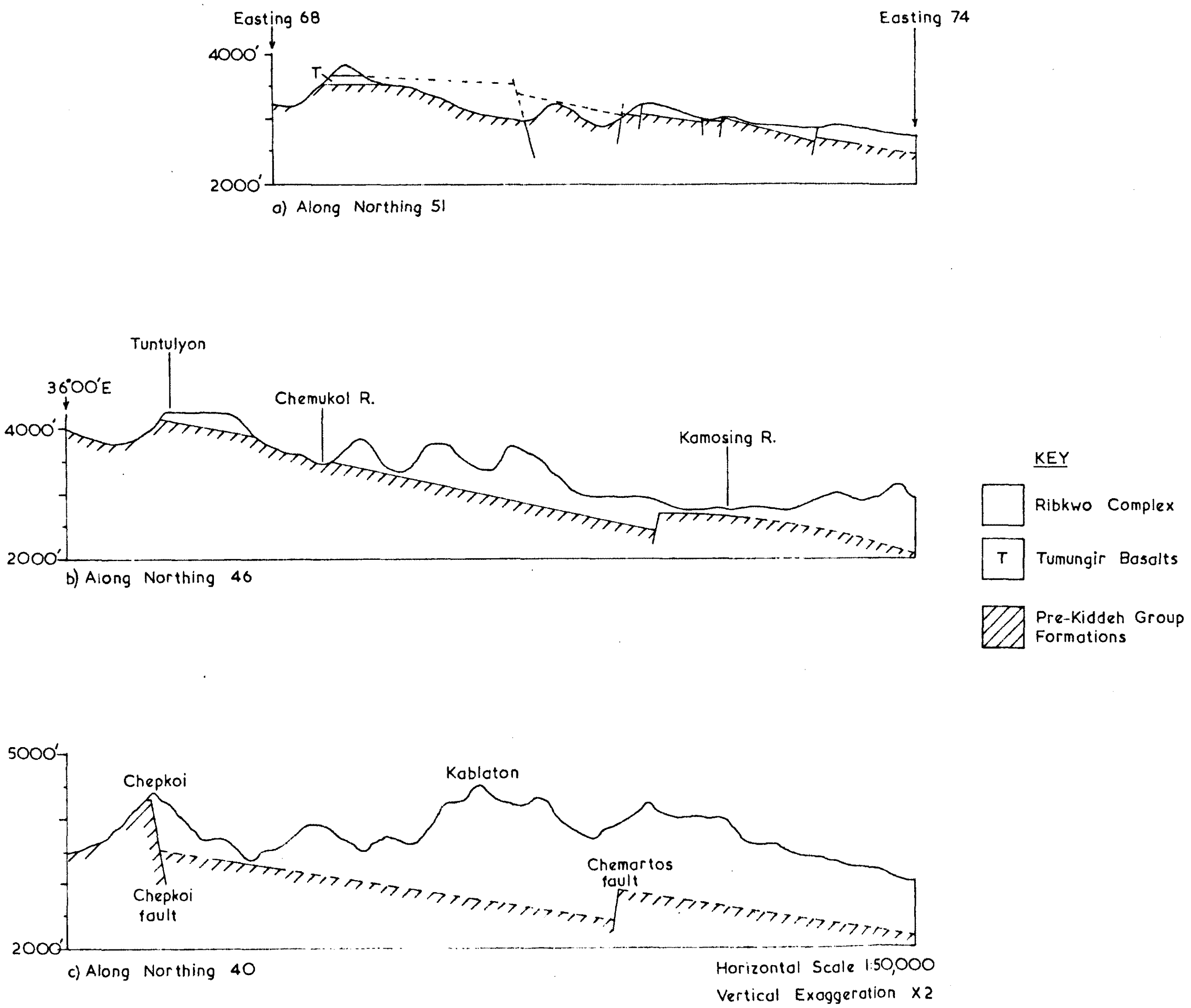


FIG. 42 The sub-Ribkwo Complex surface.

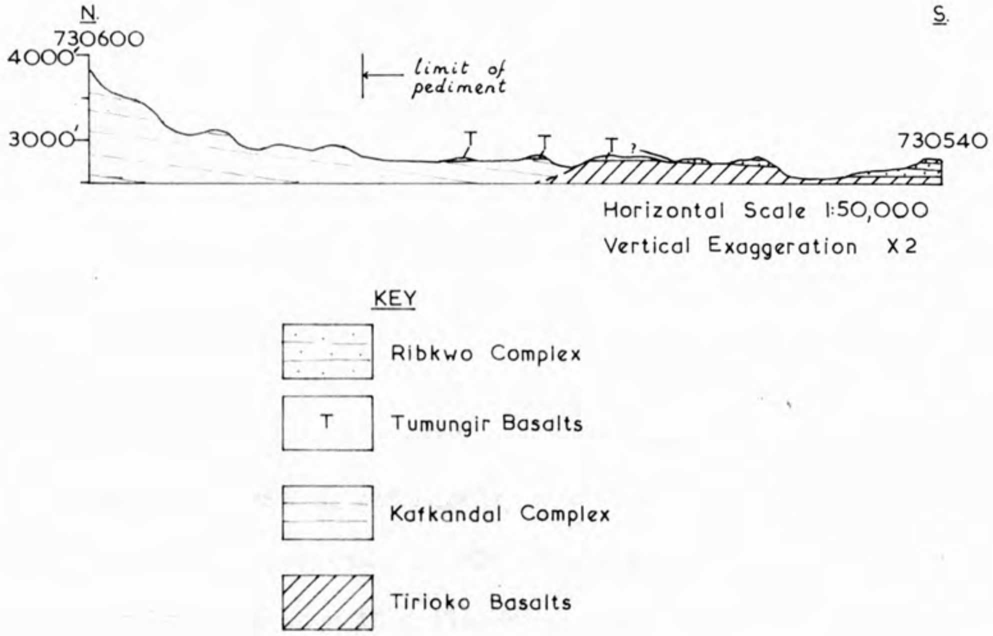


FIG. 43 Sub-Ribkwo surface at northern limit of Ribkwo Complex.

PLATE XII Kafkandal from the south.

eruption of the Tumungir Basalt, which was closely followed by the earliest phases in the build-up of the Ribkwo Complex.

(b) Ribkwo main shield

This is essentially a very low angle stratovolcano. It is composed principally of flow banded and fissile slightly undersaturated trachytes. Pyroclastics are abundant, including lapilli-tuffs, finer-grained tuffs, and welded tuffs. Olivine basalts and mugearites are present in small amount, principally near the base of the unit.

Each lithosome is generally tabular in form, but air fall tuffs may show irregularities when they blanket earlier topographies.

Correlation from one part of the flank zone to another is hindered by the fact that around square 7250, the Tirioko Basalts, Tumungir Basalts, and basalt lavas low in the Ribkwo Complex are in direct contact with each other, so cannot be separately distinguished. Thus is it by no means certain where the true base of the complex actually occurs in that area. Neverthess, Fig. 44, a reproduction of part of the main map of the area on a scale of 1:25,000, represents the most likely model.

The earliest eruptions were those west of the Chemartos fault, and consist mainly of trachytes with intercalated tuffs and at least 3 olivine basalt lavas, exposed in the Chemukol River. A sequence thought to be similar in age occurs in square 7250, and consists of a basal tuff, overlain by two basalts with an intercalated trachyte.

These trachyte/basalt eruptions were followed up by trachyte/tuff eruptions, quite conformably west of the Chemartos fault, but with a slight unconformity east of it, detectable at 725508, see Fig. 45.

Similar relations are seen south of the Chemukol River. The successions either side of the unnamed stream at 718478 are different. Fig. 46 shows these successions, and the proposed interpretation.

FIG.44 Part of the northern flanks of Ribkwo Volcano.

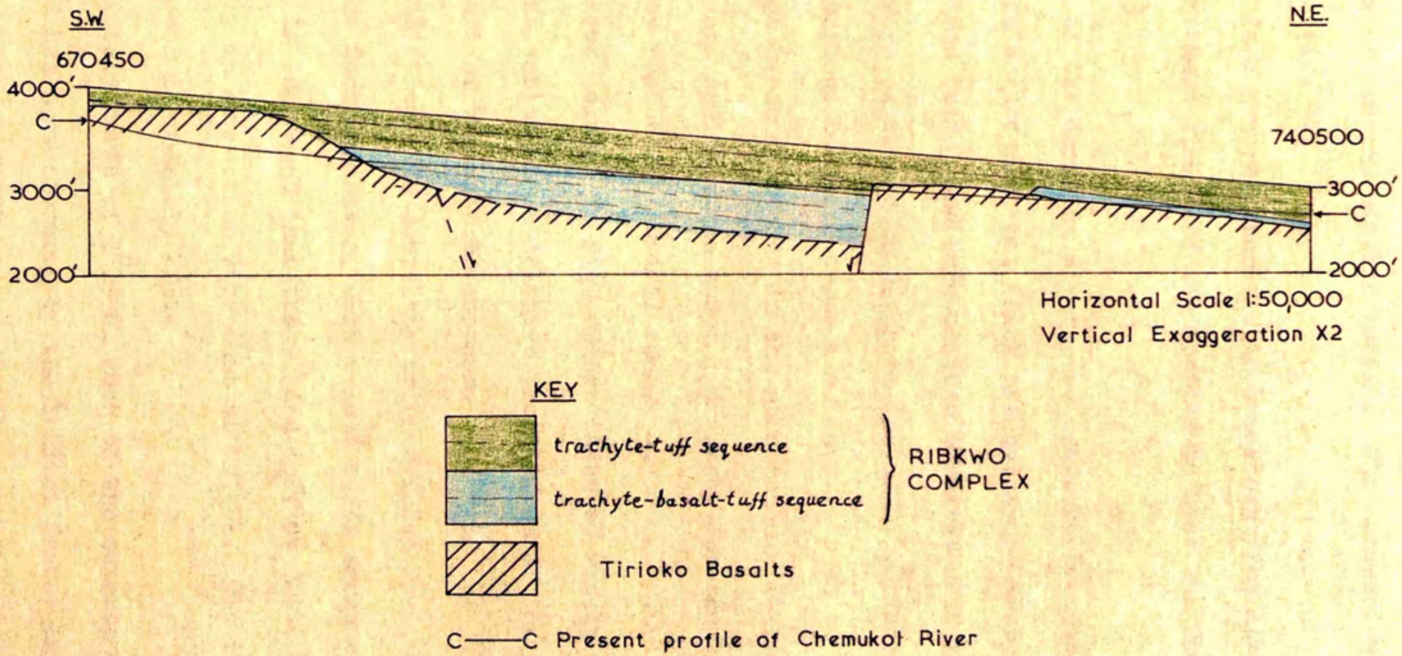


FIG.45 Schematic section along Chemukol valley.

The discontinuity between the trachyte/basalt/tuff sequence and the trachyte/tuff sequence in Fig. 46 is the same as that in Fig. 45.

The youngest rocks in the Ribkwo main shield north of the Chemukol River are those in the hill Cherelgat (square 7349) in which is a single flow of aphyric olivine basalt. The succession at Cherelgat is shown in Fig. 47.

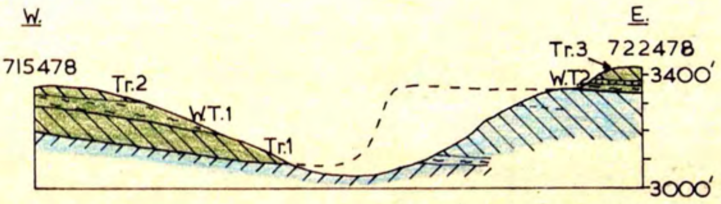
There is a general increase in thickness from north to south, from the northern limits of the complex to near the Chemukol River, see Fig. 48.

South of the Kamosing River, the sequence becomes much thicker. Pumice tuffs are scarce, but thick trachytes are present, with intercalated welded tuffs, and rare olivine basalts. The trachyte flows are not always expressed as separate features, but are distinguishable by the occurrence of scoriaceous flow tops. South of $1^{\circ}18'$N, block lavas or autobreccias appear in the succession. It is inferred that their presence reflects the general tendency for the lavas to increase in viscosity nearer the central zone.

The three columns in Fig. 49 are taken at widely spaced intervals, and show the variation in relative proportions of the major rock types from one part of the unit to another.

It is difficult to correlate units WT1,2,3 etc., established north of the Chemukol River, with welded tuffs south of the Kamosing River. It is suggested that the welded tuff at 722468, probably WT2, was formerly in connection with that at 723451. The thick welded tuff at 734462 is possibly WT3.

Immediately north of $1^{\circ}15'$N, much of the outcrop of the Ribkwo main shield has been obscured by the Lokitet Crater unit. McClenaghan's units RBC_1, RBC_8, and RBP_I are traceable into the present area, although the present writer failed to find any significant break between RBC_1 and RBP_I. RBC_8 is a crystal tuff, rich in sanidine crystals. This is



Horizontal Scale 1:8000
No vertical exaggeration

KEY (also Figs. 47 & 48)

▧ trachyte

▨ basalt

⁘ pumice tuff

┄ welded tuff

(Colours, see FIG. 45)

FIG. 46 Unconformity in lower part of Ribkwo flanks.

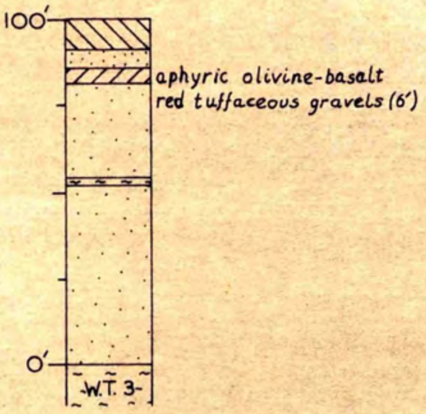
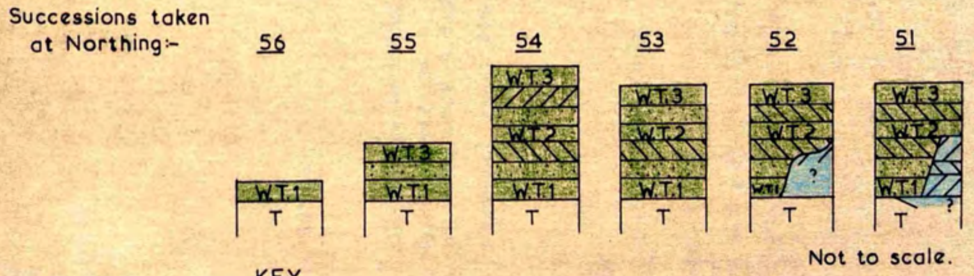


FIG. 47 Succession at Cherelgat.



KEY

Lithologies – See Fig.46

Colours – ——"——

T – Tirioko Basalts

FIG. 48 Successions taken at 1km. intervals, Ribkwo northern flanks.

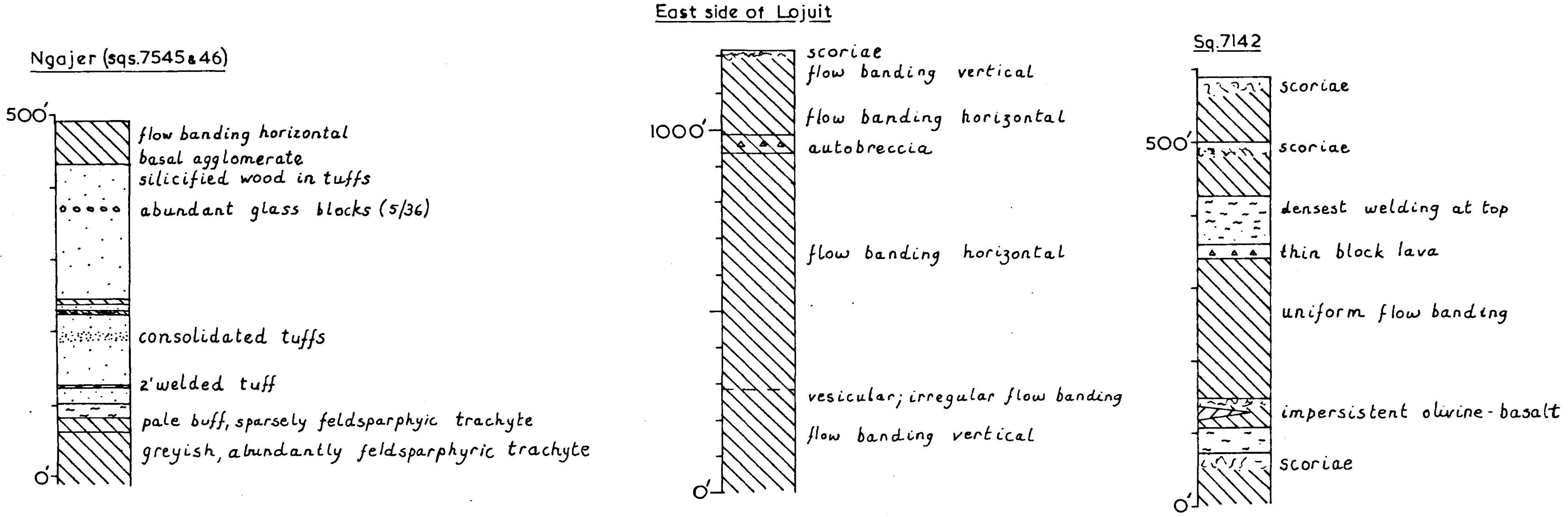


FIG. 49 Representative sections in the Ribkwo main shield unit. (Key, see Fig.46)

overlain by McClenaghan's units RBP_{II} and RBC_{11}, which are laterally equivalent, and together constitute the Kablaton unit in the present area.

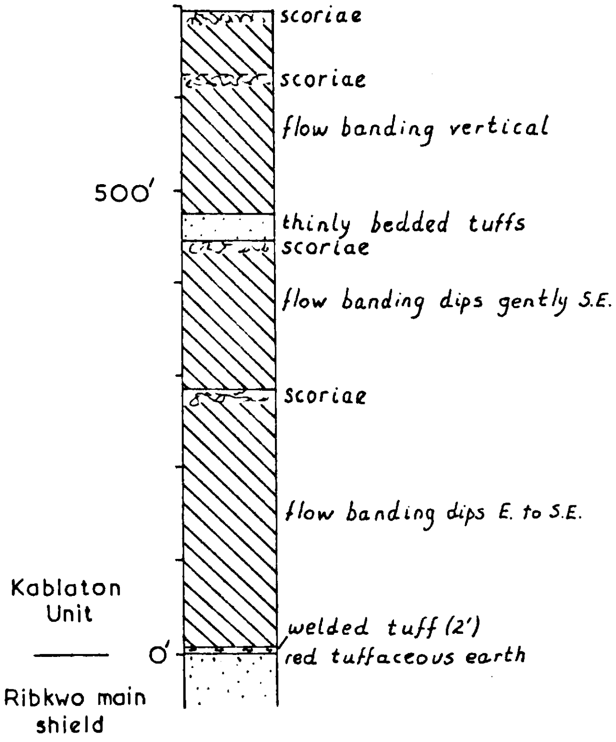
In McClenaghan's area, the upper surface of the main shield forms an eastward-dipping gently undulating plateau, often capped with a thick red sandy soil. North of $1^{\circ}15'$N, this plateau becomes increasingly dissected but is preserved again along the western outcrops of the complex at Chemirret and Tuntulyon. On Tuntulyon, pressure ridges on the trachyte flow in square 6748 can be seen, indicating derivation from the southeast.

(c) The Kablaton Unit

When the complex as a whole is viewed from high up on Kafkandal, it can be seen that the hills Kablaton, Nadangat and Lojuit project noticeably above the general level of the plateau referred to in the preceding paragraph. It is thus inferred that they constitute a unit younger than the main shield, conformable to it, but less extensive. There is no angular unconformity at the base of the unit, though 4 ft. (1.3 m.) of red sandy soils are present at 706402. Rootlets occur in a similar red bed at 726399. These red soils overlie a tuff, welded in parts, which locally appears to be the youngest representative of the main shield, and which is traceable beneath Nadangat, the north end of Lojuit, and the northern edge of Kablaton.

The Kablaton unit consists mainly of thick, tabular trachyte flows, see Fig. 50.

At 712393, trachytes are present overlying tuffs of unit RBC_8. South of this, at 713385, the trachyte is locally overlain by a welded tuff, pumice tuffs, and a further trachyte. The lowest trachyte at this locality oversteps the tuffs of RBC_8 at 709386 to rest unconformably on block lavas assigned to RBC_1.



Key–see Fig 46

FIG. 50 The Kablaton unit at Kablaton.

It is possible that the higher parts of this unit in Kablaton itself are lateral equivalents of McClenaghan's plateau units III and IV, but no direct connection is seen.

(d) Eastward tilting of the Ribkwo Complex

This is inferred to have taken place after the build-up of the main shield and Kablaton units, but before the formation of the Lokitet crater and Karisamangro caldera.

The trachytes on the western edge of the plateau in McClenaghan's area are thought to have been largely derived from centres to the east. The eastward dips of these plateau trachytes are thus inferred to be secondary.

Similarly, the trachyte in square 6748 on Tuntulyon in the present area dips gently eastnortheast, but it appears to have had its origin in the southeast. Its present attitude, and that of the plateau in McClenaghan's area, is satisfactorily explained if an eastward tilt of 5^{o}-6^{o} has been imparted to the complex.

An analysis of the drainage patterns developed on the complex also indicate an eastward tilt of this nature, see pp.105 to 106.

(e) Lokitet Crater Unit

This is a roughly circular, steep-sided depression, the rocks in which are composed mainly of pumice tuffs. Trachytes are present, and occasional welded tuffs, and the succession is at least 1,200 ft. (360 m.) thick.

The western wall of the crater is fairly well preserved. At 723385, pumice tuffs of unit RBC_{12} dip at up to 40^{o} off older trachytes. The wall is inclined inwards at about 70^{o}. Northwards, into the present area, it is not quite so steep, but tuffs of the Lokitet unit are steeply banked against older trachytes in the southeast corner of square 4340.

The northern wall has been eliminated by the formation of the Kariamangro caldera. The entire eastern half of the crater has been removed by erosion, but trachytes assigned by McClenaghan to unit RBC_{11} appear from beneath the crater deposits, and apparently represent the crater floor. Similar exposures of the crater floor occur at 740388 and at 745397.

The succession consists mainly of pumice tuffs. Fig. 51 is an illustrative section from Lokitet itself.

The trachyte and welded tuff horizons have suffered much landslipping, so that outliers of them occur at varying heights and attitudes, Plate XIII. At 772393 and 779389, trachytes have slipped off the pumice tuffs on to older trachytes outside the crater. It is thus inferred that this landslipping is of comparatively recent date, and was initiated by the removal of the softer tuffs subsequent to the erosion of the eastern side of the complex as a whole.

(f) Kariamangro Caldera

This unit of the Riblkwo Complex lies wholly within the present area. It is a roughly elliptical caldera, measuring 2½ miles (4 km.) on the north-south axis, and at least 2½ miles (4 km.), probably over 4 miles (6½ km.) on the east-west axis. The entire eastern side of the caldera is either covered by younger volcanics of the Nasaken Complex, or removed by erosion, Fig. 52.

(i) The Ring Fault

The bounding fault is well preserved along the southern edge of the caldera, where there is a zone of brecciation up to 100 ft. (31 m.) wide associated with it. It cuts across tuffs and trachytes of the Lokitet Crater unit, and also across even earlier trachytes, between 769395 and 781395. These earlier trachytes themselves include block-lavas and autobreccias which have been further fragmented by activity

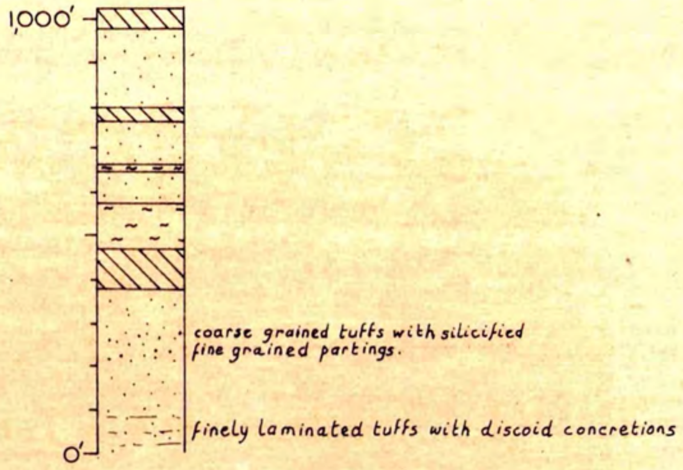


FIG. 51 Succession in Lokitet unit at Lokitet.

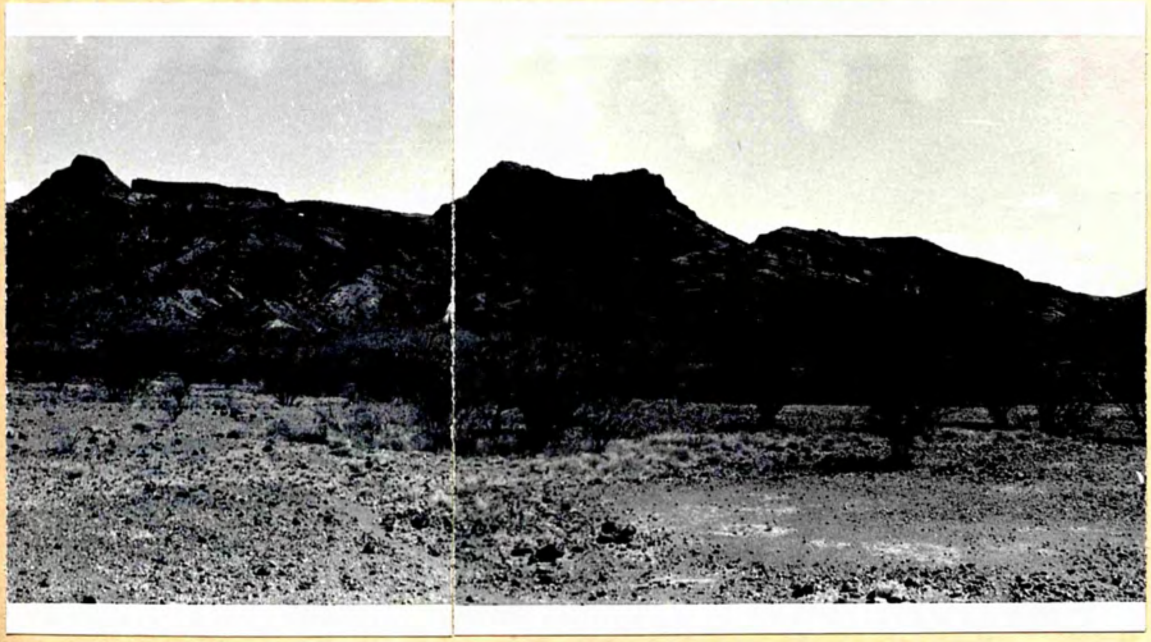


PLATE XIII Lokitet from the southeast.

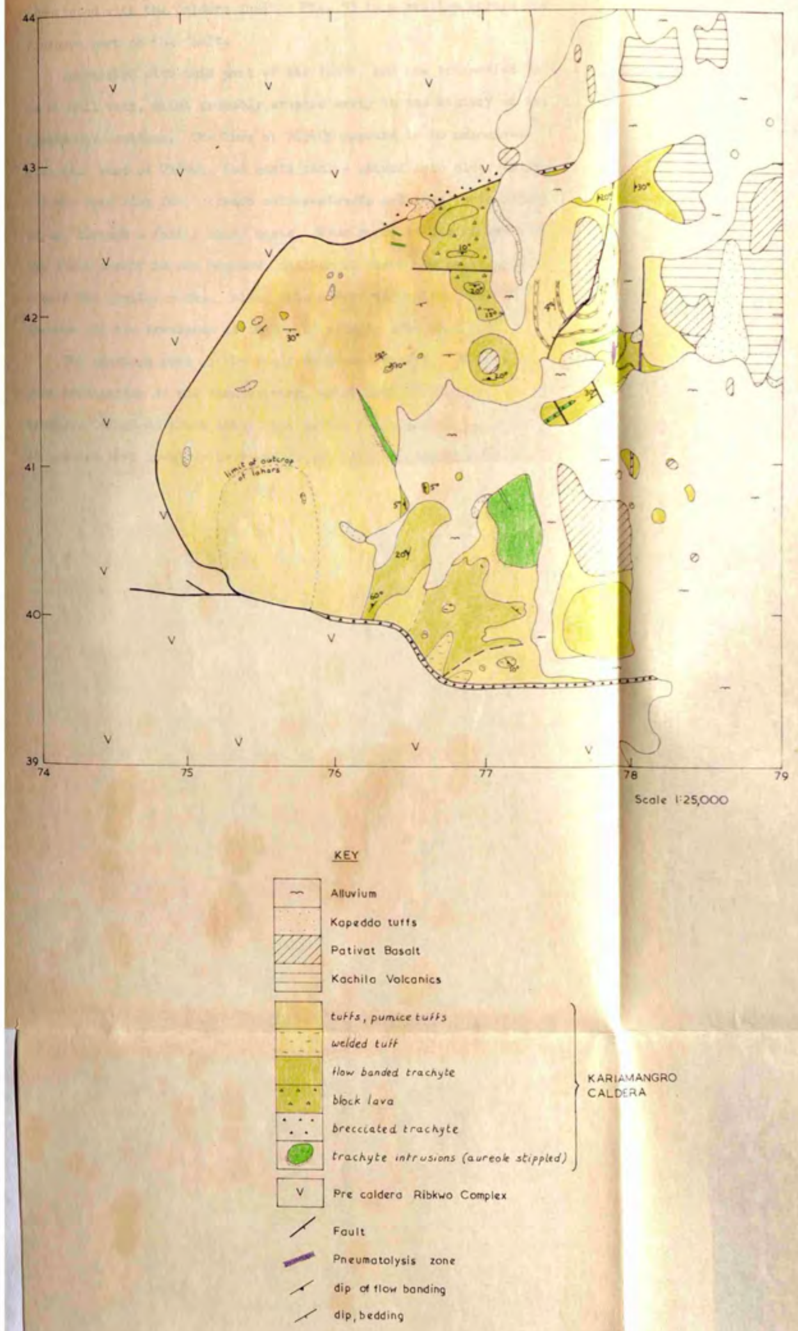


FIG.52 Kariamangro Caldera.

associated with the caldera fault. Fig. 53 is a section across the southern part of the fault.

Associated with this part of the fault, and now transected by it, is a small vent, which probably erupted early in the history of the Kariamangro caldera. The lava at 765405 appears to be associated with it. West of 752401, two small faults extend into older formations, but the main ring fault trends northwestwards and then northnorthwestwards, through a fairly sharp angle. From here, as far as about 758425, the fault itself is not exposed, neither is there any brecciation within the earlier rocks. Along this sector the caldera tuffs dip inwards off the trachytes at angles of usually less than 30°.

The northern part of the fault is quite complex. There is again much brecciation of the country rock, which locally consists of fissile trachyte lavas and block lavas, but little intrusion of new material. It appears that lava may have welled out from the fault or associated fissures since at 767424, block lavas overlie the caldera tuffs.

(ii) The Caldera Succession

This consists principally of pumice tuffs, with minor trachyte lavas and welded tuffs. Lahars occur in the southwest corner. Lavas are also present, confined almost wholly to the eastern half of the visible succession.

The floor of the caldera is not exposed in the west, but may be exposed beneath Pativat, where trachytes occur beneath gently westward-dipping tuffs.

In the west of its outcrop, the caldera succession consists principally of yellowish pumice tuffs, with subordinate welded tuffs. These dip radially inwards at up to 30°. Trachytes, intercalated in the succession, occur at 754418 and 757420.

In square 7540 three boulder-bearing horizons are intercalated

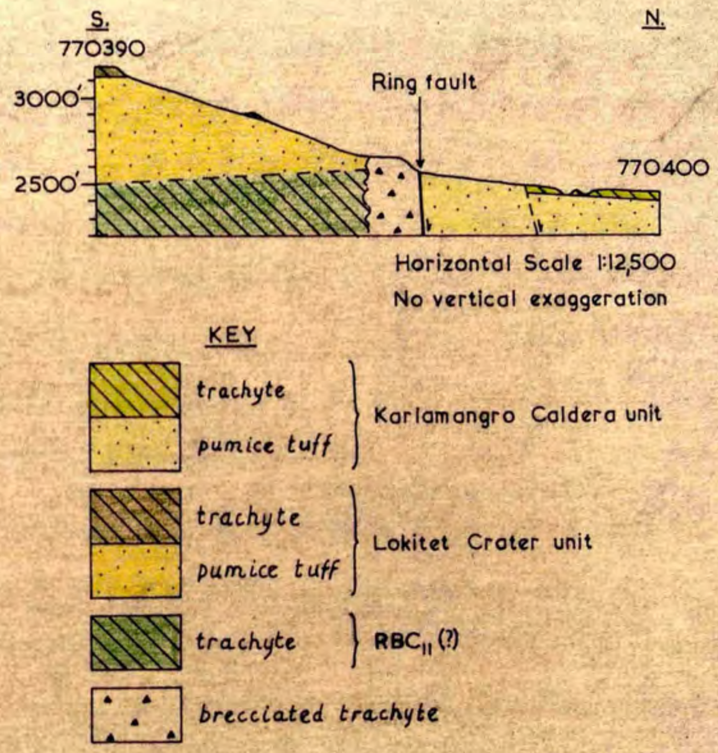


FIG. 53 Section across ring fault, Kariamangro caldera.

PLATE XIV. Lahar, Kariamangro caldera.

in the pumice tuffs. The highest and lowest are composed of angular to subangular blocks of trachyte and welded tuff up to 4 ft. (1.3 m.) wide in an illsorted matrix, Plate XIV. They are about 10 ft. (3 m.) thick, and have a surface area of about 0.9 square miles (c.2.3 sq.km.). They are considered to be lahars (Van Bemmelen, op.cit., p.191), and the large blocks of trachyte and welded tuff are thought to have been derived from the Lokitet crater succession. The formation of Kariamangro Caldera would provide the necessary conditions of instability, and a torrential rainstorm could trigger off the lahar, saturating the pumice tuffs with water, and rendering the thick trachyte and welded tuffs liable to collapse, as envisaged in Fig. 54.

This is comparable to the Sabinyo Boulder Deposit, on the flanks of Sabinyo volcano in Uganda (Combe & Simmons 1933, pp.35-39). Blocks in this consist of only one rock type but the authors consider that in view of its age relations with the surrounding volcanoes, it was produced when its parent volcano was already in a considerable state of dissection.

Contrasting with these two lahars, the middle boulder-bearing horizon is thought to be a ladu (Van Bemmelen, op.cit., p.191). It consists wholly of angular blocks of trachyte up to about 3 ft. (1 m.) across, in a poorly sorted groundmass composed principally of comminuted trachyte. This is interpreted as being the basal portion of an incandescent avalanche. Such deposits are formed when a viscous lava is erupted on to a fairly steep slope, so that during flowage, it breaks up, releasing gases and undergoing autobrecciation as it does so. If of sufficient size, such avalanches give rise to considerable clouds of dust and gas, which hover above the avalanche on its downward path. These are the "nuées ardentes d'avalanche" as opposed to "nuées ardentes d'explosion vulcaniennes" which originate from within the crater.

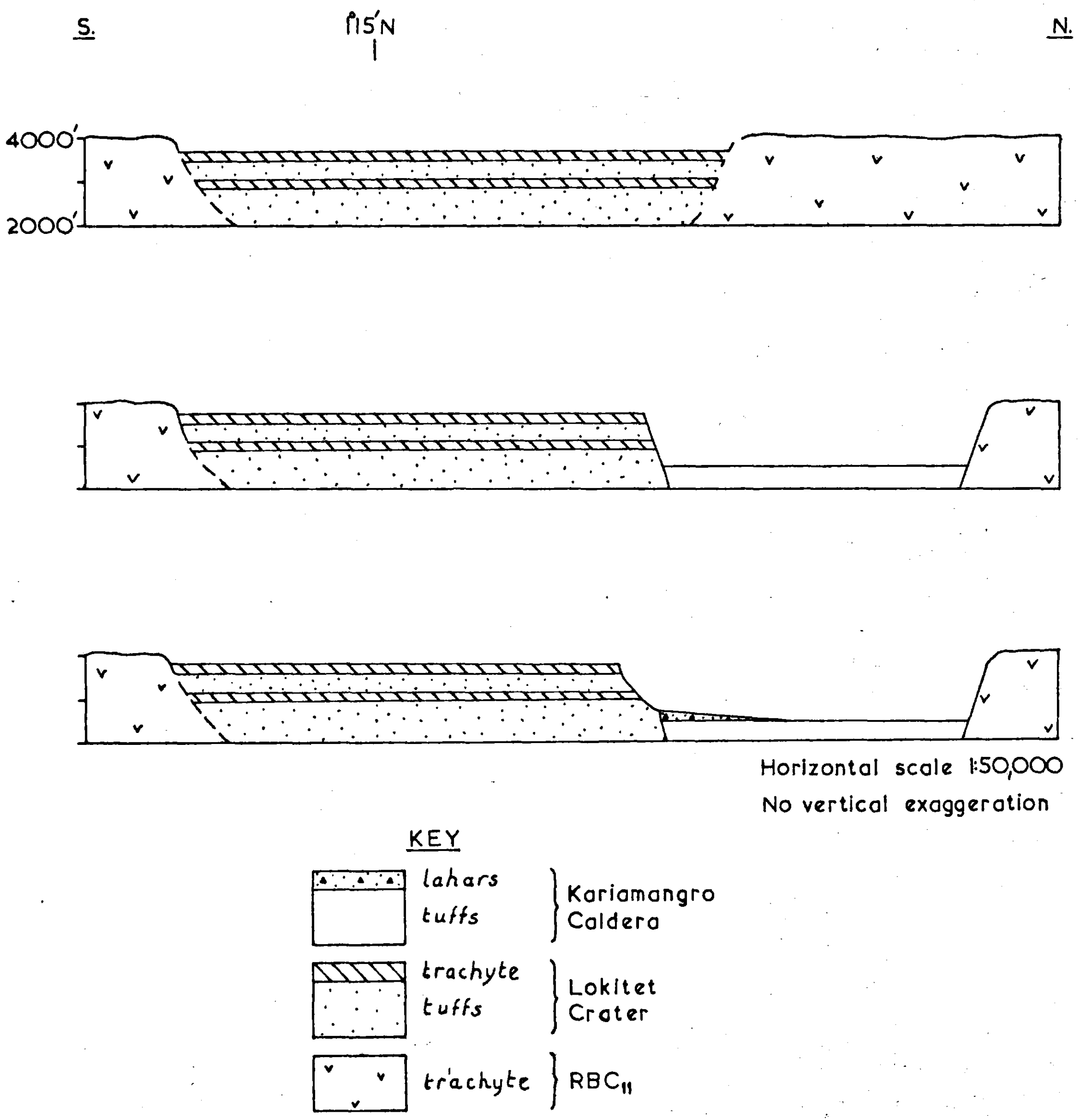


FIG. 54 Sections along Easting 755 to illustrate the supposed formation of lahars in Kariamangro Caldera.

These boulder horizons are overlain by yellow pumice tuffs with thin inextensive welded tuffs, and which contain abundant silicified wood around 757410.

Within these pumice tuffs are very fine-grained mudstone horizons, white or grey, very compact, and with thin gritty laminae. These are considered to be ash and fine-grained ejected material, deposited probably in a temporary lake. Such sediments are restricted in extent, but occur at 759401 and 762403, up to 4 ft. (1.3 m.) thick. Elsewhere, they occur as impersistent lenses.

Lavas are more abundant in the eastern half of the succession. The vent on the southern edge appears to have given rise to a flow in which welded tuff is present in the upper part, and trachyte in the lower. Such flows with mixed texture occur also around 726408, down to only 8 ft. (2.4 m.) thick, and indicate that the original eruption was a suspension of glassy droplets, which solidified partly in a vitreous state, and partly in a holocrystalline state.

Around 768426 are block lavas overlain by fissile trachytes. This assemblage overlies the caldera tuffs, and appears to have been erupted from the ring fault itself, at or near 769428, where there are thick accumulations of structureless trachytic breccia. The trachytes overlying the block lava dip southwards at low angles, and eventually overstep the block lavas to rest directly on pumice tuffs, in the hill Ngatute. Other outcrops of block lava and fissile trachyte occur in square 7741, south of Pativat, affected in part by the passage of volatiles, which have locally reduced the trachytes to a reddish, finer-grained secondary material.

In the southeast corner of the caldera, trachytes up to 60 ft. (18 m.) thick are exposed, associated with block lavas, welded tuffs and pumice tuffs.

(iii) Intrusions and related activity

Intrusions of trachyte are numerous, although none can be cited as definite sources of lava. A fairly large structureless plug of coarsely porphyritic trachyte occurs in square 7740, but most of the intrusive bodies are parallel and vertical sided dykes, rarely more than 15 ft. (4.6 m.) wide. These have no effects on the trachytes and pumice tuffs, but at 763412, the fine-grained sediments are baked to a porcellanous fine-grained off-white material, up to 10 ft. (3 m.) away from the dyke. Similarly, the pumice tuffs immediately west of the large intrusion noted above are partially indurated and noticeably reddened.

The related activity takes the form of fissures along which gases have been active, staining and sometimes destroying the bedding of the rocks through which they pass. No actual intrusion of magma seems to have taken place, however. This activity has occurred most noticeably in the pumice tuffs and sediments of the Lokitet unit, in zones up to 15 ft. (4.6 m.) wide, but usually less than 6 ft. (2 m.).

(iv) Structure of Kariamangro Caldera

It has already been stated (p.63) that the tuffs dip radially inwards, being almost horizontal in the central parts of the caldera. Beneath Pativat, the pumice tuffs and welded tuffs dip westwards at about 3^{o}-4^{o}, indicating that the lowest point of the caldera lay somewhat west of its inferred geometrical centre.

Further, the thickest accumulation of tuffs is in the southwest corner, where also occur the only lahars, indicating that subsidence was greatest in this sector. However, as nothing is known of the history of the eastern part of the caldera, these inferences cannot be substantiated.

Faulting has affected the caldera only slightly. The block lavas in the northern part have been affected by an east-west fault, along the plane of which there has been much hydrothermal activity, reducing the lavas to a soft yellowish powdery material. Faulting also affects the Pativat Basalts, and is thus considerably younger than the caldera.

Post- Ribkwo Complex, pre- Nasaken Complex erosion

The Ribkwo Complex is overlain unconformably by rocks of the Nasaken Complex and Kamosing Formation.

The early eruptions of the Nasaken and Ribkwo complexes were apparently roughly contemporaneous, as judged by similar dates of about 5.0 m.y. By the time the Nasaken volcanics had spread as far south as 1°25'N, the activity of Ribkwo Volcano had ceased. It had already undergone the eastward tilting and its flanks were being actively dissected, so that locally the earliest Nasaken volcanics rest on a topography of considerable relief.

The sub-Nasaken unconformity is largely visible east of Kafkandal, but east of the Ribkwo flanks, it is partly obscured by alluvial deposits of the Aterir River. The unconformity is visible beneath the Aterir beds, but is again obscured by the Kahanavisian Basalt.

South of 1°19'N, Nasaken volcanics are seen to overlie trachytes of the main Ribkwo shield, and also the Kariamangro Caldera succession. A date of 2.7 m.y. (± 0.2 m.y.) was obtained from the Nasaken volcanics east of Kariamangro Caldera. The latter has not been satisfactorily dated, but it is evident that the whole eastern side of the Ribkwo Complex was considerably eroded at 2.7 m.y.

The Nasaken Complex and Kachila Volcanics

These occupy most of the eastern margin of the area following a north-south trending belt from 1 to 4 miles wide. They are laterally equivalent, the Kachila Volcanics interdigitating with the Nasaken Complex.

The Nasaken Complex reaches its greatest development about 8 miles (13 km.) north of Kafkandal. The earliest eruptions took place about 5.0 million years ago. The southern flanks extend into the present area, and have been dated at about 2.8 m.y. at 1°28'N.

The Kachila Volcanics extend as far north as 1°27'N, where they are overlain and underlain by trachytes of the Nasaken Complex. They extend as far south as 1°17'N, reaching their greatest thickness of about 900 ft. (275 m.) midway between these two limits.

6. The Nasaken Complex

In the present area, this rests unconformably on older rocks of the Kafkandal Complex. Locally, the basal members are three flows of olivine-basalt, the Katirr basalts. These are considered by Weaver (op.cit.) to have flowed southwards from a source farther north of the present area. The basalts are overlain by a series of alternating fissile trachytes, in flows up to 60 ft. (19 m.) thick, and welded tuffs, with thin developments of pumice tuffs. This succession is less than 500 ft. (150 m.) thick.

A thin olivine basalt also occurs within the Nasaken Complex in square 8160, but is less than 20 ft. (6 m.) thick, and is of very limited extent.

Dips are generally eastwards at up to 6° or 7°, usually less. A very gentle southerly component, and the fact that the trachytes thin in that direction indicate that they were derived from the north.

7. The Kachila Complex

This occurs almost wholly within the present area, but members of it extend just into the area to the north, interdigitating with the Nasaken Complex, and also occur east of the present area, where they underlie the Oliyamur Volcano in Rhemtulla's area.

It differs from central complexes elsewhere in this region in two ways:-

(i) No source zone is exposed, neither are there any dykes or vents in the present area. It is supposed that the lavas either cover their sources, or that they were derived from the east of their present outcrop, from sources now concealed by the Oliyamur Volcano.

(ii) The proportion of mugearites and basalts to trachytes is much higher than in any other complex.

The Kachila Volcanics are also marked by a considerable development of pumice tuffs, which reach their maximum thickness of 600 ft. (185 m.) beneath Karianamani and Chemusowai. Related to these are the Aterir beds, in which vertebrate fossils were discovered. The Kachila Volcanics also overlie the Kariamangro Caldera, in square 7842. They range in age from about 4.0 m.y. to 2.7 m.y.

Because of the importance of the vertebrate fossils, the Aterir basin was mapped in detail, both by the present writer and by A.P. Hill. The Aterir beds are separated from the main outcrop of Kachila Volcanics by a broad belt of alluvium. Nevertheless, it is thought that they are laterally equivalent to the Karianamani tuffs, which are in turn fairly high in the Kachila Volcanics, since they are underlain to the east by the bulk of the lavas.

Fig. 55 is an attempt to relate the various units within the Kachila Volcanics.

(a) Stratigraphy of the Kachila Volcanics North and East of Aterir River

The principal feature is the abundance of pyroclastics in the western part of the outcrop, and their scarcity in the east.

In the west, the basal member is a pumice tuff with a gravelly cross-bedded base. This basal member rests on an eastward dipping pediment cut into older trachytes, of the Kafkandal Complex.

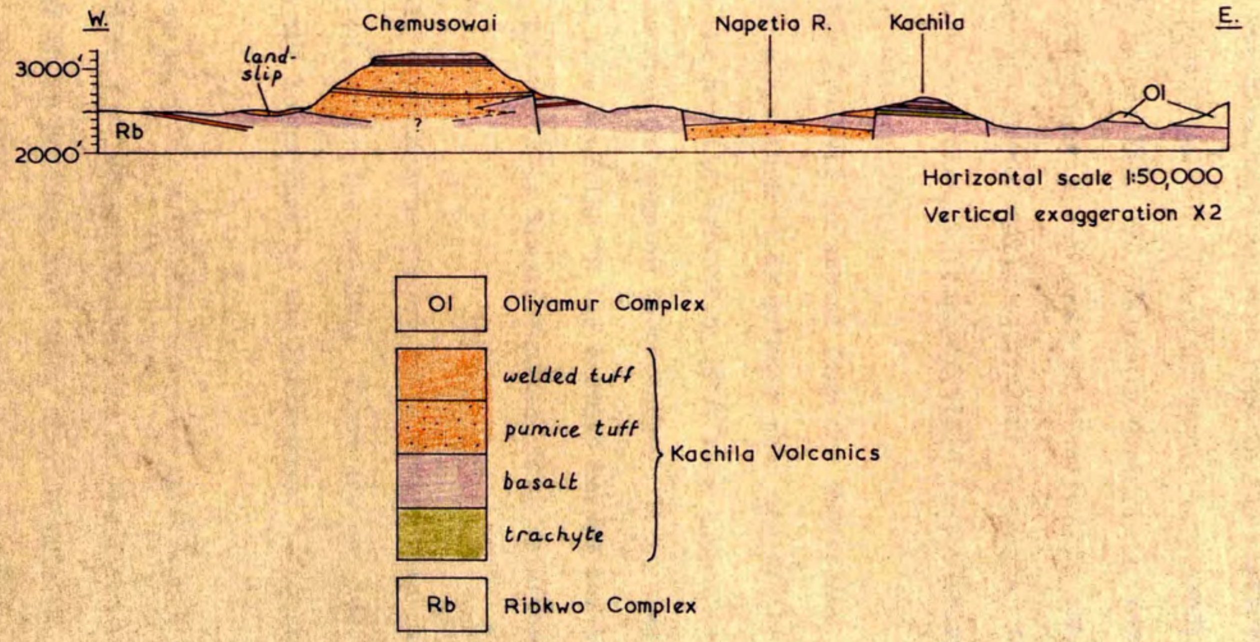


FIG. 55 Section across the Kachila Volcanics, along northing 53.

At 740567, it rests on a welded tuff of the Ribkwo Complex. At this locality, the basal member is admixed with pale brown fluviatile silt.

In the east, the base of the volcanics is not seen. The oldest known members are basalts, occurring beneath the mugearite in fault strips 1 and 2, see Fig. 56. The most complete succession there occurs in fault strip 2, see Fig. 57. In fault strip 3, a fissile trachyte (not examined in thin section) rests on basalts. If the mugearite in square 7953 is stratigraphically equivalent to that in fault strips 1, 2 and 3, then this fissile trachyte could be equivalent to that in fault strip 8, see Fig. 57.

The fissile trachyte is absent from the succession in fault strip 2, and it is possible that it is younger than any of the basalts or mugearites in the Kachila Volcanics, overlying them unconformably, but with no discernible angular discordance. It is also inferred that there was some faulting in the basalts before the eruption of the trachyte, but as it is itself faulted, this occurred in more than one phase.

At 783531, diatomaceous pumice tuffs with a thin lens of diatomite are intercalated within the basalts. These are considered to be equivalent to the lower part of the Karianamani tuffs, where basalts also occur.

From these lines of evidence, then, it is inferred that the Karianamani tuffs are lateral equivalents of the lavas to the east. In the west of their outcrop, the tuffs reach about 600 ft. (185 m.) in thickness. Three olivine-basalt flows are intercalated near the base, which thin northwards and terminate in and around square 7759. The lowest and thickest of these, the Morupuran basalt, is overlain by an anorthoclase trachyte, the Morupuran trachyte (5/158) at its southern extremity, and by a fissile trachyte (5/164) at its northern

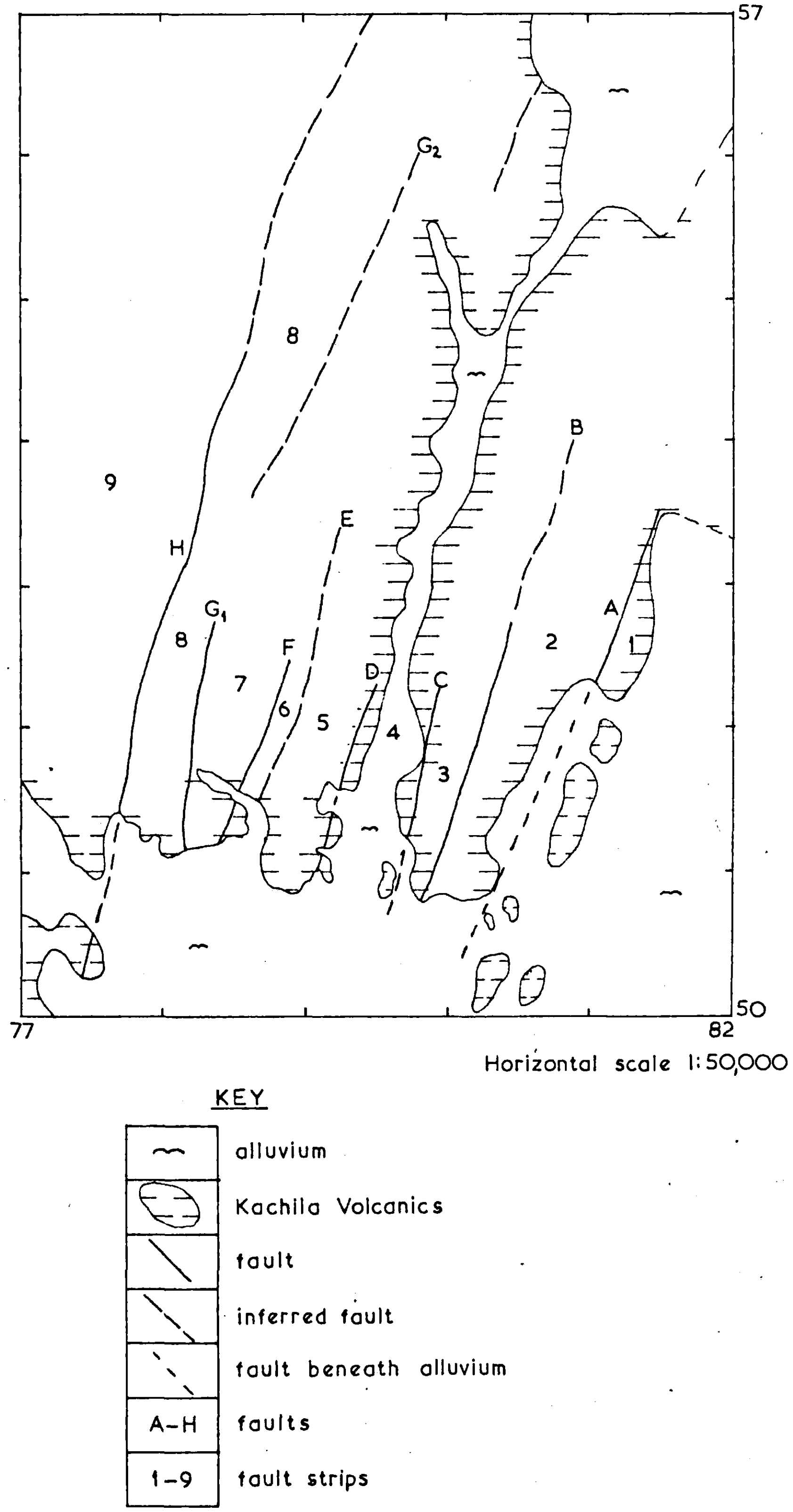


FIG. 56 Notation of faults in Kachila Volcanics.

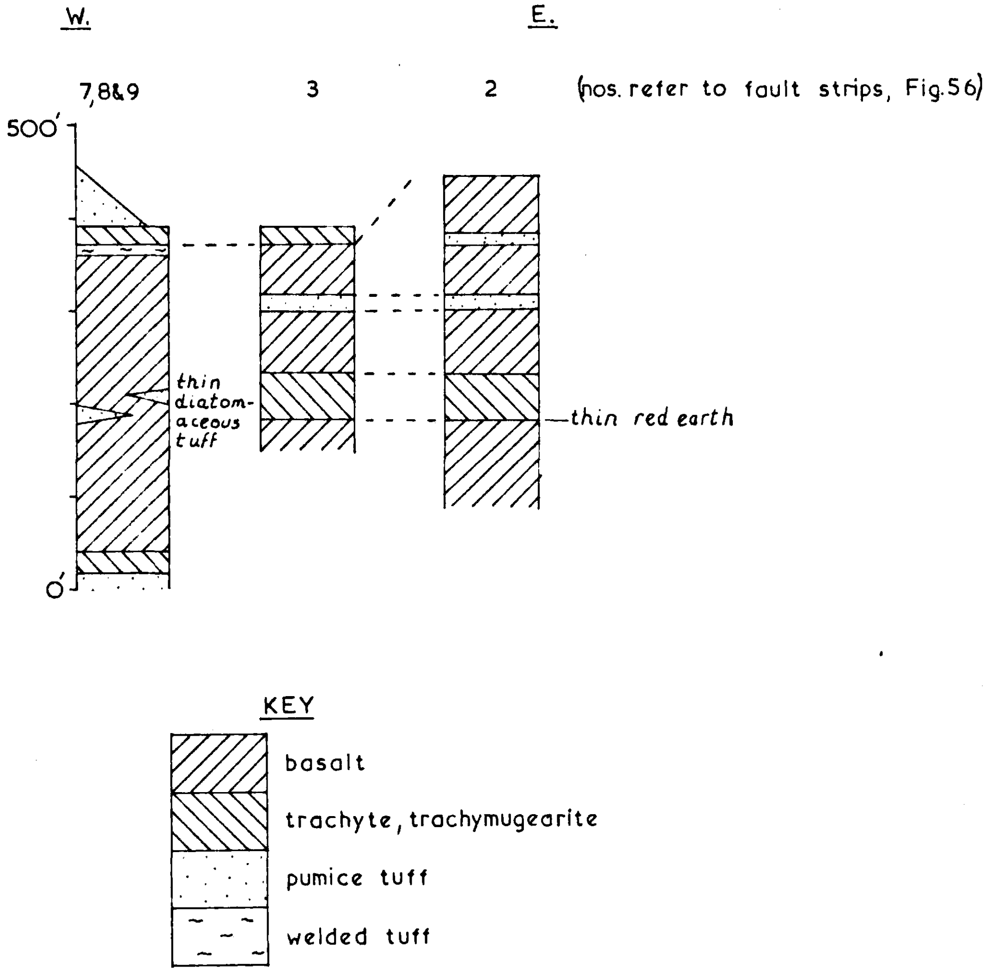


FIG. 57 Comparison of sections from west to east across the Kachila Volcanics.

extremity. The two other basalts are thinner and less extensive than the Morupuran basalt. At their northern extremity, the Karianamani tuffs are both under- and overlain by welded tuffs and trachytes of the Nasaken complex. The basal tuffs interdigitate with Nasaken trachytes at 774619. Above the lavas, the Karianamani tuffs consist mainly of uniform pumice lapilli-tuffs, with welded tuffs in the upper part. The pumice tuffs are roughly bedded in units from 1 foot to 5 feet thick, occasionally graded, and sometimes fairly finely laminated. The upper surface of the thicker units is sometimes channelled, and in general, evidence of resorting by riversis not uncommon. Lithic lapilli are common, usually under 3 cm. across, and beneath Karwatuko, a bed with large glass bombs occurs.

The Karianamani tuffs are overlain by the Chemusowai unit. This consists of two thin aphyric olivine basalts each 30-40 feet (c. 10 m.) thick, with an intercalated partly welded tuff, 10 ft. (3 m.) thick. This unit covers a wide area of the Kachila Volcanics, and is remarkably constant in appearance. It has been affected by faults F, G and H (Fig. 56), but north of 1°25' , it may have been erupted on to an already faulted topography. The Chemusowai unit is sensibly horizontal, and appears not to have been affected by the Napetio arch, see p.74 , this Chapter, and also Chapter 3.

(b) Stratigraphy of Kachila Volcanics South and West of Aterir River

The Morupuran basalt, referred to above, outcrops south of the Aterir River, as far south as 765480. Westwards, it is overlain by the Aterir beds, q.v., which consist of tuffaceous sediments, with intercalated basalts.

To the east, it is overlain by a fissile trachytic lava in square 7748, thought to be equivalent to the Morupuran trachyte, though it was not examined in thin section. This is in turn overlain by pumice tuffs with a welded tuff at their base. The pumice tuffs have thin diatomaceous seams, and are considered to be lateral equivalents of the tuffs low in Karianamani, and those at 783531.

These tuffs are then overlain by mugearitic lavas and plagioclase trachytes (5/57), which overstep to the north to rest directly on the Morupuran basalt, on Morupuran itself (7750), and on the basalt hills in squares 7551 and 7552. These lavas are similar to each other in hand specimen and in thin section, and similar to those also in Kachila, to which they are inferred to be laterally equivalent.

South of Kahanavisian, the sequence consists of pumice and welded tuffs, mugearites and olivine-basalts, and is of roughly the same age as the sequence at Kachila. A pumice tuff underlain by a welded tuff, possibly the same as that referred to immediately above, occurs in square 7746. This is underlain by fissile trachytic and basaltic lavas, and overlain in turn by more mugearites and basalts. The exact relations of this succession to that in Kachila and Karianamani are not known.

(c) History of the Aterir Beds in relation to the Kachila Volcanics

The Aterir beds consist predominantly of pumice tuffs, with two thin basalts intercalated near the base, see Fig. 58. Fig. 59, the most complete succession, is not developed to the same extent in all parts of the basin. Plate XV is a general view across part of the Aterir basin, from the west.

Stage 1 - Eruption of Morupuran basalt* and trachyte*. B_{mor} was erupted over a fairly wide area, and is thought to be present as far north and west as squares 7551 and 7552. Generally, however, B_{mor} outcrops at the present day in a north-south trending belt. This is thought to have helped form a drainage barrier during the early stages of the history of the basin, see stage 2. At the same time as the

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* Referred to subsequently as B_{mor} and T_{mor} respectively.

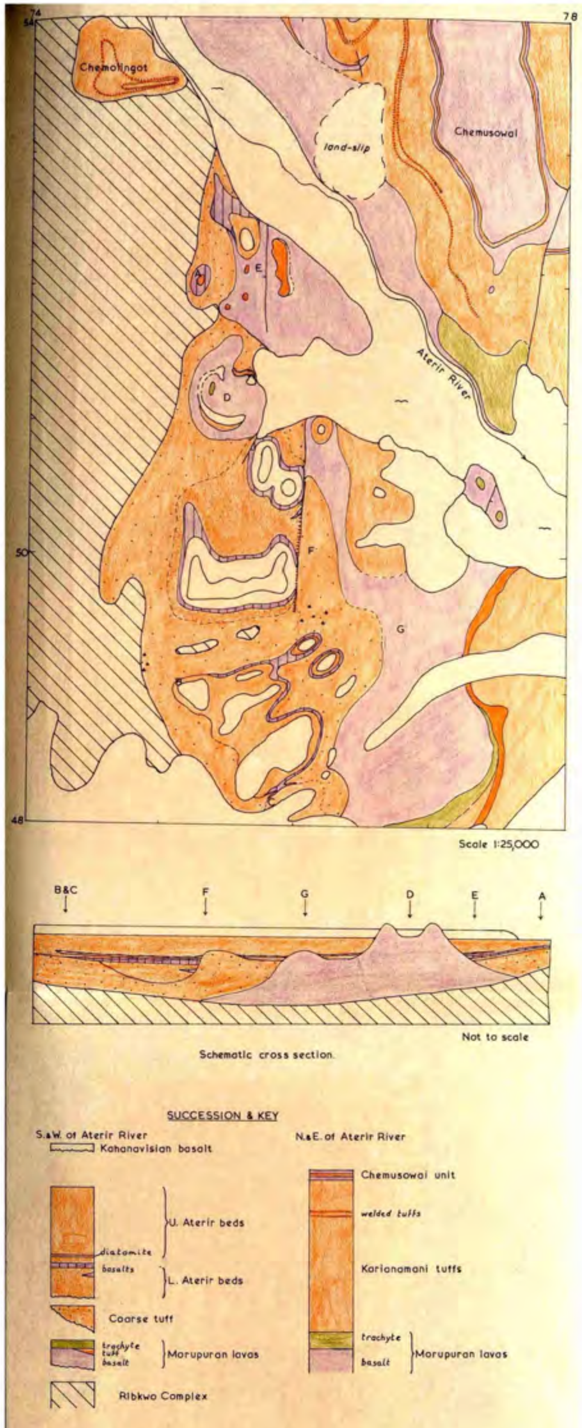


FIG. 58 The Aterir Basin.

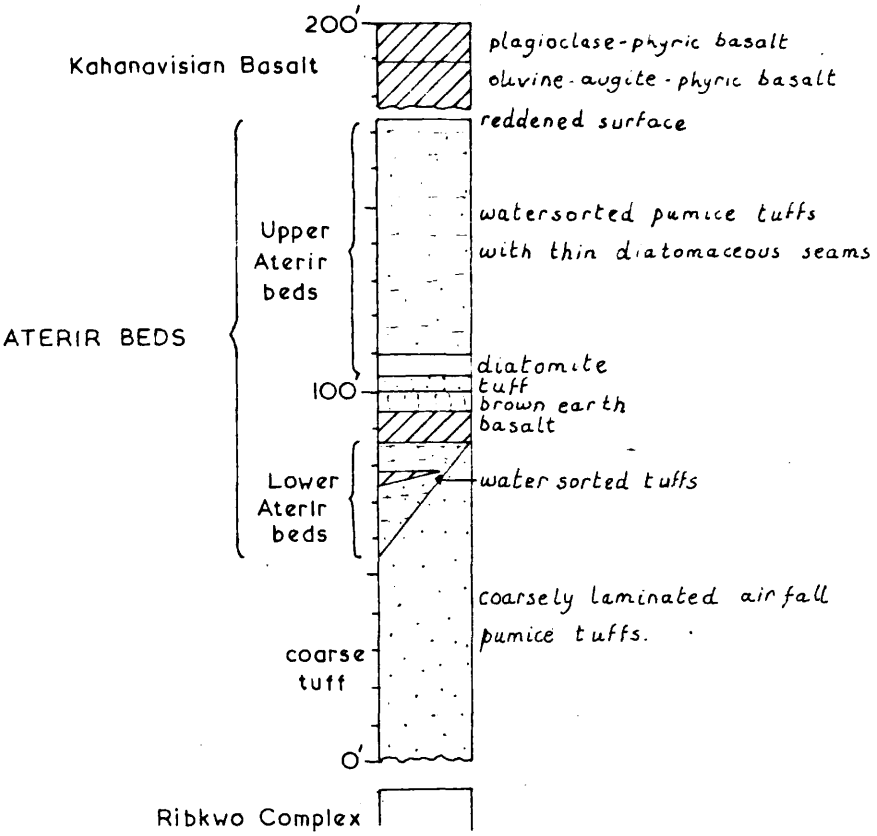
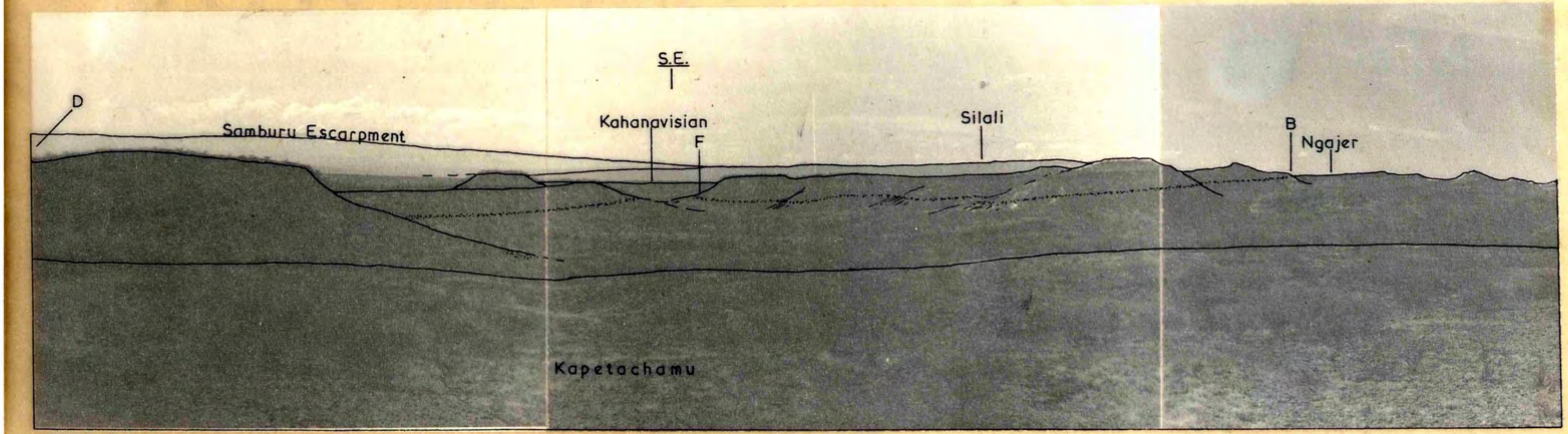


FIG. 59 Complete succession, Aterir.



D, F & B refer to Fig 58.

- diatomite

PLATE XV Panoramic view of Aterir from 748512.

PLATE XV Panoramic view of Aterir from 748512.

eruption of B_{mor} and T_{mor}, the early lavas of Kachila were being erupted.

<u>Stage 2</u> - Coarse tuff eruptions. These and later tuffs rest on a surface of considerable relief, developed on both Ribkwo Complex units (notably the welded tuff and trachyte immediately west of the basin), and Morupuran lavas. It is postulated therefore that there was a period of erosion between stages 1 and 2, in which T_{mor} was largely removed, e.g. from 773489. Outliers of it survive at 753513 and 759522.

The coarse tuffs consist of from 0-60 ft. (up to 18 m.) of subaerial pumice tuffs and agglomerates. The latter are of limited lateral extent, and occur at two localities, 762496 and 749492. At both localities, large blocks of brown vesicular glass and glassy trachyte occur in a pumiceous matrix. L.A.J. Williams (personal communication) interpreted the former locality as an eroded cinder cone. These eruptions are thought to have impeded the drainage sufficiently to divert it northwards, between the coarse tuffs and Kapetachamu. Further tuff eruptions in the north are then thought to have completely choked off this exit, so that a lake formed, initiating the next stage in the history of the basin.

<u>Stage 3</u> - Lower Aterir beds. Overlying the coarse tuff are well laminated, fairly fine-grained white tuffaceous sediments. They pothole and channel the coarse tuff, and at 760501, are banked against a steep wall of coarse tuffs. They occupy the area shown in Fig. 58. Their environment of deposition is not wholly known, but it is probably essentially fluviatile in origin. They range in thickness from nothing to 30 ft. (9 m.) northwards.

At the same time as the tuffs of stages 2 and 3 were being erupted, it is thought that the lowest Karianamani tuffs, and the lavas in the lower part of the Kachila succession were being erupted.

Within the upper part of the Lower Aterir beds is a 10 foot thick basalt, outcropping only at 760503, referred to as the Lower Aterir basalt, or B_l. Only 20 ft. (6 m.) above this is the Upper Aterir basalt, B_u, which covers a wider area than B_l, and is up to 15 ft. (4.5 m.) thick. It is present as far north as 753529 and 752522 where it overlies coarse tuffs via a reddish sandy horizon. The feather edge of B_u is seen at 758482 and 754491. Both B_l and B_u were apparently derived from sources east of the present basin, and are probably equivalent to lavas below the tuffs at 783531.

There followed a period of quiescence, during which a pale brown earth was formed, up to 2 m. thick above B_u, and up to 5 m. thick above the coarse tuffs west of the B_u feather edge, e.g. at 752490. The earth is overlain by about 2 m. of whitish airfall tuffs.

Stage 4 - Upper Aterir beds. After eruption of B_u, and minor tuff eruptions, the Lake Aterir barrier was shifted eastwards, and the area of sedimentation considerably extended. It is suggested that the new barrier was initially the rising Napetio arch. Lacustrine and fluviatile sediments appear, for the first time, east of the earlier B_{mor} barrier. Erosion had possibly by now cut down through the coarse tuffs, reopening pre-coarse tuff river valleys, so that the drainage now flowed eastwards up to the Napetio Arch. Tuff eruptions then continued in Karianamani, partly choking these rivers, and providing conditions in which temporary lakes could develop, and later coalesce. The sediments in these lakes are represented by the outcrops of diatomaceous tuffs at 783531 and 779488, and by the diatomite and associated sediments in Aterir itself. The diatoms from 783531 (5/175) are identical in form to those (5/44) from the diatomite in the Aterir Beds.

The main Aterir Lake was initially a permanent feature, and up to 4 ft. (1.3 m.) of diatomite are present. Above this are some 60 ft. (18 m.) of pumice tuffs showing abundant evidence of a sub-aqueous environment of deposition. The diatomite is thickest around 758501, and thins away from this. At 761483 two distinct bands of diatomite are present, both about 25 cm. thick, with c. 30 cm. of tuffs between. These are taken to represent a retreat and readvance of the shores of the lake. Just westsouthwest of this, the diatomite is seen to wedge out completely, apparently representing the edge of the lake, or at least the edge of the zone inhabited by diatoms. Occasional small faults affect the diatomite, Plate XVI.

By tracing the thickness and distribution of the diatomite, the palaeo-geography of Lake Aterir can be tentatively established, Fig. 60.

At 752521 (A on Fig. 60) B_u is overlain by about 40 ft. of pumice tuffs. There is no diatomite at this locality, but the upper surface of the tuffs shows evidence of reworking by river action. Further, small fragments of bone occur on this surface, including fragments of teeth of Rhinocerotidae. At 755525, 752510 and 756513, diatomite is present, all at lower topographic levels than the reworked surface at 752521. It is inferred therefore that the shore of the lake passed between 752521 and the last three localities.

Further south, the western margin of the lake is seen at two localities, 751491 and 759483 (B & C on Fig. 60), where the diatomite thins westward to nothing. Southwards, the original edge of the lake is probably in part beneath Kahanavisian, but was probably not south of 1°20'N.

Lake Aterir was broken by a few islands. The outcrops of B_{mor} in squares 7551 and 7552 (D & E, Fig. 60) were either two closely adjacent islands, or one single island. The outcrop of coarse tuff in the southwest corner of square 7650 and northwest corner of 7649

PLATE XVI Small fault in Aterir beds diatomite, 752501.

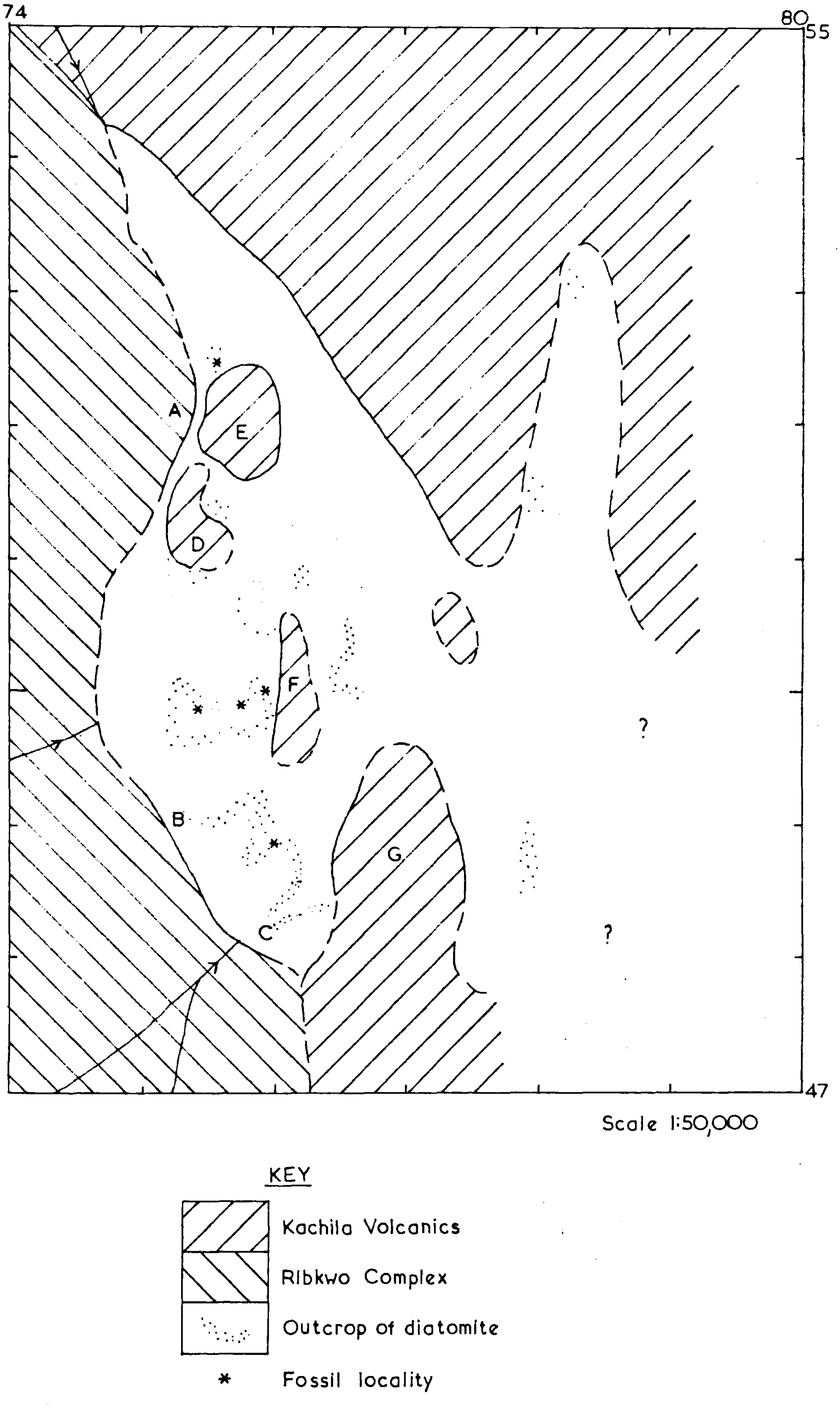


FIG. 60 Palaeogeography of Lake Aterir.

(F, Fig. 60), was already a significant topographic feature, since both the lower Aterir beds and B_u both abut against it. It continued to remain so during the deposition of the diatomite. There was possibly an island or submerged bar in squares 7648, 7649 and 7650 (G, Fig. 60) where the north-south trending strip of B_{mor} now outcrops.

The eastern margins of the lake are not precisely locatable. It probably did not extend far beyond 36°07'E. Its outlet presumably lay somewhere south of the present southern extremities of Karianamani and the Napetio arch.

During deposition of the diatomite, the lake spread greatly, fluctuating slightly at the margins. Its existence was terminated rather abruptly, as the diatomite is channelled by the waterlaid pumice tuffs which overlie it. These latter are about 60 ft. (18 m.) thick at 754499, and are crossbedded throughout most of their thickness. Thin diatomaceous seams occur, indicating periods when lacustrine conditions were temporarily regained. Elsewhere, channelling indicates penecontemporaneous erosion of the substrate. It appears that the environment of deposition was controlled by the balance between (i) rate of accumulation of material at the barrier, and (ii) amount of erosion of the barrier by rivers flowing through it. These 60 ft. (18 m.) of fluviatile and lacustrine sediments are considered to be equivalent to the middle and possibly upper parts of the tuffs in Karianamani.

The middle and upper tuffs in Karianamani have several horizons of welded tuff. Two of these are present overlying 150 ft. of pumice tuffs in the Chemolingot outlier. Current bedding in the tuffs there indicates that they were resorted by rivers flowing southeast. These are considered to have originally flowed eastwards, but to have been diverted southeastwards by the tuffs accumulating at Karianamani. A welded tuff overlies T_{mor} in square 7552, but its relation to the Aterir beds is not known. The welded tuff overlying B_{mor} in squares

7748 and 7749 is apparently quite low in the sequence, but no specific conclusions can be drawn as regards the position of any of the welded tuffs associated with the Aterir Basin.

The thickness of the Upper Aterir beds varies from a maximum of 60 ft. (18 m.) at 754498 to about 10 ft. (3 m.) at the northern, southern and eastern margins of the basin. Some of this variation is almost certainly due to erosion before the eruption of the Kahanavisian Basalt, but it is probable that the areas of greatest thickness coincide with the former deepest parts of the basin.

The fossils mainly occur within the upper part of the brown earth; but also occur above the diatomite. Table 1 is a faunal list from the five localities shown on the map, Fig. 58. The assemblage is considered to be between 3 m.y. and 4 m.y. old.

Table 1. Faunal List of Aterir Beds

REPTILIA		
Chelonia		
Pelomedusid		
Crocodilia		
MAMMALIA		
Proboscidea	cf	*Anancus* sp.
		Elephas cf *subplanifrons*
Perissodactyla		
Equidae		*Hipparion* (*Stylohipparion*) sp.
Rhinocerotidae		
Artiodactyla		
Suidae	cf	*Sus* sp.
	cf	*Nyanzachoerus* sp.
Hippopotamidae		
Bovidae		

Some of the bones are gnawed or bored, indicating that they were lying on a land surface. The crocodile and turtle remains indicate nearby standing water, which would have attracted various plains animals. This body of water was, of course, Lake Aterir.

Following the deposition of the upper Aterir beds, eruptions continued on the southern flanks of the Kachila "volcano". The youngest date obtained is 2.7 ± 0.3 m.y., from a trachymugearite at 782458.

8. The Namortoitio Trachyte

Overlying rocks of the Nasaken Complex and Kachila Volcanics are several outliers of trachyte, consisting apparently of only a single flow, up to 60 ft. (18 m.) thick. At 791598 and 796590 it overlies the Chemusowai basalt, and is thus younger than the Kachila Volcanics.

At 781606, it evidently flowed against a feature cut into the Nasaken Complex, and it is inferred that it overlies both Nasaken and Kachila Volcanics unconformably.

At 796590, the Namortoitio trachyte is 8 ft. (2.5 m.) thick, and is underlain by 7 ft. (2.1 m.) of orange laminated tuffaceous sandstone. The trachyte is very fine-grained, and not fissile, though it is flow banded. The flow banding at the base is highly contorted. Elsewhere, the trachyte is fissile and moderately porphyritic.

The outliers at Namortoitio are affected by northnortheast-trending faults.

Since the Namortoitio trachyte is younger than the Nasaken or Kachila Volcanics, and is not visibly connected to any obvious source, it is possible that it is associated with one of the younger complexes east of the present area. The most likely is the Oliyamur Volcano, the youngest of the trachyte complexes in this region. It is a large circular shield volcano, assuming the form of a very flat cone. Most of the original flanks are intact, but the western flanks end abruptly in a cliff 600 ft. (180 m.) high, 1½ miles (2.5 km.) east of the road. The Namortoitio trachyte could thus represent the farthest extremities of the western flanks of Oliyamur volcano.

Erosion of the Kiddeh Group

Erosion has affected all the complexes, to a degree depending mainly on their age. The flanks have been reduced from their original extent by the process of "wearing-back", where pediments are formed, separated from the remaining portion of the volcano by a usually well defined break of slope. This process greatly reduced the southern, eastern and western flanks of Kafkandal.

The higher parts of each volcano are all deeply incised by the local drainage. The nature of the landforms produced depends greatly on the local lithology.

The next youngest formation was erupted on to the dissected Kiddeh Group, along part of its eastern margins, so that it outcrops partly in deep river valleys, and partly on a pediment cut into the Kachila Volcanics and Ribkwo Complex. This pediment is preserved not only beneath Kahanavisian, but also in squares 7745, 7845 and 7945, where it is covered by a thick deposit of coarse gravels.

This pediment is itself undergoing dissection at the present day. These successive rejuvenations are related to downwarping of the central trough, and tilting of the rift valley sides towards it.

C5. THE KAMOSING FORMATION

This comprises three members, each of which is composed entirely of one or two olivine-basalt flows. The flows are rarely more than 40 ft. (12 m.) thick, and are frequently columnar jointed. Vesicles are present, but usually scarce.

(a) The Tuwut Basalt Member

This consists of 7 outliers of basalt in the Kamosing valley, between 693430 and 712453. The basalts are black in hand specimen, aphyric and non-vesicular. The most southwesterly of the outliers consists of two flows of columnar basalt, each about 40 ft. (12 m.) thick, Plate XVII. The other outliers all consist of only one flow.

In addition, there is a dyke of similar basalt cutting the (presumed) Ribkwo Complex trachyte at 672422, which is inferred to have acted as a feeder for the Tuwut member.

The outliers represent the disconnected parts of a formerly continuous flow, that might have originated from the dyke mentioned above, and which flowed down the then Kamosing River. It probably did not extend much further than the present northeastern limit of its occurrence.

(b) The Pativat Basalt Member

This occurs in the southeastern corner of the area, the separate outliers extending over 5 square miles (13 sq.km.). The basalts are all black, only sparsely vesicular, and non-porphyritic in hand specimen.

The highest of the outliers is at Pativat, where the base occurs at 2,680 ft. O.D. Outliers occur at lower levels in all directions around this, indicating that it was erupted on to a topography of some relief, developed on the Ribkwo Complex and Kachila Volcanics.

At Pativat, a dyke occurs, intruded along a vertical fissure which has later controlled a northnortheast-trending fault. A pipe-like source is at 792449.

An age of 2.2 ± 0.3 m.y. was obtained from a specimen at 797418. This is in accordance with the age of 2.7 ± 0.3 m.y. obtained from the Kachila Volcanics in the immediate vicinity.

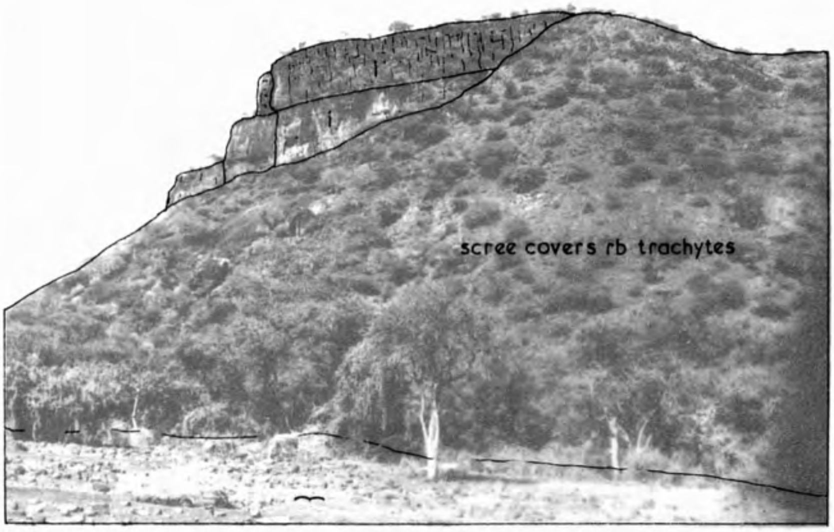


PLATE XVII Outcrop of Tuwut Basalt, Kamosing Formation, at 693430.

PLATE XVII Outcrop of Tuwut Basalt, Kamosing Formation, at 693430.

(c) The Kahanavisian Basalt Member

This is the most extensive member in the Kamosing Formation. It consists of at least two flows, which were erupted from a source in the Chemukol Valley, and which flowed initially northeastwards, and then eastwards, out of the Ribkwo Complex hills on to a pediment cut almost entirely into the Kachila Volcanics.

Nine outliers are present in the Chemukol Valley. That nearest to the source occurs at c. 3,400 ft. O.D., while the remaining outliers occur at progressively lower levels. Southeast of Cherelgat, the Kahanavisian Basalt probably flowed eastwards, across the eroded Aterir Basin and Kachila Volcanics. It is also probable that another source was located east or southeast of Cherelgat, and not far from it, because at 753497, two distinct features occur, almost certainly representing two successive flows.

The various outliers in Aterir occur at uneven heights, suggesting that there has been some relative movement. The outlier at 753497 is in fact the topographically highest, at 2,700 ft. O.D.

The distinctive topographic feature Kahanavisian represents the bulk of this member. It is 5 miles (8 km.) long by 2½ miles (4 km.) wide. Its former extent has probably been reduced by erosion, and the original eastern and southern limits are not known. Karianamani and Kachila would have prevented it from flowing much further north than its present limits in that direction. The basalt on Kahanavisian is about 25-30 ft. (c. 8 m.) thick. At 759500 and 758469, it is seen to overlie a red soil about 0.5 m. thick.

An age of 4.2 ± 0.3 m.y. from the basalt at 753499 is erroneous because it overlies lavas dated at 2.7 ± 0.2 m.y. and 3.2 ± 0.3 m.y.

The Kahanavisian Basalt Member has had far-reaching effects on the drainage of the Ribkwo Complex. It has diverted the course of several major rivers, and its effects in this respect will be considered in Chapter 4.

Erosion of the Kamosing Formation

Since the eruption of the formation, there has been further rejuvenation of the local drainage, or more probably, a continuation of that phase initiated during the eruption of the Kiddeh Group Complexes. This has led to incision and dissection of each member of the formation, although the top surfaces of the flows are thought to approximate to the original. The top surface of Kahanavisian in particular is very rough, being strewn with large blocks of basalt, up to 0.5 m. across. Between these is a brown soil, which becomes very sticky in wet weather. Small outliers have better drained top surfaces.

The upstream outliers of the Tuwut and Kahanavisian members are situated at up to 150 ft. (46 m.) above the present stream floors, whereas on the Suguta Plains, the base of the basalt is probably only 30 ft. (9 m.) above the general level of the plains.

C6. THE AGIBELBEL FORMATION

The plains of Agibelbel in the northeast of the area, Plate XVIII, and the neighbouring flat areas occupied by the Namortoitio and Kanakutu Rivers are formed of a fine-grained pale brown to ochrish soil, in which are bouldery horizons representing former river channels. These boulder beds contain large blocks of welded tuff and trachyte, and are obviously derived from the local trachyte complexes.

At 809582, a 15 cm. thick layer of pumice lapilli is also present. The lapilli are brownish on the outside, being stained with soil, but are black or dark grey and obviously fresh when broken open. In this respect, they are unlike pumice lapilli from pyroclastics in the trachyte complexes, which are always cream or white and appear crumbly and altered. Such lapilli also occur at 822611, in three separate layers each about 12 cm. thick. The lapilli are crowded together, and there is very little soil within each horizon. They

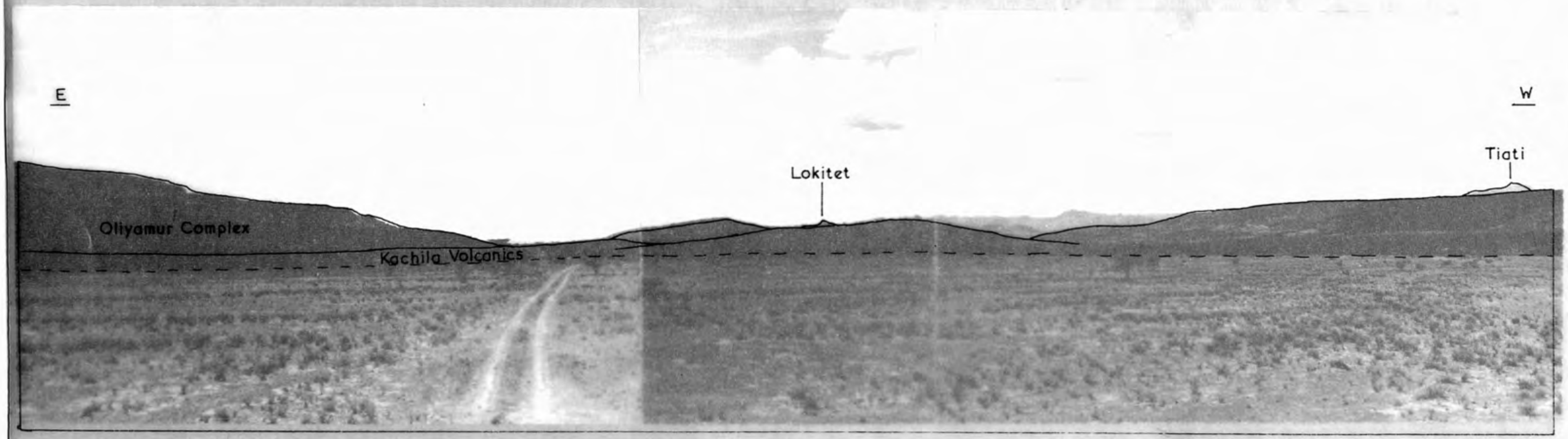


PLATE XVIII Agibelbel, looking south.

PLATE XVIII Agibelbel, looking south.

thus appear to represent a distinct eruption, and not merely resorting of older material.

In view of this, and their fresh appearance, they are thought to have been erupted from a comparatively recent volcano. The nearest recent volcano is Emuruangokolok, in the axial zone. It is situated about 16 miles (26 km.) east of Agibelbel, and the pumice horizons there are thus considered to be an airfall pyroclastic deposit attributable to that volcano.

C7. THE KAPEDDO FORMATION

This has its maximum development in McClenaghan's area, where it consists of alternating pumice tuffs and basalt lavas. The thickest development of tuffs is the Kapeddo tuffs. These are cream coloured or yellowish and around Kapeddo are at least 40 ft. (12 m.) thick. They blanket the lowest of the Ribkwo Complex foothills, being steeply banked in places against the older trachytes. The Lorusio Basalt is considered by McClenaghan to be one of the basalts in this formation. The two members in the author's area will be considered individually.

The formation is undoubtedly related genetically to the adjacent volcano Silali.

(a) The Lorusio Basalt occurs in the extreme southeastern corner of the area adjacent to the Suguta River. It forms a low feature about 4 ft. (1.3 m.) high, and consists of a single flow of olivine-basalt.

(b) The Kapeddo Tuffs in the present area are only about 10 ft. (3 m.) thick. They are present only in stream channels and as a few outliers on the floor of Kariamangro Caldera. They appear to represent the most northerly extension of a phase of pyroclastic activity associated with the central volcano Silali. At Kapeddo, the Kapeddo

Tuffs consist of pumice lapilli in a tuffaceous matrix. In the present area, the lapilli are generally broken down, and the matrix contains comminuted material derived from the Ribkwo Complex, and possibly riverine silt. They are accordingly finer-grained than at their type locality, are rather duller in colour, and have a prominent lamination, occasionally cross-bedded, consistent with the inference that they have been resorted.

Over most of the flat ground between the Ribkwo Complex foothills and Silali, the Kapeddo Tuffs are obscured by a thin veneer of brown soil.

The Agibelbel and Kapeddo Formations are the youngest volcanic formations in the area, being connected with the axial zone central volcanoes. They are probably middle to upper Pleistocene in age.

Recent Deposits

These have not been classified stratigraphically. They are distinguished on the map only on the eastern side, since most of the Kerio Plains are covered in recent gravels and alluvium. The following treatment is not stratigraphic, but purely descriptive.

(i) Alluvium. Extensive deposits of riverine alluvium occur along the Kerio River. It is light brown in colour, fine-grained, with no boulders. Over the rest of the area, and near the Suguta River, it is associated with boulder beds and gravels.

(ii) Boulder beds and gravels. Boulder beds occur in nearly every river channel, and are an effect of the seasonal distribution of rainfall. Blocks up to 20 ft. (6 m.) across were recorded in some instances. Boulder beds may grade into finer grained deposits, through gravels, into sands.

Sheets of gravel occur on the Kerio and Suguta plains. On the former, there is a high contribution of basement material, which is more obdurate than volcanic detritus. Consequently, the tuffs between the Kolloa road and the Kerio River are strewn with a gravel which contains very little tuff, but many rounded pebbles of quartz, gneiss and pegmatite.

The Suguta plains are covered with a gravel which consists almost wholly of trachyte and welded tuff pebbles. Nearer to outcrops of the Kamosing Formation, basalt contributes to the material in the gravels. Many of the pebbles are coated with a glossy desert varnish. Near Kahanavisian and the Pativat Hills, the Suguta Plains are strewn with varnished boulders of basalt.

(iii) Hot spring deposits. These occur at Lorusio, associated with the hot saline springs. The water is probably entirely meteoric in origin, since the flow from the springs is noticeably greater during times of rain. A temperature of 72°C was recorded from one of the springs. The waters are saline and quite undrinkable. Between Lorusio and the Suguta River, the spring waters are subject to a high degree of evaporation, as local daytime temperatures often exceed 105°F, and the plains are coated with a thin white crust of evaporite. X-ray fluorescence (analyst, S.D. Weaver) indicates that the salt is a carbonate and chloride of sodium and potassium. Wet chemical analysis confirms this, and indicates the presence of the sulphate radicle.

CHAPTER 3

STRUCTURE

Introduction

The structure in the present area is dominated by the anticline referred to in the introduction to Chapter 2, and by the continuation of activity on the eastern limb of this anticline into comparatively recent times. The western limb has also been affected by faulting, but there is evidence that activity ceased at an early stage in the history of the area. The following treatment of the structure and geomorphology is essentially in chronological order. Fig. 61 is a structural map of the area.

1. Structures in the Metamorphic Basement

No detailed mapping of the basement was undertaken, and hence no details concerning small scale structures are available. McClenaghan (op.cit.) distinguished large isoclinal folds with vertical axial planes, the hinges of which plunge steeply southsouthwest. In the present area, no such folds were distinguished, nor was any such pattern inferred from the foliation readings taken. However, the fact that most of the faults in the area trend between north-south and northeast-southwest suggests that there is some fundamental control.

2. The Sub-Volcanic Surface

The various flat erosion surfaces in East Africa have given rise to much discussion and hypothesizing concerning their correlation and significance. The nomenclature is extremely variable, the usual forms being erosion level, erosion surface, erosion bevel, peneplain, etc., qualified by such prefixes as end-Miocene, sub-Miocene, 4,000 ft., 6,000 ft. etc. The present author rejects the terms level and peneplain as the important surfaces are rarely either. Similarly, stratigraphic qualifiers will not be used, since surfaces are not always accurately dated. Terms such as "6,000 ft. erosion surface" are

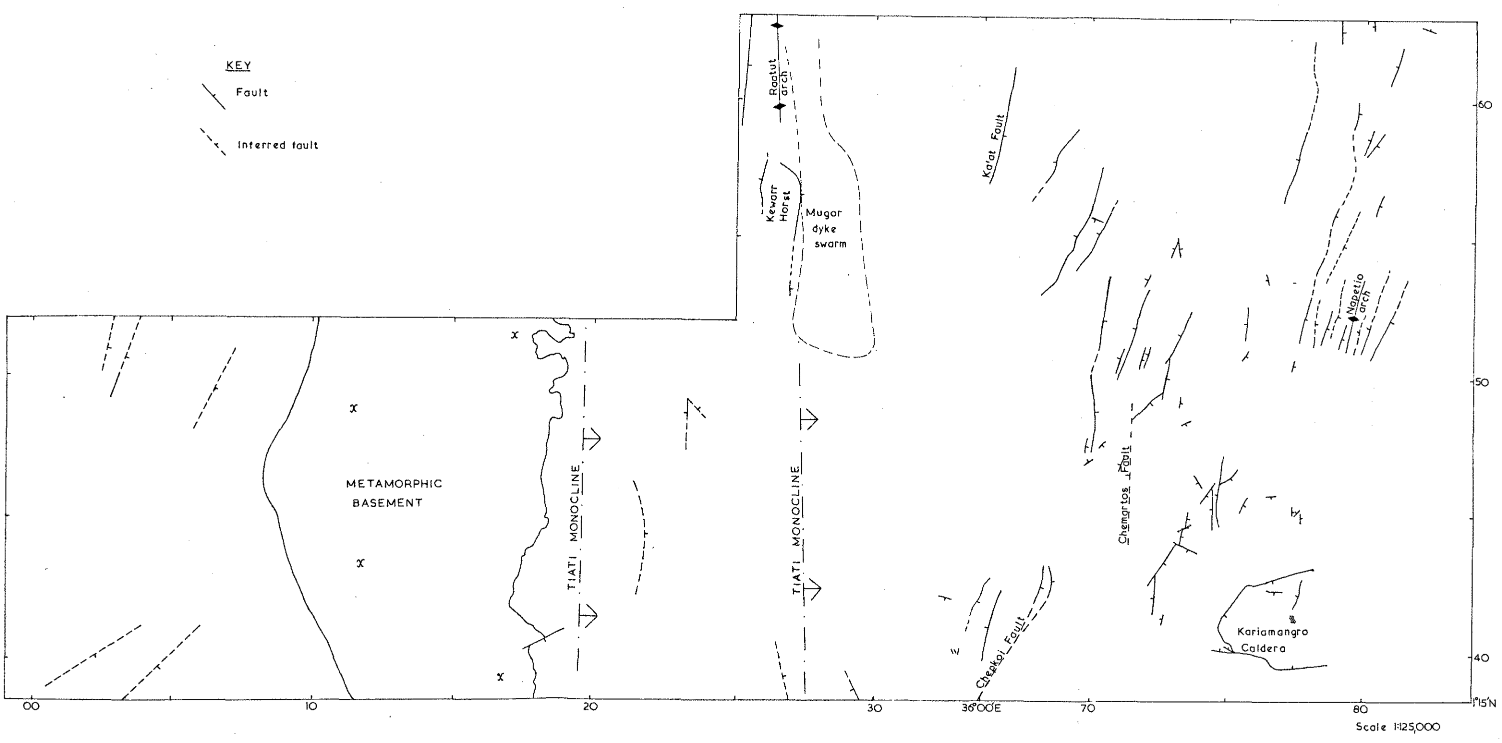


FIG. 61 Structural map.

not advocated, since a surface may be greatly affected by faulting and warping, so that it may occur at any height.

The surface presently under discussion is thus termed the sub-volcanic surface. Its outcrop in the present area has been discussed in Chapter 2. It is proposed here to discuss the surface in a regional context, and then to give an account of the nature of its deformation.

By the middle of Miocene times, a mature surface is thought to have extended over much of East Africa (Pulfrey, 1960, pp.1-3). In places, hilly regions projected above this surface, such as the Cherangani Hills or the Matthews Range on the eastern shoulders of the present rift valley (Shackleton, 1946, pp.44-45). The site of the present rift valley was occupied by a linear downwarp, so that the mid-Miocene erosion surface was not a true peneplein, Fig. 9.

The influx of coarse sediments represented by the Turkana Grits reflects, it is inferred, the earliest movements along the Elgeyo and Kulal faults. Pebbles of volcanic material occur sporadically in the lowest Turkana Grits (p. 20), possibly derived from formations equivalent to the Turkana Basalts, which have been radiometrically dated at c. 25 m.y. (Walsh & Dodson, 1969, p.40). The earliest Turkana Grits were deposited in isolated basins. One such is that in the present area, on the west of the basement arch. Downwarping towards the present position of the Elgeyo Escarpment prevented the basin from filling, so that 800 ft. (245 m.) of grits and gravels accumulated. The basin is only a local feature, since these sediments are absent from the mapping area to the south. They are present in Weaver's area, although not laterally continuous with the outcrop in the present area. However, during the middle of Kapchererat Formation times, sedimentation spread, so that in Weaver's area, the Kei Pa So sandstone rests directly on the basement.

Downwarping then continued during and after the eruption of the Kolloa and Tugen Hills Groups, on a comparatively narrow hinge zone. The faults which affect the volcanics west of the basement arch are possibly contemporaneous with later downwarping, but there is no evidence for the age of the faults, except that they do not affect the Kerio surface.

The central portion of the arch was a relatively stable block, and there seems to have been no deformation of the sub-volcanic surface there, at any stage in the history of the area.

Downwarping on the eastern side of the arch has led to the development of the Tiati Monocline. Again, the earliest movements appear to have operated over a narrow hinge zone, as there are appreciable differences in dip over short horizontal distances. This is known to be partly accounted for by local topography (Fig. 12) and it seems likely that the central portion of the arch already existed as a topographic feature, possibly determined by older structural elements which are now difficult to recognize. The sub-volcanic surface on top of the arch is neither flat nor level, as it has over 200 ft. (60 m.) of relief, see Fig. 9.

The nature of the sub-volcanic surface beneath Tiati and the younger volcanics east of it is unknown. It is almost certain to be affected by the Chepkoi and related faults, and is involved in the Tiati Monocline.

3. Structural Environment of the Kolloa and Tugen Hills Groups

The Kolloa and Tugen Hills Groups in the present area contrast greatly with their counterparts in areas further south. Not only are the eruptive products greatly different, p. 40, but the structures affecting them also differ, and it is not unreasonable to suppose that the two differences are in some way connected.

The structure of the Tugen Hills Group around 0°45'N is dominated at the present day by the Saimo Fault, which downthrows to the east at least 10,000 ft. (3000 m.) (Martyn, op.cit., p.162), and which was active very early in the history of the Group. The structure of the Tugen Hills Group became more and more complex in the Pliocene, as crestal grabens and horst blocks developed. There were also movements late in the history of the Baringo area. Northwards, the Saimo Fault passes into the Kito Pass Fault (McClenaghan, op.cit.), which breaks up into a number of splay faults at about 1°11'N. Three of these, notably the Chepkoi Fault, pass into the present area. North of 1°16'N, there are no faults of any significant magnitude east of the main watershed.

It is thought that north of 1°16'N, large faults give place to monoclines which warp the older volcanics downwards to the east.

The earliest activity of this nature is thought to have taken place at least during the eruption of the Kapchererat Formation, and possibly as early as the Turkana Grits. There is a general concentration of dykes in north-south alignment approximately along longitude 35°52½'E. Just east of this (Fig. 61) is a suspected fault affecting the Kapchererat Formation with a throw of at least 700 ft. (215 m.). Along 35°53' are the Chepachaghom Volcano and some trachyte dykes. This north-south zone is inferred to be over the early monoclinal hinge line.

Later in the history of the Tugen Hills Group in the present area, the sources of activity migrated eastwards, so that the Cheptuimet Trachyte, the Chesitoi intrusion, and the Kelan plug all occur along a north-south zone between 35°56' and 35°57'. This zone also acted as the hinge about which the Lelgrong Tuffs were tilted, Fig. 19, and is thought to be the later monoclinal hinge, Fig. 61. It continues northwards into the Raatut Arch, section 6 below.

This migration of activity towards the centre of the rift becomes increasingly obvious in the Pliocene and Pleistocene, throughout this region of the rift valley, on both the east and west sides. Associated with it is the trend for the older rocks to pass inwards beneath the younger rocks, either by repeated faulting, or by the monoclinal downwarping described above, or both combined.

Faults in the Kolloa and Tugen Hills Groups in the present area are relatively few in number. Probably the oldest is that associated with the early monoclinal axis.

West of the basement arch, there are five strike faults, striking between north-south and northeast-southwest, which cause the succession to be repeated several times. These faults are considered to be related to downwarping of this section of the area towards the position of the Elgeyo Escarpment.

East of the arch, there is an obvious scarcity of faulting in the Tugen Hills Group. The Kito Pass Fault, which downthrows at least 1,500 ft. (460 m.) to the east at 1°13'N splits up there into several smaller faults, of which the Chepkoi fault is one of the most prominent. Further, those faults that are present do not occur on any single trend. The fault in square 1840 is almost at 90° to that in square 2938. The latter fault brings up an inlier of Karu River Basalts. If these are equivalent to the Kapchererat Formation, and the top surface of the latter at 205390 is taken to dip 10° eastwards without interruption, this fault would have a throw of 5,000 ft. (1500 m.).

Two small faults in square 2348 bring up an inlier of Kapchererat Formation basalts.

The fault which affects the Molingot outlier of Cheptuimet Trachyte-phonolite in square 2743 may be a purely superficial effect consequent upon landslipping of the trachyte over the Lelgrong Tuffs.

No displacement of the tuffs was seen beneath the outlier, but this would in any case be difficult to detect in such a lithology.

Three small faults affect the Kapkaru Lavas near 330402. The throw is less than 50-60 ft. (c. 17 m.) in each case.

In contrast to the faults in the Tugen Hills Group west of the arch, those east of it tend to trend between north and northwest.

4. Pre- Tirioko Basalts Events

The Tirioko Basalts were erupted on to a topography of considerable relief, Fig. 24. However, no fault scarps were recognized, nor is there any need to invoke uplift and rejuvenation to account for the topography, since the eruption of the Tiati volcanics on to a fairly mature surface would greatly affect the drainage, lowering the relative base level, and causing immediate incision. The process was obviously aided by the high proportion of pyroclastics in the Lelgrong Tuffs and elsewhere in Tiati.

It is probable then that there were no pre- Tirioko Basalts tectonic events.

5. Pre- Kiddeh Group Events

These include both faulting, and relative uplift along the southern margin of the area.

The faulting, and its effects on the complexes of the Kiddeh Group have been discussed in Chapter 2, pp. 47-48. The southern parts of the Chepkoi and Chemartos faults are entirely pre-Ribkwo in age, but activity has continued along their northern limits into Ribkwo times. These faults thus 'young' northwards. At 1°23'N, however, these faults die out, and are replaced to the east by presumably younger faults affecting the Kachila Volcanics.

The Ka'at Fault is entirely of pre- Kafkandal Complex age as far north as 1°30'N.

Because of the great variation in thickness from south to north in the area of the Tirioko Basalts, it is suspected that much of their former thickness was removed by erosion at the southwards part of their outcrop. The presence of a thick lateritic soil supports this inference. The base of the basalts at Chepkoi is higher than at Akoret, and is higher still beneath the western edge of the Ribkwo Plateau. If this disposition was dependent only on original topography, there should be a concentration of basalt dykes in this region to account for the presence of the basalts. Since there is none, it is inferred that they reached this position by uplift after their eruption. The uplift, referred to as the Chepkoi uplift, probably occurred about an east-west axis at about $1^{o}15'$N. The exact position is not known since this area was involved in a younger, similar tilt which also affects the Ribkwo Plateau, and took place about an axis slightly south of that presently under discussion.

Further evidence of tilting is afforded by the angular unconformity between the basalts and the overlying trachytes. This is especially noticeable beneath Tuntulyon, where the Tirioko Basalts dip eastnortheast at c.10^{o}, and the trachytes dip northnortheast at 3^{o}-4^{o}.

Beneath Kafkandal, the basalts dip almost due eastwards, and it is thus inferred that the Chepkoi uplift had no effect this far north.

6. Further Development of the Tiati Monocline

The northern part of the main watershed region in the present area is affected by three structures, which are probably the same age as the earliest activity in the Kiddeh Group. They are situated, however, about 5 miles west of the north-south trending zone along which the Ribkwo, Kafkandal, and Nasaken Complexes occur, and are thus thought not to be in structural connection with it. Instead, they are considered to be a result of renewed tectonism along the northern part of the Tiati Monocline.

Activity probably started here during Tirioko Basalt times, since the basalts are very thick in this area. However, no mapping has yet been carried out beyond the limits of this sector of the present area, and it is not proposed to discuss the possible thickness and extent there of the Tirioko Basalts.

The three structures affecting this sector are:-

(a) The Kewarr Horst
(b) The Mugor Dyke Swarm
(c) The Raatut Arch.

(a) The Kewarr Horst, situated in the northwest of the area, consists of an upfaulted inlier of phonolites and tuffs, brought up between two curvilinear approximately north-south trending faults. The phonolites are similar in lithology to those in the Tiriomim Volcanics which occur between 4,000 ft. O.D. and 5,000 ft. O.D. only 2 miles (3 km.) westsouthwest. Those in the horst occur between 4,200 ft. and 4,500 ft. O.D., i.e. at the same height as those in the Tiriomim Volcanics. The faulted relationship, however, is proven by the straight contact between phonolites and basalts, and by the occurrence of brecciated basalts at 271555. At this locality, the fault plane is seen to dip eastwards at c.60°.

The northern contact is obscure, but appears to dip northwards. The southern contact is more or less horizontal at the inlier itself, but may in fact rise very gently southwards, since successive outcrops of the Tugen Hills Group occur at higher altitudes southwards, see contoured map of sub- Tirioko Basalts surface, Fig. 24. The small inlier of tuffs at 269531 is probably associated with the eastern Kewarr Horst fault.

The throw on the faults is not known. Inliers of Tiati subgroup occur in squares 2852 and 2953, at heights of c. 4,000 ft. O.D., where the sub-basalt surface is locally rising gently westwards. However, its altitude immediately east of Kewarr is not known. There is no information concerning the throw of the western fault.

(b) The Mugor dyke swarm is an impressive train of fissile trachyte dykes, aligned, individually and collectively, slightly west of north, over a length of 8 miles (14 km.) and up to 2 km. wide. The main axis of the dyke swarm passes just east of the Kewarr Horst. At 272561, a trachyte dyke has been intruded along the fault plane, but has not been affected by it, there being a strong contrast between the brecciated trachyte of the Kewarr Horst, and the unaffected trachyte dyke. Thus the Mugor dyke swarm is younger than the Kewarr Horst.

The dykes are described in Chapter 5. In the extreme north of the area, lithologically similar trachyte dykes are sparsely distributed between Mugor and Kafkandal, indicating that the Mugor dyke swarm, and the early Kafkandal Volcanics, were more or less contemporaneous.

(c) The Raatut Arch is closely associated with the Mugor dyke swarm. It consists of a slight flexuring of the Tirioko Basalts and Mugor Trachytes about an axis coinciding approximately with that of the dyke swarm. It was not recognized on the spot, but from the northern slopes of Cheptuimet where, looking northwards, the features representing individual basalt flows can be recognized and visualized in relationship to each other. The basalts on the western side of the arch dip about 7° northwestwards, but are sensibly horizontal near its centre, except for local, probably original variations.

The arching appears also to have affected the Mugor Trachytes since the outcrops in square 2559 dip gently northwestwards. They are also affected by a fault, downthrowing c. 300 ft. (90 m.) to the east.

It is envisaged that arching created a tensional field along the crest of which was injected the Mugor dyke swarm. Those dykes that broke surface gave rise to the Mugor Trachytes. Arching must have continued after magma ceased to be available, slightly updoming the trachytes. This uplift affected the drainage, altering the position of the main watershed, see Chapter 4.

This appears to be the last activity on the Tiati Monocinnal axis in the present area.

7. Events within the Kiddeh Group

These consist mainly of eastward tilting, occurring relatively early in the history of the Group, and several episodes of faulting.

Tilting of the Ribkwo and Kafkandal Complexes by 7^o-8^o took place not later than 4.5 m.y., since the Lokitet Caldera is not affected by it. It was probably not of the same magnitude in all parts. When viewed from high on Kafkandal, the northern flanks of the Ribkwo Complex are seen to be slightly flexed in a broad monoclinal warp, so that the eastern component of dip is slightly greater along $36^o03'$E, than it is either side of this line. However, the difference does not amount to more than 2^o, and was not observable whilst mapping the flanks.

Arching of the Ribkwo Volcano has also taken place about an east-west axis located at about $1^o13'$N. The western flanks of the Complex, where they are affected by this uplift, dip noticeably to the east, towards their presumed source. This uplift has also had great effects upon the local drainage. The Tirioko Basalts reach their greatest sub-Ribkwo elevation where they are involved in this uplift.

Faulting of the Kafkandal and Ribkwo Complexes is widespread, but has not greatly modified the original form of the shields. All the faults observed were normal faults with a steep or vertical fault plane. Discussion of faulting in the Ribkwo Complex is dealt with first.

Faulting in the Ribkwo Complex is most noticeable on the flanks, but also occurs in the central zone. In the central zone, the faults are probably superficial features, since they are often randomly oriented, do not extend for any distance, and do not have a great throw. Towards the flanks, they become aligned roughly northnortheast-southsouthwest, this pattern becoming more obvious at $1^{o}17'$N, until at $1^{o}21'$N, nearly all the faults trend in this direction.

This trend is obviously an important one, related to fundamental tectonic controls at depth, since the Chepkoi and Ka'at Faults are on the same trend, as are many of the basalt dykes in the Tirioko Basalts north and south of Akoret. Related to this phase of faulting are the faults affecting the Tumungir Basalts around Akoret. These also affect the southern margins of the eroded Kafkandal Complex.

The latter complex appears to be relatively unfaulted. However, only the central portion is exposed, and like the Ribkwo Complex, may not have been faulted as much as the flanks. Further, erosion of the Kafkandal flanks took place before the tilting, since the Ribkwo Complex was erupted on to the circum-Kafkandal pediment, and is involved in the tilting. Therefore, if the faulting is synchronous with the tilting, then all the faults in Kafkandal on the same trend are probably of the same age as the faults affecting the Ribkwo flanks, and not related to an earlier phase of movement.

In the Epong unit, landslipping has been common, and the faults mapped were of a superficial nature.

The Napetio Arch is a very shallow northnortheast trending anticline which plunges northwards at about 7°-8°. It was initiated during the eruption of the Kachila Volcanics, but does not affect the youngest basalts, namely the Chemusowai unit, see Chapter 2 p.71.

Just east of Chemusowai, the basalts and tuffs dip west at 2°-6°, these dips being greatest low in the succession, and decreasing upwards. North of 1°24'N, all the lavas west of the Napetio River are sensibly horizontal in the east-west sense, but dip gently northeastwards between the river and the road. At 1°25'N, the effects of the arch are no longer noticeable.

South of the Aterir River, the Kachila Volcanics beneath the Kahanavisian Basalt all dip eastwards, and it appears that the southern limits of the arch are reached fairly abruptly between 1°21'N and 1°22'N. The type of structure envisaged is shown in Fig. 62.

The arch is closely associated with strike faults parallel to the hinge line, referred to below. There is, however, no evidence for an east-west fault at the southern limits of the arch.

Faulting of the Kachila Volcanics and Nasaken Complex occurs on a northnortheast trend, parallel to that seen in the Ribkwo Complex flanks. This trend is repeated in structures in the Kajyamamuk Complex (Rhemtulla, Ph.D. thesis in preparation), in faults affecting the roughly contemporaneous Tirr-Tirr Series (Baker, 1963, p.62), and is the dominant structural grain of all the younger volcanics at this latitude of the Kenya Rift Valley. The greatest concentration of faults occurs in association with the Napetio arch, Fig. 61. With only one exception, they downthrow inwards, with a total throw of 700 ft. - 800 ft. (210 m. - 245 m.). Fig. 62 shows the relations between the arch and the faults.

Elsewhere in the Kachila and Nasaken volcanics, faults are fairly sparse. The most important is the Karwatuko fault, which extends for

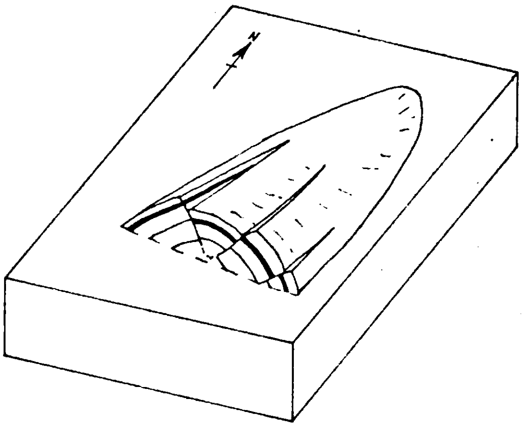


FIG. 62 Schematic block diagram of the Napetio arch.

about 5 km. (3 miles), downthrowing to the west about 100 ft. (30 m.). Near its northern limits, it has given rise to an obsequent fault line scarp, against which a trachyte has flowed.

Faulting in the extreme northeast of the area has seemingly affected the Namortoitio Trachyte, and is thus considerably younger than the Nasaken Volcanics. However, no direct evidence such as brecciation or slickensiding was seen in the Namortoitio trachyte, and it may be that they were erupted on to a pre-existing faulted topography, and possibly subjected to later small movements.

8. The Sub- Kamosing Formation Erosion Surface

This has been discussed in Chapter 2, pp. 79 & 81, but is briefly mentioned here in its structural context. It truncates lavas of the Kachila Volcanics and Ribkwo Complex, and consists of a pediment in the east, separated by an abrupt break of slope from the dissected Ribkwo Hills to the west. The pediment slopes east at about 120 feet per mile (23 m. per km.). The original slope was certainly less than this, as it is not parallel to the present Suguta plains, and has been tilted slightly eastwards since its formation. Before this pediment covered a wide area, rejuvenation occurred, and it has now been largely destroyed.

9. The Kerio Erosion Surface

This has already been introduced in Chapter 2, pp. 17 & 84, during discussion of the Chepkowagh Mugearite. It is an extremely well developed surface, truncating both basement structures and the volcanics of the Tugen Hills Group. Most of it is covered with a brownish sheet gravel up to 2 m. thick, composed of basement and volcanic material.

The period of erosion which initiated the surface started after the eruption of the Sidekh Phonolites, and continued at least up to the eruption of the Chepkowagh Mugearite, and possibly longer. The Chepkowagh Mugearite rests on the surface, but is of unknown age. Several residual hills such as Pukaleh, Kwaisagat, and Kei Pa So project up to 400 ft. (120 m.) above the surface.

The surface has a gently concave profile, the westward slope decreasing from 120 ft. to 70 ft. per mile (23 m. to 13 m. per km.). The break of slope at the foot of the Tiati Hills is very sudden. Over most of its length, it coincides with the outcrop of the sub-volcanic surface, but encroaches greatly over the volcanics in the Chepkirial valley, and southeast of Keitin. These two erosional embayments are also covered with thick sheets of gravel, but there is of course no contribution from the metamorphic basement.

The age relationships of the Kerio and sub-Kamosing Formation surfaces are not known. They are not correlatable with the "end-Tertiary erosion surface" but may be pediments produced during the same period of erosion in which the end-Tertiary surface was formed. The disparity in extent of the two surfaces reflects the fact that there was long continued quiescence west of Tiati, so that erosion proceeded without interruption. East of Tiati, however, vulcanicity proceeded fairly continuously, so that only local pediments were developed, to be quickly overwhelmed by fresh outbursts of vulcanicity. The pediment on the southern edge of Kafkandal and the sub-Kamosing Formation pediment represent the two most successful attempts to bring the topography to an equilibrium surface.

10. Post- Kamosing Formation Faulting

That this has taken place is recognizeable on Pativat, where the basalt is displaced about 70 ft. (21 m.) by a northnortheast trending fault. This is in fact the youngest observed fault in the whole area.

The Kahanavisian Basalt member is not affected by faults, although it was noticed that where it overlies the Aterir Beds, the various outliers occur at different heights. This may be due to differential uplift, or it could be that there are undiscovered sources of the Kahanavisian member so that the differences in altitude of the various outliers are then entirely original.

11. Present Day Erosion

Erosion is proceeding actively over the area at the present day. Both the Kerio and the sub-Kamosing Formation surfaces have been affected by relatively recent rejuvenation.

At Cheptokol, there is a knick-point in the basement some 40 ft. (12 m.) high, where the present day surface intersects the Kerio surface. Elsewhere on the basement arch, some of the rivers flow through narrow gorges 30 ft. (9 m.) deep, and there is obviously very little erosion of the interfluves. West of 35°45' however, the river valleys are wide and shallow, and the interfluves are gently convex, indicating that these softer lithologies have been brought nearer to an equilibrium surface.

The sub-Kamosing Formation surface has been affected by the lowering of the regional base level, to the extent that the outliers of basalt in the Chemukol valley are up to 200 ft. (61 m.) above the present stream level. This represents the amount of erosion in the last 2.3 or so million years. Near the Suguta, the base of the Kahanavisian Basalt is only 40 ft. (12 m.) above the present day plains, indicating that rejuvenation has proceeded fastest in the higher ground.

In the hills, present day erosion is proceeding very actively. The landforms produced depend almost exclusively on lithology, since the climatic differences between the plains and the higher hills are not sufficient for these to contribute towards creating different erosional régimes.

Basalts often produce rolling topography, with rather rounded profiles. Edges of features are usually not very sharp, and there is no contrast between lava and pyroclastic.

Trachytic lavas give rise to a stepped topography, especially where there are thin intercalations of pumice tuffs. In this situation, welded tuffs act the same way as lava flows, producing extensive, easily visible features, with sharp, often vertical terminations and free faces. In rejuvenated areas, the trachytes may be very deeply incised, such as by the Ngatute River in square 7340, or by the streams flowing through the western wall of Kariamangro Caldera.

The most spectacular scenery is to be found in areas where extensive pumice tuffs have accumulated. These are easily incised, and produce deep gorges. The interfluves are greatly modified by intercalated welded tuffs and lavas, so that steep faces often develop beneath them. When this is extreme, landslipping occurs, as at Lokitet.

CHAPTER 4

HISTORY OF THE DRAINAGE

Introduction

The present day drainage pattern of the area is, at first sight, quite complex. When considered in the light of the known sequence of eruptions, however, it is clear that several phases of modification have taken place, most of which now remain only in part. The present day pattern, then, is a composite one, consisting of parts of older drainage systems.

The contribution of each will be considered in turn.

1. Early Systems

No trace of the original drainage on the sub-volcanic surface remains, since its outcrop has been severely modified by the Kerio Surface, to which the drainage now conforms. The eruption of the Tugen Hills Group established the earliest Kerio-Suguta watershed, which has probably remained in approximately the same position till the present day, at least as far north as 1°22'N. The original surface of that complex nowhere remains, and so no trace of the initial drainage remains. The present day drainage of the Tugen Hills Group is controlled principally by the main watershed. On either side of this the rivers flow approximately due east or west, but their courses have been affected by the local and sometimes rapid changes in lithology.

At this stage it is necessary to consider the Kerio and Suguta drainage separately.

2. Drainage west of the main watershed (excluding the northwest of the area)

There are relatively few complications in the present day pattern, Fig. 63. The main trunk streams flow west to the Kerio River. North of the present area, the trunk streams, such as the Chepkirial River in

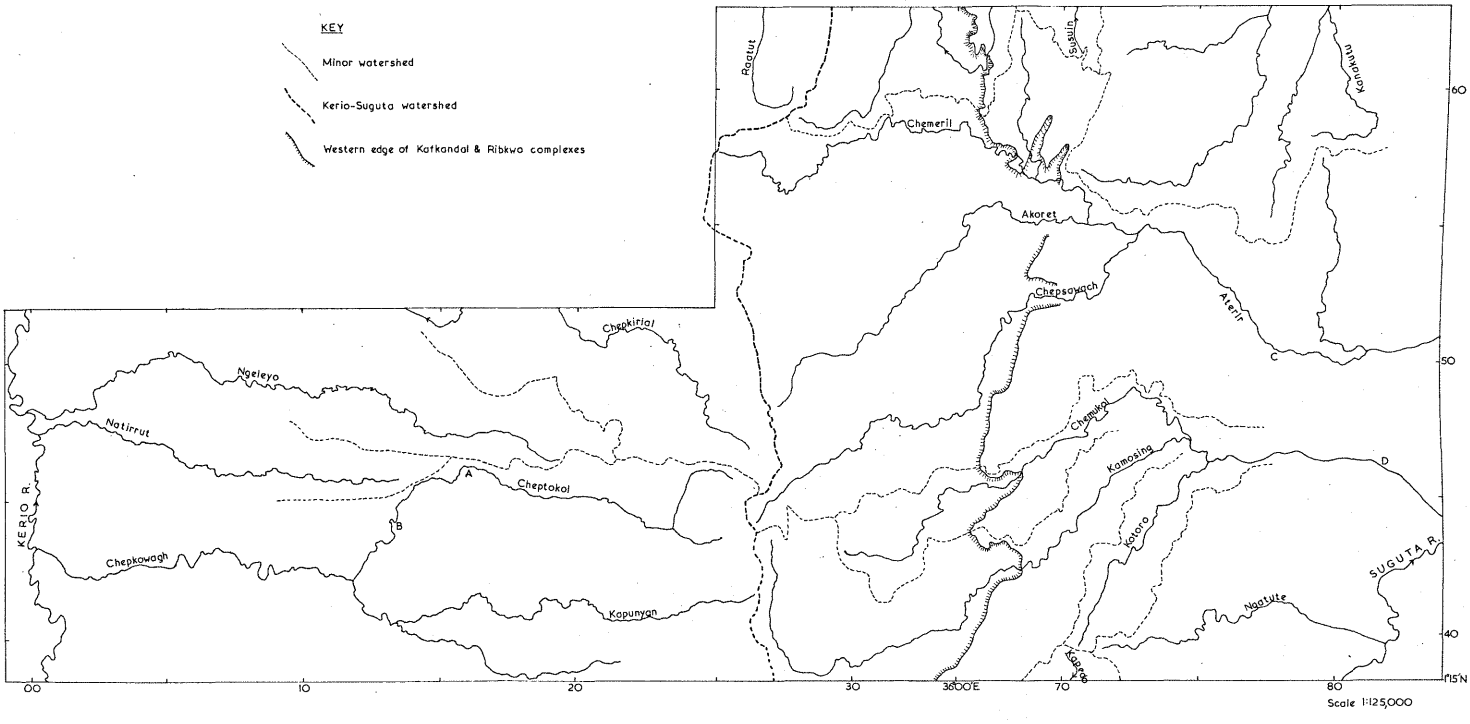


FIG.63 Drainage basins and main rivers.

its lower section flow northwestwards across the Kerio Surface.

The headwaters of the Natirrut were captured by a vigorous tributary of the Chepkowagh, creating the Cheptokol system. The Cheptokol occupies a gorge-like stream section from A to B (Fig. 63), and it is considered that the capture and this incision were initiated together.

3. Drainage east of the main watershed

The earliest drainage probably flowed more or less eastwards down the flanks of the Tiati volcanics. The earliest modifications were the eruption of the Tirioko Basalts and the first phase of arching about an east-west axis (p.93). Rivers flowing off the Tiati volcanics on to the basalts in the present area flowed northeastwards after the tilting, and this is still the dominant flow direction on the Tirioko Basalts between 1°20'N and 1°24'N.

The effects of the eruption of the Tirioko Basalts on the main watershed north of 1°22'N are not entirely known. Possibly over 2,000 ft. (600 m.) of basalts are present locally, culminating in the hill Chemakerr, which rises to 6,300 ft. + O.D. North of 1°24'N, the topographic divide lies west of the present area, along the crest of the western limits of the eroded Raatut Arch. The main watershed today lies east of the Raatut River, more or less along the topographic high occupying the crest of the east limb of the arch.

It appears that as the Raatut Arch was undergoing uplift, river erosion cut down into its centre, forming the headwaters of the Raatut basin. This flows northwards as far as 1°25'N, where it suddenly turns northwestwards. There is evidence outside the present area that it captured the headwaters of the Raatut, after incising its way through the crest of the western limb of the arch. A rejuvenated subsequent of this nature probably captured the headwaters of the Chepkirial

River, so that it too suddenly alters its course, but from due westwards to northwestwards.

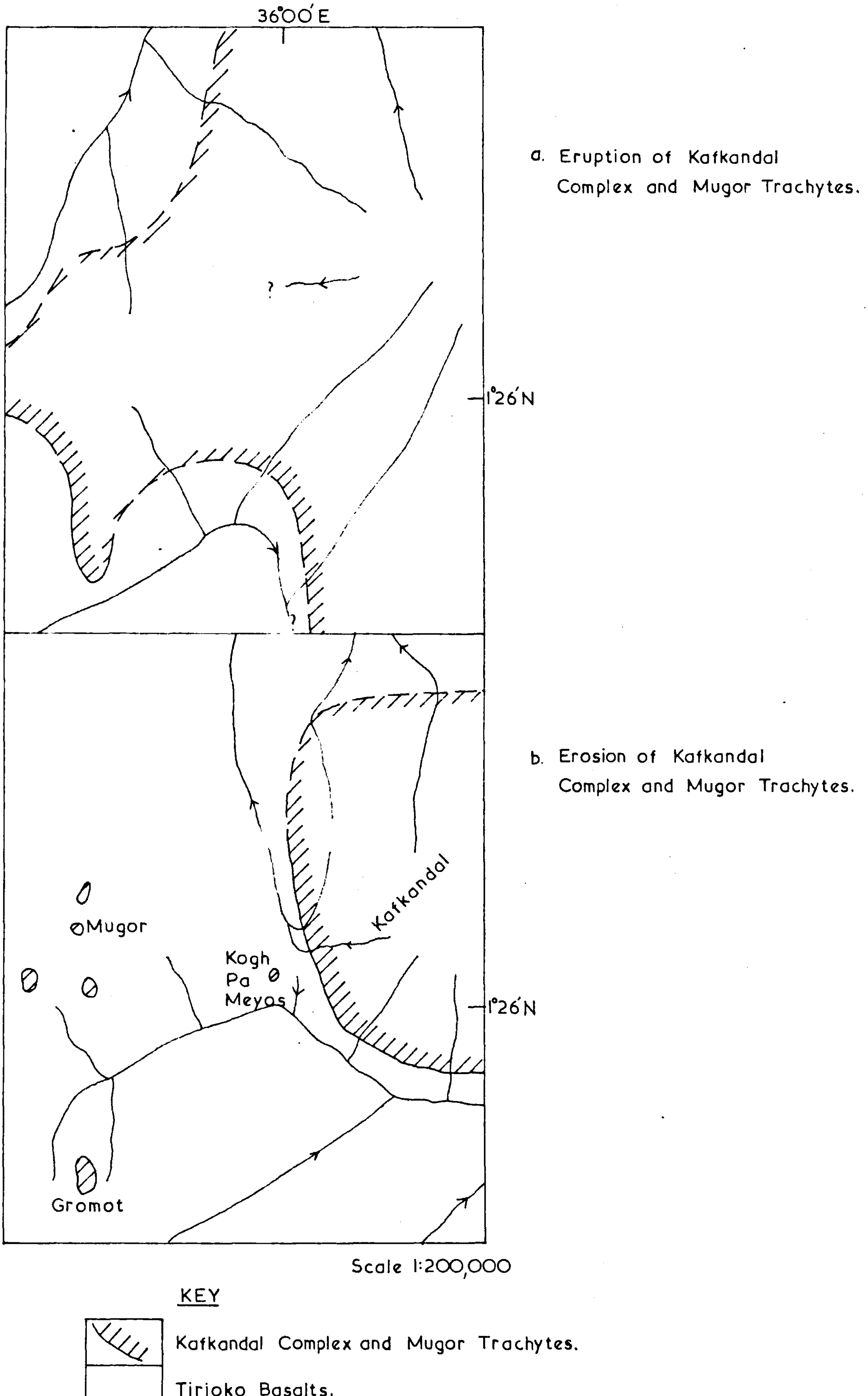
Possibly the most profound effects on the drainage east of the main watershed were those engendered by the eruption of the Kafkandal and Ribkwo Volcanoes.

Immediately prior to their eruption, it is supposed that the drainage was flowing in a northeasterly direction. The eruption of the Kafkandal Volcano caused the drainage to be diverted around it, Fig. 64(a).

The effect, at this stage, of the Mugor Trachytes is unknown, but they probably influenced the drainage in the manner shown. Subsequently, erosion reduced the limits of the Kafkandal Complex, (Fig. 64(b), but the effects of the diversions were still noticeable. Further, the radial drainage pattern is still visible.

The next event was the eruption of the Ribkwo Complex. The northwards-advancing flanks turned the drainage in the southern part of Fig. 64(b) more or less due north, Fig. 65. The diverted portions of these streams united, joining the proto-Chemeril at Akoret to flow through the gap between the two volcanoes - the Akoret Gap. Even at the present day, the Akoret Gap takes a considerable flow of water in the wet season, and has the largest basin in the present area, see Fig. 63. The Tuntulyon River is the proposed name for the river which flowed northwards or northnortheastwards in the natural gutter at the foot of the western flanks of the Ribkwo Volcano.

At this stage, the Ribkwo Volcano was being drained by subparallel radially disposed consequent streams, flowing northnortheastwards in the present area. The flanks lying west of the central zone have been tilted back, as explained in Chapter 2, p. 61, so that they must have suffered some reversal of drainage. In the



a. Eruption of Kafkandal Complex and Mugor Trachytes.

b. Erosion of Kafkandal Complex and Mugor Trachytes.

FIG. 64 Drainage west of Kafkandal.

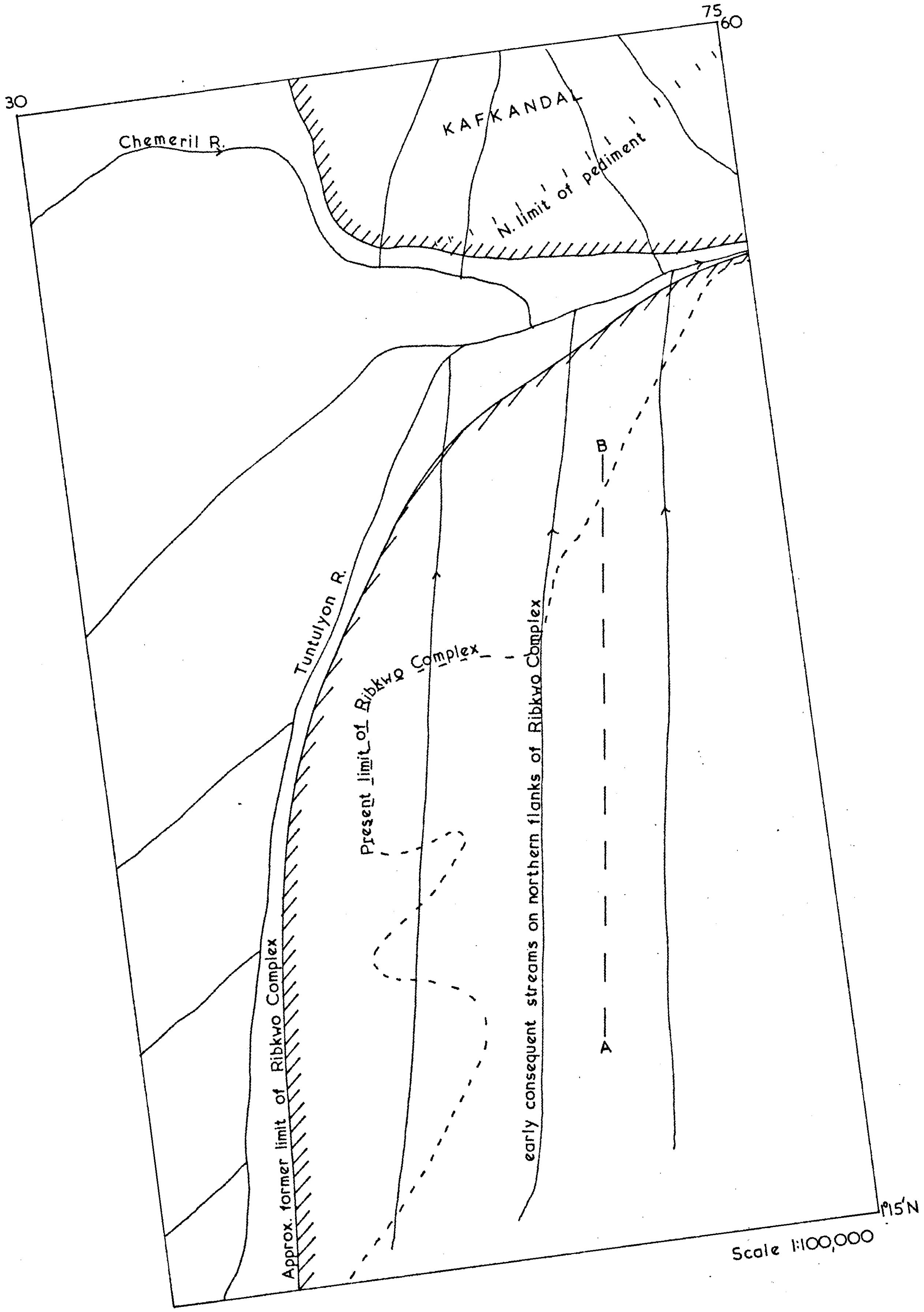


FIG. 65 Influence of Ribkwo main shield unit on drainage.

present area, these western flanks are only present near 1°15'N, where they have been deeply incised, so that very little remains of the original surface.

However, there are abundant remnants of the early drainage on the northern flanks, see Plate XIX, in which the parallel nature of the early consequent streams is clearly visible.

At this stage, the eastward tilting of the Ribkwo Volcano took place, rejuvenating the drainage, and bringing the direction of maximum slope round from northnortheast to northeast. The run-off now took this new direction, and under the impetus of rejuvenation, cut back into the volcano. If there ever was a clear topographic divide running symmetrically north-south through the centre of the northern flanks (e.g. line AB in Fig. 65), and in such a low angle shield volcano there may not have been, then this would be displaced to the western edge of the flanks by this tilt. Thus, the increase in downcutting would be most effective in that area. In this manner, the rejuvenated rivers cut right through the volcano, capturing the Tuntulyon River at 3 points. The rivers responsible were the Kamosing, Chemukol, and Chepsawach, from south to north, Fig. 66.

These three rivers also captured and divided the flank drainage as shown in Fig. 66. The earliest watersheds, between the Chepsawach Chemukol and Kamosing were initially just north of each of these rivers. This feature is still retained between the first named two, but the watersheds either side of the Kamosing have migrated to a more central position, Fig. 63.

The Kotoro River is apparently another post-tilt river, but which has not yet cut back through the western edge of the complex.

The original flank drainage still retains its northnortheasterly trend, as is seen in Plate XIX. North of 1°19'N, these streams occupy open valleys with gently rounded profiles, becoming steeper and more

Plate XIX Part of Ribkwo Complex northern flanks, illustrating drainage. See also Fig.67

Plate XIX Part of Ribkwo Complex northern flanks, illustrating drainage. See also Fig.67.

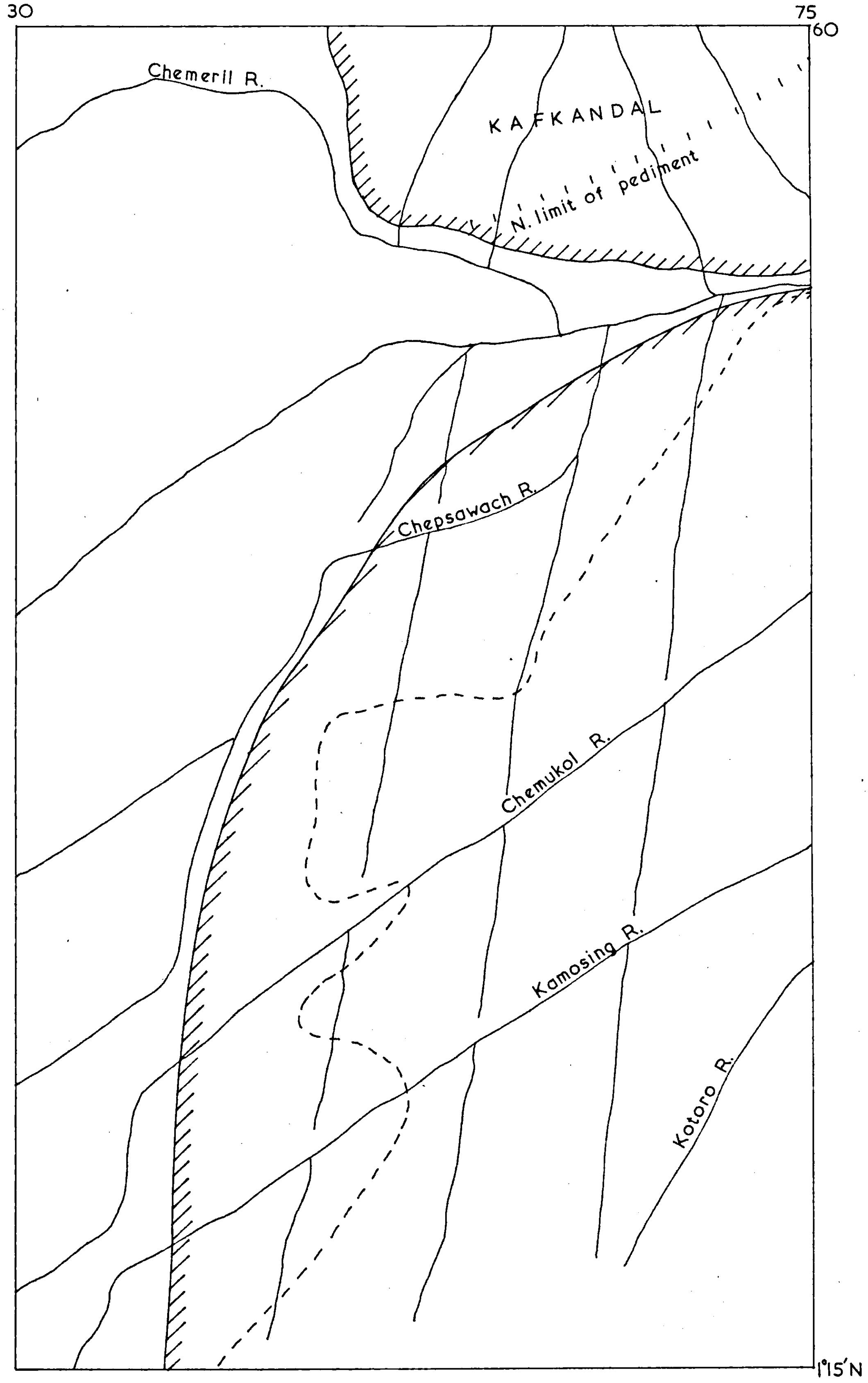


FIG.66 Effects on drainage of eastward tilting of Ribkwo main shield unit.

incised as they approach the Chemukol or Chepsawach. The tributaries flowing north into the Kamosing are all incised to a much greater degree, as are those of the Kotoro. North of 1°19'N, hanging valleys occur above the north bank of the Chemukol as shown in Fig. 67, a theoretical block diagram.

Since these modifications took place, the dismembered Tuntulyon River has migrated eastwards, so that the disjointed portions are no longer collinear. There is, of course, no evidence that they were perfectly so to begin with. The elbows of capture are still well marked, particularly in the case of the Kamosing capture, where the former headwaters of the Tuntulyon River are deeply entrenched, leaving the former trunk stream about 400 ft. (120 m.) higher, see Fig. 68.

The later stages in the history of the Ribkwo Volcano also affected the drainage to different degrees. Kariamangro Caldera probably acted as a basin of internal drainage. Subsequent erosion, however, completely removed the eastern part of the volcano prior to the eruption of the Kachila and Nasaken volcanics, so that through drainage to the east was probably established over most of the volcano at this stage.

The next event is the eruption of the Kachila and Nasaken volcanics. Together, they constituted a thick blanket of lavas and sediments which encroached on the eastern margins of the Kafkandal and Ribkwo complexes, partially blocking off the Akoret Gap. The drainage through the gaps was diverted mainly to the south, but a few of the remnant radial streams draining off Kafkandal were directed northwards, where they today form the Chepkilowan River.

Besides the Akoret drainage, the Chemukol, Kamosing and Kotoro Rivers were also affected by the Kachila Volcanics, to the extent that

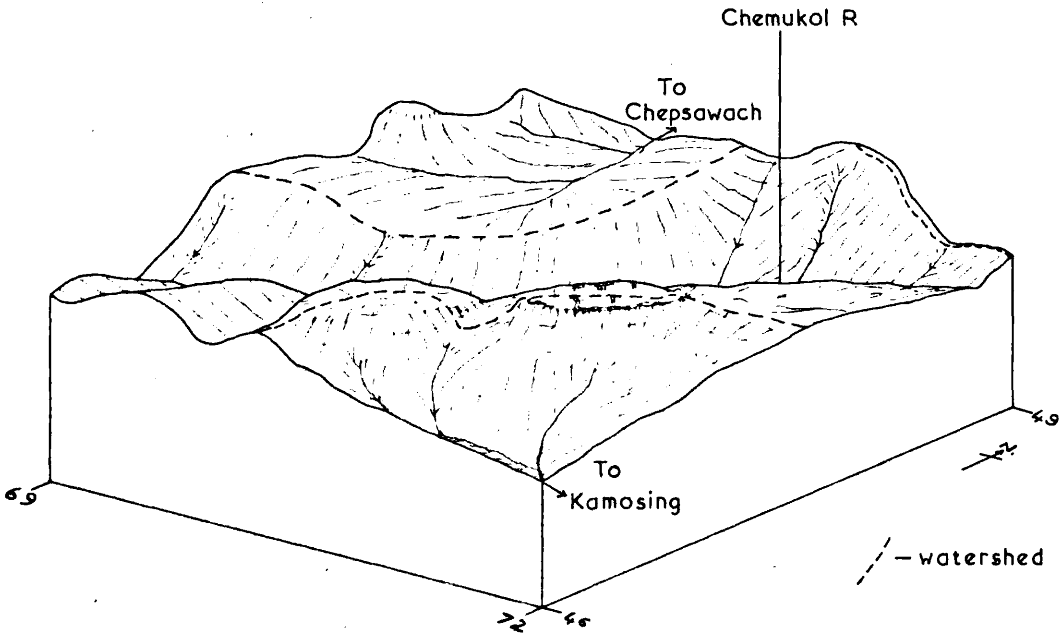


FIG 67 Intersection of younger (N.E.-S.W.) with older (N.-S.) system of drainage, N. Ribkwo Complex flanks.

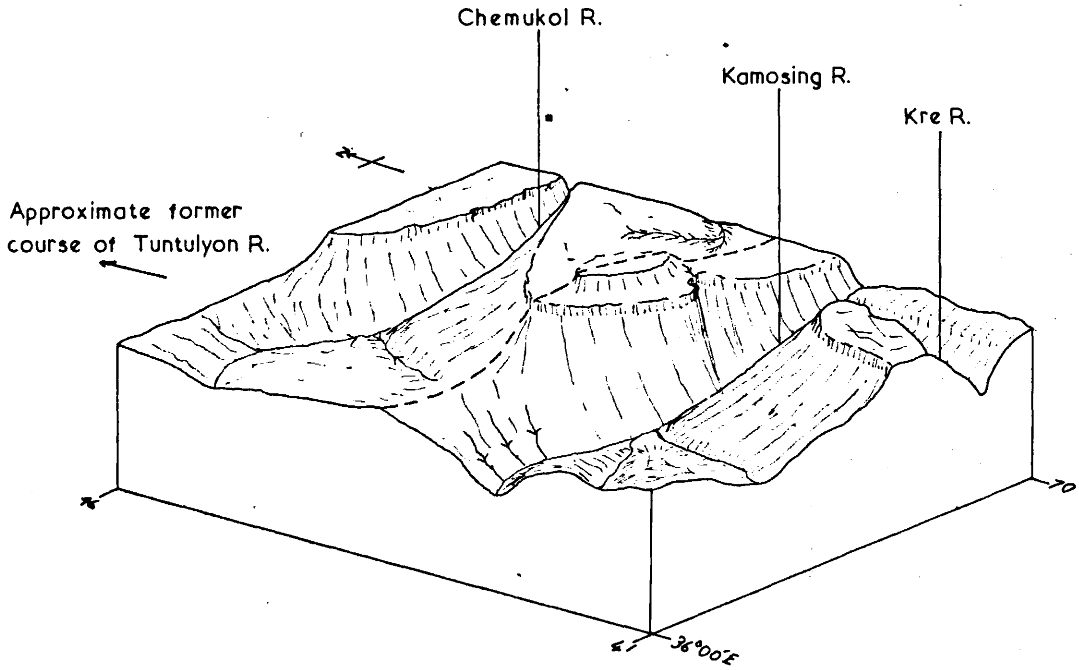


FIG.68 Schematic block diagram of the Kamosing and Chemukol gaps.

the Aterir Lake was formed, see Chapter 2 pp. 74-78 , where there is a detailed account of its development. The situation at this stage is visualized in Fig. 69.

The course of the river(s) which intermittently drained the lake is not known.

After the eruption of the volcanics, there was a period of erosion in which the sub- Kamosing Formation surface was produced. The Chepsawach, Chemukol, Kamosing and Kotoro Rivers had by now united to form the Aterir River, which ran more or less across the site of the former Lake Aterir, and then southeastwards across the pediment until it reached the central low in the rift valley. Traces of this river remain as the present Aterir River and, it is thought, as that stretch of the Kamosing River southeast of square 8146. These two portions of what are now separate rivers are perfectly collinear at the present day, from C to D in Fig. 63.

The eruption of the Kamosing Formation basalts further affected the drainage pattern. The Tuwut and Pativat Basalts appear not to have exercised much control, but the Kahanavisian member altered the Kamosing and Aterir Rivers to their present courses.

Flowing down the valley of the Chemukol as far as square 7249, it turned southeastwards out of the valley on to the sub- Kamosing Formation pediment, immediately south of the higher ground of Cherelgat. From here it flowed southeastwards and then eastwards on a fairly bro front, completely cutting across the valleys of the Kamosing and Kotoro, Fig. 70, and preventing them from reaching the Aterir River. They were thus diverted down the southern side of Kahanavisian, until they reached the dismembered lower portion of the Aterir valley, which they then re-occupied. The Aterir River was similarly affected, being completely blocked by the basalt, so that it was diverted east-

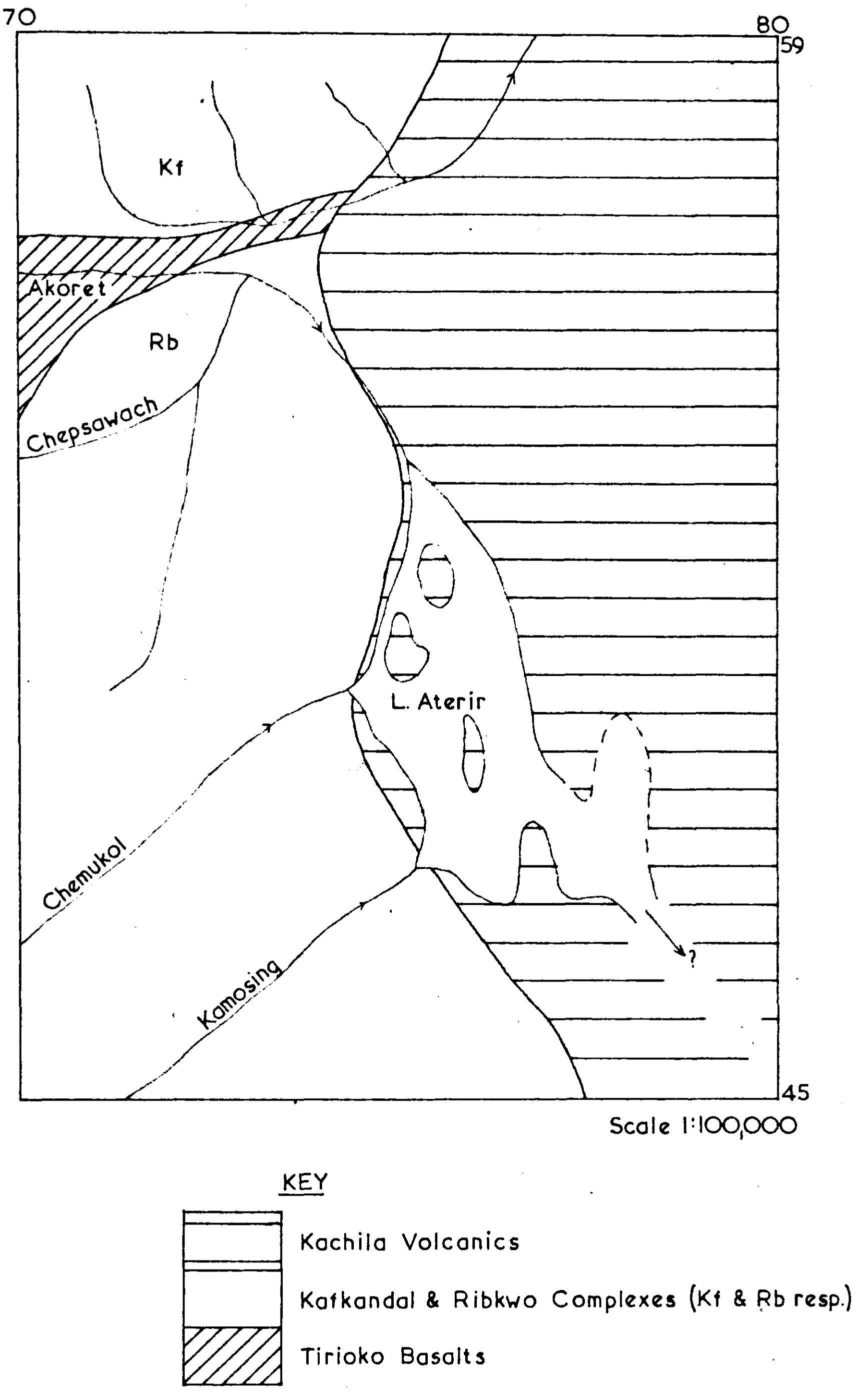


FIG 69 Drainage during eruption of Kachila Volcanics

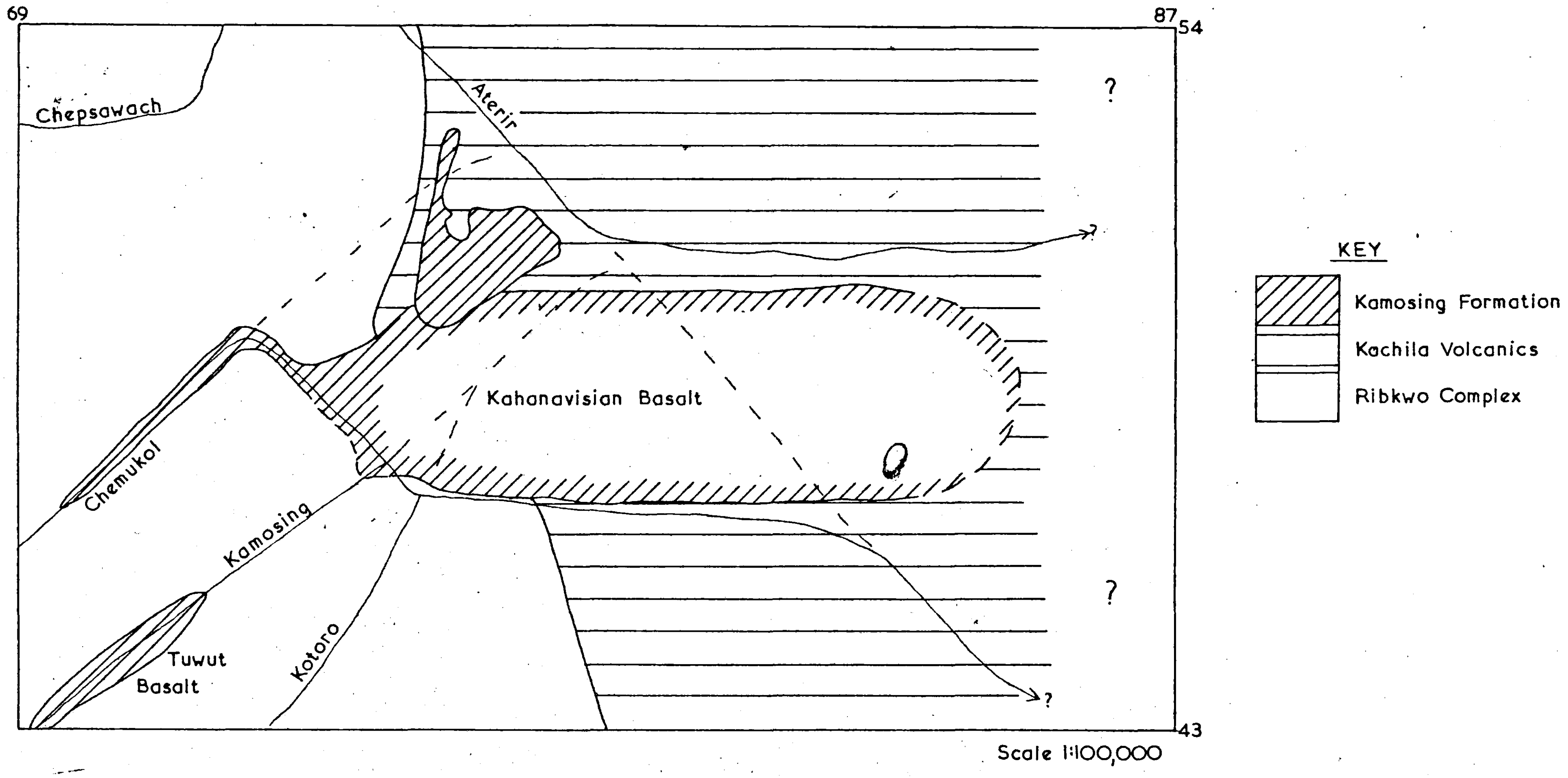


FIG. 70 Effects upon drainage of eruption of Kamosing Formation.

wards along the northern edge, Fig. 70.

Since its eruption, the Kahanavisian Basalt has been dissected by small streams, particularly in the Aterir Basin. The major water-courses, though, have not been substantially altered.

During the Pleistocene, local pediments formed adjacent to the Suguta River, and coalesced to form the Suguta Surface, a nearly planar surface which today extends from Kapeddo to Lomelo and beyond. This surface bevels the Kapeddo Tuffs, but is being actively incised at the present day by the Suguta and its tributaries. This is attributed to lowering of Lake Rudolph (Dodson, 1963, p.37), and consequent rejuvenation.

Another feature of this rejuvenation is the fact that those small streams which enter the Suguta at 819422 and 821423 have been rejuvenated to such an extent that they are about to capture the Kamocing at 766464 and 796465 respectively. Similar phenomena were seen by Chapman (personal communication), associated with large rivers flowing out of the Kamasia Hills on to the plains near Nginyang.

CHAPTER 5

MINERALOGY AND PETROGRAPHY

PART 1: MINERALOGY

1. Feldspars

(a) Alkali-feldspars are characteristic of the trachytic and phonolitic lavas and pyroclastics. They are divided into four series, based on their optical properties, which roughly correspond to their thermal histories (Deer, Howie & Zussman, 1966, pp.55-65). In the present area, all the volcanic alkali-feldspars appear to belong to the high albite-sanidine series, in which the optic axial plane is at 90° to (010).

Feldspars with less than Or_{37} (usually called anorthoclase) crystallise initially with monoclinic symmetry, but invert on slow cooling to a triclinic symmetry. If cooling is rapid, the inversion is delayed, but eventually takes place with the formation of cross-hatched twinning. With more than Or_{37}, monoclinic symmetry occurs throughout the cooling history, such feldspars being referred to as soda-sanidine and sanidine, with increasing Or.

Cryptoperthitic unmixing, detectable only by X-rays, takes place in the range Or_{25}-Or_{60}, and can be used to determine the relative proportions of Ab and Or. Determinations on apparently monoclinic feldspars from the present and neighbouring areas have indicated compositions in the range Or_{25}-Or_{35}, i.e. within the anorthoclase composition range, but without showing cross-hatched twinning.

Hence the presence or absence of cross-hatched twinning is not a reliable guide to composition. Neither are measurements of 2V, since the An content can cause variations of up to 10°, independently of the Ab/Or ratio. The 2V in fact varies from about 35° to 45° for sanidines from the present area, increasing to 55° or 60° for anorthoclase.

The terms sanidine and anorthoclase refer to alkali-feldspars distinguished only by the absence or presence of cross-hatched twinning, and are not compositionally controlled.

(i) Sanidine (correctly referred to as soda-sanidine) is recognized by the absence of cross-hatched twinning. Sanidine occurs both as phenocrysts and in the groundmass of lavas, and as inclusions in pyroclastics. It is commonly flattened parallel to (010). Ill-defined twin lamellae parallel to (010) and uneven extinction provide evidence for incipient inversion.

Sanidine phenocrysts often contain inclusions of earlier minerals, particularly aegirine-augite and ore, or have a thin peripheral zone of minute inclusions which is thicker at the (001) faces of the phenocryst. In phenocrysts with shadowy twin lamellae, that portion beyond the peripheral rim of inclusions remains untwinned. Carlsbad twinning is frequently seen, Manebach and Baveno twins are less common.

In the groundmass, sanidine commonly shows Carlsbad twinning and occasional incipient twinning. Parallel orientation of (010) faces is interpreted as being induced during flow, and gives many trachytes a well developed banding or even fissility.

(ii) Anorthoclase, conversely, is recognized by the presence of cross-hatched twinning. Even so, some simply twinned feldspar may be anorthoclase which went through the inversion temperature without developing cross-hatched twinning, but this may not occur in the volcanic environment.

It is less common than sanidine. In trachytes and phonolites, it forms large phenocrysts (5/115, 5/225) but is rarely in the groundmass. The cross-hatched twinning may extend over the whole crystal (5/115), or it may occur patchily (5/12). Carlsbad, Baveno and Manebach twins also occur. There is often a peripheral zone of inclusions as in sanidine, and similarly, the cross-hatched twinning does not extend beyond it, though Carlsbad twinning does.

Anorthoclase also occurs in trachymugearites, interstitial to plagioclase (5/108, 5/71). Untwinned alkali feldspar may also occur mantling plagioclase phenocrysts.

(b) Plagioclase Feldspars are of course present in all the basalts, and in the hawaiites and mugearites. Rocks with varying proportions of plagioclase and alkali feldspar form a natural transition between these lavas and the trachytes.

Plagioclase in basalts, i.e. of composition An_{70-50}, shows the usual features - combined twinning, zoning etc. Peripheral zones of inclusions, however, are not seen. It most usually occurs as laths, but also occurs as anhedra with low birefringence and undulose extinction.

In mugearites and hawaiites, the composition is not always precisely determinable. Michel-Levy and combined twinning methods indicate, however, that the composition of cAn_{20} and $c.An_{40}$ renders these names appropriate. Such rocks are usually only sparsely phyric, and frequently contain resorbed earlier phenocrysts of higher An content (5/25). This phenomenon is also seen in basalts (5/45).

Plagioclase is rare in trachytic rocks, but 5/385 contains oligoclase phenocrysts, mantled by untwinned alkali feldspar.

2. Feldspathoids

(a) Nepheline is present by definition in the phonolites, but occurs also in many of the trachyphonolites. It is absent from the basaltic lavas.

It occurs as phenocrysts in the black flinty phonolites of the Tugen Hills Group, but is then frequently altered to a fibrous zeolite in which the fibres are oriented parallel to an edge of the crystal. There is occasionally a thin concentration of granules of aegirine and aenigmatite around phenocrysts in these phonolites. In the groundmass, nepheline is often not distinguishable from feldspar.

In the fissile trachytes and trachyphonolites, nepheline is only identifiable as phenocrysts, and is probably only present as such. It is different from the phenocrysts associated with the Tugen Hills Group in the following respects:

(i) It shows evidence of being xenocrystic, in that it has embayed, curved margins (3/384, from McClenaghan's area).

(ii) It alters to a mixture of analcite and brownish, unresolvable material (5/13, 5/14).

(iii) There is almost invariably a fringe of aegirine and/or aenigmatite anhedra, which may be as wide as the phenocryst itself (5/13, 5/14).

However, in the author's area, no fresh, identifiable nepheline was seen in any fissile trachyte and it may be that these phenocrysts are in fact alteration products after sodalite phenocrysts. Unaltered nepheline is present however in trachyphonolites from the Ribkwo Volcano in McClenaghan's area.

(b) Sodalite is commonly found in trachytes and trachyphonolites of the Ribkwo Complex, and phonolites of the Tugen Hills Group. It is distinguished from nepheline by the fact that it is always isotropic, and from analcime by its 6-sided sections (5/141). Its most common habit is as microphenocrysts, with a sparse fringe of aegirine and/or amphibole (5/259).

A single crystal of sodalite was recorded from a welded tuff, 5/22. It is six-sided, pale blue with a dark brown margin, and is charged with minute black inclusions.

(c) Analcime. This is a widely distributed mineral in both basaltic, and trachytic and phonolitic lavas. It most commonly occurs as a meteoric mineral, i.e. of entirely secondary origin (q.v., p.117) but may also occur as a primary mineral.

Examples of the latter are 5/421 and 5/417, where analcime occurs as a late groundmass mineral in an ankaramitic basanite and an analcime basalt respectively. As a primary mineral of this nature, its occurrence is distinct from the veins and vesicles of its secondary environment. It also occurs in phonolites (5/445 and 5/437), pervading the groundmass.

3. The Pyroxenes

(a) Augite occurs most commonly in basaltic rocks. In trachytes and phonolites, the clinopyroxenes are usually greenish and probably have a certain proportion of the aegirine molecule.

In basaltic rocks, augite occurs both as phenocrysts and as a groundmass mineral. The phenocrysts may be colourless, pale brown (5/400) or rarely show the purplish tints associated with a higher than usual titanium content (5/395). The pale brown varieties often have slightly darker margins (5/425). The usual properties such as zoning, twinning and resorption are frequently present.

In the groundmass of basalts, augite occurs most commonly as small colourless grains displaying an intergranular texture with plagioclase sections. Titaniferous augite also occurs in the groundmass of some basalts, when it is invariably ophitic (5/220) or sub-ophitic (5/417, 5/235) to earlier minerals. In all the slides examined, such titan-augite precludes the presence of clinopyroxene phenocrysts, or small intergranular grains in the groundmass.

Augite occurs only rarely in trachytes. A pale green clinopyroxene occurs in 5/12 ii, in which the maximum extinction angle is 41°. This rock has no normative aegirine. In phonolites, it is replaced by a darker green clinopyroxene, thought to contain appreciable aegirine.

(b) Aegirine-augite is restricted to trachytic and phonolitic rocks. It occurs most commonly as phenocrysts, usually rounded and partly resorbed (5/415). It also occurs as anhedra in coarser grained trachytes when it appears to have crystallised at the same time as alkali feldspar. In thin section, it is pleochroic from green to yellowish green, always paler than aegirine, from which it can thus be distinguished. The margins of phenocrysts are almost invariably a darker green.

(c) Aegirine is abundant in the groundmass of trachytes and phonolites, but never occurs as phenocrysts. It is pleochroic from dark green to lighter green, the body colour frequently masking the interference colours. It occurs either as discrete anhedra (5/34 ii) or as aggregates of blade-shaped sections (5/90, 5/325). Such trachytes often appear speckled in hand specimen. It also occurs mantling earlier formed feldspathoids (5/435).

In phonolites, it occurs most commonly as very small equant dark green granules, distributed either evenly (5/445) or as mossy patches (5/415), when the hand specimen appears speckled.

4. Amphiboles

(a) Alkali amphiboles are present in nearly all of the trachytes and phonolites examined. They occur only in the groundmass, never as phenocrysts. Usually, the individual grains are too small for the optics to be fully determined, and it is thought that due to extensive substitution between the various members, the pleochroic scheme alone is not enough to fully determine the species of amphibole present. Accordingly, it is not certain how many species are recognized. From the pleochroism, two common types of amphibole were recognized:

(i) Blue-green amphibole (5/80ii, 5/122)

(ii) Brown-green amphibole (5/140, 5/152).

The blue-green amphibole corresponds most closely to arfvedsonite, on account of its pleochroism and anomalous extinction, and the greenish-brown amphibole to kataphorite.

In coarser grained rocks, and occasionally in fine grained lavas, larger sections of amphibole occur, and can be more specifically identified. In this manner, eckermannite was identified in a drusy cavity in 5/302, and magnesiokataphorite in a syenite (5/405).

In many trachytes (e.g. 5/219) two amphiboles coexist.

Aenigmatite (or cossyrite) is a dark brown chain silicate probably related to the pyroxenes. Its absorption is much greater than the brown amphiboles, completely masking the interference colours. It is very common both in trachytes (5/6) and phonolites (5/445), where it may occur as anhedra or mossy aggregates of small granules or anhedra (5/66).

(b) Brown amphibole as distinct from the brown alkali amphiboles is uncommon, and occurs only in the Kapchererat Formation. In 5/424, it occurs as partly resorbed phenocrysts. Reaction in the groundmass has led to their being surrounded by thick concentrations of granules of black opaque ore. In 5/441, the reaction has proceeded further, so that many of the sections are almost entirely replaced by opaque ore. The same mineral also occurs in 5/385, an anorthoclase-trachyte.

It is pleochroic from brown to reddish brown, with 2V(-) c. 70°.

5. Olivine

(a) Forsteritic olivine is found in nearly all of the basalts in the area. It is typically colourless, and always extinguishes evenly. It is often idiomorphic, with pyramidal terminations well developed. It is invariably altered, even if only slightly, to one of the following: a greenish material, referred to as bowlingite (5/48, 5/306), or less commonly iddingsite (5/40, 5/320). Rarely (5/35) a fibrous green mineral, possibly antigorite or talc, occurs replacing olivine, associated with opaque ore.

(b) Fayalitic olivine occurs in some trachytes (e.g. 5/303). It forms small euhedral phenocrysts with sharp pyramidal terminations. It is pale lemon yellow in colour, only weakly pleochroic, and is unaltered.

6. Micas

(a) Biotite is not common. In phonolites it occurs as phenocrysts, showing the usual strong pleochroism from dark brown to pale brown (5/427), or even from almost black to yellowish (5/410). Occasionally, reaction rims of magnetite granules are developed. It also occurs as anhedra in the associated pyroclastics.

It occurs as a groundmass mineral in some basalts of the Kapchererat Formation (5/372) and in the Kokomaa Formation (5/417) where it is pleochroic from reddish brown to straw yellow.

(b) Phlogopite was noted in only one instance. It occurs in a trachymugearite (5/71) of the Kachila Volcanics as anhedral plates. It is pleochroic from pale yellow to nearly colourless, and is pseudo-uniaxial negative.

7. Accessory Minerals

(a) Opaque black ore occurs in nearly all the rocks examined. It is probably magnetite or ilmenite, or both, since both usually occur in the norm. It may occur as dispersed grains in trachytes (5/16ii), basalts (5/240) and hawaiitic rocks (5/52), or as resorbed grains with skeletal form in basalts (5/438) and trachytic rocks (5/410). It also occurs as a late phase, moulded around groundmass minerals in basalts (5/149, 5/242).

Ilmenite is more positively identified when it occurs as wisps and shreds (5/58).

(b) Quartz appears as an accessory in some trachytes, in the Kafkandal and Mugor Trachytes, and in the Tugen Hills Group. In

5/248 and 5/311b, it occurs as shapeless anhedra occupying interstices in the groundmass. It forms no more than 5% of either rock, but appears to be a primary mineral. It occurs similarly in 5/423 and 5/382 from the Tugen Hills Group, in sections large enough in 5/423 to give a uniaxial (+) figure.

(c) Apatite is present in all the lavas examined. It occurs nearly always as clear colourless prisms, usually small in trachytes, larger in basalts (5/349), but occasionally it occurs as large dusky brown crystals, with fibrous inclusions arranged in parallel fashion perpendicular to the c axis (5/330). Such apatite is also seen in alkaline igneous rocks in Australia (Joplin, 1968, p.69).

8. Secondary Minerals

(a) Zeolites occur in many of the trachytic and phonolitic lavas and pyroclastics, and less abundantly so in the basalts. Only rarely are they specifically identifiable, since they usually occur as aggregates of small fibres and grains.

(i) Scolecite was specifically identified in 5/386, a vesicle from the Kapchererat Formation, where the mineral occurs as prisms up to 2 cm. long in association with natrolite and analcime.

(ii) Natrolite is identifiable when all the fibres of the same appearance are length slow, as in 5/386, and are birefringent up to 1st order yellow.

The other fibrous zeolites are difficult to identify, as they are in general either length slow or length fast, depending on the orientation.

(iii) Analcime, in the secondary environment, is usually faintly birefringent, the anisotropism being unevenly distributed throughout the extent of the mineral (5/234a). It occurs in cavities (234A), vesicles (5/411) and veinlets. It also occurs in the matrices of pyroclastics (5/431) and sediments (5/363). It is often associated with calcite (5/437), when it is evident that the analcite crystallized before the calcite.

Among the other non-fibrous zeolites is heulandite in 5/50ii, with 2V (+) circa 40°.

(b) Other secondary minerals include the following:

(i) Chalcedony occurs in some trachytes (5/9, associated with secondary quartz), but more often in clastic rocks such as fault breccias (5/33) or the Turkana Grits (5/363). It may occur as spherulites with a radiating structure, or in a disseminated, microgranular form.

(ii) Chlorite occurs as a secondary mineral in the groundmass of some basalts as a microgranular aggregate with pinpoint polarization (5/35), or fibrous (5/395).

(iii) Ferruginous material is present in many altered lavas, as a consequence of the breakdown and oxidation of mafic minerals. It occurs interstitial to feldspar in 5/39, a trachyte lava; disseminated throughout the matrix in 5/23, a fault breccia; as bands with irregular fronts in 5/372; and densely charging the groundmass, 5/281. Most of the ferruginous material appears to be limonite.

(iv) Calcite occurs in some basalts, and in the Turkana Grits. It occurs rarely in phonolites (5/437) in association with late stage analcime.

In basalts, it occurs as an interstitial mineral enclosing feldspar in 5/395, where it may even be deuteric, and not entirely secondary. In this slide, the calcite is in the form of large crystals. In 5/45, it occurs in vesicles, not enclosing feldspar, and with a fibrous, radial structure, the centres of crystallization being the vesicle walls. The interstices between adjacent 'fronts' are filled, partly or wholly, with a granular calcite mozaic.

It occurs also in the matrix of the Turkana Grits, microgranular in 5/351, associated with chalcedony, and as a coarser grained sparitic monomineralic matrix in 5/359.

In 5/234A, two minerals occur in vesicles, associated with analcime, which have not been seen elsewhere in the area. They are tentatively identified as follows: cassiterite, with uniaxial +ve figure, high R.I. and high birefringence; and a red prismatic mineral, possibly thulite, with the following properties: pleochroic from rose red (with cleavage E-W) to colourless (cleavage N-S), length slow, birefringence up to 2nd order blue, straight extinction.

Ferrostilpnomelane was provisionally identified in 5/104, where it occurs as laths and anhedra in the groundmass, pleochroic from green to greenish yellow, uniaxial or pseudouniaxial negative (Hutton, 1938, pp.172-206).

PART 2: PETROGRAPHY

In this section, lavas will be dealt with first, then intrusives, and finally clastic rocks. Six-figure numbers after specimen numbers are grid references pertaining to the map of the area.

1. Basalts

The majority of the basalts of the area occur in the Kapchererat, Tirioko and Kamosing Formations, with only minor amounts elsewhere.

In both the Kapchererat and Tirioko Formations, lavas other than basalt occur in minor quantity, and include mugearites, hawaiites and trachytes. These will be dealt with in later sections.

(a) The Kapchererat Formation

Basalts in this formation cover a range from aphyric olivine-free types (5/372, 5/420) to plagioclase phyric (5/365) and highly augite and olivine phyric types (5/421 & 5/425), see Table 2. The commonest texture is intergranular, in which small augite and olivine grains occur between plagioclase laths. Plagioclase also occurs as an interstitial mineral, as shapeless anhedra, with ill-defined, shadowy twin lamellae and undulose extinction. Biotite occurs as accessory in many of the specimens examined, although it is usually very rare. In 5/372 and 5/443, it is an abundant accessory.

Two basalts, 5/424 and 5/441, contain a brown amphibole. In the former slide, the amphibole is a reddish brown colour, and mildly pleochroic, and the four grains present are surrounded by fringes of magnetite grains, leaving the body of the grain unaffected. The plagioclase varies in composition from An_{75} to An_{49}. In 5/441, the crystals are almost completely replaced by magnetite. Replacement proceeds along cleavages and fractures, so that the remnant cores are already impregnated with magnetite. The body colour is a more greenish brown, and the pleochroism is more intense in basal sections. From examination of the phenocrysts and groundmass, a complete history for the crystallisation of this rock can be elucidated:

1. Apatite and magnetite.
2. Amphibole and augite phenocrysts together, since both may enclose the other.
3. Alteration of amphibole.
4. Plagioclase phenocrysts, since these enclose all earlier minerals.
5. Reaction of magma with augite, embayment of latter, and formation of spongy margins with magnetite grains. That portion of an augite phenocryst enclosed by plagioclase remains unaltered, while that part near the rim of the plagioclase phenocrysts is only a little altered, indicating that the alteration agents can only penetrate a short distance along the suture.
6. Continuing and rapid crystallisation of magnetite, plagioclase and augite in the groundmass. The plagioclase in the groundmass varies from c.An_{56} down to c.An_{40}. There may be a range in composition down to oligoclase.

Table 2. KAPCHERERAT FORMATION BASALTS

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass						Second. Minerals	Remarks
		% of Rock	Olivine	Augite	Plagioclase	Other	Texture	Olivine	Augite	Plagioclase	Ore	Other		
5/365 045472	Plag-phyric oliv. basalt	20% p > 0	Sparse, altered to idd.	-	15 mm. An_{56-70} Glomero-phyric and single	-	Inter-granular	Common, altered to idd.	Small colour-less grains	Small laths rather altered, composition not de-termined	Dissemi-nated. Mt.grains and Il. laths		Anal. & ct. in cavities	Altered
5/371 125476	Ankar-amitic oliv. basalt	30% A > 0	Slight altern. to bowl.	Pale brown, darker borders occas.with green cores Often em-bayed	-	-	Inter-granular	All gradns. from phxts.	All gradns. from phxts.	Anhedra to tiny laths An_{58-64}	Largely obscures ground-mass. Many granules	-	Bowl. after olivine	-
5/376 196452	Plag-phyric oliv. basalt	20% P > 0 > ore	Clear, unal-tered	-	10 mm. Very thin. An_{54},An_{59} recorded. Parallel texture	Magne-tite, re-sorbed	Inter-granular	Small grains	Small grains	Laths and anhedra c.An_{56}	Abundant mt. granules	Apatite clear visible prisms	Some ferrug. interst. material	-

Table 2 (cont.) KAPCHERERAT FORMATION BASALTS

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass						Second. Minerals	Remarks
		% of Rock	Olivine	Augite	Plagioclase	Other	Texture	Olivine	Augite	Plagioclase	Ore	Other		
5/421 171500	Ankaramitic oliv. basalt	40% A > O	Clear, barely altered to bowl. 5 mm. Never encloses augite	Mainly pale brown with darker rims, rarely an even, darker brown. Much resorption 3 mm. May enclose olivine	-	-	Intergranular	Abundant as small euhedra, unaltered	As pale brown grains	Laths and anhedra up to An_{62}	Abundant granules densely charging groundmass	Primary (?) anal.	Anal. & a little chlorite	-
5/441 202511	Basalt	10–15% Amph= A > P	-	Pale green, darker green rims; Occasional brownish green $2\frac{1}{2}$ mm.	> 15 mm. Up to An_{63}	1. Dusky Ap. enclosed by all phxts. 2. Brown amph. pseud. by black ore 2 mm.	Intergranular	-	Pale green prisms	Laths, ranging down from phxts & as anhedra. Composition variable	Mt. grains	Rare biotite. Apatite needles	Sparse greyish material. A very little fibrous zeolite in small rare vesicles	-

Only one specimen was taken of the Karu River Basalts. This is a subophitic olivine basalt (5/235), in which numerous olivine microphenocrysts and plagioclase laths are partly enclosed by plates of slightly titaniferous augite.

(b) The Tirioko Basalts

In this formation, all the basalts except one were seen to contain olivine, either in the groundmass or as phenocrysts. Only in 5/330 was it not definitely identified, but may be present in the groundmass, obscured by magnetite.

Many of the specimens collected come from the microphyric unit (p.43). Typical such lavas are described in Table 3, 5/246 and 5/318. The phenocrysts are seldom evident in hand specimen, but in thin section microphenocrysts of olivine, and less commonly augite, are ubiquitous. So also are plagioclase phenocrysts, and in many specimens, even those in which large plagioclase phenocrysts are few in number, there is usually a complete gradation in size from phenocrysts to groundmass plagioclase.

Only four of the lavas (267, 142, 330 & 137) are completely aphyric. Of these, the first two have a sub-ophitic texture, while the latter two are intergranular.

Ophitic and sub-ophitic lavas, however, can also be porphyritic. Augite phenocrysts never occur, but both olivine and plagioclase occur together (5/123, 5/149).

The strongly porphyritic lavas all display intergranular texture in the groundmass. Specimen 5/249 is an oceanite, Plate XX,* thought to represent a residual material, see Table 3. Its chemistry is discussed on p. 173. Lavas from the augite-olivine-phyric unit (p.45) have a lower phenocryst content than 5/249, and a higher augite to olivine phenocryst ratio. The lavas in the plagioclase-phyric unit (5/283) also have an intergranular texture. The phenocrysts are up to 2 cm. long, and are frequently arranged so that the (010) planes are sub-parallel. However,

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* Plates XX-XXXII inc., and XXXIV are after p.141.

Table 3. TIRIOKO FORMATION BASALTS

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass						Second. Minerals	Remarks
		% of Rock	Olivine	Augite	Plagioclase	Other	Texture	Olivine	Augite	Plagioclase	Ore	Other		
5/330 311499	Basalt	5%	-	-	-	Sparse 3 and 4 sided mt.	Intergranular	?	?	Laths and small anhedra. An_{46} & An_{52} otherwise obscure	Abundant small granules, densely charging groundmass	Pale brown ap.with fibrous inclusions	A little chlorite; ct. in tiny vesicles	-
5/142 316427	Oliv-basalt	0%	-	-	-	-	Sub-ophitic	A few microphxts. altering to bowl.	Anhedra of brownish violet titaug. interst. to and moulded on to plag.	Stout laths & anhedra with wavy extinction An_{54-60}	Scattered anhedra & quadrate grains	Apatite needles	A little chlorite	-
5/123 726505	Oliv-basalt	5% P = 0	.3 mm. altering to bowl.	-	4 mm. Corroded, almost free of inclusions An_{70-75}	-	Ophitic	From microphxts.to groundmass	Large plates of titaug. enclosing up to 50 fspars.	Small laths & anhedra, ranging down from phxt. to c.An_{55}	Grains,& shapeless anhedra moulded on plag.	Very scarce apatite	Chlorite	-
5/246 278603	Oliv-basalt	10%	Abundant microphxts. 1 mm. Marginal altern. to bowl. some corrosion	-	-	-	Intergranular Sub-parallel	Clear rounded grains	Numerous tiny colourless prisms	Mainly laths, sparse anhedra An_{55-60}	Small granules, abundant, but not dense	-	-	-

Table 3 (cont.) TIRIOKO FORMATION BASALTS

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass						Second. Minerals	Remarks
		% of Rock	Olivine	Augite	Plagioclase	Other	Texture	Olivine	Augite	Plagioclase	Ore	Other		
5/318 262543	Oliv-basalt	25% P > O	.2 mm. Scattered micro-phxts, altering to bowl.	-	1 mm. Range down to ground-mass laths c.An_{60}	Occa-sional quadrate ore, partly skeletal	Plag., sub-parallel; Ground-mass inter-granular	Scatte-red small grains	Numerous small clear prisms	Laths and anhedra From An_{60} to An_{52}	Numerous specks & granules	-	Some ferru-ginous material	Vesi-cular, no se-condary in-filling
5/249 663609	Ocea-nite	60% O>> A > P	2 mm. Almost unaltered Embayed	3 mm. Pale brown, no dark rims Some re-sorption	1 mm. Rather scarce, resorbed. Up to An_{72}	Mt.1.5 mm. Rounded and embayed	Inter-gra-nular	Range down from mphxt. size	Greyish grains & prisms	Laths and anhedra An_{54}	Large square sections to granules	Apatite needles	Interst. brown ferru-ginous material	-
5/283 688579	Plag. phyric basalt	20% P>>A = O	Micro-phxts in ground-mass en-closed by plag.	.4 mm. Very sparse, pale brown, corroded	1 cm. 1 of An_{60}, other-wise inde-terminate	Sparse mt., en-closed by plag.	Inter-gra-nular	Colour-less micro-phxts.	Pale brownish or greyish prisms	Laths and anhedra, mainly without lamellar twinning	Square sections to granules	Apatite needles Minor brown amph.& (?) biotite	Granular zeolite (?) in cavities and vesicles 2V(+)c.40°	

this does not impart a fissility to the rock, since the groundmass feldspars are not so arranged.

(c) The Tumungir Basalts

Of the three specimens collected, 5/254 is olivine-plagioclase-phyric, whilst 5/274 and 5/276 (Table 4) contain pale brown augite phenocrysts in addition. All three have intergranular texture, and there is a sharp distinction in each between phenocrysts and groundmass.

(d) The Ribkwo Complex

Basalts in this complex occur exclusively in the main shield unit, principally in its lower part. All are olivine bearing, and have intergranular texture. Phenocrysts are usually not larger than 2 mm., and consist principally of olivine (5/121). Specimen 5/128 also contains abundant plagioclase phenocrysts, otherwise rare in the Ribkwo Complex basalts.

Specimen 5/41 from Cherelgat (p.59) is almost completely aphyric, see Table 5, but the other basalts all contain a moderate proportion of phenocrysts.

(e) Nasaken Complex

In this, there are two occurrences of basalt in the author's area, in square 8160, and at Katirr, 7661 & 7662. The former is a single flow, greyish in hand specimen, and was identified in the field as a trachybasalt. In thin section, 5/188, it is aphyric, and too weathered for the composition to be accurately determined. Plagioclase microphyric laths are visible, and iddingsite after groundmass olivine.

The Katirr basalt member of the Nasaken Complex consists locally of three flows. Specimen 5/220, Plate XXI, is an ophitic olivine basalt, with both olivine and plagioclase phenocrysts, but 5/221, although of the same general composition, has an intergranular texture. It is not certain, from

Tables 4 & 5. BASALTS IN THE KIDDEH GROUP

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass						Second. Minerals	Remarks
		% of Rock	Olivine	Augite	Plagioclase	Other	Texture	Olivine	Augite	Plagioclase	Ore	Other		
5/276 692559	Oliv-basalt	10% O = A > P	2 mm. Slight altern. to bowl.	3 mm. Pale brown Corroded, w.spongy margins	4 mm. Very resorbed & corroded. An_{55} on one phxt.	Sparse corroded mt. crystals	Inter-granular	Small grains	V.small clear colourless prisms	A few laths & remnants of phxts. but mainly as anhedra Compn. indeterminate	Abundant small granules, partly obscuring plag.	Scattered flakes of brown amph.	Columnar zeolite w. 2V(+) c.40°	FUMUNGIR BASALTS TABLE 4
5/41 738491	Oliv-basalt	5% O > P	Micro-phxts. only, grading down to groundmass Completely altered to idd.	-	One or two corroded phxts.	-	Inter-granular	Micro-phxts.& groundmass	Colourless prisms	Sub-taxitic laths, few anhedra. Too small to determine compn.	Anhedral granules; a few square sections	Ap. needles		RIBKWO COMPLEX TABLE 5
5/111 723417	Oliv-basalt	10% O	Micro-phxts.	-	-	-	Inter-granular verging on sub-ophitic	Micro-phxts.	Pale brown prisms & anhedra	Mainly laths, a few anhedra An_{65}-An_{56}	Mainly as large ophitic plates. A few equant granules	A few ap. needles	Chlorite; v.little calcite	
5/128 744544	Oliv-basalt	20% P > O	1 mm. Altering to bowl. Embayed	-	1½ mm. Occasional cruciform clusters. Corroded An_{55}-An_{85}	-	Inter-granular	Small grains & micro-phxts.	Colourless tiny prisms & pale brown anhedra	Laths, occ. anhedra. Down to c.An_{55}	As either granules or poikilitic plates	-	Chlorite	

field relationships, whether these two specimens are from different flows, or different parts of the same flow.

(f) The Kachila Lavas

In this section are included the basalts in Karianamani and the Aterir beds. All those examined contain olivine, or pseudomorphs of iddingsite after olivine. Many of the basalts are only microphyric, bearing small phenocrysts of olivine and plagioclase, and rare augite. The commonest texture is intergranular, but 5/139 and 5/162A are ophitic, while 5/161 has a fluxion texture imparted by the parallel alignment of plagioclase microphenocrysts.

Among the oldest basalts in this unit are the Morupuran basalt (5/50) and those thought to be its lateral equivalent low in Karianamani (5/162A) and Kachila (5/168), see Table 6. These vary slightly in the relative proportions of plagioclase to olivine phenocrysts.

Four specimens of the upper Aterir basalt (5/45, 5/47, 5/129 & 5/131) were collected. These all showed a preponderance of plagioclase phenocrysts over olivine. Phenocrysts average An_{64} in composition, and the groundmass c.An_{56}.

The basalts in Kachila itself cover the stratigraphic range of the Kachila Volcanics. They are more or less consistent in that they have a higher phenocryst content than those from other formations, and in that the phenocrysts are larger. Phenocrysts may form up to 25% of the rock, plagioclase in general predominating over olivine, and also attaining a greater maximum size. Specimen 5/209 (Table 6) has the highest phenocryst content. Specimen 5/171 is distinct in that it has accessory biotite, in sections large enough to obtain a diagnostic interference figure.

Of the three specimens obtained from the Chemusowai unit, 5/157A from the lower flow consists of equal proportions of plagioclase and iddingsite after olivine phenocrysts in an intergranular groundmass. Specimens 5/176

Table 6. BASALTS IN THE KIDDEH GROUP

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass						Second. Minerals	Remarks
		% of Rock	Olivine	Augite	Plagioclase	Other	Texture	Olivine	Augite	Plagioclase	Ore	Other		
5/50 768481	Oliv-basalt	30% P > O	.5 mm. Slight altern. to bowl.	-	c.An_{58} up to $1\frac{1}{2}$ mm. corroded subparallel	Early mt. square grains, much resorption	Inter-granular	Range down from micro-phxts	Small prisms	Range from phxts.down to v.small laths Compn. indeterminate		Ilmenite wisps & rods. Mt. granules Apatite prisms	Stilbite in 2 vesicles	NASAKEN & KACHILA COMPLEXES
5/162A 751568	Oliv-basalt	5% Ol > P	1.5 mm. Altern. to bowl.	-	One or two resorbed phxts.	-	Ophitic	Intergranular to fspar. laths	As purplish weakly pleochroic plates	Mainly laths w. poorly developed lamellar twinning. Compn. indeterminate	As skeletal and irregular grains, moulded on fspar. & pyroxene. Widely spaced	A little biotite	Chlorite	
5/209 806503	Oliv-basalt	30% P > O > A	.5 mm. Very corroded Completely altered to idd..	.3 mm. Very pale brown colour	5 mm. Mainly single, a few glomerophyric clusters. Very few inclusions. An_{75}	-	Inter-granular	Small, rounded, altered to idd.	Small pale brown grains & anhedral crystals	Range in size from phxt.(An_{75}) to groundmass laths (An_{54}).Also anhedral	Shapeless blebs & grains		Brownish ferrug. material	

and 5/177 from the upper flow are much finer grained, and contain only occasional plagioclase phenocrysts. Olivine is restricted to the groundmass, which is fine grained, with an intergranular texture.

(g) The Kamosing Formation

All three members of this formation are olivine basalt lavas.

The Kahanavisian member consists of two lava types, probably related to two sources. That lava in the Chemukol River and on Kahanavisian itself is an olivine-augite microphyric basalt, represented by 5/40 in Table 7. It is seen to be very vesicular in thin section, the interstices being occupied by irregular, often connected, cavities, sometimes filled with coarsely crystalline calcite. The olivines are altering to a characteristic orange coloured iddingsite.

The other type comprises the outlier of the Kahanavisian basalt member overlying the Aterir beds. It is markedly feldspar phyric, and lacks the porosity of the facies described above. Further, the olivines are altering not to iddingsite, but to bowlingite. Of these, 5/156 in Table 7 is typical, Plate XXII. Field relationships in square 7549 indicate that this is the younger of the two types.

The Pativat member strongly resembles the feldspar phyric type of the Kahanavisian basalt member. Again, there is a slight variation in the phenocryst content, but the general rule is that plagioclase exceeds olivine. In most of the specimens, there is a range in size from phenocryst down to smallest groundmass in both olivine and plagioclase (5/27, 5/70, 5/82). In some, however (5/81, 5/62), there is an abrupt break between phenocrysts and groundmass.

The two specimens (5/107 & 5/260) of the Tuwut member are not at all similar. Specimen 5/107 closely resembles the olivine-phyric type of the Kahanavisian member, in that the olivine phenocrysts are rimmed with iddingsite, and that plagioclase phenocrysts are absent. In 5/260, however,

Table 7. BASALTS IN THE KAMOSING FORMATION

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass						Second. Minerals	Remarks
		% of Rock	Olivine	Augite	Plagioclase	Other	Texture	Olivine	Augite	Plagioclase	Ore	Other		
5/40 748475	Cliv-mela-basalt	10% O	1 mm. Marginal altern. to orange idd.	Occasional micro-phxts.	-	-	Inter-granular	Scattered grains, altering as indicated	Numerous pale brown, slightly pleo-chroic prisms & equant grains	Small laths interst. to augite c.An_{57} Also an-hedra, poss. alkali feldspar w. ill defined twinning	Scattered ophitic plates	Minute ap. needles	Ct. in vesicles & pores	Kahana-visian Member, olivine augite-phyric type
5/156 767506	Oliv-basalt	20% P > O = A	1.5 mm. Corroded Altering to greenish bowl.	Pale brown non-pleo-chroic 5 mm.	3 mm. An_{75} down-wards. Strongly zoned & corroded	-	Inter-granular	Small grains	Small pale brown prisms & granules	At least some An 55 Size and compn. vary from Phxt. down to laths and anhedra	Small equant granules	Ap; a little chlorite		Kahana-visian Member, plag-phyric type
5/260 672422	Oliv-basalt	-	-	-	Micro-phxt. only	-	Inter-granular	Small rounded grains. Slight marginal altern. to powdery black material	Pale brown to violet-brown grains & prisms	Laths from 1 mm. to smallest groundmass Also as mesostatis of anhedra	Irregular grains & smaller equant granules	Ap. needles		Tuwut Member

olivine is restricted to the groundmass. Plagioclase occurs as microphenocrysts ranging down to groundmass laths in size.

2. Mugearitic and Hawaiitic Lavas

These provide a link between basalts on the one hand and phonolites and trachytes on the other. The production of the latter two from basalt probably involves the production, during some stage of the process, of mugearitic and hawaiitic lavas. This will be more fully expounded in Chapter 6, but it is sufficient at this stage to say that a possible consequence of this process is the production of trachytic lavas bearing plagioclase phenocrysts.

Such lavas do occur in the present area, and they differ in thin section and hand specimen from the more normal fissile trachytes - the "end-product trachytes" so to speak. These lavas will be dealt with in a separate section, as they are rightly trachytes.

Mugearites and hawaiites are defined by the anorthite content of the groundmass plagioclase. The identification is usually easy in the case of hawaiites, but with the mugearites, there appears to be a structural passage between oligoclase, via K-oligoclase to anorthoclase. Potash-oligoclase (or K-oligoclase) has been reported by Macdonald (1942, pp.793-800) to have a 2V(+) as low as 10°. The author has observed groundmass feldspar in mugearites, and phenocrysts in plagioclase-trachytes with a 2V(+) c.50°, but not lower than this. It is considered, therefore, that some of the present lavas contain K-plagioclase. Further, other lavas in the present area have oligoclase phenocrysts mantled by untwinned alkali feldspar, indicating again that they have a transitional chemistry.

In hand specimen, the mugearites and plagioclase trachytes are distinctive in that they are almost aphyric, invariably fine grained, and non-fissile. They are usually buff or purplish, and are sometimes characterized by abundant smooth-walled vesicles, drawn out in the direction of flow, and usually devoid of secondary infilling.

(a) The Kapchererat Formation

One mugearitic lava, 5/440, occurs in this formation, Table 8. Four other specimens, varying in hand specimen from aphyric and structureless to strongly fissile, are plagioclase trachytes, judging by the groundmass feldspar.

Specimen 5/440 is a trachymugearite, 23% of the normative feldspar of which is orthoclase. The groundmass feldspar, however, consists almost solely of oligoclase laths, with very little interstitial or rim overgrowth material. The groundmass feldspar has 2V(+) c.60°, and is probably potash-oligoclase.

(b) The Chepkowagh Mugearite

This is a single lava flow and dyke, from the latter of which 5/360 was taken, see p.150. The dyke and lava are identical in hand specimen.

(c) The Tirioko Basalts

The leucocratic unit of this formation consists of a hawaiite (5/275) and at least two flows of plagioclase-trachyte. Specimen 5/275 shows two phenocrysts in thin section, which have albite twinning and large 2V(-). The groundmass feldspars also show albite twinning, but the composition is difficult to determine. It is thought, from the extinction angles, to be sodic andesine, see Table 9.

(d) The Ribkwo Complex

Four lavas akin to mugearites were found in the main shield unit. They are unknown at higher levels. McClenaghan (personal communication) reports that such lavas only occur in the lower part of the complex in his area.

Specimen 5/89 has microphenocrysts of feldspar with albite twinning and 2V(+) 55°-65°. Some of the groundmass feldspar has albite twinning, with extinction angles less than 10°, see Table 10.

Specimen 5/104 is distinct in that it contains sparse microphenocrysts of pale purple titaniferous augite. The groundmass feldspar is calcic

Table 8. MUGEARITE IN THE KAPCHERERAT FORMATION

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Feldspathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/440 202515	Mugea-rite	< 5% F > others	One equant, lamellar fine scale twinning 2V(-)c.60° Sieved w. alterations after mafics	-	-	-	Sub-parallel	Potash-og. 2V(+)c.60°	Original mafics & ore altered to interstitial ferruginous material		Abundant apatite needles	Black ferrug. material, red in reflected light	

Table 9. HAWAIITE IN THE TIRIOKO BASALTS

5/275 696556	Hawai-ite	<5%	Two, plagioclase 2V(-)c.60°	-	-	-	Inter-granular	Oligoclase to andesine	V.small colour-less prisms of augite	Small anhedra of yellowish pleochroic amphibole(?)	Minute ore granules		

Table 10. MUGEARITIC LAVAS IN THE RIBKWO COMPLEX

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Feldspathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/89 (i) & (ii) 763444	Mugearite	-	Microphxts., grading down to groundmass size	-	-	-	Inter-granular	Apparently mainly oligoclase	Very small prisms & grains	-	Shape-less ore grains	Much ferrugi-nous material	Only a small part of 5/89(i) is in a fresh con-dition
5/104 728462	Mugearite	-	-	-	-	-	Inter-granular	Oligoclase laths & anhedra	Very small prisms	-	Magne-tite granules	Calcite. Stilpno-melane	

oligoclase, more positively identifiable than in 5/89. This specimen also contains possible ferrostilpnomelane, see p.119.

Specimen 5/286 is a mugearite or hawaiite, but the groundmass feldspar is difficult to determine accurately. The microphenocrysts and the groundmass anhedral feldspar have 2V(+) c.60° and may be K-oligoclase or K-andesine.

The other lava, 5/108, has hand specimen properties similar to these mugearites, but in thin section all the larger feldspars have 2V(-). An analysis gives 53.34% SiO_2, low for a trachyte, but nevertheless this lava is considered to be an anorthoclase-trachyte.

(e) Mugearitic and Hawaiitic Lavas in the Kachila Volcanics

In this complex, there are lavas which have hand specimen properties intermediate between those of trachytes and basalts. They are generally purplish, buff or grey, structureless, and frequently vesicular.

In thin section, they contain phenocrysts of potash oligoclase, but the groundmass feldspar is usually impossible to determine. It frequently shows crude lamellar twinning, and may be either oligoclase or anorthoclase. Wet analyses show them to have SiO_2 contents of 53% to 57% by weight. Only occasionally can these lavas be positively designated as mugearites or plagioclase-trachytes.

Specimen 5/53 from high in the Morupuran 'basalt' is a mugearite, with 50.08% SiO_2 in the analysis, and a groundmass feldspar composition of up to An_{34}, but mainly below An_{30}.

Stratigraphically similar lavas are 5/56 and 5/130, but the groundmass contains some alkali feldspar, and these are possibly plagioclase-trachytes (q.v., p.128).

Other mugearites are 5/173, from the Kachila Volcanics on the east of Karianamani, and 5/71 and 5/100, from the complex between Pativat and Kahanavisian. They are described in Table 11.

Table 11. MUGEARITIC LAVAS IN THE KACHILA VOLCANICS

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Felds-pathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/173 796537	(Trachy-) mugearite	Low < 5%	1. Anorthoclase, 2V(-)c.60° 3 mm. 2. K-oligoclase, 2V(+)55°-60° .5 mm.	-	Pale brown augite marginal conc. of mt grains	-	Taxitic shear planes at c.30° to flow structure	Much plag. laths cp. oligoclase but some c.20% untwinned anhedral alk.fspar	Small colourless prisms, mainly altered	-	Mt. grains & specks	Nearly all mafics altered to limonitic mess.	
5/53 767497	Mugearite	<5%	.5 mm. Plagioclase variable in composition	-	-	One relict olivine, replaced by idd & ct, & as microphxts in g'mass	Randomly oriented feldspar laths	Oligoclase to sodic And.	Small pale green granules	Possibly pale brown to green kataphorite	Ore as interstitial anhedra. Relict ol mphxts.	Reddish ferruginous material	Large vesicles ct.
5/71 798435	Trachy-mugearite	-	Very scarce lamellar oligoclase .5 mm.	-	Microphxts only of pale grey augite .5 mm. scarce	0.3 mm. Phlogopite 2V(-) < 10°	Non-taxitic	A few laths, mainly plates of oligoclase much anhedral alk.fspar	Small colourless prisms	-	Abundant specks of mt. Abundant apatite needles		
5/100 776451	Mugearite	c.10%	-	-	Possible alterations after augite 0.4 mm. Scarce	Olivine 0.6 mm, Iddingsitic relics. Mt mphxts 0.2 mm.	V.poorly taxitic	Mainly oligoclase laths, some anhedral	Original mafics altered to black & red material, dull in reflected light Magnetite granules in g'mass			Reddish ferruginous material	

3. Plagioclase-trachytes

This group of lavas has been introduced in section 2 of this chapter, p. 25 . They are frequently associated with mugearites and hawaiites and are almost certainly related.

(a) Kapchererat Formation

At least four such lavas are present, in which the feldspar phenocrysts have 2V(+) 50°-60°, but in which the groundmass feldspar is twinned only on the Carlsbad law.

Specimen 5/396, Table 12, contains phenocrysts of brown amphibole, Plate XXIII, with 2V(-) 65°-70°. The feldspar phenocrysts have 2V(-) 60°-70°. In 5/390 plagioclase phenocrysts with 2V(+ & -) occur. The majority have 2V(-) large, but one gives 2V(+) 65° by Tobi's Method. This same specimen has olivine phenocrysts replaced marginally by iddingsite, and internally by anhedra of serpentine (?). Plagioclase phenocrysts with 2V(+) large also occur in 5/393, from the basal trachytic member of the formation, and also in 5/394, where they are accompanied by two phenocrysts of biotite or brown amphibole undergoing alteration to magnetite.

(b) The Tirioko Basalts

The leucocratic unit contains two flows of plagioclase trachyte lava, 5/280 & 5/282. The plagioclase phenocrysts are either positive or negative, with optic axial angles greater than 50°, Table 13. The groundmass feldspar is twinned only on the Carlsbad law and is considered to be sanidine. The fine grain of the lavas, though, renders this uncertain. Both lavas contain iddingsite pseudomorphs after olivine, and pale green diopsidic augite.

Specimen 5/291, from beneath Kafkandal, is very similar, although the mafics are all altered, and only pseudomorphs after olivine are recognizable.

(c) The Kachila Volcanics

This complex has several lavas which contain plagioclase phenocrysts

Table 12. PLAGIOCLASE-TRACHYTES IN THE KAPCHERERAT FORMATION

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Feldspathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/396 187401	Trachyte	< 5% F > others	2 mm. Plagioclase $2V(-)c.70^{\circ}$ lamellar & carlsbad twinning	-	-	1 mm. Brown amphibole dense rims of magnetite granules, $2V(-)c65^{\circ}$	Sub-parallel	Mainly sanidine, some plagioclase	Original Mafics altered		Ore, altered to haematite(?) dull red in reflected light	Yellowish material after interstitial mafics	

Table 13. PLAGIOCLASE-TRACHYTE IN THE TIRIOKO BASALTS

5/280 703553	Plag.-trach.	5-10% F > 0	Andesine & labradorite Cruciform or single xtals; resorbed 4 mm.	-	Scarce pale green diopsidic augite, 1 mm.	1. Strongly resorbed olivine replaced by iddingsite, 1 mm. 2. Resorbed magnetite $\frac{1}{2}$ mm.	Taxitic sub-parallel	Mainly sanidine, some plagioclase	Colourless augite	Scarce anhedra of pale green to pale yellow pleochroic amphibole	Interstitial ore		

with 2V(+) 55°-65°, and in which the groundmass feldspar twinning is not sufficiently distinct for plagioclase to be identified with certainty. This is true of specimens 5/49, 5/52, 5/56, 5/57 and 5/130. Of these, 5/49 contains fairly abundant iddingsite pseudomorphs after olivine in a non-taxitic altered groundmass. Specimens 5/52, 5/56 and 5/57 contain sparse potash-oligoclase phenocrysts with 2V(+) c.60°, and pale greyish augite phenocrysts in a taxitic groundmass, see Table 14. Specimen 5/130 is altered, and the groundmass is charged with black ferruginous material.

In specimens 5/75 and 5/169, Table 14, the groundmass feldspar is recognizable alkali feldspar, although the phenocrysts are of course plagioclase, 2V(+) c.60°. In 5/75, the plagioclase phenocrysts are extremely resorbed and unstable. The groundmass is a sub-taxitic felt of thin sanidine laths rich in minute wisps and thin shreds of reddish material, with scattered euhedral granules of magnetite.

4. Trachytes and Phonolites

These lavas are the most extreme differentiates in the present area. They occur abundantly, and possess distinctive hand specimen properties.

The basis of their classification is the amount of modal feldspathoid, Fig. 71.

Phonolite
\- - - - - - - - - - - 15

Trachyphonolite 10 % Modal Feldspathoid

\- - - - - - - - - - - 5
Phonolitic trachyte
\- -Trachyte - - - - 0

Quartz trachyte 5
% Modal Qu
\- - - - - - - - - - - 10
Alkali rhyolites

Fig. 71. Classification of Trachytes & Phonolites

Table 14. PLAGIOCLASE-TRACHYTE IN THE KACHILA VOLCANICS

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Feldspathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/75 793435	Plag.-trach.	5-10% San > Plag > mag.	1. 4 mm. Plagioclase 2V(+) 60°-70° 2.Sanidine	-	-	Sparse magnetite, square sections, resorbed	Sub-taxitic	Sanidine laths	Original mafics altered to brownish inter-stitial material		Magnetite scat-tered eu-hedra 0.1 mm.		
5/52 781487	Plag.-trach.	< 5%	Sparse oligoclase microphxts. 0.3 mm.	-	Sparse pale grey diopsidic augite		Taxitic w. shear bands	Anortho-clase &/ or og. laths	V.small colour-less prisms & granules	Kataphorite anhedra	Anhedral magnetite	Yellowish inter-stitial material	
5/169 809524	Plag.-trach.	low	One of An44 by twinning; Two twinning extinction of 3° - oligoclase(?)	-	V.scarce pale green augite 2 mm.	0.5 mm. Magnetite, euhedral, embayed & resorbed	Taxitic, shear band 30° to flow banding	Sanidine & anortho-clase laths	Reddish granules-alteration after augite ?	Brown-green anhedral plates of kataphorite	Dusky apatite prisms 0.7 mm. V.rare; magnetite specks & abundant apatite needles		

No alkali rhyolites occur in the present area. Those trachytes containing between 10% modal quartz and 10-15% modal nepheline are usually taxitic, and the presence of quartz or nepheline can only be confirmed in thin section. There is often a well marked planar structure which sometimes gives rise to a fissility, especially in trachytes, seen in thin section to be due to the parallel arrangement of the groundmass sanidine platelets, which are flattened parallel to (010). This fabric is commonly regarded as being induced during flow, but the c-axes of individual crystals are not preferentially aligned within the plane of fissility. Similarly, the (010) planes of feldspar phenocrysts are coplanar but the c-axes are not parallel, and it is possible that the fissility was produced after movement had ceased, but while the flow was still liquid, by flattening under the stresses of load compaction. This fissility is not present in all cases. Occasional flows may appear structureless in hand specimen, but may show taxitic texture in thin section.

The phonolites on the other hand, though frequently flow banded, are rarely fissile. They are almost always finer grained than trachytes, are commonly black when fresh, weathering to a white cortex, and have a flinty texture, with a smooth fracture. The flow banding is usually more evident in weathered specimens, often showing folds produced during flow.

These flinty phonolites are present only in the Tugen Hills Group, but fissile trachytes occur from the base of the Kapchererat Formation to the top of the Kiddeh Group in the present area, and are present in other areas in the Pleistocene to Recent central volcanoes of the axial rift zone. They reach their greatest development in the trachytic complexes of the Kiddeh Group.

(a) Kapchererat Formation

At the base of this formation is a fissile trachyte. A specimen from it (5/393) in the Kapunyan River is a trachyte with plagioclase phenocrysts. Specimen 5/380, from 178438, is an aphyric lava, but the feldspars are completely obliterated by minute fibres of a length slow secondary mineral that is birefringent up to 1st order yellow. The mafics are altered to interstitial mossy black material, dull red in reflected light. Quartz is present as single anhedra up to 0.2 mm. across. They are not obviously primary in that the taxitic texture is not diverted around them, but they do not fill obvious vesicles either.

(b) Tugen Hills Group

As mentioned above, this is the only stratigraphic unit in which flinty phonolites occur. They occur in conjunction with fissile trachytes which range from nepheline to quartz bearing. It is proposed to deal with these rocks in order of decreasing silica saturation.

(i) Quartz trachytes. Only two exposures of quartz-trachyte lava were found. Specimen 5/301, from the Kewarr Horst, is a coarse grained aphyric trachyte, in which quartz occurs as anhedra occupying cavities in the groundmass, either partly or completely. When only partly so, they are often terminated by straight edges, along which there is a concentration of finely divided turbid matter, and it is thought that the quartz grew into the cavity, and is therefore secondary. It forms less than 5% of the rock.

Specimen 5/423, from Singelel, has between 5% and 10% of quartz occupying cavities in the groundmass. It stands sharply in contrast to the turbid, altering feldspars. It always completely occupies its cavities, encloses feldspar sub-ophitically, and is inferred to be a late stage primary mineral.

(ii) Trachytes without quartz or visible nepheline occur. If the quartz in specimen 5/301 is secondary, this would be an example, Table 15. Others occur sporadically in the Sigatgat Hill Complex, 232421, on Kiptugun, 2549, and associated with the Chepachaghom centre, 209478 and 214456. Anorthoclase phenocrysts are often present (5/401, 209478) and phyric biotite laths occur in 5/408, 232421. Other trachytic rocks, particularly dykes, have been recorded from the Lelgrong Tuffs, but they are usually too altered for a complete determination to be made. Even in the above four mentioned

Table 15. TRACHYTES AND PHONOLITES FROM THE TUGEN HILLS GROUP

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Feldspathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/301 272559	(Quartz) trachyte	-	-	-	-	-	Taxitic	Sanidine, $2V(-)30^\circ$ (1 mm.) Altering to fibrous secondaries	Prisms & aggregates of aegirine	-	Reddish secondary material. Quartz - possibly secondary	Quartz	
5/140 323414	Trachyphonolite	5% Ne=Sod >F	Scarce sanidine 3 mm.	Microphxts of sodalite & nepheline .2 mm.	-	-	Subtaxitic	Sanidine	Aegirine as mossy patches	-	Cossyrite as mossy patches & fringing fspathoid		Prior's KENYA TYPE (see p.134)
5/226 333402	Trachyphonolite	Ne > Sod > F = A	Occasional sanidine .7 mm.	Nepheline & sodalite .3 mm.	Occasional pale green diopsidic augite .4 mm.	Magnetite, rare equant grains .2 mm.	Subtaxitic	Sanidine	Aegirine & cossyrite in mossy patches	-	-	Chabazite (?) in vesicles	KENYA TYPE
5/228 327400	Trachyphonolite	5% - 10%	-	Nepheline ± sodalite .5 mm. Altered to brownish material	Very scarce green diops. augite 1 mm.	Very small magnetite grains	Taxitic	Sanidine in sheaves	Aegirine interstitial to fspar	Kataphorite $2V(-)c.0^\circ$	-	Analcime in vesicles	KENYA TYPE
5/324 271497	Trachyphonolite	20% F > Ne	Sanidine 5 mm. 1 mm.	Nepheline slight alteration 1 mm.	Green diopsidic augite 1 mm.	Equant mt, resorbed .3 mm.	Poorly taxitic in patches	Sanidine laths & alkali-fspar anhedra	Interstitial aggregates of aegirine granules	-	Cossyrite as mossy patches & fringing nepheline		KENYA TYPE

Table 15 (cont.) TRACHYTES AND PHONOLITES FROM THE TUGEN HILLS GROUP

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Felds-pathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/432 253474	Trachy-phonolite	c.5% Fsp > F	Very occasional sanidine 5 mm.	Microphxts of nepheline or sodalite altered to brownish material .2 mm.	Occasional prisms of pale green diopsidic augite .3 mm.	-	Taxitic	Sanidine	Inter-stitial aegirine		Inter-stitial cossyrite; Occasional square granules of mt.		KENYA TYPE
5/437 226485	Phonolite	5% > Ne~F	Sanidine .5 mm. Unaltered	Nepheline .5 mm. square & hex. sections V. fresh	Scarce microphxts of pale green diopsidic augite	-	Flow-banded, non-taxitic	Sanidine laths. Poor orientation	Aegirine as anhedra & rimming diopsidic augite	Cossyrite. A little kataphorite	Analcime & calcite		LOSUGUTA TYPE
5/445 255515	Phonolite	-	-	-	Rare diopsidic augite with thin aegirine rim	-	Flow-banded	Sanidine laths	Aegirine as dispersed & clumped granules	Mossy patches of cossyrite. Isolated anhedra of kataphorite	Analcime		INTERMEDIATE TYPE

specimens, the mafics are altered to a reddish secondary product, and only in 5/444 from 2549 does a little aegirine remain unaltered.

(iii) Phonolitic trachytes and trachyphonolites occur abundantly throughout the Group. They may contain between 0% and 15% of modal feldspathoid, see Fig. 71, but in practice usually contain between 2% and 10%. Percentages below refer to actual point counts done on numbered specimens. In hand specimen, they are commonly dark grey to black and have a sub-flinty to rough fracture. Fissility in general is absent, even in those lavas which are coarser grained than the average. Specimens 5/140 and 5/141 are typical.

In thin section, these rocks are commonly altered. The feldspathoid is invariably replaced to some extent by a brownish turbid aggregate of zeolite (?), ± analcime, and it is not always certain whether the original feldspathoid was nepheline or sodalite. They frequently show hexagonal outlines, and are often surrounded by fringes of aegirine. Specimen 5/140 is typical of the flinty varieties. It contains scarce sanidine phenocrysts up to 3 mm. long, abundant microphenocrysts of fresh sodalite as hexagonal sections, and fresh nepheline as four-sided and six-sided sections, the feldspathoids being surrounded by thin fringes of cossyrite. Specimen 5/140 contains 5.0% modal feldspathoid. The groundmass is a sub-taxitic plexus of sanidine laths, with mossy aggregates of aegirine and cossyrite anhedra, see Table 15.

Specimen 5/226, Table 15, is very similar in hand specimen, namely black, fine grained and with a sub-flinty fracture. In thin section, however, the feldspathoids are seen to be altered to a brownish partly fibrous material. Many of the sections are rectangular, indicating the former presence of nepheline. Six-sided sections might be nepheline or sodalite. A modal count of 9.7% feldspathoid was recorded. Sparse pale green phenocrysts of diopsidic augite with thin darker green rims occur. In these cases mentioned, the groundmass texture is sub-taxitic, with a tendency for some sanidine laths to be across the general textural grain.

In specimen 5/228, Table 15, the groundmass mafics occur in widely spaced mossy aggregates, leaving areas composed almost wholly of sanidine, Plate XXIV. The latter occur as laths grouped together in sheaves, and laminae of such sheaves are separated by thin "shear bands", formed when crystallisation was nearly complete. The feldspathoids are commonly fringed by aegirine and kataphorite. Large irregular vesicles occur in which analcite crystallised. The earliest stages were completely isotropic, but the last 20% or so is birefringent up to low 1st order grey, with 2V(+) up to 70°.

The fissile and non-flinty trachyphonolites are restricted almost wholly to the Cheptuimet Trachyte*. Specimens in this formation contain between 4.3% and 6.0% of modal feldspathoid. In fresh specimens, sodalite has not been recorded, and it is thus possible that all the pseudomorphs after feldspathoid were originally nepheline. Specimens 5/324 and 5/326 from Cheptuimet and Chesitoi respectively are not taxitically textured. The other specimens from Molingot, Kokomaa, or other outlying parts of the formation have taxitic texture determined by parallel orientation of both groundmass and phyric sanidine. These taxitic lavas tend also to have a slightly lower modal nepheline content, but since only one slide from Cheptuimet was counted, this may not be valid. Two specimens of the Cheptuimet Trachyte are described in Table 15. In this formation, the sanidine phenocrysts often show finely developed polysynthetic twinning, but not the cross-hatched appearance of anorthoclase.

(iv) <u>Phonolites</u> with over 15% modal feldspathoid are restricted to the lower part of the Group. They occur in the Sidekh Phonolites, and the Tiriomim Volcanics, but are absent from other formations.

One of the earliest classifications of phonolites was that of Prior (1903, pp.228-263, esp. pp.235-241), who classified them as follows:

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* Cheptuimet Trachyte is synonymous with Cheptuimet Trachyphonolite.

(a) With large nepheline phenocrysts, seldom fringed by aegirine	LOSUGUTA TYPE	Sanidine laths in groundmass give the lava some degree of taxitic texture. Cossyrite, kataphorite and aegirine scattered uniformly throughout the rock.
	KAMASIA TYPE	No taxitic texture, and the groundmass mafics are very unevenly distributed, occurring as large mossy patches, with intervening mafic free spaces.
	INTERMEDIATE TYPE	Intermediate in character to the above two.
(b) With small nepheline phenocrysts, often altered to isotropic material resembling sodalite	"4th" TYPE	Characterized by the presence of sphene and the absence of alkali amphiboles.
	KENYA TYPE	The nepheline phenocrysts are fringed with aegirine. The feldspar phenocrysts are often anorthoclase, and the groundmass has good taxitic texture.
(c) Nepheline confined to groundmass	NO TRIVIAL NAME	Nepheline occurs interstitial to groundmass feldspar laths. The mafics are alkali amphiboles and aegirine.

Only types (a) and (b) occur in the present area.

According to Prior's scheme then, the trachyphonolites examined so far are akin to the Kenya Type. It will be seen that the feldspathoidal lavas in the Ribkwo Complex are even more similar to the Kenya Type.

The phonolites (sensu stricto) in the present area belong to Prior's Losuguta and Intermediate type. Analyses of two of these specimens, 5/437 and 5/445, give 17.64% and 21.56% normative nepheline respectively. This is determined partly by the content of nepheline phenocrysts, and partly by the groundmass feldspathoid. Analcime is present in the groundmass of even very fresh phonolites, and is considered to be primary. Nepheline has not been positively identified, as the groundmass is usually very fine grained.

Specimen 5/437 is an example of the Losuguta type, Plate XXV. The phenocrysts are described in Table 15. The groundmass is fine grained, with sanidine laths (microliths of Prior, op.cit.), aegirine anhedra and cossyrite more or less evenly distributed throughout a mesostasis composed of analcime and brownish turbid material. Portions of the rock are banded due to the parallel alignment of mafic free seams and lenticles composed of analcime with an occasional central zone of calcite. These seams contain feldspar microlites, and the analcime grains which terminate in calcite are often bounded by euhedral crystal faces. Throughout the rest of the groundmass, analcime occurs as disconnected interstitial pools with ramifying, diffuse margins. The flow banding is thought to have been induced during the later stages of flow. The analcime is probably primary, and so might be the calcite.

Specimen 5/445 is similar, except that the groundmass mafics tend to occur in clumps or mossy patches. This is more noticeable with cossyrite, whereas aegirine may also occur as dispersed granules. This habit of the mafics places the rock in the Intermediate Type.

These sub-classes of Prior's, however, are transitional, and other phonolites in the present area may be assigned to the Kamasia Type. It is thought, however, that the groundmass mafics are not segregated enough to justify this.

The two specimens selected above are the freshest available, in which the groundmass features are clearly discernible. In all those examined, though, the phenocryst content rarely exceeds 5%. Phyric biotite is occasionally present, e.g. in 5/299 and 5/409. In the latter, the pleochroic scheme is from dark reddish brown to nearly colourless, and the single lath present is surrounded by a thick concentration of magnetite granules.

In other specimens, alteration has occurred, so that the nepheline (and ultimately the sanidine) phenocrysts are replaced by fibrous natrolite. The groundmass mafics break down to a limonitic aggregate, and spherulitic recrystallisation in the groundmass mesostasis takes place. In hand specimen, these thoroughly altered rocks are white to cream coloured, and may be confused with ash or tuff, but can be distinguished in thin section by the unshattered nature of the phenocrysts. Crystal inclusions in tuffs are invariably anhedral and obviously fragmental.

(c) Tirioko Basalts

Trachytes occur only rarely in this formation, and phonolites or trachyphonolites not at all. Three trachytes occur intercalated in the microphyric unit in Tuntulyon, from the highest of which specimen 5/152 (Table 16) was taken. The feldspar phenocrysts have well developed polysynthetic twin lamellae, principally parallel to the c axis in twinned crystals. A centred figure gave 2V(-) 48° by Tobi's method, and although cross-hatched twinning is not developed, the phenocrysts are considered to be anorthoclase. The groundmass is notable for the absence of pyroxene.

(d) The Kiddeh Group

In this is the greatest development of trachytes in the area. Feldspathoidal lavas are almost entirely restricted to the Ribkwo Complex, whereas quartz trachytes occur in other complexes. Flow banding is frequently present, often lending the lavas a marked fissility. Even in non-fissile lavas, the groundmass feldspars are taxitically arranged to some degree.

(i) The Kafkandal Complex & Mugor Trachytes are variable in mineralogy. They commonly have sanidine phenocrysts which have crude

Table 16. TRACHYTES IN THE TIRICKO BASALTS

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Feldspathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/152 694515	Trachyte	10% - 15%	Anorthoclase 3 mm. Twinned parallel to c only	-	Limonitic 8-sided pseudomorphs after augite (?)	-	Taxitic	Sanidine or anorthoclase laths	-	Interstitial kataphorite & arfvedsonite in equal quantities	A little magnetite	Some interstitial golden yellow material - stilpnomelane?	

Table 17. TRACHYTES FROM THE KAFKANDAL COMPLEX AND MUGOR TRACHYTES

5/302 336599	Phonolitic trachyte	c.10% F > Fspoid	Sanidine 4 mm. Includes diopsidic augite	Pseudonephelines(?) with aegirine 0.2 mm.	Pale green diopsidic augite 0.5 mm.	-	Subtaxitic	Sanidine laths. Also dispersed & aggreg. grains & mozaic	Very small shreds of aegirine	1.Cossyrite 2.Eckermannite arfvedsonite (see text, pp.115 & 138)	-		Ngapawoi unit, Kogh Pa Meyos.
5/219 771611	Trachyte	25% F >> other	Sanidine 2 mm. Resorbed; frequently, margins sieved with shreds of amphibole	-	-	1.Red-yellow 2V(-)c.0° mica-like mineral. 2.Iddingsite and serpentine after olivine?, scarce	Non-taxitic	Unoriented laths and anhedra of sanidine ; Anhedra more abundant	Aegirine	1.Arfvedsonite, as prisms with anomalous extinction	1.Cossyrite. 2.A little quartz, interst. to fspar		

Table 17 (cont.) TRACHYTES FROM THE KAFKANDAL COMPLEX AND MUGOR TRACHYTES

Rock No. & Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Feldspathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/311 664596	Trachyte	10% F >> other	Sanidine	-	-	1.Yellow-red mica-like mineral. 2.Pale yellow mineral 2V(-)c.35° see text	Non-taxitic	Sanidine laths and anhedra, laths more abundant	Prisms of dark green aegirine	Arfvedsonite	-		
5/244 275604	Trachyte	5%	Sanidine 2 mm.	-	-	-	Perfect taxitic	Sanidine laths, generally 0.2 mm.	Aegirine	Arfvedsonite? 2V(-)c.55° α deep blue-green β yellow-brown γ dark brown			Rather coarse-grained, from a very thick flow

polysynthetic twin lamellae, but not cross-hatched twinning, and in which 2V(-) measured by Tobi's method may be as high as 40°. Pseudomorphs of pale brown granular material after feldspathoid are visible in four specimens only, out of nearly 30 examined. In specimen 5/302 (Table 17), they occur in both 4 and 6 sided sections, fringed by aegirine, and appear to have originally been nepheline. In the other slides, they might have been either nepheline or sodalite. These specimens come either from the Mugor Trachytes (5/302, 323, 325) or low in the Ngapawoi unit, 5/250.

Other phyric minerals are: Diopsidic augite, pale green in colour, extinguishing up to 43°, sometimes rimmed with darker green aegirine, in continuity with the body of the phenocryst. This has been observed in two slides only (5/302 and 5/250), both of which are feldspathoid-phyric. Possible Fayalite occurs as small stumpy prisms c.0.2 mm. in length, with pyramidal terminations, straight extinction, and the slower ray parallel to the cleavage. Pleochroism weak or absent, from pale yellow to even paler yellow. This may, however, be identical to an unidentified mica-like mineral, according to X-ray studies. In thin section, this mineral is commonly zoned from reddish in the core to pale yellow at the margins, or it may be entirely red or dark yellow throughout. It is prismatic, with a straight length slow cleavage, and straight extinction. It has 2V(-) very low or near zero, and the interference figure has several colour rings. This is a very common mineral in both the Kafkandal Complex (e.g. 5/166) and the Kamungechot volcanics (5/287), but is rare in the Ribkwo Complex lavas.

Another, rather rare phyric mineral is also unidentified. It is pale yellow, non-pleochroic, with moderate relief and R.I. c.1.60-1.65. It occurs as prisms with square terminations, has no cleavage, straight extinction, and is length slow. It has low birefringence, and 2V(-) c.35°, by Tobi's method. The interference figure has no colour rings.

Its body colour is evenly distributed, and for these reasons it is thought not to be the mica-like mineral referred to above. It occurs in 5/303 and 5/311.

Groundmass minerals include sanidine, occurring as thin laths, and less identifiable alkali feldspar occurring as anhedral grains either singly or aggregated in a mosaic arrangement, in which sanidine laths are set. In lavas with such granular alkali feldspar, taxitic texture is only partly developed. The common groundmass mafics are aegirine, cossyrite, and alkali amphibole, all of which occur as interstitial anhedra. Cossyrite is commonly aggregated to some extent, but aegirine and amphibole are usually fairly evenly disseminated.

The alkali amphiboles include arfvedsonite (5/219), with deep blue pleochroic colours; eckermannite, with pale bluish-green and brown colours (5/302), and kataphorite, with deeper brown to greenish pleochroism (5/305).

Quartz is present as an accessory in some lavas, as a late stage but primary groundmass mineral.

Texturally, the lavas range from taxitic and aphyric (5/300), through taxitic porphyritic (5/305, 5/248), to subtaxitic (5/250) and even non-taxitic (5/243). In the latter, the leucocratic minerals in the groundmass form a microgranular mesostasis with isotropic fabric, in which are disseminated shreds of aegirine, cossyrite and amphibole.

A selection of these lavas is listed in Table 17. One lava flow contained streaky layers of dark brown glass. In thin section, 5/252, it is pale brown with a close streaky appearance like dry varnish, and has well developed perlitic cracks. It contains crystals of sanidine, scarce apatite needles, and one or two square sections of magnetite.

(ii) The Ribkwo Complex differs from the Kafkandal Complex in that a greater proportion of the trachytes contain altered nepheline phenocrysts and phyric anorthoclase. Such lavas belong, or are closely related to Prior's Kenya type of phonolite.

Of 48 thin sections examined, 17 (35%) contained altered or fresh feldspathoid phenocrysts. The proportion of feldspathoidal lavas appears to increase slightly from the main shield unit to Kariamangro caldera, i.e. the volcano takes on a more undersaturated character as it gets younger. In six slides the modal feldspathoid was point counted, results ranging from 2.9% to 6.9%.

Mineralogically, there are some differences between these trachytes and those of Kafkandal. The first is the greater abundance of altered feldspathoid. In the Ribkwo lavas, this occurs as four-, six-sided and anhedral sections of brownish granular material (5/6). Less commonly (5/37, Plate XXV), the feldspathoid has been replaced by a single plate of pale brown, fibrous looking length slow material, with straight extinction. This is considered to be hydronephelite, a variety of natrolite. Less frequently, a colourless isotropic mineral is present which is probably sodalite, but may be analcite replacing sodalite or nepheline. Thin fringes of aegirine, cossyrite or aegirine and arfvedsonite are invariably present.

Sanidine phenocrysts are common in all the lavas, but anorthoclase phenocrysts also occur either alone (5/115) or with sanidine (5/6), Plate XXVII.

Pale green clinopyroxene phenocrysts are also much more common, particularly in lavas from the Kariamangro Caldera. They have thin dark green rims and extinguish at angles of c.45° maximum, and are usually referred to as diopsidic augite.

The red to yellow mica-like mineral referred to on p.137 is very rare in the Ribkwo Complex. It was observed in lavas from Lokitet crater unit replacing diopsidic augite (5/1), and having properties similar to those mentioned above.

Fayalite was not observed in any of the Ribkwo lavas. The groundmass minerals are similar to those of the Kafkandal trachytes. Sanidine laths are almost ubiquitous, in association with interstitial anhedral aegirine, cossyrite, or less commonly arfvedsonite and kataphorite.

Texturally, there is possibly greater variation than in Kafkandal. Two specimens of glassy lavas were examined. Specimen 5/34i, pale green and aphanitic in hand specimen, is fine grained in thin section, and consists of minute sanidine laths in a turbid grey isotropic mesostasis. Thin lenticles of brownish turbid material are considered to be altered glass. Flow banding is rather turbulent with occasional sharp 'folds', Plate XXVIII. In specimen 5/116, the flow banding is almost ruler-straight, except where it diverges around vesicles. The rock consists of small sanidine laths interstitial to which are small patches of brownish turbid material, and orangey-red unaltered isotropic glass.

Most of the lavas, however, are holocrystalline, porphyritic and flow banded.

Table 18 lists some descriptions of Ribkwo Complex trachytes.

(iii) <u>The Nasaken Complex</u> is similar to the Kafkandal and Ribkwo Complexes in that it contains very few basalts, hawaiites or mugearites, and a great abundance of trachytes.

The latter are generally sanidine phyric, anorthoclase being absent either as phenocrysts or in the groundmass. The sanidine phenocrysts are generally resorbed to some extent, but frequently enclose pale green clinopyroxene phenocrysts. Other phyric phases in these trachytes include pale green clinopyroxene (diopsidic augite), with thin dark green or yellow-green borders, occasionally not in optical continuity with the body of the phenocryst (5/191).

The same red-yellow mineral as occurs in the Kafkandal trachytes also occurs in many of these, where it has the same properties, but

Table 18. TRACHYTES FROM THE RIBKWO COMPLEX

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass						Secondary Minerals	Remarks
		% of Rock	Feldspar	Feldspathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other			
5/14 772408	Trachyphonolite	10% Fspd > F	5 mm. Anorthoclase with sanidine rims sieved with inclusions	Nepheline, altered to pale brownish material. Cossyrite fringes. .7 mm. 6.4% modal	Scarce diopsidic augite, some enclosed by anorthoclase. .4 mm.	Occasional magnetite	Poorly taxitic	Sanidine as microphxts down to small laths	Aegirine amhedra	Scarce kataphorite	Cossyrite, A little interstitial magnetite	Analcime in vesicles	
5/1 779389	Trachyte	5% F > Px	3 mm. sanidine	-	Prisms of diopsidic augite, alt.to red length slow mineral. 1 mm.	-	Poorly taxitic	Sanidine	Aegirine	-	Mossy cossyrite	Some turbid interstitial granular material	
5/105 723457	Trachyte	Microphxts only	Very small stumpy sanidine .1 mm.	-	-	1.Resorbed magnetite .2 mm. 2.Iddingsite after ol(?), sharp pyramid terminations .1 mm.	Non-taxitic very vesicular Laths in two directional open lattice	Sanidine laths, commonly in two directions at 90°.	-	-	Magnetite dust charging a mesostasis, clear isotropic		

Table 18 (cont.) TRACHYTES FROM THE RIBKWO COMPLEX

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Felds-pathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/115 710407	Trac-hyte	20%	Anortho-clase 9 mm. Rim sieved with in-clusion Much re-sorption	-	Possible ferrugi-nous relics after augite	-	Non-taxitic	Sanidine laths & anhedral alkali feldspar	Original mafics altered to reddish and black turbid material		Small square magnetite grains	Some zeolite in vesicles	Phenocrysts very dis-tinctive in hand specimen
5/259 672422	Trac-hyte	Micro-phxts of so-dalite 6.9%	Single phxts of carlsbad twinned fsp 2V(-) 42° ± 1°	0.2 mm. sodalite or anal-cime re-placing sod. or ne.	-	-	Eu-taxitic	Very thin sanidine laths	Aegirine in rather mossy am-hedral patches interst. to fspar.	-	Cossyrite	-	-

the 2V(-) may be as high as 25°.

In specimen 5/204, phenocrysts of a dark reddish, non-pleochroic mineral with no cleavage and very high relief up to 1 mm. across occur. This may in fact be the same as forms the core of the red-yellow mineral. The interference figure, however, appears to have 2V(+) of zero.

A notable feature is the complete absence of feldspathoid.

In the groundmass, these trachytes have the usual minerals - sanidine, aegirine, cossyrite, arfvedsonite, kataphorite (in that order of importance) and generally magnetite as small equant granules and specks.

Texturally, these lavas tend not to be taxitic. The groundmass feldspar in thin section is frequently seen to be a structureless mozaic of granular anhedra, in which is a varying proportion of small sanidine laths. The hand specimens reflect this property, being mainly structureless, except for an alignment of phenocrysts (5/189) or slight colour banding (5/190).

Some of these lavas are described in Table 19. Specimens 5/185 and 5/191 represent the textural extremes, being noticeably taxitic, and completely non-taxitic respectively.

(iv) The Kachila Volcanics differ from the previous formations in the Kiddeh Group in that they contain a higher proportion of basalts, mugearites, and plagioclase trachytes. Only fonr specimens - 5/26, 5/101, 5/158 and 5/164 - of plagioclase-free trachytes were collected. In hand specimen, 5/164 is a greyish noticeably banded lava. Specimen 5/158 is black, fine grained, but its taxitic nature is defined by a parallel alignment of phenocrysts and a streakiness of the groundmass. Specimen 5/101 is an aphyric purple lava with abundant flattened vesicles, and 5/26 is greyish and structureless.

Table 19. TRACHYTES IN THE NASAKEN COMPLEX

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Felds-pathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/185 793614	Trachyte	5%	2 mm. Sanidine resorbed	-	-	1. Red-yellow mineral .3 mm. 2. V.scarce magnetite, resorbed 0.2 mm.	Poorly taxitic, with shear planes	Sanidine laths & anhedral grains	Aegirine, dispersed granules through-out the slide	-	Cossy-rite dis-persed anhedra	-	Taxitic though not fissile in hand specimen
5/191 800660	Trachyte	10% F > others	4 mm. Resorbed sanidine enclosing clinopx.	-	Pale green diopsidic augite 0.3 mm.	Magnetite 0.2 mm. much re-sorbed	Non-taxitic	The groundmass consists of a granular mozaic of weakly birefringent alkali feldspar, crowded with shreds of aegirine, cossyrite & arfvedsonite, & specks of magnetite. See also 5/195 below.					Fine grained & black, structure-less in hand specimen
5/195 814657	Trachyte	10%	5 mm. Sanidine, much re-sorption	-	Pale green diopsidic augite	1. Red-yellow mineral 2 mm. 2. Scarce re-sorbed mt.	Non-taxitic	Laths set in a meso-stasis similar to above	Aegirine grains	A little arfvedsonite	Cossyrite shreds	Orange material after mafics	Very vesicular with parallel flatte-ning

Table 20. TRACHYTES IN THE KACHILA VOLCANICS

Rock No.& Local.	Name of Rock	Phenocrysts (max. size in mm.)					Groundmass					Secondary Minerals	Remarks
		% of Rock	Feldspar	Felds-pathoid	Pyroxene	Other	Texture	Feldspar	Pyroxene	Amphibole	Other		
5/26 783422	Trachyte	10%	Sanidine 2 mm. slight re-sorption	-	Aegirine, pleochroic from green to greenish-yellow. V. low extinction	-	Non-taxitic	Sanidine laths and anhedra	aegirine, as dis-crete prisms & grains	A very little arfvedsonite	Magne-tite as scat-tered grains	Some turbid brownish material	
5/101 774453	Trachyte	c.5%	Mainly sanidine polysyn-thetic lamellae, some anor-thoclase 1 mm.	-	-	Occasional square mt euhedra 0.5 mm.	Non-taxitic felt of sanidine laths	Sanidine laths	Original mafics altered Probably not abundant - very little interstitial ferruginous material		-	Ferrugi-nous material after mafics	Numerous rounded vesicles
5/158 771516	Phono-litic trachyte	5% F > Px	3 mm. Equal pro-portions of sanidine & anortho-clase w. cross-hatched twinning & 2V(-)large	Small rounded bodies of brownish zeolite after neph? or sod? Thin fringes of aeg. 0.3 mm.	2 mm. Prisms & basal sections of green non-pleo-chroic diops. augite	0.2 mm. magnetite	Texture w. irre-gular shear bands	Sanidine laths	Aegirine mossy patches or grains	-	Dis-persed shreds of mt.	-	-
5/164 764577	Trachyte	0%	-	-	-	-	Taxitic	Sanidine laths	Aegirine shreds	Arfvedsonite shreds	Cossy-rite	Inter-stitial pinpoint polarizing zeolite?	

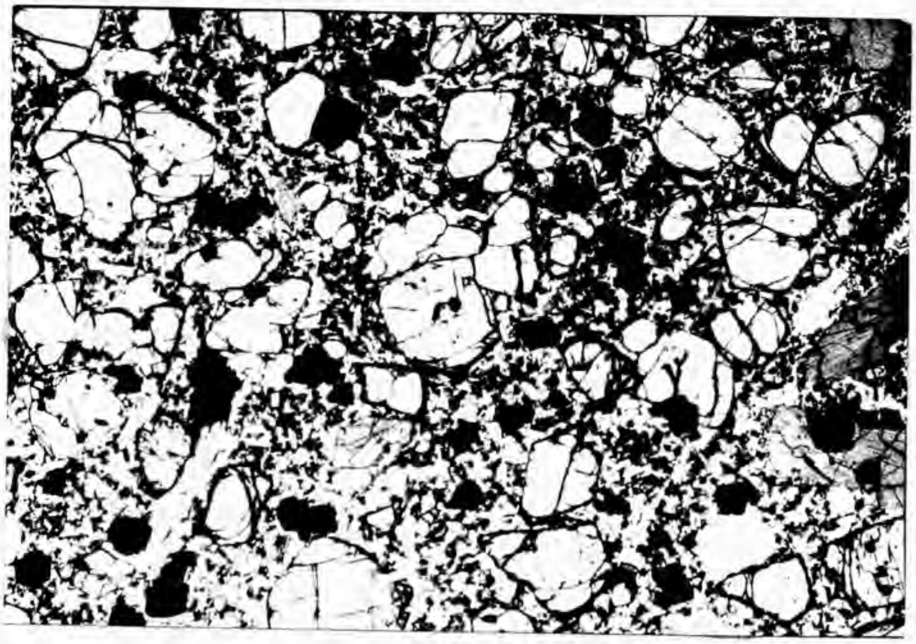

Plate XX: 5/249; Oceanite, Tirioko Basalts; p.p.l., x 10.

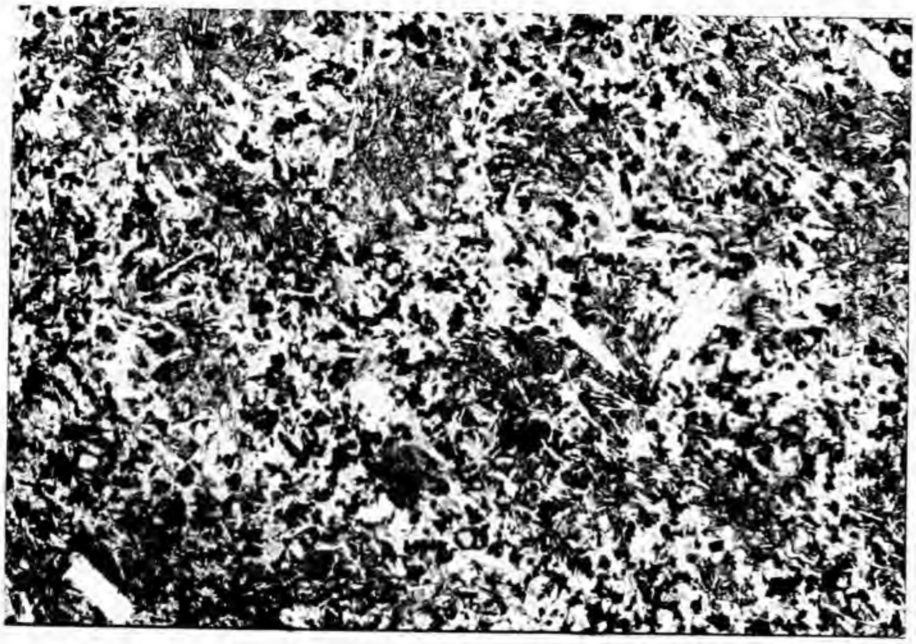

Plate XXI: 5/220; Ophitic olivine-basalt, Katirr basalts, Nasaken Complex; p.p.l., x 25.

Plate XXII: 5/156; Plagioclase-phyric basalt, Kahanavisian Member; Kamosing Formation; crossed polars, x 20.

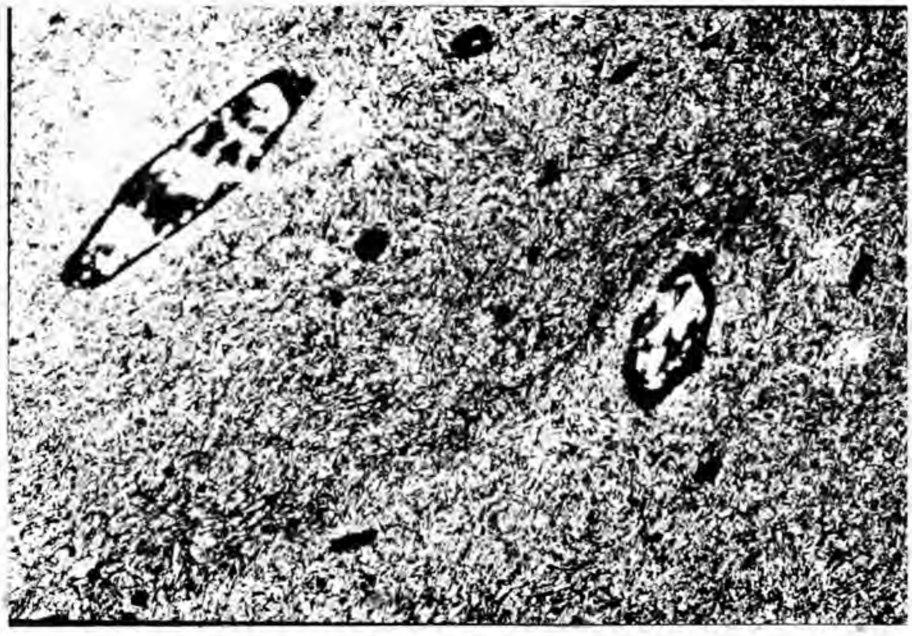

Plate XXIII: 5/396; Plagioclase-trachyte, Kapchererat Formation, showing brown amphibole phenocrysts with reaction rims of magnetite; p.p.l., x 20.

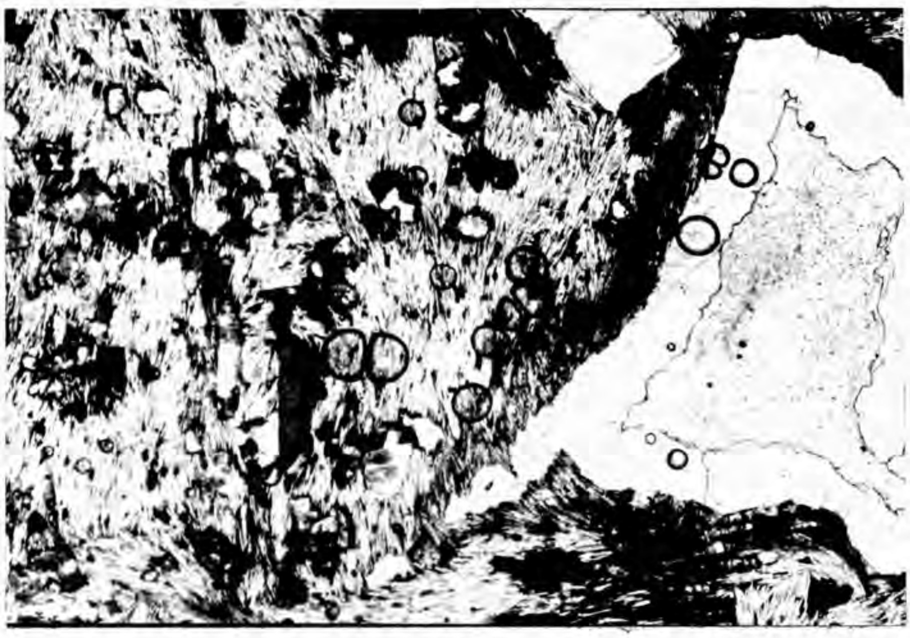

Plate XXIVA: 5/228; Trachyphonolite, Kapkaru Lavas; showing mafic aggregation, feldspathoid microphenocrysts, and analcime in vesicle; p.p.l., x 20.

Plate XXIVB: 5/228; Same, crossed polars, showing isotropic and anisotropic analcime.

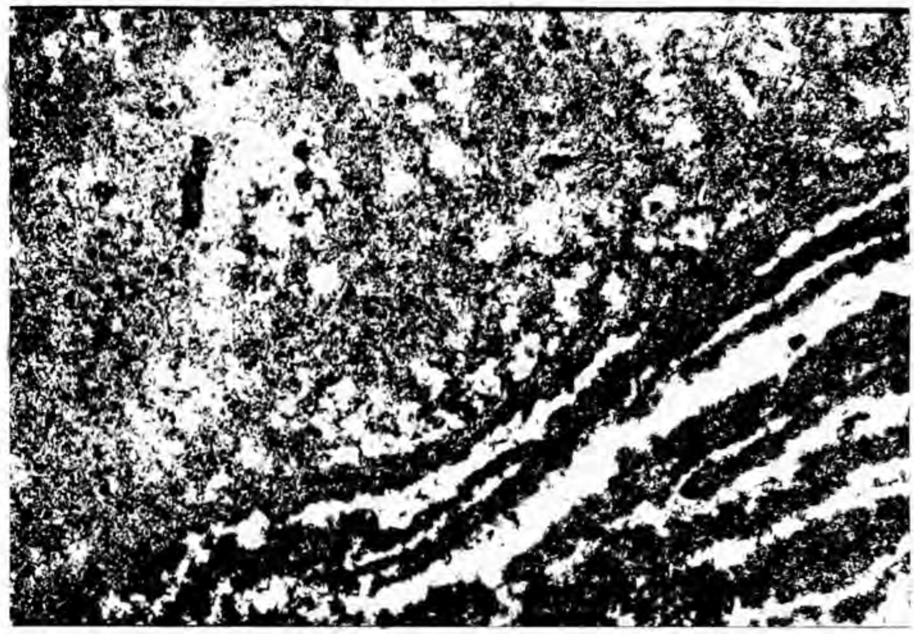

Plate XXV: 5/437; Losuguta-type phonolite, Tiriomim Volcanics; showing flow banding and dissemination of mafics; p.p.l.; x 10.

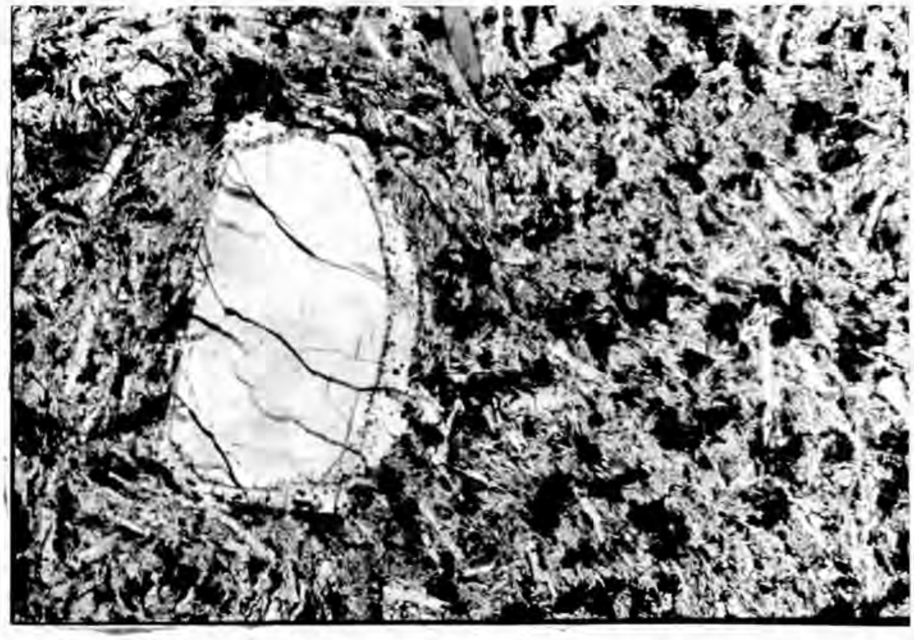

Plate XXVI: 5/37; Trachyphonolite, main shield unit, Ribkwo Complex; showing sanidine phenocryst with marginal inclusions, and feldspathoid microphenocrysts; p.p.l., x 25.

Plate XXVII: 5/6; Trachyphonolite, Lokitet unit, Ribkwo Complex; showing anorthoclase phenocryst with untwinned margin. Crossed polars, x 20.

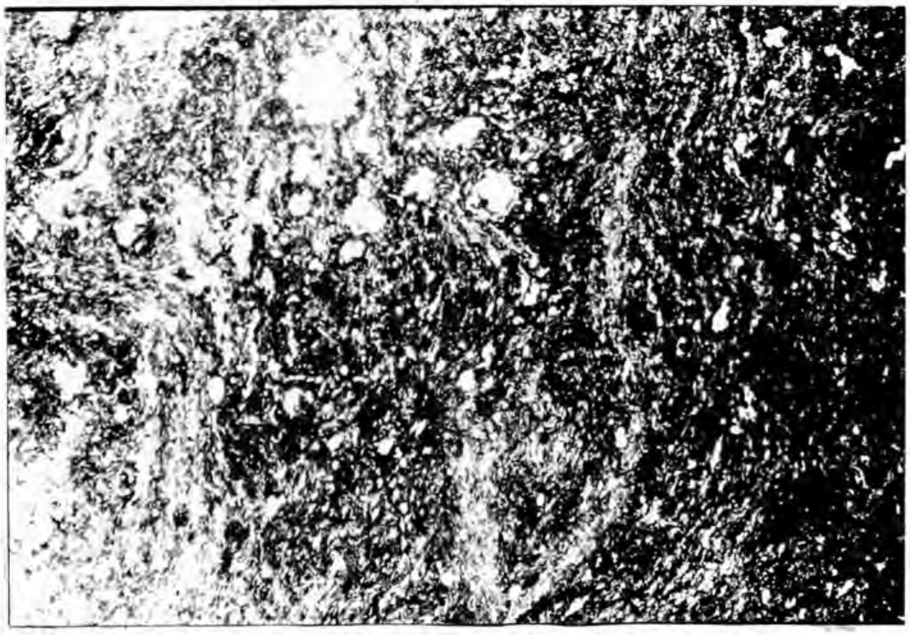

Plate XXVIII: 5/34(i): Fine grained trachyte, Ribkwo Complex, showing contorted flow banding; p.p.l., x 10.

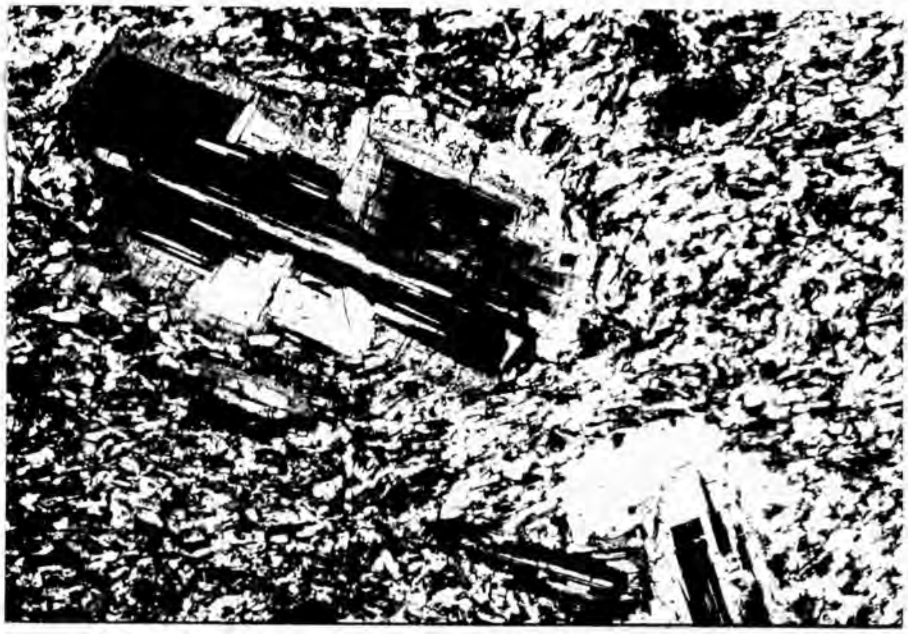

Plate XXIX: 5/385; Keitin trachyte intrusion; showing plagioclase phenocryst with untwinned mantle; crossed polars, x 25.

Plate XXX: 5/362; welded tuff, Sidekh Phonolites; showing pale fiamme, and lithic and crystal inclusions in dark mesostasis; p.p.l., x 10.

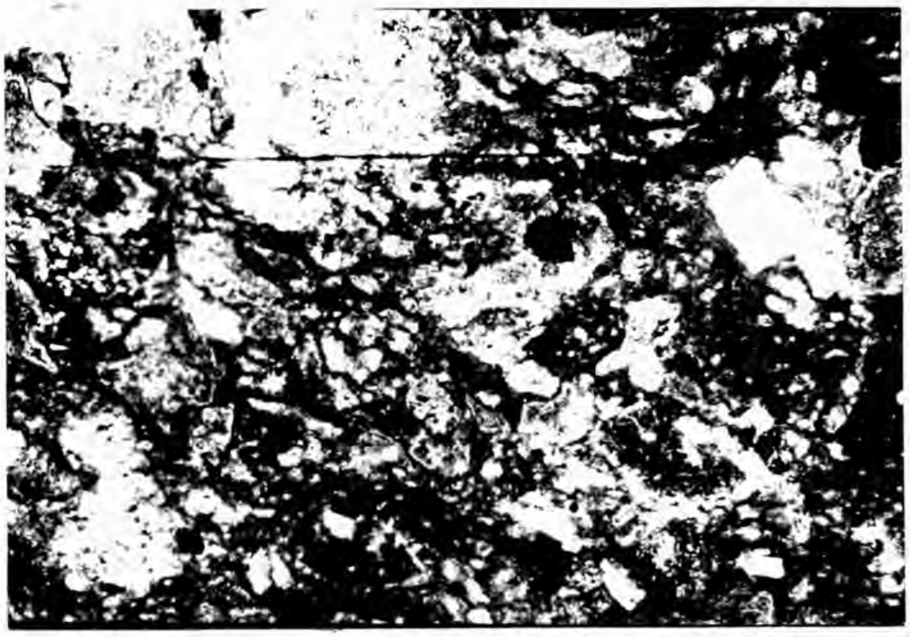

Plate XXXI: 5/414; welded tuff, Lelgrong Tuffs; showing clastic texture in mesostasis; p.p.l., x 25.

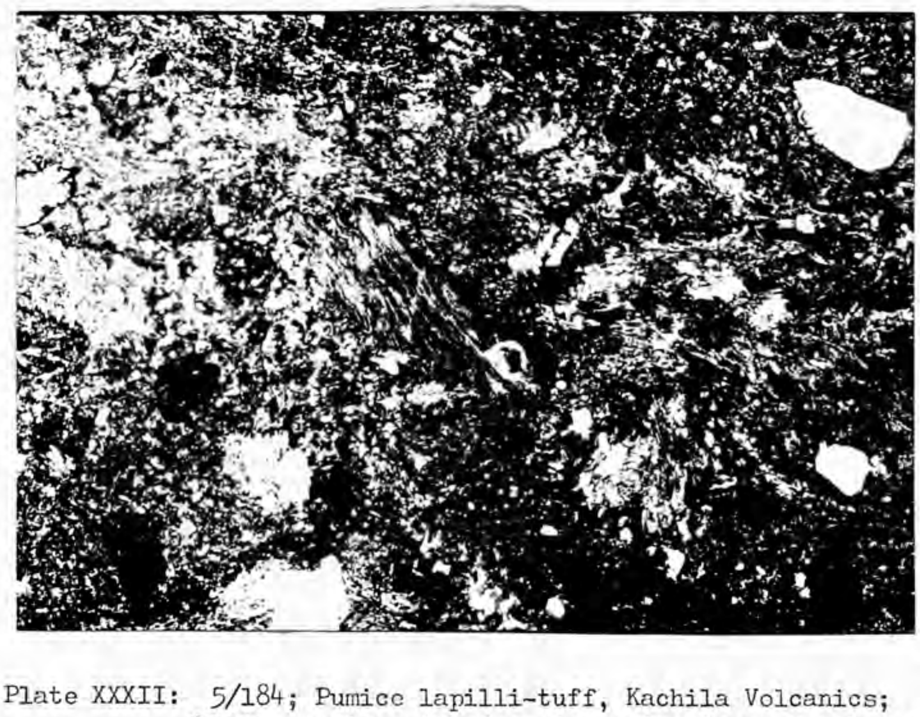

Plate XXXII: 5/184; Pumice lapilli-tuff, Kachila Volcanics; showing pumice with frayed terminations; p.p.l., x 50.

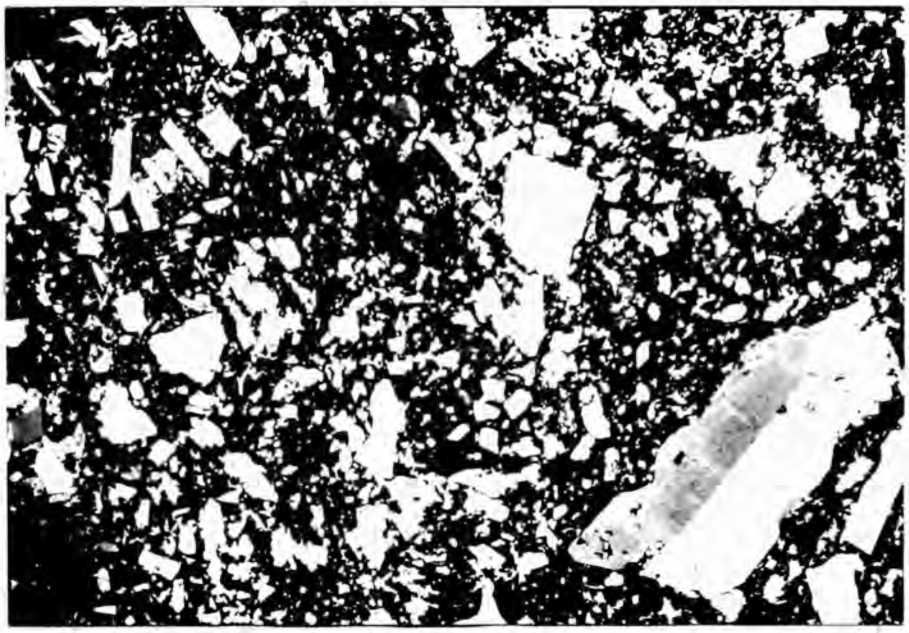

Plate XXXIV: 5/331; Crystal tuff, Epong unit, Kafkandal Complex; showing numerous angular fragments of sanidine; obliquely crossed polars, x 10.

Their thin section properties are described in Table 20. Specimen 5/158 is distinctive in that it contains alteration products after feldspathoid, otherwise unknown in the Kachila Volcanics.

(v) The Oliyamur Complex, as mentioned in Chapter 2, p.79, may occur in the present area as outliers of trachyte overlying Nasaken age volcanics. Only two specimens were examined, of which 5/183 is a very altered non-taxitic trachyte, and of which 5/180 has the following characteristics.

It is greenish grey in hand specimen, banded, but not fissile. In thin section it is seen to contain fairly abundant sanidine phenocrysts in parallel alignment, and sparse green non-pleochroic diopsidic augite phenocrysts.

The groundmass is a granular mesostasis of alkali feldspar with poikilitic quartz in which are abundant small sanidine laths, aegirine shreds, kataphorite anhedra, and clumps of cossyrite anhedra.

5. Intrusive Rocks

These will be considered in approximate stratigraphic order. In many cases, however, the upper age limits of intrusive bodies are not known.

(a) Associated with the Kapchererat Formation

(i) West of the Basement Arch, two plugs of basalt occur. In neither case are the contacts exposed, but they stand out as small but abrupt residuals on the Kerio surface. Specimen 5/349 (square 0440) is sparsely phyric, containing highly resorbed phenocrysts of plagioclase, magnetite and olivine. The magnetite encloses large clear apatite euhedra, which also occur unresorbed in the groundmass. The latter is fine grained, consisting mainly of plagioclase laths in a turbid mesostasis densely charged with magnetite specks.

Specimen 5/361 (square 0543) is augite-phyric, the phenocrysts being pale brown augite with darker margins and occasional marginal concentrations of ore granules. The groundmass is fine grained and intergranular, with abundant olivine microphenocrysts altering marginally to bowlingite.

(ii) Basalt dykes occur on the Basement Arch. Three of these, in squares 1844, 1745 and 1750 are augite phyric in hand specimen, and look exactly like the augite phyric lavas that occur on Pukaleh and other adjacent outliers. A dyke at 175407 is extremely altered but appears to be aphyric.

(iii) The Keitin intrusions comprise a large ovoid intrusion (1900 ft. x 1100 ft., 580 m. x 340 m.) and two smaller plugs 200 ft. (61 m.) across of non-fissile anorthoclase trachyte. They are generally structureless but the two smaller intrusions have strongly developed roughly north-south trending vertical joints.

Specimen 5/383, from the northern smaller plug, is a medium grained leucocratic rock, consisting mainly of feldspar, most of which occurs as laths with thin polysynthetic twin lamellae. 10% or less of the feldspar laths have regular albite twinning with an extinction angle of below 8°. In addition, there is an untwinned anhedral form, occupying interstices between laths and mantling oligoclase microphenocrysts. The original mafics are altered to black interstitial material. Magnetite is present as interstitial anhedra, and clear apatite needles.

Specimens 5/384 and 5/385 from the large intrusion are similarly leucocratic, but the groundmass feldspar appears to be wholly sanidine or anorthoclase, with 2V(-) 30°-50°. The feldspar phenocrysts are potash-oligoclase, with alkali feldspar mantles, Plate XXIX. These latter constitute from 10% to 90% of the bulk of the phenocryst, and have 2V(-) c.50°. These two specimens differ, however, from 5/383 above in that they contain moderately abundant brown amphibole phenocrysts, reduced for the most part to a weakly birefringent mesostasis densely charged with black ore granules, a little poikilitic biotite, and some chlorite. In 5/384, the original groundmass mafics are altered as in 5/383, but in 5/385, very pale greenish augite occurs as prisms and anhedral grains, plus accessory reddish brown biotite. Magnetite occurs as small scattered euhedra.

(b) <u>Associated with the Tugen Hills Group</u>

(i) Three small gabbro plugs occur just north of Chepachaghom. One of these (209483) intrudes trachytes of the Chepachaghom centre, and is itself cut by a dyke of plagioclase phyric basalt. Two specimens, 5/399 (198479) and 5/442 (207483) were collected. Both are dark grey, heavy, and coarse grained in hand specimen. In thin section, 5/399 contains the following minerals in order of crystallization: apatite, large clear prisms up to 0.5 mm. long; magnetite euhedra, up to 0.5 mm. across; olivine, slight marginal alteration to brown turbid material, 0.6 mm.; pale purplish-brown titanaugite plates; large plagioclase crystals of labradorite composition; brown hornblende with large 2V(-), X or α orangey brown, Y or β reddish brown, Z or γ deep red-brown; biotite, with reddish brown to very pale yellow pleochroism, and which also occurs as thin coronae around magnetite and apatite. The rock has a colour index of c.50.

Specimen 5/442 differs in that it has a lower colour index, and the mafic minerals occur as smaller crystals. The pyroxene is colourless, the biotite is pleochroic from chocolate brown to pale yellow, and the amphibole pleochroic from green to greenish brown, all indicating a lower TiO_2 content.

(ii) A suite of plagioclase phyric basalt dykes occurs east of the Basement Arch, cutting the Kapchererat Formation. They are generally aligned a few degrees east of north, and are remarkably uniform in appearance. They resemble the plagioclase-phyric lavas of the Kapchererat Formation, but are probably younger. In two recorded instances (at 204482 and 209483) they cut the lowest lavas of the overlying Tugen Hills Group, and hence the age of the whole suite of plagioclase phyric dykes is uncertain.

Specimens 5/376 and 5/377 from 196452 are from the outer and inner zones respectively of a 6 ft. wide zoned dyke of plagioclase phyric basalt. The plagioclase phenocrysts are concentrated in zones 0.5 m. wide at the edges of the dyke, leaving the central zone relatively deficient in phenocrysts. The plagioclase phenocrysts are up to 15 mm. long, and range in composition from An_{55-65}. No other phenocrysts occur. The groundmasses are similar in each specimen, consisting of intergranular augite grains and labradorite laths, with olivine microphenocrysts and abundant magnetite. Analcime is common in 5/377 filling rounded vesicles.

(iii) A nepheline-syenite plug occurs in square 2538. At its western margin, the adjacent tuffs are crumpled and contorted, and tinted purple and pink, possibly because of hydrothermal alteration.

The intrusion is about 3000 ft. (915 m.) in diameter, and consists of a coarse grained leucocratic nepheline syenite, foliated at the margins, but internally structureless.

Specimen 5/405 from the margin is strongly porphyritic, containing fresh nepheline and scarce sanidine phenocrysts in a taxitic groundmass composed of thin sanidine laths up to 1 mm. long, and mafics. The latter are aegirine, cossyrite, an amphibole near to magnesiokataphorite, and reddish brown biotite. The first three occur fringing nepheline. Magnetite is present as occasional granules, and analcime occurs in pools in the groundmass, and also replaces nepheline. All the mafics occur interstitially, as clots drawn out in the direction of the taxitic texture.

Specimen 5/406 from near the centre of the intrusion is coarser grained, non-porphyritic and structureless. The same minerals are present. The amphibole has a small 2V(-), with the optic axial plane parallel to (010), and a large $Z \wedge c$. Magnetite is interstitial to feldspar. Analcime is again present, replacing nepheline to a greater extent than in 5/405, and as interstitial pools.

(iv) A phonolitic plug, 1500 ft. (460 m.) across, cuts the Sidekh Phonolites in the southwest of the area. It is visibly crystalline and dark grey in hand specimen. In thin section (5/346) nepheline phenocrysts up to 1 mm. long, largely altered to a granular weakly birefringent mozaic of zeolite, are set in a non-taxitic altered groundmass, composed of sanidine laths, occasional subhedral aegirine augite prisms, granular aegirine, and anhedral mossy arfvedsonite and cossyrite.

(v) Intrusions of flinty phonolite are almost unknown. A single dyke at 238388 is purplish and fine grained in hand specimen. In thin section (5/404) it contains sparse nepheline euhedra up to 1 mm. across, altered to length slow natrolite (?), in a fine grained altered groundmass in which there are no unaltered mafics. A less weathered dyke, with a flinty groundmass of Losuguta type bearing sanidine and biotite phenocrysts (5/437), occurs at 259451.

The scarcity of intrusions of flinty phonolite has been noted from other areas (Martyn, Chapman, Carney, pers.comms.).

(vi) Trachyte and trachyphonolite intrusions are common in the Tugen Hills Group. The largest is that of Chesitoi, an ovoid body

1800 ft. x 800 ft. (570 m. x.240 m.) in extent, composed of coarsely porphyritic trachyphonolite. In hand specimen, it is similar to the trachyphonolite comprising Cheptuimet and Kepsetan, and is thought to be an intrusive body related to these, Fig. 22. In 5/326, from Chesitoi, the nepheline has largely been replaced by analcime, which also occupies irregular vesicles and cross cutting veins. Sanidine phenocrysts also occur.

The Kelan intrusive complex (square 2741) consists principally of a trachyphonolite agglomerate, from which a block of olivine basalt was recovered. A sinuous outcrop of flinty phonolite on its southern edge is separated from the main pipe by a belt of agglomerate, and may not be related. Smaller dyke-like bodies of moderately fissile trachyte invade the agglomerate, and may be feeders for the outlier of Cheptuimet Trachyphonolite at Molingot.

The remaining trachytic intrusions are nearly all dykes. The summit of Tiati, however, is a small circular plug of trachyphonolite, with a crude sheeting parallel to the outer walls. It consists of sodalite or analcime microphenocrysts in a flowbanded groundmass consisting mainly of sanidine laths with interstitial aegirine and a little cossyrite (5/136).

A few dykes, particularly those cutting the Lelgrong Tuffs west of Tiati and Cheptuimet, contain small microphenocrysts of sodalite or analcime after nepheline, e.g. specimen 5/435 (240471). Mostly, nepheline is absent, but 5/410 (246428) from a small plug contains small biotite laths, together with abundant resorbed sanidine phenocrysts, and sparse pale green diopsidic augite phenocrysts. Biotite laths also occur in 5/412, a fine grained aphyric altered dyke from 234434.

Specimens 5/419, 5/411 and 5/428, from 236463, 249431 and 256453 respectively, contain neither nepheline nor quartz. The groundmass in each case is flowbanded, and phenocrysts are rare.

Specimen 5/382 (192437) is remarkably similar to the outlier of trachyte at Singelel, in that it is aphyric, the mafics are altered to a similar blackish material, and quartz occurs in pools, probably as a secondary mineral.

Specimen 5/439 (224486) is from an altered leucocratic dyke, which contains waterclear quartz crystals over 1 inch long in drusy cavities. Set in the groundmass are pale green, opaque stumpy hexagonal prisms. In thin section, the rock is seen to be largely altered. A single phenocryst of nepheline (?) altered to fibrous and granular material with a birefringence of about 0.01 was observed, in a groundmass of granular secondary minerals. Vesicles contain quartz, which encloses small prisms of altered feldspar. The mafics are entirely altered to brownish clots of limonitic material.

A trachyte dyke at 194518 shows a concentration of feldspar phenocrysts at the margin. The dyke is 3 m. wide, and the feldspar rich margins 0.5 m. wide. In this manner it resembles the plagioclase phyric basalt dyke at 196452, p.145.

(c) Intrusions associated with the Tirioko Basalts

These are exclusively dykes, generally less than 15 ft. (5 m.) wide, usually fairly straight, and uniform in composition.

They are entirely basaltic, there being no known sources for the trachytes or lavas in the leucocratic unit. They are remarkably similar in lithology to the lavas already described. Most have intergranular texture, but ophitic (5/288) and sub-ophitic (5/240) textures also occur.

Olivine is ubiquitous as microphenocrysts and in the groundmass, but is not as commonly phyric as augite and plagioclase (5/242, 5/289).

(d) Intrusions associated with the Kiddeh Group

These consist entirely of dykes and small plugs ranging from trachyte to trachyphonolite in composition. Particularly noteworthy is the swarm of dykes* associated with the Mugor Trachytes, lithologically similar to the Mugor Trachytes themselves. Of three specimens examined, 5/293 (271594) from a thick dyke is coarse grained and non-porphyritic. Aegirine and arfvedsonite occur interstitial to sanidine laths, which range in size from 1 mm. down to smallest groundmass laths and anhedra. Specimen 5/268 (277562) is aphyric, and the original mafics are entirely altered to limonitic material. In 5/323 (278518), sparse sodalite microphenocrysts occur in a taxitic groundmass composed of sanidine laths and interstitial aegirine and arfvedsonite.

The dykes associated with the Kafkandal Complex, or which occur near its western margin are similar to lavas in the complex. Specimen 5/311 contains both the red-yellow mineral and the pale yellow mineral mentioned on p.137.

Specimen 5/247 is a glass margin from a trachyte dyke at 308630. Several of the trachyte dykes in the vicinity have thin glass margins and it is considered that the basalts into which they were intruded are better conductors of heat than trachytes or tuffs, so that the liquid magma quenched more quickly. However, this is not always the case, and other trachyte dykes intruded into basalts have crystalline margins. In 5/247, the glass is pale brown in plane polarized light, with a banded fabric. Abundant spherulites are seen between crossed polars.

In the Ribkwo Complex, trachytic intrusions are concentrated near the central zone, and in the Lokitet and Kariamangro units. Only two specimens from the main shield unit were examined. Specimens 5/39 and 5/99 are leucocratic, although the mafics in each

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* There is also an agglomeratic plug at Kamtil, square 2853.

case are altered to reddish limonitic material. Specimen 5/39 is aphyric, but 5/99 contains abundant sanidine phenocrysts.

Dykes in the Lokitet unit are usually altered, but appear to contain neither quartz nor feldspathoid. Chalcedony is common, both in radial and granular form, in small vesicles. The intrusive bodies are usually dyke-like, but plugs, e.g. at 758385 and 739385, also occur.

Specimen 5/64, from a dyke which cuts the Kariamangro Caldera unit at 763413, is distinctive in that it contains anorthoclase phenocrysts, as do several lavas from the Kariamangro Caldera unit.

In other respects, apart from those mentioned, in grain size, texture and mineralogy, the intrusive bodies in the Ribkwo Complex resemble the lavas with which they are associated.

(e) Intrusions associated with the Kamosing Formation

A 1 m. wide dyke of intergranular textured olivine basalt (5/260) cuts the valley outlier of Ribkwo Complex trachyphonolite at 672422, and is considered to be a possible source of the Tuwut Basalt Member.

For the Pativat Member, a single dyke immediately southwest of the triangulation station at Pativat was seen.

In the case of the Kahanavisian Member, two circular intrusive bodies, 5/58 and 5/102 at 784498 and 792449 respectively, occur. These are similar in lithology to the main mass of Kahanavisian Basalt.

(f) Intrusions associated with the Chepkowagh Mugearite

This formation consists of a single dyke and lava outlier. They are very similar in hand specimen, consisting of a buff-greyish fluxion textured, but not fissile, non-vesicular rock. Specimen 5/360 (053427) contains a few phenocrysts of labradorite up to An_{64}, in a groundmass composed of oligoclase laths and iddingsite after olivine or pyroxene.

6. Welded Pyroclastic Rocks

These occur in the author's area in the Tugen Hills and Kiddeh Group, but particularly in the latter. They vary in thickness from c. 6 ft. (2 m.) to 60 ft. (18 m.), and their characteristics indicate that they were originally clastic, but subsequently underwent recrystallisation and alteration. A single welded tuff occurs associated with the Tumungir Basalts.

Introduction

Before considering their distribution and petrography in the present area, it is necessary to examine the development of the concepts concerning them.

It was realized in the 19th century that there was a group of rocks which had properties transitional between lavas and clastics. These rocks are generally streaky, contain devitrified glass shards and lithic inclusions, and are tabular in form, consistent with deposition in a fluid medium.

The earliest theory was that of Abich (1882) who advanced the idea that rocks with these characteristics from Armenia had been formed as a result of a gas charged acid lava erupted as a coherent liquid, but which subsequently vesiculated so that it frothed up, forming pumice and glass shards. These were then flattened and drawn out in the direction of flow, subsequently welding together.

After the eruptions of Mont Pelé in 1902 and 1903, Iddings (1909) proposed that violently erupted glass fragments may fall together and become welded, although no welded deposits were formed during the Pelé eruptions.

Fenner (1920, pp.569-606) interpreted the Katmai 'sand-flow' as a welded deposit with a Peléan origin.

The term ignimbrite was introduced by Marshall (1932), in application to sheet rhyolites which he supposed to have been formed from an incandescent shower, but his definitions were not clear.

Other theories developed were those of Vlodavetz (1953) who proposed that the streaky nature of these rocks was caused by the intermingling of rhyolitic lenses in a dacitic medium, and Steiner (1960) who invoked liquid immiscibility, but met with much criticism.

An often invoked mechanism is the nuée ardente (glowing cloud). In modern terms, this is essentially an expanding gas cloud charged with small droplets of glassy magma, hot ash, wall rock xenoliths etc.. The lower part is relatively dense, tends to move over the ground as a turbidity current, and may cool only slowly. This is the ash flow of Smith (1960, pp.795-842). If of sufficient size and initial temperature, it may be hot enough for the constituent particles to fuse or weld together upon coming to rest. Small ash flows, however, may not be hot enough to do this. The upper part of a nuée ardente is a dust-laden glowing, gaseous cloud, very turbulent, and continually being fed by gases liberated from the basal portion or ash flow. The liberation of these gases from the ash flow fluidizes it, and enables it to move at great velocities, and to surmount gentle gradients.

Probably all the truly clastic welded tuffs originated in this manner, or one similar. The necessary conditions are that the magma should build up sufficient pressure in the conduit, so that when the confining pressure is released at the commencement of eruption, the gas starts exsolving, and the primary material is erupted as a gaseous medium with suspended solid and liquid particles.

If the pressure is too high, however, sudden release of the confining pressure may cause a violently explosive eruption, with large volumes of pumice being shot vertically into the air. In doing so, they would cool quite quickly, and would not weld together upon compaction.

Apart from the possibility of welded tuffs having originated as a pyroclastic, there is the froth-flow hypothesis of Abich (1882), later supported by Iddings (1899), outlined above. Lacroix (1930) put forward the analogue of boiling milk, in which a liquid magma vesiculated or 'boiled up', flowing over the crater lip as a bubbling, foaming mass. This was later supported by Kennedy (1955) and McCall (1962, pp.343-344).

Other eruptive associations of ignimbrites or welded tuffs of the clastic variety are fissures and calderas.

Vast sheets of rhyolite in the southwest U.S.A. are considered to have been erupted from fissures, which were subsequently concealed by the erupted material (Smith, op.cit., pp.817-818).

The association of welded tuffs and calderas was first described by Ross (1931, pp.185-186), in the Valles Mountains of New Mexico, but has since been recognized elsewhere in the U.S.A. (Byers et al., 1969, pp.87-97); Kenya (McCall, 1965, pp.1148-1195); and Australia (Branch, 1967, pp.41-50).

Secondary Effects

Due to the volatile content and temperature of welded tuff systems, they are very susceptible to autometamorphism during cooling. Vapours passing up through a cooling and solidifying mass of glass droplets hydrate the glass, causing crystals to grow over and obscure the welded shard boundaries. All the glass may be altered in this way, and original pumice hard to detect.

Further, crystallisation of feldspar and tridymite takes place in pore spaces, sometimes as spherulitic intergrowths. These two secondary effects can render an ash-flow deposit quite solid and compact, giving it a welded appearance, when in fact it may not have actually been welded in the true sense, i.e. sticking together and merging of hot plastic glass because of its high temperature. This point is emphasized by Smith (op.cit., pp.825-828).

Another secondary effect is that of laminar flow (Walker & Swanson, 1968, pp. B37-B47) in which the partly welded mass of glass shards moves by laminar flowage, under its own weight.

In the following sections, the welded tuffs in the present area will be described, and commented on in the light of observations made by others.

(a) Welded Tuffs in the Tugen Hills Group

These occur only sporadically. The welded tuff in the Sidekh Phonolites is the most obvious. It probably covered an area of at least 50 sq.miles (130 sq.km.), but is not more than 20 ft. (6 m.) thick in any of its outcrops. It is welded throughout its vertical extent, no vertical zonation being seen. It is greenish-black to khaki in colour, compact, with occasional flattened vesicles, and porcellanous texture. It has a streaky banding marked by small folds and contortions, and which deviates around the numerous lithic and crystal fragments. The largest of these are about ¾-1 cm. across.

The textural features are well seen in thin section (5/350, 5/362 and 5/366). Specimen 5/350 contains abundant lath-like sanidine crystals. Their regularity of form suggests that they were not involved in an explosive eruption. Scarce biotite laths also occur. The groundmass is streaky, but any clastic particles have been obliterated by the intense recrystallisation. This has led to the development of a brownish, turbid, opaque mesostasis in which are abundant spherulites with dark brown turbid nuclei. There is much analcite in small, irregular pore spaces.

Specimens 5/362, Plate XXX, and 5/366 are fairly similar. Both contain abundant fairly regularly formed crystals of sanidine largely altered to analcite, together with occasional biotite and nepheline. The crystals are up to 3 mm. long. Rounded lithic lapilli occur, altered to isotropic granular material with abundant small rod shaped crystals.

The rock in each case consists of two distinct parts. There is a mesostasis, pale to medium brown, very finely granular, which shows a faint banding adjacent to large lapilli, but is otherwise structureless. Set in this are much paler streaks and lenses with frayed ends (the fiamme of many authors) of coarser grained material consisting essentially of an analcitized base with numerous small fluffy, greenish black aggregates of unidentified material. These are often segregated, leaving thin lenses of analcite-rich base, into which project tiny microlites. They appear to be flattened pumice, the analcite lenses representing flattened bubbles. The ragged and frayed ends support this view. These paler streaks vary from 0.2 mm. to over 10 mm. long. In 5/362, they are rich in spherulitic clusters of feldspar (?).

In each of 5/362 and 5/366, the crystal and lithic fragments are included in the dark mesostasis. The pale streaks are almost entirely free of such inclusions, are subparallel, and are moulded fluidally around crystal and lithic fragments.

Any conclusions regarding the mode of eruption of this welded tuff must be tentative, in view of the amount of alteration. Nevertheless, the unshattered nature of the included crystals, and the fairly homogeneous texture of the brown mesostasis point to a fluid, unexplosive origin. The present writer hesitates to call it a froth-flow, however, in the strict sense.

At 246403, a welded tuff occurs in the Sigatgat Hill Complex. It differs from that in the Sidekh Phonolites in that in thin section (5/414) the brownish mesostasis or groundmass has a definite clastic texture, Plate XXXI. Each clast is angular, and consists of a pale brownish microcrystalline aggregate of secondary minerals, with a darker brown rim. These clasts are packed closely together, with only a limited amount of pale brown isotropic interstitial material. The fiamme are brownish or greyish, coarser grained than the clasts in the mesostasis, and have ragged ends. They give rise to a banded texture, paralleled to some extent by that in the mesostasis.

This welded tuff then appears to have been primarily clastic, and is probably a pyroclastic flow deposit. The author is aware, however, that, because of vapour phase crystallisation, the absence of primary vitroclastic texture is not diagnostic of a fluid origin. Neither is its presence conclusive proof of a clastic origin, since clastic texture may be induced in a froth-flow, over the limited 1-2 cm. present in a thin section.

Welded tuffs only occur at widely spaced intervals in the Lelgrong Tuffs, and none was examined in thin section. They do occur, however, in the Kameiyun Volcanics, and in the inlier presumed to be of equivalent age in the Kamosing valley at Takeiwut, and east and north of Cheptuimet.

Four specimens were examined in detail. In hand specimen, they vary considerably in colour, proportion of fiamme to mesostasis, and degree of compaction.

Specimens 5/143 and 5/262 are black or greenish black, very compact, denser than most welded tuffs, and have a flinty fracture. In 5/143, there are few fiamme or inclusions, but the mesostasis in 5/262 is crowded with included material. In both specimens, fiamme are only visible on a wet surface.

In 5/263 and 5/328, however, the colour varies from purplish to cream in the latter. Also, 5/328 is porous and not very compact, and the fiamme are not distinct from the mesostasis.

In thin section they consist of pale fiamme in lenticles up to $1\frac{1}{2}$ cm. long, in a darker, usually greenish groundmass. In two cases (5/143, 5/263) there is no sign of vitroclastic texture, but in 5/262 and 5/328 the dark brown mesostasis has a relict clastic texture.

In 5/143, the mesostasis is a white, clear fine-grained, unresolvable aggregate, closely crowded with a flocculate, green mineral, and less closely with irregular cossyrite patches. Very small rounded crystals of pale green clinopyroxene occur, and angular fragments of sanidine, showing slight resorption. Small grains (0.2 mm.) of brown amphibole also occur, with rims of magnetite granules. The fiamme are coarser grained, are highly leucocratic, and consist mainly of an isotropic or near isotropic groundmass with abundant feldspar microlites. Internally, the fiamme are almost structureless. They occur from about 1 cm. long down to small irregular shreds. Trachytic lithic lapilli occur, always well rounded. Analcite has also crystallised in sparse veins and small cavities.

Specimen 5/263 is similar, but the groundmass is dark brown and turbid, and heavily ferruginized. The paler streaks are generally less than 3 mm. long. Abundant rounded to angular sanidine fragments and small rounded trachyte lapilli occur.

Specimen 5/262 consists basically of a dark brown mesostasis in which there are relicts of fiamme with frayed ends. It is turbid in plane polarized light, isotropic, and the fiamme are so nearly of the same material as the groundmass that only examination with a low power objective reveals their presence. Small fresh fragments of sanidine occur.

In 5/328, the fiamme and mesostasis are again distinct, but the greyish-brown mesostasis is full of streaks and inclusions of fiamme-like material which has undergone spherulitic recrystallisation. The streaky texture is very well marked. The only crystal inclusions are sanidine, generally subhedral, rounded and embayed. Trachytic lapilli also occur.

The four specimens above thus display quite significant textural variations. It becomes apparent that there may be no single solution for the 'ignimbrite problem', but that more than one process is operative even in a single vent at different times.

(b) Welded Tuff Associated with the Tumungir Basalts

This occurs on Tumungir Udei, p.55, beneath the basalt lava. It is only 1.5 m. thick, and is welded in the central portion. In hand specimen, it is dark grey, fine-grained, compact, with a faint streaky texture. In thin section, 5/277, sparse inclusions of sanidine and altered lava occur in a brownish altered groundmass.

(c) Welded Tuffs in the Kiddeh Group

The relationships of welded tuffs to the volcanic edifice becomes more apparent in younger formations, which are more likely to be preserved complete.

In the central zone of the Ribkwo Complex, there are no welded tuffs. They only occur on the flanks. It has been suggested by Gibson (1970, p.109) that this is because welded tuffs are not deposited near their source, but flow down the flanks before coming to rest. In this case, they may even thicken distally, but this was not noticed in the present area.

Even in the Ribkwo Complex, however, there is a marked asymmetry in the distribution of welded tuffs. Nearly all those that pre-date the Lokitet unit occur in the northern flanks. It is suggested that their direction of eruption was controlled, and that the volcano had an inherent tendency to asymmetry. This is further reflected in the fact that the Lokitet unit occurs on the northern edge of the central zone, and that the Kariamangro Caldera occurs in turn, north of the Lokitet unit.

Of the Kafkandal Complex, only the central zone has survived erosion, and welded tuffs are not common.

Welded tuffs also occur in the Nasaken and Kachila Volcanics.

Those specimens examined show considerable variation in hand specimen. Generally, they are greenish or purplish. Fiamme are up to 3 cm. long (5/5) or only occur as small thin streaks (5/184). In 5/5, they have frayed terminations, and are darker than the mesostatis, which has a streaky, finely banded appearance itself. The mesostasis itself varies from fine grained but not aphanitic (5/22) to flinty and compact (5/205).

In thin section these rocks show similarities to those from the Tugen Hills Group. It is proposed therefore to deal only with selected features of these welded tuffs in thin section.

In general, spherulitic secondary crystallisation is uncommon. It occurs not in the mesostasis, but in larger fiamme and in some inclusions, and usually consists only of divergent clusters of feldspar (?) needles which have nucleated on the walls of what are taken to be collapsed bubbles.

Specimen 5/184 has suffered least from the effects of recrystallisation. The fiamme are seen to be yellowish and clear in plane polarised light, but to consist of an aggregate of granular secondary minerals between crossed polars. They are porous, and have flamy ends and a streaky texture, and are inferred to be collapsed pumice, Plate XXXII.

The mesostasis is a darker brownish clouur, and has a well preserved clastic texture. The clasts are less than 0.5 mm. across, are more or less equant to thin and curving or horn-like. There are numerous fragments of sanidine, a few of green clinopyroxene altering to ferruginous material, and similarly altered trachytic lapilli, up to 1.5 mm. across. The sanidine fragments have parallel (010?) faces, but broken, irregular, unresorbed terminations.

In 5/5, some of the trachytic inclusions are quite fresh, with unaltered aegirine and arfvedsonite. The crystal fragments are sanidine, completely anhedral, with concavoconvex outlines and sharp, cuspate projections, and aegirine augite. Both are usually unaltered, but the feldspars are occasionally clouded, due, it is inferred, to hydrothermal alteration.

The field characteristics of the welded tuffs in the Kiddeh Group are as follows: They are from 6 ft. (2 m.) to 60 ft. (18 m.) thick. They are usually welded throughout their vertical extent, but the top is often less welded than the base. There is usually a thin cavernous rubbly zone at the base - indicative of a nuée ardente origin according to most authors. They often develop columnar jointing, which then usually extends from the base to the top of the unit. They extend laterally for at least 10 km. (W.T. 1, Ribkwo Complex).

They may occur anywhere in the local succession, intercalated in trachytes, thick pumice tuffs, or successions composed of both. It appears then, since the eruption of welded tuff depends on pressure conditions in the conduit, these are liable to sudden change, and that regular eruptive cycles do not occur in the present area.

7. Non-welded Pyroclastic Rocks

In this section, the terms pyroclastic, epiclastic, volcanic and sedimentary are used in the sense defined by Fisher (1966, pp.287-298) and the American Geological Institute (1960, a & b) as follows:-

Pyroclastic: pertaining to rocks in which the clastic fragments are produced during the eruption or ejection of material from a volcano or other volcanic vent.

Epiclastic: pertaining to rocks in which the clastic fragments are derived from older, already existing rocks.

Volcanic: pertaining to, produced by (&c.) a volcano, crater or other eruptive vent, or volcanic agencies (Am. Geol.Inst. 1960a, p.315).

Sedimentary: pertaining to or produced by (&c.) solid material in suspension, or transported in a fluid medium and which has come to rest (Am.Geol.Inst. 1960b, p.59).

A "pyroclastic sandstone" is thus distinct from a "volcanic sandstone", which has a much less restricted meaning. Difficulties in nomenclature arise when pyroclastic and epiclastic grains become mixed, particularly when they are of the same composition, as in a volcanic area. Fisher (op.cit.) lists seven different schemes for grain size limits. The present writer's terms are mainly field terms, and are given below.

Grain size	Clast	Rock Name	
c. 30 mm. and over	Block	Agglomerate, Breccia	
Between c. 2 mm. & 30 mm.	Lapillus	Lapillistone	Lapilli-tuffs have roughly equal quantities of lapilli and ash.
c. 2 mm. and less	Ash Particle	Tuff	

(a) Agglomerates. The blocks are generally sub-angular, grading into a breccia with increasing angularity. They may be in mutual contact, or separated by the matrix. The latter corresponds to a lapilli-tuff in most cases. If the blocks make up less than about 50% by volume, the rock is referred to as an agglomeratic tuff.

Agglomerates are not abundant in the present area. They occur locally in the Kapchererat Formation east of the basement arch as agglomeratic tuffs, consisting of blocks of basalt in a matrix composed of basalt cinders and ash.

Agglomerates and agglomeratic tuffs occur in the Tugen Hills Group, up to 40 ft. (12 m.) thick, associated with the top of the Sigatgat Hill complex flank deposits and the adjacent Lelgrong Tuffs, and also at the base of the Lelgrong Tuffs, where they overlie the Kapkaru Volcanics. They take the form of large sub-angular blocks of trachyphonolitic lava in a tuffaceous matrix. They tend to terminate abruptly. An agglomeratic horizon is present in the Cheptuimet Trachyphonolite, but was not examined in the field.

A vent agglomerate forms the hill Kelan (square 2741). It is a vertical, pipe-like body 1500 ft. (450 m.) in diameter, cutting the Lelgrong Tuffs. It consists of boulders and blocks of trachyte, trachyphonolite xenoliths and basalt in a tuffaceous matrix. Larger outcrops of lava are probably dykes later than the agglomerate. Agglomerates are uncommon elsewhere in the Tugen Hills Group, but occasional agglomeratic tuffs occur in the Kapkaru Volcanics and Kameiyun Volcanics, particularly in the latter. The blocks are usually lava, but at 323463 are a black glass, 5/335.

Basaltic agglomerates occur in the Tirioko Basalts north of 1°22'N. They consist of spindle bombs varying from 2 cm. to 1 m. across, in a bluish or mauve cindery matrix. The bombs make up 25%-75% of the volume. Similar deposits occur at Mechwet, Kapusyuin and Torkoit, p.42 and Fig. 25.

Agglomerates are not uncommon in the Kiddeh Group, particularly forming the basal facies of pumice lapilli tuffs, and passing smoothly up into evenly sorted lapilli tuffs. This is inferred to be a form of graded bedding. Plate XXXIII shows such a basal agglomeratic facies at 733538. Elsewhere, they occur as horizons within tuff sequences,

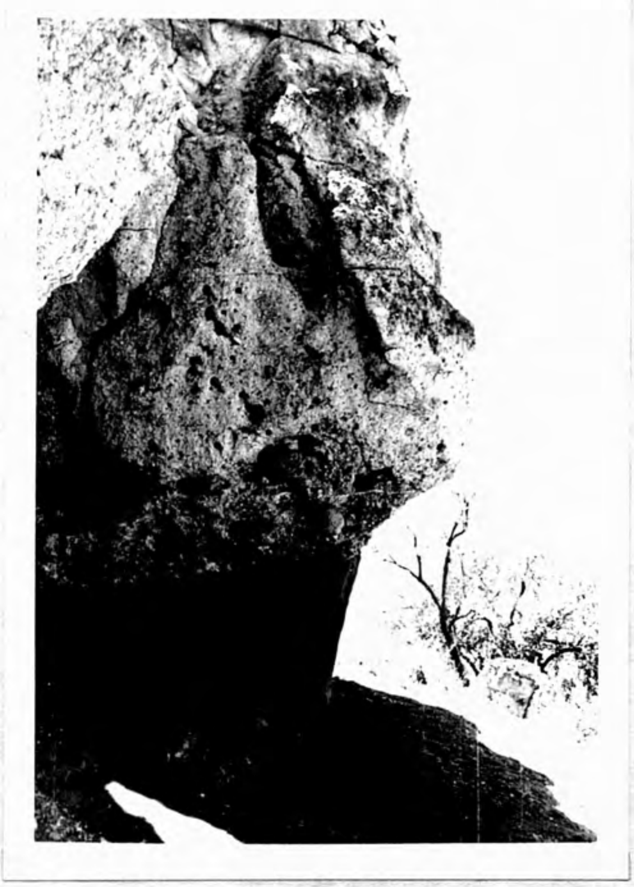


Plate XXXIII. Air fall tuff with agglomeratic base, 733538.

in the Lokitet Crater unit of the Ribkwo Complex, and at scattered localities in the Karianamani tuffs of the Kachila Volcanics.

The lahars and ladu in the Kariamangro Caldera unit, p.64, are genetic terms for special types of agglomerate, and are described in that section.

(b) Lapillistones contain at least c.75% by volume of lapilli. The lapilli can be either lithic or pumice, and are most commonly the latter, though both invariably occur. Most of the thick sequences of pyroclastics in the present area are lapilli tuffs, but within these, horizons and discontinuous bands of lapillistone can occur.

However, discrete horizons of pumice-lapillistone occur in the Agibelbel beds (q.v., p.82). At least three bands, 15-20 cm. thick, occur consisting almost entirely of grey pumice lapilli up to 1.5 cm. in diameter. They are very poorly consolidated, for which type of deposit the term lapilli-gravel is proposed.

(c) Lapilli-Tuffs are defined by Fisher (op.cit., p.292) as "mixture-rocks", the ratio of lapilli to ash in which "depends upon the prejudices of the individual" (op.cit., p.293). In the present area, a lapilli-tuff contains from c.25% to c.75% of lapilli, in a finer grained tuffaceous matrix. Blocks also occur, but are usually isolated.

This kind of pyroclastic is common in the present area, especially in the Tugen Hills Group and Kiddeh Group. In them, the commonest lapilli are pumice, but almost always, from 10% to 50% of the lapilli are lithic, either phonolitic and trachytic (5/426 from the Lelgrong Tuffs), syenitic cognate xenoliths (5/234B, from the Lelgrong Tuffs, 5/4 from the Ribkwo Complex, see below), or accidental xenoliths, such as the basalt lapilli low down in the Kaparerr volcanics at 232494.

Pumice lapilli are usually altered to a whitish material, turbid and opaque in thin section. Occasionally, they remain fresh, as in 5/160, from the Kachila Volcanics, in which pumiceous isotropic yellow glass occurs, with perlitic texture.

Ubiquitously present are inclusions of crystals, usually sharply angular and unresorbed. These are most commonly sanidine, which occurs in all lapilli-tuffs and tuffs in the Tugen Hills and Kiddeh Groups. The angularity is taken to indicate an explosive origin. Other crystal inclusions are biotite in lapilli-tuffs from the Tugen Hills Group (5/356 from the Sidekh Phonolites, 5/429 from the Lelgrong Tuffs); anorthoclase (5/314, Kameiyun Volcanics); green clinopyroxene (5/160, Kachila Volcanics); and plagioclase (5/426, Lelgrong Tuffs). The latter is present as rare grains in many of the pyroclastics in the Tugen Hills Group, and though it is not seen in any of the lavas, it may form at depth as a transitional phase.

In hand specimen, the majority of these rocks are white or cream in colour, and moderately consolidated.

In the field, they are rarely structureless. They are nearly always bedded in units from 6 ins. to 6 ft. (15 cm. to 2 m.) thick. Grading is sometimes shown, the percentage of lapilli diminishing upwards. Interfaces between successive units are generally uniform, but are sometimes channelled, as in the Karianamani tuffs, indicating a longer quiescent period. There may also be thin interleavings of finer grained tuffs, sometimes closely laminated. Such deposits occur around Lelgrong, and include pure white paper shales. Such fine grained deposits with good lamination may have been deposited in temporary lakes as the finer ash settled. Specimen 5/344 from 322432 was examined for diatoms, but none were found. Similar deposits in the Kariamangro Caldera at 762412 show slump folds, indicating an aqueous environment. Slump folds also occur low in the Lokitet Crater unit.

Walker and Croasdale (1971, pp.1-43), in a study of lapilli tuffs in the Azores, have attributed fine grained intercalations of varying thickness not only to variations in the force of eruption, climatic conditions etc., but to "base surge", and postulate that they are pyroclastic flows, and not airfall deposits. No such deposits show welding, however, although they contain carbonized tree remains, indicating a high temperature during their emplacement. Welded tuffs occurring in lapilli-tuff sequences in the present area, e.g. the Karianamani tuffs, Lokitet Crater unit, may similarly be thought of as base surge eruptions, representing changing conditions of pressure and rate of supply of magma in the conduit. Moore (1967, pp.336-363), however, commenting on base surge deposits in the Philippines, estimates their emplacement temperature at less than 100°C.

An unusual variety of lapilli-tuff is the rain drop lapilli-tuff observed at infrequent intervals in the Lelgrong Tuffs (5/431 from 252471), and the Ribkwo Complex, at 760410. The lapilli are ovoid, up to 1 cm. long, and consist of thin fine grained hollow shells, filled with coarser grained tuff. They are considered to be formed when rain falls through an ash cloud. Walker (op.cit., p.47) mentions "accretionary lapilli" in connection with rain flushing, which are possibly similar.

The syenitic xenoliths referred to above deserve special mention. They are rounded blocks from 1 cm. to 0.5 m. across, generally very leucocratic, and varying from fine to coarse grained. In thin section, they are seen to consist principally of perthitic feldspar, alkali amphibole and aegirine.

Specimen 5/234B from the Lelgrong Tuffs differs from such xenoliths from the Kiddeh Group in that it contains nepheline. It also contains abundant interstitial analcime, reflecting, it is believed, the inherently more undersaturated character of the Tugen Hills Group.

The other minerals present are perthitic feldspar, acicular aegirine in radial clusters, and a green-blue pleochroic amphibole, with 2V(+) c.60^{o}-70^{o}. A little reddish brown biotite is present, and a golden yellow prismatic accessory mineral, possibly låvenite or a related mineral. Specimen 5/343 is a fine grained syenitic xenolith, which contains abundant small subhedra of brown amphibole.

Many of the specimens from the Ribkwo Complex have a cumulophyric texture, in which the rock is formed largely of subhedral feldspars, with interstitial mafics. Such xenoliths are often not very compact. An example is 5/4ii, composed essentially of perthitic feldspar and green-greenish yellow pleochroic aegirine. Nepheline, biotite and amphiboles are absent. Such xenoliths are abundant in the Lokitet and Kariamangro units of the Ribkwo Complex, but also occur elsewhere in the complex, and in other complexes in the Group. They only occur very rarely in lavas, where they have a similar mineralogy (5/29). Compositions of analysed minerals from 5/4i are given in Chapter 6.

It is considered that these coarse grained xenoliths could be derived in either of two ways:

(i) A trachytic magma solidifies at depth to syenite, and is subsequently incorporated as accidental xenoliths in an erupting magma. Such xenoliths would have a compact texture, and may yield "high-pressure phases" such as brown amphibole.

(ii) A trachytic magma at high levels undergoes fractionation so that a "scum" of feldspar crystals forms, to be incorporated in the products of explosive eruption. A certain proportion of the magma may also solidify around the edge of the magma chamber, and be similarly incorporated.

(c) Tuffs are generally accepted as being composed of indurated ash. Up to 25% or so of clasts larger than 2 mm. across may be present, and usually are.

It is not always possible to distinguish between primary air-fall ash and secondarily derived material. This difficulty has largely been ignored in the following account.

Tuffs are usually well sorted. They represent the finer material produced during an explosive eruption, and are generally found peripheral to a volcano, way out on the flanks. Material may not accumulate so rapidly, and erosive and transport agents usually affect the unconsolidated material. In this manner, they are often laminated, and may show structures such as slumping (5/65 from 762412); false bedding, upper Aterir beds, and grading (5/430 from 241462).

Tuffs occur in the Kapchererat Formation, particularly west of the basement arch. They are red, pink, yellow and white, well laminated (5/353), and occasionally cross-bedded, and well sorted. They are generally silty to fine sand grade, but finer grained laminated tuffs with a brick red colour (5/367) are intercalated at 073460. At the base, there is a variable admixture of epiclastic basement material, in the form of quartz grains from 2 cm. down to less than 0.5 cm. in size (5/355). East of the arch, the tuffs are bluish in colour, and have a higher proportion of cinders and lapilli.

In the Tugen Hills Group, tuffs are present in the Lelgrong Tuffs (5/344), the Kameiyun Volcanics (5/314, 5/345), and in the Kaparerr and Sigatgat Hill volcanoes. They are usually white, laminated, and contain varying proportions of pumice lapilli, lithic lapilli, glass lapilli and blocks (5/335), occasional rain drop lapilli (5/236), and angular crystal fragments including sanidine, anorthoclase (5/314), and biotite (5/334). Tuffs also occur in the Chepkoi Tuffs, intercalated with the pumice lapilli-tuffs.

Tuffs are absent from the Tirioko Basalts, but are present in the Kiddeh Group. They vary in hand specimen from coarse grained, with up to c.25% of pumice and lithic lapilli (5/72, Kachila Volcanics) to very fine grained (5/79, Kariamangro Caldera). They are usually compact, laminated and sometimes show evidence of subaqueous deposition.

They also show a variety of textures in thin section. Specimen 5/72 (791438) preserves a very good vitroclastic texture. The individual shards are roughly 0.1 mm. to 0.2 mm. across, with cuspate outlines. They are completely devitrified, opaque and brown, with imperfect spherulitic texture. Larger clasts of pumice, lithic material and sanidine fragments are also present.

Specimen 5/273 (704576) is much finer grained. It consists of a microgranular yellowish matrix, in which no separate particles are discernible, and which appears to be comminuted ash. Numerous very small sanidine fragments occur, together with larger fragments of sanidine and analcitized trachyte up to 1 mm. across.

Specimen 5/79 (759401) is one of the finest grained tuffs seen. It has a brownish turbid mesostasis in which are minute fragments of feldspar and (aegirine)-augite. It has a lamination defined by occasional thin bands of trachyte grains up to ½ mm. across. It is greyish in hand specimen, and its field relations indicate that it is a temporary lake deposit.

Other varieties of tuffs are crystal tuffs such as 5/258 (704389) in which numerous sanidines, both whole and fragmented, occur in a yellowish friable tuffaceous matrix. Specimen 5/331 (724611) is similar, but all the sanidine is fragmented, and numerous small square magnetite crystals about 0.2 mm. across also occur, Plate XXXIV.

8. Epiclastic Sediments

These are present in most formations to some extent, but only rarely are they stratigraphically significant. In most cases they consist of reworked volcanic material, and are recognized as epiclastic not under the microscope, but by their field relations. They are discussed below in stratigraphic order.

(a) Turkana Grits. These are comprised mainly of pebbles and sand grade material derived from the basement. In the Chepkirial River (186522) pebbles of basalt occur, and at other localities the matrix is in part an altered purple material, possibly altered ash. Other common matrix minerals are calcite and chalcedonic silica.

(b) Kapchererat Formation. West of the basement arch is the Kei Pa So sandstone. It is fine grained (0.2 mm. - 2 mm.), bedded in units of c.3 ft. (1 m.), and composed mainly of basement quartz grains and chalcedonic silica (5/373), which has embayed the quartz grains. A few feldspar and muscovite grains also occur. East of the basement arch, a calcareous mudstone with thin shell remains (5/397) occurs at 182399.

No epiclastic sediments were recognized in the Tugen Hills Group.

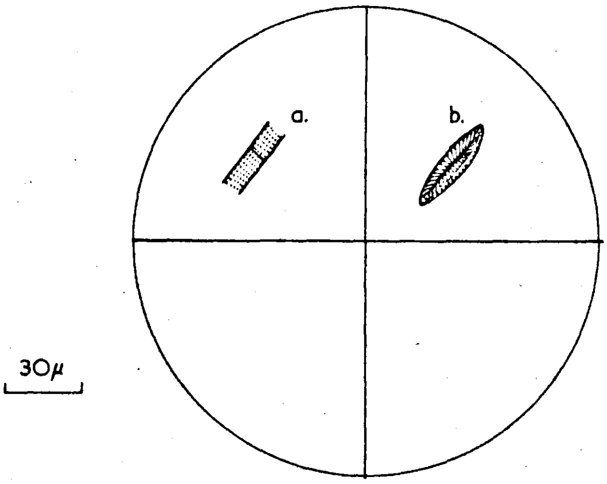
(c) A diatomite occurs in the Tirioko Basalts at 689519. It is imperfectly shaly, nearly pure white, and is about 3 ft. (1 m.) thick. The diatoms (5/307) are illustrated in Fig. 27.

(d) The Kiddeh Group has several epiclastic horizons. The most common are volcanic sandstones, i.e. rocks composed of clasts from c.0.5 mm. to 2 mm. which are derived from pre-existing volcanic rocks. In the field, they often have a reddish colour, are not very well consolidated, and have red soils associated with them, e.g. at 732539, between two tuff units on the northern flanks of the Ribkwo Volcano. A similar sandstone occurs beneath the Kablaton unit at various localities, e.g. 726398, where there are red soils with rootlets, and at 706402. At the latter, the epiclastic horizon is about 5 ft. (1.5 m.) thick, consisting of a gravelly sandstone followed up by a mottled red soil. At 707397, about 4 ft. (1.2 m.) of sandstone (5/114) occur, consisting of sub-angular sanidine grains from 0.1 mm. to 3 mm. across, and rounded grains of trachyte in a reddish porous matrix. Microgranular secondary zeolite (?) occupies pore spaces.

Specimen 5/182 is a volcanic sandstone from 797590, beneath an outlier of Namortoitio Trachyte. It has a reddish colour, and is well laminated and sorted. Besides trachyte grains and sanidine fragments, it contains rounded fragments of fresh orange glass, and less fresh but still readily identifiable flattened pumice. These are thought to be primary pyroclastic material, and it is envigaged that after the completion of the Nasaken Complex, erosion of it supplied epiclastic material which became mixed with pumice showers from Oliyamur Volcano. The Namortoitio Trachyte is considered (p.79) to be a trachyte lava from the Oliyamur Volcano.

The diatomite in the Aterir beds is considered to be epiclastic. The diatoms (5/54) are illustrated in Fig. 72. A diatomite such as that referred to grades into diatomaceous tuffs, such as 5/175.

The lahars in Kariamangro Caldera are also epiclastic. Their form and origin are referred to on p.64.



Relative abundance

form a.	c. 99%
form b.	c. 1%

FIG. 72. Diatoms, Aterir beds at 764501, (5/54).

CHAPTER 6

PETROLOGY

Introduction

This chapter serves to discuss the chemistry of the lavas in the present area, without attempting to relate them on a regional basis. The results obtained from the variation diagrams illustrate the general evolution of the lavas with time. Proposals for a differentiation mechanism put forward by McClenaghan (op.cit.) are then discussed in the light of evidence from the present area.

1. Rock Analyses and Norms

The compositions of 53 analysed lavas from the present area are presented in Tables 21 to 26. The norms accompanying them are C.I.P.W. norms, with a slight modification of the treatment of TiO_2 introduced by Weaver and McClenaghan. The stratigraphic distribution of analyses is as follows.

(a)	Kolloa Group:	6
(b)	Tugen Hills Group:	7
(c)	Tirioko Basalts:	8
(d)	Kiddeh Group:	25
(e)	Komosing Formation:	7

The norms are generally thought to be valid, except where the rock is weathered. In such cases, the % age of Fe_2O_3 often greatly exceeds that of FeO, and normative haematite appears, which is not thought to be a common primary mineral. Examples are 5/110, an olivine-basalt from the Kamosing Formation, and 5/413, a weathered phonolite from the Tiriomim Volcanics. High H_2O and CO_2 values also indicate secondary alteration.

(a) Kolloa Group. Most of the analysed rocks, Table 21, are salic lavas, and so no comments can be made on the Group as a whole. From microscopic evidence, it is evident that there is wide variation in the

Table 21. Compositions of lavas in the Kolloa Group

Rock No.	392	421	396	440	384	394
SiO_2	45.94	45.90	58.70	57.95	57.44	61.38
TiO_2	2.00	2.22	1.14	1.22	1.09	0.96
Al_2O_3	16.13	12.83	18.08	18.90	18.21	18.04
Fe_2O_3	5.89	4.01	5.90	6.49	6.14	4.80
FeO	5.33	6.72	0.14	0.00	0.29	0.23
MnO	0.20	0.17	0.06	0.18	0.14	0.04
MgO	4.63	9.08	1.01	0.15	1.75	0.60
CaO	8.55	12.66	1.76	2.55	2.20	1.32
Na_2O	5.39	3.31	6.76	6.66	6.13	6.90
K_2O	2.39	0.76	3.79	3.31	4.12	4.19
H_2O	2.71	2.37	2.46	2.10	1.98	1.28
P_2O_5	0.70	0.35	0.35	0.62	0.42	0.34
CO_2	0.25	-	-	-	-	-
	100.11	100.38	100.15	100.13	99.91	100.08

CIPW Norms

Qu		-	-	0.59	2.61	-	2.45
Or		14.12	4.49	22.40	19.56	24.35	24.76
Ab		20.32	15.22	57.20	56.36	51.87	58.39
Ne		13.70	6.93	-	-	-	-
An		12.76	17.91	6.45	8.60	8.17	4.33
Di	Fe	1.29	3.24	-	-	-	-
	Mg	7.50	12.91	-	-	-	-
	Ca	9.81	17.79	-	-	-	-
Hy	Fe	-	-	-	-	-	-
	Mg	-	-	2.52	0.37	3.96	1.49
Ol	Fa	0.54	1.88	-	-	-	-
	Fo	2.83	6.80	-	-	0.28	-
Wo		-	-	-	-	-	-
Ac		-	-	-	-	-	-
Mt		8.54	5.81	-	-	-	-
Il		3.80	4.22	0.42	0.38	0.91	0.57
Sph		-	-	-	-	-	-
Rt		-	-	0.92	1.02	0.61	0.66
Ap		1.62	0.81	0.81	1.44	0.97	0.79
Cor		-	-	0.50	1.21	0.67	0.57
Hm		-	-	5.90	6.49	6.14	4.80
H_2O		2.71	2.37	2.46	2.10	1.98	1.28
Ct		0.57	-	-	-	-	-
		100.11	100.38	100.15	100.13	99.91	100.08
σ		20.60	5.21	7.10	6.66	7.27	6.69

$$\sigma = \frac{(Na_2O + K_2O)^2}{SiO_2 - 43} \quad \text{(wt. \%ages)}$$

(Rittman, 1962, pp.109-111)

rock types present. Specimens5/392 and 5/421 are both augite-olivine-phyric basalts with interstitial analcime. Both are nepheline-normative, but are thought not to represent the "parent" Kapchererat Formation basalt, on account of the high proportion of phenocrysts.

The remaining rocks, Table 21, include two mugearitic lavas, a Keitin intrusive trachyte, 5/384, and a trachyte lava, 5/394. The two mugearitic lavas, 5/396 and 5/440 were identified as plagioclase-trachyte and trachymugearite. They are chemically very similar, and similar also to 5/384, from the largest of the Keitin intrusions. The normative feldspars in each are in roughly the same proportion. In 5/396, there is 6.45% normative An. If a little of this is accounted for in alkali feldspar, then there remains c.5.0%. If this is combined with albite to give oligoclase (which occurs in the mode, see Table 21) of composition c.An_{20}, then roughly 20%-25% of the rock should be oligoclase. However, oligoclase phenocrysts account for less than 5% of the rock, and it is therefore likely that some of the groundmass feldspar is oligoclase, whereas in the mode it was identified as 'sanidine'. This again illustrates (see also p.109) the uncertainty of identifying groundmass feldspar by twinning alone. Specimen 5/384 was similarly identified as a trachyte, while 5/440 was identified as a mugearite.

Specimen 5/394 is from approximately the same stratigraphic position as the other two salic lavas, probably higher than 5/396. It is more acid than the others, has a lower An content, and the normative feldspars have more similarity to the mode. It was identified in thin section as a trachyte with anorthoclase phenocrysts and subordinate oligoclase phenocrysts.

The significance of the various phenocrysts in these rocks is discussed below, p. 179.

(b) <u>Tugen Hills Group</u>. In Table 22, compositions and norms of seven

Table 22. Compositions of lavas in the Tugen Hills Group

Rock No.	413	437	445	140	141	324	336
SiO_2	58.12	54.65	55.64	57.11	58.46	59.84	60.15
TiO_2	0.55	0.47	0.35	0.65	0.67	0.36	0.52
Al_2O_3	19.37	19.81	20.11	17.51	16.82	17.26	17.15
Fe_2O_3	6.89	2.41	2.67	4.65	4.08	3.60	3.68
FeO	0.00	2.13	1.91	1.95	2.73	2.66	2.35
MnO	0.65	0.25	0.28	0.22	0.22	0.23	0.24
MgO	0.26	0.49	0.37	0.66	0.66	0.27	0.49
CaO	0.25	1.66	1.19	1.29	1.23	1.78	1.96
Na_2O	6.04	7.78	8.33	7.30	7.03	6.68	6.13
K_2O	5.34	6.12	6.07	5.12	5.30	5.52	5.61
H_2O	3.07	3.49	3.37	3.67	3.09	2.13	1.71
P_2O_5	0.05	0.09	0.06	0.07	0.06	0.04	0.07
CO_2	-	1.15	-	-	-	-	-
	100.59	100.50	100.35	100.20	100.35	100.37	100.06

CIPW Norms

Qu		1.77	-	-	-	-	-	-
Or		31.56	36.16	35.87	30.26	31.32	32.62	33.15
Ab		51.11	33.28	29.84	45.93	46.44	49.19	50.38
Ne		-	17.64	21.56	8.47	5.73	3.97	0.81
An		0.91	0.38	-	-	-	0.81	2.71
Di	Fe	-	-	1.43	-	1.14	1.74	0.86
	Mg	-	-	0.90	1.64	1.19	0.67	1.22
	Ca	-	-	2.30	1.90	2.38	2.31	2.17
Hy	Fe	-	-	-	-	-	-	-
	Mg	0.65	-	-	-	-	-	-
Ol	Fa	-	1.24	0.02	-	0.33	-	-
	Fo	-	0.86	0.01	-	0.32	-	-
Wo		-	-	-	0.58	-	0.93	0.57
Ac		-	-	0.74	0.19	2.18	-	-
Mt		0.53	3.49	3.50	5.12	4.82	5.22	5.33
Il		1.04	0.89	0.66	1.23	1.27	0.68	0.99
Sph		-	-	-	-	-	-	-
Rt		-	-	-	-	-	-	-
Ap		0.12	0.21	0.14	0.16	0.14	0.09	0.16
Cor		3.32	0.25	-	-	-	-	-
Hm		6.53	-	-	1.06	-	-	-
H_2O		3.07	3.49	3.37	3.67	3.09	2.13	1.71
Ct		-	2.62	-	-	-	-	-
		100.59	100.50	100.35	100.20	100.35	100.37	100.06
σ		8.56	16.58	16.39	10.92	9.85	8.83	8.05

salic lavas are presented. Specimens 5/437 and 5/445 are flinty phonolites. The high normative nepheline content is reflected in the analyses by lower SiO_2 and higher total alkalies and alumina values than trachyphonolites from the same Group. Specimen 5/413 is a weathered phonolite. The main effects of the weathering are leaching out of alkalies and lime, and oxidation of ferrous iron. Even such differences, amounting to no more than ±5%, cause the lava to be quartz normative.

The other lavas are trachyphonolites, from the Kameiyun Volcanics (5/140, 5/141) and from the Cheptuimet Trachyphonolite (5/324 and 5/336). Although chemically similar, there are slight differences between the two formations (based on these 4 analyses only), such as the slightly higher SiO_2 content in the Cheptuimet Trachyphonolite, and its slightly lower Na_2O/K_2O ratio. These are reflected in the norm, so that the Cheptuimet Trachyphonolite is just less undersaturated.

Another fact that emerges, from this Group and others, is the apparent absence of phonolitic lavas with 10%-15% normative nepheline. All the undersaturated salic lavas analysed contain either 0%-10% normative nepheline (phonolitic trachytes and trachyphonolites) or over 15% (phonolites).

(c) Tirioko Basalts. Within this formation, as in the Kapchererat Formation, not only basalts are present, but salic lavas with up to 58.86 per cent SiO_2, Table 23. A further similarity is that the progressive chemical changes are not in any stratigraphic order. There is a tendency for SiO_2 to increase from the bottom to the middle of the formation, but above the leucocratic unit, olivine rich basalts appear again. Further, the trachytic differentiates form no unit of their own, but are interspersed within other basaltic units.

Specimen 5/249 is an augite-olivine-magnetite cumulate, containing 70.79% normative mafics, corresponding to the observed mode.

Table 23. Compositions of lavas in the Tirioko Basalts

Rock No.	249	35	43	330	283	275	280	291
SiO_2	36.97	42.66	42.55	46.47	49.42	53.65	58.68	58.86
TiO_2	4.12	2.95	4.33	2.57	2.30	1.86	1.07	1.09
Al_2O_3	6.07	15.40	13.60	16.95	17.31	16.13	17.02	16.91
Fe_2O_3	8.19	6.52	6.78	5.65	3.05	8.73	6.51	7.82
FeO	19.71	7.20	7.78	6.38	7.14	1.08	0.65	0.40
MnO	0.37	0.22	0.24	0.23	0.21	0.31	0.13	0.09
MgO	14.90	6.98	4.72	3.83	2.71	1.63	0.76	0.35
CaO	4.86	10.80	10.27	7.90	7.67	4.32	2.08	1.78
Na_2O	1.76	2.51	3.05	4.54	4.58	5.58	6.39	6.49
K_2O	0.84	0.96	1.11	1.71	2.27	3.03	3.84	3.75
H_2O	1.77	2.59	2.94	1.93	2.57	2.94	2.50	2.26
P_2O_5	0.50	0.80	1.87	1.62	0.85	0.65	0.27	0.28
CO_2	0.24	0.37	0.36	-	-	0.15	-	-
	100.30	99.96	99.59	99.78	100.08	100.06	99.90	100.08

CIPW Norms

Qu		-	-	0.40	-	-	1.50	2.45	3.44
Or		4.96	5.67	6.56	10.11	13.41	17.91	22.69	22.16
Ab		14.89	21.24	25.81	34.95	33.85	47.22	54.07	54.92
Ne		-	-	-	1.88	2.66	-	-	-
An		6.18	27.92	20.14	20.82	19.97	10.02	6.42	5.93
Di	Fe	2.02	1.10	0.88	0.76	2.66	-	-	-
	Mg	3.21	5.69	5.22	2.23	2.50	2.25	0.77	0.39
	Ca	5.49	7.56	6.81	3.25	5.23	2.60	0.89	0.45
Hy	Fe	0.25	0.28	1.10	-	-	-	-	-
	Mg	0.40	1.44	6.54	-	-	1.82	1.12	0.49
Ol	Fa	16.25	1.54	-	1.91	3.49	-	-	-
	Fo	23.48	7.18	-	5.12	2.98	-	-	-
Wo		-	-	-	-	-	-	-	-
Ac		-	-	-	-	-	-	-	-
Mt		11.87	9.45	9.83	8.19	4.42	-	-	-
Il		7.82	5.60	8.22	4.88	4.37	2.94	1.65	1.04
Sph		-	-	-	-	-	-	-	-
Rt		-	-	-	-	-	0.31	0.20	0.54
Ap		1.16	1.85	4.33	3.75	1.97	1.51	0.63	0.65
Cor		-	-	-	-	-	-	-	-
Hm		-	-	-	-	-	8.73	6.51	7.82
H_2O		1.77	2.59	2.94	1.93	2.57	2.94	2.50	2.26
Ct		0.55	0.84	0.82	-	-	0.34	-	-
		100.30	99.96	99.59	99.78	100.08	100.06	99.90	100.08
σ		-	-	-	11.27	7.51	6.96	6.68	6.62

Specimens5/35, 5/43 and 5/330 are all basalts, with differing degrees of silica saturation in the norm. However, none are perfectly fresh, and the 0.40% normative quartz in 5/43, which contains sparse altered olivine phenocrysts, should be disregarded. Specimen 5/330, containing 1.88% normative nepheline, is apparently olivine-free in the mode, though the fine grain of the rock makes this a little uncertain.

Specimen 5/283 is a plagioclase-phyric trachyte, with higher SiO_2, Al_2O_3 and total alkalies than the other basalts, and lower MgO, CaO and total iron. It is nepheline normative, and has a slightly higher Or content, but otherwise differs little from the other basalts.

Specimens 5/275, 5/280 and 5/291 are leucocratic lavas. The first two are from the leucocratic unit and were identified microscopically as a hawaiite and plagioclase trachyte respectively. Specimen 5/291 is a trachyte from the plagioclase-phyric unit, very similar compositionally to 5/280. It too has sparse feldspar phenocrysts, only some of which show albite twinning.

Both the analyses and microscopic evidence indicate that differentiation in this formation did not proceed as far as in the Kapchererat Formation.

(d) Kiddeh Group. Tables 24 and 25 contain 25 analyses of basalts, trachytes and intermediate lavas. Of these, only 4 are nepheline normative, all basalts, while nearly all the intermediate and trachytic lavas are quartz normative. Some specimens are obviously altered, such as 5/110, which contains iddingsite pseudomorphs after olivine in the mode.

None of the Ribkwo Complex trachytes in Table 24 have normative nepheline, whereas of the 9 analysed, 5 have pseudonepheline phenocrysts in the mode. This discrepancy is secondary, at least in part. The most oversaturated rock, with 18.99% normative quartz, is 5/36, a hydrated glass block from pumice tuffs in the Ribkwo Complex.

Table 24(i). Compositions of lavas in the Kiddeh Group (Tumungir Basalt, Mugor Trachytes & Ribkwo Complex)

Rock No.	248	268	274	12	14	28	63	66	67
SiO_2	63.07	64.07	43.69	60.51	59.79	60.41	58.25	59.79	60.79
TiO_2	0.50	0.36	2.21	0.86	0.58	0.79	0.54	0.59	0.65
Al_2O_3	15.41	16.14	14.78	16.22	15.80	14.58	12.44	14.22	13.53
Fe_2O_3	4.25	5.45	4.28	3.77	4.82	5.94	9.85	5.98	6.36
FeO	2.09	0.15	8.07	3.07	3.14	2.61	2.37	3.46	3.40
MnO	0.13	0.12	0.17	0.26	0.23	0.33	0.45	0.25	0.26
MgO	0.36	0.14	9.06	0.76	0.49	0.52	0.44	0.48	0.24
CaO	0.51	0.54	11.58	1.93	1.45	1.54	1.04	1.43	1.12
Na_2O	6.76	6.43	2.14	6.55	6.58	6.43	7.43	6.73	6.67
K_2O	4.90	5.44	1.04	4.87	4.59	5.07	4.60	4.94	5.02
H_2O	2.07	1.46	2.41	0.92	2.41	1.67	2.46	2.80	2.35
P_2O_5	0.03	0.07	0.45	0.17	0.06	0.10	0.04	0.01	0.02
CO_2	-	-	-	-	-	-	-	-	-
	100.08	100.37	99.88	99.89	100.04	99.99	99.91	100.68	100.41

CIPW Norms

		248	268	274	12	14	28	63	66	67
Qu		4.67	5.55	-	-	0.69	2.57	0.27	0.39	2.77
Or		28.96	32.15	6.15	28.78	27.12	29.96	27.18	29.19	29.66
Ab		51.98	52.73	13.87	55.42	55.72	46.77	38.38	45.64	41.65
Ne		-	-	2.30	* -	* -	-	* -	* -	-
An		-	-	27.65	0.47	-	-	-	-	-
	Fe	0.52	-	2.69	1.48	1.46	1.12	1.43	2.35	2.16
Di	Mg	0.44	0.35	7.64	1.76	1.22	1.30	0.68	0.75	0.31
	Ca	0.98	0.40	11.21	3.34	2.70	2.48	2.05	2.94	2.27
Hy	Fe	0.53	-	-	0.09	-	-	0.89	1.40	1.96
	Mg	0.45	-	-	0.11	-	-	0.42	0.45	0.28
Ol	Fa	-	-	4.06	0.02	-	-	-	-	-
	Fo	-	-	10.46	0.02	-	-	-	-	-
Wo		-	-	-	-	0.15	0.44	-	-	-
Ac		4.60	0.44	-	-	0.71	6.73	21.58	9.96	13.03
Mt		3.86	1.48	6.21	5.46	6.63	5.24	3.47	3.68	2.69
Il		0.95	0.57	4.20	1.63	1.10	1.50	1.03	1.12	1.23
Sph		-	0.14	-	-	-	-	-	-	-
Rt		-	-	-	-	-	-	-	-	-
Ap		0.07	0.16	1.04	0.39	0.14	0.23	0.09	0.02	0.05
Cor		-	-	-	-	-	-	-	-	-
Hm		-	4.94	-	-	-	-	-	-	-
H_2O		2.07	1.46	2.41	0.92	2.41	1.67	2.46	2.80	2.35
Ct		-	-	-	-	-	-	-	-	-
Ns										
		100.08	100.37	99.88	99.89	100.04	99.99	99.91	100.68	100.41
σ		6.56	6.48	-	7.47	7.56	7.59	9.50	8.11	7.69

* Pseudonephelines in the mode

Table 24(ii). Compositions of lavas in the Kiddeh Group (Ribkwo Complex cont.)

Rock No.	104	109	110	108	36	37	39
SiO_2	42.92	42.00	42.46	53.34	59.09	60.01	65.50
TiO_2	3.24	4.20	2.62	2.34	0.55	0.65	0.69
Al_2O_3	16.19	14.37	15.79	16.03	12.96	16.67	14.17
Fe_2O_3	4.90	12.91	10.60	9.88	8.15	4.72	6.31
FeO	7.72	3.00	2.21	0.72	1.84	2.17	0.07
MnO	0.19	0.17	0.15	0.22	0.33	0.27	0.13
MgO	6.13	4.51	4.58	1.18	0.30	0.51	0.03
CaO	9.34	10.25	11.45	3.65	1.38	1.68	0.40
Na_2O	3.29	2.98	2.46	5.48	3.90	5.91	6.01
K_2O	2.09	1.01	0.92	3.94	3.69	5.71	5.09
H_2O	3.49	3.57	4.69	1.90	7.93	2.30	2.08
P_2O_5	0.60	0.79	0.48	0.73	0.04	0.06	0.07
CO_2	0.42	0.35	1.55	-	-	-	-
	100.52	100.11	99.96	99.41	100.16	100.66	100.55

CIPW Norms

Qu		-	-	2.00	0.13	18.99	0.86	12.13
Or		12.35	5.97	5.44	23.28	21.80	23.74	30.08
Ab		16.18	25.22	20.82	46.37	33.00	50.01	44.55
Ne		6.31	-	-	-	-	* -	-
An		23.24	22.85	29.33	7.51	6.59	2.09	-
	Fe	1.60	-	-	-	-	-	-
Di	Mg	4.75	7.44	5.25	2.11	-	1.27	0.08
	Ca	6.90	8.61	6.07	2.44	-	1.47	0.09
Hy	Fe	-	-	-	-	-	-	-
	Mg	-	2.97	6.16	0.83	0.75	-	-
Ol	Fa	2.73	-	-	-	-	-	-
	Fo	7.37	0.58	-	-	-	-	-
Wo		-	-	-	-	-	0.97	-
Ac		-	-	-	-	-	-	5.56
Mt		7.10	-	0.02	-	5.41	5.99	-
Il		6.15	6.70	4.97	1.99	1.04	1.23	0.42
Sph		-	-	-	-	-	-	0.93
Rt		-	0.67	-	1.29	-	-	0.09
Ap		1.39	0.83	1.11	1.69	0.09	0.14	0.16
Cor		-	-	-	-	0.14	-	-
Hm		-	12.91	10.59	9.88	4.42	0.59	4.39
H_2O		3.49	3.57	4.69	1.90	7.93	2.30	2.08
Ct		1.00	0.80	3.53	-	-	-	-
		100.52	100.11	99.96	99.41	100.16	100.65	100.55
σ		-	-	-	8.56	3.58	7.94	5.47

* Pseudonepheline in the mode.

Table 25. Compositions of lavas in the Kiddeh Group (Kachila Volcanics)

Rock No.	25	50	53	56	57	59	71	75	100
SiO_2	46.12	45.96	50.08	53.68	56.80	62.26	52.70	53.88	51.45
TiO_2	3.45	3.38	2.21	1.72	1.52	0.76	2.14	1.90	2.43
Al_2O_3	16.07	15.73	15.97	16.54	17.14	11.78	16.32	16.45	16.48
Fe_2O_3	10.30	3.89	9.00	8.31	6.70	3.48	9.42	7.54	9.83
FeO	2.28	9.80	1.00	1.32	0.71	5.97	0.47	1.13	1.05
MnO	0.21	0.21	0.29	0.21	0.25	0.35	0.24	0.42	0.19
MgO	3.51	5.07	1.57	1.70	0.87	0.30	1.85	2.12	1.79
CaO	9.53	7.88	7.29	4.46	3.75	0.92	4.60	4.58	5.48
Na_2O	4.11	3.58	5.23	5.70	6.12	7.30	5.24	5.26	5.27
K_2O	1.48	1.91	2.52	2.98	3.14	4.60	3.12	3.47	2.55
H_2O	2.26	1.98	2.40	2.86	2.72	2.10	2.64	2.05	3.10
P_2O_5	0.75	0.63	0.57	0.52	0.37	0.03	0.90	0.55	0.60
CO_2	0.36	-	1.88	-	-	-	-	-	-
	100.43	100.02	100.01	100.00	100.09	99.85	99.64	100.35	100.22

CIPW Norms

		25	50	53	56	57	59	71	75	100
Qu		-	-	0.50	0.22	2.23	7.50	1.32	0.33	0.37
Or		8.75	11.29	14.89	17.61	18.56	27.18	18.44	20.51	15.07
Ab		31.88	26.46	44.26	48.23	51.79	34.98	44.34	44.51	44.59
Ne		1.57	2.08	-	-	-	-	-	-	-
An		21.03	21.21	12.66	10.74	10.02	-	11.80	11.03	13.78
Di	Fe	-	2.39	-	-	-	1.89	-	-	-
	Mg	6.88	3.15	2.85	2.88	2.17	0.14	1.86	2.92	3.42
	Ca	7.96	5.75	3.30	3.33	2.51	1.82	2.15	3.38	3.96
Hy	Fe	-	-	-	-	-	8.46	-	-	-
	Mg	-	-	1.06	1.35	-	0.61	2.75	2.36	1.04
Ol	Fa	-	5.56	-	-	-	-	-	-	-
	Fo	1.30	6.64	-	-	-	-	-	-	-
Wo		-	-	-	-	-	-	-	-	-
Ac		-	-	-	-	-	10.07	-	-	-
Mt		-	5.64	-	-	-	-	-	-	-
Il		5.26	6.42	2.73	3.23	2.03	1.44	1.02	3.28	2.62
Sph		-	-	-	-	0.11	-	-	-	-
Rt		0.68	-	0.77	0.02	0.40	-	1.60	0.17	1.05
Ap		1.74	1.46	1.32	1.21	0.86	0.07	2.09	1.27	1.39
Cor		-	-	-	-	-	-	-	-	-
Hm		10.30	-	9.00	8.31	6.70	-	9.42	7.54	9.83
H_2O		2.26	1.98	2.40	2.86	2.72	2.10	2.64	2.05	3.10
Ct		0.82	-	4.28	-	-	-	-	-	-
Ns							3.58			
		100.43	100.02	100.01	100.00	100.09	99.85	99.64	100.35	100.22
σ		10.00	10.18	5.66	7.06	6.21	6.21	7.19	6.99	7.23

The normative feldspars vary more or less systematically. With increasing SiO_2 content, the Or content increases from c.10% in basalts to up to 40% in trachytes. In all the mugearites and plagioclase-trachytes, the total orthoclase is less than 37%, and the alkali feldspars probably fall in the anorthoclase compositional field. In the trachytes, however, the Or content varies from 26.2% to 40.3%.

Basalts in the group have 30%-50% normative mafics. The intermediate lavas tend to be leucocratic, with colour indices ranging from 15%-20%, although in each case there is between 4% and 10% normative haematite, Table 25 and 5/108 in Table 24. None of the intermediate lavas have acmite in the norm, although 5/59, a glass block from tuffs in the Kachila Volcanics, has 10.07% normative acmite and no normative haematite. It is thought to be nearer to the composition of the original magma than an equivalent salic lava, see p. 181.

The trachytes in Table 24 have a variable content of normative mafics ranging from c.12% to 32%. Most of them have normative acmite, but none have sodium metasilicate.

(e) Kamosing Formation. Under the microscope, the analysed lavas, Table 26, from this formation generally show little alteration. Olivine phenocrysts are usually replaced marginally by iddingsite, but the groundmass mafics are usually quite fresh. This is reflected in the norms, which show a far greater degree of consistency than in older formations. None of the lavas are hypersthene normative, and only one is not nepheline normative. The petrographic similarity between the Pativat member and the plagioclase-phyric type of the Kahanavisian member (5/48) is expressed also in their compositions. Specimen 5/40, from the olivine-augite-phyric type of the Kahanavisian member (see p.124) has noticeably higher MgO, CaO and K_2O, and lower SiO_2 and Al_2O_3. It also has 11.22% normative nepheline, compared to less than 2% in other specimens, though neither nepheline nor analcite were recognised in thin section.

Table 26. Compositions of lavas in the Kamosing Formation

27-88 - Pativat Member
40 & 48 - Kahanavisian Member

Rock No.	27	70	74	81	88	40*	48
SiO_2	45.72	44.29	45.51	44.68	44.35	43.29	46.73
TiO_2	1.79	3.36	2.18	2.90	3.48	2.46	2.30
Al_2O_3	17.60	14.55	16.18	15.72	14.48	13.63	16.08
Fe_2O_3	4.13	3.56	4.52	4.93	6.07	4.82	3.03
FeO	6.58	9.48	7.63	8.40	7.94	6.66	8.70
MnO	0.16	0.22	0.20	0.22	0.25	0.22	0.22
MgO	6.91	7.52	7.43	6.25	6.05	9.32	5.88
CaO	12.06	10.95	11.00	10.25	10.73	13.38	9.88
Na_2O	2.52	2.45	2.88	3.21	3.21	3.06	3.44
K_2O	0.49	0.93	0.68	0.88	1.03	1.47	1.02
H_2O	1.61	2.03	1.42	1.60	1.38	0.76	2.49
P_2O_5	0.28	0.76	0.33	0.76	1.08	0.80	0.47
CO_2	-	-	-	-	-	0.25	-
	99.85	100.14	99.96	99.80	100.05	100.12	100.24

CIPW Norms

Qu		-	-	-	-	-	-	-
Or		2.90	5.50	4.02	5.20	6.09	8.69	6.03
Ab		21.32	20.52	21.92	24.40	24.79	5.19	25.86
Ne		-	0.30	1.33	1.50	1.29	11.22	1.76
An		35.26	25.78	29.21	25.89	22.06	19.11	25.42
	Fe	2.26	3.07	2.47	2.41	2.03	2.51	3.35
Di	Mg	6.48	6.17	6.49	5.38	7.16	12.69	4.86
	Ca	9.49	9.85	9.69	8.35	10.07	16.89	8.57
Hy	Fe	0.07	-	-	-	-	-	-
	Mg	0.19	-	-	-	-	-	-
Ol	Fa	2.84	4.83	3.53	3.52	1.74	1.61	5.20
	Fo	7.39	8.80	8.42	7.14	5.56	7.37	6.86
Wo		-	-	-	-	-	-	-
Ac		-	-	-	-	-	-	-
Mt		5.99	5.16	6.55	7.15	8.80	6.99	4.39
Il		3.40	6.38	4.14	5.51	6.61	4.67	4.37
Sph		-	-	-	-	-	-	-
Rt		-	-	-	-	-	-	-
Ap		0.65	1.76	0.77	1.76	2.50	1.85	1.09
Cor		-	-	-	-	-	-	-
Hm		-	-	-	-	-	-	-
H_2O		1.61	2.03	1.42	1.60	1.38	0.76	2.49
Ct		-	-	-	-	-	0.57	-
		99.85	100.14	99.96	99.80	100.05	100.12	100.24
σ		3.33	9.06	5.05	9.94	13.31	70.7	5.34

* ol-aug-phyric type

2. Suite Affinities

The suite of lavas from the present area belongs to the alkaline-olivine-basalt association. In the basalts themselves, affinities with this association rather than the tholeiitic association are shown petrographically by:

(i) The coexistence of olivine and pyroxene phenocrysts, (Tilley, 1950, pp.37-61);

(ii) The absence of a pyroxene reaction rim around grains of groundmass olivine (Kuno, 1957, p.194);

(iii) The occasional presence of an analcite residuum rather than a glassy siliceous residuum.

The alkaline character of the salic lavas is shown by the frequent occurrence of minerals such as aegirine, cossyrite and alkali-amphiboles.

Chemically, the same can be shown in several ways, e.g. Fig. 73, a plot of weight percentages of MgO against Al_2O_3 in SiO_2, a method introduced by Murata (1960, pp.247-252). The lavas in this diagram fall either on or close to the alkaline-olivine-basalt trend. Rittman's suite index σ, (Rittman, 1962, pp.109-111), where:

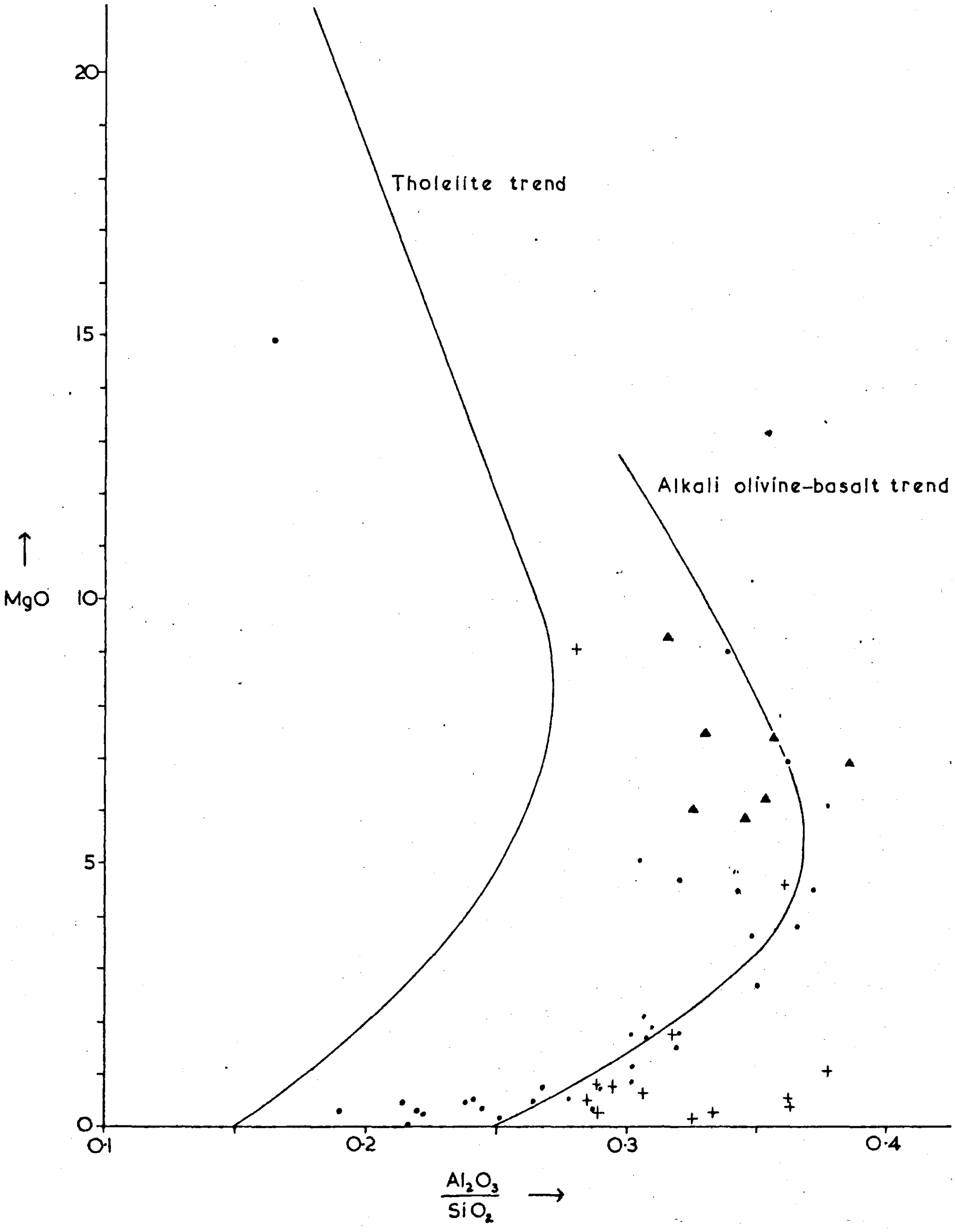
$$\sigma = \frac{(Na_2O + K_2O)^2}{SiO_2 - 43} \quad \text{and} \quad \begin{array}{c|cl} \uparrow & 5 & \text{Atlantic (} \quad \text{alkaline-olivine)} \\ & 4 & \text{Transitional} \\ & & \text{Pacific (} \quad \text{tholeiitic)} \\ \sigma & 0 & \end{array}$$

& 5/27)

varies from 5 to 20 with only two exception (5/36 ^, see Tables 21-26. Fig. 74 shows the alkali-lime indices (Peacock, 1931, pp.54-67) for lavas from the present area.

3. Origin of the Lavas

In many volcanic provinces, salic lavas form only 5% or so of the total volume of eruptives, the rest being almost exclusively basaltic. In East Africa, the salics form about 50% of the total erupted volume.



KEY

▲ Kamosing Formation

• Tirioko Basalts and Kiddeh Group

\+ Kolloa and Tugen Hills Groups

(applies to all subsequent diagrams in this chapter)

FIG 73 Murata diagram (1960, pp. 247-252)

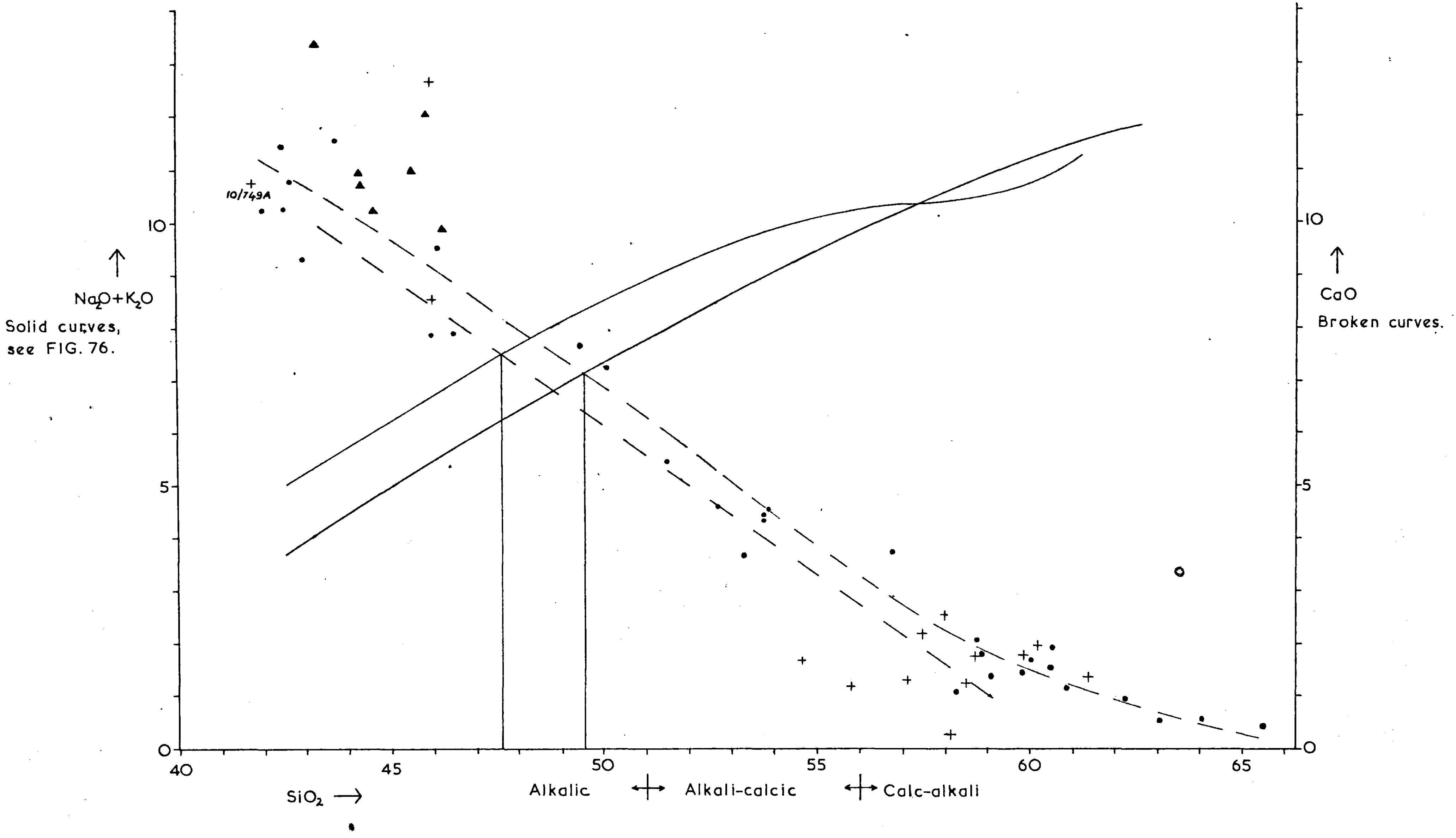


FIG. 74 Alkali-lime indices for the two oldest trends.

It appears difficult, then, to explain their origin purely in terms of differentiation from a basalt parent. Alternatives are crustal assimilation and fusion, which has received criticism from Wright (1965, pp. 541-557) and Nash et al. (1961, pp.409-439), or an upper mantle origin. The latter alternative is that phonolitic and trachytic liquids are derived from the upper mantle, either by fractional crystallisation of a basaltic liquid in the upper mantle, or by direct partial melting of upper mantle, without an intervening basaltic liquid stage.

The evidence for an upper mantle origin for some phonolites and trachytes is summarized by Wright (1971, pp.1-5).

In the E.A.G.R.U. research areas, there is evidence that the early lavas, including the flinty phonolites, were produced at greater depths than later lavas, and that the abundant trachytes of the Kiddeh Group were produced at relatively high levels. This view is supported both petrographically and chemically, and is expanded below.

When the compositions of the lavas from all the E.A.G.R.U. areas are plotted on suitable graphs, the field of the phonolite lavas in the older formations is seen to be distinct from that of the younger formations, and the basalts to be similarly distinct, with only a slight degree of overlap in each case (McClenaghan, op.cit.). He defines three trends, which are closely parallel, overlap slightly, and move towards tholeiitic tendencies with decreasing age, see also Fig. 74. These trends are listed below, together with the stratigraphic units they embrace in the present area.

Differentiation trends	Major units in present area
1. Upper Miocene & Lower Pliocene	Kolloa & Tugen Hills Groups
2. Middle & Upper Pliocene	Tirioko Basalts & Kiddeh Group
3. Pleistocene	Kamosing Formation

In the present area, thick units of basalts alternate with thick units of salics. Each pair, consisting of basalts below and salics above, is considered here to represent a cycle, and the first and second cycle therefore correspond exactly to McClenaghan's first two trends. The evidence in the present area for a third cycle is less secure, since there are no Pleistocene salics, but it is evident in Fig. 76 that the Kamosing Formation occupies a field nearer to the 'tholeiite line' than the fields defined by older basalts.

In each cycle, it is considered that, from a basaltic parent, basalts and the small proportion of associated salics are produced mainly by fractionation. During the time represented by the unconformity below the overlying salic unit, fractionation proceeds without interruption to produce great volumes of salic, differentiated magma. The mechanism of transfer to the surface, and storage in magma chambers, if any, is not known, nor can these be envisaged at the present time. It is evident, though, from the high proportion of pyroclastics, that gas plays an important part in at least the later history of the magmas.

Fig. 75 shows the analyses plotted using Kuno's solidification index, where $S.I. = \frac{MgO \times 100}{MgO + \text{total Fe} + \text{total Alk.}}$ (Kuno, op.cit., p.194). It can be seen that the salic differentiates from the older formations have lower total iron, higher alumina, and slightly higher alkalies. Such differences become indistinct, or do not exist, when the solidification index is high. It is inferred therefore that the primary magma in each trend is fairly similar, and that subsequent diversification depends more upon the processes involved during differentiation, and the environment in which they take place.

The curve for MgO is particularly smooth. This is taken by Harkin (1960, p.155) to indicate that phenocrysts in porphyritic rocks are intratelluric rather than cumulative. An obvious exception is 5/249, a magnetite-augite-olivine-cumulate.

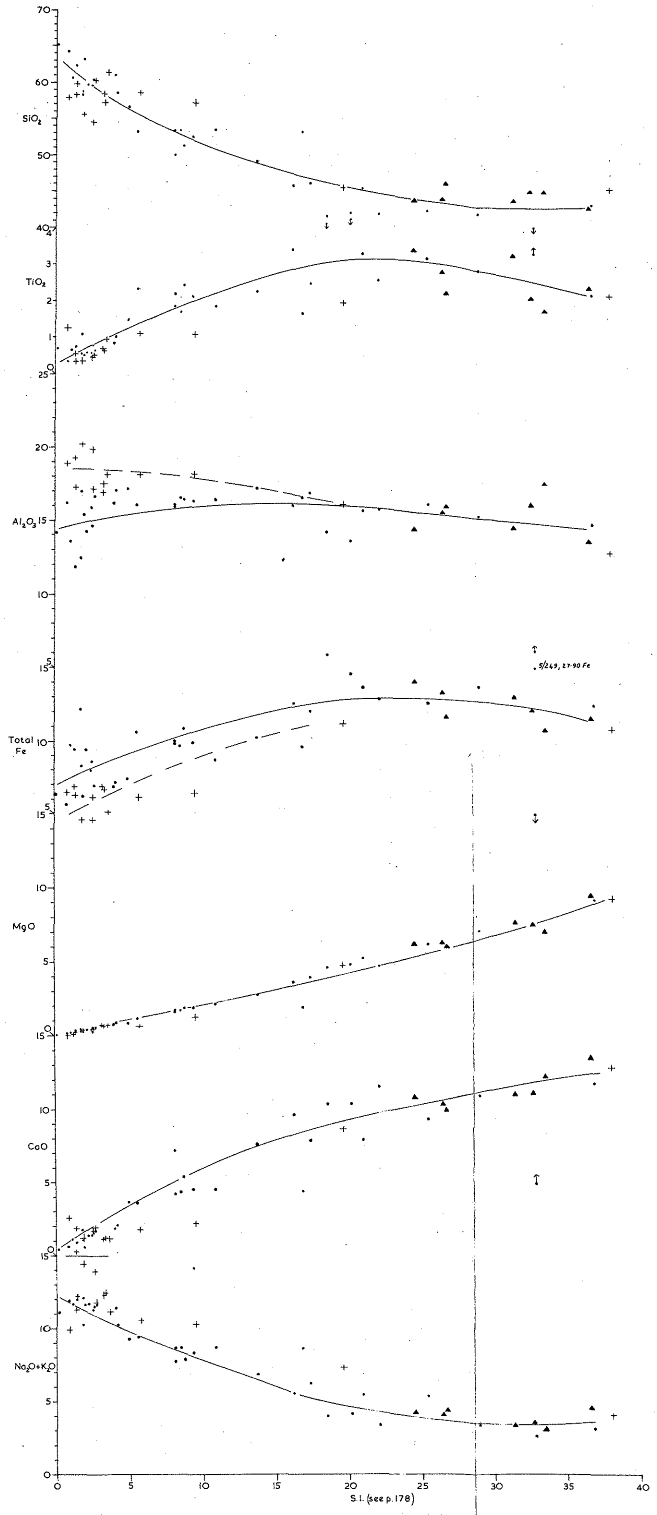


FIG.75 Solidification index plotted against major oxides.

The major trends and subtrends are shown on an alkali-silica diagram, Fig. 76; an AMF diagram, Fig. 77; and a Von Wolff diagram, Fig. 78. In each, the trend comprising the Kolloa and Tugen Hills Groups stands fairly distinct from the younger trends. Specimen 10/749A on the oldest trend (present author's first cycle) is the most basic aphyric basalt from the equivalent of the Kolloa Group in area 10, Fig. 1. McClenaghan thinks that compositionally, it is close to the parental Kapchererat Formation basalt.

Such a basalt gave rise, it is postulated, to the basalts, trachytes and mugearites of the Kapchererat Formation. The salic lavas plot in the field of the Kiddeh Group salic lavas, and might therefore have been derived by similar processes. In the Tugen Hills Group, McClenaghan invokes differentiation by crystal fractionation, Fig. 79. From the parental basalt B, salic differentiates between B and E are produced by the fractionation of kaersutitic amphibole. However, the diagram expresses compositions only in terms of SiO_2, Al_2O_3 and alkalies, and it is difficult to plot precisely the composition of kaersutite. The evidence for its fractionation arises though, not directly from Fig. 79, but from subtract calculations performed by McClenaghan, and from the presence of brown amphibole xenocrysts in basalts (5/424) and salic lavas (5/385) from the Kolloa Group, and in phonolites from outside the present area.

The phenocrysts of brown amphibole from the present area give 2V(-) compatible with kaersutite. The less undersaturated salic lavas are derived by a combination of amphibole subtraction, and plagioclase subtraction, probably at shallower depths. The latter comes into effect at G, driving the trends over to the right, Fig. 79, leading either to undersaturation (5/140, 5/141) at F, in which amphibole separation is still dominant, or to more saturated lavas (5/394, 5/384) in which plagioclase separation is dominant. The latter two specimens are the

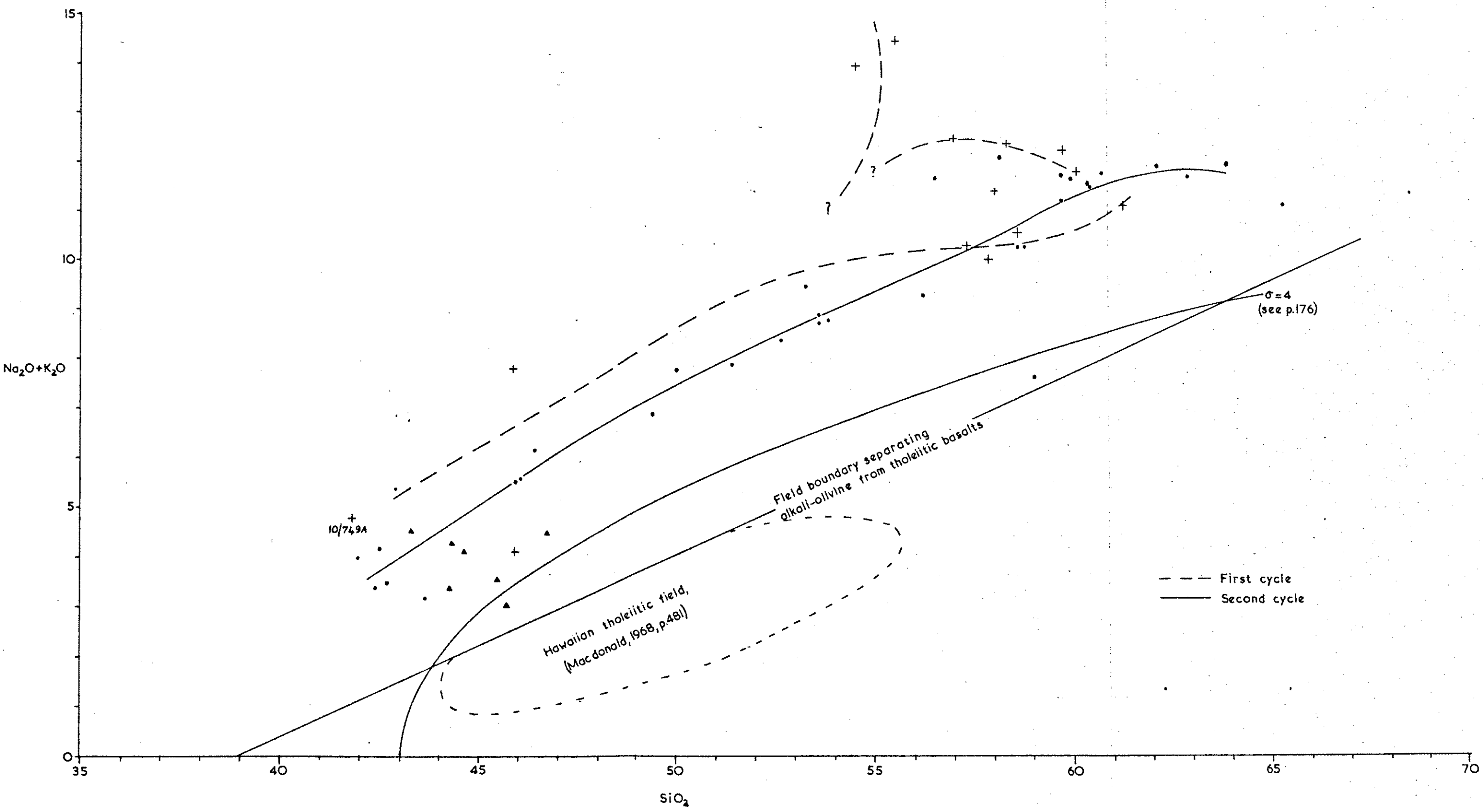


FIG 76 Alkali-silica diagram

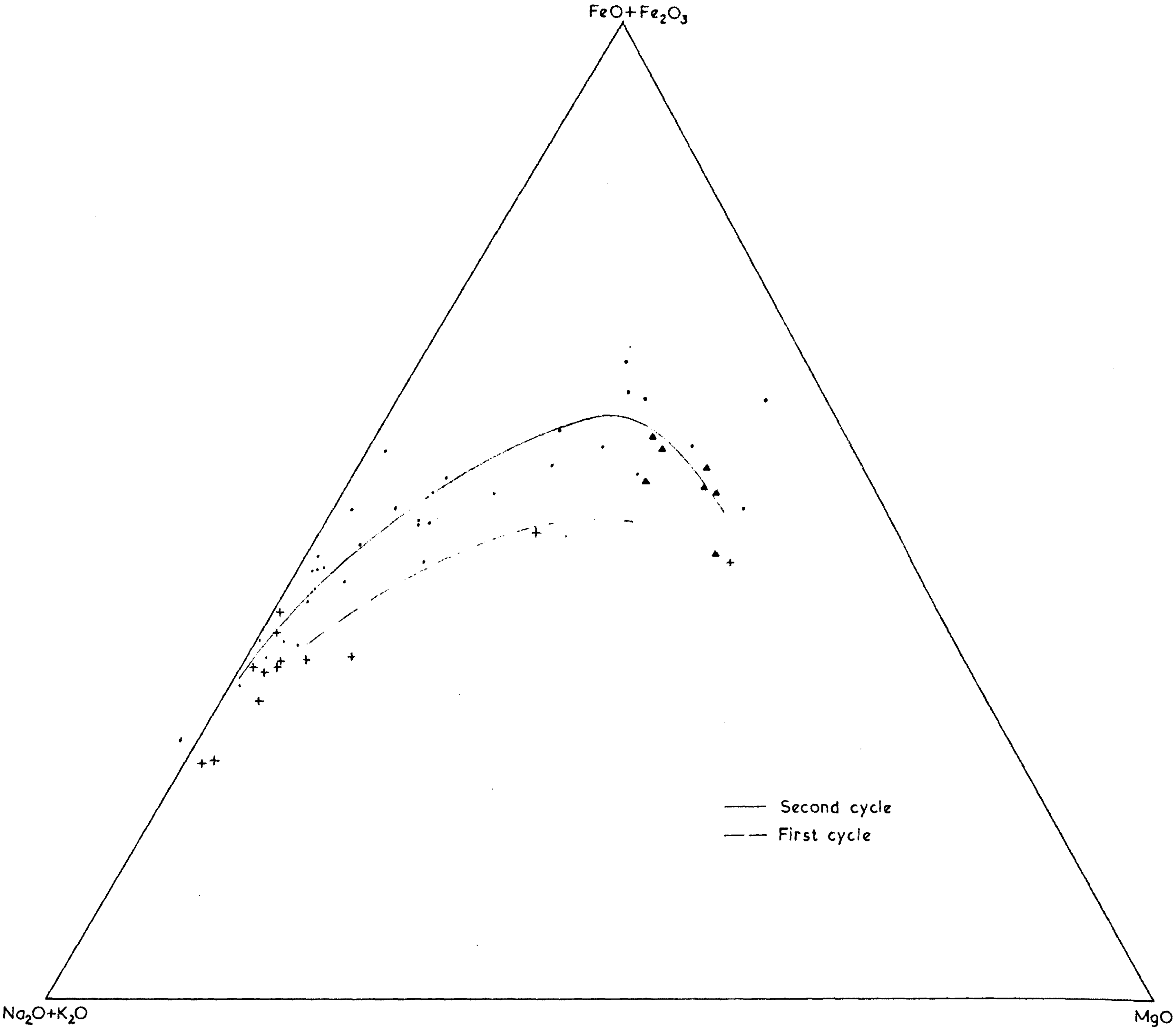


FIG.77 AMF Diagram.

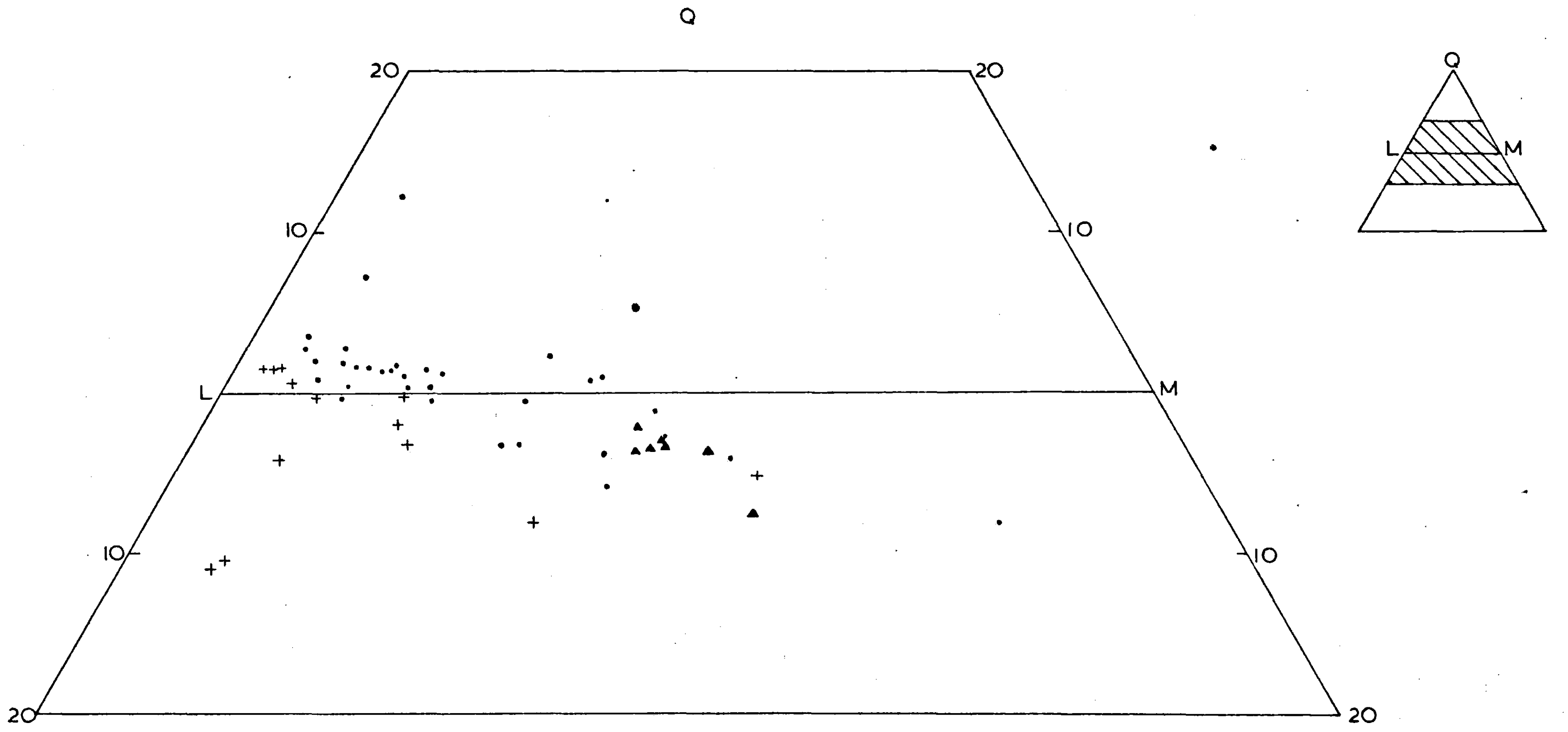


FIG. 78 Von Wolff diagram

plagioclase-trachytes or mugearites from the Kapchererat Formation. The trachyphonolite 5/336 is anomalous in that it contains modal nepheline, and yet falls on the more saturated trend. Evidence for the separation of plagioclase phenocrysts lies in their occurrence in the salic lavas of the Kapchererat Formation; the frequent occurrence of plagioclase fragments in tuffs of the Tugen Hills Group, p.164; and in the presence of the plagioclase-phyric dykes cutting the lowest rocks of the Tiriomim Volcanics.

The trend towards C involves separation of alkali feldspars ± nepheline. Both occur as phenocrysts in lavas that plot between C and F, though nepheline naturally occurs in the less saturated lavas, nearer F. The subtrends within the Tugen Hills Group are also shown in Figs. 76 and 78. The field of the phonolites stands distinct from that of the trachyphonolites, and from the salic lavas of the Kolloa Group. In Fig. 77, the trend as a whole is seen to be more iron poor than younger lavas.

Although not proven, the following synthesis is a possible sequence of events that took place to produce the first cycle of volcanism:

(a) Melting in the upper mantle to produce an alkaline basaltic liquid, which undergoes separation, near the locus of melting, of kaersutitic amphibole.

(b) Some of this liquid moves into the crust. Crystallisation of the amphibole stops, and is replaced by crystallisation of plagioclase, olivine and augite. The latter two minerals form cumulates. Continuing separation of plagioclase and alkali feldspar lead to the production of salic liquids. From time to time, each liquid becomes available for eruption.

(c) Meanwhile, in the upper mantle region, fractionation of amphibole has been continuing, with the consequent production of a large volume of phonolitic liquid, which then becomes available for eruption, due to unknown causes.

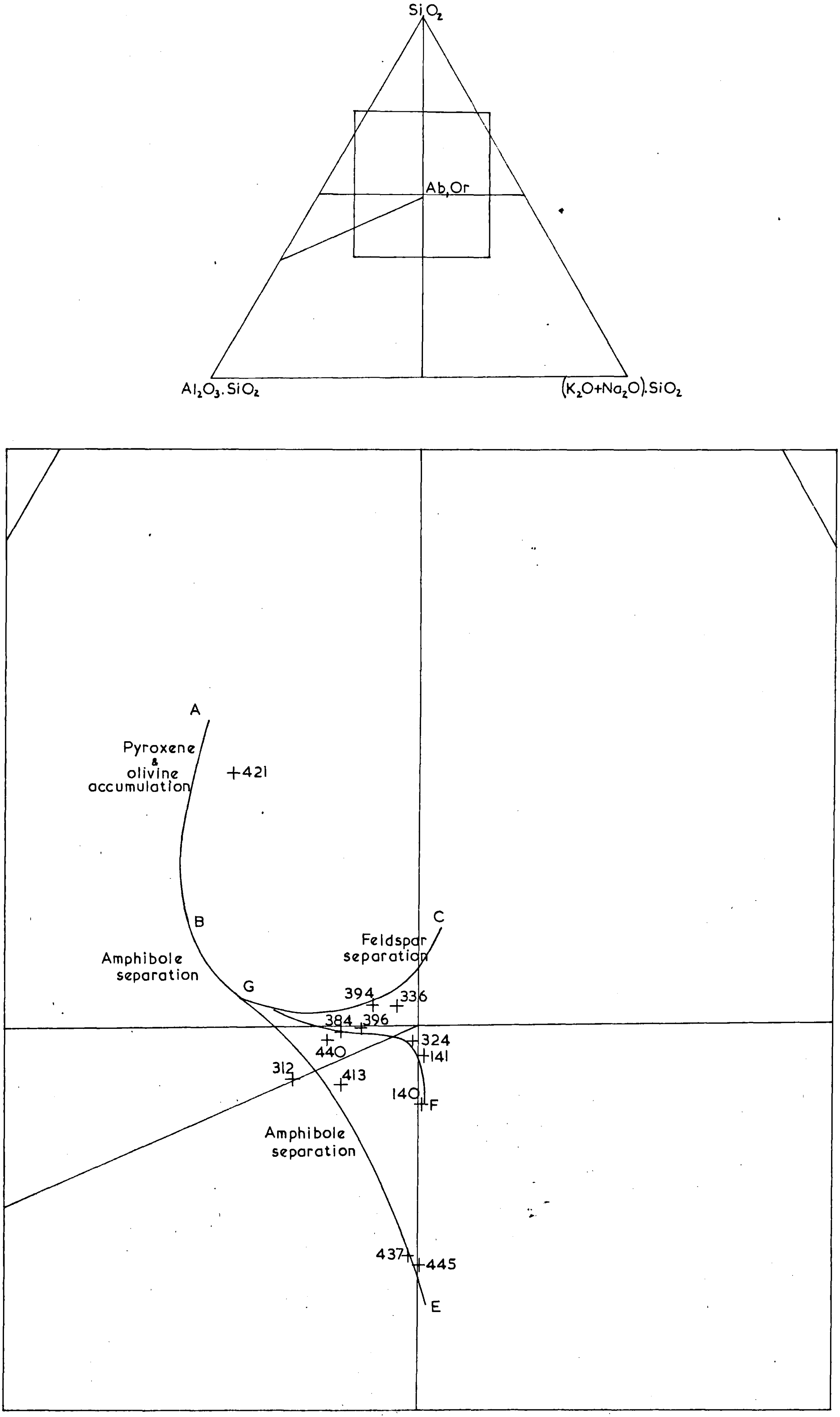


FIG.79 First cycle of magmatism.

The rocks of the middle trend (present author's second cycle) are shown in Figs. 76-78 and in Fig. 80. McClenaghan (op.cit.) again selected the most basic aphyric basalt, from the equivalent of the Tirioko Basalts, which plots at P in Fig. 80. From this, lavas such as 5/249 are derived by accumulation of augite and olivine phenocrysts. Specimens 5/283 and 5/330 both occur in the theoretical field of plagioclase cumulates, and although 5/283 is in fact from the plagioclasephyric unit of the Tirioko Basalts, 5/330 is totally nonporphyritic, and olivine-free.

Basic lavas are derived from P by the subtraction of kaersutite from P to B. From B to C subtraction of augite, olivine and plagioclase operates, such that the albite content of the feldspar gradually increases. At C, the subtract has a composition near to alkali feldspar, pushing the resultant differentiates towards E, Fig. 80. It is considered that the syenitic blocks described on p.165 are cumulates derived by such subtraction of feldspar crystals from the melt. An analysis of the minerals in 5/4, a block from the Lokitet unit of the Ribkwo Complex, is given in Table 27. The feldspar corresponds compositionally to typical 'sanidine' phenocrysts observed in the trachytes, which have been analysed by X-ray diffraction, see p.109. The pyroxene corresponds to nearly pure aegirine, while the amphibole is intermediate between kataphorite and arfvedsonite.

From C to D the trachyte lavas fall on a fairly well defined trend, but beyond D, there is a scatter of points, indicating that besides feldspar fractionation, other processes are operating.

One such process is the removal of soda by volatiles. Romano (1970, pp.694-700), studying a single pantellerite flow, shows that soda increases from 5.28% near the base to 7.76% near the top. He attributes this to the formation of mobile sodium metasilicate (ns) during the final stages of crystallisation, involving also the removal

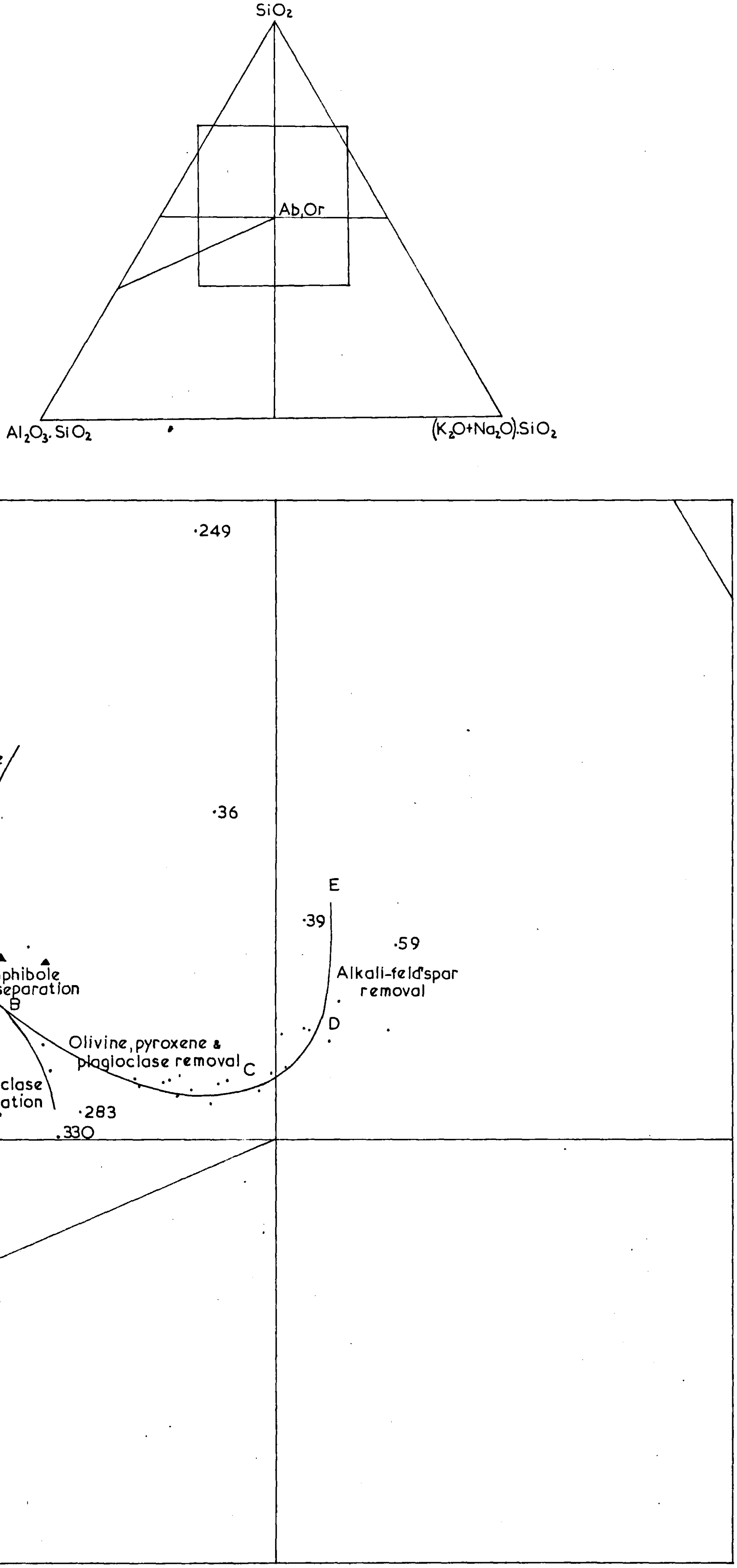


FIG. 80 Second cycle of magmatism.

Table 27. Analysis of minerals in 5/4

	Pyroxene	Amphibole	Feldspar
SiO_2	50.40	46.84	66.00
TiO_2	0.97	0.90	0.05
Al_2O_3	1.17	1.72	19.10
Fe_2O_3	27.52	15.22	0.52
FeO	5.02	19.53	(as Fe_2O_3)
MnO	0.67	1.30	0.02
MgO	0.45	1.38	0.00
CaO	1.92	3.02	0.47
Na_2O	11.45	7.37	7.28
K_2O	0.32	1.44	6.56
H_2O+	0.27	1.06	not
F_2	0.05	0.40	determined
P_2O_5	0.03	0.07	0.02
	100.19	100.08	100.02

.Recalculated mineral formulae:-

Pyroxene $(Na_{0.86}\ K_{0.01}Ca_{0.08})(Fe^{3}_{0.80}Fe^{2}_{0.16}\ Mn_{0.02}\ Mg_{0.03}$

$Ti_{0.03}\ Al_{0.01})(Si_{1.95}\ Al_{0.05})(O_2OH_{0.07})$

Amphibole $(Na_{2.29}\ K_{0.27}\ Ca_{0.52})(Fe^{2}_{2.62}\ Fe^{3}_{1.83}\ Mg_{0.33}\ Mn_{0.17})$

$(Si_{7.49}\ Al_{0.33}\ Ti_{0.11})O_{22}(OH_{1.14}\ F_{0.21})$

Feldspar $Ab_{60}\ Or_{36}\ An_{4}$

of chlorine and fluorine. The conclusion is that crystalline peralkaline salic lavas may not represent the composition of the liquid from which they were formed. In this respect, specimen 5/59 (Table 25) is significant. It is a glass block from tuffs in the Kachila Volcanics, and appears not to have undergone much secondary alteration (see below). It contains 3.58% normative ns , which appears to have been retained in this rapidly quenched liquid, but which does not occur in any crystalline lava, from the Kachila Volcanics or any other trachyte from the present area. Thus, if the removal of soda, and possibly potash, though this shows little variation in Romano's analyses (ibid., p.696), operates in this manner on salic peralkaline lavas, their compositions would not plot on the expected trend DE in Fig. 80.

Another process which could cause a similar deviation is secondary leaching by groundwater. In glasses, this causes an increase of total water, and a decrease in soda, and possibly silica and potash. This is certainly the case in 5/36, which falls right off the trend DE in Fig. 80, and which (Table 24) contains only 7.59% total alkalies (compared to 11-12% in trachytes); has a Na_2O/K_2O ratio of 1.06 (compared to 1.2-1.6 in trachytes); and a total water content of 7.93% (compared to c.2.5% in trachytes). These observations are all symptomatic of secondary hydration of the glass (Ross & Smith, 1955, pp.1071-1089 ; Noble, 1967, pp.280-285). The same process can occur in crystalline rocks, and is suspected if the mafics are reduced to limonite, or the feldspars show signs of alteration.

An important point of difference between the two trends described above is the diminished importance of kaersutite separation in the younger trend. Kaersutite is regarded as forming at high water pressures (McBirney & Aoki, 1968, pp.541-543), and usually shows reaction rims of black ore when it occurs in lavas (5/396). Plagioclase, olivine and augite subtraction are regarded as occurring at higher levels in the upper mantle or lower crust. In McClenaghan's youngest trend, kaersutite separation is not invoked, and the locus of melting and differentiation is considered to be at even shallower depths. This trend is not considered any further because of its limited relevance to the present area.

The origin of each primary magma is unknown. Macdonald (1968, pp.477-518) favours for the Hawaiian Volcanoes a single primitive magma of olivine-tholeiite composition, derived from the upper mantle. From this, olivine-poor tholeiites, alkali-olivine basalts, and nephelinic lavas are supposedly derived by crystal fractionation at increasing depths, the most alkalic being produced at the greatest depths.

Kushiro and Kuno (1963, pp.75-89) postulate that tholeiites, alkali-olivine basalts, and nephelinic lavas may each be generated as a primary magma, by the process of partial melting of the mantle, the degree of alkalinity and undersaturation increasing as the depth of locus of melting increases, i.e. the same relationship proposed by Macdonald.

In the present area, and those nearby, it appears that there is a general increase in tholeiitic character from Miocene to Pleistocene. The alkali lime index in the present area, Fig. 74, increases from 47.6 in the older trend to 49.5 in the younger trend. Further evidence for progressive increase in tholeiitic character is seen in the alkali-silica diagram, Fig. 76, and in the Von Wolff diagram, Fig. 78. It seems reasonable, therefore, that in this part of the Gregory Rift, the locus of melting is rising with time.

CHAPTER 7

CONCLUSIONS

Several conclusions can be drawn regarding the geology of the area, the most important of which are the following.

The first is the comparative simplicity of the stratigraphy, and the ease with which it can be divided into several groups. These groups find their equivalents both on the east and west sides of the rift although they are not present everywhere. The oldest group extends as far south as 1°05'N on the west side of the rift and as far south as the equator on the east side. The overlying phonolites are more widespread, occurring not only within the rift zone, but on its shoulders as well. Volcanics younger than this show considerable local variations in rock type. In the present area, the axial zone volcanics are distinct from the flank zone volcanics, but in other areas, there is an almost continuous sequence. Generally, then, the present area can be fitted into the regional stratigraphic scheme.

However, important differences, already mentioned in chapters 2 and 3 are restated here. They are:-

(i) The abrupt change at c.1°13'N in the Tugen Hills Group from plateau type eruptions to central type eruptions, and the greater proportion of pyroclastics in the Group in the present area. Chemically, the lavas compare closely with their equivalents in the plateau sequence to the south, and hence this difference in eruptive pattern is thought to depend on process, rather than on the composition of the magma.

(ii) The presence of trachyte volcanoes in the Kiddeh Group. This is another manifestation of an eruptive pattern which is rare further to the south, where lavas of corresponding stratigraphic position are coalesced fissure eruptions, albeit with a higher pyroclastic content than the Tugen Hills Group.

(iii) The absence of a large fault scarp and the presence instead of the Tiati monocline, which is considered to be the true western edge of the rift valley.

All three features are considered to be related, though none can be properly considered to be causal. This relationship, between monoclinal rift margins and central volcanic activity on the one hand, and between large fault scarps and plateau-like eruptions on the other is the second conclusion to be drawn.

Thirdly, it is considered that the structures of the area can be related to a tensional field acting transverse to a northnortheast, trending axis, the evidence for which lies in the abundance of dykes and the ubiquitous normal faulting, both of which occur frequently on the same trend.

The fourth conclusion is that chemically, the lavas follow the regional pattern, i.e. they become less alkaline with decreasing age. There are local exceptions to this however. The Loyamarok Phonolite, in Chapman's area, dated at 0·6 m.y., contains appreciably more nepheline than most trachytes from the Kiddeh Group. Another feature of the present area and the whole region is the scarcity of lavas intermediate between basalts on the one hand, and trachytes and phonolites on the other. This indicates that although such lavas are produced, they are only rarely available for eruption. Further, it is not yet clear whether or not phonolites, or even trachytes are generated wholly by simple fractionation of a basaltic liquid. Regional chemical studies, particularly of trace elements may eventually solve this question.

More generalized conclusions concerning the nature of the rift valley may be made in the light of the investigations of others. Geophysical data have recently been published, notably by Khan & Mansfield (1971, pp. 72-75), who report the presence of a gravity "high" superimposed on the regional negative Bouguer anomaly. The latter coincides with the general trend of the rift, observed values ranging from c.-120 mgals. on the rift shoulders to c.-200 mgals. in the rift itself (Bullard, 1936, Map 2, after p.531), and is supposedly due to a projection of sialic matter into the mantle (ibid., p.510). The gravity high is a narrower feature, of up to 50 mgals. amplitude. It coincides with the axial zone of the rift valley for some distance north and south of the equator, but at 1°N, trends west of it, where it also widens. Its presence was supposed by Girdler et al (1969, pp.1178-1182) to be due to the intrusion of basic material to within 1 km. of the rift floor. Khan & Mansfield combine their own data with seismic data of Griffiths et al (1971 pp.69-71) and conclude that the gravity high is caused by the presence of a body of material intermediate in terms of density and seismic velocity between crust and mantle. Having regard to the volcanic history of the rift, it is possible that this material is composed of accumulated pyroxene, olivine and plagioclase crystals, drawn off from magma during the generation of salic lavas. It is difficult, though, to reconcile this with the observed deviation of the high, north of 1°N, away from the zone of Pleistocene volcanism, where it may be supposed that such residual material would be nearer to surface. However, the geophysical evidence is open to various interpretations; thus Girdler et al (ibid.) and Baker & Wohlenburg (1971 pp.538-542) favour a density inversion in the lower crust, while Khan & Mansfield reject the idea.

The wider aspects of rifting have lately been analysed by Mackenzie et al (1970 pp.243-248) in the light of plate tectonics. In order to reconcile an inferred differential movement pattern between the Red Sea and Gulf of Aden, both of which are regarded as the result of crustal separation, they calculate that there have been 70 kms. of separation in the Ethiopian rift, diminishing to 30 kms. in the northern part of the Kenya rift. The virtual continuity of older rocks such as the Tugen Hills Group phonolites across the rift floor at c.0°30'N, and the presence of metamorphic rocks in horst blocks within the rift at

$2^{\circ}30'$N appears to preclude such a separation. Baker & Wohlenburg (ibid. p.539) postulate a separation of no more than 10 kms., a value derived mainly from extension due to normal faulting, consequent upon uparching of the Kenya Dome, but also partly ascribed to "some sub-crustal process". In arriving at their estimate of 10 kms. they assumed a mean angle of dip of fault plane of 63°. In the present writer's area, aerial photographic evidence indicates an appreciably higher angle of dip, so that extension due to faulting could be as low as 5 kms.

The arguments of Mackenzie et al have met with criticism from Le Bas (1971 pp.85-87) who points out several differences between the Kenya rift and oceanic ridge systems and concludes that they differ fundamentally. Le Bas further mentions that the Somalia Plate of Mackenzie et al (ibid. p.243) is composed of several domes, along the major axes of which occur the rift valleys, and which have behaved differently at different times. Both Le Bas and Bailey (1964 pp.1103-1111) see a connection between doming and the occurrence of peralkaline volcanism. Bailey (p.1108) appeals to the migration of volatiles as a mechanism for heat transfer, and relates partial melting to a release in pressure consequent upon domal uplift. He ascribes the latter however to lateral compression, for which there is no evidence. Magnitsky & Kalashnikova (1970 pp.877-885) contend that the uplift is due to rising geotherms initiating a phase change in the upper mantle, producing less dense material thereby.

Considering the above evidence, the present writer concludes that although the Kenya Rift, in common with other continental rifts, has geophysical characteristics which distinguish it from closely adjacent regions, it is not merely a continental extension of the ocean ridge system. Its tectonic pattern, and volcanism can be related to successive epeirogenetic movements of the Kenya Dome, and it is believed that all three are related to, and are the effects of, unknown processes in the upper mantle.

APPENDIX A. SPECIMEN LOCALITIES

(all specimens except those marked* are from the author's area)

SPECIMEN No.	MAP REF.	SPECIMEN No.	MAP REF.	SPECIMEN No.	MAP REF.
1	779389	70	795417	160	759542
4	776390	71	798435	161	754547
5	776389	72	791437	162	751568
6	767394	74	789433	164	764577
9	780394	75	793435	166	751581
12	773409	79	760402	168	812524
13	771408	80	769421	169	809524
14	772408	81	777437	171	807527
16	751401	82	772430	173	796537
22	778415	88	763444	175	783531
23	781417	89	763444	176	800560
25	782423	90	758394	177	791568
26	783422	99	759440	180	802578
27	792424	100	776451	182	796591
28	779399	101	774453	183	796591
29	776397	102	792449	184	789602
33	767397	104	728462	185	793614
34	744457	107	712453	188	812606
35	718448	108	716452	189	813606
36	756459	109	724428	190	803611
37	718454	110	723424	*191	800660
39	720446	114	707398	204	775619
40	748475	115	710407	*205	772633
41	738491	116	705402	209	806503
43	718485	121	727503	219	771611
44	757499	122	727496	220	764617
45	752502	123	726505	221	764617
47	752496	128	744544	225	680396
48	762509	129	754527	226	333402
49	759468	130	758524	227	329402
50	768481	131	758509	228	327400
52	781487	136	265438	232	298391
53	767497	137	292441	234	292384
54	767500	139	319421	235	292389
56	774505	140	323414	236	293387
57	784497	141	325421	237	276411
58	785498	142	316427	240	283389
59	777499	143	321438	242	678508
62	770417	144	325441	*243	682634
63	766417	149	722542	246	278603
64	763413	152	694515	247	307629
65	766412	156	767506	248	330623
66	766407	157	774520	249	663609
67	760397	158	771516	250	669593

SPECIMEN No.	MAP REF.	SPECIMEN No.	MAP REF.	SPECIMEN No.	MAP REF.
252	670591	331	724611	394	193414
254	720559	334	331480	395	194418
258	704389	335	323463	396	187401
259	672422	336	273462	397	182399
260	672422	337	276448	399	199480
262	682426	343	327447	400	201480
263	672419	344	323432	401	210478
267	296580	345	323434	404	238389
268	276562	346	032384	405	254388
273	705577	348	038404	406	257389
274	700567	349	043402	408	232420
275	696556	350	065391	409	239426
276	692559	351	088424	410	245429
277	691562	352	100426	411	248431
278	694566	353	083397	412	233435
280	703553	355	117385	413	234407
281	675575	356	069392	414	254404
282	690550	359	063432	415	263405
283	688579	360	053427	417	229465
286	698532	361	059432	418	231463
287	709551	362	004417	419	236463
288	671561	363	074448	420	179499
289	325559	365	045472	421	171500
291	672612	366	026477	423	184514
293	271595	367	073460	424	148490
299	267572	368	083495	425	155485
300	272559	369	096493	426	263438
301	272559	372	071495	427	259452
302	336599	373	051506	428	256452
303	699614	376	196452	429	241462
305	682606	377	196452	430	241462
306	681533	380	177439	431	253471
307	689519	381	184443	433	254494
311b	664596	382	192438	435	239470
314	300540	383	185427	437	226485
318	262543	384	184429	438	226489
320	284541	385	181429	439	224486
323	278517	386	199436	440	202515
324	271497	389	178462	441	202511
325	267492	390	183462	442	207484
326	271497	391	188470	443	208486
328	264514	392	186471	444	253498
330	311499	393	185409	445	255515

APPENDIX B. AGE DATES, IN ORDER OF STRATIGRAPHIC GROUPS

Specimen No.	Rock Type	Map Reference	% K_2O	Age (m.y.)	Stratigraphic Position	Remarks
5/46	Olivine - basalt	753499	0.91	4.2 ± 0.3	Kahanavisian Basalt	Too old.
5/70	"	795417	0.98	2.2 ± 0.3	Pativat Basalt	Acceptable.
5/157a	Olivine - basalt	774520	0.81	4.1 ± 0.9	Chemusowai unit	Too old, should be c 2.6 m.y.
5/185	Trachyte	793614	5.20	2.6 ± 0.2	Nasaken Complex	Acceptable.
5/190	"	803611	5.00	2.9 ± 0.3	"	"
5/52	"	781487	3.05	2.7 ± 0.2	Kachila Volcanics	"
5/71	Trachymugearite	798435	3.29	3.2 ± 0.3	"	"
5/169	Trachyte	809524	2.99	4.8 ± 0.2	"	Too old.
5/158	"	771516	4.91	4.3 ± 0.2	"	Younger limits acceptable.
5/50	Olivine - basalt	768481	1.97	4.6 ± 0.6	"	" " "
5/12	Trachyte	773409	4.98	5.2 ± 1.4	Kariamangro Caldera unit	c 4.3 m.y. acceptable.
5/6	"	764394	5.54	4.4 ± 0.2	Lokitet unit	Acceptable.
5/90	"	758394	5.40	4.5 ± 0.2	"	"
5/126	"	729531	5.28	4.4 ± 0.3	Ribkwo Main Shield unit	5/126 & 5/127 are from the same lava flow.
5/127	"	731541	3.76	4.9 ± 0.8	"	
5/294	Trachyte	275591	5.19	5.9 ± 0.2	Mugor Trachytes	Acceptable.
5/337	Trachyphonolite	276448	5.03	6.1 ± 0.2	Cheptuimet Trachyphonolite	Too young.
5/433	Phonolite	254494	5.10	12.5 ± 0.5	Tiriomim Volcanics	Acceptable.
5/393	Trachyte	185409	5.11	16.6 ± 0.5	Base of Kapchererat Formation	Acceptable.

APPENDIX C. ABBREVIATIONS, CHAPTER 5.

A - augite

amph - amphibole

anal - analcite

ap - apatite

bowl - bowlingite

comp - composition

ct - calcite

F - feldspar

ferrug - ferruginous

Fsp - feldspathoid

fspar - Feldspar

gmass - groundmass

gradns - gradations

idd - iddingsite

Il - ilmenite

interst - interstitial

mt - magnetite

Ne - nepheline

O,ol - olivine

P,plag - plagioclase

phxt - phenocryst

pseud - pseudomorphed

px - pyroxene

Sod - sodalite

titaug - titanaugite

v - very

w - with

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